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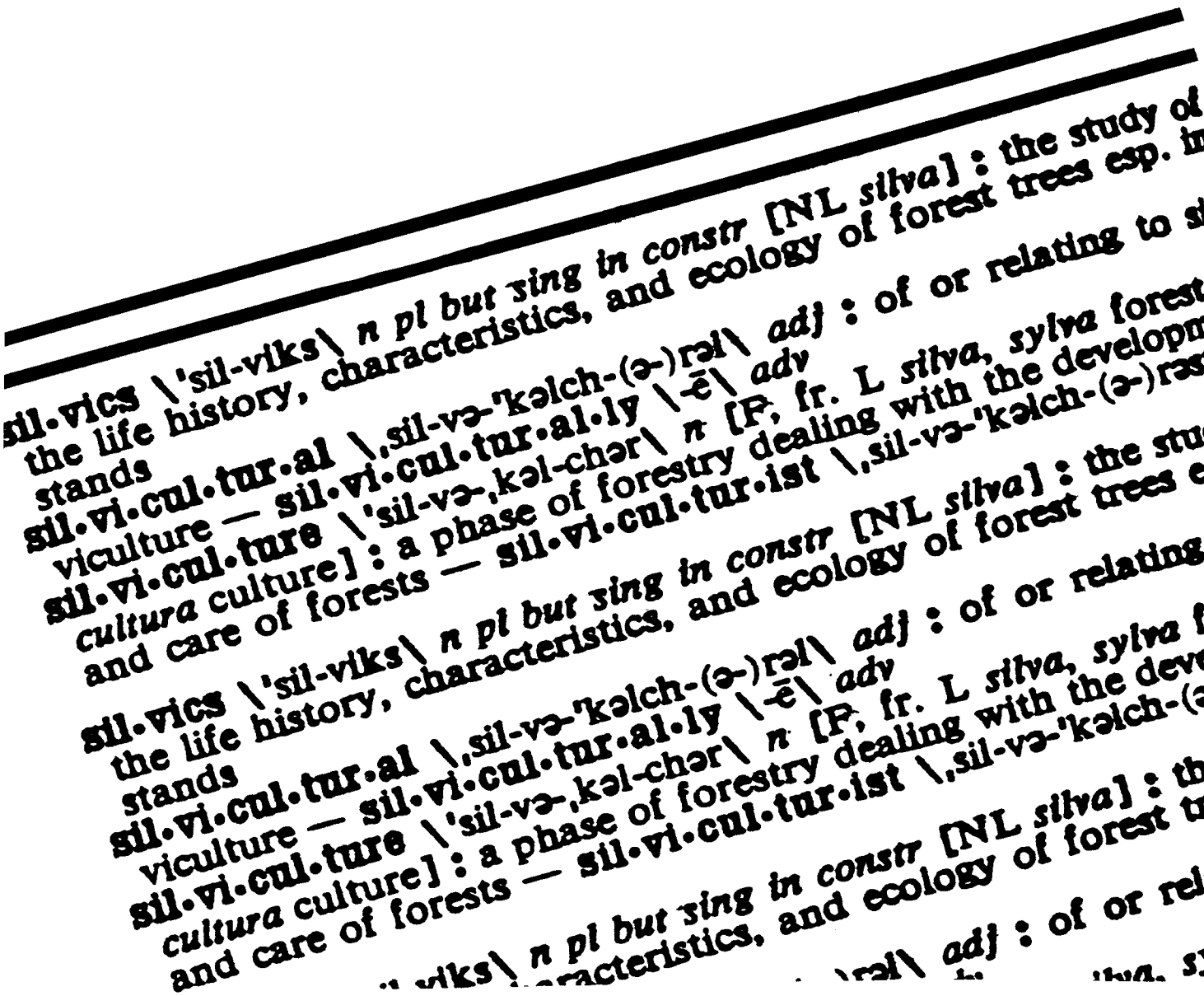
Auburn, Alabama
November 1-3, 1994



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Eighty-eight papers and two abstracts address a range of issues affecting southern forests. Papers are grouped in several categories including a general session, ecosystem management, vegetation management, pest management, natural disturbance, biometrics, economics, site productivity, site impacts, ecophysiology, genetics, regeneration, silvicultural systems, stand development, and intermediate management. Fourteen papers, on varying topics, are presented from a poster session.

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Proceedings of the Eighth Biennial Southern Silvicultural Research Conference

Compiled by

M. Boyd Edwards

Auburn, Alabama
November 1-3, 1994

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PREFACE

Thii proceedings represents the research of 189 investigators studying the patterns and processes of managed southern forests through 104 reported studies. These contributions emanate from scientists located at various universities, forestry industries, and public agencies. Their approaches and findings lead the way to efficient and wise management of our nation's forest resource.

A general session on "Silviculture -A Pivotal Role In A Changing Profession" kicked off the conference with five distinguished presenters sharing their experience and insight.

A poster session was included in the program and consisted of 15 presentations. This served to allow another research session within the time constraints of the allotted time for the conference.

The field tour served to inform conference participants about ongoing research activities in the Auburn University area.

Acknowledgments are made to the conference cochair, James H. Perdue and the steering committee. Sincere appreciation is herebv expressed to each of them for their concern and diligent assistance in making the conference a great success. The committee was composed of the following representatives:

Craig Blair, Resource Management, Inc.
John Brissette, Northeastern Forest Experiment Station
J.L. Chambers, Louisiana State University
Howard Duzan, Weyerhaeuser Company
Vic Ford, Westvaco
Paul Frey, Louisiana State Forester
Milt Lougridge, Buchanan Timber Company
Michael Messina, Texas A&M University
Brian Oswald, Alabama A&M University
Mike Shelton, Southern Forest Experiment Station (SOFES)
Shi-Jean Susana Sung, SEFES
Mary Anne Sword, SOFES
David Todd, Champion International
Thomas Waldrop, SEFES

Special recognition is also offered to the excellent panel of distinguished moderators that led each session. I would like to thank Billie Jo Alexander and Thomas Waldrop for their perseverance in getting this proceedings to press.

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

M. Boyd Edwards
Program Chair
Southern Research Station

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General Session
Silviculture - A Pivotal Role in a Changing Profession

Moderator:

EMMETT F. THOMPSON
Auburn University

Keynote Address
A DIFFERENT PARADIGM
HOW WE GOT THERE
WHERE WE ARE
WHERE WE NEED TO GO'

Ronald E. Stewart'

Abstract-A review of the history of the USDA Forest Service timber sales program suggests five phases in land management philosophy culminating in a period of expanding gridlock. This indicates the need for a new paradigm for management that prevents zoning of the landscape for single- or dominate-uses and that emphasizes ecosystems and dupliitii of more natural processes. This paradigm shift has significant implications for silvicultural research.

INTRODUCTION

I believe that the practice of siiviculture is at a major crossroads. We can take one path that continues to put us in a defensive posture, desperately hanging on to the past and protecting turf. But, as someone has said, "the definition of folly is to continue to do the same thing the same way and expect diierent results." Therefore, I believe that a diierent path that leads to new options and a fresh approach is the only choice.

To understand where we need to go, we must first know where we are and how we got there. I also believe that a look at the history of the forces shaping the USDA Forest Service timber sales program tells us much about our present circumstances. While the forces and trends that I will be discussing may not have impacted Southern forestry to the same extent as in the West, I assure you that the wave of change is coming your way. I say this with some confidence because these forces and trends are driven by national laws and regulations and by the values of a growing urban population. For example, in California today, about 95 percent of the population is considered urban; in only a few years, 80 percent or more of the nation's population will be urban. Think of the potential consequences to forest land management policy and practice as Congress and state legislatures increasingly reflect this shift in political power.

I want to stress that the views and opinions expressed are my own and do not reflect USDA Forest Service policy. Rather, they represent my observations after serving as a scientist, research administrator, and Regional Forester in the western United States for more than 20 years. I also have liberally used an article by Lynton Caldwell, Charles Wilkinson, and Margaret Shannon in the Journal of Forestry (Caldwell, et al. 1994) for additional background information. Further, I have used a graph of the USDA Forest Service timber sales program between 1905 and 1994 to identify key phases in forest management philosophy (Figure 1).

Let's begin by looking at some highlights of how we got to where we are today.

HOW WE GOT THERE

Phases in Forest Service Land Management Philosophy

Custodial management (1905-1940).
Gifford Pinchot's famous 1905 letter set out the basic philosophy for national forest management. He said,

> "You will see to it that the water, wood, and forage of these reserves are conserved and wisely used for the benefit of the home builder first of all, upon whom depends the best permanent use of lands and resources alike...where conflicting interests must be reconciled the question will always be decided from the standpoint of the greatest good of the greatest number in the long run."

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*Associate Deputy Chief for Research, USDA Forest Service, Washington, D.C.

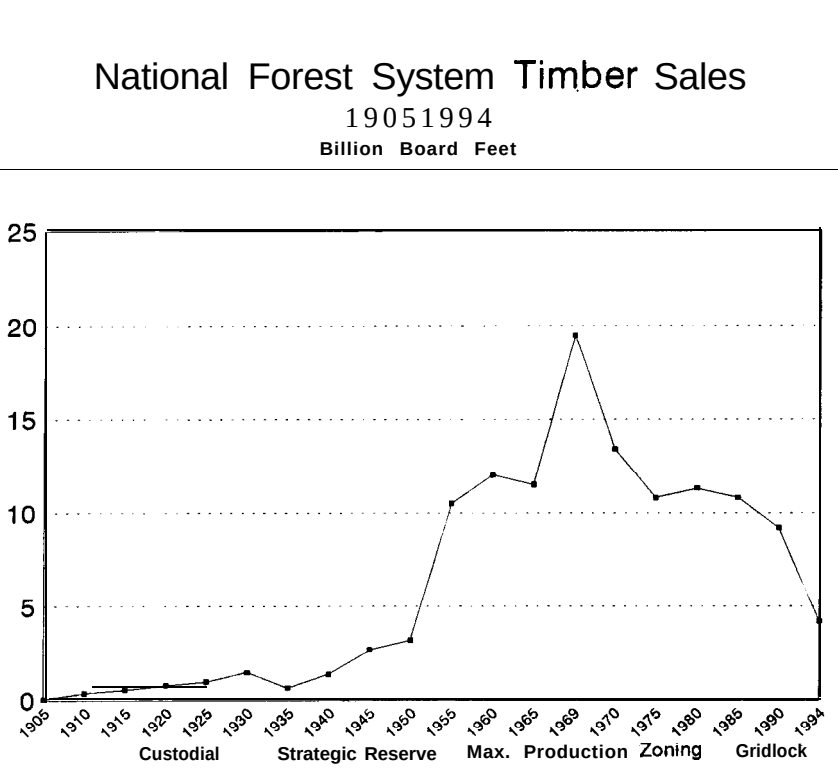

Figure l-Phases in USDA, Forest Service, National Forest timber sales from 1905 to 1994.

This simple, straight forward policy has largely influenced national forest management up to the present time.

This early period was characterized by a generally low level of timber extraction from the national forests. A low national population in relation to the resource base resulted in a situation where demand could be largely met from private lands. Development of the sustained ield philosophy occurred during this period. The concept may have originated with a forest industry consultant in the 1930's with the idea that it would only be applied to federal forest lands. This suggests that it was designed to limit supply from federal lands and thereby keep timber prices up. Contrast this with timber industry's concerns today about federal timber supplies.

National forests viewed as **a** strategic reserve (1940-1960).

The nation turned to the national forests to meet strategic World War II needs. This provided high quality spruce for aircraft, lumber for building military facilities, and control of raw material costs. Colonel F.G. Sherrill of the Army Corps of Engineers said, "It took three trees to equip and maintain one soldier' [quoted in Caldwell, et al. 1994.1

After the war, the economy expanded and the single-family house became an American prerogative. Demand for softwood from the national forests increased, with strong Congressional support, to fuel the economy and to provide low-cost housing. Returning war veterans started families, leading to the "Baby Boom."

The public attitude of the time is reflected in a letter of May 16, 1954, from Clair Engle, longtime California Congressman and Chair of the House Committee on Interior and Insular Affairs, to B.H. Payne, Director of Timber Management for the Pacific Southwest Region of the USDA Forest Service:

> "In my recent trip through the district I still encountered widespread complaint among the operators that adequate timber was not being made **available...It** seems to me that the answer to these complaints is for the Forest Service to annually offer for sale the allowable sustained yield **cut...It** seems to me to be completely unjustified to permit mills to close down while national forest timber is rotting and falling down."

Maximize commodity production within **a** multiple-use context (1960-1970).

Public acceptance of the Forest Services's multiple-use philosophy was codified with passage of the Multiple-Use/Sustained Yield Act in 1960 and the Wilderness Act in 1964. But during the period, the Forest Service seemed to move toward a policy to maximize productivity on suitable timber lands and

adoption of even-aged management using clearcutting as the predominant management system.

With the dawning of the Environmental Age came passage of the Endangered Species Act, National Environmental Policy Act, Freedom of Information Act, Clean Water Act, Clean Air Act, and formation of the Environmental Protection Agency during the late 1960's and early 1970's. This signalled a major shift in public thinking about industrial development and natural resources. The economy had grown, most people were relatively well-off, with a roof over their heads, clothes on their back, and food in their stomachs. In fact, individual incomes rose more during the 1960's than at any other time before or since (Caldwell, et al. 1994). This fostered a condition where the nation began to think about other issues. In 1965, Peter Drucker predicted the emergence of a new power center in American politics dominated by urban youth, in which "noneconomic issues may well become the core of political belief and action and focus upon quality of life, rather than the division of the economic products' (quoted in Caldwell, et al. 1994).

This changing public and political view would lead to a speech by Forest Service Chief Ed Clii in 1970 entitled, "Challenge for Change." He said,

> "The Forest Service is in an era of change never before experienced during its existence. For years, our leadership was accepted in the field of conservation. We wore the white hat of the hero saving forests from devastation. In our earlier years the Forest Service developed the multiple-use philosophy. We initiated the Wilderness movement. We were the principal advocate and leader in the philosophy and establishment of sustained yield. Today the reaction is different."
>
> "Programs and policies that were established without public reaction a decade ago are suddenly the subject of numerous law suits and appeals. Instead of maintaining the role of leader in wilderness philosophy and establishment we now are frequently portrayed as destroyers or enemies of wilderness. Our efforts to maintain multiple-use on certain controversial areas has earned us the reputation of single-use sellouts to commercial interests.
>
> "Conservationist groups feel that our allowable cut is too high, and our cutting methods too harsh for the environment. Timber interests generally believe we are too conservative in establishing the allowable cut and our requirements for cutting operations are too restrictive."
>
> "The bombardment from organizations, private citizens, and industry is not our only source of criticism. We are critical of our own performance and policies. We should be..."

Chief Clii outlined a multiple-use planning process and called for development of an efficient system of coordinated data collection, identifying resource management possibilities and alternatives at the local level and at specific locations so that they could be aggregated at Forest, Regional, and National levels. This was a forerunner of the forest planning process that emerged out of the Forest and Rangeland Renewable Resources Planning Act of 1974 (RPA) and the National Forest Management Act of 1976 (NFMA). He further said, "Such a system should also recognize changes in direction caused by changing needs of people, multiple-use planning or new concepts of environmental quality. Our systems must readily accept decisions for change."

The 1960's ended with growing disenchantment with government and large institutions in general. The "If you can't trust your banker, who can you trust' slogan of the 1950's gave way to "Don't trust anyone over 30" by the late 1960's. Forestry got caught up in the growing environmental movement and the public dissatisfaction with government. A committee of university experts convened by Senator Metcalf of Montana and chaired by Dean Bolle of the University of Montana examined Forest Service practices on the Bitterroot National Forest and concluded, "Multiple use management, in fact, does not exist as the governing principle on the Bitterroot National Forest...Quality timber management and harvest practices are missing."

Released in 1970, the Bolle report was quickly followed by challenges to forest practices on the Monongahela National Forest in 1975 and in hearings conducted by Senator Frank Church on the practice of clearcutting. The ink was hardly dry on the Forest and Rangeland Renewable Resources Planning Act of 1974 when Congress amended it by the National Forest Management Act of 1976.

Zoning for multiple-use to minimize land use conflicts (1970-I 988).

"The NFMA substantially constrained where and under what conditions timber harvesting could take place on national forests. It inserted environmental protection requirements into the legislative mandate for national forests and began the shift in management away from the previous emphasis on economic development and community stabilii (Caldwell, et al. 1994). In my view, it also accelerated implementation of a strategy for multiple-use management.

My training as a forester in the early 1960's told me that the way to practice multiple-use management was to segregate the uses over the landscape because many uses were conflicting and incompatible. I actively spoke against what had been termed the "succotash

syndrome," that is, the attempt to practice more than one use on the same acre. The idea of zoning uses, or to separate them in time and space, to avoid conflict was apparently institutionalized by the Forest Service through its forest and land management planning process. However, I believe that experience has shown that this approach only works if the issues or uses are visually-based and location sensitive, and the demands on the resources are relatively low to moderate; i.e., the land base is able to support the range of uses.

Today, the issues, such as spotted owls, marbled murrelets, red-cockaded woodpeckers, and ancient forests, transcend visual qualii and are less location sensitive. Further, they cross watershed, forest, and even traditional political and ownership boundaries. At the same time, the demands of a growing population on a shrinking natural resources land base are beyond the capability of a zoning land management strategy to address.

The forest planning process ultimately lead to a strategy of zoning of the land for individual or dominant uses. This strategy also included continuation of the policy to maximize timber production on the capable, available, and suitable (CAS) land base. Thii was thought to be appropriate since other natural resource values had been dealt with in other land use classifications. And, through application of intensive silvicultural practices on the remaining CAS lands, it was thought that we could maintain near historic levels of timber harvest However, this required levels of investment that were never funded and relied on the very practices most disliked by the public, such as clearcutting, use of herbicides, monocultures, etc. We inadvertently identified an industrial zone in the middle of a nice suburban neighborhood.

Public attention now almost exclusively focuses on the CAS land activities, especially even-aged management. As a result, the portion of the national forests in active timber management is continually decreasing. In other words, we are fighting over a small part of the land base and are potentially ignoring what is occurring on the majority of the federal forest lands where we are accumulating a legacy of declining forest health and increasing threat of catastrophic fire.

WHERE WE ARE

Expanding Gridlock (1986-Present)

We now seem to be in a period of potentially expanding gridlock. As indicated, public attention is now focused mostly on that portion of the federal lands under active management The general strategy to limit practices that the publii does not generally support is to reduce further the amount of land upon which they are practiced by moving lnd from the CAS base to non-timber land classifications. This has resulted in a significant erosion of the land base under management In many national forests in the West today only 10- to 25- percent of the land is under active forest management. For example, in the Pacific Southwest Region of the Forest Service, only about 3 million acres of the 20 million acres of national forests in California are included in the timber land base.

This has also inadvertently resulted in the establishment of wildlife refuges (essentially zoological gardens) and other isolated habitats and single- or dominant-use zones across the landscape. We now have created an issue of habitat fragmentation. Because of the often isolated and scattered nature of these areas, we now find that we must designate a new land classification, migration corridors, to assure gene exchange and dispersal of individuals between areas of suitable habitat.

In my personal view, thii approach has resulted in loss of agency credibilii with all parties: (1) With environmentalists due to the Forest Service's continued emphasis on clearcutting and maximization of timber production on the CAS lands at the expense of other multiple-use values and (2) With timber industry and local governments due to the Forest Service's inability to meet either historic harvest levels or even the lower levels implied in the forest plans.

WHERE WE NEED TO GO

Changes in policy toward the role of the national forests in meeting the nation's need for wood in the 1950's were generated by public pressure. Similarly, the current changes have been generated by a new public view of the role of the national forests.

We continue to repair rips in a worn out fabric. Continued fine tuning and adjusting of a basically flawed, out-of-step approach will no longer work.

Continuation in the current direction will result in:

- Expanded zoning for individual uses.
- Inability to manage forests with a resultant build up of forest fuels, continuing forest heatth problems, and large stand-destroying fires.
- Loss of forest industry capacity needed to accomplish forest management goals.
- Continued economic decline in timber-dependent communities.
- Continued gridlock.
- Continued loss of agency productivity and credibilii.
- Increased litigation and frustration.

Continuation of the old paradigm results in more restrictive solutions to environmental problems and failure to satisfy anyone. its time for a paradigm shift or else!

THE NEW PARADIGM

Objectives of a New Paradigm

In my view, we need a new paradigm for management of the nation's federal forest lands. Thii new paradigm should accomplish the following six objectives:

1. Implement the ecosystem management policy of the Chief of the USDA Forest Service.

2. Generally mimic pre-European settlement patterns of disturbance. (At a minimum, pre-European disturbance patterns should be the benchmark for management.)

3. Harmonize uses across the landscape rather than zone for them.

4. Provide habitat for all species across the landscape.

5. Avoid fragmentation of habitat and do not create barriers to migration-in so far as possible, the whole forest should be a migration corridor.

6. Provide for forest health and fuels management. Manage as much of the landscape as possible, excluding only those areas that should be managed differently for legal or biological reasons.

What Does A New Paradigm Mean for Silvicultural Research?

This shift in management emphasis requires some shifts in how we organize to do research and in research priorities. For example, in the Forest Service, we tend to organize our research program around Research Work Units and problems. In the future, we may need to organize around ecosystems. This paradigm also requires the development of ecosystem-specific conceptual models to guide the research and to assure that when all is done, the pieces add up to the whole. In fact, such models could become the organizing principle for focusing interdisciplinary research and research conducted by different organizations and individuals on the same ecosystems.

This new paradigm places a premium on the understanding of natural patterns of forest dynamics at both the local and landscape scales. Study of forest dynamics includes such factors as size, distribution, and causes of openings; stand disturbance patterns; and a renewed interest in stand structure. Intuitively, it seems reasonable that if we understand and mimic the effects of these natural disturbance processes and patterns through appropriate silvicultural practices, we can have healthy ecosystems, wildlife, visual quality, and other forest values while providing wood to meet the nation's needs-we literally can have our cake and eat it too. Other important areas of research where silviculturists can make a difference are ecosystem restoration, management of riparian ecosystems, and quantifying uncertainty and risk.

We also will have to provide the manager with good decision support systems and other analytical tools. Although the focus will be on broad landscapes, we will need to provide information on the special needs of species with restricted ranges, restricted mobilii, and specialized habitats, such as seeps. Finally, we will need to develop more efficient monitoring strategies and techniques, including appropriate measures of ecosystem sustainability. Some of our most important future contributions may arise from the results of carefully monitored operational land management activities and from well-designed landscape level expenmental studies, both as part of an adaptive management strategy. This is not a new concept, but a return to Gifford Pinchot's principle, "we learn to practice."

The South still has the time to make an orderly transition to a new paradigm in forest management and the supporting silvicultural research. We all tend to change only when change is forced upon us; but, to wait for forced change will bring chaos and will delay the development of the forest practices and technology needed to implement change. While making the shift now may be diicult, I believe that this can be done if we are willing to be leaders rather than managers-a manager gets things done right while a leader gets the right things done.

Along the path of change, we will need to revisit the perceived constraints of the old paradigm, such as species shifts, expected growth and yield reductions, increased costs, more roads, and steady-state technology, that we generally accept. Some of these, such as species shifts may not be important in the near future, while others, such as increased costs and construction of more roads, may not be necessary if we start with the premise that we will find ways to reduce costs and the density of roads through modified practices or new technology.

The people in this room, both land managers and scientists, have the responsibility to have the information and technology ready when the wave that is crossing the nation from the West hits. I believe that you are up to the task.

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ECOSYSTEM MANAGEMENT: A NEW BEGINNING'

Nelson S. Loftus, Jr. and Philip S. Aune[2]

Abstract-Abstract.-Ecosystem management means renewed responsibilities for sllvicultural research. Our past focus on developing technologies to manage, protect, and utilize the timber resource must now shift to managing forest vegetatii for sustainable benefits to the American people. New research must address multiple scales and species, examine ecosystem condiii, develop restoratiin technology, explain cause-effect relationships, provide decision support systems, understand human-natural resource interactions, and inwrporate science into action through adaptive management. Contributing to this knowledge base is the challenge to sllvicultural research as we enter the 21 st century.

The keynote speaker, Ron Stewart (1995), set the stage for the opening session of the conference by reviewing paradigm shifts evolving from the competition, conflicts, and often tensions between protecting forest ecosystems and using them. His paper takes us through the 20th century and into the 21st century as we continue to witness a heightened concern for the long-term sustainability of forest lands, not just the products removed. This evolving approach to land stewardship is currently referred to as "ecosystem management". Within this context, we have been asked to consider the questions: (1) Why ecosystem management is important to American silvicutture? and, (2) What is the role of research in implementing ecosystem management into silviculture? Actually, we think that the emphasis should be on silvicutture and have rephrased the questions to examine its role in ecosystem management. Our questions are:

1. What exactly does "ecosystem management' mean? And, what do we mean by a new beginning?

2. What is the role of science? And, What are the opportunities for silvicuttural research?

3. And, finally, What do we need to do to redeem our responsibilities?

WHAT EXACTLY DOES "ECOSYSTEM MANAGEMENT" MEAN? AND, WHAT DO WE MEAN BY A NEW BEGINNING?

First, What Exactly Does "Ecosystem Management Mean? Textbooks tell us that an ecosystem is a community of organisms and its environment that functions as an integrated unit. Ponds, rivers, rotting logs, mountains, and the planet earth are ecosystems. So are forest trees, forest stands, forests, and forested landscapes. We also know that ecosystems occur at many different scales, from micro sites to the biosphere. That they are constantly changing in species composition, structure, and function over time. And, that ecosystems generally do not have natural boundaries, but grade into a matrix of larger ecosystems.

Webster's dictionary defines management as the act or art of handling or directing something with a degree of skill. Thus, to the siivicutturist, "ecosystem management" could be defined as: the use of science, skill and care in handling forest vegetation and its environments. As silviculturists have always been concerned with the management of forest ecosystems, but usually for specific purposes such as: producing, restoring, or sustaining certain ecological conditions; desired resource uses and products; vital environmental services; and aesthetic, cultural, or spiritual values.

What Do We Mean By A New Beginning? Or, do we really mean renewed responsibiliies for silviculturists as we adapt an ecosystem approach to managing our forests. This question can be answered by referring to some of our traditional textbooks and reviewing some of the major societal changes that have a affected our work. The following quotes and historical trends may be generally known, but it is useful to revisit them. First, let's compare what we interpret as the purpose of silvicutture as expressed by Giiord Pinchot with more recent writers such as Hawley and Smith; and Daniel, Helms and Baker. In his book Breakina New Ground (1947), Pinchot tells us that:

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> "One of our first jobs was to go and find out about what we named the silvics of our trees, by which we meant their behavior as they grew in the forest. We needed to know their rate of growth in height and diameter, the amount of wood or lumber produced by a tree or an acre; the coming of seed years; the tolerance of young seedlings for shade and sunlight; and all of the other facts, necessary but then unknown, about the reproduction and growth of dozens and dozens of important forest trees. We had to learn that we might practice (emphasis added)."

Clearly our early management focus and research agenda centered around the production of wood crops. This role served us and society well. However the winds of change were gaining momentum as expressed by Hawley and Smith in the 6th edition of The Practice of Silviculture (1954) where they state that the purpose of silviculture is:

> "...the production and maintenance of such a forest as will best fulfill the objectives of the owner and yield him the highest return in a given time. Returns from silviculture are generally thought of in terms of wood production, although it is not uncommon for owners of forests to have diverse objectives, which do not necessarily include growing wood."

Hawley and Smith also suggested the idea of sustaining productivity, conserving biodiversity, and maintaining forest health by writing that:

> "It must be understood that good silviculture and, in a larger sense, forestry itself require single-minded acceptance of a long-range viewpoint that recognizes the necessity of building up and maintaining a permanent forest. This involves operating in such a way that productivity of the site is not impaired and the health of the forest and its safety from destruction are preserved."

Finally, in the 2nd ediion of Principles of Silviculture. (1979), Daniel, Helms, and Baker continue to describe this evolution of thought about the changing role of silviculture with their observation that:

> "In the last three decades, considerable changes have occurred in the evolution of the forestry profession. These are primarily due to changes in society, of which forestry is an integral part. Foresters and society as a whole have entered a new era of general concern for conservation, which means 'wise use," of our natural resources. In addition, society is rightly expecting its forests to produce more that just wood products. Sustained and efficient wood production is still the prime objective in forestry, but this must be achieved simultaneous/y with increase outputs of high-quality water, wildlife, recreation, and aesthetics, and without environmental degradation."

With these textbook references in mind, lets now take another brief look at some of the social changes discussed by Stewart (1995) that have effected natural resource management policies and our silvicultural research priorities over the last 40 to 50 years.

Until the latter part of the 1960's, the primary focus of forest management in the United States was on improving yields of timber outputs to meet society's needs. We practiced "good" forestry to produce fast growing, healthy stands of commercially valuable trees. Forest managers were concerned with the rapid establishment of regeneration, maintaining fully stocked stands, harvesting schedules, and improvement activities to increase yields. Our research was focused on developing technology to manage, protect and utilize the timber resource. We considered other values, such as wildlife or water quality, but frequently only to the degree that they did not conflict with timber production objectives. We were asked to provide the technology to maximize timber production and we did an outstanding job.

It is an understatement to say that times have changed. The environmental movements of the 60's and 70's together with the passage of the National Forest Management Act in 1976 signaled our growing awareness of human impacts on the environment and the importance of managing forests for purposes beyond timber production and other commodity outputs. A report by the National Academy of Science's National Research Council (1990) called this change a "New environmental paradigm." Public interest in the environment had reached the point where a larger, more diverse population was taking an active role in planning the management, use and protection of "their" forest resources.

And, in the early 90's, ecosystem management evolved as public concern about the environment, together with the new thinking by scientists and resource managers, led to a new philosophy about how we manage forest resources. This philosophy says that we can manage forest lands to sustain their full array of values and uses for current and future generations. But this calls for changes in the traditional ways of managing resources. It is an attitude, an approach, and a philosophy about how we carry out sustainable forest management.

This ecosystem management philosophy includes two elements of particular interest to this conference. First, it implies a specific goal of sustainability. And, second, it legitimatizes our understanding of silviculture, that is, "...the production and maintenance of such a forest as will best fulfill the objectives of the owner . .." Silviculture

has always had a landscape objective, but the focus on timber production in the 50's and 60's as the primary land management objective interrupted the broader landscape perspective. Maximizing timber production was the unifying concept of the past, but we now have a larger unifying concept, that is, managing forest vegetation to sustain forest productivity and maintain forest health for people. Our working circle is larger-it includes tradition silviculture research of the past and more.

WHY IS SCIENCE IMPORTANT? AND, WHAT ARE THE OPPORTUNITIES FOR SILVICULTURAL RESEARCH?

What Is The Role Of Science? At a Congressional hearing in Washington, DC, last February, Forest Service Chief Jack Ward Thomas said the following about the role of science in resource management:

> "The underpinning of good resource management by the Forest Service has been and will be science. Through science, we can describe options for addressing management problems and provide assessments of their consequences. But science simply will not and can not give society "the answer." Science is only a tool-in the end, all managerial decisions are moral, not technical."

Developing this technical underpinning for ecosystem management will require not only sound science, but the right science-knowledge and understanding of how major ecosystems function, how they can support human use, and how policies and management decisions affect resource use, environmental impacts, and recovery.

To support ecosystem management, scientific understanding of how ecosystems work is absolutely essential. To take an ecological approach to management of the Nation's forest resources-requires knowledge of ecological structure, function, processes, multiple-stress responses, and potential for recovery, at multiple scales in space and time. Understanding the way that large systems function over long periods of time is critical to sustainable management of forest ecosystems. Contributing to this knowledge base is the challenge to silvicultural research as we enter the 21st century.

What Are The Opportunities For Silvicultural Research? Silvicultural research has a long record of providing scientific information and guidelines for maintaining and sustaining productive forests for the citizens of the United States and beyond. Our research programs have emphasized the production aspects of forest management to meet the demands for forest products by an ever expanding society. In addition to this role, research has also quietly pioneered some of the modern ecological framework for solving the complex problems facing forest managers today. Basic and applied silvicultural research has resulted in a better understanding of the ecological, physiological, and genetic factors that control the development of individual trees, stands, and forests, and associated ecosystems on a variety of landscapes from temperate and tropical forests to arid lands.

However, the complexity of ecosystem management challenges all of us to change the way we approach and carry out our silvicultural tasks. A recent discussion of this change relative to the practice of silviculture, is provided in an article by O'Hare, Seymour, Tesch and Guldin entitled, "Silviculture and Our Changing Profession" (1994). For this discussion, we will refer to a number of recurrent science issues that represent opportunities for silvicultural research. They are:

Ecology at Multiple Scales: There is a well-known discrepancy between the typically small plot, usually less than an acre, generally utilized in forestry research and the larger geographic scales at which ecosystems are expected to be managed. Although small-scale studies provide a basis for understanding some of the functions of larger ecosystems, there is a critical need for applied silvicultural research at watershed and larger landscape scales such as the Ouachita National Forest ecosystem project.

Multiple Species **Science:** A great deal is known about the silvics of single species, but very little about the interactions between species, groups of species, and the site or habitat that supports them. Silvicultural research can provide a much better understanding of what determines site (habitat) quality, how it is created, maintained, restored and destroyed, the timing and effects of natural variability, and how it is altered by human disturbance.

Benchmarks of Ecosystem Condition: There is a shortage of methods for comparing degraded ecosystems with fully functioning ecosystems. These "benchmarks" include fully functional reference sites, measurable indicators of ecosystem condition, and measures of progress by which ecosystem management can be evaluated and modified. Development of these indicators and measures offer considerable opportunity for silvicultural research. We have an opportunity here to expand the use of our Research Natural Areas, Long-term Ecological Reserves, experimental forests and other research areas.

Ecological Restoration Technology Development: There has been very little interest in restoration research to date, probably because

there has been very little funding for this activity and a limited market for the technology. But thii situation is changing, for example, in the South with the increasing interest in restoration of the longleaf pine ecosystem.

Monitoring and Evaluation: Ecological monitoring is an indispensable part of ecosystem management yet we lack accepted protocols and data applicable to monitoring large-scale projects. The long-term nature of much of our silvicultural research, especially studies of cutting methods, soil productivii, growth and yield, and genetic improvement, provide us with an opportunity to make a significant contribution to the solution of this problem.

Quantifying Uncertainty and Assessing Risk: Silvicultural research can make a major contribution to ecosystem management by helping to explain cause-effect relationships. We have the expertise and long-term research experience to develop ecological risk assessment models and data bases for assessing the key ecological consequences of various silvicultural options.

Modeling: The limitations of our current modeling capability in support of ecosystem management are again related to scale and species. In silviculture for example, most of our modeling has addressed the growth and yield of commercial species in even-aged forest stands. Many of our current models of growth and stand development could be linked and extended to watershed and other larger landscapes. We have the expertise and experience to develop simulation models to predict changes in ecosystem function and productivity relative to changes in land use or changes in silvicultural approach. Particular effort should be dedicated to the development of decision support systems. We also have the capabilii to develop conceptual models to guide and coordinate our research activities.

Human Dimensions of Natural Resource Use: As we consider the management of natural resources it is clear that the needs of people dictate the use and the misuse of our forest ecosystems. Efforts to understand the role of people in natural resource management have been minimal, yet most controversies and shortages ultimately arise from human activity. You know better than anyone else the importance of private landowners in managing the South's forest ecosystems. Perhaps silviculturists should take a proactive role in working with social scientists to better understand the human-natural resource interactions.

Adaptive Management: Adaptive management provides one of the best, if not the best, opportunity for silvicuttural research to contribute to the implementation of ecosystem management. It is appropriate because our understanding of ecosystems is not, and may never be, complete. Since ecosystem management must continually rely on the "best" science available, adaptive management gives us an opportunity to rapidly incorporate new silvicultural knowledge into action. It also gives us reason to monitor results and evaluate outcomes of our guidelines and prescriptions. Adaptive management is a relatively straightforward concept, but its application requires a science-based understanding of cause-and-effect relationships in both the biological and social systems.

We think that you will generally agree that these research activities are fundamental to advancing the concept and application of ecosystem management. These activities are the "WHAT' of silvicultural research in support of the ecosystem approach. The primary hurdle that we and other research disciplines face are a broad range of questions about the "HOW?" In answering the "HOW' we will now address the third major question presented at the beginning of thii paper:

WHAT DO WE NEED TO DO TO REDEEM OUR RESPONSIBILITIES?

Redeeming our responsibilities in establishing a role for silviculture in implementing ecosystem management should not be a difficult struggle! As scientists, you have spent your entire professional lives redeeming your responsibilities for conducting sound research. However, the focus is changing and so should the way we plan and conduct our research. We are suggesting a thorough reassessment of the way you conduct silviculture research by systematically addressing the following questions:

- How do you organize for and attack complex ecosystem research questions?
- How do you identify the pieces and which ones can you work on?
- How do you fit an enormous number of pieces together in a useful and efficient manner with the tasks and work force available?
- How do you incorporate individual pieces of information from a range of sources and disciplines into a comprehensive research program to better understand ecosystems?

- How do you adequately plan for and meet analytical and decision making needs across a range of landscapes, numerous jurisdictions and ownerships, time frames, and levels of detail that satisfy individual interests?

- How do you foster cooperative efforts between natural and social scientists?

- And, How do you overcome the budget, political and bureaucratic constraints and the many other non-scientific factors that often influence the content of your research programs?

We all can agree that forest ecosystems are incredibly complex and that it is highly unlikely that we will ever completely understand how they function. We have however, developed an impressive depth of knowledge about forest vegetation and its management, especially at the stand level. We must build on this collective knowledge to address both the WHAT and the HOW of ecosystems research as we design our silvicultural programs for the 21st century.

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THE ENDANGERED SPECIES ACT AND ITS IMPACTS ON SILVICULTURE'

Rhett Johnson'

Abstract-Ths Endangered Species Act as it is presently constituted and enforced can Pose problems for many silvicultural activities. Threats to protected species most frequently are in the form of adverse modification of ctitiil habitat. Efforts to mitigate unavoidable conflicts or to alter operations to minimize impacts present possibilites for compromise. Incomptible silvicultural objectives may be permitted by the Habitat Conservation Plan Process. Early cooperative efforts by all involved parties offer the best chance for successful conflict resolutii.

INTRODUCTION

The Endangered Species Act has been termed the most powerful environmental legislation in the history of the United States. It has also been called the "pit bull of environmental law". Few communities have been forced to deal with its provisions more often than the forestry community. The impact of efforts to protect and, ultimately, recover threatened plant and animal species has been felt across the nation by a broad spectrum of citizens and groups, but the natural link between forest management and habitat puts forestry and silviculture squarely in the sights of the Endangered Species Act Horror stones abound, with tales of wasteful government spending, infringement on private property rights, "politically correct" but scientifically unsound court decisions, abandoned or radically altered development plans, and costly rulings that seem to favor animal and plant welfare over that of humans. Proponents argue that most of these stories are simply over-reactions and hyperbole, or that harsh actions may be warranted and even necessary to preserve the health of the planet. The truth, as usual, probably lies somewhere between these extremes. Is the act abused or misused? Probably so, in many instances. Do egregious transgressions occur deliberately2 Again, probably so. Does a sensible middle ground exist which affords necessary protections for the environment on the limited species scale as well as a larger ecosystem scale while allowing society to use its natural resources for its own ends? That remains to be seen, with many on both sides of the issue holding out for the whole loaf or none, much like the debates over gun control and the First Amendment right to free speech.

A RATIONALE FOR AN ENDANGERED SPECIES ACT

Do we need an Endangered Species Act? I contend that we do and, borrowing on a philosophy proposed by Steve Carey of the University of Mobile at a 1992 Alabama Wildlife Federation Endangered Species Symposium, here's why I feel that way. I can think of three good reasons for a protective act for species of plants and animals in danger of extinction. Some, possibly many, species have potentially valuable roles to play in our lives by contributing to our knowledge of medicines or other helpful chemicals or natural processes. The Pacific yew, whose bark contains a substance dubbed taxol, with apparently potent cancer fighting properties, comes to mind immediately. The Eastern indigo snake, a protected species, is immune to the venom of all species of North American snakes. The prospect of adding that protection to our medicine chest is appealing and would be severely diminished if the indigo slips into the oblivion of extinction. We can't retroactively recover them, only God can make a species out of whole cloth.

On a less selfish note, some species function as "keystone" species, upon which whole ecosystems hinge. One that comes to mind here in the Southeast is the gopher tortoise. This terrestrial turtle, closely akin to the desert tortoise, is indigenous to the deep sandy ridges of the South, where it excavates long sloping burrows to provide it protection from its enemies and to escape the rigors of torrid summer days and chilly winters. The burrows, often 30 feet long and 8 to 9 feet deep, remain at a fairly constant and moderate temperature throughout the year and attract a community of commensal animals dependent on its existence. The Eastern indigo snake, the diamondback rattlesnake, the dusky gopher frog, and a group of some 80 or so species are dependent on or use gopher tortoise burrows as a vital component in their environment. The loss of the gopher tortoise and, subsequently, its burrow would likely mean the loss of that entire community.

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The third reason I think we must have an endangered species act is the weakest one, the one least supported by science, yet the one perhaps best understood by the general public. We, as a society, have indicated through our chosen representatives, that we do not wish to be the cause of the loss of plant and animal species. The species most often identified with this intrinsic set of values are sometimes only hat-jokingly characterized as "charismatic megafauna". They include grizzly bears, bald eagles, California condors, whooping cranes, and Florida panthers. They do not include top knot snails, Furbish lousewort, fat pocketbook mussels, and others. There is little likelihood that these animals are potential suppliers of gallbladders or other organs to be exploited for the medicinal benefit of the human race. By and large, they have little ecological importance anymore. There are simply too few of them. If the last Florida panther passed away tomorrow, there would be no explosion of the prey populations they depend on. The ecosystem they function in is no longer affected significantly by their absence or presence. On the other hand, we have recognized the fact that we don't want to live in a world without grizzlies, bald eagles, black footed ferrets, and others and are willing to make sacrifices so that we won't have to.

CURRENT STATUS AND COSTS

Given that reasoning, where's the rub? Well, species are not being de-listed as fast as they are being added, and the list is growing at an unprecedented rate. As of July 1, 1994 there were 895 species native to the United States on the threatened and endangered list. There are currently, as of August II, 1994, 3,941 species proposed for listing. The Clinton administration has expressed a willingness to consider extending protection to non-listed candidate species. Only a handful of species have been removed from the list since 1970 and most of those because of erroneous listings. In July of 1994, 471 plants and 424 animals were listed under the provisions of the act. Thirty percent of those animals are invertebrates. The candidate list in August proposed 2,044 additional plants and 1,897 animals, over 70 percent of which are invertebrates (Gordon and Streeter, 1994). Not many "charismatic megafauna" in the group. A consequence of that is the fact that many of the proposed species are not only unfamiliar to the general public, but are poorly known to all but a select group of scientists, who often do not know very much about life histories, critical habitats, ranges, and ultimately, populations. The protection afforded to subspecies and populations, often poorly distinguishable, as well as distinct species, only complicates the political, economic. and biological debates that surround each listing.

The act is not infrequently invoked in an attempt to "monkey wrench" proposed activities by opponents of those projects. This is as true of silvicuttural activities as it is of highway or hydroelectric projects. The costs of saving a species are estimated in recovery plans, but are frequently wildly exceeded. For instance the estimated cost of recovery for the Florida scrub jay was exceeded by an estimated 33,340 percent in the first three years (Gordon and Streeter, 1994).

Many costs are not even calculated, much less made public prior to listing and critical habitat designation. In a directed study exercise with Steve Meyers, an Auburn University graduate student, this summer, we calculated the value of the timber on public lands taken off the market in perpetuity as a result of the red-cockaded woodpecker recovery effort. The recovery target for the red-cockaded woodpecker is 15 distinct geographical populations of at least 250 breeding pairs each. It is generally assumed that virtually all of those populations will be recovered on public lands, primarily U.S. Forest Service and Department of Defense lands. Current policy is to protect the immediate colony site for each group of birds, each containing only one breeding pair, as well as a potential replacement colony site should the active one be destroyed by natural or other causes. Using the set of assumptions listed in Table 1, we arrived at what we considered some fairly astounding figures. Based on those assumptions, which are not unrealistic and conservative in every instance, timber foregone for just those two practices (protecting the cluster site and providing a protected replacement stand), for just one species, would be valued at somewhere between $241,875,000 and $360,000,000! Drawing on a statement attributed to the late Illinois Senator Everett Dirksen, "A few million here and a few million there, and, before you know it, you're talking about real money."

SILVICULTURAL IMPACTS

Now, how does this impact specifically on the practice of silviculture? The profession has often viewed the Endangered Species Act as antagonistic to its own interests. There are any number of instances where conflict can and does occur. Almost every silvicultural practice is fraught with the possibility of violating the Endangered Species Act. Harvests, particularly clearcuts, frequently draw the ire of preservationists and like-minded activists and certainly give the impression that they are inimical to any nearby endangered species and its habitat. Harvesting is at the very heart of controversies over the spotted owl and the red-cockaded woodpecker, both strongly associated with mature forests. Both are afforded protection through protection of their habitat. Extended rotation lengths, admittedly on diierent temporal and spatial scales, and severely restricted harvests in relatively large blocks of critical habitat are parts of the recovery plans for both species. For red-cockaded woodpeckers in the south, elaborate schemes have been developed to provide foraging and nesting habitat for the birds on public and private lands while still allowing production of some reduced timber supply and associated income. On public lands, basal areas are assiduously monitored

Table 1. List of Assumptions and Calculations - RCW opportunity costs for protecting cavity sites and replacement stands

Recovery targets	15 populations of 250 breeding pairs' each.
Number of protected clusters and replacement stands	3,750[2]
Average protected cluster size	10 acres
Average acreage in replacement stands	10 acres'
Acres protected in cluster sites and replacement stands	75,000
Target basal area in protected sites/stands	60 -90 ft^2/Acre
Average tree size and form class	16 inches DBH, 3 logs, FC 80[4]
Average tree volume	150 board feet (Doyle)
Trees per acre' at BA 60, BA 70, BA 80 & BA 90	43, 50, 57, 64
Average volume protected per group'	129 MBF (Doyle) @ BA 60 to 192 MBF (Doyle) @ BA 90
Timber Stumpage Values'	50 % Pine Poles/50 % Sawtimber - $500.00/MBF (Doyle)
Average timber value foregone per group	$64,500 @ BA 60 $96,000 @ BA 90

'Minimal number - some sites would be protected to assure 250 minimum, others would be "single bird groups", also afforded protection.
[2]Minimal - (250 X 15), see previous note.
[3]An absolute minimum.
'Conservative, particularly if species is longleaf.
'Based on average DBH of 16".
[6]Cluster site and replacement stand.
'Representative stumpage prices from Timber Mart South over past three years.

and timber harvested accordingly to provide forest conditions that favor the woodpeckers. Non-commercial hardwood midstory removal is commonly practiced in colony or cluster sites and prescribed burns are tailored to fit the birds habitat preferences. As previously mentioned, some stands are retained to provide present and future nesting habitat, others are regenerated using a variety of means but with a preference for modified shelterwood systems which retain some residual seed trees through the life of the next generation, despite evidence that that practice can retard growth and yield.

Harvesting, even intermediate cuts, in and immediately adjacent to red hills salamander habitat poses a different kind of threat to that species. Even if excessive erosion and soil disturbance is avoided, the potential for windthrow and/or subsequent drying of the site threatens habitat suitability for the moist soil loving salamander. International Paper Company, owner of a large portion of the limited range of the salamander in Alabama, has recently completed a habitat conservation plan which will allow management to proceed on some marginal salamander habitat, possibly resulting in limited permitted "incidental take", while providing complete protection in the prime habitat areas (McGlincey, et al, 1993). This approach is open to all affected landowners, but becomes problematic for those with small landholdings, with little opportunity to offer lands in mitigation. Statewide HCP's for red-cockaded woodpeckers, intended to offer blanket relief to private landowners whose objectives are compromised by the presence of the woodpeckers, are currently being developed in Alabama, Georgia, and South Carolina.

Aquatic species protected by the act typically impact on silvicultural activities only where operations change water quality. Strict adherence to existing BMP's and herbicide and pesticide labels typically can relieve forest managers of most concerns about Section 9 "taking" violations in regard to those species. Sedimentation, excessive woody debris, elevated water temperature, and chemical run-off are the most commonly cited concerns by Fish & Wildlife Service biologists when dealing with forest managers and mussels, fish and other aquatic species.

Plants, of course, make up a large number of the species protected by the Endangered Species Act. They are obviously potentially effected by herbicides, but also by harvests, fire, and other site and soil disturbance. Activities which change hydrology and/or sunlight levels are more likely to cause significant harm to plants than actual mechanical damage. For instance, some species require deep shade and moist soils, while others respond well to release. Pitcher plants often respond positively to clearcutting, when removal of the overstory admits not only sunlight, but causes a rise in the water table. Bog communities are also dependent on fire to control competing woody vegetation and languish in its absence. Fire lines which alter the hydrology of these sites even marginally can be fatal to the pitcher plants, however. Protection of endangered and threatened plants is mandatory on public lands. On private lands, a "take" is triggered only when a state law, such as a trespass law or a state endangered species statute, is violated (Quarles, Macleod, and Lundquist, 1991). EPA is in the process of developing county wide range maps for endangered species for herbicide applicators on private lands.

In the case of the Louisiana Black Bear, anticipating a decision to list the sub-species, forest industry and other interested parties began to study the bear's habits and habitat. When the bear was eventually listed, a special Section 4 (d) exemption was granted to exclude most forestry practices from prohibited habiiat modifications. Research had indicated that managed

forests, particularly the early successional stages following regeneration harvests, were critical components in the bear's habitat. Bottomland hardwood conversion to farmland or pines posed the greatest threat among forest practices and is restricted. Gopher tortoises and, by association, the accompanying suite of associated species, are naturally adapted to the grassy open pine savannas and sunlit forest floors maintained by frequent fire and selective harvests or other disturbances. Most research into the animals' biological needs and choices also indicate that they adapt very well to young pine plantations prior to complete crown closure. The herbaceous forage close to the ground and the abundance of sunny open spots for nest incubation suit their habit needs perfectly, particularly if longleaf pine is the species chosen for planting. Its open growth form delays crown closure for several years and its tolerance of fire allows use of that tool to control woody brush, detrimental to the qualii of gopher habit.

No doubt, the habitat needs of many other protected species can be integrated into sound and ongoing silvicuttural operations. Others, like the red hill salamander, offer liie opportunity to accommodate both forestry operations and habitat protection. The continued listing and proposal for listing of poorly known and understood species poses other problems for managers; as scientists, foresters, environmentalists and others struggle over the listing process and the identification of real habit needs. Today's critical habitat may be discarded tomorrow as research broadens understanding, but the trend has been to protect more than is necessary as a precaution, and to add to, not take away, restrictions on land use. I'll close with a quote from theologian and novelist C.S. Lewis, "Of all tyrannies, a tyranny exercised for the good of its victims may be the most oppressive. It may be better to live under robber barons than under omnipotent moral busybodies."

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Ecosystem Management

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SMALL MAMMAL AND AVIAN COMMUNITIES ON CHEMICALLY-PREPARED SITES IN THE GEORGIA SANDHILLS'

Jeffrey J. Brooks, Jane L. Rodrigue, Marcia A. Cone, Karl V. Miller, Brian R. Chapman, and A. Sydney Johnson'

Abstract—The effects of **3 forestry herbicide site preparation treatments (hexazinone, picloram + trklopyr, and imazapyr) on small mammal and avian cornmunitii were compared at pm-treatment, and 1, 2, and 3 years post-treatment.** Few **differences in small mammal capture rates occurred among treatments. Capture rates declined imrnediitely following site preparation, but returned to pre-treatment levels by 18 months post-treatment.** The **greatest winter avian abundance occurred at 3 years post-treatment; however, no differences in winter avian abundance were observed among treatments. In year 3 post-treatment, summer birds favoring forest edge + scrub habitats were higher on hexazinone-treated sites. Summer avian abundance was strongly associated with residual woody vegetation.**

INTRODUCTION

Although most herbicides are relatively non-toxic to wildlife (Newton and Norris **1976),** their use can indirectly impact wildlife species through altering habit **conditions.** Several authors have reported the importance of vegetative structure and composition as factors influencing small mammal and avian populations (Dueser and Shugart 1978; Geier and Best 1980; MacArthur and MacArthur 1961; Meyers and Johnson 1978). The selectivity of various herbicides may have varying effects on habitat conditions for some **wildlife** species. The objective of this study was to compare the abundance and composition of small mammal and avian populations among 3 herbicide treatments.

STUDY AREA AND METHODS

The study area was a **157-hectare** tract located in the Sandhills **physiographic** region of Marion County, Georgia. After **a** timber harvest in 1989, residual hardwoods remained on approximately 30 percent of the area. A thorough description of the study area and small mammal sampling methods can be found in Brooks (1992) and Rodrigue (1994).

A randomized complete block design was established with 3 replications of 3 treatments. Treatment plots ranged in size from **15-20** hectares. Treatments consisted of hexazinone **(Pronone™)--16.3** kgs. **a.i./ha,** picloram + 2,4-D (Tordon **101™)--2.7** kgs. **a.e./ha** + triclopyr (Garlon **4™)--10.9** kgs. **a.e./ha,** and imazapyr **(Arsenal™)--4.1** kgs. **a.e./ha.** The hexazinone treatment was broadcast in May 1990; then in August 1990, the other 2 treatments were broadcast sprayed in a total volume of 70 **liters/ha.** Prescribed burning in October 1990 completed site preparation, and in January 1991, 1-0 **loblolly** pine (***Pinustaeda***) seedlings were hand-planted at a 1.8-X 2.4-m spacing.

Small mammals were sampled by removal with snaptraps. Trapping dates in May were pm-treatment and at 1 and 3 years post-treatment, while August and February trap dates were at **1, 2,** and 3 years **post-**treatment.

Winter bird surveys were conducted during December, January, and February at 2 and 3 years post-treatment. One transect was established near the center of each treatment plot with observation points flagged at 50-m intervals along the transect. The observer recorded all birds seen or heard within a 25-m radius of the observation point for a period of 5 minutes. In addition, at 2 and 3 years post-treatment, all woody stems within the 25-m radius circle were recorded by height and diameter at breast height (DBH). All surveys were conducted during the morning on days with little wind **(<** 10 kph) and no rain.

In May, June, and July, at 2 and 3 years **post-**treatment, surveys were conducted from a central observation point within the treatment plot. All birds seen or heard within a 100-m radius of the observation point were recorded.

ANALYSIS

A two-way analysis of variance **(ANOVA)** was used to determine significant differences in small mammal

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abundance, avian abundance, and vegetation parameters. Means were separated with Duncan's Multiple Range Test and multiple regression analysis was used to compare mean avian abundance with stems and snags. The Shannon-Wiener index (H'), evenness index (J), and mean number of species was used to evaluate species diversity (Magurran 1988).

Birds were analyzed not only by total numbers, but also migratory status and habit associations. Four habitat association groups were established: forest interior specialists, forest interior + forest edge, forest edge + scrub, and forest edge + field.

RESULTS AND DISCUSSION

Small Mammals

We captured 1,060 mammals representing 8 species in 14,520 trapnights. *Peromyscus* spp. accounted for 83 percent of the total. Mammals captured include oldfield mice *(P. polionotus),* cotton mice *(P. gossypinus),* white-footed mice *(P. leucopus),* golden mice *(Ochrotomys nuttalli),* cotton rats (Sigmodon hispidus), harvest mice *(Reithrodontomys humulis),* house mice *(Mus musculus),* and least shrews *(Cryptotis parve).*

Following treatment, capture rates declined until February 1992 when captures more than doubled over any previous sampling period (Table 1). The only treatment difference occurred in February 1992 for oldfield mice which were significantly lower in abundance on pidoram + triclopyr-treated plots. Capture rates of oldfield mice were positively correlated with grass abundance, while cotton mice and golden mice were captured most frequently in areas with woody vegetation (Brooks 1992). The hexazinone and picloram + triclopyr plots had the greatest abundance of woody vegetation for all 3 years post-treatment (Brooks 1992; Rodrigue 1994). Capture rates of oldfield mice, which prefer open, grassy areas, were consistently lower on the pidoram + triclopyr sites which was likely a result of the higher density of woody vegetation.

Table l-Mean number of small mammal captures per 100 trapnights on chemically-prepared sites, Marion County, Georgia, 1990-I 993

	Treatment		
Trap Date	Hexazinone	Picl + Tric	Imazapyr
5/90 (Pre-treat)	8.9	8.7	10.0
2/91	7.6	12.4	8.1
			1.2
8/91	1.8	2.5	0.9
2/92	20.0	20.5	23.5
8/92	4.0	3.7	4.2
2/93	11.4	12.2	13.3
5/93	3.7	6.4	5.0
8/93	0.7	2.7	1.8

Avian Community

Fifi bird species were identified during both winter and summer surveys. There were no significant differences in winter avian abundance among treatments (Table 2). However, for summer birds of the forest interior + edge and forest edge + scrub groups, avian abundance was different ($P < 0.05$) among treatments (Table 3). The greater abundance of forest interior + edge species found on imazapyr-treated sites is likely a result of a higher density of residual snags remaining on these areas, while the higher abundance of forest edge + scrub species on hexazinone-treated plots may be attributed to a greater density of shrubs, particularly sparkleberry *(Veccinium arboreum)* and sassafras *(Sassafras albidum)* on these sites (Brooks 1992).

Table 2-Winter avian density by habitat association group on chemically-prepared sites at 2 and 3 years post-treatment, Marion County, Georgia (for each year, means within a column with the same letter are not significantly different ($P > 0.05$))

	Mean Avian Density (# birds/plot) Habitat Association Group			
Treatment For Int[1]	Int-Fdae	Edae-Scrub	Field-Em	
1991-92				
Imazapyr	O.OOA	0.26A	0.09A	0.00A
Pid + Tric	O.OOA	0.08A	0.39A	0.59A
Hexazinone	O.OOA	0.07A	0.26A	0.26A
1992-93				
Imazapyr	O.OOA	0.44A	0.50A	0.28A
Picl + Tric	0.07A	0.51A	0.76A	0.13A
Hexazinone	0.02A	0.38A	0.55A	0.31A

'For Int = forest interior specialists: Int-Edae = forest interior/ edge generalists; Edge-Scrub = edge/scrub species; Field-Edge = field/edge species (Whitcomb et al. 1981).

Table 3-Summer avian density by habit association group on chemically-prepared sites at 2 and 3 years post-treatment, Marion County, Georgia (for each year, means within a column with the same letter are not significantly diierent ($P > 0.05$))

	Mean Avian Density (# birds/plot) Habitat Association Group			
Treatment For Int	Int-Edae	Edge-Scrub	Field-Edge	
1991-92				
Imazapyr	0.09A	5.09A	4.35A	2.00A
Pid + Tric	O.OOA	4.26AB	3.70A	1.57A
Hexazinone	O.OOA	2.438	4.74A	2.91A
1992-93				
Imazapyr	0.20A	4.93A	4.80A	2.67A
Picl + Tric	0.07A	5.00A	3.408	2.37A
Hexazinone	0.03A	2.408	5.90A	2.47A

Avian species diversity (H'), during winter and summer, did not differ between years or among treatments although summer bird communities had higher diversity values as well as a greater abundance than winter bird communities (Table 4). Tramer (1968) and McComb and Rumsey (1983) reported similar findings. Meyers and Johnson (1978) demonstrated that density and species diversity are highly correlated in breeding bird communities.

Table 4-Bird species diversity at 2 and 3 years following chemical site preparation, Marion County, Georgia (Within a row, means with the same letter are not significantly different (P > 0.05))

	Treatment		
Index[1]	Imazapyr	Picl + Tric	Hexazinone
Winter 1991-92			
H'	1.4A	1.2A	0.5A
J'	0.9AB	0.9A	1.0B
n	1.7	4.0	1.3
Winter 1992-93			
H'	1.0A	0.8A	1.4A
J'	0.9A	0.8A	1.0A
n	4.0	4.0	4.3
Summer 1992			
H'	2.7A	2.5A	2.4A
J'	0.9A	0.9A	0.9A
n	21.7	19.3	16.7
Summer 1993			
H'	2.8A	2.7A	2.4A
J'	0.9AB	0.9A	0.88
n	22.3	21.0	18.0

[1] H' = Shannon-Wiener Diversity; J' = Shannon Evenness; n = mean number of species per treatment plot

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

All treatments initially reduced small mammal abundance though population recovery was apparent 18 months post-treatment. With the exception of oldfield mice (February 1992), no treatment effects were observed. Small mammal capture rates were correlated with vegetative characteristics (Brooks 1992), but the variabilii within treatments and unassessed microsite conditions may have contributed to the inabilii to demonstrate a treatment difference. The choice of site preparation method may influence small mammal populations by altering vegetation composition and structure; however, these effects likely decrease over time.

The significance of residual hardwoods to songbird use has been demonstrated in other studies. Structurally diverse sites should support a greater abundance and diversity of avian species. Therefore, the number of hardwoods remaining after harvest may be more critical to avian habitat selection than the herbicide used.

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SILVICULTURAL CONSIDERATIONS IN LIGHT OF POPULATION TRENDS FOR NEOTROPICAL MIGRATORY BIRDS WITH SPECIAL REFERENCE TO THE KISATCHIE NATIONAL FOREST, LOUISIANA'

Bernard R. Parresol, Margaret S. Devall and Robert X. Barry[2]

Abstract—Silvicultural practices can have a direct bearing on distribution and abundance of neotropical migratory birds (NTMB). The Kisatchie National Forest (KNF) of north and central Louisiana has 118 species of NTMB in 9 orders. An analysis of breeding bird survey data for 1966-1989 of these 118 species in Louisiana shows 11 species with no change, 33 with nonsignificant increases, 12 with significant increases, 32 with nonsignificant decreases, and 10 with significant decreases. There was insufficient information to classify 20 species. It is recommended the KNF acquire or increase the percentage of hardwood and/or mixed forests because these habiits are the most suitable for the majority of NTMB of concern, and to decrease the amount of forest edge to reduce nest predation and parasitism of forest-interior species.

INTRODUCTION

Recently, evaluations of breeding bird population data have indicated that populations of neotropical migratory birds (NTMB) have undergone declines in many areas of North America (Robbins and others 1986). The combined effects of forest fragmentation on the breeding grounds, tropical deforestation in wintering areas, and other habitat changes have been suggested as primary factors responsible for these declines (Barry and others, in press). The USDA Forest Service is a lead agency in the National Fiih and Wildlife Foundation's Neotropical Migratory Bird Conservation Program, because the National Forest System includes the largest amount of breeding habitat for forest-dwelling neotropical migrants in the country. The Kisatchie National Forest (KNF) of Louisiana includes approximately 600,000 acres, and provides breeding habitat for numerous NTMB.

Silvicultural practices can directly influence the distribution and abundance of NTMB. Timber harvesting radically changes bird habitat and consequently bird communities (Dickson and others 1993). Clearcutting often causes a nearly complete change of bird species, while partial removal of the forest overstory may result in a decrease, increase, or little change in relative abundance (Webb and others 1977; Crawford and others 1981; Thompson and others 1992).

POPULATION TRENDS

Annual breeding-bird surveys seem to indicate that population declines are widespread (Robbins and others 1989). For example, Hill and Hagan (1991) analyzed 53 years of spring-migration data for migrants in eastern Massachusetts and concluded that overall population trends are negative. However, mature forest species are not undergoing declines in all land management units. During 1982-83 Wilcove (1988) repeated breeding-bird censuses that had been conducted in 1947-48 and found that neotropical migrant populations of the Great Smoky Mountains did not show any significant changes.

The KNF of north and central Louisiana (figure 1) has 118 species of NTMB in 9 orders. An analysis by the linear route-regression method of Geissler and Noon (1981) of breeding bird survey (BBS) data' for 1966-1989 of these 118 species in Louisiana show 11 species with no change, 33 with nonsignificant increases, 12 with significant increases, 32 with nonsignificant decreases, and 10 with significant decreases. Significance was judged with an $\alpha=0.10$. There was insufficient information to classify 20 species. The 22 species showing significant changes are listed in table 1, along with their level of abundance. Note that 2/3 of the species showing a significant increase are already common while only 1/3 are listed as uncommon or rare, but 40 percent of those species showing a significant decrease are uncommon or rare, and need increased management attention. For those interested, detailed information on the BBS and other monitoring programs can be found in Robbins and others (1986) and Butcher and others (1993).

Hunter and others (1993) list 46 species of NTMB in need of increased conservation attention in the

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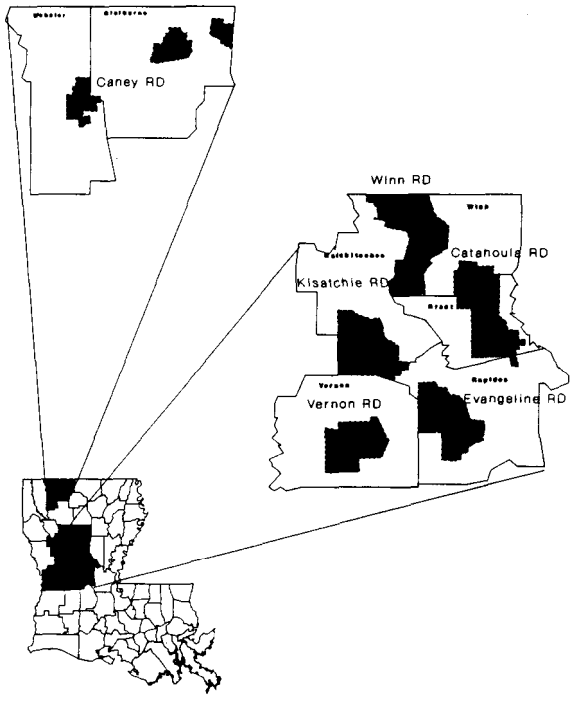

Figure 1 --Locatin of six ranger districts of the Kisatchie National Forest. RD=Ranger District. Parish names are given in small type.

Southeast based on the Partners in Flight species prioritization scheme. Of these 46 species, 28 occur on the KNF and are listed in table 2, along with their seasonal status. About 1/3 of the species in need of increased conservation attention (table 2) are not declining, however, all suffer from one or more of the following 3 problems (Hunter and others 1993): (1) limited distribution and a high degree of threat during breeding and/or non-breeding seasons, (2) widespread signs of recent or long-term decline, and/or (3) use of habitats within the Southeast Region that are essential for conservation of the full variation inherent within the species.

Two species in table 2 occur as accidentals, but one, Bachman's warbler, *Vermivora bachmanii*, may be extinct. A number of species, 25 percent, are transients. Several species listed in table 2 are worthy of mention because their rangewide population trends over the period 1966-89 were significantly negative. The eastern kingbird, *Tyrannus tyrannus,* cerulean warbler, *Dendroica cerulea*, prothonotary warbler, *Protonotaria citrea*, and orchard oriole, *Icterus spurius,* are generally known to be common summer residents in Louisiana and throughout their range. Not only have population trends for these passerines declined over their entire range during this period, but declines have been apparent for Louisiana as well.

Table l-Species on the Kisatchie National Forest, LA which show a significant population trend in Louisiana based on breeding bird survey data for 1966-89

Species	Population trend[a]	Species undance[b]
Osprey		
Pandion haliaetus	↑	UC
Yellow-bellied sapsucker		
Sphyrapicus varius	↓	A
Yellow-bellied flycatcher		
Empidonax flaviventris	↑	UC
Eastern kingbird		
Tyrannus tyrannus	↓	C
Tree swallow		
Tachycineta bicolor	↑	C
Barn swallow		
Hirundo rus tica	↑	C
Ruby-crowned kinglet		
Regulus calendula	↓	A
Cedar waxwing		
Bombycilla cedrorum	↑	C
Golden-winged warbler		
Vermivora chrysoptera	↓	UC
Yellow warbler		
Dendroica petechia	↑	C
Magnolia warbler		
Dendroica magnolia	↑	C
Yellow-throated warbler		
Dendroica dominica	t	C
Cerulean warbler		
Dendroica cerulea	↓	R
American Redstart		
Setophaga ruticilla	↑	C
Prothonotary warbler		
Protonotana citrea	↓	C
Worm-eating warbler		
Helmitheros vermivorous	↑	UC
Swainson's warbler		
Limnothlypis swainsonii	↑	R
Blue grosbeak		
Guiraca caerulea	↑	C
Vesper sparrow		
Pooecetes gramineus	↓	UC
Savannah sparrow		
Passerculus sandwichensis	↓	C
Grasshopper sparrow		
Ammodramus savannarum	↓	UC
Orchard Oriole		
Icterus spurius	↓	C

[a] Key to symbols: ↑=significant increase, ↓=significant decrease.
[b] Key to symbols: A=abundant, C=common, R=rare, UC=uncommon.

EFFECTS OF FOREST MANAGEMENT PRACTICES

Any species of wildlife is undeniably a product of its habitat and the juxtaposition of these habitats with the edaphic features in which they occur, hence alteration of the mosaic of habitat types on a forest will produce changes in the associated fauna. This section summarizes some of the published studies on the effects of silvicultural practices on the avifauna of forest ecosystems. This has direct bearing on management considerations for the KNF.

Two broad categories of timber stand management determine the way in which forest vegetation changes—even-aged and uneven-aged harvests. Under even-aged management, the main techniques are shelterwood, seed tree, and clearcutting. Even-aged management favors early seral stages and is most suitable for producing monotypic stands of timber. In a seed tree or shelterwood cut, all standing timber is not removed as in clearcutting, but these techniques produce essentially the same conditions. Uneven-aged management is basically accomplished through selective removal of single trees or groups of trees with as little disturbance to the surrounding timber as possible. Under this type of management, all seral stages are maintained at all times, but this technique is used almost exclusively on relatively small private holdings.

Succession of bird communities generally follows forest succession from early seral stages, produced through even-aged management, toward climax communities The reasons for the decline of these and other species may be difficult to ascertain because there is usually no common thread to follow. For instance, the eastern kingbird and orchard oriole prefer fairly open habitats with scattered hardwoods and nest within the canopy, but the cerulean warbler prefers mature hardwood stands with an open understory and the prothonotary warbler nests in cavities over water in wooded swamps.(Crawford and others 1981; Dickson and others 1984; Hodorff and others 1988; Johnston and Odum 1956; Meyers and Johnson 1978; Noon and others 1979). Clearcutting followed by site-preparation burning can eliminate habitats for most birds for a short period of time (Wood and Niles 1978). Forest-interior birds may be excluded for many years while the stand regenerates; however, most of these species do not make extensive use of pine-dominated, *Pinus* sp., stands. Conner and Adkisson (1975) found that after 1 year, a regeneration stand in a mixed oak, *Quercus* sp., woodland in southwestern Virginia had the lowest diversity of breeding birds among six stands in later successional stages. These authors also found that species diversity was highest in the regeneration stand 7 years after cutting and that forest-interior birds (wood thrushes, *Hylocichla mustelina*) were first recorded in a regeneration stand 12 years after cutting. Similarly, Conner and others (1979) found that species diversity

Table 2-Species on the Kisatchie National Forest, LA which need increased conservation attention

Order Species	Louisiana population trend 1966-89'	Seasonal status[b]
Falconiformes		
Amer. swallow-tailed kiie *Elanoides forficatus*	+	SR
Mississippi kite *Ictinia mississippiensis*	-	SR
Cuculiformes		
Black-billed cuckoo Coccyzus *erythropthalmus*	+	T
Yellow-billed cuckoo Coccyzus *americanus*		SR
Passeriformes		
Eastern wood pewee *Contopus virens*		SR
Acadian flycatcher *Empidonax virescens*	+	SR
Great crested flycatcher *Myiarchus crinitus*		SR
Wood thrush *Hylocichla mustelina*		SR
White-eyed vireo Vireo *griseus*		SR
Bell's vireo *Vireo belliiperipheral*		A
Yellow-throated vireo *Vireo flavifrons*	+	SR
Bachman's warbler *Vermivora bachmanii*	0	A
Blue-winged warbler *Vermivora pinus*		T
Golden-winged warbler *Vermivora chrysoptera*	↓	T
Chestnut-sided warbler *Dendroica pensylvanica*		T
Black-throated blue warbler *Dendroica caerulescens*	o	T
Blackburnian warbler *Dendroica fusca*	+	T
Prairie warbler *Dendroica discolor*		SR
Cerulean warbler *Dendroica cerulea*	↓	SR
Prothonotary warbler *Protonotaria citrea*	↓	SR
Worm-eating warbler *Helmitheros vermivorous*	↑	SR
Swainson's warbler *Limnothlypis swainsonii*	↑	SR
Louisiana waterthrush *Seiurus motacilla*	+	SR
Kentucky warbler *Oporonis formosus*	+	SR
Hooded warbler Wilsonia citrina	+	SR

Table 2-Continued

Order Species	Louisiana population trend 1966-89[a]	Seasonal status[b]
Passeriformes (continued)		
Canada warbler *Wilsonia canadensis*	-	T
Painted bunting *Passetina ciris*		SR
Orchard oriole *Icterus spurius*	↓	SR

[a] Key to symbols: ↑=significant increase, ↓=significant decrease, +=nonsignicant increase, -=nonsignificant decrease, o=no net change.
[b] Key to symbols: A=accidental, SR=summer resident, T=transient.

increased along the continuum of regeneration stands 3 to 30 years after cutting but decreased in mature stands. Three of the species from table 2, yellow-billed cuckoo, Coccyzus *americanus,* Acadian flycatcher, *Empidonax virescens,* and Louisiana waterthrush, *Seiurus motacilla*, occurred only in stands 30 years or more after cutting, but the wood thrush was found in regeneration stands as soon as 10 years after cutting.

Even-aged management is not without benefit to at least some species. For instance, American redstarts, *Setophaga ruticilla*, respond favorably to disturbed habitats (Tierington and others 1979; Webb and others 1977), and species that prefer open, mature pine stands would benefit. Seed tree and shelterwood cuts may not be favorable for most forest-interior bird species; however, these changes will be beneficial for a different set of community dominants and provide better foraging opportunities for species such as raptors (Noon and others 1979). Thompson and others (1992), however, found some of the forest-interior species to be more abundant in sapling or pole-sawtimber stands that had previously been clearcut than in stands with no recent harvest Those authors hypothesized that species such as the Kentucky warbler, *Oporomis formosus,* and worm-eating warbler, *Helmitheros vermivorus*, were keying on the high density of the woody stems present, even though the overstory was not mature.

The abundance, number, and diversity of species were found to be highest in interior-edge habitats on the border of clearcuts (Strelke and Dickson 1980), which indicates that some amount of clearcutting benefits at least some birds. Though this may be true on a landscape level, the same may not hold true at the stand level. If there is a large tract of relatively contiguous forest behind a particular edge, these benefits may be realized; however, with habitat fragmentation comes many problems.

One problem is an outright loss of habitat. Groups of species directly impacted by habitat loss through fragmentation include those with large home ranges, specific microhabitat requirements, and poor dispersal abiliies. However, most neotropical migrant declines are associated with qualitative changes in the remaining habitat through "edge effects" (Faaborg and others 1993). As landscapes become fragmented there is an increase in the amount of edge relative to interior area. Along edges there is an increase in biotic interactions, such as predation, brood parasitism, and competition. Edge effects may extend 600 m into the forest though some studies suggest 50 to 100 m as a threshold. Most NTMB utilize small territories (<2 ha) but may disappear from fragments tens or hundreds of times larger than their territory size due to edge effects.

Under uneven-aged management, high densities of forest-interior birds are favored due to improved vertical diversity of the forest canopy, which provides a greater variety of foraging situations; however, species diversity is reduced due to reduced horizontal diversity (Temple and others 1979). Horizontal diversity of forest vegetation can be improved, with a resultant increase in species diversity, through crown and selection thinning, which stimulates understory growth (Wood and Niles 1978).

Prescribed fire is a common tool of management that is used for a variety of purposes, including site preparation, fuel reduction, and hardwood control primarily in pine types. In some forest types, e.g. longleaf pine, *P. palustris*, fire is essential to the phenology of forest development. The influence of a fuel-reduction fire on the structure of vegetation is generally short lived and can dramatically improve the vigor and quality of fire-adapted species, especially those in the understory. This should benefit NTMB with an affinity for early successional habits, such as the prairie warbler, *Dendroica discolor,* and indigo bunting, *Passerina* cyanea. Johnson and Landers (1982) found that densities of breeding birds were higher in burned than unburned slash pine, *P. elliottii*, flatwoods in Georgia, and Bock and Bock (1983) found that populations of breeding birds either increased or remained the same following prescribed burning in ponderosa pine, *P. ponderosa,* stands in Colorado.

The maintenance of streamside management zones (SMZ) on lands under timber harvest provides travel corridors and possibly limited habitat for some species associated with mature forests (Dickson and Huntley 1985). In addition, nesting and foraging sites are provided, and habitat diversity and edge are created when these forest buffers are left during timber harvest. Gates and Giffen (1991) found that NTMB tend to concentrate at forest-stream ecotones, much as many species do at forest-field edges. Therefore, these linear habitat patches are important to NTMB in areas under intensive timber management. Though the effect of

edge areas may be beneficial to some degree, species nesting near these edges may also be subjected to unusual amounts of predation and/or nest parasitism. Thus, by leaving SMZ that are too small, which increases the chance of nests being destroyed or parasitized or which are the only habitat patches remaining in an extensive clearcut, an ecological sink or trap is created with potentially disastrous results for breeding NTMB.

The above review is a brief highlight of silvicultural effects. Wii knowledge of a) species requirements, and b) effects of silviculture on avifauna, managers can choose which species to favor. Three excellent references that can assist managers are Finch and Stangel (1993), Hagan and Johnston (1992), and Hamel (1992).

SUGGESTED FOREST MANAGEMENT PRACTICES

It is encouraging that populations of some NTMB are stable or increasing in some parts of Louisiana. However, in general, populations of NTMB have been declining in much of North America, so some changes to current management practices are suggested that may be beneficial to NTMB.

Although many NTMB inhabit stands dominated by pines, only 20 percent of the KNF is composed of hardwood and mixed pine-hardwood forests, which are the most suitable habitats for the majority of NTMB of concern. It is obvious that management of this portion of the forests will have the most effect on NTMB. Acquisition of hardwood forests or an increase in the percentage of hardwood and/or mixed forests would benefit these NTMB. It is encouraging to know that in the land management plan for the KNF (USDA FS 1985) there is a stated desire to increase hardwood acreage by 74 percent (see page II-15 and B-17). The authors support this goal and encourage expansion of it in the next management plan.

Traditionally, forest management in the United States has favored species that prefer the forest edges rather than species that prefer the forest interior. The warblers, thrushes, and vireos (46 of the NTMB on the KNF) are usually forest-interior species. Reversing the current trend by managing to decrease the amount of forest edges would increase the amount of suitable habitats for these NTMB and would reduce the risk of creating a situation in which these birds might fall into the ecological sink. Finally, for the next lo-year forest plan, we suggest the KNF move away from the use of habitat generalists as management indicators (figure 2)

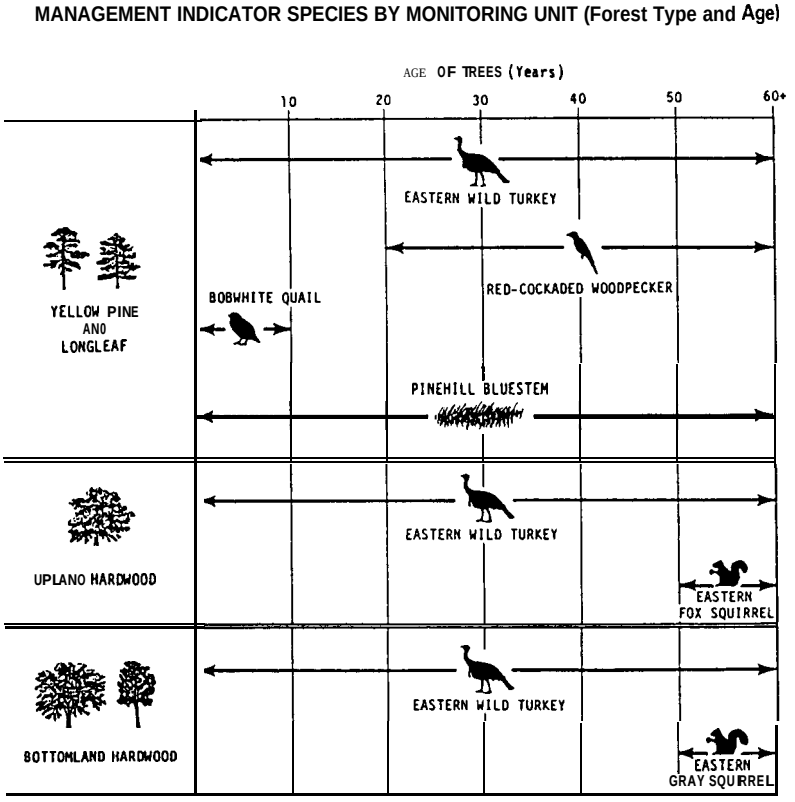

Figure 2-Management indicator species by forest type and stand age. Redrawn form Final Land and Resource Management Plan: Kisatchie National Forest (U.S. Department of Agriculture, Forest Service 1985).

and integrate a landscape perspective into their management planning (i.e. ecosystem management) for conservation of neotropical migrant landbirds and other nongame species.

RESEARCH AND INFORMATION NEEDS

Although the distribution of NTMB throughout the State is generally known, there are large gaps in the data. For instance, data on the occurrence of NTMB species for this paper were available for only three of the six forest districts (Hamilton and Lester 1987; Hamilton and Yurkunas 1987; Tucker 1980). To obtain a better knowledge of the distribution of NTMB on the forest, survey routes should be established for both breeding and wintering birds on each district, stratified by habitat type. So too, there are knowledge gaps in the ecology of many species. Barry and others (in press) did detailed species abstracts for 13 NTMB, and point to species where basic biological information is lacking, such as many of the raptors, warblers and vireos.

CONCLUSION

Twenty-two of the 118 NTMB species that utilize the KNF show significant changes in abundance, and 28 species listed by Hunter and others (1993) as needing increased conservation attention occur there.

Previous studies have demonstrated the benefits of various forest management practices to NTMB. Even-aged management benefits some bird species, while uneven-aged management favors many forest-interior species. Prescribed fire benefits NTMB that inhabit early successional habits. The maintenance of adequate SMZ on the forest is important to NTMB.

Although there are several causes for the decline of NTMB, changes in forest management practices on the KNF can be helpful to many of these species. The proposed increase in hardwood and\or mixed forests should benefit a number of NTMB. We also suggest managing to decrease the amount of forest edge, not using habit generalists as management indicators, and landscape level management. More surveys and studies to obtain biological and ecological data would be benefical.It appears that the KNF may be a major staging area for many of the continent's eastern NTMB, so management and research on this forest could have a large effect on their future.

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ENDNOTE

'Data from Louisiana breeding-bird survey routes; compiled by U.S. Fish and Wildlife Service, Office of Migratory Bird Management, Laurel, MD (Courtesy of Sam Droege).

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SILVICULTURAL OPTIONS FOR RECOVERING THE ENDANGERED SMOOTH CONEFLOWER: PRELIMINARY RESULTS'

Carlen M. Emanuel, Thomas A. Waldrop, Joan L. Walker and David H. Van Lea?

Abstract---Smooth consfiower (*Echinacea laevigata* (Boynton and Beadle) Blake) is a rhiiomatous perennial with extant populations in Georgia, South Caroiina, North Carolina, and Virginia (Murdock **1992). It was listed** as an endangered **species** in November 1992, thus requiring management for **recovery.** Thi **paper** introduces a project to identify **habitat characteristics** of colonies found **in Oconee County, South Carolina and provides a preliminary comparison of silvicultural treatments designed to prom&e regeneration. Results suggest that smooth conefiowers benefitted by treatments which** removed **forest** floor **litter.** Removing the **litter layer** by raking **was more effective** for promoting regeneration than **was** prescribed burning **or** canopy removal.

INTRODUCTION

Smooth coneflower **(*Echinacea laevigata*** (Boynton and Beadle) Blake) was listed as an endangered species in November 1992. This plant is a rhiiomatous perennial herb with extant populations in Georgia, South Carolina, North Carolina, and Virginia (Murdock 1992). Plants occur singly or in clumps and emerge from a basal rosette with one to eight or more leaves. Leaves are glabrous, yellow-green in color, and have parallel **venation**. The inflorescence appears in May through July and is purple to pink or white in color. The infructescence is brown and the awn of the pale is incurved. Seeds are prismatic achenes which mature in September or October. The only known mechanism of seed dispersal is gravity.

During **1990, 21** populations were known to exist in the Southeast. Fourteen of these populations were declining in number, one was increasing, and six were considered to be stable (Gaddy 1991). These populations had a total of approximately 6,000 plants but only 800 were flowering.

Smooth coneflower populations at one time were reported to number as high as 59, covering 24 counties in eight states **(Murdock,** 1992). Their decline is thought to have several causes: collection for **horticultural** and medicinal purposes, competition from woody plants, absence of natural disturbance, industrial and residential development, and right-of-way maintenance with herbicides.

Little is known about the habitat characteristics and regeneration requirements of smooth coneflower. Much of the current information about the plant in South Carolina is based on observations which are presented in a status report (Gaddy 1991) to the U.S. Fish and Wildlife Service. Gaddy's observations can be summarized as follows: the plant usually occurs on magnesium- and calcium-rich soils, it may require repeated disturbance and **little** competition, bare soil may be required for seeds to germinate, and seed **viability** and mechanisms of pollination are unknown.

Gaddy (1991) found smooth coneflowers most often on sites with abundant insolation, such as road cuts, open woods on exposed south-facing slopes, and young clearcuts where sunlight reached the forest floor. He also found colonies in densely-vegetated sites with closed canopies. However, plants in these habiiats appear to be declining in vigor and number. For these reasons, it is thought that the species may **benefit** from removing trees and other competing vegetation to increase light availability. Also, removing all or **a** portion of the forest floor may stimulate growth and reproduction.

The limited knowledge of the life history of this plant suggests that it is either a fire-associate (occurring under habitat **conditions** similar to burned areas) or a fire-dependent plant (requiring some mechanism that can be provided only by fire). Natural fires and grazing are **a** part of the land-use history over the range of smooth coneflower and many associated herbs require periodic disturbance (Murdock 1992). Before federal listing, fire was used to sustain two colonies on the Andrew **Pickens** Ranger District, Sumter National Forest. One colony, in a young clearcut, showed a large increase in numbers of plants and flowers after a winter burn. The second colony, which is in an open mature hardwood-pine stand, was also winter burned.

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The number of plants increased in this stand but few flowered. In thii case, the fire may have stimulated growth without providing enough sunlight to promote flowering.

The objective of this paper is to introduce a new study of smooth coneflower habitat. The first phase of the study was to search for previously unmapped colonies of smooth coneflower in Oconee County, SC and to describe habitat conditions. The second phase was to examine flowering, fruiting, and recruitment after several silvicultural treatments designed to improve smooth coneflower habitat. This paper describes preliminary results of both phases.

METHODS

The first phase of this study was to search for previously unmapped smooth coneflower colonies in Oconee County, SC and to describe habitat conditions where they occurred. The search was concentrated, at first, on ridgetops and south-facing slopes where the plant was thought to be most common. However, the search was expanded to include a wide range of aspects and slope positions. Searches were conducted during May and June of 1993, when plants were flowering. Additional searches continue on an irregular basis. The following data were collected at each colony site: slope position, slope gradient, aspect, composition of competing plants, terrain shape index (McNab 1989), distance from the nearest canopy opening, number of coneflower rosettes and flowers, and the size of the area occupied by smooth coneflowers. Although not a component of this paper, these data will be used to define common habitat attributes and to produce GIS maps of sites with those attributes for additional searches.

The second phase of the study began with selection of colonies for the study of habitat manipulation. Twenty-one colonies were chosen from among those found during the searches described above. Each chosen colony was on Federal- or state-owned land, under a forest canopy, and considered unlikely to persist without some form of disturbance. Seven treatments were assigned to these colonies in a completely random design and replicated three times. Treatments included:

1. removal of understory trees,
2. removal of understory trees and winter prescribed burning,
3. removal of understory trees, raking the forest floor, and clipping competing vegetation,
4. removal of all trees,
5. removal of all trees and winter prescribed burning,
6. removal of all trees, raking the forest floor, and clipping competing vegetation, and
7. no treatment (control).

Two levels of tree removal will allow a comparison of smooth coneflower response to differing levels of light. In southern Appalachian hardwood stands, most shading comes from understory trees. Removal of the understory may provide adequate light while allowing overstory trees to remain for aesthetic, wildlife, or timber objectives. Removal of overstory trees eliminates all overhead shading but may increase basal sprouting of trees that will compete with coneflowers. Both felling treatments were conducted in January and February, 1994. Understory trees (2 feet tall through suppressed and intermediate crown classes) were cut from all plots (except controls). All other trees were cut from half of those plots. Directional felling was conducted by research crews to ensure coneflower protection.

After felling, each plot was randomly assigned one of three treatments designed to disturb the forest floor: prescribed burning, raking, or no disturbance. Six plots were burned in February 1994 using the strip-headfire technique. A winter burn was selected for this study because of the success of previous fires conducted by the Andrew Pickens Ranger District. Annual summer burning is the most successful regime for eliminating hardwood competition (Waldrop and others 1992); however, summer burns might interfere with seedling establishment because seed production occurs throughout summer. All burns were cool (flames less than 3 feet tall) and consumed only a potion of the leaf liier layer.

The raked plots were cleared of all leaf liier in February 1994 using leaf blowers. Efforts were made to remove the entire L layer, leaving the F and H layers intact. Competing vegetation within 3 feet of each plant was clipped during the first week of April, May, and June, 1994. This raking and clipping treatment was designed as a comparison to prescribed burning to determine if smooth coneflowers require fire or simply the conditions created by fire. Branches and tops created by tree felling were removed from raked sites to simulate burned conditions.

Measurements of coneflowers were conducted in September 1993, before treatment, and again in September 1994. Data included: numbers of coneflower clumps and rosettes, number of leaves per rosette, length and width of the largest leaf per rosette, length of the inflorescence stalk (peduncle), number of leaves per peduncle, and percent cover by trees, vines, shrubs, and herbs. Soil samples were collected from each plot for nutrient analysis. Of these data, only the number of rosettes and flowering plants are presented here.

RESULTS AND DISCUSSION

Status Survey

The survey of sites, conducted during the spring of 1993, showed a substantial increase in the number of smooth coneflower plants, in Oconee County, SC, over

that reported in the 1990 status report (Gaddy 1991). Our survey found 3,253 plants as compared to only 382 plants in 1990 (Table 1). Flowering plants numbered 506 in 1993, but only 123 in 1990. These increases are thought to be due to survey technique rather than true increases in plant numbers. Our survey was conducted over a two-month period with a six- to eight-person crew. The previous survey was limited to one person and a shorter time period.

Table 1 -Status of smooth coneflowers in Oconee County, SC in 1990 (Gaddy 1991) and 1993

	1990	1993
Number of colonies	6	5
Number of plants	382	3,253
Number of flowerina plants	123	506

Colony sites were found most often in mixed-species stands. Forty-eight percent of the colonies were in the hardwood-pine type and 34 percent were in the pine hardwood type (Table 2). An additional 17 percent of the colonies were in pure hardwood stands. Only one colony was in a pure pine stand; this colony was on the edge of a young planted loblolly pine (*Pinus taeda* L.) stand.

Table 2-Selected characteristics of smooth coneflower sites found in Oconee County, SC in 1993

Characteristic	Percent of all colonies
Forest cover type	
Hardwood	17
Hardwood-pine	48
Pine-hardwood	34
Pine	1
Aspect	
Southeast	6
South	39
Southwest	42
West	13
Slope position	
Ridgetop (75-100 percent)	25
50-75 percent	45
25-50 percent	24
Bottom (O-25 percent)	6

The observation that smooth coneflowers require high levels of sunlight (Gaddy 19991) appears to be supported by the limited range of aspects on which the plant occurred. The majorii of the colonies had a southwestern (42 percent) or southern (39 percent) exposure (Table 2). A few sites had western (13 percent) or southeastern (6 percent) exposures. No plants were found on sites with eastern or northern exposures.

Smooth coneflower colonies were not limited to ridgetops and drier sites. Only 25 percent of the colonies were found on ridgetops, while 69 percent were at midslope (Table 2). This result may suggest that smooth coneflowers prefer fertile, well-drained soils or they do not compete well on harsh, exposed sites. Six percent of smooth coneflower colonies were found on slope bottoms, but most of these sites included the heavily disturbed bottom areas of roadcuts.

Response to Habitat Manipulation Treatments

The total number of smooth coneflower plants in study plots after one growing season was similar to the number counted prior to treatment (Table 3). Apparently, the plant is not adversely affected by disturbance. Increases in plant numbers were observed in treatment plots with the two heaviest levels of disturbance, i.e., understory removal + raking and total tree removal + raking. Complete canopy removal did not provide additional benefits over removal of the understory alone. Moreover, prescribed burning did not affect plant numbers. These treatments may show increased plant numbers in 1995. Smooth coneflower seeds do not drop until late autumn or winter, therefore, any response of seedling establishment to treatments cannot be observed until 1995.

Tabie 3-Total number of plants by treatment and year

Treatment	1993	1994
Control	124	126
Remove understory	91	89
Remove understory and burn	65	74
Remove understory and rake	121	167
Remove all trees	230	191
Remove all trees and burn	77	78
Remove all trees and rake	184	238

Reductions of plant numbers were observed only in plots where all trees were removed and the forest floor had no other disturbance (Table 3). This response may be the result of shading or physical barriers from the large amounts of woody debris created by this treatment. In other treatment plots, small branches were either consumed by fires or removed by hand.

The total number of flowering plants remained small in all study plots except where all trees were cut and the forest floor was raked (Table 4). In these plots, only four plants flowered in 1993 prior to treatment but 42 plants flowered in 1994. Greater responses may be provided by removing more of the forest floor than did the treatments used in this study.

CONCLUSIONS

Study results are preliminary and conclusions stated above may change after data analysis is complete. Our survey found more smooth coneflower colonies and

Table 4-Total number of flowering plants by treatment and year

Treatment	1993	1994
Control	4	5
Remove understory	1	5
Remove understory and burn	5	3
Remove understory and rake	3	10
Remove all trees	3	5
Remove all trees and burn	6	11
Remove all trees and rake	4	42

plants in Oconee County, SC, than a previous survey. However, these increases probably result from intensive searching techniques and are not true population increases. Plants were found more frequently on middle to upper slope positions than on the ridgetops where we expected to find them. Smooth coneflowers were not adversely affected by disturbance and appeared to have benefitted by removing the litter layer by raking. The differing levels of light, provided by canopy removal treatments, did not affect plant numbers. Flowering responses were minimal the first year after treatment, but the greatest increases occurred where the liier layer was removed. This study will be followed for several years to allow data collection on longer-term responses to treatments.

ACKNOWLEDGEMENTS

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GIS AS A DESIGN TOOL FOR BIOLOGICAL STUDIES'

Rose M. Sumerall and F. Thomas Lloyd[2]

Abstract—High quality geographic data **can be developed from early aerial photographs, to provide historical informatii for biological studii. The USDA Forest Service is developing Historical Digital Orthophotos from aerial photography taken in 1951 over the Savannah River Site. In this paper, we describe the development process, which** involves scanning, **ground** control and **softcopy photogrammetry. Survey-grade GPS technology tied ground control points into the National Geodetic Network with an accuracy of 0.5 meters or better. One of the most difficult challenges was locating the same feature (ground control point) both today and in 1951. The orthophotos will be incorporated into** a Geographic **Information System and used, in part, to identify old-field sites for** a **biological** study.

INTRODUCTION

The Southeastern **Forest** Experiment Station recently initiated two studies funded by the Department of Energy at the Savannah River **Site** (SRS). One study was a biological study that used historical image data to select suitable study sites; the second study involved developing historical image data for the SRS. This report on the application and development of the historical image data presents the methods we used to create precise, **high-quality,** objective, historical images for **multidisciplinary** research at the SRS. Our references to the biological study are used to demonstrate one application of the historical image data.

The biological study is designed to investigate ecological development within old-field sites (Thompson and Lloyd 1995). The old fields function as a baseline state for studies of successional change. The selection of old-field sites reduces the influence of historical landcover in order to clarify the successional role of other variables such as soils and landforms. In the planning phase of the biological study, referred to as the "Old-Field Project" in the remainder of this paper, we used GIS to select study sites. In a later phase, we will use the historical image data to refine the selection process.

In the second study, referred to as the "Historical Orthophoto Project", historical photographs provide detailed information on the location of old-field sites. Photographs contain **distortion** which is eliminated when they are transformed into orthophotos. A digital orthophoto is **a** digital image that has the properties of an orthographic projection (USDI 1992). As an orthographic projection, the orthophotos will be planimetrically correct so that measurements of location, area, **distance** and direction are reasonably accurate. Digital orthophotos have the high-information content of a photograph as well as the usefulness of a map.

Data in digital format can be input into a Geographic Information System (GIS) where it can be combined with other data describing the same geographic area. GIS is sometimes defined as a decision support system involving the integration of spatially referenced data in a problem solving environment **(Cowen** 1990). Because a GIS can spatially reference data and integrate one type of data with another, it serves as a bridge between the sciences **(Cowen** 1990) and has greatly enhanced interdisciplinary research.

Integration among spatial data is made possible through georeferencing. Georeferencing transforms the **x,y** coordinates of spatial data into real-world coordinates in a standardized reference system. To incorporate the Old-Field Project and the Historical Orthophoto Project into the GIS at the SRS, both sets of data were georeferenced to the Universal Transverse Mercator (UTM) reference system based on the North American Datum (NAD) 27.

Georeferencing was accomplished through Global Positioning Systems (GPS). Using GPS technology, we can derive the coordinate position for a selected point on the surface of the earth in terms of a standardized reference system. GPS estimates a position based on several ground-to-satellite distance determinations. Distances are determined by precisely calculating the time required for a satellite transmission traveling at the speed of light to be received by a GPS unit on the ground. We used GPS receivers to georeference the historical orthophoto data, and the sampling grid for the Old-Field Project.

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[1] **Paper presented at Eighth Biinial Southern Silvicultural Research Conference, Auburn, AL, November 1-3, 1994.**

[2] **Geographer and Project Leader, respectively, USDA Forest Service, Southeastern Forest Experiment Station, Clemson, SC.**

STUDY AREA

The Savannah River Site (SRS), a nuclear weapons facility recently converted by the Department of Energy (DOE) into a National Environmental Research Park, is the site of the Historical Orthophoto Project. The 300-square-mile SRS, located in the Upper Coastal Plain Province of South Carolina, is adjacent to the Savannah River which marks the state's southwestern boundary with Georgia.

Land use and land cover on the SRS has changed considerably since its purchase by the Atomic Energy Commission in 1950. At the time of purchase, the SRS was a rural farming community (Figure 1) when the DOE orchestrated the removal of about 6,000 structures including two small towns, and the relocation of the area's residents (Brooks and Crass 1991). Today, pine plantations and hardwood forests cover the landscape (Figure 2). The agricultural fields were planted to pine in the early 1950's in an effort to reduce soil erosion. Currently, about 90 percent of the SRS is forested, and is managed by the USDA Forest Service (Jones and others 1981). The Savannah River Forest Station has developed a GIS using Arc/Info[1] software, to help manage this land.

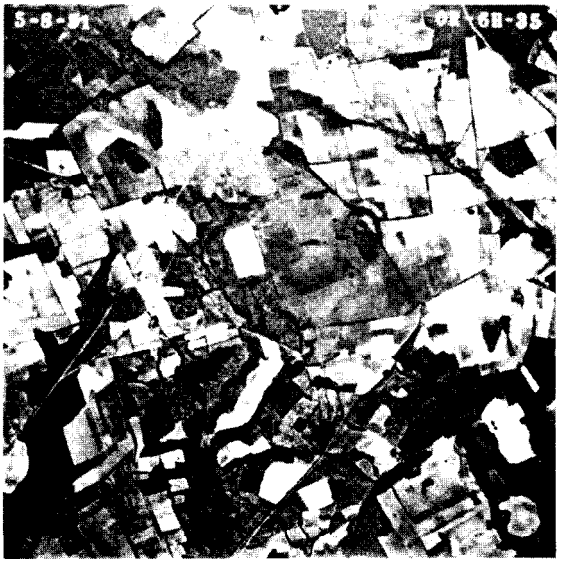

Figure l-Black and white aerial photograph taken in May 1951 by the Soil Conservation Service at a scale of 1:20,000 is an example of remote sensing source data used in the Historic Orthophoto Project. The light areas are agricultural fields.

[1] The use of trade or firm names in this publication is for reader information and doss not imply endorsement by the U.S. Department of Agriculture of any product or service.

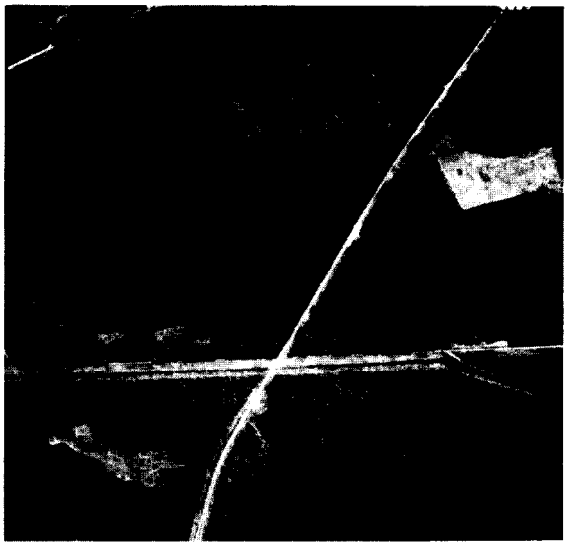

Figure 2-Infrared aerial photograph taken in January 1992 by the USDA Forest Service showing the extensive pine forest on approximately the same land area in Figure 1.

Figure 3 is a forest stand planted to pines in the early 1950's and selected by the GIS as a potential study site for the Old-Field Project. About one-half the area of this forest stand qualifies as old-field sites, which underscores the need to use the historic aerial photography to refine the site selection process. Areas which were not fields may have contained a lot of residual vegetation or new woody plant invasion, which would confound the analysis planned for the Old-Field Project. The grid was created in the GIS and replicated in the field. The sampling grid shown on the map illustrates how the old-field information could be used to either reduce the amount of field work by restricting sampling to old-field sites or to stratify the data for analysis based on historic landcover.

The old-field locations in Figure 3 were mapped using a simple rubber-sheeting rectification process. In the following sections, we describe the more rigorous and accurate method of rectification used in the Historical Orthophoto Project and efforts to collect coordinate data on ground control points for the project.

DEVELOPMENT OF DIGITAL ORTHOPHOTOS

Digital orthophotos can be generated through a two-stage process: in the first step, the source photography is scanned to produce a digital image; and in the second step, a soft-copy photogrammetric workstation transforms the digital image into a digital orthophoto. This transition involves operations that georeference

Figure 3--GIS map of a forest stand at the Savannah River Forest Station. The lighter areas of the map show the location of old-field sites, the darker areas probably show pastures, hardwood inclusions, and cutover areas in 1951, and the points indicate the sampling grid for the Old-Field Project.

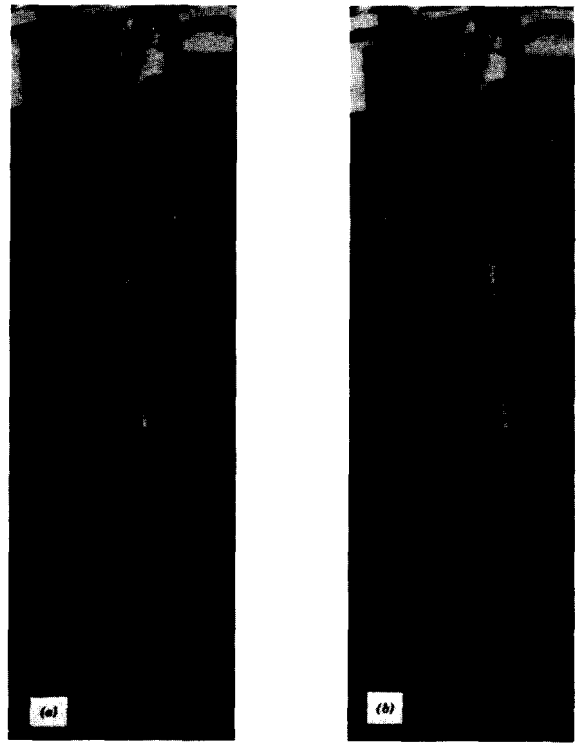

Figure 4--Classic example of an aerial photograph before and after orthorectification. The picture on the left is of an unrectified photograph containing distortion. The picture on the right is an orthophotograph containing the geometric properties of a map. From Remote Sensina and Imaae Interpretation, by Thomas M. Lillesand and Ralph W. Kiefer, copyright 1987. Reprinted by permission of John Wiley and Sons, Inc.

the image and remove geometric distortion. Figure 4 illustrates the difference between a distorted aerial photograph (4a) and an orthophotograph (4b). In the following discussion, we describe the source data, the scanned image, and the photogrammetric software designed to correct these spatial data problems.

The source data for the Historical Orthophoto Project is a set of 251 black and white aerial photographs (including stereo overlap). Aerial photographs record the intensity of electromagnetic energy reflected from the ground (Jensen 1986). The degree of energy reflected from an object, as manifested in its tone or color, provide valuable information about the physical properties of that object Differences in tone or color on a paper photograph are converted during scanning into rows and columns of numerical brightness values to produce a digital image that can be processed by a computer.

To capture the full information content of the photographs, film diapositives were scanned at a density of 25 microns, which equals 1,000 dots per inch (dpi). Because the photographs were nine inches square, the scanning produced an image composed of an array of 9,000 x 9,000 cells (pixels). Therefore, each image contained 81 ,000,000 pixels, and each image file was approximately 81 megabytes in size.

This photo series has a nominal scale of 1:20,000 (i.e., one inch on the photo is equal to 508 meters on the ground). Because each inch on the photo was sampled at 1,000 dpi, the ground distance between samples is approximately 0.5 meters. The half-meter spatial resolution of our digital imagery is shown in Figure 5. The photos were scanned to 156 levels of gray at a cost of $38 per photo including calibration checks and duplicate copies.

Because the camera captures a remote perspective view, the attitude of the airplane changes from moment to moment (tilt), and the topography varies, aerial photography contains geometric distortion (Lillesand and Kiefer 1987). Studies by Bolstad (1991) indicate

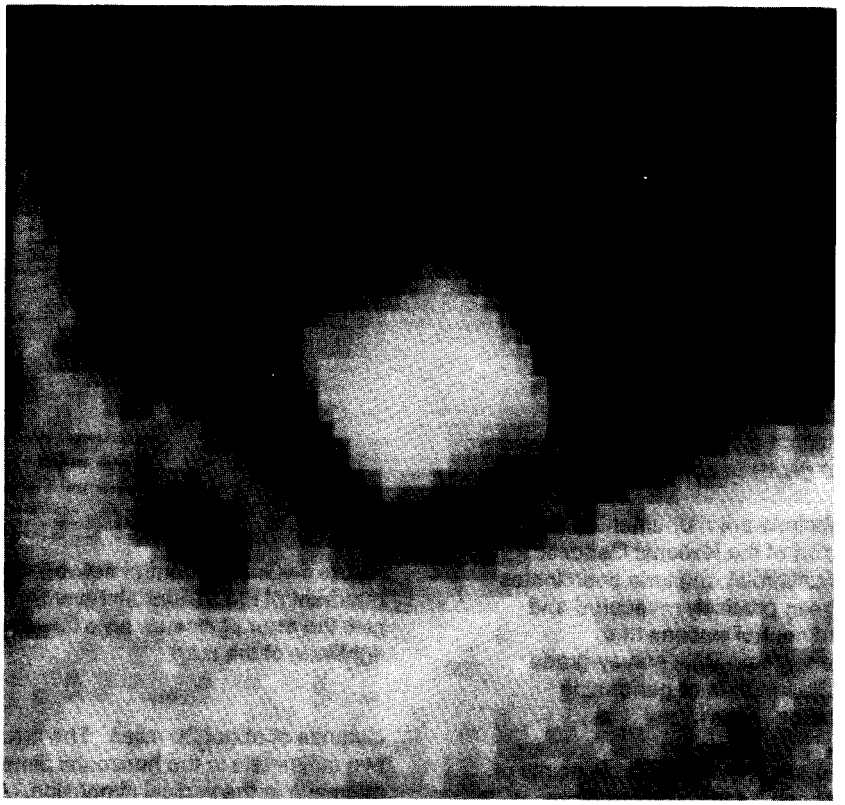

Figure &Photograph of a scanned image showing 0.5 meter pixel resolution. The object in the center is a building.

that tilt produces an average error in point positioning from 4 to 77 meters.

Several techniques are available to correct these distortions. Each technique requires the determination of ground coordinate positions for points located on the imagery, known as ground control points. Once these points on the photograph are associated with some geographic coordinate system, an image can be transformed either through a rubber-sheeting rectification process or through differential rectification.

Differential rectification is more accurate than rubber-sheeting rectification because it corrects distortion systematically. The resulting otthophotograph has the combined advantages of photographic detail and planimetric accuracy (Thrower and Jensen 1976). Other advantages include the need for fewer ground control points, improved accuracy with the Z dimension in its calculations, and continuity between adjacent photographs.

Orthophotos can now be produced on a digital softcopy photogrammetric workstation such as the Imagine OrthoMAX[3] marketed by the ERDAS Corporation'. In this package, image orientation is determined through triangulation, which establishes the mathematical relationships between the individual images in a block of photos and the ground (ERDAS 1990). The geometry of the sensor, the orientation of the imaging plane of each photograph, and the relationship to ground coordinates in a specified map projection are taken into consideration. Inputs to the triangulation process are GPS ground control points, camera parameters, and image tie points. Tie points are points in the overlap areas of the photographs that tie a photo to its neighboring photos. When the triangulation solution is computed, the images can be orthorectified with the additional input of Digital Elevation Model (DEM) data describing the topography. For this project, we used fourteen 7.5 minute, level 2, DEM's in standard USGS format. This orthorectification process corrects the image by removing the effects of distortion from all sources.

For the Historic Orthophoto Project, we used OrthoMAX software on a SUN[3] Sparc 10 workstation. In addition to performing orthorectification, this software package can produce DEM data from stereo pairs, and can also perform three-dimensional viewing and

mensuration. OrthoMAX works with satellite data as well as photography.

GROUND CONTROL

Survey-grade GPS technology enabled us to achieve an accuracy of better than 0.25 meters for our ground control points, which is less than one-half the ground resolution of an image pixel. We collected data with four Trimble[3] series-4000 GPS survey receivers and used TRIMVEC-Plus' software for data processing.

The GPS data were collected in a static survey mode. The four field receivers were stationed at separate locations and collected data synchronously for one hour. Our field crews generally completed four one-hour sessions per day. Between sessions, the equipment was either left on a station or moved to other ground control or geodetic control stations.

The geodetic control stations are monumented points, installed by NOAA as part of the National Geodetic Control Network. The Latitude/Longitude coordinates for these points have been precisely measured and serve to link our ground control stations to a standardized reference system. With survey-grade GPS, collecting Base Station data or performing differential correction is unnecessary.

Ground control stations are photo-identifiable points of known coordinates that can be used to georeference images. For these points, we selected locations such as the intersection of two roads, the intersection of a road and a railroad, the intersection of a road and a hedgerow, or the center of a bridge. One of our greatest challenges was identifying points stable enough to be found on both the 1951 photos and on the landscape today. GPS data were collected during the winter 1993-l 994 on 86 ground control stations and 7 geodetic control stations. Approximately 10 percent of these points will be reserved to test the positional accuracy of the final product

When this GPS data is processed with Trimvec Plus software, vector relationships are computed between the survey stations. Figure 6 is a computer printout of our GPS network for the northeast quadrant of the SRS. In this figure, the points represent the GPS stations and the lines represent the computed vectors. For this set of data, we had four geodetic control stations, one station positioned in each of the four corners.

To test the integrity of the data, we ran a loop closure process in the software. In this process, a traverse is run between two known geodetic control stations, similar to a traditional boundary survey. The error of closure on this traverse reflects the quality of the data. Several network vectors have been highlighted in Figure 6 to illustrate a traverse. This traverse encompasses a total of nine points and covers a

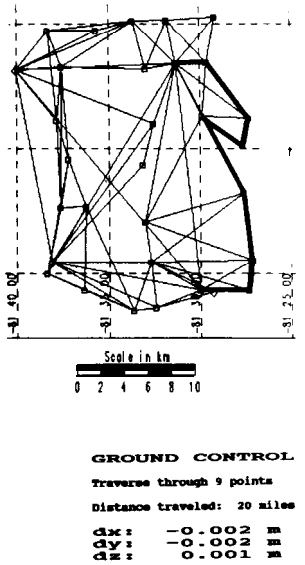

Figure 6--Ground control network for the north-east quadrant of the Savannah River Site. Numerical values give the error of closure on a traverse running down the right side of the map.

distance of about 20 miles. The error of closure was two millimeters in the horizontal dimension and one millimeter in the vertical dimension. After the data is reviewed with loop closures, a network adjustment is performed to deriie coordinate locations and errors for the ground control points.

CONCLUSIONS

To date, we have collected and processed the ground control data, scanned the photographs, and are currently engaged in the orthorectification of images. Global Positioning Systems, Geographical Information Systems and Remote Sensing technology have been instrumental in helping us develop this historical image data. The GPS data is very precise, the scanned data is quite detailed, and the process of triangulation should identify any problems with ground control points. A qualii orthophoto data layer will make it possible to obtain accurate information about the location and boundaries of old-field sites. Biological data collected on these old-field sites can be evaluated independent of historical influences. Ultimately, the development of this historical orthophoto data may contribute to a more complete understanding of the historical influences and ecological processes that shape our landscape.

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PREDICTIVE VALUE OF AN ECOLOGICAL CLASSIFICATION SYSTEM AS A MANAGEMENT TOOL FOR LANDSCAPE-SCALE DECISION-MAKING'

N. Jane Thompson and F. Thomas Lloyd'

Abstract—The objective of this study **is** to **evaluate** the **performance** of a **previously** developed **Ecological Classification** System (ECS). The **study tests** the null **hypothesis** of no differencee in **observed *and* predicted *woody* plant *composition.*** The **tests** use **stand composition** in **old-field plant** communitii thet ***am* 40-years *old.*** Preliminary reeulte **revealed that** the Ecological **Classification** Syetem is a **valid predictive model. The** observed **compositional differences** between **Ecological Classification System** lend **units (ecoclasses)** dii **match those** indii epeciee **identified** in the model. As predicted by the model, the **non-oak species,** wlth the exception of **sassafras (*Sassafras albidum*), *dii not* exhibit** differencee between **ecoclasses. Sassafras** exhibited a generel **increase** In **propagule** frequency ***as* ecoclass increased** in dryness.

INTRODUCTION

Forest management is performed in a spatial context, yet very **little** spatial data is available in the form of a predictive tool. A previously developed Ecological Classification System (ECS) for the upper Coastal Plain found that certain late-successional vegetation exhibits spatially-dependent patterns (Jones et al. 1984). These patterns are delimited by the ECS model using soil map data to describe land units called ecoclasses. However, these ECS models are oniy a first step in developing a useful forest management tool. To reach full development, these types of models must be independently validated and employed in future research as a context in which to understand and predict responses to management across ecoclasses.

To test the predictive value of Jones' ECS of the upper Coastal Plain, we used the old-field plantations on the Savannah River Siie (SRS). Approximately 40 percent of the land purchased from the local residents for use by the Atomic Energy Commission in 1951 consisted of agricultural fields (Swingle 1977). These abandoned fields were among the earliest sites planted by the USDA Forest Service in a massive effort to rapidly control erosion. Today thousands of acres of these old-field stands remain and we used them to examine the relationship between 40-year-old successional vegetation and the predicted ecoclass vegetation.

This study is a second step in meeting the long-term goal of producing a spatial templet to which management prescriptions and guidelines could be linked. The primary objective is to test the null hypothesis of no differences in the composition of woody plant propagule frequencies among four upland ecoclasses delineated from soil maps.

METHODS

Site Selection

Stand selection was based on four criteria. First stands were dominated by one or more of the four upland ECS ecoclasses defined by Jones (1989). The four upland ecoclasses are defined by indicator plants and depth of sandy epipedon (Table 1). Ecoclasses have been generated in a GIS model from digitized soil survey data. The primary soil attribute (depth of sandy epipedon) was used to group soil series into ecoclasses. The resulting ecoclass polygons were overlaid with stand map polygons to identify suitable study sites. Second, selected stands were planted between 1951 and 1954 with either **loblolly** or **longleaf** pine. Third, stands were free of thinning activity during the last **five** years in order to minimize short-term vegetative responses to increased solar radiation in the understory. And fourth, selected stands were predominantly abandoned agricultural fields as verified by aerial photos taken in 1951.

Measurements

Sample plot locations were established for each stand using a grid of plot centers generated by GIS and overlaid on the stand map polygons. Not all grid points will be used in future analysis because stand boundaries are not based precisely on historical old-fields. Digital orthophotography from 1951 will be used

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'Forester and Project **Leader,** respectively, USDA **Forest** Service, Southeastern Forest Experiment Station, **Clemson,** SC.

Table 1. Indicator plants and soil characteristics for the four upland ecoclasses of the upper Coastal Plain defined by Jones (1989) ECS model

Ecoclass	Indicator Species and Soil Characteristics
Mesic	White Oak (*Quercus alba*)-Post Oak (*Q. stellata*)
	Typic and Aquic Paleudutts (sandy epipedon < 20 inches)
Submesic	Blackjack Oak (C?. *marilandica*) - Deerberry (*Vaccinium stamin ium*)
	Arenic Paleudults (sandy epipedon 20 - 40 inches)
Subxeric	Bluejack Oak (C?. incana) - Dwarf Post Oak (Q. *margaretta*)
	Grossarenic Paleudults (sandy epipedon 40 - 80 inches)
Xeric	Turkey Oak (Q. *laevis*) - Dwarf Huckleberry (*Gaylussacia spp.*)
	Quartzipsamments (sandy epipedon > 80 inches)

to eliminate those grid points that do not fall within old-field boundaries (Sumerall and Lloyd, this proceeding). This preliminary test uses all grid points because the digital orthophotography study has not been completed. Sensitivity of future analysis should be improved by the screening process that the orthophotographs will provide.

The Global Positioning System (GPS) tied the ground plot centers into the GIS grid. The Criterion 4000' laser survey equipment was used to survey plot centers starting from the GPS tie-point. The GIS-implemented model categorized each georeferenced plot center into one of the four ECS units.

At each plot center, a circular l/l 00th-acre (11.8 ft. radius) area was established, and all hardwood species greater than 4.5 feet tall were counted. The diameters of the developing hardwood component taller than 4.5 feet were also recorded in one of five dbh classes: <1 in., 1-2 in., 2-3 in., 3-4.5 in., and >4.5 in. In a 1/500th-acre plot (5.3 ft. radius) nested within the l/l 00th-acre plot trees less than 4.5 feet tall were counted by species in one of two height classes; those less than 1 foot tall and those greater than a 1 foot tall, but less than 4.5 feet. Total basal area was estimated for the pine and hardwood component separately using a variable radius, probability- proportional-to-size sampling procedure.

Data Analysis

The information estimated from plot data consists of per acre propagule frequencies for all woody understory plants. Community composition was measured as the multivariate mean propagule frequency. Thii multivariate mean is easily visualized when only two species are analyzed as a point on an xy graph. Comparing more than two species requires visualizing this mean as a point in n-dimensional space, where n equals the number of species evaluated. This statistic simply becomes the pairwise distances between these multivariate means associated with each ecoclass.

RESULTS AND DISCUSSION

A total of 1,040 plots was sampled with 316, 345, 319, and 60 plots in the mesic, submesic, subxeric, and xeric ecoclasses, respectively. Plots on xeric sites are few in number because few old-field sites existed in an ecoclass inherently unsuitable for agriculture. All hardwood species present by abundance and ecoclass are summarized in Table 2. This information was the source of propagule frequencies used in our analysis.

We began the species grouping process by testing the non-oak communities. Because Jones' model did not identify these non-oaks as the source of indicator plants, we did not expect trends in compositional differences to occur. However, trends in compositional differences did appear (Table 3). The pattern showed that compositional differences increased as ecoclass pairs became further apart on the moisture gradient.

Propagule frequency data in Table 2 suggests that sassafras could be the reason for these trends because it both dominates the other species in magnitude of propagule counts and is positively related to ecoclasses. By making the same computations with sassafras removed, we saw the pattern of compositional differences disappear (Table 3). We speculate that sassafras was not identified as an indicator plant in the original ECS modeling research for a number of reasons. These reasons could include: being absent in late-successional communities, being similar in abundance across late-successional communities, or being so abundant, as in these early successional communities, that it was not considered a good indicator plant. Therefore, with the exception of this minor difference, our analysis supports the ECS model predictions.

[1]The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Table 2. **Propagule** frequencies per acre by **species and ecoclass** 88 estimated **from early-successional** data

specie8	Stems Per Acre			
	Mesic	Submesic	Subxeric	Xeric
	0	**4**		
Turkey **Oak**	**3**	**59**	80	311
Bluejack Oak			313	563
Blackjack **Oak**	1	13	18	52
Dwarf Post Oak	115	172	513	283
Post **Oak**	**39**	115	83	3
Southern Red Oak	**316**	283	172	0
Laurel Oak	2646	332	1048	360
Water Oak	755	930	1034	836
Sand Hickory	48	94	237	33
Mockernut Hickory	44	74	153	12
Dogwood	164	15	33	18
Persimmon	191	188	215	314
American Holly	16	26	39	0
Sweet Gum	92	193	116	0
Black Gum	31	67	186	43
Plum	**20**	22	5	0
Elm	**502**	3	3	0
Red Maple		170	295	168
Sassafras	1208	1495	1790	2248

Table 3. **Compositional differences quantified** with 8 **multivariate** measure of distance between **ecoclass** means for non-oak hardwoods with **and** without sassafras

Ecoclass	**Ecoclass**			
	Mesic	Submesic	Subxeric	**Xeric**
	-non-oak **hardwoods-**			
Mesic	***	39.1	54.0	85.7
Submesic	***	***	30.0	62.5
Subxeric	***	***	***	45.9
Xetic	***	***	***	***
	-non-oak hardwoods excluding **sassafras-**			
Mesic	***	34.9	32.7	33.2
Submesic	***	***	21.2	25.3
Subxeric	***	***	***	31.8
Xeric	***	***	***	***

Table 4. Compositional differences quantified with a multivariate measure of distance between ecoclass means for indicator oaks predicted by Jones (1989) model

Ecoclass	Ecoclass			
	Mesic	Submesic	Subxeric	Xeric
Mesic	***	22.2	102.6	133.0
Submesic	***	***	86.6	122.4
Subxeric	***	***	***	84.0
Xeric	***	***	***	***

We decided to complete this preliminary analysis by examining the indicator oaks identified by Jones (1989). Table 4 shows the mean compositional differences for the indicator oak group (Table 1). The difference in mean composition between pairs of ecoclasses as they move further apart on the moisture gradient is clearly increasing. All differences in Table 4, except the difference between mesic and submesic, are greater than the average difference (29.8 trees per acre) in the bottom part of Table 3, where no trends in differences are detected

CONCLUSIONS

The observed abundance of indicator oaks in these early successional communities matched the predicted composition across the four upland ecoclasses. The presence and abundance of the suite of non-oak hardwood species did not show significant composition differences across ecoclasses, with the exception of sassafras. These preliminary results validate Jones' ECS model as a predictive tool. These results also indirectly show that existing soil maps are sufficiently accurate to delimit ecoclasses that capture compositional differences in the indicator plants.

ACKNOWLEDGMENTS

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LANDSCAPE ECOSYSTEM CLASSIFICATION OF SUCCESSIONAL FOREST COMMUNITIES IN THE SOUTHERN APPALACHIANS'

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Abstract-Successional forest communities were described within six Landscape Ecosystem Classification site units in the Hih Rainfall Belt of the Nantahala National Forest, North Carolina. Two to three seral communities were identified within each site unit. Vegetational trends across the landscape and diagnostic vegetation were described for each seral community.

INTRODUCTION

The purpose of Landscape Ecosystem Classification (LEC) is to integrate vegetation, soils, and landform in order to identify ecologically equivalent site units in terms of type, structure, and productivity of vegetation. The methods were initiated by Barnes and others (1982) in Michigan and later applied in South Carolina by Jones (1991). The LEC approach is hierarchical with major environmental factors taken into account by the recognition of physiographic provinces, regions, and subregions based on climate, topography, soils, and geology. Wiiin a given region, ecologically equivalent site units can be recognized on the basis of the interrelationship between vegetation and soils, between vegetation and landform, and between landform and soils.

In the absence of disturbance, the distribution of individual species in competition with their associates is more a function of environmental conditions and less a function of the amount of disturbance. Therefore, Phase I of LEC involves the identification of site units within a region with steady state or near steady state vegetation. The discriminating landform and soil variables are also identified. In Phase II, the successional communities for each site unit identified in Phase I are described. Phase Ill consist of mapping site units, and Phase IV involves management interpretations for each site unit (Jones and Lloyd 1993).

METHODS

Phase I of LEC

The study area is in the High Rainfall Belt of the Southern Appalachians located on the Highlands Ranger District of the Nantahala National Forest in North Carolina. The area is composed mostly of high grade metamorphic rocks (McKniff 1967), and the elevation ranges from approximately 700 to 1525 meters. Rainfall averages 203 centimeters per year (U. S. Weather Bureau 1896-I 958), and precipitation exceeds evapotranspiration.

Six site units and their discriminating soil and landform variables were identified and described in Phase I (Gattis 1992). The site units were delineated through ordination and cluster analysis. The site units in the high elevations (above 1219 meters) were mesic, intermediate, and xeric. A similar pattern was found in the mid elevations (792-I 219 meters). The discriminating landform variables were elevation and landform index (McNab 1989) and the soil variable was solum thickness (Gattis 1992). A diicriminant function (SAS Institute 1985) was developed for each site unit based on soil and landform variables for the purpose of identifying site unitsthroughout the region.

Phase II of LEC

Phase II of LEC was completed in 1994 (Carter 1994). Forest stands representing major successional conditions were sampled across the range of site conditions from mesic to xeric. The solum thickness, landform index, elevation, and vegetation were sampled in each plot. The sample plots were then classified into their appropriate site unit using refined discriminant functions from Phase I. The Phase I discriminant functions were refined to increase precision by the inclusion of diagnostic vegetation. Once plots were classified into their site units through diicriminant functions, cluster analysis was used to assign them to seral communities.

RESULTS

Mid Elevations

Wiihin the early successional communities of the mid elevations, there were a number of vegetational trends.

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Yellow-poplar was the dominant overstory species on all site units. Second in overstory dominance was black locust. Carolina silverbell was a common midstory species throughout although its constancy decreased on xeric sites. White pine and red maple trees and saplings were common in all mid elevation sites but were never dominant (Carter 1994).

The early successional communities were termed a yellow-poplar black locust-flowering dogwood type on mesic sites, a yellow- poplar-northern red oak-black locust type on intermediate sites, and a white pine-mixed oak-black locust on the xeric sites (Carter 1994). There were some distinctive differences in the early successional communities. Flowering dogwood and cherry birch trees along with false hellebore were found only on mesic and intermediate sites. In contrast, galax was found only on intermediate and xeric sites. Pignut hickory trees, American chestnut saplings, and sedge species were common only on intermediate sites while Christmas fern was diagnostic for mesic sites. Scarlet oak trees were common only within the xeric site unit (Table 1). The presence or absence of these species can be used as indicators for the first seral communities.

Table l-Distribution of selected diagnostic species in the mid elevation early successional communities. The arabic numbers 1 and 2 indicate tree and sapling size classes, respectively.

Mesic	Intermediate	Xeric
Christmas fern		
Flowering dogwood 1	Flowering dogwood 1	
Cherry birch 1	Cherry birch 1	
Northern red oak 1	Northern red oak 1	
Catesby's trillium	Catesby's trillium	
False hellebore	False hellebore	
	American chestnut 2	
	Sedge	
	Chestnut oak 1	Chestnut oak 1
	Sourwood 1	Sourwood
	Galax	Galax
		Lowbush blueberry
		White oak 1
		Scarlet oak 1
		Mountain laurel

The middle successional communities were termed a white oak-blackgum-black locust type on mesic sites and a northern red oak-white oak-huckleberry on intermediate sites. The xeric communities were a chestnut oak-sourwood-yellow-poplar type followed by a scarlet oak-sourwood white pine type (Carter 1994). The middle successional communities retained some early successional species such as black locust and yellow-poplar treesand Carolina silverbell saplings, but they were less common. Flowering dogwood was still present on mesic and intermediate sites. Christmas fern remained prevalent on mesic sites with Catesby's trillium the dominant herbaceous species. Species such as Solomon's seal were absent from the xeric sites but present on the mesic and intermediate sites. Within the intermediate sites, sedge species were still common with northern red oak the dominant tree. Sourwood was prevalent on the intermediate and xeric sites but absent from the mesic sites. Diagnostic species for xeric sites included lowbush blueberry and pitch pine (Table 2).

Table 2-Distribution of selected diagnostic species in the mid elevation middle successional communities. The arabic numbers 1 and 2 indicate tree and sapling size classes, respectively

Mesic	Intermediate	Xeric
Cherry birch 1		
Christmas fern		
False hellebore		
Flowering dogwood 1	Flowering dogwood 1	
Solomon's seal	Solomon's seal	
	Sedge	
	Chestnut oak 1	Chestnut oak 1
	Sourwood 1	Sourwood 1
	White oak 1	White oak 1
	Galax	Galax
		Lowbush blueberry
		Scarlet oak 1
		Mountain laurel

The steady state vegetation was called a northern red oak-eastern hemlock-birch type on mesic sites, a mixed oak-hickory-huckleberry type on intermediate sites, and a scarlet oak-chestnut oak-huckleberry type on xeric sites (Gattis 1992). The steady state communities lacked many successional species. Flowering dogwood was uncommon as a tree or sapling in all site units, and cherry birch was found only in the mesic site unit. Carolina silverbell saplings were less prevalent on intermediate sites and absent on xeric sites. However, it remained on mesic sites. Herbaceous species such as false hellebore, Catesby's trillium, and sedge species were uncommon. On mesic sites, diagnostic vegetation included eastern hemlock and rosebay rhododendron with Christmas fern prevalent in the understory. Common intermediate vegetation included northern red oak,chestnut oak, and pignut hickory

trees. Species diagnostic on xeric sites were **lowbush** blueberry, mountain laurel, and **galax** (Carter 1994 and Table 3).

Table **3--Distribution** of selected diagnostic species in the mid elevation steady state communities. The arabic numbers 1 and 2 indicate tree and sapling size classes, respectively

Mesic	Intermediate	Xeric
Eastern hemlock 1		
Rosebay rhododendron 2		
Christmas fern		
Northern red oak 1	Northern red oak 1	Northern red oak 1
	Pignut hickory 1	
	Chestnut oak 1	Chestnut oak 1
	Sourwood 1	**Sourwood** 1
		Lowbush blueberry
		Mountain laurel
		Galax
		Scarlet oak 1

High Elevations

There were several early successional **species** common in all high elevation site units. Tree species such as black locust and black cherry were common throughout although their constancy and importance values were lower on xeric sites. Red maple was present as a tree and sapling in all site units at all successional stages. **White** oak and **pignut** hickory saplings were common on all sites along with Catesby's trillium, blackberry, and greenbrier. The site units tended to have many herbaceous species in common (Carter 1994).

The earliest seral communities were termed a black locust-pin cherry-black cherry type on mesic sites, a black cherry-black locust-pignut hickory on intermediate sites, and a **white** oak-scarlet **oak-** sassafras on xeric sites (Carter 1994). A number of diagnostic species were found in the earliest seral communities. Pin cherry trees were present on the mesic site unit **along** with Carolina **silverbell** saplings and Indian cucumber-root and wood-anemone. Species common **only** in the mesic and intermediate sites were cherry birch trees and saplings, striped maple **saplings,** and New York fern. The intermediate and xeric sites shared common species in scarlet oak and white oak trees, American chestnut saplings, and azalea species. Xeric sites were unique in having sassafras trees and a mountain laurel **midstory** (Table **4).**

Table **4--Distribution** of selected diagnostic species in the high elevation early successional communities. The arabic numbers 1 and 2 indicate tree and sapling size classes, respectively

Mesic	Intermediate	Xeric
Pin cherry 1		
Carolina silverbell 2		
Indian cucumber-root		
Wood-anemone		
Cherry birch 1	Cherry birch 1	
Striped maple 2	Striped maple 2	
New York fern	New York fern	
	Scarlet oak 1	Scarlet oak 1
	White oak 1	White oak 1
	American chestnut 2	American chestnut 2
	Azalea	Azalea
		Sassafras 1
		Mountain laurel

The middle seral communities were a northern red **oak-** red maplschestnut oak type on mesic sites, a northern red oak-white oak-chestnut type on intermediate sites, and a mixed oak-heath type on xeric sites (Carter 1994). The middle seral communities still contained black locust, but its dominance had decreased. Black cherry trees were absent from the mesic and xeric sites but still present in the intermediate sites. Indian cucumber-root had a high constancy on mesic sites and was found with wood-anemone, eastern hemlock, and **rosebay** rhododendron. Scarlet oak and white oak were present on the intermediate and xeric sites. False Solomon's seal and five-finger were diagnostic on intermediate sites (Table 5).

The steady state vegetation was a northern red **oak-** eastern hemlock-witch hazel type on mesic sites, a northern red oak-white oak-hickory type on intermediate sites, and a scarlet oak-white oak-heath type on xeric sites (Gattis 1992). The steady state vegetation lacked common successional species such as black locust. On mesic sites, northern red oak and eastern hemlock were dominant trees with witch-hazel and **rosebay** rhododendron common shrubs. Indian cucumber-root and New York fern were common herbaceous species. The intermediate sites were a mixture of northern red oak, white oak, and **pignut** hickory trees with American chestnut saplings and azalea shrubs. The herbaceous layer was dominated by false Solomon's seal. On xeric sites, white oak and northern red oak were always present and had high importance values. American chestnut and mountain laurel were common **midstory** species with huckleberry in the understory. Xeric herbaceous vegetation was sparse (Carter 1994 and Table 6).

Table 5--Distribution of selected diagnostic species in the high elevation middle successional communities. The arabic numbers 1 and 2 indicate tree and sapling size classes, respectively

Mesic	Intermediate	Xeric
Eastern hemlock 1		
Rosebay rhododendron 2		
Indian cucumber-root		
Wood-anemone		
New York fern	New York fern	
	Black cherry 1	
	False Solomon's seal	
	Five-finger	
	Pignut hickory 1	
	White oak 1	White oak 1
	Scarlet oak 1	Scarlet oak 1
		Azalea 2
		Huckleberry
		Mountain laurel

Table 6-Distribution of selected diagnostic species in the high elevation steady state communities. The arabic numbers 1 and 2 indicate tree and sapling size classes, respectively

Mesic	Intermediate	Xeric
Eastern hemlock 1		
Rosebay rhododendron 2		
Witch-hazel 2		
Indian cucumber-root		
New York fern	New York fern	
Northern red oak 1	Northern red oak 1	Northern red oak 1
	False Solomon's seal	
	Pignut hickory 1	
	White oak 1	White oak 1
	Azalea 2	Azalea 2
	American chestnut 2	American chestnut 2
		Scarlet oak 1
		Huckleberry
		Mountain laurel

Overall Vegetational Trends

There were some distinctive differences in the high and mid elevation vegetation. While yellow-poplar dominated many mid elevation sites along with flowering dogwood and white pine, these species were uncommon in the high elevations. In contrast, pin cherry was found only in the high elevations, and black cherry was prevalent on many high elevation sites but less common in the mid elevations. In the midstory, witch-hazel and striped maple were common on moister high elevation sites but rare in the mid elevations. In the high elevations, white oak was excluded from the mesic sites while eastern hemlock was found only on these sites. Midstory species less common in the high elevations but common in the mid elevations were flowering dogwood and blackgum. Tree species abundant in the mid elevations but lacking in the high elevations were sourwood and pitch pine. See Carter (1994) for more detailed descriptions.

In general, the species that dominated the steady state vegetation were present in the early seral stages although they were not dominant. The exception was eastern hemlock. It did not appear until the middle seral community but was dominant in mesic steady state vegetation in the high and mid elevations.

IMPLICATIONS

The identification of LEC site units and the description of the vegetation, soils, and landform could provide a basis for ecological management in the High Rainfall Belt. Once the area has been mapped, species and management techniques can be matched to the appropriate site unit. Also, LEC has potential to improve site productivii predictions and the management of noncommodity resourcea such as rare and endangered species.

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Appendix-Common and scientific names'

Common name	Scientific name and authority
Striped maple	*Acer pensylvenicum* L.
Red maple'	*Acer rubrum* L.
Wood-anemone	*Anemone quinquefolia* L.
Cherry birch	*Betula lenta* L.
Sedge	*Carex spp.* L.
Pignut hickory	*Carya glabra* (Miller)
American chestnut	*Castanea dentata* (Marshall) Borkhausen
Flowering dogwood	*Cornus florida* L.
Galax	*Galax aphylla* L.
Huckleberry	*Gaylussacia ursina* (M.A. Curtis) Torrey and Gray
Carolina silverbell	*Halesia Carolina* L.
Witch-hazel	*Hamamelis virginiana* L.
Mountain laurel	*Kalmia latifolia* L.
Yellow-poplar	*Liriodendron tulipifera* L.
Indian cucumber-root	Medeola *virginiana* L.
Blackgum	Nyssa *sylvatica* Marshall
Sourwood	*Oxydendrum arboreum* de Candolle
Pitch pine	*Pinus rigida* Miller
White pine	*Pinus strobus* L.
Solomon's seal	*Polygonatum biflorum* (Willd.) Pursh
Christmas fern	*Polystichum acrostichoides* (Michaux) Schott.
Five-finger	*Potentilla canadensis* L.
Pin cherry	*Prunus pensylvanica* Linne
Black cherry	*Prunus serotina* Ehrhart
White oak	*Quercus alba* L.
Scarlet oak	*Quercus coccinea* Muenchhausen
Chestnut oak	*Quercus prinus* L.
Northern red oak	*Quercus rubra* L.
Rosebay rhododendron	*Rhododendron maximum* L
Azalea	*Rhododendron spp.* L.
Black locust	*Robinia pseudoacacia* L.
Blackberry	*Rubus spp.* L.
Sassafras	*Sassafras albidum* (Nuttall) Nees.
False Solomon's seal	*Smilacina racemosa* (L.) Desfontaines
Greenbrier	*Smilax rotundifolia* L.
New York fern	*Thelypteris noveboracensis* (L.) Nieuwiand
Catesby's trillium	*Trillium catesbai* Elliott
Eastern hemlock	*Tsuga canadensis* (L.) Carriere
Lowbush blueberry	*Vaccinium vacillans* Torrey
False hellebore	*Veratrum parviflorum* Michaux

'nomenclature follows Radford and others 1968

DEFINING OLD GROWTH: IMPLICATIONS FOR MANAGEMENT'

David L. White and F. Thomas Lloyd[2]

Abstract—This paper describes the USDA Forest Service Eastern oldgrowth definition project. Major definitlon elements are described using examples from the dry and dry-mesic oak-pine oldgrowth type. Few oldgrowth types approximate steady-state conditions and some are ephemeral on the landscape. Prescribed fire is required for the maintenance of some old-growth types. Other silvicultural tools can be used to retain some old-growth characteristics in stands managed for multiple objectives. Understanding the relationships between various types of disturbances and the living and dead components of old-growth forests is critiil to their restoration and/or maintenance.

INTRODUCTION

USDA Forest Service (USFS), with the help of scientists from The Nature Conservancy (TNC), Forest Service Research and other organizations, is developing old-growth definitions for 35 forest types within the Eastern United States (U.S.). Old-growth forests were officially recognized as a resource by the USFS in 1988 and shortly thereafter, the Eastern Old-Growth Definition Project began. Initially, an old-growth task group drafted a generic definition that stated: "Old-growth forests are ecosystems distinguished by old trees and related structural attributes. Old growth encompasses the later stages of stand development that typically diier from earlier stages in a variety of characteristics which may include tree size, accumulations of large dead woody material, number of canopy layers, species composition, and ecosystem function." The primary objective of the project was to describe current knowledge about broad forest types and identify gaps in that knowledge.

Much of the land in the Eastern U.S. has been dramatically affected by humans, especially since the arrival of Europeans. Therefore, defining old growth in the Eastern U.S. requires a somewhat diierent approach than that used in parts of the U.S. where large areas of old growth exist. The definitions will vary in quantity and quality, largely because the amount of available literature and the number of existing old-growth sites vary with forest type. Nevertheless, when complete, the definitions will be useful to land managers whose objectives include either restoring or maintaining old-growth forests or incorporating certain old-growth characteristics into the management of forests with multiple objectives. Our paper describes the USFS Eastern Old-Growth Definition Project and the major elements of the old-growth definitions. We use information from the dry and dry-mesic oak-pine old-growth type to illustrate the definition process and the management implications.

OLD-GROWTH DEFINITIONS

The framework used by the old-growth task group to develop the initial list of Eastern old-growth forest types included the following parameters: 1) all natural ecosystems that contain trees in any density; 2) ecosystems with any combination of disturbance regimes, including ecosystems that contain short-lived tree species that regenerate after catastrophic disturbance; and 3) the forests, woodlands and savannahs within USFS Southern and Eastern regions and TNC's Eastern, Midwestern, and Southeastern regions. Item two represents a deviation from the perception of old growth as steady-state, self perpetuating, climax communities. Thirty-five old-growth forest types have been identified for the Eastern U.S., and approximately 24 of these have ranges that include the Southeastern U.S. Of these 24, 14 are terrestrial types and 10 are palustrine types (Table 1). These old-growth types represent broad forest types. For example, types 21 and 25 occur across most of the physiographic regions of the Eastern U.S. and include the intermediate to dry site oak-hickory and oak-pine community types, respectively.

Each old-growth definition will contain the following major elements: 1) an introduction, 2) a description of the forest type group, 3) a table of old-growth attributes, 4) a narrative of old-growth conditions, 5) a description of forest dynamics and ecosystem function, and 6) a list of representative old-growth stands.

Description of Forest Type Group

The description of the forest type group includes links or crosswalks with SAF cover types and other classification systems as well as a description of disturbance regimes, vegetation composition and distribution of the forest type. To be useful to managers, definitions must link the old-growth types to existing classification systems. Because few old-growth oak-pine stands exist in the Piedmont, a variety of

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Table l-Eastern old-growth types of the Southeastern U.S.

#	Old-Growth Forest Type Name
	Terrestrial Forest8
1	Northern hardwood forests
2	Conifer-northern hardwood forests
5	Mixed mesophytic and western mesophytic forests
6	Coastal Plain upland mesic hardwood forests
21	Dry-mesic oak forests
22	Dry and xeric oak forests, woodlands, and savannahs
24	Xeric pine and pine-oak forests and woodlands
25	Dry and dry-mesic oak-pine forests
26	Upland longleaf and S.Florida slash pine
27	Seasonally wet oak-hardwood woodlands
31	Montane and allied spruce and spruce-fir forests
34	Sand pine forests and woodlands
37	Rocky, thin-soiled excessively-drained cedar woodlands
36	Barrier Island mixed forests & woodlands
	Palustrine Forests
10	Hardwood wetland forest
12	Hardwood freshwater tidal swamps
13	River floodplain hardwood forests
14	Cypress tupelo swamp forests
15	Tropical and subtropical wetland forests and woodlands
16	Mangrove swamps
28	Eastern riverfront forests
29	Southern wet pine forests, woodlands and savannahs
40	Atlantic white cedar forests
41	Bay forests

site/vegetation studies were examined to best assess where the old-growth oak-pine would probably develop. Several studies eliminated stands that contained pine species (Farrel and Ware 199, Kasmer and others 1984, Keever 1973, Jones 1988), while others included pine species in their attempts to define site/vegetation relationships(Golden 1979, Oosting 1942, Peet and Christensen 1980, Schafale and Weakley 1990). Both types of studies provided information relevant to the characteristics and/or distribution of old-growth oak-pine forests.

Peet (unpublished data') compiled a table of synonymous communities for the NC Piedmont from various sources including Oosting (1942), Peet and Christensen (1980), Schafale and Weakley (1990) and others. This table and the original studies allowed us to infer which identified oak-dominated communities occupied sitss where the dry and dry-mesic oak-pine type would probably occur, given sufficient canopy and/or forest floor disturbance (e.g. fire, wind and ice storms, insects). Table 2 shows approximately equivalent community types from three diierent classification systems that occupy the types of sites where old-growth oak-pine occurs.

Predictive ecosystem classification systems are especially valuable tools for planning and management because the variables, soil and landform characteristics in some cases, can often be incorporated in a geographical information system (GIS). National Forests and other organizations are developing various forms of these systems. Jones (1988) sampled old-growth hardwood stands in the SC Piedmont and developed a predictive landscape ecosystem classification (LEC) system integrating landform, soil and late successional vegetation. While Jones' system predicts the late successional vegetation type from soil and landform variables, it is important to acknowledge that multiple ecological outcomes are possible on a given site unit. Different forest types will develop for each combination of soil, landform and disturbance regime. Based on descriptions of Jones' site units, literature information and our sampling, the dry and dry-mesic oak-pine type would probably develop on xeric, sub-xenc and intermediate site units (Table 3). A more intense disturbance would probably be required for pine to become established on the intermediate site unit because conditions are more favorable for hardwoods.

Old-Growth Attributes

The table of old-growth attributes includes density, basal area, number of 4 in. size classes, age and diameter of codominant and dominant trees, abundance of snags and coarse woody debris (CWD), and size and distribution of canopy gaps. Studies describing age, snags, CWD, size and distribution of canopy gaps and other descriptions of disturbance are lacking for many old-growth types (Table 4). The John de la Howe (JDLH) tract is the only stand with a complete set of attribute data. A portion of these data is shown in Table 5 to illustrate the kind of information presented in an old-growth attribute table.

Forest Dynamics and Ecosystem Function

The section on forest dynamics and ecosystem function describes ecological processes during the old-growth stage, presettlement disturbance regimes,

[1] Files of Dr. Robert K Peet, University of NC, Chapel Hill, NC.

Table 2. Portion of community synonymy table showing communities that correspond to the sites where the dry and dry-mesic oak-pine type may occur.

Community Synonymy for North Carolina Piedmont		
Peet and Christensen 1980	Oosting 1942	Schafale and Weakley 1990
Dry Mesotrophic - Clayey phase - Sandy phase	White oak-black oak-red oak (in part)	Dry-mesic oak hickory
Dry Oligotrophic	White oak	Dry oak-hickory
Dry Eutrophic	White oak-post oak	Basic oak-hickory

Table 3. Late successional community types, soil, and landform characteristics from the SC Piedmont LEC (Jones 1988) corresponding to site units supporting old-growth type 25.

Siie Unit and Community Type	Distinguishing Soil Characteristics	Landform Description
Xeric: Post oak-black oak-and lowbush blueberry[1]	heavy clay subsurface horizon 12 in. from surface or bedrock within 24-36 in.	Exposed ridge flats upper slopes of any aspect
Subxeric: White oak-scarlet oak-deerberry[2]	clay or sandy clay sub-surface horizons at 12-24 in. or:	ridge flats, upper slopes of any aspect or mid-slope with a S. aspect southerly aspect
	heavy clay horizons within 12 in. of surface or bedrock within 24-36 in.	less exposed mid slopes with N. or E. aspects
Intermediate: White oak-northern red oak[3]-false solomon's seal[4]	sandy clay loam or clay loam at 12-24 in.	mid slopes with N. or E. aspects or mid- to lower slopes with S. aspects

[1] Vaccinium vacillans Torrey.
[2] Vaccinium stamineum L.
[3] *Quercus rubra* L.
[4] *Smilacina racemosa* (L.) Desf.

Table 4. Locations of old-growth oak-pine stands showing the availabilll of attribute data.

Region and Siie	Density	BA	4 inch'	Age[2]	DBH[2]	CWD	Gaps
Piedmont							
John de la Howe (SC)	+[4]	+	+	+	+	+	+
Duke Forest (NC)	+	+	-[5]	-	-		
Southern Appalachians							
Scarlet Oak N.A.(NC)	+	+	+	+			-
GSNP (TN) [3]			-	+	-	-	
Gulf Coastal Plain							
Kisatchie NF (LA)	+	+	+				
Ouachita Mountains							
Roaring Branch RNA (AR)	+	+	+	+	+		
Lake Winona RNA (AR)	+	+	+	+			-
Hot Springs NP (AR)	+	+	-	+		+	

[1] Refers to number of 4 in. size classes.
[2] Age and diameter of large trees (dominants and codominants).
[3] Ongoing studies.
[4] Data available.
[5] Data not available.

successional trends and other aspects important to managing for a given type. Given the relative scarcity of old-growth in the East, using a variety of information from the past and present helps in formulating definitions of Eastern old-growth types. Examples from the dry and dry-mesic oak-pine type are used to illustrate how this varied information can be used to characterize old growth.

First, the historical distribution of oak and pine species and their response to disturbance are discussed. Then, perceptions of the presefflement composition in the Southeastern Piedmont are presented. Finally, mortality-related disturbance patterns in an old-growth oak-pine stand in the SC Piedmont are reviewed.

Historical Development of the Oak-Pine Type.

To gain a more complete understanding of the prevalence of oak-pine types in the Eastern U.S., a review of the relative importance of these two species groups on a broad time scale is useful. Upon the arrival of humans to Eastern North America 12,000 years ago (Delcourt and Delcourt 1987), plant taxa were migrating northward in latitude and upwards in elevation in response to global warming that began after the height of Wisconsin glaciation (18000 b.p.). Global warming reached its maximum approximately 6000-7000 b.p., followed by a gradual cooling period. Approximately 8000 b.p., oaks exhibited a slight decline in paleodominance in the Southeastern U.S. while southern pine dominance increased (Delcourt and Delcourt 1987). The apparent shift in relative dominance of upland oaks and southern pines during the mid-holocene interval (5000 b.p.) is believed to be the result of increased fire frequency associated with hunting practices of Native Americans. Although climatic warming, more frequent fire, and growing populations and activities of Native Americans may have affected oaks and pines differently, both species were probabty in association for thousands of years. Buckner (1 989) described the pine-hardwood type as a "mid-seral stage that is ephemeral on a given site and is maintained in a changing landscape mosaic where scattered disturbances re-initiate succession in a stochastic manner."

While the role of fire and other disturbances in maintaining pines is well established, their effects on oak species are less clear because many have been viewed historically as relatively stable "climax" species. It is now generally accepted that oaks require disturbance for successful establishment as canopy dominants. Fire is regarded as an important disturbance agent for establishing upland oaks in eastern deciduous forests (Abrams 1992, Christensen 1981, Van Lear and Watt 1993). Fire reduces competition from fire intolerant species and increases the accumulation of oak advance regeneration. Van Lear and Watt (1993) also suggest that understory fires may provide more favorable conditions for germination and seedling establishment. If sufficient oak advanced regeneration is present, canopy disturbances will promote further oak development and eventual dominance. Since oaks are more shade-tolerant than

Table 5. Potion of old-growth attribute table for old-growth oak-pine stands from the John de la Howe tract in South Carolina

Quantifiable Attribute	Value Range[1]	Mean
Age of Large[2] Trees		
Shortleaf pine[3]	89-205	144
Loblolly pine	79-I 89	117
White oak	82-207	149
Hickory species	142-207	179
Post oak	101-216	144
Southern red oak	64-I 90	124
Yellow poplar	94-194	160
Standing Dead (# acre^{-1})		
Snags ≥ 4 in. dbh	15-69	33
Snags ≥ 20 in. dbh	2-16	8
Coarse Woody Debris		
Volume (ft.^{3} acre-')	747-2528	1545
Mass (tons acre-')	7.4-25.4	15.4
Tree Canopy Structure		
Number of canopy layers	2-3	
Percent canopy in gaps	24-80	37
Mean gap size (acres)[4]	.002-.503	.060

[1] For standing dead, CWD and percent canopy in gaps, range represents the range of means from areas showing diierent degrees of mortality.

[2] Codominant and dominant trees.

[3] Scientific names given in order shown above:!? *echinata* Miller, *P.taeda* L., *Quercus alba* L., *Carya* spp (C. *tomentosa* (Poiret) Nuttall, C. *ovata* (Miller) K. Koch, C. *glabra* (Miller) Sweet.), *Q. stellata* Wang., *Q.* coccinea Muenchh., *Q. falcata* Michaux., and *Liriodendron tulipifera* L.

[4] Canopy gaps ≤ 1 acre in size. Gaps exceeding 1 acre were variable sized patches of extensive pine mortality accounting for 58 percent of the total gap area.

associated pine species, they generally require smaller canopy disturbances.

Post-settlement logging and fire probably increased the oak component beyond its presettlenent distribution in parts of North America, even though use of fire by Native Americans prior to settlement also favored oak establishment.

This historical information provides two important points: 1) oaks and pines have been components of the eastern deciduous forest for thousands of years and shifts in their relative abundance have been related to climate changes and to fire used by aboriginal people in the past 10,000 years, and 2) the oak and pine species that dominate the dry and dry-nesic oak-pine type require disturbance to maintain their dominance.

Presettlement Forests of the Piedmont. The composition of Southeastern Piedmont forests prior to European settlement has been characterized (Brender 1974, Nelson 1957, Peet and Christensen 1987, Plummer 1975, Skeen and others 1980, Skeen and others 1993) but no clear agreement exists. While most view pine species as minor components of the "original" forest, Nelson (1957), citing a number of sources from the 1800's, describes the original forest of the GA Piedmont as ranging from pure pine to pure hardwoods. The oak-hickory types were more abundant in the "red lands"(35-40 percent of the GA Piedmont), while shortleaf pine and post, white and red oaks occupied the "gray sandy lands"(45 percent of the

region). Pine dominated the remaining 15 percent of the Piedmont, the Elberton granitic formation. Plummer (1975) used survey records of the GA Piedmont and Blue Ridge from the settlement period, 1733-1832, to provide more specific information. Pine was especially abundant on steep slopes and upland soils of micaceous origin. Soils with higher clay content supported more post oak. The ratio of oak:pine:hickory was 53:23:8 on over one-half million acres surveyed.

Early writings by explorers and settlers, as well as early land surveys provide a general sense of the vegetation composition prior to widespread settlement by Europeans. Because this information describes conditions at a single point in time, they must be regarded with some caution. For example, Native American populations are thought to have declined dramatically from exposure to European diseases introduced by explorers 200 years prior to settlement (De Viio 1991). Population decline would have resulted in less fire (after 1500 AD), affecting the structure and composition of forests surveyed and described at the time of settlement. Fire suppression policies of this century have also altered the composition and structure of forests. Impressions of presefflement forests that are based on present day forest composition must also be viewed with caution. It is important to acknowledge that presefflement forests were dynamic rather than static.

Mortality Patterns in an Old-Growth Piedmont Stand

The JDLH forest tract in South Carolina is, to our knowledge, the best example of the dry and dry-mesic oak-pine type in the Piedmont This 120-acre, 200+ year old stand of mixed oak-shortleaf-loblolly pine has recently undergone significant levels of pine mortality. The stand is located in an area disturbed to varying degrees by European settlers in the mid 1700's, abandoned just prior to 1800 and protected since. Scattered cutting has occurred in the periphery of the stand and pine has been salvaged in a few areas in more recent years.

We sampled the area systematically and eliminated plots with cut stumps or other obvious signs of human disturbance. Characterization of 0.25 acre plots was based on 4 levels of mortality, described in terms of canopy openness or percent of canopy in gaps (Figure 1): 1) low - <25% in canopy gaps; 2) intermediate - 25-50% in canopy gaps; 3) high/old - >50% in canopy gaps that formed 3 or more years prior; and 4) high/new - > 50% in canopy gaps that occurred within I-2 years prior to sample. Soils were predominantly the Cecil series with some Pacolet Based on the LEC described by Jones (1988), most of the area was characterized as subxeric and intermediate with a few xeric sites. Sampling was similar to that described by Shifley and others (1991), with modifications for CWD and canopy gaps. CWD was sampled using a modified version of a technique described by Van Wagner (1968) and Brown (1974). Gaps were sampled along transects that bisected the stand along plot grid lines.

Mortality in the JDLH stand was 62 percent pine, 23 percent hardwood and 15 percent pine-hardwood. Areas of low and medium levels of mortality were characterized by a relatively continuous canopy (Figure I), broken up by variable sized canopy gaps, generally less than 0.3 acres and averaging 0.06 acre (58 ft in diameter). While, the mean gap size and range found on the low to medium mortalii areas (Table 5) was similar to that found by Clinton and others (1993) in a mature Southern Appalachian mixed oak forest, the percent of the total area in gaps at JDLH was higher. In the JDLH high mortality areas, overstory canopy openness ranged from 60-80 percent. These open patches ranged in size from 0.5 to 10 acres. Almost all mortality occurred in shortleaf and loblolly pine.

Across this gradient of canopy related disturbance, certain old-growth characteristics varied considerably. Figures 2 and 3 show snag density and CWD abundance across the same mortalii classes illustrated in Figure 1.

Snag density $\geq$ 4 in. dbh ranged from 15 per acre in areas of low to medium mortality to 70 per acre in areas of high mortalii. In Kentucky, McComb and Muller (1983) reported from 14 to 32 snags ($\geq$ 4 in. dbh.) per acre in old-growth beech (*Fagus grandifolia* Ehrhart.) and chestnut oak (*Quercus prinus* L.) forests, respectively. Sabin (1991) reported 11 snags per acre across a range of 20-60 year old Piedmont forest types in South Carolina. Large snag density ($\geq$ 20 in. dbh) in the JDLH high mortalii areas was >10 per acre compared to 0 to 3 per acre (1 O-35 in. dbh) in Kentucky (McComb and Muller 1983).

CWD follows the same pattern (Figure 3) except that the high-recent mortality area had low inputs. Most recent pine mortality remained standing as snags while most of the mortality occurring 3-20 years ago was on the ground as CWD. The 25 tons acre^{-1} of CWD in the high-old mortality class is much higher than the 8-11 tons acre-' found in several old-growth mixed oak-hardwood forests of the Eastern U.S. (Harmon and others 1986, Lang and Forman 1978, MacMillan 1981, Muller and Liu 1991). However, this quantity was less than one-half that reported for mature uneven-aged pine stands on the SC Coastal Plain following Hurricane Hugo (Myers and others 1993). Large inputs of CWD from insect-related mortalii at the JDLH and large scale disturbances such as Hurricane Hugo, represent large but infrequent pulsed inputs. The dynamics of these inputs and their effects on various ecosystem processes are not well understood (Van Lear and Waldrop 1995).

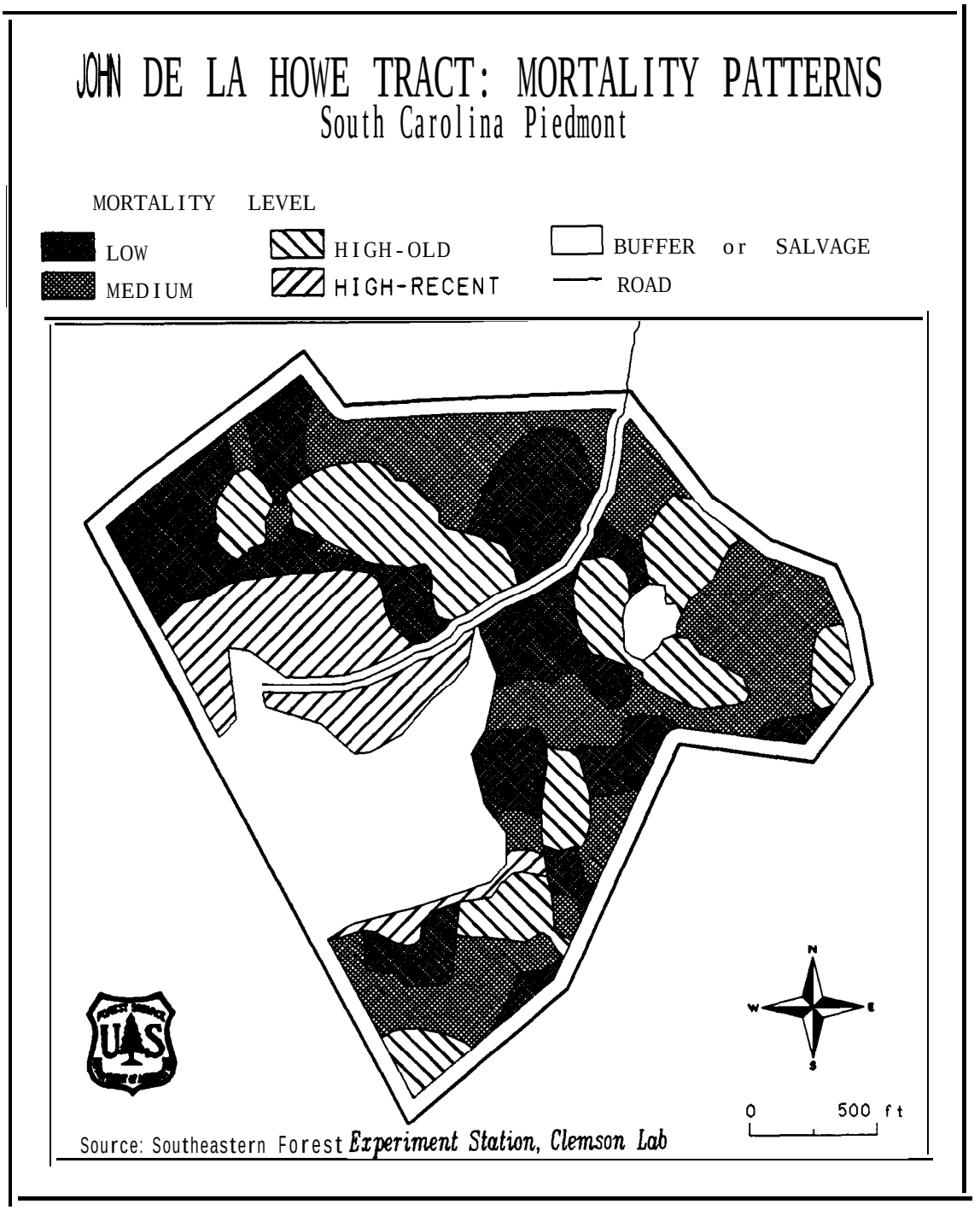

Figure I-Map of mortality **pattens** on the JDLH tract in the SC Piedmont.

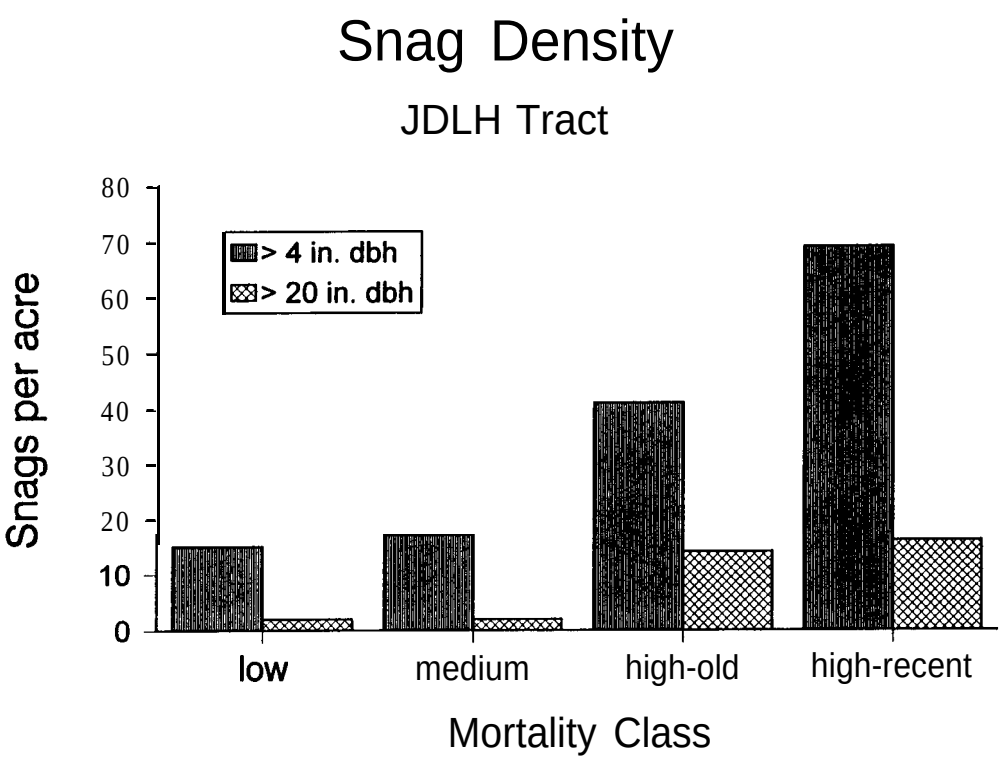

Figure 2--Snag density by dbh and mortality class for the JDLH tract.

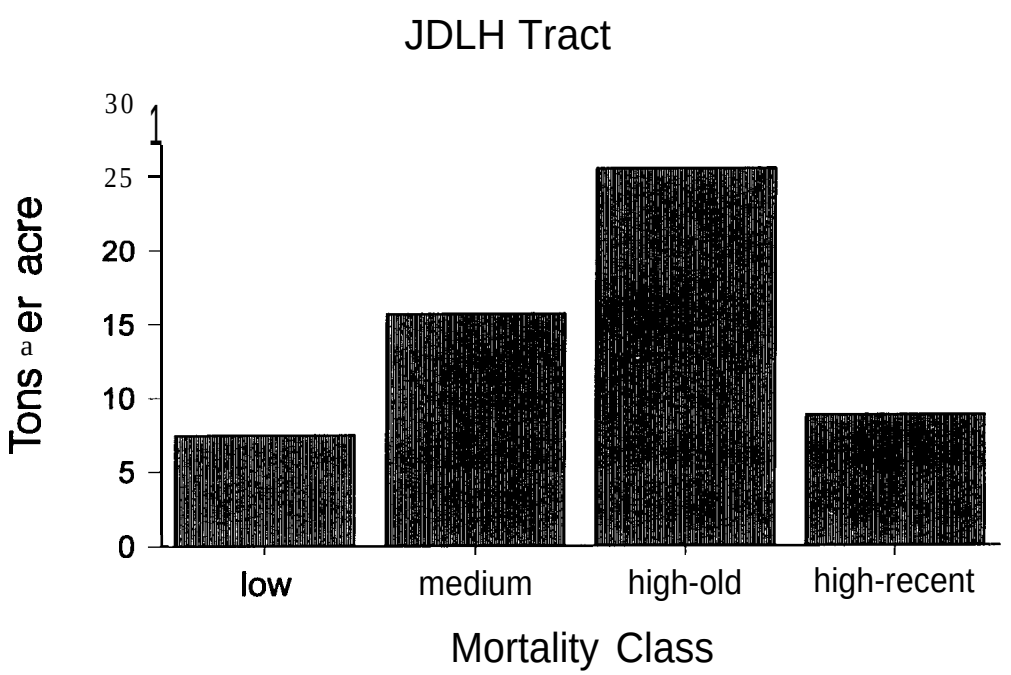

Figure 3--Coarse woody debris (tons $acre^{-1}$) by mortality class for the JDLH tract.

CWD mass and snag density in low to medium mortality areas of the JDLH corresponded to the ranges reported for old-growth forests previously cited. These similarities are temporary because pine mortality will probably increase on these sites in the near future. When most pines in the stand have succumbed to southern pine beetle (SPB), liieleaf disease or other pathogens, oaks and other hardwoods will assume dominance. Without forest floor disturbance, such as that caused by fire, pine species will become minor components of this stand in the future.

IMPLICATIONS FOR MANAGEMENT

We have described and, in some cases, used specific examples of the types of information contained in old-growth definitions. The historical distribution of a forest type or historical composition of a region where specific old-growth types occur, identifies what the potential old-growth types would be for a given site. A greater understanding of historical disturbance regimes as well as species response to varying levels of disturbance should clarify management options for creating and maintaining certain old-growth types on the landscape.

Generally, some old-growth definitions will reinforce acceptance of the importance of a wide range of types, scales and intensities of disturbance required to maintain certain forest types. Early concepts of old-growth forests were based on the steady-state, equilibrium view of forest dynamics. While some forest types may approximate steady-state dynamics, many types may not. A number of papers have presented alternative views of forest succession for specific types or described forest dynamics in a way that includes a wider range of disturbances as an integral component (Christensen 1988, Denslow 1985, Egler 1954, Glitzenstein and others 1986, Harper 1977, Oliver 1981, Pickett and White 1985, Platt and Schwartz 1990, Sprugel 1991, Spurr and Barnes 1973). Conceding the relative "untidiness" of forested ecosystems is critical to their wise management.

Canopy and forest floor disturbance is required to regenerate or maintain the dry and dry-mesic oak-pine type (25). Natural disturbances, such as insect related mortality, wind and storm damage, and fire may interact to provide conditions necessary for pine and oak establishment The spatial and temporal variation of disturbance over broad landscapes may cause the loss of pine in some oak-pine patches which will then become oak-mixed hardwoods. Other non-pine patches occurring on similar sites may be subjected to a combination of disturbances that support pine establishment. The ephemeral nature of the oak-pine type illustrates the concept of the shifting landscape mosaic. Multiple ecological outcomes are possible for comparable sites. Acknowledging the importance of these concepts is crucial for developing long-term management strategies for large areas, especially when the land manager has muitiple resource objectives.

If maintaining some old oak-pine forests is an objective, the role of insects and other pathogens that affect the composition and structure of old growth (Haack and Byler 1993) and the interaction between old growth and surrounding stands are important. For example, in the Piedmont, SPB and liieleaf disease are the most serious pests affecting conifers (Belanger and others 1986). Shortleaf pine, has the widest range of the southern pines and grows on a variety of soils and is most susceptible to liieleaf or to liieleaf-SPB interactions. Risk multiplies on sites that are severely eroded and contain a high percentage of heavy plastic clays. Therefore, these sites should be avoided when managing for the dry and dry-mesic oak-pine type if maximizing the longevity of the pine component is the objective.

The impact from SPB is less in mixed pine-hardwood stands than in pure pine stands because pine continuity is interrupted by hardwoods (Belanger and others 1986, Showalter and Turchin 1993). If maintaining old-growth oak-pine on landscapes mixed with more intensiveiy managed stands is the objective, managing for pine-hardwood mixtures rather than pine monocultures may minimize the risk and extent of insect and other disease outbreaks. When managing for old-growth oak-pine, susceptibility to SPB and other pathogens will increase as the pines reach old age. While pine mortality is to be avoided from the perspective of fiber and timber production, it is integral to the vegetation dynamics in some old-growth forests. The management challenge is to allow natural disturbance to occur in old-growth forests, while minimizing losses in surrounding stands. Separating intensively managed stands (high pine component, disease risk dependent on stand conditions) from old-growth oak-pine stands (moderate pine component, moderate to high disease risk) with pure hardwood stands or with mixed pine-hardwood stands may reduce disease-caused losses.

To protect old growth core areas from fragmentation and to produce a sustained yield of functionally dynamic old growth forests in the Interior Highlands, Guldin (1991) suggested surrounding old growth core areas with buffer stands managed under "big-tree" uneven-aged silvicultural systems. This could be accomplished through structural control-BDq[1] methodology with targets derived from existing old-growth stands (Guldin 1991). Application of silvicultural techniques (fire, timber extraction etc.) to the buffer stands would continue until the live tree composition and structure was similar to that of the target old-growth stand. After this point, significant time would elapse before these buffer stands would be considered old growth.

[1]Basal area-maximum diameterq factor method.

Retaining Old-Growth Characteristics in Managed Stands

What old-growth attributes are desirable in stands managed for multiple values? Generally, large living and dead trees (large for site), various habitats and conditions they support, and relatively continuous forest canopies are valued in old-growth forests for spiritual inspiration, aesthetics, wildlife habitats, timber, etc. Snags and downed CWD serve multiple and important ecosystem functions (Van Lear 1994, Van Lear and Waldrop 1995). What cutting practices would maintain some of these desirabie characteristics and simultaneously allow for the economical harvest of commercial species?

Information is lacking on even- and uneven-aged management techniques for retaining old-growth characteristics. Modified shelterwood methods may be compatible with this goal since this method allows indefinite retention of older trees and more frequent fire (Pell, personal communication). Research on uneven-aged management and natural regeneration of shortleaf and loblolly has been conducted (Baker and others [In press]) but less is known about uneven-aged management for mixed pine-hardwood stands (Waldrop 1991). One approach might involve group selection harvest of oaks and pines, leaving snags and "snag candidates" in and around openings. Opening size could vary but should be large enough to support pine regeneration. If pine regeneration is insufficient following logging disturbance of the forest floor, prescribed fire could be used, though burning group openings is logistically challenging. Patchy forest floor disturbance combined with a variable light regime within a given opening, as well as among diierent sized openings, would enhance regeneration of pines, oaks and other hardwoods. Regardless of the silvicultural system, if maintaining some old-growth characteristics is the goal, techniques that focus on retaining these characteristics are needed.

SUMMARY

Defining Eastern old growth is a complex, evolving process using limited information. Completed definitions will describe the composition and structure of live and dead components, site types and associated disturbance regimes. Definitions will also help identify old-growth and potential old-growth sites and contribute to restoration and management strategies. Few old-growth types function as steady-state climax communities. Given the stochastic nature of disturbance, some old-growth types should be viewed as ephemeral patches on the landscape. Some old growth, such as the oak-pine type, will require management to endure on the landscape.

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COARSE WOODY DEBRIS CONSIDERATIONS IN SOUTHERN SILVICULTURE[1]

David H. Van Lear and Thomas A. Waldrop[2]

Abstract-Coarse woody debris (CWD)-standing dead trees, fallen trees, and decomposing large roots serve a number of ecological functions. CWD loadings are dynamic in response to inputs from tree breakage and mortality and to losses from decomposition and fire. Two very different natural processes, gap-phase dynamics and major episodic disturbance, contribute to inputs in addition to forest management activities. Decay and combustion are similar in that, if complete, both yield CO_2 and water. However, neither is usually complete, and the combustion process leaves some rapidly-altered CWD, whereas decay results in the gradual formation of humic substances. Current forest management practices often contribute to low loadings of CWD in southern forests. The FORCAT gap model was used to simulate formation and decompositii of coarse woody debris (CWD) for two forest ecosystems on tha Cumberland Plateau in east Tennessee. Model results showed a decrease in CWD loads in early years as logging slash decomposed. After year 32, CWD loads increased rapidly and peaked around year 90. CWD loads in older stands gradually decreased through the remainder of the simulation period. The assumed decomposition rate strongly influenced CWD loading. Model results correspond closely to observed loadings in old-growth stands on the Cumberland Plateau.

INTRODUCTION

Standing dead trees (snags), fallen trees, and decomposing large roots are components of coarse woody debris (CWD) which exert ecological influences on a site for decades or even centuries (Franklin and Waring 1980). CWD functions as seed germination sites, reservoirs of moisture during droughts, sites of nutrient exchange for plant uptake, and as critical habit components for forest organisms. During later stages of decomposition, it promotes favorable soil structure (Harmon and others 1986, Maser and others 1988). Dead root systems have been neglected as a component of CWD. However, decomposing roots contribute to the heterogeneity of the soil, provide increased infiltration and percolation of soil water, enhance gas diiusion throughout the rooting zone, and provide habitat for soil-dwelling organisms (Lutz and Chandler 1955).

Loadings of CWD are dynamic, i.e., constantly changing in response to inputs from tree breakage and mortalii and losses from decomposition and fire. The dynamic nature of CWD is reflected in gradual or episodic changes in mass, density, and volume of standing dead and fallen trees.

Coarse woody debris, in this paper, refers to any dead standing or fallen tree stem (or dead root) at least 7.6 cm in diameter. This minimum diameter was arbitrarily chosen, primarily because it corresponded to a measured size-class in a number of cited studies in the South. For obvious reasons, the dynamics of root biomass of dead trees have received little study.

Little information exists in southern forestry literature regarding levels of CWD found in "natural" or managed forest ecosystems. This paper 1) summarizes our current understanding of CWD dynamics in southern forests, 2) models CWD loading on xeric and mesic sites, and 3) identifies gaps in our knowledge of CWD.

INPUTS OF COARSE WOODY DEBRIS

The flow of above-ground CWD within terrestrial ecosystems is summariied in diagrammatic form (Figure I), as adapted from Harmon and others (1986). Within terrestrial ecosystems, mortalii and breakage of living trees add CWD, while decay and fire remove or transform CWD (Harmon and others 1986, Maser and others 1988). The balance between inputs and losses of CWD within the forest ecosystem represents the standing crop, or loading, of CWD.

Inputs of CWD occur when living trees are killed by fire, wind, lightning, insects, disease, ice storms, competition, or by man. Disturbances may kill scattered individual trees, groups of trees, entire stands, or even devastate entire landscapes and are now widely recognized as a natural part of the ecology of the southern forest (Christensen 1991, Sharitz and

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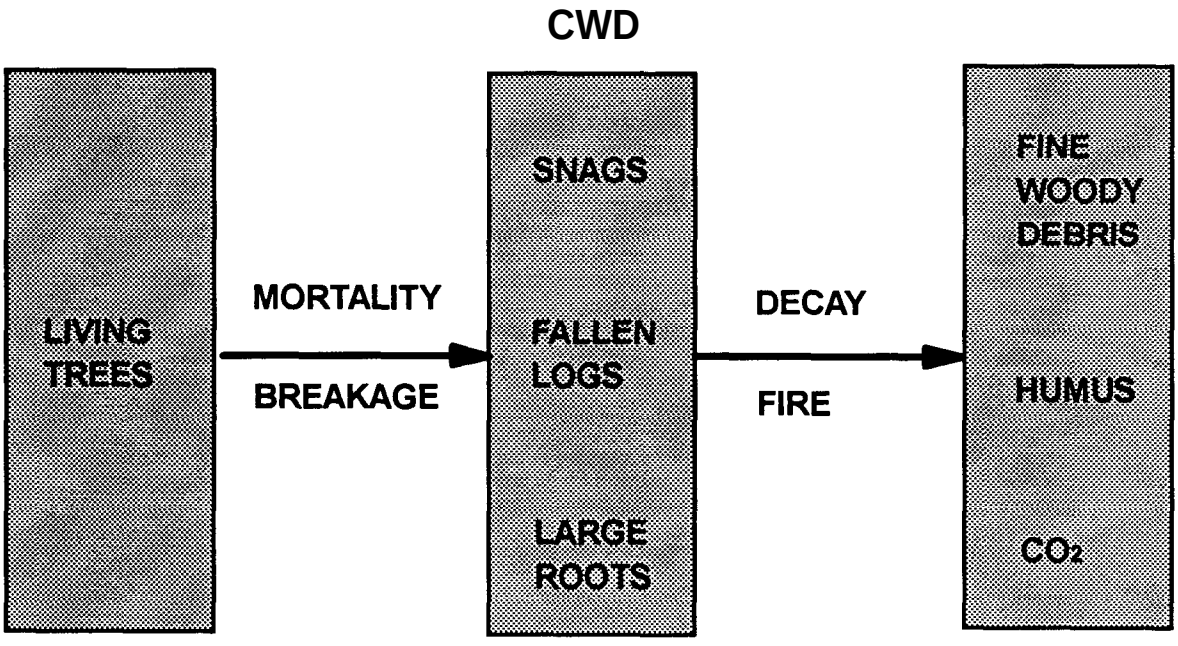

Figure 1. Flow diagram of the dynamics of CWD in terrestrial ecosystems.

others 1992, Skeen and others 1993). Major disturbances contribute large quantities of CWD, which are added to pm-disturbance CWD already accumulated in the stand. For this reason, loadings of CWD are often highest soon after major forest disturbances.

Gradual Inputs of CWD by Gap-Phase Dynamics

CWD inputs in southern forests from gradual gap phase dynamics, i.e., the occasional death of individual trees or groups of trees within the forest, are not well documented. Large canopy gaps can contribute substantial quantities of CWD. For example, Smith (1991) estimated that canopy gaps created in pitch pine stands by pine beetles in the Southern Appalachians contained 35.6 t/ha of CWD. Loadings from insect damage in more productive forest types could be much higher.

Some information on snag densities (numbers/area) and recruitment rates is available from the wildlife literature. Generalizations from published research include: 1) snags are most common in hardwood stands and least common in pure pine stands (Harlow and Guynn 1983, McComb and others 1986b, Sabin 1991), 2) snags are more frequent in lowlands and riparian zones than on upland sites, and 3) unmanaged private land and national forests generally have higher densities of snags than lands managed intensively for wood production (McComb and others 1986a, 1986b).

The length of time that snags remain standing varies with species and size, although most snags fall within a decade or less in Southern forests (Dickenson and others 1983, McComb and Rumsey 1983, Sabin 1991). However, occasional American chestnut snags are still standing in Southern Appalachian forests 70 years after the chestnut blight. White pine and white oaks are generally longer standing than snags of other pine and oak species (Hassinger and Payne 1988). Large diameter snags stand longer than smaller ones (Bull 1983, Raphael and Morrison 1987).

Snag densities in the relatively young forests of the South vary widely. In the Appalachian deciduous forest, Carey (1983) found snag densities ranging from 11 to 55 snags/ha. Sabin (1991) reported an overall snag density of 28.1 snags/ha in relatively young (20 to 60+ yrs) forest types in the Piedmont and noted that snags were being lost at an average rate of 0.52 snags/ha/yr. Relatively few areas and little acreage in the Southeast support over-mature or old-growth forests where snag recruitment rates and densities are unknown. Such information is needed to serve as baseline data against which forests managed more intensively could be compared.

Major Episodic Disturbances Which Create Heavy Loading of CWD

In contrast to gap-phase disturbances where natural succession proceeds at a relatively gradual rate, large-scale natural disturbances, such as catastrophic wildfires and hurricanes, are episodic in nature and may

kill trees over large forest areas. As a result of these natural disturbances and timber harvesting by man, few forest ecosystems in the Southeastern United States succeed to a vegetative climax condition or even develop undisturbed for as long as a century.

Forest fires affect the loading of CWD by simultaneously adding CWD by killing liie trees and reducing CWD by consuming dead trees. Fire regimes in the South range from those where fire reoccurs infrequently (on the order of several decades to perhaps a century or more) and fuel loading is heavy to those where fire occurs on almost an annual basis and fuels are light Sand pine and tabie mountain pine regenerate after catastrophic stand-replacement fires which function to open serotinous cones, kill hardwood understory competition, and prepare seedbeds (Outcalt and Balmer 1983, Della-Bianca 1990), as well as contribute a large pulse of CWD. At the other extreme, the longleaf pine-wiregrass ecosystem typifies a regime of frequent fire, which prevents the buildup of fuels to levels where high rates of fire-induced tree mortalii would be expected. Boyer (1979) reported an annual mortality of only 1 tree/ha in mature longleaf pine stands throughout the longleaf region.

Stand-replacement fires which kill all above-ground biomass obviously make heavy contributions to CWD. The author knows of no studies in the South where CWD inputs have been estimated following stand-replacement fires. However, estimates of above-ground living biomass are available for some forest types and site conditions and provide a rough approximation, when corrected for small branch and foliage components, of potential CWD inputs. About 70-80% of the above-ground biomass of these forest types is above the minimum size class of CWD. For loblolly pine, the most studied of the southern pines, above-ground biomass ranges from about 100 t/ha in thinned 41-year-old plantations on poor sites (Van Lear and others 1983) to approximately 158 t/ha for unthinned lb-year-old plantations on good sites (Wells and Jorgensen 1975). Above-ground biomass of mixed hardwood stands averaged 178 and 175 t/ha at Coweeta Hydrologic Laboratory and Oak Ridge National Laboratory, respectively (Mann and others 1988), similar to the 164 t/ha estimate from forest survey data for fully stocked stands of mature hardwoods in the Southeast (Phillips and Sheffield 1984).

Hurricanes, tornadoes, and other strong winds are common in the southeastern United States and strongly influence CWD dynamics. These strong winds create in a matter of hours loadings of CWD that would never be achieved during centuries of gap-phase natural succession (Hook and others 1991). For example, Myers and others (1993) measured loadings, after limited salvage, of almost 90 t/ha of downed woody material and 16 t/ha of snags in mature, uneven aged pine stands two years after Hurricane Hugo. Strong winds either snap stems of well-anchored species or uproot shallow-rooted species. Although catastrophic winds (probably category V force winds) will destroy any stand, such winds normally occur over only a relatively small portion of the area affected by most hurricanes.

Forest damage from hurricanes and tornados has increased in recent decades due to the regrowth of mature forests following the extensive harvest of old-growth forests that occurred between 1885-I 930 (Hooper and McAdie 1993). In addition to stand age, site (Croker 1958, Foster 1988), community type (Duever and McCollum 1993, Sharitz and others 1993), species (Touliatos and Roth 1971, Hook and others 1991, Gresham and others 1991, Sharitz and others 1993) and tree morphology (Gratkowski 1956, Nix and Ruckelshaus 1990) markedly influence the damage (and CWD loadings) to forests by strong winds.

Other environmental factors, e.g., insect and disease outbreaks, ice storms, and mass movement of soils, can dramatically increase loadings of CWD. Some native insects, the Southern pine beetle for example, periodically reach epidemic proportions and kill whole stands of various pine species across large portions of the landscape. Introduced insects like the gypsy moth continue to expand their range southward and devastate hardwood stands over extensive areas. Certain diseases, for example, fusiform rust, have become more prevalent in recent decades. Ice storms periodically wreak havoc on forests in some portions of the South, e.g., in the Sandhills region.

The quantity of CWD contributed to sites by all these factors is a function of the proportion of the stand killed (and consumed in the case of fire) by these agents and the proportion of the trees above the minimum CWD size class. Contributions range from the mortalii of scattered individual trees killed in non-episodic events to the mass deaths of trees on thousands of hectares during major episodic events, during which the loading of CWD across the landscape is increased dramatically. Information on CWD inputs from all types of catastrophic events is needed in order to fully evaluate the environmental effects of these disturbances.

LOSSES OF CWD

Within terrestrial ecosystems, CWD is lost through decay and fire. Decay and combustion by fire are similar processes in some respects, but also have important differences. The relative importance of each process vanes by site-decay dominates on mesic sites, while fire is more important on xeric sites (unless fire-suppression efforts are effective). Although its natural role as a major ecological factor has often been overlooked by ecologists and land managers, fire has

been a dominant factor shaping the structure and composition of southern forest ecosystems for millennia.

Decay

Decay of CWD is initiated by an invasion of white, brown, and soft rot fungi, causing a loss of density (Kaarik 1974). insects are known to be important inoculators of these decay microbes (Abbott and Crossley 1982). Toole (1965) described the deterioration of unlopped hardwood logging stash in Mississippi and found that, for most of the species studied, small branches had disintegrated after 6 years and only a small portion (<15%) of the large branches and bole had not settled on the ground. Twigs and small branches decayed most readily, followed by the larger sapwood and finally the heartwood. Decay may be retarded when the bark sloughs off early, allowing the surface of the sapwood to dry quickly and become casehardened. Smith (1991) documented changes in decomposer communities of pitch pine CWD during decomposition. During early stages of decomposition, bark beetles and blue-stain fungi dominated, although neither had much effect on decomposition, i.e., wood density was not markedly reduced. White rots, brown rots, ants, and termites dominated later stages of decomposition. As the wood structure is broken down, fragmentation becomes a major mechanism of decay.

Fragmentation of CWD refers to a reduction of volume via physical and biological forces during the decay process (Harmon and others 1986, Maser and others 1988). Fragmentation is normally preceeded by a lag period in which both density and mass of fresh CWD decrease, but volume remains constant. Snags fragment when portions of the standing dead tree or the entire tree break and fall to the ground. Biological fragmentation of snags and fallen logs is caused by both plants and animals. Invertebrates utilize the dead wood as a food source, creating galleries which serve as avenues for microbial colonization and further decay. Bears, birds, and other animals shred the rotting wood while foraging for insects. Plants roots grow into fallen trees after initial stages of decay have been completed and further fragment the partially decomposed materials. During the entire decay process, the physical forces of water and gravity relentlessly transport fragmented materials from snags and fallen logs to the forest floor, where they undergo further decomposition and are ultimately converted to CO_2 or decay-resistant humus. The final products of decay of CWD are fine woody debris, humus, and CO_2 (Maser and others 1979, Harmon and others 1986, Spies and Cline 1988).

Although perhaps not as good an index of decay as volume diminution, changes in wood density have frequently been used to measure initial stages of physical decay. Following clearcuttting of a mixed hardwood stand in the Southern Appalachians of North Carolina, wood-density decay coefficients varied widely, ranging from 0.18/yr for species such as dogwood and persimmon to 0.03/yr for decay-resistant species like black locust and American chestnut (Mattson and others 1987). Little information is available regarding decay of *pine* CWD in the South. Barber and Van Lear (1984) calculated a wood-density decay coefficient of 0.075/yr for large loblolly pine slash (excluding bark) following clearcutting in the South Carolina Piedmont, while Smith (1991) found a decay constant of 0.048/yr for pitch pine CWD in the Southern Appalachians.

In addition to species differences, other factors affect the rate of decay of CWD (Barber and Van Lear 1984, Mattson and others 1987). Aspect of the site is important-CWD decays faster on north and northeastern aspects, probably due to the generally greater availability of soil moisture. Relative position of the fallen tree affects decay rates-CWD in contact with the ground decays faster than aerially suspended CWD. Large woody debris decays slower than small woody debris. In streams, saturated CWD decays at extremely slow rates. Decomposition rates in the Southeast are generally higher than those reported for other regions, presumably because temperature and moisture conditions are more favorable for microbes and invertebrates involved in the decay process.

The chemical nature of CWD changes during decomposition. Workers in the Pacific Northwest (Sollins and others 1980, Graham and Cromack 1982) and elsewhere have noted that the C/N ratio of CWD decreases and the concentration of lignin increases as decay progresses. Concentrations of nitrogen and phosphorus increases in large logging slash following harvest of loblolly pine (Barber and Van Lear 1984) and in pitch pine CWD following pine beetle attack (Smith 1991). However, after initially being a sink for nutrients, CWD later becomes a source when fragmentation dominates the decay process.

Long-term studies are underway which will better document decay rates of CWD. However, more information is needed concerning decay rates of different species under diierent site conditions and management regimes. What is the best method for measuring decay? Sampling wood density in various states of decay is frequently used, but the method becomes biased during mid to late stages of decay when only the most resistant pieces of wood remain. Adjustment of decay chronosequences for past fragmentation is necessary, but often difficult, if mass losses are to be estimated correctly (Harmon, personei communication'). When does decaying wood become a source, rather than a sink for nutrients? What types

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of decay models best describe the decay process? These and many other questions reflect gaps in our knowledge of the decay process.

Fire

Fire and decay are similar processes in that both are essentially oxidation reactions and that, if both went to completion, the final products would be CO_2 and water (Brown and Davis 1973). However, fire is the rapid oxidation, or combustion, of fuels, while decay is a much more gradual oxidation of organic materials. In neither process is oxidation generally complete. In forest fires, complete combustion is obviously uncommon, as evidenced by dead snags and downed trees on burned sites. Decay is also generally incomplete, as evidenced by the presence of residual CWD and the formation of humus.

Some of the effects of fire on CWD are similar to those of decay, i.e., fire promotes fragmentation of large pieces of wood and bark into smaller pieces and release of CO_2 and other gases into the atmosphere. However, the two processes obviously differ in the speed of their reactions and in the type of substrate produced (charred vs. uncharred). Also important is the fact that the decay process generally tends to mesify microsites because of incorporation of humified products into the soil, while fire tends to xerify microsites, at least in the short run, by oxidizing humus from the forest floor and exposing the soil surface to greater insolation.

There are many deficiencies in our knowledge of the role of fire in CWD losses. What is the effect of charring on decay? Under what conditions can fire be used which minimize CWD loss? Is fire compatible with management for snags? What burning regimes are appropriate to achieve and maintain desired loadings of CWD? This last deficiency assumes that we eventually will have some concept of what desired loadings are. Southern forests evolved in regimes of more or less frequent fire. How this major environmental factor influenced CWD loadings on a landscape scale represents a major gap in our understanding of CWD dynamics.

LOADINGS OF CWD IN SOUTHERN FOREST ECOSYSTEMS

There is relatively little data in the South concerning loadings of CWD following major episodic disturbances or through various stages of succession. Studies are needed to characterize more thoroughly loadings of CWD in old-growth forests. How do loadings vary in response to different fire regimes? Are there some forest types where CWD loadings are low because of rapid decay rates or because fire is a frequent visitor? How can management be modified to enhance CWD loadings on both stand and landscape scales? These types of questions must be answered so that managers might have guidelines relative to loadings of CWD in managed stands versus those in stands which have not been manipulated. As research further demonstrates the ecological significance of CWD in Southern forests, current management strategies may need to be altered to achieve certain levels of CWD.

This lack of information prompted the simulation study described in this paper. A previously-developed model of forest succession was used to simulate stand dynamics and CWD loading was predicted from tree mortalii. The objectives of this exercise were to provide basic information on long-term CWD dynamics in southeastern ecosystems and to identify information gaps.

The selected model was FORCAT (FORests of the CAToosa Wildlife Management Area), which was developed for mixed-species forests in East Tennessee (Waldrop and others 1986). FORCAT was selected because it is one of only a few existing models capable of simulating long-term stand dynamics for managed, mixed-species stands (Waldrop and others 1989). It is a member of a family of models based on the widely-used FORET gap model (Shugart and West 1977). Gap models are a special case of single-tree models and have demonstrated adaptability to simulate forest succession over a wide range of forest types (Shugart 1984).

The FORCAT model was developed through numerous modifications to FORET, making it more specific to managed sites on the Cumberland Plateau (Waldrop and others 1986). The model simulates stand dynamics on a M-acre plot using 30 hardwood and 3 pine species commonly found in the region. Simulation begins with a mature stand which is immediately clearcut. After clearcutting, sprouts and seedlings are stochastically added to simulated plots. Diameter and height growth are calculated each year for each tree as a function of site, species, competition, and environmental stress. Trees are killed stochastically each year based on age, species, and current growth rates.

Few changes to FORCAT were required to predict CWD loading. During any simulated year, if a tree died it was then considered CWD and its biomass was estimated. Biomass was estimated for both stems and crowns using regression equations given by Clark and others (1986). The total biomass of CWD on a plot was calculated for each year and reduced by a constant rate to allow for decomposition. Decomposition rates of 6% and 8% (Harmon 1982) were used to examine the differences these rates caused in CWD accumulation.

Stand dynamics and CWD accumulation were simulated for two site types (xeric and mesic) to give insight into the effect of site productivity on CWD accumulation. The xeric site was south facing,

dominated by upland oaks, and had a site index of 60 feet. The mesic slte was north facing, dominated by yellow-poplar, and had a site index of 100 feet. Simulations began with mature stands, which were immediately clearcut. No artificial regeneration or site preparation was allowed. A simulation period of 200 years after dearcutting was used for each of 100 simulated 1/5-acre plots. Details of model development were given by (Waldrop and others 1986). Modeling CWD dynamics with FORCAT and the limitations of this approach were discussed in greater detail by Waldrop (1995).

The patterns of CWD accumulation predicted by FORCAT (Figure 2) for xeric and mesic sites (using a 6 percent decomposition rate for both sites) were similar to the curve proposed by Spies and Cline (1988). These patterns resembled a bell-shaped curve that peaked during the first half of their respective periods (100 years for simulated xeric and mesic sites, 450 years for measured Douglas-fir stands). Later, CWD in each system gradually decreased until a point, late in succession, where an equilibrium between inputs and decomposition may have been reached.

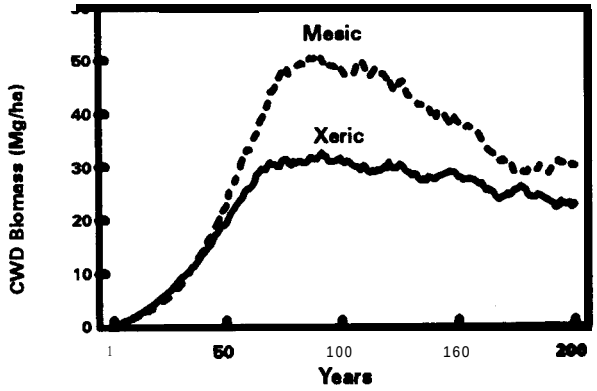

Figure 2.--Accumulation of coarse woody debris for xeric and mesic sites as predicted by FORCAT (6 percent decomposition rate for both sites).

CWD accumulation on both simulated sites remained low for 30 to 40 years as trees grew to the minimum size for CWD (10 cm), even though there was significant mortality during this period. Between years 30 and 75 there was a rapid increase in CWD for both simulated sites. FORCAT predicted decreases in stand basal area during this period as crown closure occurred and a few large trees began to die. On the xeric site, for example, predicted stand basal area decreased from 84 ft^2 at year 50 to 69 ft^2 at year 100.

The period of rapid CWD accumulation on the xeric site lasted until the stand was about 70 years old, when CWD was 13.6 tons/ac. CWD continued to accumulate, but at a slower rate, to a maximum of 14.4 tons/ac at year 91. For the remainder of the 200-year simulation period, decomposition slightly exceeded inputs and CWD loads gradually decreased.

Tree growth on the simulated mesic site exceeded that on the xeric site, producing a more rapid rate of CWD accumulation. On this site, CWD accumulated rapidly from years 30 through 75, reaching a total of 22.0 tons/ac. Maximum CWD loading during the simulation period was 22.9 tons/ac in year 89. Between years 90 and 200, CWD loading decreased much more rapidly than on the xeric site. Species on the mesic site were longer lived than those on the xeric site and the trees continued to grow. Mortality was higher on the xeric site during this period due to moisture stress. Therefore, CWD inputs were less on the mesic site than the xeric site.

An important component of CWD dynamics in managed stands is logging debris. This debris provides regenerating stands with a structure that can be important habit for small mammals (Evans and others 1991, Loeb 1994) as well as a source of nutrients (Mattson and others 1987). Logging slash was added to model projections of CWD inputs immediately after simulated clearcutting. Total CWD loading at that time was assumed to equal the biomass of crowns from harvested trees.

The estimated CWD load immediately after clearcutting was 21.8 tons/ac on the xeric site and 30.7 tons/ac on the mesic site (Figure 3). On both sites, these levels were higher than at any other time during the 200-year simulation period. Logging debris decomposes rapidly in clearcuts but it provides some CWD during a period when there is little input. FORCAT simulations showed that decomposition exceeded inputs through year 32. At that time CWD totaled 7.5 tons/ac on the xeric site and 8.1 tons/ac on the mesic site (assuming a uniform decomposition rate of 6 percent). By year 32, all logging slash had decomposed, and thereafter, these curves were identical to those without logging slash.

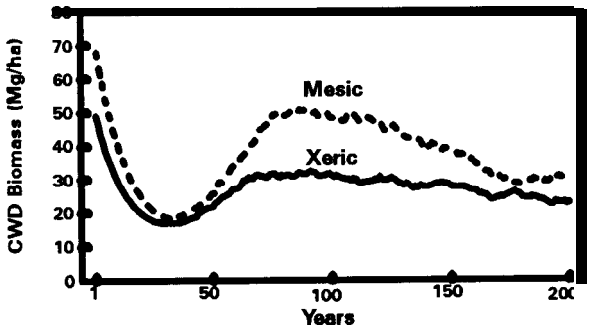

Figure 3.-Dynamics of coarse woody debris after clearcutting xeric and mesic sites predicted by FORCAT (using a 6 percent decomposition rate for both sites).

An assumption used until now is that decomposition rates were uniform across site types. The work of Abbott and Crossley (1982) indicates that decomposition rates are higher on moist sites. By assuming a decomposition rate of 8 percent on the mesic site and 6 percent on the xeric site, the difference in simulated CWD loads between sites was greatly reduced (Figure 4). Even though CWD loading was much higher on the mesic site in year 1, it decomposed to a smaller amount than the xeric site by year 32 (5.5 vs. 7.5 tons/ac). By year 75, CWD was again greater on the mesic site. Beyond that point, however, the lines converged. During the last 50 years of the simulation, CWD loads on the two simulated sites were nearly identical.

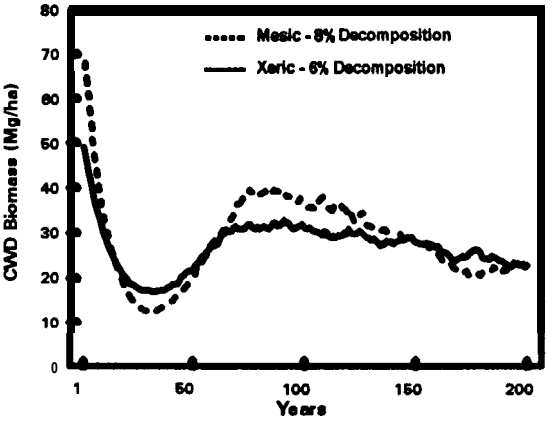

Figure 4.--FORCAT projections of coarse woody debris loads by site type and decomposition rate.

This comparison illustrates the observation of Abbott and Crossley (1982) that differences in decomposition rates between sites can be more important than differences in sizes of CWD. Even though the mesic site produced far more CWD biomass than the xeric site, the relatively small difference in decomposition rates (8 vs. 6 percent) produced similar CWD loading throughout the 200-year simulation.

Muller and Liu (1991) suggested that CWD loading was a function of regional temperature patterns. Their measurements on dry sites correlated well with published estimates from warm temperate zone deciduous forests. Likewise, their CWD measurements on moist sites correlated well with published estimates from cool forests. Muller and Liu (1991) observed higher CWD loads on cool (moist) sites than on warm (dry) sites, suggesting that decomposition rates were not higher on moist sites or that higher productivity on moist sites compensated for higher decomposition rates. Broad-scale relationships, such as this, are oversimplified because CWD decomposition on any given site is controlled by a combination of moisture, temperature, soil fertility, species, size, and any number of other factors.

CONCLUSIONS

The ecological importance of CWD is only recently being appreciated by foresters and other land managers in the South. Based on the documented importance of CWD in the Pacific Northwest and other areas, as well as on the information presented at this workshop, it would be prudent for land managers in the Southeast to recognize CWD as an important structural and functional component of forest ecosystems, rather than as a hindrance which must be removed-even if at a high cost.

Simulation results show general trends of CWD accumulation over seral stages for two southeastern forest ecosystems. This study shows the importance of leaving CWD after harvesting and it emphasizes that differences in decomposition rates, possibly due to differences in site productivity, can significantly affect CWD loading. Due to a number of limitations, however, model projections should not be considered accurate predictions of CWD loading at any given age.

A major limitation of this study was the lack of information on inputs and decomposition rates for different tree species, sizes of CWD, and types of sites. Other knowledge gaps were discussed by Van Lear (1995) including the relationship of CWD inputs to natural and anthropogenic disturbance. Some of this missing information could be supplied by additional research and a broader modeling effort. For example, CWD dynamics after natural disturbances such as tornados or ice storms could be predicted by gap models if the return frequency of those disturbances was known. Also, CWD inputs from management activities such as thinnings or selection harvests could be predicted. This effort would allow managers to use model projections to help determine how to alter the level or timing of their activities to better meet their goals for CWD.

Managing for CWD will certainly not be a primary objective on all forest lands in the South. The South is obviously an important timber producer for the nation and the world, and many of the South's forests will be managed primarily for timber. However, managers should be aware of the important functions of CWD and use this information as they strive to achieve the balance between commodity production and environmental values across the landscape.

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Vegetation Management

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RESPONSE OF LOBLOLLY PINE PLANTATIONS TO WOODY AND HERBACEOUS CONTROL-EIGHTH-YEAR RESULTS OF THE REGION-WIDE STUDY-THE COMPROJECT'

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Abstract—Eight-year response of planted **loblolly** pine to woody and herbaceous control following slte **preparation,** studied at 13 **locations,** differed by pine **response variable** and **hardwood level** grouping. Treatments **affected** average pine **height** the same **at** both **low hardwood (<6 ft²/ac basal** ares **at** age 6) and high **hardwood (>13 ft²/ac)** levels, and **ranked: total** control (woody + herb **control) >** herb control **only >** woody **control** only **>** no control. The **same** ranking **held** for pine dbh, basal **area/ac,** and volume **index/ac** at **the low** hardwood **level. However, at** the high **hardwood level, dbh** response from **woody** control only **exceeded that** for **herb control** only, whib **basal area/ac** end **volume index/ac response were equal** for **the two treatments. Volume** index increases over no **control** on the **low and** high hsrdwood levels averaged 127% and 336% greeter with **total** control; 32% and 57% **greater** with **woody** control only; **and** 92% and 73% with **herb** control **only, respectively.** Treatment effects on all pins response variables were sddiive at the low hsrdwood level, and more **than** sddiiie **at** the high hsrdwood **level.**

INTRODUCTION

Over the past 20 **years** a wealth of research has been published summarizing the impact of woody and herbaceous competition on the growth of southern pines, principally loblolly pine, *Pinus taeda* L. Wiih the exception of work done by Clason **(1978, 1984),** Bacon and Zedaker **(1987),** and **Haywood** and Tiarks **(1990),** individual studies have generally focused on the effects of controlling herbaceous (e.g. Nelson et al. 1981, Creighton et al. 1987, Lauer et al. 1993) or woody (e.g. **Langdon** and **Trousdell 1974,** De Wii and Terry 1982, Glover et al. 1991) vegetation alone, or controlling both components (e.g. Swindell et al. 1988, Shiver et al. 1990). As a result, our understanding of how woody and herbaceous control may interact to influence response of loblolly pine is limited.

In the early **1980's** the Competition Omission Monitoring Project (COMP or COMProject) was developed, in part, to compare the relative effects of herbaceous control, woody control and their interaction on the response of planted loblollypine across a wide range of sites throughout the Southeast. One feature of this region-wide study is that a uniform study design and protocol have been used at each study location. This uniformity makes consolidation of data and comparison of results across study locations more reasonable compared to attempting a similar effort across studies established by independent research workers.

Results from the COMProject have been reported previously following the first and second (Miller et al. **1987),** third (Zutter **1988),** fourth (Zutter 1990) and **fifth** (Zutter 1990, Miller et al. 1991) growing seasons. A summary of vegetation dynamics, focusing on prevalence of herbaceous and woody species/genera across the study locations, through eight seasons has been reported by Miller et al. (1995b). In addiion, a tabular summary of data by location through age eight will soon be published (Miller et **al. 1995c).** The present paper summaries effects of herbaceous control, woody control, and their interaction on the response of loblolly pine eight growing seasons since study establishment. A companion paper in these proceedings projects **yields** and economic outcomes using the **age** eight data (Miller et al. 1995a).

STUDY AREAS

Study locations were distributed across several physiographic provinces from Louisiana to Virginia. In general, most sites were previously occupied by loblolly pine or **loblolly/shortleaf** pine (*Pinus echinata* L.)-hardwood stands, harvested in late 1982 or **early** 1983, chopped and burned in the spring or summer of 1983, and planted in early 1984. Site-specific information may be found in Miller et al. (1991).

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METHODS

Study Design and Plot Layout

In general, a randomized complete Mock design was used to establish four blocks of four plots at each location. Treatment plots were typically 0.25 ac in size (104 ft x 104 ft) with interior pine measurement plots of approximately 0.09 ac (63 ft x 63 ft). At most study sites, planting locations were established on a 9 ft x 9 ft spacing, with two 1-0 loblolly pine seedlings hand-planted 1-ft apart at each planting location. Seedlings were thinned, with selection made at random, to one seedling at each planting location after one growing season. Double-planting was used to help ensure adequate initial planting survival and minimize effects of variabilii in stocking on long-term results. Additional details and slight departures from the above noted procedures for specific sites can be found in Miller et al. (1991).

Application of Treatments

Four treatments were randomly assigned to plots within each block:

1) No *control.* No treatment of competing herbaceous or woody vegetation following site preparation except for treatment of infestations of vines and injection of large residual hardwoods missed in site preparation. Vines were treated with directed foliar sprays of glyphosate (Roundup) or triclopyr (Garlon) in water or wick applications of tridopyr. Trlclopyr was used for injection at the few locations where large residuals needed to be removed.

2) Woody control Hardwoods and shrubs were treated with herbicides during the first five growing seasons. Treatment usually involved directed foliar sprays of giyphosate in water and/or basal wipes or sprays of triclopyr in diesel fuel.

3) *Herbaceous* control. Herbicides were applied one or more times during each of the first four growing seasons to control herbaceous plants. Treatment typically involved application of sulfometuron (Oust) at 2-5 oz ai/ac in the spring of each year prior to emergence of herbaceous plants followed in the summer by directed foliar sprays of glyphosate to regrowth. All vines and semi-woody plants such as blackberry (*Rubus* spp.) were included in the herbaceous component.

4) Total *control.* Hardwoods, shrubs and herbaceous vegetation were treated using a combination of treatments above to control all competing vegetation.

Assessment and Analysis

Following eight growing seasons (years), total height and diameter at breast height (dbh) were measured on all pines within each pine measurement plot (49 planting spots per plot). A volume index was computed for each measured tree as follows: dbh*dbh*(total height)/3, where both dbh and total height are in feet. Mean total height and dbh, density in trees/ac, basal area/ac, and volume index/ac was computed for each treatment plot for use in statistical analyses.

Eighth-year pine data were analyzed by first placing each of the 13 study locations into one of two groups based on the level of arborescent hardwood basal area/ac at age eight on the herbaceous control only treatment Basal area/ac for the "low hardwood' group averaged 3.5 ft^2/ac (n=5, range= 2.1-5.4 ft^2/ac) and the "high hardwood" group averaged 17.3 ft^2/ac (n=8, range= 13.2-22.7 ft^2/ac). Mean site index (base age 25) was approximately 65 ft for both groups (Miller et al. 1995b).

A separate analysis was done for each of the two hardwood levels (groups). The analysis of variance for each hardwood level included tests of the main effects of woody treatment ((woody control + total control)/2) versus ((no control + herb control)/2), herbaceous treatment ((herb control + total control)/2 versus ((no control + woody control)/2), and the interaction of woody and herbaceous treatment. When the interaction was statistically significant, Tukey's HSD test was used to separate the individual treatment means. All statistical tests were made at p=0.05. For the sake of clarity, references to effects of woody treatment or herbaceous treatment will refer to tests of main effects, whereas references to no control, woody control only, herbaceous control only or total control will refer to the four treatments within the study design.

RESULTS

Density Response

After eight years, pine stocking averaged across locations was very good, exceeding 90 percent for all treatments. Neither woody nor herbaceous treatment had significant effects across low or high hardwood levels. Under low hardwood levels density averaged 517, 506, 513, and 517 trees/ac and under high hardwood levels density averaged 505, 486, 491, and 505 trees/ac for no control, woody control only, herbaceous control only, and total control, respectively.

Height Response

Mean pine height through eight years was positively affected by woody and herbaceous treatment at both low and high hardwood levels (Table 1). Rankings in response among treatments followed the same pattern under both levels of hardwood: total control > herb control only > woody control only > no control (Table

Table l-Mean pine height and dbh, basal area/acre, and volume index/acre after five and eight growing seasons, gain over no control after eight growing seasons, and growth from age five to eight by vegetation control treatment and hardwood (hdwd) level[a].

Vegetation control	Height		Dbh		Basal area		Volume index	
	Low hdwd	High hdwd	Low hdwd	High hdwd	Low hdwd	High hdwd	Low hdwd	High hdwd
	(feet)		(inches)		(ft^2/acre)		(ft^3/acre)	
Age 8								
None	23.8	22.6 d	4.16	3.62 d	51.1	38.0 c	548	399 c
woody	26.1	24.7 c	4.65	4.56 b	62.1	56.5 b	723	627 b
Herb	29.9	27.1 b	5.27	4.27 c	80.4	53.5 b	1056	689 b
Total	31.4	32.1 a	5.61	5.87 a	91.0	95.7 a	1245	1343 a
Gain over no control - Age 8								
woody	2.3	2.1	0.48	0.94	11.0	18.5	175	228
Herb	6.1	4.5	1.11	0.65	29.3	15.5	508	290
Total	7.6	9.5	1.45	2.25	39.9	57.7	697	944
Age 5								
None	12.1	11.2	1.88	1.49	11.1	7.7	66	45
woody	13.6	12.5	2.22	2.03	14.9	12.7	96	78
Herb	17.0	15.5	3.06	2.40	28.0	18.6	221	146
Total	17.8	18.5	3.32	3.61	33.3	38.1	275	323
Growth - Aae 5 to 8								
None	11.6	11.5 c	2.28	2.13	40.0	30.3 d	482	353 c
woody	12.6	12.2 b	2.43	2.52	47.2	43.8 b	627	549 b
Herb	12.9	11.6 c	2.21	1.87	52.3	34.8 c	834	543 b
Total	13.5	13.6 a	2.29	2.26	57.7	57.6 a	970	1020 a

[a] Statistical analyses performed on age eight response and growth from age five to eight only. Separate analyses were conducted at low and high hardwood levels (All tests of significance at p=0.05). Main effects of woody treatment and herbaceous treatment were significant in each instance at both low and high hardwood. The woody x herbaceous treatment interaction (W x H) was not significant at low hardwood level in any instance, but was significant at high hardwood for all but dbh growth from age five to eight. Where W x H was significant, means are separated using Tukey's HSD test(p=0.05).

1). However, under high hardwood the interaction between woody and herbaceous treatment was significant due to combined effects of herbaceous and woody treatments being more than addiie. Controlling both woody and herbaceous components (total control) yielded a gain in height of 9.5 ft compared to 6.6 ft when gains from controlling woody vegetation only (2.1 ft) and herbaceouo vegetation only (4.5 ft) are summed. In comparison, under low hardwood, gains from woody and herbaceous control were additive, 7.6 ft with total control versus 8.4 ft when gains from woody control only and herb control only are summed.

Ranking among treatments for mean pine height did not diier between ages five and eight at either level of hardwood (Table 1). Woody and herbaceous treatment each had a significant effect on height growth from age five to eight at both low and high hardwood, with a significant interaction between woody and herbaceous treatment noted only at high hardwood. At low hardwood, growth followed the pattern noted at age eight for total height: total control > herb control

only > woody control only > no control, while at high hardwood: total control > woody control only > herb control only = no control (Table 1).

Dbh Response

Levels of arborescent hardwood had a decidedly diierent influence on the effects of treatments on pine dbh compared to height As noted for height, effects of woody treatment and herbaceous treatment were significant and positive for both low and high hardwood levels, with the interaction between woody and herbaceous treatment being significant only with high hardwood. However, while rankings among the treatments for dbh at low hardwood levels followed that noted for height total control > herb control only > woody control only > no control; at high levels of hardwood the ranking of response to herb control only and woody control only was reversed (Table 1). The gain from control of both woody and herbaceous vegetation (total control) was more than addiie where hardwood levels were high: 2.25 in. from total control versus a sum of 1.59 in. from woody control only (0.94 in.) and herb control only (0.65 in.); and additive where hardwood levels were low (1.45 in. versus 1.60 in. (0.49 + 1.11)).

Ranking in effects on pine dbh through age five was identical for both levels of hardwoods, following the pattern noted for dbh at age eight for low hardwood. Dbh growth from age five to age eight at both low and high hardwood levels was greatest for woody control only. Dbh growth at high hardwood was over 0.6 in. greater with woody control only compared to herb control only, resulting in the reversal in the ranking of response for those two treatments from age five to age eight.

Basal Area and Volume Index Response

Trends in effects of treatments and hardwood level on basal arealac and volume index/ac roughly paralleled those noted for dbh (Table 1). Effects of woody and herbaceous treatment each had a significant positive effect at both hardwood levels, with the interaction of woody and herbaceous treatment being significant only at high hardwood. Rankings among treatments at low hardwood were the same as those noted for mean height and dbh: total control > herb control only > woody control only > no control. At the high hardwood level, ranking of response was similar, except response from woody control only and herb control only did not differ (Table 1), hence the significant woody and herbaceous treatment interaction.

Average gains over no control in basal arealac and volume index/ac from woody control only were greater at high compared to low hardwood levels (18.5 versus 11 .O ft^2/ac, 228 versus 175 ft^3/ac), while gains from herb control only were greater at low compared to high hardwood levels (29.3 versus 15.5 ft^2/ac, 508 versus 290 ft^3/ac). Gains over no control from controlling both woody and herbaceous vegetation (total control) were additive for low hardwood (39.9 versus 40.3 ft^2/ac, 697 versus 683 ft^3/ac) and more than additive for high hardwood (57.7 versus 34.0 ft^2/ac, 944 versus 518 ft^3/ac). Expressed on a percent basis, volume gains over no control on the low and high hardwood levels averaged 127% and 336% greater with total control; 32% and 57% greater with woody control only; and 92% and 73% with herb control only, respectively.

DISCUSSION

The more than addiie effect when woody and herbaceous treatments are combined on sites where hardwood levels are high is not too surprising. Hardwoods may usurp from the pines some of the additional resources made available as a result of controlling only herbaceous plants, with a much larger uptake at high hardwood levels. In addition, this increased acquisition of resources by hardwoods allows them to attain a larger size and have a greater long-term effect on pines than if herbaceous plants had not been controlled. Average hardwood basal arealac was 5 ft^2/ac greater (17.3 ft^2/ac versus 11 .9 ft^2/ac) and mean heights of those hardwoods 3.0 ft greater (14.8 ft versus 11.8 ft) on herbaceous control only compared to the no control treatment. The greater than additive effect noted at high hardwood by combining woody and herbaceous control is consistent with the idea that control of one competitive component will increase the response of other competitive component(s), and this response will limit the resources available to the crop.

The change noted in the ranking between woody control only and herbaceous control only treatments for dbh, basal area/ac, and volume index/ac from age five to eight under high hardwood levels illustrates the greater influence of herbaceous plants relative to arborescent hardwoods during the first few years of stand development, and an increase in the influence of hardwoods as the stand closes. Based on growth from age five to age eight, it appears likely that cumulative basal arealac and volume index/ac response of pines under woody control only should exceed that from herb control only sometime in the next few years.

SUMMARY AND CONCLUSIONS

Grouping of COMProject locations by level of arborescent hardwoods, and analyses of treatment means by these hardwood groups yielded the following observations:

1) For all response variables, except density, the control of both woody and herbaceous plants resulted in responses which, compared to the sum of responses of controlling each component separately, were addiive under low hardwood levels (<6 ft^2/ac basal area/ac at age eight) and more than additive under high hardwood levels (>13 ft^2/ac).

2) Rankings among treatments for total pine height were identical at both low and high hardwood-levels at ages five and eight Rankings were: total control > herb control only > woody control only > no control

3) At age five, rankings among treatments for dbh, basal area/ac, and volume index/ac at both low and high hardwood levels were identical to those for height

4) By age eight, rankings among woody control only and herb control only treatments had changed at high hardwood levels for dbh, basal area/ac, and volume index/ac. Ranking for dbh was: woody control only > herb control only, and the ranking for basal area/ac and volume index/ac: woody control only = herb control only.

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RESPONSE OF LOBLOLLY PINE TO COMPLETE WOODY AND HERBACEOUS CONTROL: PROJECTED YIELDS AND ECONOMIC OUTCOMES-THE COMPROJECT'

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Abstract—Age-8 and -9 data from the 13 study plantations of the Cornpetiion Omission Monitoring Project (COMP) were used to project yields and derive economic outcomes for loblolly pine (*Pinus taeda* L.). COMP treatments were chop-bum, complete woody plant control, complete herbaceous plant control for 4 years, and complete woody and herbaceous (W+H) control. Yiilds projected wtth the NCSU Managed Plne Plantation Simulator were greatest for W+H control followed by woody control. Rankings for the other two treatments depended on site index. Profitability increased as site index increased and discount rate and hardwood densities decreased. Woody control was the most profitable on productiie sites at discount rates below 5 percent.

INTRODUCTION

Vegetation control treatments with herbicides are widely **used** in Southeastern forests for establishing southern pine plantations, but the rotational growth gains and economic returns are still unknown. Herbicide treatments accelerate pine volume growth, producing greater volumes sooner, resulting in a stand age advance. Early volume advances equivalent to 1 to 6 years have been documented for loblolly pine (*Pinus taeda* L.) after control of woody and herbaceous vegetation on sites across the Southeast (Bacon and Zedaker 1987, Cain and Mann 1980, Colbert and others 1990, Lauer and others 1993, Michael 1985, Nelson and others 1981, Rheney and Pienaar 1992, Zutter and others 1986). Significant growth increases from herbaceous control (in combination with woody control) have been reported from a network of sites through age 9 (Lauer and others 1993). Growth projections of these data indicate an average 3-year advance in volume for a 25-year rotation. Total volume growth gains from early woody and herbaceous control have been maintained for up to 11 years, with continued gains from herbaceous control in question (Haywood and Tiarks 1990). In the longest term study in the region, woody control responses up to age 27 have been sizable and highly dependent upon control effectiveness (Glover and Zutter 1993). Indications are that herbaceous control enhances early growth (ages 1-4) and that woody control is more dynamic, depending on woody species and their relative **densities and** growth rates (Clason 1978, Miller and others 1991, Perry and others 1993).

The region-wide network of the COMP sites was established to study the long-term influence of woody and herbaceous competition on loblolly pine plantations (Miller and others 1987, 1991). Growth responses through age 8 for the 13 plantations are reported by Zutter and others in these Proceedings. The near-absolute conditions studied by COMP of complete control of woody and herbaceous vegetation, separately and in combination, permits examination of some of the most intensive cultural situations for growing loblolly pine. Since evidence is mounting that significant amounts of growth can be lost by even small amounts of either woody or herbaceous competition (Perry and others 1993, Glover and Zutter 1993), growth gains from complete vegetation control or complete component control should represent near upper limits of pine growth (without fertilizer additions or insect control). Economic returns from the large investments required to achieve these complete control conditions should define upper bounds of investment-return for vegetation management options, indicating the more profitable alternatives. Until long-term data is available, projections of yields and economic outcomes must be relied upon for current decisions and forest planning.

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METHODS

Growth and Yield Projections

The four COMP treatments from an operational perspective were: chop-burn, woody plant control only leaving herbaceous competitors, herbaceous plant control only leaving hardwood and shrub competitors, and woody plus herbaceous control (W+H control). Specific treatment methods are discussed by Zutter and others in these Proceedings (1995), while levels of control achieved were discussed by Miller and others (1991).

Pine and hardwood responses by location and treatment were projected with the North Carolina State University Managed Pine Plantation Growth and Yield Simulator, version 3.2 (Hafley and Smith 1991). The inputs for the model were actual age-8 pine and hardwood basal areas, hardwood type (excurrent, decurrent, or mixed), stocking (pine trees per acre, TPA), percent fusiform rust infection and hazard zone (table 1). An advantage of this model is the internal function for hardwood competition, although none exists for herbaceous competition influences. Merchandising criteria for wood output were specified by the following diameters inside bark (d.i.b.) at the small end: pulpwood, 4 to 8 inches; chip-n-saw, 6 to 8 inches; and sawlogs, greater than 8 inches.

Height-age curves were another model input. Height-age curves (base 25 years) for the chop-burn treatment were estimated for each location by equations from Burkhart and others (1987) using age-9 heights of the tallest 300 TPA. An age translation of these height-age curves was used to estimate heights over time that might be realized by the vegetation control treatments (Lauer and others 1993). By substituting the age-9 tree heights for the other treatments into the equation for chop-burn and solving the equation for age, the age advance could be determined for each treatment. This age advance was added to the age variable in the height-age curve for input into the simulator (footnote, table 1). This conservative approach assumes that the shape of the height-age curve does not change with vegetation control treatments, but rather is simply shifted, usually to the left as an advance. Competition control actually tends to make the initial part of the height-age curve more linear, while effects on later stages still are unknown (Miller and others 1991).

Economic Outcome Projections

We calculated the economic outcome of the test treatments on land expectation value (LEV) and net present value (NPV). LEV (or bare land value) is the present value of all net cash flows (revenues minus costs) from the management of a tract of land calculated for an infinite time horizon. It is the maximum amount one could pay for a tract of land, manage it for timber by the prescriptions and costs specified, and obtain the rate of return used to discount the cash flows. LEV's are useful for comparing management strategies with unequal rotation periods. NPV is the present value of returns and costs over a single rotation. Taxes were not considered in these analyses.

Product prices were taken from Timber-Mart South. Monthly prices were averaged for 12 Southeastern States from November 1992 to October 1994. Product prices rounded to the nearest dollar were: (1) pine sawtimber, $186/thousand board feet (MBF) Scribner scale; (2) pine chipn-saw, $47/cord; (3) pine pulpwood, $21/cord, and (4) hardwood pulpwood, $10/cord. For some States, regional average product prices are conservative. A "higher-price" projection used a 12-month average for the State with the highest prices.

Published southwide averages (Belli and others 1993) were used for costing chop-burn site preparation, at $84/acre, and planting at a 9-by-9-ft spacing (538 TPA), at $57/acre. Since complete control is not achieved by normal operational herbicide applications (Shiver and others 1990, 1991, Michael 1985), regional averages for woody and herbaceous control could not be used. Besides, control comparable to COMP treatments would cost considerably more than published averages. Cost for complete woody-plant control was estimated at $158/acre to pay for a high-rate, aerial application of herbicide and prescribed burning for site preparation ($123/acre) plus a directed spray application in year 2 to eliminate remaining woody plants ($35/a). The cost for complete herbaceous-plant control was estimated at $200/a for a prescribed burn after harvest and three consecutive years of high-rate aerial spray applications ($60/acre/yr). Then the estimated cost of both woody and herbaceous control, at $338/a, combined the costs of both treatment regimes minus $20/acre for improved efficiency when both are applied. All prices and costs were assumed to increase at the inflation rate.

Both LEV and NPV were calculated for real discount rates from 3 to 7 percent. Economic outcome was calculated for both a 25-year rotation without thinning and an economic optimal rotation with two thinnings. The economic optimal rotation age was determined as the maximum LEV using 5-year intervals from 25 to 40 years. The two possible thinnings were made before age 25 when pine basal area exceeded 100 ft^2/acre, with thinning back to 70 ft^2/acre and a 30 percent reduction of any hardwood basal area.

The relationship between yield and site index by treatment was examined with linear regression.

Table 1 .-Input variables for the North Carolina State University Managed Pine Plantation Growth and Yield Simulator age-8 data except dominant pine heiaht which are age-9 data for the tallest 300 trees per acre (TPA)

Location	SI_{25}	Control treatment	Pine		Hwd[a] BA	Dom. pine height	Age[b] advance	Fusiform	
			TPA	BA				infect.	Haz.[c]
	(ft)		(no./a)	(ft^2/a)	(ft^2/a)	(ft)	(yr)	(pct)	
Low hardwood sites									
Counce, TN	58	Chop-burn	535	47.8	1.8	26	0.0	1	0
		Woody	532	52.3	0.0	27	0.3	1	0
		Herb	513	54.7	2.9	29	1.2	2	0
		W+H	518	78.2	0.0	30	1.7	1	0
Warren, AR	62	Chop-burn	527	51.4	2.2	27	0.0	1	10
		Woody	527	88.9	0.8	30	0.8	2	10
		Herb	527	93.7	3.8	34	2.5	4	10
		W+H	519	101.5	0.0	35	2.7	2	10
Pembroke, GA	65	Chop-burn	527	38.4	1.1	28	0.0	a	40
		Woody	519	80.1	0.1	34	2.0	9	40
		Herb	515	85.0	2.1	36	2.5	13	40
		W+H	523	77.0	0.0	38	3.5	22	40
Jena, IA	75	Chop-burn	475	56.1	2.1	31	0.0	0	20
		Woody	450	51.0	0.9	31	-0.2	1	20
		Herb	505	88.9	5.4	37	1.4	1	20
		W+H	513	100.3	0.0	38	1.9	0	20
Monticello, GA	79	Chop-bum	513	83.1	9.3	33	0.0		70
		Woody	497	77.5	0.0	38	0.6	19	70
		Herb	499	89.7	3.2	38	1.1	21	70
		W+H	505	97.8	0.0	38	1.1	27	70
High hardwood sites									
Appomattox, VA	50	Chop-bum	499	21.1	18.0	23	0.0	0	0
		Woody	425	48.0	0.2	28	2.1	0	0
		Herb	401	24.1	21.5	24	0.5	1	0
		W+H	453	74.0	0.2	31	3.8	0	0
Arcadia, LA	55	Chop-bum	517	44.1	5.0	25	0.0	1	10
		Woody	517	80.1	0.1	28	0.4	2	10
		Herb	497	83.3	13.2	30	2.1	5	10
		W+H	525	101.0	0.0	34	3.8	7	10
Tallassee, AL	58	Chop-bum	502	33.4	19.1	25	0.0	11	40
		Woody	483	52.7	0.0	27	0.8	10	40
		Herb	497	42.8	22.7	29	1.4	13	40
		W+H	521	93.1	0.0	35	4.1	23	40
Atmore, AL	59	Chop-bum	521	34.1	8.1	28	0.0	a	40
		Woody	494	52.1	0.0	30	1.2	8	40
		Herb	455	44.1	15.1	30	1.4	7	40
		W+H	508	90.9	0.0	36	3.7	24	40
Liverpool, IA	83	Chop-burn	527	34.8	6.5	28	0.0	2	50
		Wood7	530	51.4	0.0	30	0.8	7	50
		Herb	510	63.9	14.8	35	2.4	4	50
		W+H	513	95.1	0.0	37	3.4	10	50
Camp Hill, AL	85	Chop-bum	802	38.1	7.0	28	0.0	a	50
		Woody	491	50.3	0.0	29	0.2	7	50
		Herb	499	39.4	14.4	30	0.6	a	50
		W+H	497	99.8	0.0	38	3.1	14	50
Liberty, MS	77	Chop-bum	381	41.2	20.1	32	0.0	12	60
		Woody	376	88.1	0.0	38	0.8	11	80
		Herb	453	83.9	21.6	42	2.5	13	80
		W+H	442	113.2	0.0	44	3.2	21	60
Bainbridge, GA	88	Chop-burn	518	58.1	12.0	36	0.0	18	60
		Woody	532	69.5	0.1	38	4.2	25	80
		Herb	513	88.8	15.9	39	0.8	34	80
		W+H	521	99.8	0.0	43	1.8	48	80
Overall average	85	Chop-bum	501	43.2	8.4	28	0.0	a	35
		Woody	490	58.8	0.2	31	0.7	7	35
		Herb	491	83.9	12.0	33	1.8	10	35
		W+H	504	93.8	0.0	37	2.9	18	35

[a]The hardwood type was specified as "mixed" for ail locations.
[b]The height-age curve equation (Burkhart and others 1987) for input is:
HT=EXP(LN((SI$_{25}$ * (25/(A+AGEADV))^(-.02205))* EXP(-2.83285*(1/A + AGEADV)-.04))); AGEADV=Age advance.
[c]Hazard zone for fusiform.

RESULTS AND DISCUSSION

Growth and Yield

The input variables for the NCSU Simulator are presented in table 1, grouped by hardwood amounts and listed by increasing site indices (hardwood groupings as discussed by Zutter and others in these Proceedings). These input variables can be used to determine yields for management scenarios not explored here. Averages for these variables are shown at the bottom of table 1 (referred to later as the "average COMP location"). Estimated site indices at age 25 (SI,) averaged 65 ft for the 13 sites and ranged from 50 to 88 ft. Compared to the chop-burn treatment the mean advance in the height-age curves was 0.7 years for woody control, 1.6 years for herb control, and 2.9 years for W+H control (table I).

The following are the mean merchantable pine volumes (ft^3/acre) and sawtimber volumes (MBF/acre, Scribner) for the 13 sites projected for each treatment using a 25-year rotation without thinning, showing percent increases over chop-burn:

	Pine volume		Sawtimber volume	
Chop-burn	3,652	-	2.2	-
Herb control	3,758	3% increase	3.0	36% increase
Woody control	4,341	10% increase	3.6	63% increase
W + H control	4,800	32% increase	4.0	122% increase

The mean pine volume yields at 25 years are the simplest indicators of projected biological outcome as far as pines for these treatments. The much larger gains in sawtimber volumes compared to total pine volumes result from additional stems crossing the minimum size cutoff for sawtimber (8 inches d.i.b., small end). Larger trees were produced sooner, but these trees have a larger core of juvenile wood that may affect value.

Figure 1 shows the linear regressions relating projected pine volume (PV) in cords/acre for a 25 year rotation to SI_{25} for the four treatments. The regression equations, R^2s, and root mean square errors (RMSE) are:

Treatment	Equation	R^2	RMSE
Chop-burn	PV = 40.5 + 1.4 SI	0.76	8.86
Woody control	PV = -44.9 + 1.6 SI	0.98	2.72
Herb control	PV = -63.8 + 1.8 SI	0.76	11.36
W + H control	PV = -38.4 + 1.6 SI	0.98	2.69

For the range of site indices examined, W+H control had the greatest yields followed by woody control. By adding herbaceous control to woody control (W+H control) a constant 6.5 cord increase is suggested across all SI's because of the common slopes. The third moat productive treatment was chop-burn below a site index of 61 ● ndharbacaouscontrolabovaatta index of 61.

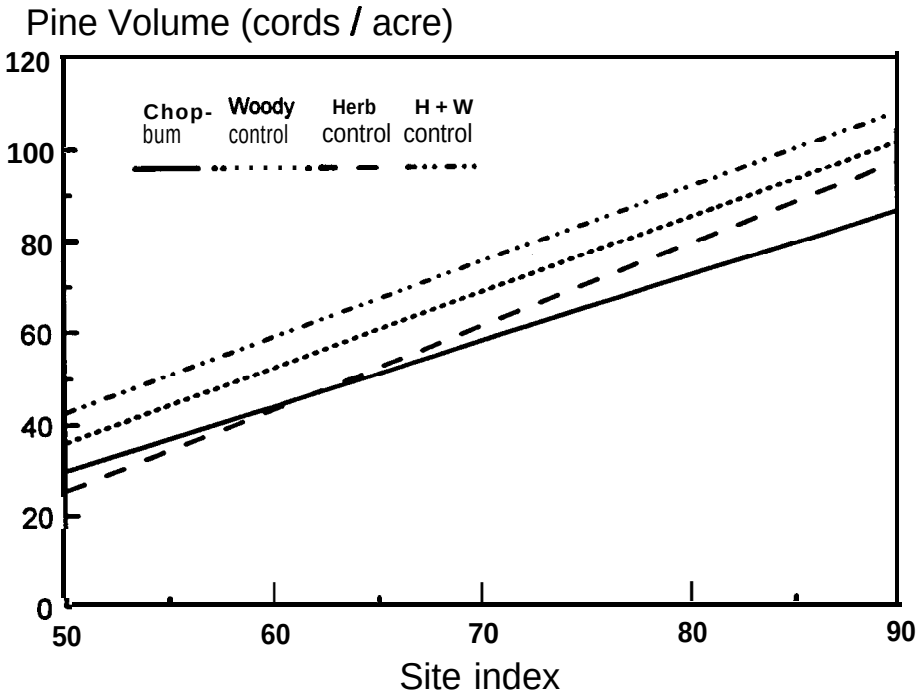

Figure 1 .-Relationship of site index (base 25 years) and projected pine volume yields at age 25 for the four COMP treatments across the 13 COMP locations.

Table 2.--Means, standard errors (SE), and range in projected yields for the 13 COMP locations by product categories from two thinninga and harvests at four rotation lengths

Thinning (yr) and harvest[a]	Sawtimber				Chip-and-				Pine Pulpwood				Hardwood Pulpwood			
	Mean	SE	Low	High	Mean	SE	Low	High	Mean	SE	Low	High	Mean	SE	Low	High
	(MBF)				(cords)											
Chop-bum																
T1(11-18)	0	0	0	0	0	0	0	0	3.4	0.37	2.2	8.4	0.2	0.11	0	1.0
T2(16-20)	0	0	0	0	0	0	0	0	8.4	0.68	4.8	11.2	0.1	0.09	0	1.0
H25	3.7	1.03	0	11.7	4.2	1.12	0	11.1	12.2	0.74	8.4	15.5	1.0	0.30	0	3.0
H30	8.9	1.61	0	17.7	2.3	0.86	0	9.7	13.9	0.78	10.0	17.3	1.2	0.43	0	5.0
H35	9.9	1.93	0	23.6	1.6	0.80	0	8.0	13.9	1.15	7.2	18.7	1.4	0.40	0	4.0
H40	13.0	2.36	0	29.7	1.2	0.73	0	8.1	13.2	1.39	5.4	21.0	1.5	0.46	0	5.0
Woody control																
T1(10-15)	0	0	0	0	0	0	0	0	3.3	0.26	2.2	6.4	0	0	0	0
T2(15-20)	0	0	0	0	0	0	0	0	8.7	0.89	3.8	12.6	0	0	0	0
H25	5.2	1.21	0.4	13.0	3.7	1.09	0	10.4	11.6	0.91	5.8	18.1	0	0	0	0
H30	8.9	1.83	1.9	20.3	1.6	0.82	0	7.5	12.7	1.10	8.6	17.5	0	0	0	0
H35	12.5	2.06	3.4	27.3	0.6	0.34	0	4.6	12.4	1.35	4.6	17.0	0	0	0	0
H40	18.0	2.43	6.0	33.5	0.1	0.09	0	1.1	11.6	1.47	3.0	18.8	0	0	0	0
Herb control[b]																
T1(9-18)	0	0	0	0	0	0	0	0	3.4	0.20	2.4	4.8	0.1	0.08	0	1.0
T2(14-20)	0	0	0	0	0	0	0	0	8.8	0.72	4.1	11.1	0	0	0	0
H25	4.7	1.21	0	11.9	3.1	1.00	0	9.9	12.1	1.01	2.5	18.7	0.9	0.28	0	3.0
H30	7.9	1.72	0	17.5	1.8	0.72	0	9.0	13.4	1.11	4.5	17.9	1.5	0.39	0	4.0
H35	10.9	2.08	0	23.3	0.8	0.54	0	7.0	14.0	1.36	8.1	18.9	1.8	0.48	0	5.0
H40	14.1	2.67	0	29.2	0.8	0.42	0	6.8	12.4	1.47	6.1	20.5	2.0	0.58	0	7.0
Woody + herb control																
TI (8-12)	0	0	0	0	0	0	0	0	2.9	0.28	1.8	4.8	0	0	0	0
T2(13-17)	0	0	0	0	0	0	0	0	7.0	0.89	3.6	12.6	0	0	0	0
H25	7.3	1.29	1.3	16.9	2.2	0.83	0	9.5	12.8	0.82	7.1	17.4	0	0	0	0
H30	11.0	1.72	3.0	22.9	0.7	0.38	0	4.9	13.1	1.08	8.8	17.7	0	0	0	0
H35	14.8	2.08	4.9	29.3	0.2	0.16	0	2.0	12.2	1.28	4.8	17.7	0	0	0	0
H40	18.2	2.46	8.8	36.3	0.1	0.04	0	0.5	11.0	1.41	3.4	17.7	0	0	0	0

[a] T1= first thinning; T2 = second thinning with the range of ages when thinnings occurred in parenthesis and H = rotational harvests at 25, 30, 35, and 40 years.

[b] Appomattox, VA, did not have a first or second thinning for this treatment and Tallassee, AL, did not have a second thinning for this treatment. Zeroes for these omitted treatments are not included in the mean.

Table 3.-Optimal rotation age by treatment and discount rate (percent), showing the median value (since rotation age waa examined in 5-year intervals) and the range

Control treatment	Discount rate					Discount rate				
	3	4	5	6	7	3	4	5	6	7
	---(year)---					(year)				
	median					range				
Chop-burn	35	35	35	30	25	30-40	25-40	25-35	25-35	25-30
Woody (W)	40	35	35	30	25	30-40	25-40	25-35	25-35	25-30
Herb (H)	35	30	30	25	25	30-40	25-40	25-35	25-30	25-30
W + H	35	30	25	25	25	30-40	25-35	25-30	25-30	25-30

The yields by treatment and product category for stands managed with two thinnings and rotation ages of 25, 30, 35, and 40 years are summarized in table 2. First thinnings (before age 25) were performed sooner after W+H and woody control treatments compared to the other two. Thinnings increased sawtimber yields for all treatments at 25 years. Over rotation ages examined, sawtimber yields were in the order of W+H control > woody control > herb control > chopburn.

Economic Outcome

To illustrate the interaction between the present value of revenues (derived from selling the above predicted yields) and present value of costs, figures 2 a and b show these values projected for rotation ages up to 45 years using the "average" COMP location (see bottom of table 1). This interaction of revenues and costs results in the NPV shown in figure 2 c, which is similar to the LEV-outcome in figure 2 d. With this example, woody control has the greatest value followed by chop burn. Herb and W+H control have similar but lower value outcomes, with the optimal rotation age being 6 years earlier for W+H control.

It is evident that the peaks of all four curves are fairly flat with definable minor optimal peaks. This would indicate that an optimal rotation age occurs within 1 to 2 years but the penalty for missing the optimal is not severe. Figure 2 e shows the LEV when higher prices are used (see methods), which indicates that LEV's (as well as NPV's) are extremely sensitive to prices. Price changes can cause a different ordering of treatment profitability, but optimal rotation ages did not change. Softwood lumber prices are projected to increase over the next 50 years by about 1 percent per year (Haynes and Adams 1992), which could increase the relative profitability of the more intensive treatments.

Optimal rotation age ranged from 25 to 40 years for all sites and treatments, and the optimal age decreased with increasing discount rate (table 3). Linear regression analysis shows that optimal age was not correlated to site index or hardwood abundance. Median optimal age for the two hardwood groupings only diiered from the table 3 values for the 5 percent discount rate and herb control, which was 30 years with low hardwood and 25 years with high hardwood.

The LEV's for each location and treatment are presented in table 4, grouped by hardwood abundance and listed by increasing site index. As discount rate increased, the lower investment treatments were the more profitable on an increasing number of sites. Chop-burn was the most profitable option at 2, 3, 5, 9, and 11 locations as discount rate increased from 3 to 7 percent. Woody control was the most profitable on 7, 6, 7, 4, and 2 sites with increasing discount rates. The most intensive treatment of W+H control was the most profitable on 4, 4, and 1 locations for 3, 4, and 5

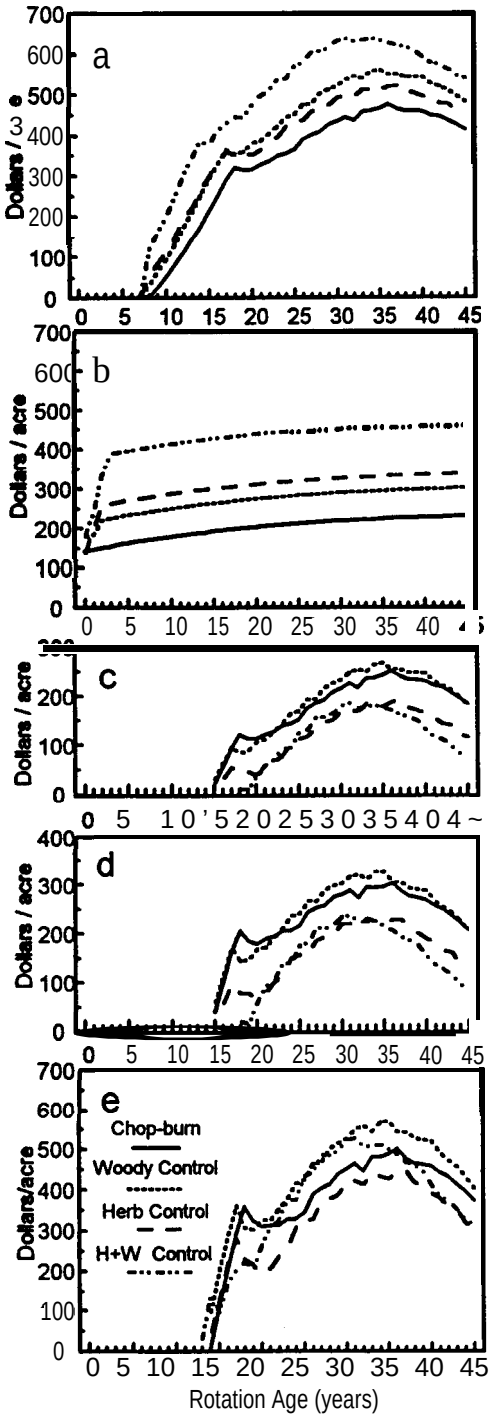

Figure 2.-The economic variables and outcomes for modeling four COMP treatments for the "average" COMP site (SI_{25}=65, see table 1 for stand characteristics) by rotation age (includes two thinnings) using a 5-percent real discount rate: a. present value of revenues, b. present value of costs, c. net present value, d. land expectation value, and e. land expectation value with higher prices.

Table 4.-Land expectation values by discount rate (real) for each COMP location and treatment, calculated using a optimal rotation age

Location	Control treatment	Discount rate (pct) 3	4	5	6	7
		(dollars)				
Low hardwood sites						
Counce, TN	Chop-burn	666	329	153	60	3
SI=58	Woody (W)	563	245	119	41	-12
	Herb (H)	532	237	113	35	-17
	W + H	496	1%	83	11	-36
Warren, AR	Chop-burn	903	497	270	136	54
SI=62	Woody	965	487	246	116	46
	Herb	1004	520	261	116	U
	W + H	933	439	210	100	28
Pembroke, GA	Chop-bum	1002	539	297	149	61
SI=65	Woody	1031	542	279	126	41
	Herb	970	497	233	100	31
	W + H	920	426	182	81	15
Jena, IA	Chop-hum	1767	1050	666	425	2%
SI=75	Woody	1657	965	5%	368	237
	Herb	1771	1043	628	360	242
	W + H	1780	1011	584	373	234
Monticello, GA	Chop-burn	1943	11%	744	4%	313
SI=79	Woody	2130	12%	811	511	311
	Herb	2083	12%	760	463	300
	W + H	2087	11%	697	437	283
High hardwood sites						
Appomattox, VA	Chop-bum	5	87	-107	-131	-145
SI=50	Woody	2%	43	-49	-1%	-144
	Herb	-433	-237	-209	-1%	-1%
	W + H	115	-62	-136	-158	-169
Arcadia, LA	Chop-burn	450	216	100	27	-23
SC%	Woody	450	2%	88	1	-32
	Herb	304	154	57	-5	47
	W + H	434	177	61	-9	-53
Tallassee, AL	Chop-bum	2%	131	39	-20	-59
SI=56	Woody	484	1%	45	-22	-64
	Herb	137	58	-12	-56	-86
	W + H	433	125	8	-50	-66
Atmore, AL	Chop-burn	502	2%	96	21	-27
SI=59	Woody	656	299	109	14	-34
	Herb	353	125	38	-17	-55
	W + H	621	225	64	-8	-54
Liverpool, LA	Chop-burn	607	415	207	a7	13
SI=63	Woody	906	453	218	81	-5
	Herb	748	358	142	36	-17
	W + H	989	476	189	U	-17
Camp Hill, AL	Chop-burn	915	483	259	130	48
SI=65	Woody	993	519	262	104	20
	Herb	650	277	130	51	-3
	W + H	1108	563	2%	83	13
Liberty, MS	Chop-burn	1408	a15	484	2%	169
SI=77	Woody	2004	1170	730	454	271
	Herb	1676	984	5%	340	175
	W + H	2057	1197	707	399	1%
Bainbridge, GA	Chop-bum	2389	14%	945	625	429
SI=88	Woody	2664	1579	1000	646	430
	Herb	2220	12%	859	587	403
	W + H	2659	1579	964	615	414

percent discount rates. Thus, woody control was the most profitable treatment on more sites when discount rates were below 5 percent.

SUMMARY

Projections of early stand data indicate that yields can be consistently enhanced by intensive vegetation control treatments, used during establishment, for sites widely ranging in qualii. Yields were increased most by controlling both woody and herbaceous competition. On average, control of woody competition increased yields more than control of only herbaceous competition. This may be partly because equations relating herbaceous competition to yields are not part of the NCSU projection model, while integral woody equations subtract increasing yields with increasing woody competition. Competition control increased both total pine volume and sawtimber volume, but increases were proportionally greater for sawtimber.

The profitability of investments in intensive vegetation control depends on discount rate, site index, and hardwood abundance, in addition to costs and prices. Chop-burn was the most profitable treatment when site indices were low and discount rates were high. It also appeared that chop-burn was the more profitable option on low hardwood sites compared to high hardwood sites. In general, investments in woody control were more profitable on more locations than herbaceous control or W+H control. Investments in woody control and W+H control became more attractive on high hardwood sites at discount rates below 5 percent and site indices above 60.

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HERBACEOUS WEEDS AFFECT SOIL EXPLOITATIVE EFFICIENCY OF LOBLOLLY PINE'

Terry R. Clason and Kenneth W. Farrish[2]

Abstract--The root system sorptii zone and herbaceous weed interaction an loblolly pine growth was evaluated for a Wolfpen soil series. Two sdum depths, 50 and 70 inches, were selected as root system sorption zone treatments. Two levels of herbaceous weed competition, suppressed and unsuppressed, were assigned to each sorption zone treatment with factorial treatments being replicated three times in a completely random manner. Total stand and dominant tree growth indicated that soil exploitative efficiency st each solum depth was affected by herbaceous weed competition.

INTRODUCTION

A field fumigation study planted at 1,210 trees/acre (TPA) showed that age 6 loblolly pine, *Pinus taeda* L., diameter and height growth on treated plots exceeded untreated plots by 0.9 inch and 4.5 feet (Hansbrough et al., 1964). Since the fumigation treatment eliminated weed and grasses during the first two growing season, the early growth enhancement was attributed to herbicidal rather than nemacidal activity. Data collected between ages 6 and 30 were used to analyze the effect of the early growth response on long-term plantation development. Plantation development was accelerated by 3 years, with treated plot total wood yields at age 20 being 500 ft^3/acre greater than the untreated plots (Clason, 1989). In addition, significant volume growth differences *were* detected among plots within treatments. A preliminary soil survey revealed that depth to the unaltered, unconsolidated geologic material (C horizon) varied randomly within the study area, ranging from 40 to 80 inches. Therefore, a study was initiated to determine whether herbaceous weeds affect soil exploitative efficiency of loblolly pine.

METHODSANDPROCEDURES

The original growth and yield study was established in 1957 on an old field having a Wolfpen loamy sand soil and a site index of 64 feet at age 25. Prior to planting, the 4-acre study area was cleared of existing vegetation and disked several times to eliminate encroaching woody vegetation. Original experimental design consisted of two nursery bed fumigation treatments and three field fumigation treatments arranged factorially in a Latin square with six rows and six columns (Hansbrough et al., 1964).

The soil sorption zone exploitative efficiency of loblolly pine was evaluated by factorially combining two root system sorption zone depths and two levels of herbaceous weed competition. Soil sorption zone depths were grouped into shallow solum (<50 inches) and deep solum (>70 inches), and the weed competition levels were weed suppression and no weed suppression. Root sorption zone-weed level factorial treatments were designated as: 1) shallow solum-weed suppression (SWS), 2) shallow solum-no weed suppression (SNWS), 3) deep solum-weed suppression (DWS), and 4) deep solum-no weed suppression (DNWS). Each treatment was replicated three times with individual treatment plot distribution based on the preliminary soil survey.

A comprehensive soil analysis was conducted on each treatment plot using a five-point cluster sampling design. At each cluster point, soil cores were taken from the surface to the top of the C horizon. Soil samples were collected from extracted cores as follows: 1) top 6 inches Ap horizon, 2) bottom 6 inches E horizon, 3) top 6 inches Btl horizon, 4) bottom 6 inches Bt2 horizon, and 5) 6 inches above the C horizon. Soil sample physical characteristics were ocularly estimated in the field, while N and P levels were determined with standard laboratory procedures (Page et al., 1982). Growth data collected for the previous growth and yield study (Clason, 1989) were used to evaluate impact of the factorial treatments on plantation growth and on the growth of 10 dominant trees per plot from planting to age 20.

All data were analyzed using SAS general linear model (SAS Institute Inc., 1986) analysis of variance procedures at a 0.05 level of probability. Plantation

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growth was analyzed using treatment plots as experimental units and block X treatment interaction as the experimental error, while dominant tree growth was analyzed using individual trees as experimental units and the tree X block X treatment interaction as the experimental error. Individual mean differences were tested using two sets of orthogonal comparisons. Set 1 compared growth impact of root sorption zone depth on herbaceous weed competition levels: i) SWS and DWS versus SNWS and DNWS, ii) SWS versus DWS, and iii) SNWS versus DNWS. Set 2 compared growth impact of herbaceous weed competition levels on root sorption zone depth: i) SWS and SNWS versus DWS and DNWS, ii) SWS versus SNWS, and iii) DWS versus DNWS.

RESULTS

Mean treatment solum depths were 49, 49, 74, and 77 inches for SWS, SNWS, DWS, and DNWS treatments, respectively (Table 1). Ap, E, and Btl horizon thickness did not diier among treatments, averaging 5, 9, and 11 inches. Thickness of the Bt2 and Bt3 horizons did diier, with the deep solum Bt2 and Bt3 horizons being 8 and 17 inches thicker than the shallow solum horizons. N and P concentrations did not vary among treatments and were similar for each horizon within treatment solums (Table 1).

Pine Plantation **Growth**

Root Sorption Zone Depth Impact

Herbaceous Weed Suppression. No growth differences were detected between SWS and DWS treatments at ages 6, 10, and 14 (Table 2). However, plantation growth differed significantly by age 17, with SWS pine mortalii between ages 14 and 17 exceeding DWS mortality by 150 TPA. SWS periodic growth for dbh, height, basal area, and merchantable volume averaged 0.4 inch, 3 feet, -10 ft^2/acre, and 90 ft^3/acre, while DWS mean periodic growth was 0.5 inch, 7 feet, 20 ft^2/acre, and 640 ft^3/acre. During the 3 year interval, SWS merchantable volume mean annual increment (VMAI) declined from 169 ft^3/acre at age 14 to 145 ft^3/acre at age 17. Age 20 merchantable volume for the SWS treatment averaged 2,800 ft^3/acre, which was comparable to the DWS volume at approximately age 15. Thus, the shallow solum planted at 1,200 TPA without weed suppression lengthened the production cycle by 5 years.

No Herbaceous Weed Suppression. Plantation growth diiered between SNWS and DNWS treatments by age 6 (Table 2). Although treatment pine density was similar, averaging 1180 TPA, DNWS dbh, height basal area, and merchantable volume growth exceeded SNWS by 0.9 inch, 3 feet, 21 ft^2/acre, and 150 ft^3/acre. At age 20, treatment pine density was still similar, but VMAI differed significantly with SNWS and DNWS being 105 and 158 d/acre, respectively. SNWS merchantable volume at age 20 was 2,100 ft^3/acre, which was equivalent to the DNWS volume at age 14. Therefore, the shallow solum without weed suppression reduced early plantation growth and lengthened the production cycle for similar yields by 6 years.

Herbaceous Weed impact

Shallow Solum. Weed suppression significantly increased early pine growth (Table 2). By age 6, SWS mean dbh, height, basal area, and merchantable volume exceeded SNWS by 1.9 inches, 8 feet, 60 ft^2/acre, and 510 ft^3/acre. Although SWS pine density was 130 TPA less than SNWS at age 20, SWS merchantable volume and VMAI exceeded SNWS by 700 ft^3/acre and 35 ft^3/acre, respectively. SNWS

Table 1. Treatment soil physical and chemical characteristics by horizon

Treatments	Ap Horizon	E Horizon	Btl Horizon	Bt2 Horizon	Bt3 Horizon
			Depth (inches)		
SWS	5	9	10	10	15
DWS	5	11	11	20	27
SNWS	6	7	10	13	13
DNWS	5	9	11	18	34
			Nitrogen (mg/kg)		
SWS	935	299	482	368	276
DWS	831	222	341	246	228
SNWS	794	269	418	386	298
DNWS	990	330	325	240	184
			Phosphorus (mg/kg)		
SWS	140	18	1	1	1
DWS	108	22	1	1	1
SNWS	158	18	2	1	1
DNWS	83	22		1	1

Table 2. Plantation growth attributes by treatment from age 6 to 20

Treatments	Age 6	Age 10	Ase 14	Aoe 17	Aoe 20
			Density (TPA)		
sws	1210	1040	1020	800	690
DWS	1200	1080	1050	980	800
SNWS	1200	1090	1050	970	820
DNWS	1160	1060	1020	960	870
			dbh (inches)		
sws	3.4	4.9	5.4	5.8	6.5
DWS	3.2	4.8	5.4	5.9	6.7
SNWS	1.5	3.5	4.2	4.7	5.4
DNWS	2.4	4.4	5.0	5.6	6.2
			Height (feet)		
sws	19	34	43	46	49
DWS	20	33	42	49	52
SNWS	11	26	37	44	47
DNWS	14	31	40	47	50
			Basal Area (ft^2/acre)		
sws	75	135	160	150	160
DWS	65	135	165	185	195
SNWS	15	50	100	115	130
DNWS	36	60	140	165	182
			Merchantable Volume (ft^3/acre)		
sws	570	1,650	2,300	2,460	2,800
DWS	460	1,600	2,560	3,200	3,360
SNWS	60	670	1,300	1,700	2,100
DNWS	210	1,200	2,200	2,670	3,160

treatment production cycle for 2,100 ft^3/acre was 7 years longer than the SWS treatment

Deep Solum. Treatment growth diierentials on the deep solum were less but still significant (Table 2). Although treatment pine density was similar at ages 6, 10, 14, 17, and 20, treatment VMAI differed significantly for all 5 ages. DWS VMAI exceeded the DNWS VMAI by 42, 40, 25, 31, and 8 ft^3/acre for the respective ages. Without weed suppression the production cycle for 3,160 ft^3/acre on the deep solum was lengthened by 3 years.

Dominant Pine Growth

Root Sorption Zone Depth Impact.

Herbaceous Weed Suppression. Mean tree basal area growth was similar for both suppression treatments at age 6 (Table 3). By age 10, mean tree basal area differed significantly with the SWS basal area being 0.043 ft^2 less than the DWS basal area. Basal area MAI (BAMAI) for both treatments peaked at age 10, averaging 0.017 and 0.021 ft^2 for SWS and DWS, and each treatment maintained that BAMAI through age 20. Age 20 mean dominant tree basal area on the shallow solum was reduced by 0.080 ft^2.

No Herbaceous Weed Suppression. SNWS and DNWS treatment mean tree basal area diiered at ages 6, 10, 14, 17, and 20 (Table 3). SNWS mean tree BAMAI peaked at age 20, averaging 0.014 ft^2, while DNWS BAMAI peaked at age 17, averaging 0.015 ft^2. Shallow solum age 20 mean tree basal area was 0.020 ft^2 less than the deep solum basal area.

Herbaceous Weed Impact

Shallow Solum. SWS dominant tree basal was significantly larger at all ages (Table 3). Tree basal area growth between ages 14 and 17 averaged 0.048 and 0.053 ft^2 for the SWS and SNWS treatments, respectively. This growth differential combined with high mortality and a reduction in plantation periodic volume growth during the same interval (Table 2) suggests that intraspecific competition on the SWS treatments had reached a critical level by age 14. Mortality losses reduced SWS pine density from 1020 TPA at age 14 to 690 TPA at age 20. Subsequently, SWS dominant tree basal area growth from age 17 to 20 exceeded SWS growth by 0.009 ft^2.

Deep Solum. DWS and DNWS treatment mean dominant tree basal area differed at all ages (Table 3). Mean tree basal for DWS was larger than DNWS differing by 0.060, 0.070, 0.084, 0.096, and 0.120 ft^2 at ages 6, 10, 14, 17, and 20. Since DWS periodic basal area growth exceeded DNWS growth for all growth intervals, no critical level of intraspecific competition was indicated. Between age 17 and 20, however, DWS treatment mortality was 90 TPA more than

Table 3. Dominant tree growth attributes by treatment from age 6 to 20

Treatments	Age 6	Age 10	Age 14	Age 17	Age 20
			dbh (inches)		
SWS	4.1	5.6	6.4	7.1	7.9
DWS	4.3	6.2	7.2	8.1	8.8
SNWS	2.1	3.8	5.5	6.4	7.2
DNWS	2.7	5.1	6.0	6.8	7.4
			Height (feet)	51	
SWS	24	38	48	54	54
DWS	21	37	50		57
SNWS	13	29	41	45	51
DNWS	16	32	45	50	54
			Basal Area (ft^2)		
SWS	0.090	0.170	0.224	0.272	0.340
DWS	0.102	0.210	0.280	0.351	0.420
SNWS	0.024	0.080	0.168	0.221	0.280
DNWS	0.042	0.140	0.196	0.255	0.300

DNWS and periodic plantation volume growth was 330 ft^3/acre less than DNWS (Table 2), suggesting the DWS treatment was approaching a critical level at age 17.

DISCUSSION

Soil sorption zone depth and herbaceous weeds significantly affected loblolly pine plantation growth and development, SWS and DWS mean merchantable volume at age 10 was 400 ft^3/acre greater than DNWS volume, and volume growth on the SWS treatment was comparable to the DWS and DNWS treatments through age 14 (Table 2). Age 20 merchantable volume for SWS was 2,800 ft^3/acre, and the DNWS production cycle for this volume was 2 years less than SWS and 3 years more than DWS. Since weed suppression mitigated the effect of soil sorption zone depth on plantation growth, herbaceous weeds had an apparent effect on pine soil exploitative efficiency.

Herbaceous weeds had an impact on site quality evaluation, particularly site index (Table 3). Age 20 dominant tree height averaged 54, 57, 51, and 54 feet for SWS, DWS, SNWS, and DNWS treatments, respectively. Age 25 site indices for old field loblolly pine (Golden et al., 1981) for the respective treatments were 63, 67, 60, and 63 feet. Herbaceous weeds not only reduced site index values on similar solum depths by 5 to 6 percent but also altered height-diameter distributions. Although the SWS and DNWS age 20 site index value was 63 feet, SWS and DNWS mean dominant tree dbh averaged 7.9 and 7.4 inches (Table 2). This height-diameter discrepancy could prejudice growth model volume predictions for herbaceous weed suppression.

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IMPORTANCE OF EARLY SEASON COMPETITION CONTROL IN ESTABLISHING EASTERN COTTONWOOD (*Populus deltoides*) PLANTATIONS'

Dr. Andrew W. Ezell[2]

Abstract-Eastern cottonwood is one of the fastest growing commercial tree species in the United States. However, the species is extremely sensitive to competition and control of competing vegetation is essential if successful plantation establishment and optional growth are to be achieved. This need is especially critical in the early growing season when mechanical cultivation is often prohibited by site conditions or can result in damage to newly-emerged cottonwood sprouts.

Thirty-six different herbicide treatments were applied for preemergent control of broadleaf weeds in February, 1 992. Treatments were evaluated for both weed contrd efficacy and crop species tolerance. Based on the results of the 1992 work, five rates of oxyflurofen were applied to evaluate rate response and time of application.

Overall, the results of these applications demonstrate the importance of early season competition contrd for cottonwood plantation establishment. Cottonwood survival and operational flexibility were both greatly enhanced by the use of pm-emergent herbicide applications. Mechanical cultivation during the later part of the growing season is still a useful management tool, but herbicides are a better choice for early season competition contrd.

INTRODUCTION

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

Thii study actually involved two projects designed to examine early season competition control. The first project was a screening trial in which preemergent products were evaluated for treatment efficacy and damage to cottonwood sprouts.

The second project was an outgrowth of the screening effort in which multiple rates of oxyfluorofen were tested for rate response and overall efficacy. This project also tested diierent application timings in an attempt to increase flexibility for field operations.

MATERIALS AND METHODS

Study Sites

Study sites were made available by James River Corporation at Fitler Managed Forests which would provide both the planted cottonwood and comparable study areas. Fiier Plantation is located in the Mississippi River floodplain approximately 30 miles north of Vicksburg, MS. Eastern cottonwood was planted as cuttings on a 12 ft. x 12 ft. spacing with the cutting located in the intersection of subsoil trenches. All sites were former eastern cottonwood plantations which had been harvested and received identical mechanical site preparation. Three sites were used in the screening trials and two additional sites were used in the oxylluorfen project.

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Treatments

In the screening project 36 diierent treatments involving 14 chemicals were applied. The products involved and treatment rates are found in Table 1.

Table 1. Products and Rates Used in Initial Screening Trials.

Product	Rates Per Acre
Scepter	10.20.40 oz
Pursuit	4, 8, 16 oz
Stomp	1.67, 3.33, 6.66 lbs
Goal	80, 120, 6.66 lbs
Assure II	2.5, 5.0 oz
Sinbar	2, 3, 4 lbs
Gallery	0.67, 1.33 lbs
Lexone	0.5, 1.0, 1.5 lbs
Escort	0.25, 0.33, 0.50 oz
Harmony	0.67, 1.33 oz
Express	0.67, 1.33 oz
oust	0.75, 1 .oo oz
Surflan	0.5, 1.0 gal
DPX-V9360-44	0.5, 1.0, 2.0 oz

In the oxyflurofen project five rates of Goal 1.6E were applied at two separate times. The five rates of oxyflurofen applied on per acre basis were as follows: 80 oz, 100 oz, 120 oz. 140 oz, and 160 oz. All five rates were applied in conjunction with 32 oz. of Gramoxone per acre with the Gramoxone being added to control winter wheat and sunflowers which had been planted in the area for wildlife habitat improvement. In addition to the five rates applied with Gramoxone, one application of Goal at 80 oz/acre was applied without Gramoxone to test the efficacy of a combination of Goal with Triton AG-98 added at 0.25% v/v.

Oxyfluorfen is a herbicide which is typically applied during the dormant season near the end of January or the first part of February. One application in this study was made to reflect the traditional timing and one application was made in mid-December (December 14) in order to test the possibilii of increasing the flexibilii of application timing. All treatments were installed with a CO, backpack sprayer which was equipped to utilize 2-liter bottles. Applications ere made over-the-top of the planted cottonwood cuttings and a 6 ft. wide band was utilized for all treatment applications. Two replications of each treatment were installed at each application time. An untreated control plot was marked for evaluation in each study replication. The total number of cottonwood stems involved in the study exceeded 800.

Evaluation

All plots were evaluated by ocular estimate. Plots were evaluated for weed control at 30, 60, 90, and 120 days after treatment (DAT). At each interval, the percent clear ground within the application treatment band was evaluated. In addition to the evaluation times previously listed, the mid-December plots were evaluated 150 days after treatment although weed control from the herbicide was not a requisite for thii study at that timing interval.

In addition to evaluating the plots for weed control and herbicide efficacy, the cottonwood cuttings were checked for any herbicide damage as the study progressed. At the end of the first growing season, the cottonwood trees were measured in early December to determine the average height and survival within the diierent treatments.

RESULTS

The screening project yielded a large amount of useful information. Some products proved to be very effective in competition control, and while part of these treatments resulted in damage to the cottonwoods, others did not. Of all the treatments tested, the applications of Scepter, Oust, and Goat gave the best results. It should be noted that Scepter is not currently labelled for use in cottonwood management, and while Oust is labelled for use in hardwoods, the rates in thii project were below label recommendations. Higher rates of Oust have been noted to cause damage to cottonwood, especially when applied for post-emergence control. Goal 1.6E is labelled for use in cottonwood management, gave excellent competition control, and caused no damage to cottonwoods. It was, therefore, decided to further examine the use of oxyflurofen. The results of that project are presented according to time application.

The percent clear ground in the mid-December treatment plots is found in Table 2. As can be seen from the tabular presentation, all rates provided excellent weed control. The 80 oz rate which was applied without the addiion of Gramoxone worked as well as those rates applied with Gramoxone with the exception of winter wheat. Oxyfluorfen does not control winter wheat, but this would not be a major obstacle in establishing eastern cottonwood plantations as it is an introduced species used for wildlife food plots. All treatments provided excellent control of native competing vegetation at the 30, 60, 90, and 120 DAT evaluations. The notable decrease in percent clear Qround for the 80 oz rate without Gramoxone was due almost entirely to winter wheat growth and development. By comparison, the control plot which received no herbicide application had virtually no clear ground by 90 days after treatment. This would be a typical situation facing an operator for mechanical cultivation in these types of plantations.

The percent clear ground for the January-February plots is found in Table 3. Once again all treatment8 provided excellent weed control at all evaluation times.

Table 2. Percent Clear Ground in Mid-December Treatment Plots.

Treatment	Evaluation Timing (DAT)			
	30	60	90	120
	(percent)			
80 oz (NO GR)	90	80	50*	50'
80 oz + Gr	100	100	100	90
100 oz + Gr	100	100	90	90
120 oz + Gr	100	100	100	95
140 oz + Gr	100	100	100	95
160 oz + Gr	100	100	100	95
Control	80	50	10	5

Winter wheat in plots

Table 3. Percent clear ground in January-February treatment plots.

Treatment	Evaluation Timing (DAT)			
	30	60	90	120
	(percent)			
80 oz (NO GR)	100	100	100	80
80 oz + Gr	100	100	100	80
IOOoz+Gr	100	100	90	90
120 oz + Gr	100	100	100	90
140 oz + Gr	100	100	100	90
160 oz + Gr	100	100	100	90
Control	70	40	10	5

Winter wheat was not present on this site and the difference is notable for the 80 oz without Gramoxone application as compared to Table 2. At the 120 DAT evaluation, competition control is beginning to break down but all rates still demonstrated 80% clear ground or higher (see Table 2). Cottonwood growth and development was excellent in these plots, and mechanical cultivation could now begin with very little risk of damage or mortality to the cottonwood sprouts due to cultivation efforts. As was observed in the mid-December application plots, the control plots had virtually no clear ground by the 90 DAT evaluation. Operationally, these plots would have been extremely difficult to cultivate by the first of April, and if weather or site conditions precluded cultivation prior to that time, serious losses in growth and survival would result. Once again all treatments were evaluated for any negative effects on the eastern cottonwood plantings, and none were observed.

The average tree height and survival for all treatment plots can be found in Table. 4. These are first-year growth measurements, and while the differences in height growth are not great, the differences in survival are most notable. The control plots which received no herbicide but were cultivated mechanically as all other plots had a 40-50% reduction in survival. In essence, if the entire plantation had achieved only 43% survival, it is highly questionable as to whether or not it would have been feasible to continue management of the area. The average tree height is impressive for a one year old tree as compared to most other species, but this parameter is not intended to be a measure of the success of the different rates of herbicide treatment. Many factors influence cottonwood height growth including site qualii, genetics, timing of cultivation, and climatic variables. Height was measured in this study to compare the effect of early weed control to areas without similar competition control. It is notable that the control plots had appreciably less height growth on the trees which did survive.

Table 4. Average First-Year Height and Survival.

Treatment	Average Tree Height	Survival
	(Feet)	(%)
80 oz (NO GR)	10.1	80
80 oz + Gr	9.2	80
100 oz + Gr	10.5	90
120 oz + Gr	11.5	90
140 oz + Gr	11.3	90
160 oz + Gr	10.7	90
Control	8.1	43

DISCUSSION

Overall, all oxyflurofen treatments provided excellent weed control with no damage to the crop species. Based on the results of this study, oxyfluorfen is an excellent choice to use for preemergent weed control in eastern cottonwood plantations. It is worth noting that competition control through the use of herbicides is only one component of successful cottonwood plantation establishment and management Mechanical cultivation during the first years of the plantation is still highly desirable for a number of reasons, and the timing of cultural operations can have a great impact on growth and development of the cottonwoods. However, use of mechanical treatments in the first 120 days following planting is very often difficult to achieve due to weather and site conditions and quite often results in damage and/or destruction of the planted cuttings. For that reason competition control through the use of herbicides is highly desirable for plantation establishment. Survival and growth of the crop trees were both enhanced by the use of herbicides as compared to control plots in this study. Generally, the results of this study would have application to most if not all eastern cottonwood plantation establishment.

Both application times involved in the oxyflurofen project gave excellent results. It is important to

recognize that the mid-December application represents new technology for oxyfluorfen use in cottonwood. This application timing may prove to be very important for use in areas where weather and site conditions often prohibit field operations in the early months. There was no significant response to increased rates of oxyfiuorfen application. In essence, the 80 oz/acre rates provided adequate competition control and increasing the rate up to and induding 160 oz/acre only increased the level of competition control at the 120 DAT evaluation and later. As mechanical means will typically be employed to cultivate these plantations after that length of time, the importance of residual control from the oxyfluorfen becomes diminished.

The results of these projects provide eastern cottonwood plantation managers with an option with which they can avoid early mechanical cultivation. The potential impact for thii option on cottonwood production is significant. In the past, some planted areas have suffered excessive mortality from early season competition and subsequent attempts at mechanical cultivation. It is hoped that the results of this study will enable cottonwood plantations to be established in a more cost effective manner and that the total production will be enhanced from this improved establishment.

A COMPARISON OF HERBICIDE TANK MIXTURE FOR SITE PREPARATION -EVALUATION OF TREATMENT EFFICIENCY AND POSSIBLE ANTAGONISM'

Drs. Andrew W. Ezell, Joe Vollmer, Patrick J. Minogue, and BruceZutter[2]

Abstract—A total of **52 different herbicide mixtures were applied as site preparation treatments to test effi and evaluate possible** antagonism in the **tank mixtures. Each treatment was replicated three times, and study trees were tagged in each treatment plot for evaluation following the first, second, and third growing seasons after application. A total of 1,560 stems were evaluated for the duration of the 3 year study. Results Indiited that Arsenal AC was effective in controlling competing vegetation and that there was a significant increase in mortality of competing stems between 1 YAT** and **2 YAT.**

Overall, Arsenal AC mixed well with Garlon 4,2,4-D (amine and **ester)** and **2,4-DP. However, negative responses were noted in mixtures of Arsenal AC and Garlon 3A, Tordon K, and Banvel or Banvel 720.**

INTRODUCTION

Control of competing vegetation is a **major** concern in **pine plantation establishment.** The problem is typically such **that a major portion of the total establishment cost is spent on controlling residual stems or newly colonized plants which invade recently harvested** areas.

An essential feature of any vegetation management strategy is cost-effectiveness. To meet that criteria forest managers have incorporated the use of herbicide tank mixtures to either lower cost, increase spectrum of control or both. Since the onset of tank mixture application, the search for the optimum combination of different chemicals has continued, quite often without the benetit of extensive field research on which to base decisions.

Since the introduction of imazapyr as a forest management chemical, interest is tank mixtures involving Arsenal Applicator Concentrate has been high. Thousands of acres are now treated annually with tank mixtures using imazapyr for both site preparation and release. However, when chemicals are mixed, there is always a possibility that the combination could be less effective than application of a single product due to antagonism between the two products. It is therefore desirable to evaluate combinations of diierent chemicals **and different** rates of the chemicals involved in the mixtures.

PURPOSE OF THE STUDY

The purpose of this study was to evaluate combinations of imazapyr with eight other registered forestry herbicides. Diierent amounts of each product were combined with Arsenal AC to evaluate any rate response which might occur, either positive or negative.

MATERIALS AND METHODS

A **total of six separate projects were involved in** the **completion of this study. Each project involved the combination of various rates as a different herbicide(s) with Arsenal AC. In each project, Arsenal AC was applied as a comparison. A listing of tank mixture** for each project can be found in Tables I-6. From all projects, **a** total of 52 different treatments were applied with three replications of each treatment installed. Each replication consisted of a plot 30 **ft** X 50 ft with 10 tagged sample trees in each plot. Species consideration for inclusion in the study included **availability** of stems across the study areas, size of stem, and potential for response to treatment. Based on those criteria, **sweetgum** (*Liquidambar styraciflua*) was chosen for evaluation in all projects.

Each treatment was applied with a CO_2-**powered** backpack sprayer equipped with an extended pole sprayer attachment. This equipment was employed to simulate an aerial application.

Prior to spraying, plot center lines were marked using PVC pipe with flagging stretched between the two markers. This facilitated both the accurate application of treatments and the location and subsequent relocation of sample stems.

Following application, 10 **sweetgum** trees were located and tagged with aluminum tags imprinted with an

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identification code. The location of each sample tree was then mapped for all plots based on distance along the center line from one PVC marker and perpendicular distance from the center line.

All treatments were applied to study areas located on the Noxubee Wildlife Refuge and Mississippi State University School Forest. Study area location was south of Starkville, MS, in the east central portion of the state.

Ail treatment application was completed in September, 1991, and evaluated 45 days after treatment (DAT) for percent brown-out. Each sample tree was then evaluated 1, 2, and 3 years after treatment (YAT) for response to treatment During the evaluation, each sample treated was rated as one of nine possible response codes. They included (1) completely dead, (2) defoliation, (3) green cambium, (4) bud break/little leaf expansion, (5) incomplete leaf expansion, (6) no injury, (7) root collar sprouts, (8) root sucker sprouts, and (9) no sprouting. A total of 1,560 sample trees were tagged and evaluated one or more years. Of the original sample trees, more than 99 percent were relocated and evaluated all three years of the study.

The field data were statistically analyzed to evaluate trends of response. Based on inspection of percentage responses in each response code, it was decided to complete an ANOVA using the "completely dead" data as that was the overwhelming majority of responses in the study.

RESULTS

Results for the study will be discussed on an individual project basis. Of particular interest in the conduct of the study were additive or negative effects resulting from diierent mixes. Data analysis indicated consistent trends in some results across all projects. In addition, projects were analyzed individually to avoid confusion in interpretation of the results. Review of the observations indicated that the most meaningful comparisons could be accomplished using the "completely dead stems" information. All results and comparisons presented are based on those observations.

Arsenal and Garlon 4 Mixes

The most notable results of this project are as follows (Table 1):

- There was a significant increase (p=O.OOOl) in dead stems from 1 YAT to 2 YAT, but no change from 2 YAT to 3 YAT.
- There was no significant effect in adding Garlon 4 (32-128 oz) to Arsenal at 16 or 24 oz.
- There was no significant effect from the rates of Garlon 4 added to Arsenal AC.
- Overall, 3 YAT mortality in this project ranged from 66.7% to 93.3% depending on treatment.

Table 1. Percent completely dead stems by year of observation for arsenal +Garlon 4 mixtures.

Treatment		Completely Dead Stems		
Arsenal AC	Garlon 4	1 YAT	2YAT	3YAT
---oz/a---		---Percent---		
16		73.0	90.0	90.0
16	32	43.0	66.7	66.7
16	64	73.3	93.3	93.3
16	96	56.7	73.3	73.7
16	128	53.3	76.7	80.0
24	32	46.7	70.0	66.7
24	64	70.0	80.0	82.8
24	96	86.7	86.7	89.7

Arsenal AC + 2,4-D (amine and ester)

The most notable results from this project are as follows (Table 2):

- There was a significant increase (p=O.OOOl) in mortality from 1 YAT to 2 YAT, but little change from 2 YAT to 3 YAT.
- There was no significant effect of adding 2.4-D (amine or ester) to Arsenal AC.
- There was no significant differences between the 2,4-D formulation when added to Arsenal AC.
- There was no significant effect of the rate of 2,4-D added to Arsenal AC.
- Overall, 3 YAT mortality ranged from 50.0% to 83.3% depending on treatment.

Table 2. Percent completely dead stems by year of observation for Arsenal and 2,4-D mixtures.

Treatment			Completely Dead Stems		
Arsenal AC	2,4-D Amine	2,4-D Ester	1 YAT	2YAT	3 YAT
--oz/a--	---lb/a---		---Percent---		
24	--	--	43.3	80.0	83.3
24	0.25	--	66.7	73.3	80.0
24	0.50	--	63.3	70.0	70.0
24	1.00	--	46.7	56.7	53.3
24	1.50	--	66.7	66.7	73.3
24	2.00	--	63.3	66.7	66.7
24	4.00	--	23.3	53.3	56.7
24	--	0.50	53.3	56.7	56.7
24	--	1.00	30.0	50.0	50.0
24	--	2.00	73.3	73.3	73.3
24	--	4.00	56.7	60.0	60.0

Arsenal AC + 2,4-DP Mixes

The most notable results from this project are as follows (Table 3):

- There was a significant increase (p=O.OOOl) in mortality from 1 YAT to 2 YAT, but little change from 2 YAT to 3 YAT.
- There was no significant effect from adding 2,4-DP to Arsenal AC.
- There was no significant effect from the rate of 2,4-DP added to Arsenal AC.
- Highest overall mortality of all project treatments.
- Overall, 3 YAT mortalii for thii project ranged from 83.3% to 1 00.0% depending on treatment

Table 3. Percent completely dead stems by year of observation for Arsenal and 2,4-DP mixtures.

Treatment		Completely Dead Stems		
Arsenal AC	2,4-DP	1 YAT	2YAT	3YAT
--oz/a--	--lb/a--	----------Percent----------		
24	-	58.7	86.7	90.0
24	0.25	73.3	83.3	93.3
24	0.50	93.3	96.7	100.0
24	1.00	53.3	83.3	83.3
24	2.00	90.0	96.7	96.7
24	4.00	83.3	80.0	83.3
24	8.00	66.7	90.0	93.3

Arsenal + Garlon 3A Mixes

The most notable results from this project are as follows (Table 4):

- As compared to other projects there was no significant change in mortalii from 1 YAT to 2 YAT.
- There was a significant (p=0.0174) negative effect from adding Garlon 3A (32-96 oz) to Arsenal AC at 16 or 24 oz.
- There was no significant effect from the rate of Garlon 3A added to Arsenal.
- Although not statistically significant (p=0.1223), the 24 oz rate of Arsenal resulted in 14 percent greater mortalii than 16 oz rate.
- Overall, 3 YAT mortality ranged from 40.0% to 76.7% depending on treatment.

Table 4. Percent completely dead stems by year of observation for Arsenal and Garlon 3A mixtures.

Treatment		Completely Dead Stems		
Arsenal AC	Garlon 3A	1 YAT	2YAT	3 YAT
-oz/a-		----------Percent----		
16		56.7	60.0	63.3
24		90.0	76.7	76.7
16	32	43.3	60.0	60.0
16	64	33.3	50.0	53.3
16	96	46.7	56.7	56.7
16	192	70.0	66.7	66.7
24	32	36.7	40.0	40.0
24	32	46.7	32.3	66.7
24	32	56.7	66.7	66.7

Arsenal + Tordon K Mixes

The most notable results from this study are as follows (Table 5):

- There was a significant (p=0.0012) increase in mortalii from 1 YAT to 2 YAT, but no change from 2 YAT to 3 YAT.
- There was a significant (p=0.0570) negative effect from adding Tordon K to Arsenal.
- There was no significant difference between use of X-77 and Dash surfactants added to 24 oz Arsenal.
- There was no significant effect from the rate of Tordon K added to Arsenal.
- Overall, 3 YAT mortality ranged from 56.7% to 86.7% depending on treatment.

Table 5. Percent completely dead stems by year of observation for Arsenal and Tordon K mixtures.

Treatment		Completely Dead Stems		
Arsenal AC	Tordon K	1 YAT	2YAT	3YAT
------oz/a------		----------Percent----------		
24	-	66.7	82.1	82.1
24	-	90.0	86.2	86.7
24	16	56.7	73.3	71.4
24	32	53.3	56.7	56.7
24	64	60.0	76.7	76.7
24	96	48.3	62.1	62.1
24	128	60.0	80.0	80.0

Arsenal + Banvel and Banvel 720 Mixes

The most notable results from the study are as follows (Table 8):

- There was a significant (p=0.0012) increase in mortality from 1 YAT to 2 YAT and 1 YAT to 3 YAT, but the change from 2 YAT to 3 YAT was not significant
- There was a significant negative effect from adding either Banvel (p=0.0053) or Banvel 720 (p=0.0063) to Arsenal.
- There was significant (p=0.0837) negative effect from the rate of Banvel herbicide added to Arsenal.
- There was no significant effect from the rate of Banvel 720 added to Arsenal.
- Overall, 3 YAT mortality ranged from 8.7% to 75.9% depending on treatment

Table 6 Percent completely dead stems by year of observation for Arsenal and Banvel or Banvel 720 mixtures.

Treatment			Completely Dead Stems		
Arsenal AC	Banvel	Banvel 720	1 YAT	2YAT	3YAT
----oz/a----			----Percent----		
18	--	--	88.7	79.3	75.9
18	18	--	30.0	80.0	80.0
18	32	18	17.2	48.7	48.7
16	48	32	43.3	50.0	50.0
18	84	84	83.3	50.0	50.0
18	96	96	10.0	23.3	23.3
18	128	128	13.3	8.7	8.7
18	--	18	40.0	40.0	40.0
18	--	32	38.7	30.0	30.0
18	--	84	40.0	40.0	40.0
18	--	96	38.7	33.3	40.0
18	--	128	20.0	31.0	34.5

While the "completely dead" stems represented the largest consistent observation at 3 YAT, other categories were worth mentioning. The vast majority of stems in the study which were not dead were either "incomplete leaf expansion" or "root collar sprouts". This combination of three observations accounted for more than 90% in all treatments except one • 18 oz Arsenal AC + 18 oz Banvel 720.

SUMMARY

Overall, the results of this study reflect three major items of interest. First, it is obvious that tank mixes utilizing imazapyr are very effective for competition control in site preparation treatment. The use of sweetgum as a target species did not serve as the most vigorous test of imazapyr efficacy, but it did afford an excellent perspective of negative interactions. All projects within the study consistently demonstrated that imazapyr alone was very effective in controlling sweetgum, and addition of companion products could do little to improve treatment efficacy.

Second, results from the various projects consistently indicated that two years following application may be the best time to evaluate treatment efficacy. Control significantly improved between the first and second year after treatment evaluations. While imazapyr is known to be a comparatively slower acting product, this study confirms the potential problems associated with early evaluations.

Third, some tank mixes resulted in negative interactions and reduced treatment efficacy. The individual projects indicated that imazapyr would mix and perform well with Garlon 4,2,4-D formulations, and 2,4-DP. However, the individual projects clearly demonstrated that Garlon 3A, Tordon K, Banvel, or Banvel 720 caused a negative interaction when mixed with imazapyr. While not all these products demonstrated a response to rate changes, the overall combinations resulted in reduced efficacy.

Tank mixtures remain a highly desirable option for site preparation treatment. For most effective results, a number of variables should be considered, and certainly the combination of products to be applied should be a positive interaction if optimal efficacy is to be achieved.

INFLUENCE OF HARDWOOD CONTROL ON LOBLOLLY PINE (*Pinus taeda* L.) SEEDLING AND HERBACEOUS SPECIES DEVELOPMENT IN THE GEORGIA PIEDMONT[1]

Judith A. Fitzgerald, Phillip M. Dougherty, and M. Boyd Edwards[2]

Abstract—A pine regeneration study **was established in** September of **1990** in the Georgia Piedmont. The study **objective was** to determine the effects of 6 different **regeneration-management** regimes **on** the growth and diversity of plant species. **Planted** pine showed no **significant difference** in **survival** between **herbicided and non-herbicided plots.** Tip moth **damage was greatest on herbicided** Plots in **year** 2 **compared** to the **non-herbicided (67 to 36 percent respectively), but had decreased by year 3 (11 to 6 percent respectively). The average number of plant species decreased over tii.** However, **forbs increased** in the **non-herbicided** plots. **The** number of **hardwood stems/acre increased** fur ail but the **herbicided** plots **which decreased.** There was an increase in browsed stems **in year 3 over year 1 in**all **treatments** except fur **the forbs in the** non-herbicided **plots.** There was greater browse in the **herbicide plots** in year 3 *than* **in the non-herbicided and control plots. Coverage increased for all vegetation** types **over** time except for the hardwood stems in **the herbicided** Plots. **Broomsedge increased on** the site from 12 percent coverage to **30** Percent coverage in the herbicided plots and from 12 to **25** and 21 Percent fur the **non-herbicided** and control plots, **respectively.**

INTRODUCTION

Herbicides can control herbaceous competition for young planted pine. Wiih the increased use of herbicides, there has been concern over the loss of plant diversity as well as impacts on **wildlife** habitats. Forest managers and small landowners today should weigh not only the cost of herbicides to improve timber production, but also the effects they will have on the plant species and resulting **wildlife** habitat. This study was designed to investigate the effects that a range of management regimes had on the vegetation of a young planted pine stand.

METHODS

The study is located on the University of Georgia's Daniel B. **Warnell** School of Forest Resources' B.F. Grant Memorial Forest. Located outside Eatonton, Georgia, an upland Piedmont **site with** a Davidson Clay Loam (clayey, kaolinitic, thermic, Rhodic Kandiudutt) soil type was chosen. The site had been farmed in the past resulting in highly eroded soils. A stand of natural loblolly pine with an average age of 55 years and dbh of 15 inches with a history of thinnings and prescribed burns was selected. Basal area was reduced to approximately 45 square feet in 1986 with the most recent prescribed burn in March of 1990. In the fall prior to study establishment, **a** randomized complete block with five replications of 6 treatments was established:

1. Seed tree - with herbicide
2. Seed tree - without herbicide
3. **Clearcut -** plant with Loblolly - with herbicide
4. **Clearcut -** plant **with** Loblolly - without herbicide
5. **Clearcut -** herbicided pine component
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). This paper will focus on the planted pine plots versus the control plots.

Loblolly pine **1-0 bareroot** seedlings were hand-planted by dibble on a 10 X 7 foot spacing **(3m** x 2m) or 622 trees per acre. Percent survival, height, ground line diameter and damage estimate measurements were made in January **1992, 1993** and 1994. DBH measurements were added in 1994 because by then many of the trees reached 4.5 feet in height.

On the herbicided plots 2 months after planting, **a spotgun** was used to apply **a** 6 foot radius spot around each pine of 5 oz. active ingredient/acre Oust@. Hardwood stems were basal sprayed with a Solo backpack sprayer and 5 percent by volume Garlon **4®** in a diesel carrier during June of 1992 and 1993 when temperatures were below 85" F. On the control and non-herbicided plots, there was no further management.

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To survey species composition within the treatment plots (Fitzgerald et al. 1992), twenty-five 1 m^2 quadrats per 0.25 acre plot were established on random coordinates. Species frequency and an ocular estimate of percent cover were recorded for trees, shrubs, vines, forbs, and grasses. Browsed stems were tallied to determine which species were favored by wildlife, mainly white-tailed deer (*Odocoileus virginianus)* and eastern cottontail rabbit (*Sylvilagus floridanus*). Vegetation surveys were made in September-October 1991 and again in September-October 1993.

RESULTS AND DISCUSSION

Pine

There was no difference in the mean height of the planted loblolly pines between the herbicide treated (35.16 cm) and the non-herbicided (35.49 cm) plots (Table 1) after the first growing season. However, by year 2, there was a significant difference in height between the treatments (76.77 cm and 70.25) with the greatest difference occurring in year 3 (118.67 and 108.52). Growth between year 1 and year 2 (41.8 and 34.8) and between year 2 and 3 (41.5 and 37.9) was significantly diierent between treatments (Table 1), however, within a treatment, the average growth rate was constant for those two periods.

Groundline diameters of planted pines were significantly larger in plots with competition control for all three years (Table 1). Average groundline diameters for both treatments more than doubled between year 1 and year 2 from 5.80 cm to 14.94 cm on the herbicided plots and 5.01 cm to 11.44 cm on the non-herbicided plots.

Differences in planted pine survival were not significant in the first year (86 percent versus 85 percent). By year 3, there was still no significant difference in survival among the treatments (80 percent versus 79 percent). Most of the mortality occurred in the first year. In the herbicided plots mortality was likely due to volatilization of herbicide (25 percent in 1992 and 65 percent in 1993 of dead pine), while in the non-herbicided plots mortality was likely due to competition.

In the first growing season, there was no treatment difference for the percent of browsed pine seedlings (14 percent versus 15 percent). There was little browsing on planted pine in year 2 or 3.

Tip moth (*Rhyacionia frustana*) damage was significantly higher with competition control (24 percent of planted pines) compared to plots without competition control (11 percent) in the first year (Table 1). This may account for the similarii in heights between the herbicided and the non-herbicided plots in that year. In year 2 there was a substantial increase in tip moth infestation. The herbicided plots had a 67 percent

Table 1- Planted Loblolly Pine Results[1]

Year	Herbicided Plots	Non-herbicided Plots
	Average Heights (centimeters)	
1991	35.19A (0.29)	35.55A (0.30)
1992	76.77A (0.86)	70.258 (0.76)
1993	118.67A (1.27)	108.528 (1.17)
	Average Height Growth (centimeters)	
1991-1992	41.79A	34.758
1992-1993	41.48A	37.868
	Ground Line Diameter (millimeters)	
1991	5.80A (0.05)	5.018 (0.04)
1992	14.94A (0.18)	11.448 (0.13)
1993	22.68A (0.26)	17.278 (0.20)
	Survival (percent)	
1991	86A	85A
1992	82A	82A
1993	80A	79A
	Tipmoth Infestation (percent)	
1991	27	12
1992	67	38
1993	11	8

'Means within a row followed by different letters are significantly diierent at the ($p < 0.05$) level using the Duncan's Multiple Range test. Standard errors in parentheses.

infestation while the non-herbicided plot had 38 percent. By year 3, these numbers dropped to 11 percent and 8 percent, respectively. Tip moth damage has been shown to increase the risk for disease such as fusiform rust (*Cronartium quercuum*) (McPherson and Douce 1992). Of the 23 fusiform infected stems found in 1993, 17 had previous tip moth damage .

Plant Community

A total of 124 plant species were identified on all plots. The number of individual hardwood, forb, and grass species decreased from year 1 to year 3; however forbs increased in the untreated plots (Figure 1). Some

of the species that dropped out after the first year were early successional species such as fireweed (*Erechtites hieracifolia*) and sicklepod (Cassia *obtusifolia*). The number of woody vine species (9) remained constant among treatments over the years. The major species were yellow jessamine *(Gelsemium sempervirens),* honeysuckle *(Lonicera japonica),* blackberries (*Rubus* spp.) and greenbriar (*Smilax* spp.)

The number of stems of hardwoods, woody vines, and forbs increased over time except for the plots which were treated with Garlon 4® where the number of hardwood stems and woody vines decreased by 71 percent and 6 percent, respectively, and the number of forbs increased by 14 percent (Figure 2). Although the forbs increased in the herbicided plots, this increase was not as large as that which occurred in the untreated plots (47 and 42 percent). Low rainfall in 1991, the year of Oust® application, may have resulted in poor herbaceous control.

There was a substantial increase in year 3 of stems browsed by deer and rabbi over year 1 with the majorii of the browsing occurring in the herbicided plots (Figure 3). This increase may be due to the increased ease of movement and spotting preferred species within these plots versus the other two treatments. The species browsed included winged elm (*Ulmus alata*), hawthorn (*Craetagus* spp.), blueberries *(Vaccinium* spp.), honeysuckle, yellow jessamine, and various asters. This supports Thill's (1983) findings that in clearcuts, deer diets were dominated by woody plants. Johnson et.al. (1995) found that for white-tailed deer, clearcuts provided the best nutritional needs of browse and other forages during the growing season.

In 1991, the average height of the planted pine (35 cm) was similar to that of both hardwood stems and forbs (Figure 4). By year 3, the decrease in forb height from an average of 35 cm to 20 cm was due to the fireweed dying out. Planted pine outgrew all other vegetation types in all treatments in year 3.

The average percent ground coverage increased from 1991 to 1993 except for the hardwoods and forbs (81 and 6 percent reduction respectively) in the herbicided plots (Figure 5). There was a substantial increase in the grasses, especially broomsedge *(Andropogon virginicus).* Broomsedge increased in the herbicided plots from 12 to 30 percent coverage, while the non-herbicided plots increased from 12 to 25 percent and the control plots from 11 to 21 percent. Hardwoods and grasses increased in coverage in the non-herbicided plots, but the percent coverage by forbs differed little in the two years (approximately 22 percent).

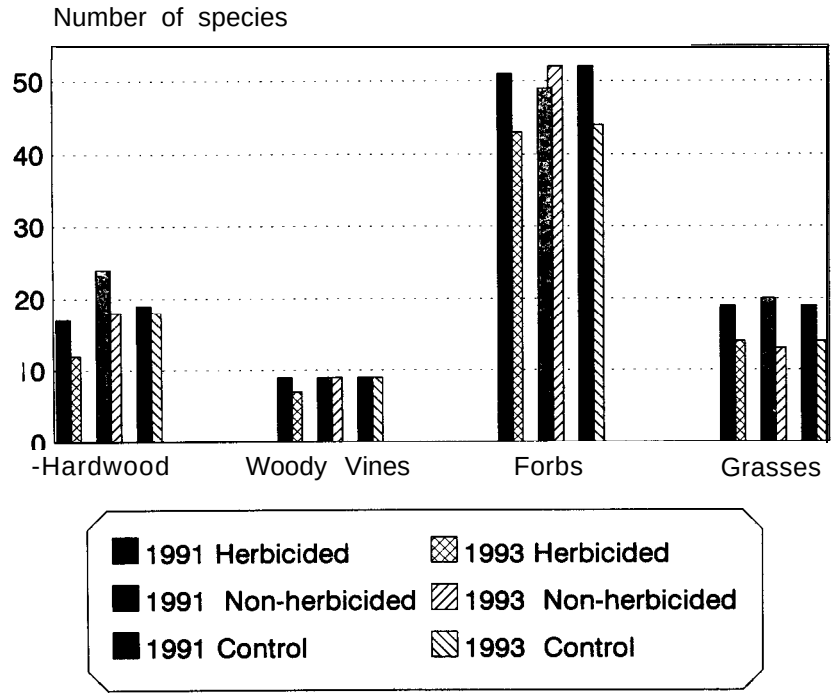

Figure 1- Number of species by vegetative type in herbicided, non-herbicided and control plots.

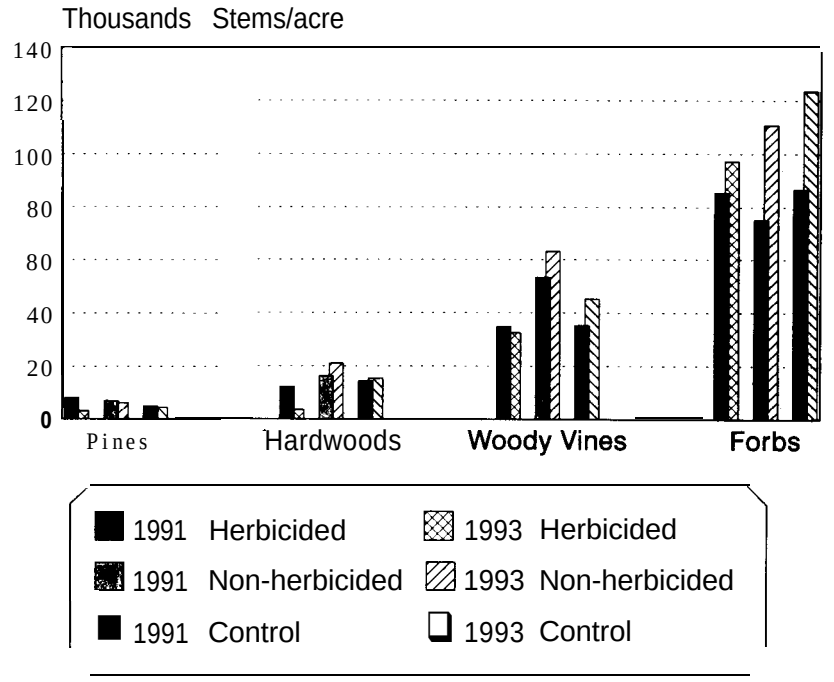

Figure 2– Number os stems per acre by vegetative type in herbicided, non-herbicided and control plots.

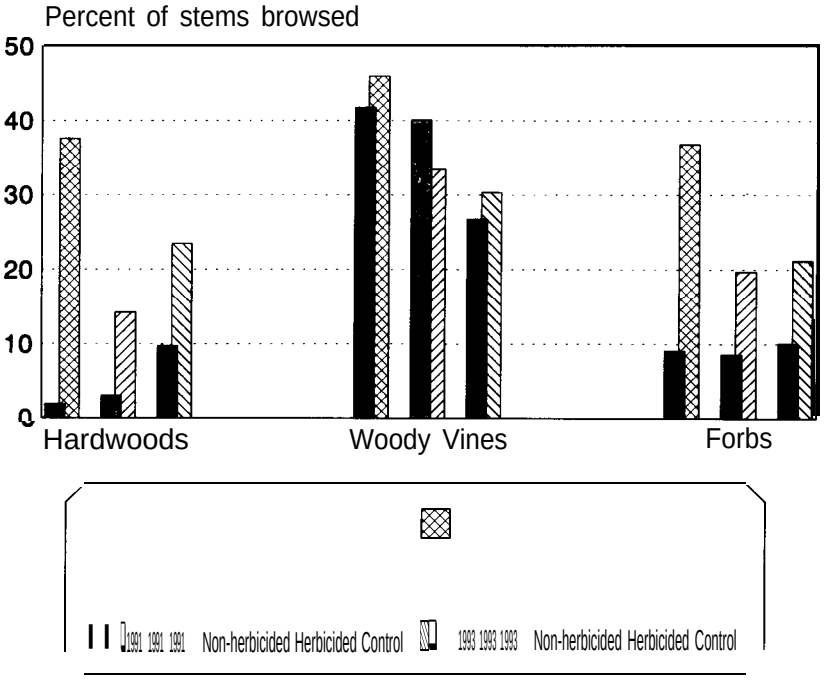

Figure 3– Percent of stems by vegetative type browsed by wildlife in herbicided, non-herbicided and control plots.

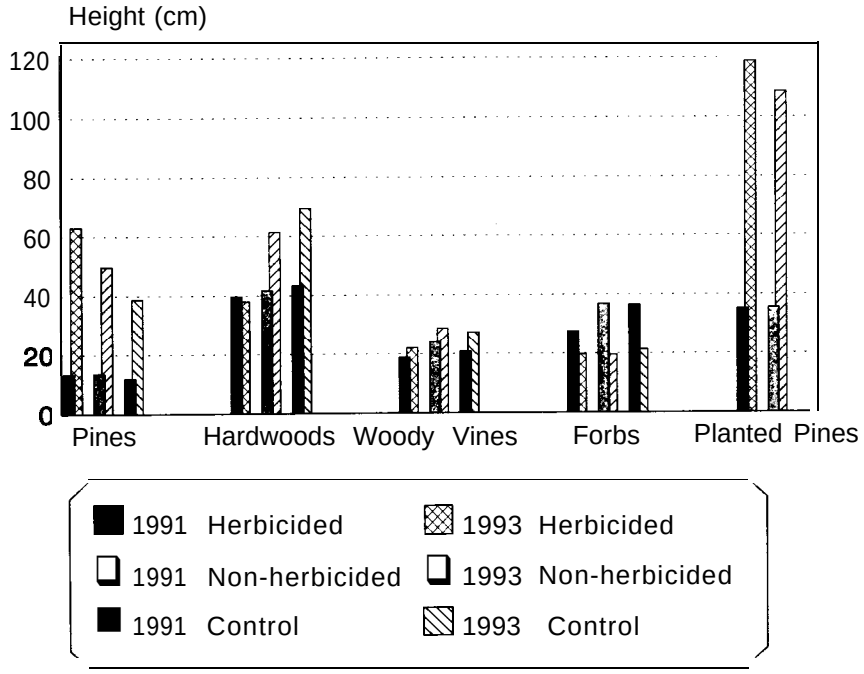

Figure 4-- Height in centimeters of stems by vegetative type in herbicided, non-herbicided and control plots.

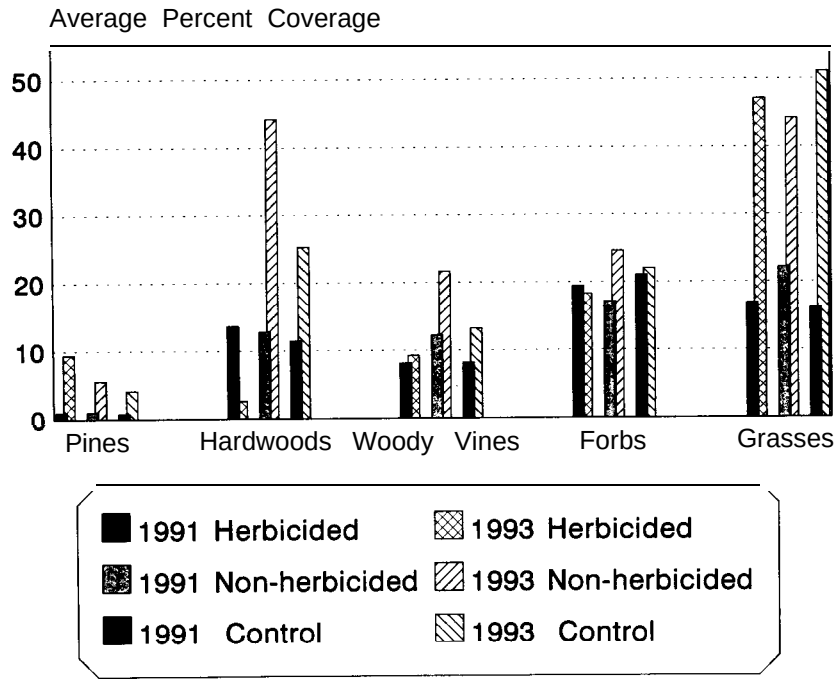

Figure 5-- Average percent coverage by vegetative type in herbicided, non-herbicided and control plots.

SUMMARY AND CONCLUSIONS

Planted pine in the herbicided plots responded to release from hardwoods. However, there was an increase in broomsedge in all plots that may have reduced the growth of the pine. Perry et.al. (1993) found that broomsedge and sweetgum (*Liquidambar stryaciflua* L.) decreased first year pine growth. Priester and Pennington (1978) reported an allelopathic effect of broomsedge on pine seedlings, but Morns et.al. (1993) showed no such effect. Brooks (1992) found a Garlon 4® and Tordon 101® tank mix, as opposed to two other herbicide treatments, resulted in a higher component of broomsedge which may have contributed in lowering the number of forbs on the site. On similiar sites in the Piedmont, broomsedge may increase following hardwood removal, therefore, herbaceous weed control, selective for grasses, may prove advantageous. In high risk areas for tip moth invasion, fusiform resistant loblolly pine seedlings should be planted.

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SEPARATE EFFECTS OF BROADCAST BURNING AND IMAZAPYR TANK MIXTURES ON VEGETATION DEVELOPMENT AFTER CLEARCUTTING'

Timothy B. Harrington, Patrick J. Minogue, Dwight K. Lauer, and Andy W. Ezell[2]

Abstract—On three **upland** sites in **Alabama,** Louisiana, and South Carolina, second-year **vegetation responses** were compared **among** 8 **imazapyr treatments applied** with and without a subsequent **broadcast** bum. In **combination** with herbicides, burning increased grass **(p=0.001)** and shrub **abundance (p=0.003)** and **decreased** blackberry **(p=0.072)** ad tree abundance (p-0.003). Regardless of **burning, blackberry** cover **was less ($p \leq$0.013)** after tank mixtures (5-Q percent) than after **straight-imazapyr** treatments **(16-22** percent). On burned plots, **grass** cover after **straight-imazapyr treatments (45** percent) was **less (p=0.038)** than after tank mixtures (53 percent). Tree and shrub **abundance** differed **little ($p \geq$ 0.0.176)** between **straight-imazapyr** and **tank-mixture** treatments, regardless of **burning.**

INTRODUCTION

Site preparation with combinations of herbicides and broadcast burning have proven to be extremely effective at controlling woody vegetation that competes with planted southern pine (Minogue et al. 1991). **Imazapyr (Arsenal®),** a broad-spectrum herbicide with some soil-residual activity, is used extensively alone and in mixture with other herbicides during site preparation to control a variety of woody and herbaceous species (Minogue et al. 1991). Broadcast burning is used in site preparation to reduce fire hazard, improve planter access, and control competing vegetation (Wade 1985).

Although considerable long-term research has been conducted in the South on vegetation responses to understory burning in pine stands **(Langdon** 1981, Waldrop et al. **1987),** few studies have quantified responses to site preparation resulting from combinations of herbicides and fire. In addition, only a limited understanding exists of changes in the abundance and species composition of plant communities following herbicides **(Zutter** and Zedaker 1988, Wilkins et al. 1993). Furthermore, specifications for imazapyr treatments vary considerably among users, and they are based on a limited amount of published information. Therefore, the objective of this research was to compare vegetation responses among treatments which vary imazapyr rate and mixture with other herbicides, with and without a subsequent broadcast burn.

METHODS

At three upland sites (Selma, AL; Pollock, **LA;** and Newberry, SC), each of 8 herbicide treatments were aerially applied July-August 1991 to strips 60 to 90 m in width (Table I). Herbicides plus 0.17 to 0.5 percent non-ionic surfactant (X-77@) were applied with water at **a** spray volume of 140 l/ha (15 gallons/acre).

In September 1991, half of each of the Selma and **Newberry** sites were broadcast burned. The experiment is a randomized incomplete block with 3 replications (sites) of the 16 treatments (2 burn levels x 8 herbicide treatments) arranged in a split-plot design with burn **level** as the main plot and herbicide treatment **as** the splii plot.

In each treatment replication, 3 (Newberry) or 5 (Selma and Pollock) 0.0%ha circular subplots were located systematically. In August **1993, 2** growing seasons after treatment, rootstock density (#/ha) of each of trees and shrubs was determined. Within each of 4 quadrants per subplot, cover (percent) was estimated visually for each of grasses and blackberry (*Rubus* spp.), and these values were averaged by subplot. The resulting subplot values for density and cover were averaged by treatment replication.

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Table l-List of 8 herbicide treatments used in the comparisons of vegetation response

Herbicide in tank mixture with imazapyr		
Imazapyr (Arsenal® AC) Rate'	Common name (Trade name)	Rate
0.56 (16)	none	
0.56 (16)	glyphosate (Accord@)	2.24 (64)
0.56 (16)	trlclopyr (Garlon® 4)	2.24 (64)
0.56 (16)	pidoram (Tordon® 101 M)	0.91 (192)
0.84 (24)	none	
0.84 (24)	glyphosate (Accord@)	1.12 (32)
0.84 (24)	triclopyr (Garlon® 4)	1.12 (32)
0.84 (24)	picloram (Tordon' 101 M)	0.61 (128)

'Herbicide rates are expressed as kg a.i./ha (oz/acre).

Absence of burning at the Pollock, LA site precluded testing the interaction of burn level x herbicide treatment on vegetation responses. Therefore, the data were separated by burning level, and each set was subjected to analysis of variance with testing of the following orthogonal contrasts (a-0.05):

1. high vs. low imazapyr rate.
2. straight imazapyr vs. tank mixture.
3. glyphosate vs. triclopyr in mixture with imazapyr.
4. mean(glyphosate+triclopyr) vs. picloram in mixture.

To test the effects of burning as additive to those from herbicides, a paired t-test was applied to mean vegetation responses from adjacent burned and unburned strips.

RESULTS

Second-year comparisons of burned vs. unburned plots revealed increases in grass cover (50.0 vs. 38.1 percent, p=O.OOl) and shrub density (4510 vs. 1470 rootstocks/ha, p=0.003), with associated decreases in blackberry cover (7.9 vs. 11.5 percent, p=0.072) and tree density (3250 vs. 5480/ha, p=0.004) (Table 2).

Of the 4 orthogonal contrasts tested, significant ($p \leq 0.05$) vegetation responses were detected only for the comparison of straight-imazapyr vs. tank-mixture treatments (Table 3). For both burned and unburned plots, blackberry cover 2 years after tank-mixture treatments (4.6 and 8.6 percent, respectively) averaged less ($p \leq 0.013$) than values observed after straight-imazapyr treatments (16.3 and 22.2 percent, respectively). On burned plots, straight-imazapyr treatments reduced (p=0.038) grass cover (44.8 percent) relative to that observed from tank-mixtures (52.9 percent). Regardless of burning level, density of each of trees and shrubs differed little ($p \geq 0.339$) between straight-imazapyr and tank-mixture treatments.

Table 2-Paired t-test comparisons of mean vegetation abundance on upland sites in Alabama and South Carolina 2 years after chemical site preparation with and without a subsequent broadcast burn

Variable	Burned	Unburned	SD'	p^b
Grass cover (pct)	50.0	38.1	0.9	0.001
Blackberry cover (pct)	7.9	11.5	6.9	0.072
Shrub density (x 100/ha)	45.1	14.7	31.6	0.003
Tree density (x 100/ha)	32.5	54.8	23.5	0.004

'Standard deviation of the difference between means.
[b]Significance level of the paired t-test (n=14).

DISCUSSION AND CONCLUSIONS

Second-year results indicate that burning decreased the abundance of blackberries and trees, while it increased the abundance of grasses and shrubs. Similar results were observed 1 year after treatment, except that grass cover was decreased and exposure of mineral soil was increased by burning (Minogue et al. 1994). Perhaps in the second year grass was able to occupy the new growing space made available by the fire. Langdon (1981) reported a lo-percent reduction in density of sweetgum (*Liquidambar styraciflua* L.) and blackgum (Nyssa *sylvatica* Marsh.) following a single summer burn in a pine understory. He found that summer burns must be repeated annually for 10 years in order to reduce hardwood density by 80 percent or more.

Regardless of burning level, tank mixtures were more effective than straight-imazapyr treatments at reducing blackberry cover. Although imazapyr is a broad-spectrum herbicide, certain genera of plants (e.g., *Aesculus*, *Rubus*, and *Ulmus*), are known to tolerate it (Minogue et al. 1991). Reduced abundance of imazapyr-susceptible species may release and promote the development of imazapyr-tolerant species. Such release responses may explain the observed differences in blackberry cover between straight-imazapyr and tank-mixture treatments.

On burned plots, grass cover was less after straight-imazapyr than after tank-mixture treatments. In this treatment, greater exposure of mineral soil from burning may have enhanced the soil-residual activity of imazapyr on grass species.

Second-year results suggest that imazapyr treatments will vary in their abilii to control competing vegetation, depending on the growth form of target vegetation and whether the treatment is followed by a broadcast burn. Although these findings may imply specific treatment recommendations, we feel additional research is needed to confirm the vegetation responses observed following the herbicide and fire combinations.

Table 3--Orthogonal contrasts of mean vegetation abundance on upland sites in Alabama, Louisiana, and South Carolina 2 years after chemical site preparation with straight-imazapyr or imazapyr tank-mixture treatments with and without a subsequent broadcast burn

	Burned				Unburned			
Variable	Straight imazapyr	Tank mixture	*RMSE*	*p*[b]	Straight imazapyr	Tank mixture	*RMSE*	*P*
Grass cover (pct)	44.8	52.9	5.1	0.038	41.0	40.4	10.2	0.913
Blackberry cover (pct)	16.3	4.6	31.9	0.013	22.2	8.6	7.8	0.004
Shrub density (x 100/ha)	36.9	50.2	[illegible]	0.519	24.7	30.4	11.7	0.339
Tree density (x 100/ha)	42.4	29.4	13.7	0.176	42.8	41.4	12.5	0.819

'Root mean-squared error from the analysis of variance.
[b]Significance level of the F-test for the orthogonal contrast.

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PINE AND COMPETING VEGETATION RESPONSE TO HERBACEOUS WEED CONTROL AND LEVELS OF SHRUB CONTROL IN THE FLATWOODS'

Dwight K. Lauer and Glenn R. Glover[2]

Abstract-Largest responses to operational-like vegetation control in stash pine (*Pinus elliottii* Englem. var *elliottii*) after five growing seasons were due to shrub control. There were no differences due to duration of shrub control (first year vs annual), and no differences in pins response due to first year herbaceous weed control when combined with shrub control. Age 5 pine dbh and height averaged 3.0 inches and 17.7 feet, respectively, for shrub control treatments. Thii response is close to that observed for mere intensive vegetation control treatments in ether studier.

Shrub volume increase between years 2 and 5 was three times faster for no shrub control than for first year shrub control. Competing vegetation can get progressively worse as the stand ages if managers do not control shrubs at time of stand establishment.

INTRODUCTION

Members of the Auburn University Silvicultural Herbicide Cooperative installed this flatwoods site preparation study in 1988. The objective was to quantify pine response to control of non-arborescent woody (shrub) and herbaceous vegetation, the two major life-forms of competing vegetation in the flatwoods region. The major shrubs present at this location were gallberry, *Ilex glabra* (L.) A. Gray., waxmyrtle, *Myrica cerifera* L., palmetto, *Serenoa repens* (Barb.) Small., greenbrier, *Smilax* spp., ti-ti, *Cyrilla racemiflora* L., lyonia, *Lyonia* spp., blueberry, *Vaccinium* spp., and huckleberry, Gaylussacia spp. The major herbaceous vegetation species were bluestems *(Andropogon* spp.), panic grasses, *Panicum* spp., and brackenfern, *Pteridium aquilinum* (L.) Kuhn.

There are major differences in control methods for these two life-forms. Shrubs are perennial and once controlled may be slow to recolonize. However, shrubs are sometimes difficult to control and there is often resprouting after one application of herbicide. Mechanical site-prep methods do not typically provide long-term control of shrub species, particularly gallberry (Shub and Wilhite 1974). Herbaceous vegetation may be easier to control than shrubs, but can recolonize a site rapidly since many species rely on wind blown seed or seed that can germinate at diierent times during the growing season. For this reason, annual application of moderately persistent herbicides are often required to maintain reasonable control of herbaceous vegetation through each growing season.

In general, herbicides that control shrubs are not selective. They must be applied before pines are planted, applied in a directed spray once pines are planted, or applied in the understory of pine stands past the sapling stage to limit foliar uptake by the crop species. The operational feasibility of these methods diem. Directed applications are usually cost prohibitive. Understory applications in older stands may be efficacious, reduce the shrub component in the following rotation, and be a remedial treatment in existing stands, but the early growth gains due to control at time of stand establishment are lost.

Herbaceous weed control herbicides are usually applied over the top of pines in early spring because pm-emergent, early post-emergent chemistry is used to achieve selectivii. Herbaceous weed control is often done in the spring of the first growing season since it has been shown to provide the most gain in survival and growth when trees are small (Lauer, Glover, and Gjerstad 1993). Also, selective herbicides are more cost effective on weeds that have not had a chance to become established. The level of herbaceous vegetation present during the first growing season can be reduced by pre-plant applications of herbicide, but this reduction is variable and poorly understood.

There is a large potential response to total control of competing vegetation early in the rotation in this region (Swindel et al. 1988, Shiver et al. 1990). Competing vegetation can also reduce growth by 0.2 to 0.5 cds/ac/yr when present at mid-rotation (Oppenheimer, Shiver, and Rheney 1989). This implies that

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recolonization of vegetation may limit tong term growth potential.

This study considers these operational constraints by comparing slash pine response to levels of control of two vegetative life-forms under likely operational scenarios. Three levels of non-arborescent woody vegetation (shrub) control, consisting of no control, first year control only, and annual control for the first three yearn, are compared with and without first year herbaceous weed control.

METHODS

A recently harvested slash pine plantation was selected in Taylor Co., Florida, for study installation. The site had some residual pine and a gallberry root mass after harvest. Site-preparation consisted of chop, burn, spot rake, and bed before the end of April, 1988. Slash pine was planted on a 5'x 10' spacing during the 1988-89 planting season.

Vegetation control was done with applications of triclopyr, glyphosate, and sulfometuron. The annual and first year shrub control treatments received an initial application of 5 lb ae/ac triclopyr in water for a total spray volume of 28 gal/ac as a pm-plant broadcast application on October 11, 1988. A follow-up directed application of glyphosate was made in the spring of the first year to further reduce the level of tolerant shrubs. Dormant season basal sprays of triclopyr and diesel and foliar sprays of triclopyr + glyphosate were used for the next two seasons on the annual shrub control treatments. First year herbaceous weed control (HWC) was a broadcast application of 3 oz ai/ac sulfometuron applied in early spring followed by directed applications of glyphosate in June.

Competing vegetation was evaluated on 10 randomly located competition measurement plots (CMP) within each pine measurement plot (PMP) in August or September of the first and second growing seasons. CMPs were 6 feet in length along the direction of the bed. CMP widths (approx. 10 ft) coincided with the actual distance between beds. Overall CMP and bed widths were recorded to the nearest 0.1 ft. Average crown height of each major shrub species on a CMP was estimated to the nearest 0.1 ft. Shrub cover and herbaceous cover were ocularly estimated (Gnegy 1991) using cover classes (to the nearest 1 % for covem less than 1% and greater than 99%, nearest 5% for covers of 1% to 5% and 96% to 99%, and nearest 10% for covem between 6 and 95%) for major species *groups* separately for the bed and inter-bed portions of the CMP. Percent cover was estimated for the three most dominant species groups of shrubs and two most dominant species groups of herbaceous vegetation on a CMP. Cover was estimated for additional species if they had 5% or more cover. If cover was estimated for a species group on one portion of the CMP, then cover was estimated on the other as well, even if it was zero.

Total bare ground, excluding cover due to crop pines, was also estimated. At the end of the second growing season, vegetation cover calls were made for major vegetative groupings of total non-arborescent, herbaceous, grasses, sedges, broadleaf, and bare ground in addition to estimates for species groups. This same technique was used in December at the end of the fifth growing season. The December evaluation was done due to logistical considerations and may underestimate species that are dormant during the winter. Nonetheless, estimates of the shrub component and dormant bluestem component appeared to be reasonable. Estimates of panic grasses, greenbrier, oaks (*Quercus* spp.), and broadleaf herbs are probably under-estimated due to reduced leaf area at this time of year but these species were minor components.

Percent cover and a volume index were calculated using weighted averages because each CMP varied in size. Percent cover was computed as percent cover x CMP area summed across all ten CMPs in a PMP and then divided by the total area of all ten CMPs. The weighted volume index was computed for each shrub species as the sum of volume index for a shrub species on the sampled area divided by the acreage sampled. A volume index for each species on each CMP was computed as: (percent cover/100) x CMP area in sq ft x mean height of shrub species in feet.

Pine height and diameter were measured to the nearest 0.5 ft and 0.1 inch, respectively, for each pine on the PMP. Disease, insect, and other damage was assessed for each pine. Disease assessments included fusiform rust evaluations. Lower stem sweep and lean were also evaluated for each tree. Total volume outside bark was calculated using a volume equation developed for slash pine (Brister et al. 1980).

Analysis of variance was performed for both pine and vegetation attributes. Specific preplanned comparisons were performed as follows:

1. Shrub control vs none: Comparison of treatments with shrub control (both annual and first year) to those without shrub control.
2. Shrub control duration: Comparison of annual shrub control to first year shrub control.
3. HWC vs no HWC: Comparison of treatments that received first year HWC to those that did not.
4. Overall interaction: Interaction of HWC treatments with shrub control treatments. This overall interaction was partitioned into the HWC x shrub control and HWC x duration interactions.
5. HWC x shrub control: Interaction of HWC with shrub vs no shrub control treatments.
6. HWC x duration: Interaction of HWC with shrub control duration.

Significant interaction indicates that main effects of HWC and shrub control are not additive and comparison of individual treatments is required. Comparisons were made using Tukey-type confidence intervals (Miller, 1981) which controls the maximum experimentwise error rate (0.05 used here).

RESULTS

Pine

Control of shrubs, either first year or annual control, significantly increased age 5 pine basal area per acre, volume per acre, number of trees per acre with fusiform rust on the stem, and number of trees per acre with any symptom of fusiform rust. Surviving trees/acre was not affected by treatment Number of trees with lower stem sweep was lower for shrub control treatments, but incidence of stem sweep was low over all treatments with a maximum of 5 trees/acre occurring for the HWC only treatment. Response due to annual shrub control did not diier from response due to first year shrub control for any of these attributes. There was no difference due to HWC and no significant interaction between HWC and shrub control for any of these attributes (Table 1).

Major responses at this location were due to shrub control. Basal area averaged 31 and 15 ft^2/ac and volume averaged 332 and 132 ft^3/ac for the four shrub control treatments and two no shrub control treatments, respectively. Treatments that increase growth usually increase the incidence of fusiform rust This study was no exception in that there were twice the number of trees/acre with stem rust for the shrub control treatments compared to no shrub control (17% vs 9%).

Average pine dbh and height were increased by HWC alone and shrub control alone. However, HWC did not provide additional response when combined with shrub control. The significant HWC x shrub control interactions for age 5 pine DBH (p=0.0137) and pine height (p=0.0179) indicate that responses due to shrub control and herbaceous weed control are not additive. Tukey-type confidence intervals were used to compare dbh and height treatment means in Figure 1. Means followed by the same letter are not significantly different from each other at the 0.05 level of probability. HWC alone increased average age 5 dbh from 1.6 to 2.3 inches. Shrub control, with or without HWC, increased average dbh to 3.0 inches (Figure 1). Age 5 height response followed a similar pattern with average heights of 11, 14, and 18 ft for the check, HWC only, and shrub control with or without HWC treatments, respectively (Figure 1).

Vegetation

Vegetation control treatments did not involve complete vegetation control. Therefore, vegetation assessments were conducted so the actual level of control and levels of residual vegetation could be characterized. The objective of these measurements was to evaluate treatment efficacy and characterize vegetation. There are major limitations in the resolution of measurements based on ocular estimates due to observer bias. However, treatment efficacy, comparison of relative overall vegetation levels among treatments, and

Table l-Summary of treatment means and statistical comparisons for per acre pine attributes

Treatment	Density	Fuslform on tree	Fusiform on stem	Lower stem sweep	Basal area	Volume
	(trees/acre)				(ft^2/ac)	(ft^3/ac)
1. No SC', no HWC[b]	635	52	32	3	10.7	83
2. HWC	592	96	73	5	19.1	181
3. First year SC	566	123	97	2	28.4	303
4. First year SC + HWC	577	163	128	0	29.8	321
5. Annual SC	671	111	81	0	33.2	355
6. Annual SC + HWC	577	109	89	0	31.9	348
Statistical Comparisons	(Probability of a greater F-value)					
SC vs no SC	0.716	0.003	0.007	0.031	<0.001	<0.001
SC duration	0.324	0.076	0.128	0.668	0.278	0.297
HWC vs no HWC	0.326	0.072	0.073	0.964	0.274	0.243
HWC x SC interaction	0.602	0.371	0.603	0.656	0.285	0.353
HWC x (SC vs no SC)	0.979	0.424	0.458	0.424	0.133	0.167
HWC x SC duration	0.322	0.248	0.505	0.668	0.658	0.736

[a] SC=shrub control. [b] HWC=herbaceous weed control.

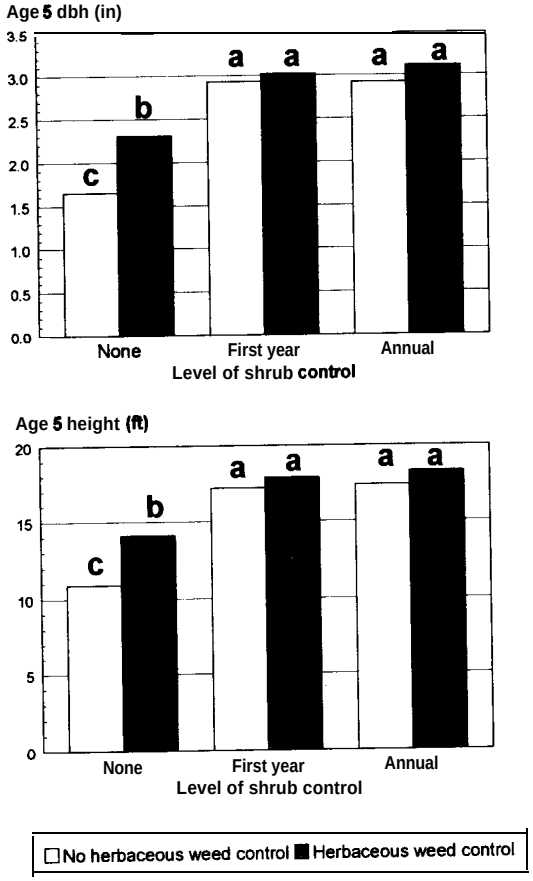

Figure I-Comparison of age 5 pine dbh and height by treatment. Treatments followed by the same letter are not significantly different from each other using Tukey's studentized range test.

identification of major species at a location are possible.

General implications on stand management and treatment efficacy are made from these assessments. No attempt is made to examine diversity or detailed successional pathways.

Age 2 herbaceous cover, shrub cover, and shrub volume all diiered due to shrub control, and shrub cover diiered due to duration of shrub control (Table 2). Age 2 herbaceous cover differed only between the no shrub control and shrub control treatments with 35% and 57% cover, respectively. Shrub cover diiered among all shrub control levels at age 2 with 43%, 20%, and 13% shrub cover for no shrub control, first year shrub control, and annual shrub control, respective& Shrub volume differed only due to shrub control with shrub volumes averaging 43 and 5 thousand ft^3/ac for no shrub control and shrub control treatments, respectively.

Age 5 herbaceous cover, shrub cover, and shrub volume all differed due to shrub control (Table 2). Herbaceous cover also differed due to first year HWC. Age 5 herbaceous cover increased from 27% to 67% due to shrub control, but also increased from 49% to 58% due to first year HWC. Age 5 shrub cover and shrub volume decreased with increasing level of shrub control. Shrub cover averaged 63%, 23%, and 12%, and shrub volume averaged 112, 30, and 14 thousand ft^3/ac for the no shrub control, first year shrub control, and annual shrub control treatments, respectively.

DISCUSSION

This study presents the best and worse of situations for pine growth. The check treatment is a worst-case scenario in that the site was prepared early in the year and shrubs allowed to recolonize over an entire growing season. Pine response to a late bedding treatment may have fared better. Antithetically, shrub control treatments present the best of situations. Average age 5 height and dbh for shrub control treatments were 17.7 ft and 3.0 inches, respectively. By comparison, average age 5 height for spodosols for a site-prep treatment of chop, burn, bed, and complete vegetation control was 16.5 ft (Shiver, Rheney, and Oppenheimer 1990). A study in north Florida that included a treatment of total vegetation control had a slash pine response of 13.8 ft in height and 3.0 inches dbh at age 4 (Colbert, Jokela, and Neary 1990). Although there is no complete vegetation control treatment in this study, age five pine response is close to what has been achieved by total and intensive vegetation control treatments in these other studies.

There are several interesting trends in vegetation development. First, percent cover was comparable for shrub control treatments between ages 2 and 5 with 20-25% cover for first year shrub control, and 12-I 3% cover for annual shrub control. However, shrub volume index increased between age 2 and 5 for these treatments. This suggests that site occupancy (cover) has not changed but height has continued to increase. Thii was not the case for the no shrub control treatments which had increases in both percent cover and shrub volume index. This relatively large increase in shrub volume index will likely impact future pine growth.

The difference in shrub volume index at age 5 between first year and annual shrub control treatments suggests that future pine growth may start diverging for these treatments. However, the magnitude of this difference is small compared to the amount of vegetation on the no shrub control treatments, and may take a number of years to detect.

Table 2-Summary of treatment means and statistical comparisons for vegetation attributes

	Herbaceous		Shrubs		Shrub Volume	
	Age 2	Age 5	Age 2	Age 5	Age 2	Age 5
Treatment	(percent cover)				(thousands ft³/ac)	
1. No SC', no HWC[b]	38	22	44	66	46	107
2. HWC	33	32	43	60	41	117
3. year	58	59	20	25	5	32
4. First year SC + HWC	52	68	21	22	7	29
5. Annual SC	60	67	13	13	5	14
6. Annual SC + HWC	57	75	13	12	4	14
Statistical Comparisons	(Probability of a greater F-value)					
SC vs no SC	<0.001	<0.001	<0.001	<0.001	<0.001	~0.001
SC duration	0.272	0.098	0.012	0.004	0.668	0.021
HWC vs no HWC	0.113	0.019	0.927	0.285	0.490	0.699
HWC x SC interaction	0.888	0.979	0.951	0.759	0.638	0.611
HWC x (SC vs no SC)	0.899	0.853	0.846	0.539	0.411	0.344
HWC x SC duration	0.643	0.932	0.808	0.689	0.653	0.804

[a] SC=shrub control. [b] HWC=herbaceous weed control.

Managers should be aware that lack of shrub control favored slow pine growth and allowed shrubs to increase in volume through early stand development. This increased level of shrub competition may continue to reduce future growth below that observed for shrub control treatmenta.

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Pest Management/Natural Disturbance

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ANIPEL FAILS TO REPEL RODENTS FROM DIRECT SEEDED LONGLEAF PINE SEEDS'

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Abstract—Direct seeding success requires that the seeds be coated with thiram to repel birds and endrin to repel rodents. Endrin, whkh is extremely toxk, is no longer produced in the United States, so a substitute is needed. Anipel", was used as a candiie, but tests of several formulations indicate that it has little potential as a rodent repellent. The laboratory and field tests are well suited for evaluating other chemicals.

INTRODUCTION

Direct seeding of southern pines is a versatile low-cost alternative to planting on many sites needing reforestation across the South. It is also an appropriate technique to use to supplement natural regeneration in cases where seedfall is inadequate to establish a new stand in a timely manner. Techniques were thoroughly researched during the 1950s and 1960s by Derr and Mann (1971) and the 1970s by Campbell (1981b, 1981 c). Scores of studies show that success depends on protection of seeds from birds and rodents (Derr and Mann 1971; Campbell 1981b, 1981c). The recommended formulation of thiram and endrin gives a high degree of protection against all important species of seed-eating birds and deters small mammals common to most southern pine sites (Campbell 1981a).

Thiram, a fungicide currently marketed as Gustafson 42-S®, is safe, effective, and easy to use. Anthraquinone is almost as effective as thiram, but is more diicult to use since it is in a powder formulation. However, it is a good alternative bird repellent.

Endrin, an insecticide, is very toxic. Although still registered for rodent repellency in forestry due to the small quantities used (Bamett and others 1980), endrin is no longer being manufactured in the United States. Thus, continued use of direct seeding is southern forestry may depend on finding a satisfactory substitute for endrin.

In a series of tests, Campbell (1981a) could not find a replacement, Recently, however, the chemical Anipel® showed promise as an animal repellent when sprayed on foliage. Derived from natural plant sources, Anipel is nontoxic. Its repellency is attributed primarily to its extreme bitterness. In thii paper, I describe evaluations of Anipel as a rodent repellent for direct seeding. Although thii chemical was not effective, I believe the testing procedures will suffice for the continued search for a rodent repellent

METHODS

Candidate chemicals must meet two key criteria: (1) they must be relatively benign to the seeds themselves, and (2) they must repel the target animals. The first tests described, therefore, measure effects of various formulations of Anipel on germination of longleaf pine (*Pinus palustris* Mill.) seeds.

Longleaf seeds were chosen for the evaluations because they are the most sensitive of the southern pines to such treatments. Germination was tested under standard laboratory conditions for 28 days (Association of Official Seed Analysts 1980) and was recorded three times weekly during periods of peak germination. Three replications of 100-seed samples from each of three seed sources were tested. The seed treatments included an untreated control, various dilutions of Anipel with water, various dilutions of Anipel with thiram, and an Anipel-clay mixture that might improve binding of larger amounts of the chemical to the seeds. The Anipel formulation contains latex, so no additional latex was added for a sticker. The treatments and resulting germination from these preliminary tests follow in table 1.

These tests indicated that Anipel alone or incorporated with clay has no adverse effect on germination of longleaf pine seeds. Thiram or thiram in combination with Anipel reduced germination. We have long known that thiram reduced germination in the laboratory, but the reduction in these tests was more than we have experienced in the past Based on these results, further evaluations of Anipel were initiated.

Longleaf pine seeds from a single South Carolina lot of seed-orchard origin were selected for additional

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Table 1 .-Effects of Anipel and thiram on the germination of longleaf pine seeds

Treatment	Seedlot 1	Seedlot 2	Seedlot 3	Average
	percent			
Control	52	80	71	68
Anipel	50	75	69	65
Anipelhvater 1:1	44	80	72	65
Anipelhvater 1:2	47	78	71	65
Anipel/water 1:3	47	86	73	69
Anipel/thiram 1:1	44	33	47	41
Anipel/thiram 1:2	35	33	27	32
Anipel/thiram 1:3	38	29	28	32
Thiram	48	47	29	41
25% Anipel + clay	45	58	59	54
Anipel + clay	62	75	76	71

evaluation. Empty seeds were removed from the lot by pentane flotation (Barnett 1971). Random samples were drawn for treatments. Repellent treatments were applied, and seeds were air-dried overnight. Viabilii after treatment was determined in the Alexandria Forestry Center Seed Testing Laboratory by testing six replications of 100-seed samples.

Prior to field tests, it would be logical to evaluate candidate rodent repellents in caged animal tests. However, the Alexandria Forestry Center no longer has the facilities to conduct such tests, and field tests are needed in any case. We therefore skipped the intermediate step and moved directly to field tests of the effectiveness of the chemical. Two types of tests were installed on the Palustris Experimental Forest in central Louisiana.

Test 1 evaluated four seed treatments: (1) an untreated control, (2) Anipel (90 mL/pound of seeds), (3) Anipel plus clay (90 mL Anipel and 45 g clay per pound), and (4) Anipel with thiram (45 mL each per pound). Test 2 evaluated three treatments: (1) an untreated control, (2) thiram (90 ml/pound), and (3) thiram with Anipel(45 mL each per pound). Treatment plots consisted of four, 18-inch circular spots (each sown with 100 seeds) arranged around a central stake. Each of the plots was randomly selected for a particular treatment and marked with a flagging pin. Thirty replications, separated by a least 50 feet, were established on a previously bush-hogged site. Plots were arranged in a randomized block design. Seed germination and loss were observed weekly for 6 weeks after sowing on February 17, 1993, and on March 3, 1993.

Since the plot size in this study was small and subject to overwhelming predation, we purposely evaluated the plots frequently to determine germination and predation patterns for the four treatments. If repellency was indicated, larger operational-scale studies were planned. Germination was to be determined by locating, marking, and counting new germinants on a weekly basis. Seedling losses were measured by counting the number of seedlings remaining on each plot on a weekly basis. Losses due to predation of germinated seeds, e.g., due to clipping by rabbits, were deducted from seed losses.

RESULTS AND DISCUSSION

The laboratory germination data on the test seed lot confirmed the preliminary evaluations on the effect of Anipel on seed performance. Coating with Anipel had no effect on seed germination, but the combination of Anipel and thiram markedly reduced germination (Table 2). Campbell (1981a) also found that thiram alone reduces laboratory germination, but he reported less impact on germination in the field.

Table 2.-Laboratory germination of the longleaf pine seedlot used in field tests

Replicate	Control	Anipel	Anipel +clay	Anipel + thiram
	percent			
1	68	58	62	34
2	68	64	70	40
3	58	68	56	40
4	46	58	70	36
5	48	58	44	38
6	66	66	68	36
Average	59	62	62	37

Results from the field evaluations indicated that the seeds were subjected to heavy predation. One week after sowing, essentially all seeds in test 1 from the control, Anipel, and Anipel/clay treatments were missing from the plots (Table 3). Forty-six percent of the seeds that were treated with thiram and Anipel remained after 7 days. However, at 14 days after sowing, no seeds remained on any of the treatments. We had expected heavy seed losses due to the small plot size, but not to the severe extent that was experienced. This test showed that thiram was offering considerable protection, but it seemed that Anipel-treated seeds performed no better than controls. There was no thiram alone treatment in test 1, so there was no opportunity to determine if there was any synergistic benefit from the combination of thiram and Anipel. Test 2 was installed to evaluate this relationship.

Test 2 data confirmed those from test 1: predation was great and no control seeds remained 7 days after sowing (Table 3). The repellency of thiram was also demonstrated again in that 53 percent of seeds remained at 7 days. Seeds from the thiram/Anipel

Table 3.-Percentages of seeds remaining and undamaged on each plot 7 and 14 days after sowing. Tests 1 and 2 were seeded 2/17/93 and 3/3/93, respectively

Test 1			Test 2		
Treatment	Germ. at 7 days and 14 days		Treatment	Germ. at 7 days and 14 days	
	percent			percent	
Control	2.7	0.0	Control	8.4	0.0
Anipel	0.2	0.0	Thiram	52.8	0.0
Anipel/clay	0.4	0.0	Thiram/Anipel	10.7	0.0
Thiram/Anipel	4 5 . 5	0.0			

combination were subjected to greater losses than those in the thiram alone treatment. Presumably, the cause was the lower concentration of thiram in the combination treatment This result further indicates that Anipel has little potential as a repellent on southern pine seeds.

It is difficult to state with any certainity whether birds or rodents were the primary predators in this study. Seedcoat fragments that remained on plots suggested that both birds and rodents were feeding on the longleaf seeds.

The heavy predation on our small plots shows that field plots alone can be used to evaluate potential repellents. This result is important because few organizations have the capability to conduct caged animal tests with field-collected rodents.

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RELATION OF MECHANICAL SITE PREPARATION TO OAK ABUNDANCE, PINE GROWTH, AND FUSIFORM RUST INCIDENCE IN A SLASH PINE PLANTATION'

Roger P. Belanger, Thomas Miller, Robert A. Schmidt, and James E. Allen[2]

Abstract-Water, laurel and bluejack oak are the most prevalent oak species in the Atlantic Coastal Plain, and are recognized as being important alternate hosts in the spread of fusiform rust. This study determined the origin, abundance, and development of oaks associated with four mechanical site preparation treatments: (1) Chop, (2) Chop + Disk, (3) KG, and (4) KG + Disk. First-year measurements showed that KG + Disk was the most effective treatment, reducing the number of oak rootstocks by 79 percent and the projected crown area by 92 percent. Chopping was the least effective treatment with a 25 percent reductii in rootstock and a 74 percent reduction in projected crown area. From the first through the fourth growing season, the number of rootstocks per acre did not change significantly within treatments. However, the projected crown ares of susceptible oaks increased greatly over time. The crown area increased 19,105 and 111 percent in the second, third and fourth years across all treatments. During the fourth year, hardwoods were competing with pines and oaks were a potential source of abundant rust inoculum in all treatment plots. Total height and rust incidence on planted slash pine were measured after the third, fourth, and fifth growing seasons. Results indiite that in high-rust hazard areas, rust incidence appears more closely related to the height growth of pines than to the abundance of on-site oaks.

INTRODUCTION

Surveys indicate that water oak (*Quercus nigra* L.), laurel oak (Q. *laurifolia* Michx.), and bluejack oak (Q. *incana* Bartr.) are common and widely distributed oak species in the Atlantic Coastal Plain of Florida and Georgia (Schmidt et *a/. 1990).* These oaks are ranked (Dwinell 1974) as moderately to highly susceptible to infection as alternate hosts to fusiform rust, caused by *Cronartium quercuum* (Bartr.) Miyabe ex Shirai f. sp. *fusiforme.* Where abundant, these oaks can contribute significantly to the distribution and abundance of rust in slash and loblolly pine plantations (Squillace et a/. 1978). In general, these oak species are most abundant on moderately well to well drained soil groups and least abundant on poorly drained soil groups (Schmidt *et* a/. 1990). Research has also shown rust incidence is higher on well drained soil groups than on poorly drained groups (Schmidt *et* a/. 1988, 1990). Soil classification systems can be used to determine the relative risk of rust incidence on a regional or county basis. However, the significant variation that exists in rust incidence and oak abundance within and among soil groups reduces the ability to accurately predict rust hazard for individual plantations (Schmidt et *al.* 1990).

Previous land use, method and intensity of site preparation and cultural treatments can influence oak abundance, pine growth and fusiform rust incidence on a site. Yet little research has been done to quantify rust incidence in relation to oak abundance and pine growth at the stand level. The objectives of this research were: (1) to determine the origin, abundance and development of oaks following four methods of mechanical site preparation, and (2) to examine relations between on-site oaks, pine growth, and rust incidence.

STUDY SITE AND METHODS

The study site, estimated at 240 acres, is located in Lowndes County (south-central) Georgia. Soils were grouped as moderately to well drained, contained large numbers of host oaks, and were classified as high risk for fusiform rust. Most mature plantations in the area contained trees with abundant stem and branch galls. Historically, the study site was first harvested, mechanically site prepared, and planted with slash pine (*Pinus elliottii* Engelm. var. *elliotti*) in 1967. High rust incidence was a management consideration in deciding to clearcut the plantation in the spring of 1988.

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In November 1988, a split plot design was installed to accommodate four methods and intensities of mechanical site preparation.

Method	Intensity
Chop - no Diik	Low
Chop + Disk	Low - moderate
KG - no Diik	Moderate - high
KG + Diik	High

The Chop or KG combination was randomly applied to the whole plots; the Diik or no Disk combination was randomly applied to subplots within each whole plot The four treatments were replicated three times. Average size of the treatment subplots was approximately 20 acres. Thirty-five 1/1 OO-acre circular sample plots were systematically located within each subplot. Each sample plot was permanently marked to insure reliable comparisons based on annual measurements over the 5-year study period.

Information and measurements recorded for oaks prior to and after site preparation were species, number of rootstocks, and the average crown diameter of individual seedlings or sprout clumps within each sample plot Average crown diameter was used to calculate projected crown area per plot Oak development was based on annual surveys for 4 years following treatment.

Site preparation treatments were applied in October - November 1988. A tractor-drawn 1 l-ton chopper was used for tha chop treatments; a 1 -ton disk harrow was used for the disk treatments. The study area was hand-planted with slash pine seedlings in December 1 988. Seed was from a managed seed production area located about 2 miles from the study site. The inherent degree of rust resistance for the seedlings is not known.

Total tree height and the occurrence of stem or branch galls were recorded for all pine seedlings on each sample plot following the third, fourth and fifth growing seasons. ANOVA (SAS Institute, Inc. 1988) was used to determine the degree of statistical differences among site preparation treatments.

RESULTS

Prior to treatment, the study area contained an average of 380 oak rootstocks per acre. Equating this to rust hazard, regional surveys showed an average of about 250 oaks per acre on high risk sites compared to 40 oaks per acre on low risk sites (Schmidt et a/. 1990). Average crown area projected by these oaks was 4610 ft^2 per acre. Oaks were well distributed throughout the study area with over 55 percent of the sample plots stocked with oak species within each of the three replications. Water, laurel, and bluejack oak represented 82 percent of the initial oak sample population.

First-year measurements showed that the KG + Disk combination was the most effective treatment, reducing the number of oak rootstocks by 79 percent (Figure 1). Chopping alone was the least effective treatment with a 25 percent reduction in the number of rootstocks.

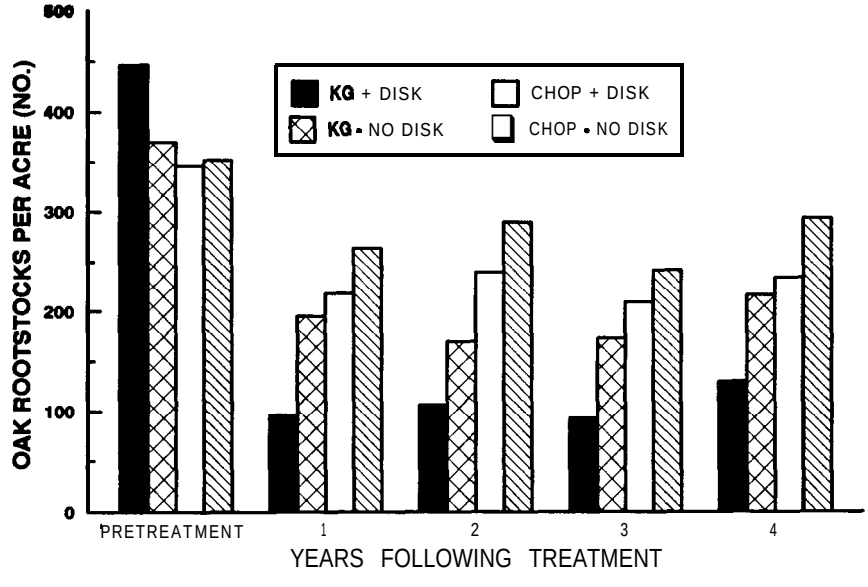

Figure l-Number of oak rootstocks following four mechanical site preparation treatments in a high fuaiform rust hazard area

None of the treatments promoted a significant proliferation in the average number or distribution of oaks. Fourth-year measurements showed that the KG + Disk plots still had the fewest oaks (130 rootstocks per acre) and the Chopped plots had the most (294 rootstock8 per acre).

Post-treatment surveys conducted at age 3 years indicated that 90 percent of the oaks originated from stump sprouts. The remaining 10 percent originated from acorns, root sprouts, and stem (epicormic) sprouts.

More telling in terms of competition and potential for inoculum production, was the projected crown area. Again, first-year measurements showed that the KG + Disk combination was the most effective treatment, reducing the projected crown area of oaks by 92 percent (Figure 2). Chopping alone was least effective, but still reduced the projected crown area by 74 percent.

The projected crown area of susceptible oaks had increased greatly over time. In the second year following treatments the crown area increased 19 percent; in the third year, 105 percent; and in the fourth year, 111 percent. In the fourth year, oaks were starting to compete with pines.

Total height and incidence of rust on planted slash pine were measured after the third, fourth, and fifth growing seasons (Table 1). There were no statistical differences in height growth or rust incidence among treatments. On an individual sample plot basis there were no statistical correlations between pine growth or rust incidence and the number or projected crown area of susceptible oaks. Trends did indicate, however, that rust incidence was more closely related to seedling height than to oak abundance. For three out of the four treatments (Chop, KG, and KG + Disk), average rust incidence increased concomitant with an increase in pine height.

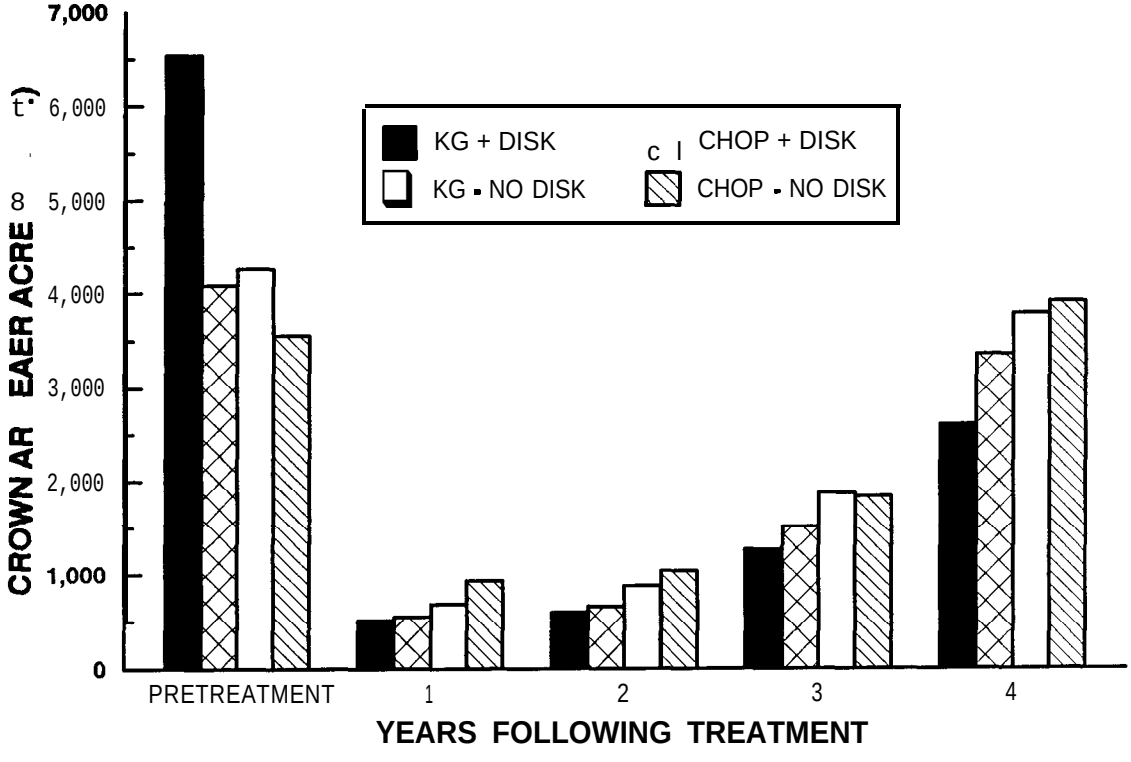

Figure 2-Projected crown area of susceptible oaks following four mechanical site preparation treatments in a high fusiform rust hazard area.

Table 1 -Total height and fusiform rust incidence of planted slash pine following four mechanical site preparation treatments in a high fusiform rust hazard area.

	Total heiaht (ft)			Rust incidence (%)		
Treatment	3 yr	4 yr	5 yr	3 yr	4 yr	5 yr
KG + Disk	4.8	7.0	0.2	12	27	28
KG - No Disk	4.4	6.5	7.7	10	22	24
Chop + Diik	4.4	6.7	8.1	7	18	20
Chop - No Disk	4.2	6.2	7.6	8	19	23

DISCUSSION

Results from thii study provide added insights into the relation between the abundance of on-site oaks, the height growth of pine seedlings, and the incidence of fusiform rust. First-year measurements showed that the relative reductions in number and projected crown area of host oaks were directly and significantly related to the intensity of mechanical site preparation treatments. KG + Disk was the most intensive and effective treatment in reducing oak competition, whereas the low-intensity Chop treatment was least effective. None of the treatments promoted an excess proliferation in the number or distribution of oak sprouts. However, over the 4-year measurement period significant increases in the total projected crown area of host oaks were observed for all treatments. It is unlikely that the small crown area of individual - or collective - rootstocks offered much competition to pine seedlings during the first and second growing seasons. Oaks did become a major source of competition and potential source of rust inoculum during the third and fourth growing seasons.

Rust incidence was more closely related to pine seedling height than to oak abundance. For three of the four treatments, rust incidence increased as average pine height increased. There was an inverse relation between the total number or projected crown area of host oaks and rust incidence of pines. The two treatments that had high rust percentages (KG and KG + Disk) had low numbers of oaks, whereas less rust occurred in treatment areas that had large numbers of oaks (Chop and Chop + Disk). Although statistical correlations between height growth, oak abundance, and rust incidence are weak, these trends deserve attention since results are in close agreement with the study reported by Schmidt *et* a/. (in press).

Results from this study and research reported by Schmidt et a/. (in press) were from potentially high-rust hazard areas. In both studies, rust incidence associated with on-site conditions were likely influenced by the large number of off-site oaks in nearby drainages and adjacent plantations. Off-site oaks, usually not practical or even possible to control, will continue to be a potential source of rust inoculum for newly established pine plantations in the area. The importance of the off-site oaks for increased rust potential on pine is enhanced as on-site cultural treatments increase the growth of pine. In conclusion, the rust hazard (rust incidence on pine in the surrounding plantations), the abundance of off-site rust susceptible oaks and factors affecting pine growth (site quality, cultural treatments, genetic selections) must be considered to best determine potential fusiform rust problems and the allocation of rust-resistant seedlings for intensively managed pine plantations.

CONCLUSIONS

1. The relative reduction in numbers and projected crown areas of host oaks were directly and significantly related to the intensity of mechanical site preparation treatments.
2. Rust incidence for planted slash pine was more closely associated to seedling height than to the abundance of on-site oaks.
3. Results are specific to plantations located in high-risk rust areas.
4. Rust incidence on pine in the surrounding area (rust hazard), the abundance of rust-susceptible, off-site oaks and factors affecting pine growth must be considered to best determine potential fusiform rust problems and the allocation of rust-resistant material for intensively managed pine plantations.

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A FOREST TENT CATERPILLAR OUTBREAK IN THE MISSISSIPPI DELTA: HOST PREFERENCE AND GROWTH EFFECTS'

T.D. Leininger and J.D. Solomon[2]

Abstract-An outbreak of forest tent caterpillars (FTC) began in spring, 1989 and lasted three years. This is the first recorded epidemic of FTC in the Mississippi Delta. Species fed upon and defoliated, or nearly defoliated, include: willow oak, water oak, nuttall oak, overcup oak, green ash, and sweetgum. Water hickory, and sugarberry were not fed upon. Tree crowns recovered to near normal condition by the end of each *growing season* during the epidemic, and showed few effects of defoliation at Delta National Forest (DNF) and Delta Experimental Forest. Slight growth decreases in nuttall, willow, and water oaks occurred during the outbreak at the DNF.

INTRODUCTION

A forest tent caterpillar, ***Malacosoma disstria*** Hübner, infestation began in the **Delta National** Forest, near Rolling Fork, MS in the spring of 1989. It became an epidemic in 1990 and spread to surrounding **areas** in the Mississippi Delta (MD), including the Delta Experimental Forest (DEF), near Stoneville, MS, where the infestation was less intense than that on the DNF. Solomon estimated that about 30,000 acres were completely defoliated in the DNF in 1990 (Layton 1991). Following the 1991 growing season, in which defoliation was lighter in some areas, but heavier in others, the population collapsed. This is the first recorded epidemic of the FTC in the MD.

The FTC is a well known hardwood defoliator in other parts of the country where epidemics are either more or less continuous (flooded tupelo stands in Louisiana and Alabama) or cyclic and predictable (northern and eastern states) with epidemics occurring at 6 to 16 year intervals (Batzer and Morris 1978, Ciesla and Drake 1969). Tree species infested in mixed deciduous stands in south Louisiana include: sweetgum, *Liquidambar* ***styraciflua*** L.; tupelo gum, Nyssa ***aquatica*** L.; swamp blackgum, Nyssa ***sylvatica*** var. biiora (Walt.) Sarg.; black willow, ***Salix*** nigra Marsh; water oak, Quercus *nigra* L.; willow oak, Quercus ***phellos*** L.; cherrybark oak, *Quercus* ***falcata*** var. pagodaefolia Ell.; swamp chestnut oak, ***Quercus*** *michauxii Nut;* and pecan ***Carya*** spp. (Oliver 1964).

The effects of insect defoliation on tree health have been reported for upland forests in the North and East (Kulman 1971, Wargo 1981), but are poorly documented for species on bottomland sites **in the South. The** DNF and DEF are bottomland hardwood forests subject to seasonal flooding during winter and spring. In studies by Crow and Hicks (1990) of upland oaks and other species in an Appalachian forest of West Virginia, mortality, after 1, 2, and 3 consecutive years of defoliation, averaged 27, 37, and 33 percent, respectively. Basal area of aspen in Minnesota was reduced an average 58 percent in a three year period including two years of heavy defoliation and a year of recovery (Duncan and Hodson 1958). In bottomland gums in the South, heavy defoliation can cause considerable dieback and mortality, and can cause severe loss of annual growth (USDA 1985). Heavy defoliation to sugar maple orchards in the Northeast can severely weaken trees and reduce the amount and quality of sap (USDA 1985). Efforts to document the effects of insect defoliation on tree health often utilize an analysis of annual growth rings (Swetnam et al. 1985, Swetnam and Lynch 1993).

Changes in climate may adversely affect tree health and favor pest populations (Anderson 1990, Wagner 1990), and insect outbreaks may be provoked by climatic events such as drought (Mattson and Haack 1987 a,b). Since there is no history of an FTC epidemic in the MD the question arises, "did changes in climate and/or other conditions trigger the epidemic"? It was not possible to answer that question with this study, but it was possible to examine FTC host preferences, as well as crown recovery and growth effects of southern bottomland oaks and associated species following FTC defoliation **in the MD. Determining the role of climate change in FTC outbreaks, even by simple correlation, would require subsequent epidemics.**

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EXPERIMENTAL APPROACH

Crown Health

In June 1990, the percentage of tree crowns defoliated by the FTC was estimated for 18 trees of 8 species at the DNF. Species selected were: sweetgum; green ash, *Fraxinus pennsylvanica* Marsh.; water oak; overcup oak, *Quercus lyrata* Walt.; willow oak; nuttall oak, Quercus nuttallii Palmer; water hickory, *Carya aquatica* (Michx f.) Nutt.; and sugarberry, *Celtis laevigata* Willd. Sample trees were growing in compartments 2, 3, 8 and 17 in the northern one third of the DNF. The following June, on the DEF, percent defoliation by FTC was estimated for 18 trees of the same species, except for water oak of which 4 trees were sampled. Trees were growing in compartments 69, 70, 81, and 82 of the DEF. Differences in defoliation between species were determined by performing a one-way analysis of variance test on the arcsine-transformed percent defoliation values. Crown condition (volume of healthy crown as percent of total crown volume) and sparseness indices (amount of foliage area as a percent of normal foliage area) were estimated at the DNF in mid September 1990, early October 1991, mid September 1992, and early October 1993; and were estimated at the DEF in mid September 1991, early November 1992, and mid October 1993. Crown condition and sparseness indices were compared between species for each separate year for the two forests by analyzing arcsine transformations of recorded percentages using one-way analysis of variance.

Tree Growth

Increments cores were taken from each tree on the DEF in May 1994, and from each tree on the DNF in August 1994. Cores were taken early at the DEF due to an February 1994 ice storm which broke tops out of most trees and introduced another variable. Growth was measured using a dendrochronograph (Fred Henson Co., Mission Viejo, Ca). Growth, as radial growth, and basal area increment (BAI), prior to the outbreak (1969 to 1988) was compared to growth during (1989 to 1991) and after (1992 to 1994) the outbreak using analysis of covariance, with average annual precipitation as the covariate. The covariate was applied across the three treatment periods without regard to treatment, and was applied within individual treatment periods in an effort to detect interactions between growth and precipitation within individual treatment periods. Measuring annual growth of sweetgum (even when cores were stained) proved too difficult because growth rings are diiuse porous.

RESULTS AND DISCUSSION

Crown Defoliation

Average defoliation as estimated for each species at the DNF in June 1990 was as follows: sweetgum, 100 percent; green ash, 98 percent; water oak, 97 percent; willow oak, 94 percent; overcup oak, 92 percent; nuttall oak, 88 percent; water hickory, 9 percent; and sugarberry, 1 percent. Percent defoliation for water hickory and sugarberry are significantly different (p=0.05) from those of the other six species. Average defoliation as estimated for each species at the DEF in June 1991 were as follows: overcup oak, 94 percent; sweetgum, 91 percent; nuttall oak, 83 percent; green ash, 78 percent; willow oak, 76 percent; water hickory, 0 percent; and sugarberry, 0 percent Percent defoliation for water hickory and sugarberry are significantly different (p=0.05) from those of the other five species. Clearly, water hickory and sugarberry are not preferred by the FTC. Red maple, *Acer rubrum* L., and boxelder, *Acernegundo* L., (not part of the study) were present in the stands but were not fed upon by the caterpillars.

Crown Recovery

Crown condition (Figure 1) values for DNF at the end of the 1990 and 1991 growing seasons, the second and third years of the epidemic, are similar to each other and are similar to those of 1992 and 1993, the years immediately following the epidemic. Sparseness index values follow this same pattern (Figure 2). These findings indicate that crowns recovered to a near normal condition by the end of the growing season following severe defoliation. The fact that crown condition and sparseness index of all species, including the non-host species sugarberry and water hickory, had fairly consistent values and rankings from 1990 to 1993 suggest that FTC feeding had little effect on crown health. In light of these similarities, significant means separations which were intended to detect differences in recovery between species are not particularly meaningful. However, means separations do suggest that crown condition and sparseness index for a given species are somewhat characteristic and repeatable from year to year. Crown condition (Figure 3) data for the DEF indicate a rapid recovery of crown health following the severe defoliation in spring 1991. Crown condition and sparseness index (Figure 4) data for 1992 and 1993 provide additional examples of the range of normal crown health for these species. Recovery of crowns by the end of each growing season is likely due to the fact that FTC feeding occurs before leaves are fully expanded, a condition that would leave trees with some energy reserves for refoliating crowns. Additionally, the long growing season (average Autumn frost date is November 8) in the Mississippi Delta allows trees time to develop crowns and store energy for the next year in spite of severe defoliation in spring.

Mortality

One water oak, two nuttall oaks, and one water hickory died during the study on the DNF, but these deaths appeared to be due to root or bole rot fungi and not

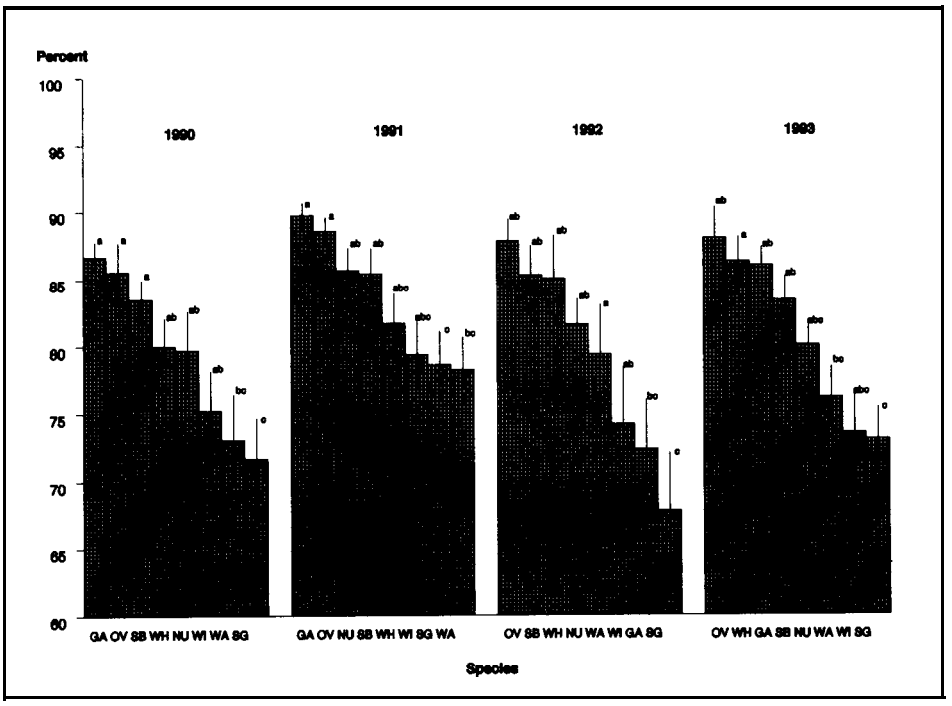

Figure 1- Average percent crown condition of eight species from 1990 to 1993 at the Delta National Forest, near Rolling Fork, Ms. Means separations between species within years, as determined by Duncan's Multiple Range Tests, are indicated by diierent lower case letters. Species codes are as follows: GA= green ash, NU= **nuttall** oak, OV= **overcup** oak, **SB=** sugarberry, SG= sweetgum, WA= water oak, WH= water hickory, WI= willow oak.

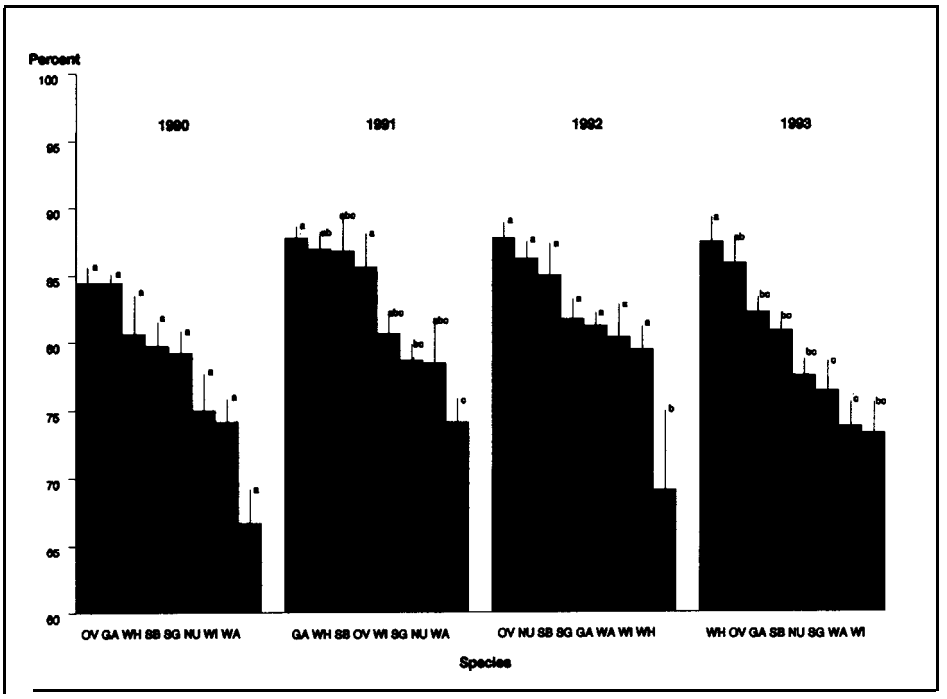

Figure **2--** Average percent sparseness index of eight species from 1990 to 1993 at the Delta National Forest, near Rolling Fork, Ms. Means separations between species within years, as determined by Duncan's Multiple Range Tests, are indicated by diierent lower case letters. Species codes are as follows: GA= green ash, NU= **nuttall** oak, OV= **overcup** oak, SB= sugarberry, SG= sweetgum, WA= water oak, WH= water hickory, WI= willow oak.

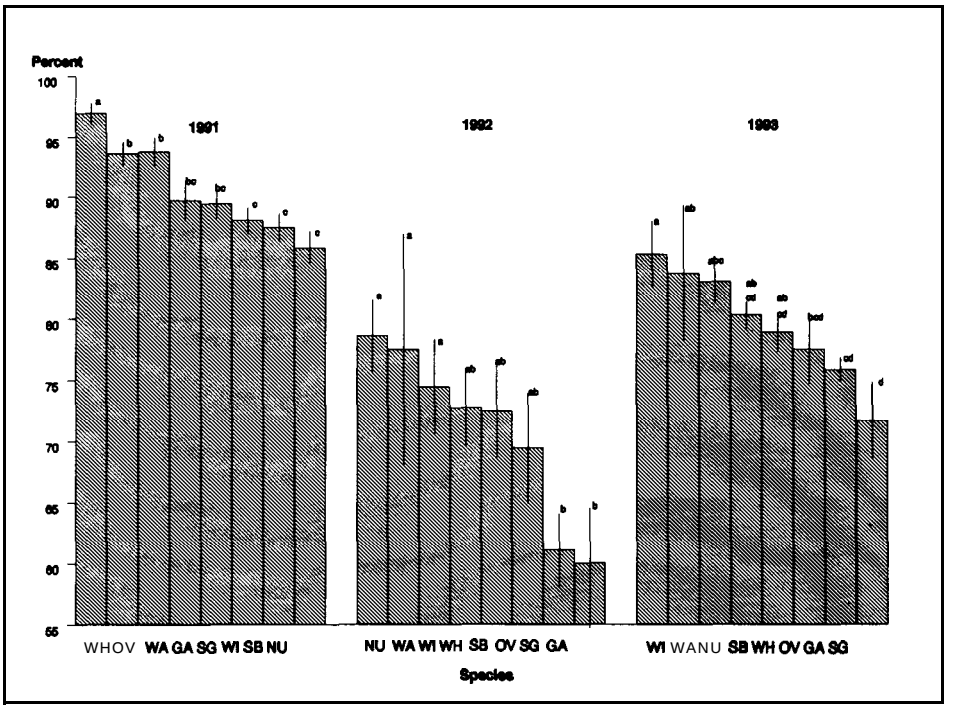

Figure 3-- Average percent crown condition of eight species from 1991 to 1993 at the Delta Experimental Forest, near Stoneville, Ms. Means separations between species within years, as determined by Duncan's Multiple Range Tests, are indicated by different lower case letters. Species codes are as follows: GA= green ash, NU= nuttall oak, OV= overcup oak, SB= sugarberry, SG= sweetgum, WA= water oak, WH= water hickory, WI= willow oak.

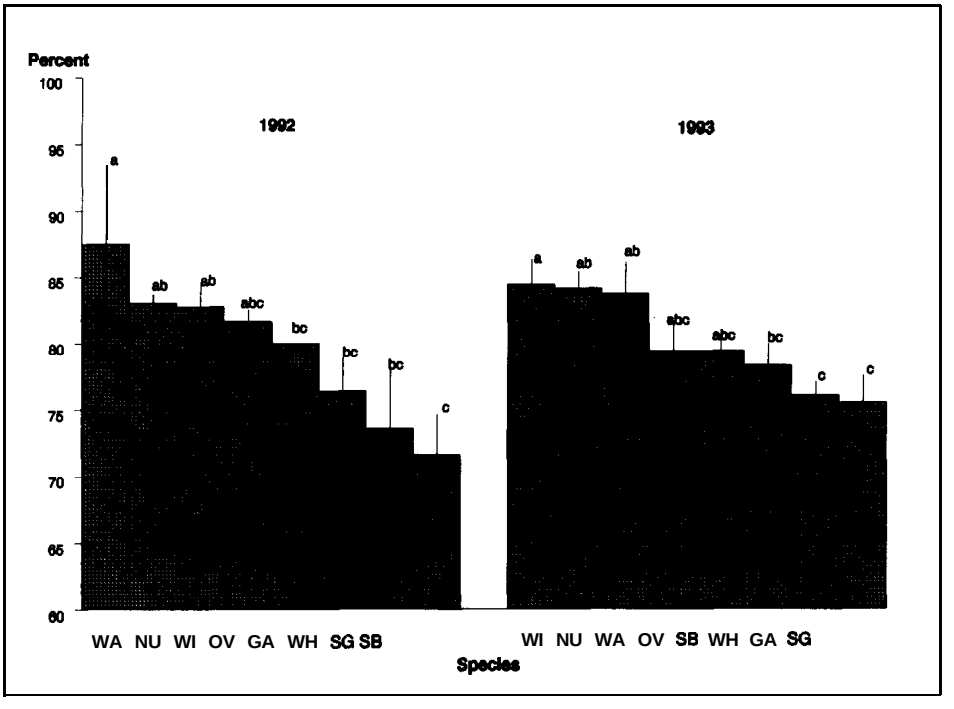

Figure 4-- Average percent sparseness index of eight species from 1991 to 1993 at the Delta Experimental Forest, near Stoneville, Ms. Means separations between species within years, as determined by Duncan's Multiple Range Tests, are indicated by diierent lower case letters. Species codes are as follows: GA= green ash, NU= nuttall oak, OV= overcup oak, SB= sugarberry, SG= sweetgum, WA= water oak, WH= water hickory, WI= willow oak.

due to FTC feeding. One sugarberry died as a result of the February 1994 ice storm on the DEF.

Growth Effects

Average annual BAI and average annual ring width of nuttall oak were less (p=0.05) during the epidemic than before and after the epidemic (Table 1) indicating a temporary decline in growth due to FTC feeding. Average annual BAI and average annual ring width of willow oak and water oak were less (p=0.05) during the epidemic than before the epidemic, and tended to increase after the epidemic. Precipitation interacted (p=0.01) with treatments for water oak BAI. Increased growth of overcup oak during the post-epidemic period compared to the previous periods is not consistent with FTC feeding. Other biotic or environmental factors are likely responsible for differences in growth across treatments of the non-host species, sugarberry and water hickory. None of the differences in growth between treatments for any species of the DEF are consistent with FTC feeding (Table 2); that is, a decrease during the epidemic followed by an increase after the epidemic. These results are consistent with the initial assessment that the epidemic had a lesser impact on host trees of the DEF. Precipitation interacted (p=0.02) with treatments for overcup oak BAI.

SUMMARY

This report documents the first known occurrence of a forest tent caterpillar outbreak in the Mississippi Delta beginning in 1989 and ending in 1991 as recorded for two forested sites. There is no history of epidemic cycling in the MD as occurs in many parts of the country. The question arises; have conditions of climate, stand structure or usage, seasonal flooding, or natural enemies changed to a degree that signals future epidemic defoliation cycles?

Sweetgum, green ash, water oak, overcup oak, nuttall oak, and willow oak are fed upon readily. Sugarberry and water hickory are not fed upon. Crowns of preferred species at both sites recovered rapidly by the end of the growing season from 100 percent, or near 100 percent, defoliation in the spring, and showed no apparent negative effects in post-epidemic years. Rapid recovery may be due in part to a long growing season in the Mississippi Delta. Three years of FTC feeding (two years, light to moderate and one year, heavy) at DNF resulted in slight reductions in the growth of nuttall, willow, and water oaks followed by a recovery after the epidemic. Two years of defoliation at DEF did not result in apparent growth loss.

Table 1. Growth, as average annual basal area increment and average annual ring width, during pm-epidemic, epidemic, and post-epidemic periods for Delta National Forest

	BAI (cm^2)			Rina Width (cm)		
	Pre	Epi	Post	Pre	Epi	Post
GA	39	44	36	.32	.30	.29
NU	47 A[b]	32 B	44A	.27 A	.16 C	.22 B
0 0	41 B	46 B	58A	.29 B	.27 B	.34 A
WI	36 A	24 B	26 B	.21 A	.12 B	.14 B
SB	25 B	30 AB	22A	.20	.21	.22
WH	20	17	17	.15 A	.12 B	.13 AB
WA[c]	A7 A	?A B	36 AR	.32 A	21 B	25 B

[a] Species codes are as follows: GA= green ash, NU= nuttall oak, OV= overcup oak, SB= sugarberry, SG= sweetgum, WA= water oak, WH= water hickory, WI= willow oak.

[b] Separations of growth variable means by Duncan's multiple range tests for species are indicated by diierent upper-case letters (p=0.05).

[c] The covariate, precipitation, was significant (p=0.01) across the three treatments.

Table 2. Growth, as average annual basal area increment and average annual ring width, during pm-epidemic, epidemic, and post-epidemic periods for Delta Experimental Forest

	BAI (cm^2)			Ring Width (cm)		
	Pre	Epi	Post	Pre	Epi	Post
GA	10	10	10	.18 A	.14 B	.12
NU	27 B[b]	37A	24 B	.21 A	.23 A	.14 B
OO[c]	24 B	34A	39 A	.23	.22	.26
WI	31 B	58A	56A	.26	.31	.29
SB	11 B	21 A	20A	.16	.18	.16
WH	12	12	13	.12	.11	.12

[a] Species codes are as follows: GA= green ash, NU= nuttall oak, OV= overcup oak, SB= sugarberry, SG= sweetgum, WH= water hickory, WI= willow oak.
[b] Separations of growth variable means by Duncan's multiple range tests for species are indicated by different upper-case letters (p=0.05).
[c] The covariate, precipitation, was significant (p=0.02) across the three treatments.

ACKNOWLEDGEMENTS

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USE OF LINDGREN TRAP DATA IN ANNUAL FOREST MANAGEMENT PLANNING ON INDIVIDUAL FORESTS'

Donald J. Lipscomb'

Abstract—Lindgren funnei **trap data** was used to predict **Southern** Pi **Beetle** (SPB) buildups following **Hurricane** Hugo on a 3033 hectares pins forest **located** near Georgetown, South Carolina. Lindgren **funnel** trap data was **collected** from four **widely** dispersed traps for **six** to eight weeks each spring from **1990** to **1994**. Coior aerial infra-red **(IR)** photographs were taken after each respective growing season through **1993**. SPB to **Clerid** beetle (CB) **ratios,** and SPB per trap per day counts, were used to **predict** the potential for SPB outbreak for the current growing season each year. Trap **ratios successfully indicated** a SPB outbreak in the **1990 growing** season and indiied reiativeiy endemic populations during the remaining evaluation years. **Comparison** of SPB percent and SPB counts from the Lindgren traps to SPB **spot** frequency by size **class** from aerial photographs, for each growing season, indicated that **Lindgren** traps may **provide** a bw **cost** method for **predicting surveillance** and **control** needs as a **part** of forest management planning each season. Four years of trap data was **insufficient** to evaluate iong range trends **in** population **cycles,** therefore this study **only** evaluated their utiiii in short range (seasonal) management planning. However use of trap data appears to be effective for prediition of seasonal beetle **trends.**

INTRODUCTION

Southern Pine Beetles (*Dendroctonus frontalis* Zimmermann) are considered one of the most destructive pest in southern pine forest (Belanger et al. 1982; Carter et al. 1991). A great deal of research has studied the characteristics that predispose pine forest or stands to Southern Pine Beetle (SPB) outbreaks (Thatcher et al. 1981). This forest and stand characteristics approach, provides **a** method of focusing silvicultral activities to reduce **susceptibility,** and perhaps reduce long range losses. Traditionally it included an aerial surveillance technique (Billings and Doggett 1980) which detects an outbreak after a build up has **occured.** However systems based on these characteristics do not provide a reliable means of predicting when outbreaks will occur (Blanche et al. 1983; Hicks et al. 1980; Mason et al. 1985). Once a build up has occurred and extensive mortalii is evident in the forest, salvage and other direct treatments require additional time to plan and execute a response. Recent studies provide an additional technique that gives some time to prepare for salvage operations before build up has occurred and helps to focus detection efforts in a way that may be very desirable for use at the individual forest level.

The introduction and use of pheromone traps in the south (Billings and Cameron 1984; Billings 1988) provided a possible means to measure and predict SPB population trends. Pheromone traps provide a way to collect data on airborne SPB and their closely associated predator insects, such as Clerid beetles (*Thanasimus dubius* F.), which use the same pheromone attractants to locate bark beetle prey. By building information on the number of airborne SPB to expect when conditions are endemic and by monitoring the **ratio** of SPB to Clerid beetles, it is possible to determine when build ups are occurring and thus when an outbreak is likely to occur. When enough trap data has been accumulated to identify patterns of normal cycling between endemic and outbreak this technique might give as much as a year to prepare for direct control of outbreaks. When numbers of SPB trapped are very low and comprise a very small portion of the total trap count of SPB and Clerids combined, aerial surveillance might be reduced or even eliminated for a season.

At the present time there are a number of studies and operational activities to trap and monitor SPB and Clerid populations at the state and regional levels. However, SPB outbreaks can occur in specific areas smaller than those measured by this level of monitoring. In addition it takes **time** to collect, analyze, summarize, and report information at a regional level. This time may be very valuable if an outbreak is about to occur. Therefore the trap technique may be very useful in monitoring and managing SPB in smaller physiographic areas or even at the individual forest level.

We used Lindgren Funnel Traps to monitor SPB and **clerid** population trends on Hobcaw forest after Hurricane Hugo. Hobcaw forest was damaged by wind

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and salt water (storm surge) from Hurricane Hugo in September 1989 (Gardner et al. 1991; Gresham et al. 1991). Little is known about the build up of SPB after hurricanes, although there has been speculation that such perturbation among the forest trees would predispose a rapid build-up (Berry et al. 1982; Carter et al. 1991). Furthermore, little data is available on the application of the trap technique at the individual forest level. Hurricane Hugo provided an opportunity to document build-up and decline after such an event. The pheromone traps provided a means to actually measure the numbers of airborne SPB and clerids. This was also an opportunity to test applicability of trap data to the surveillance and management of SPB on an individual forest ownership.

METHODS

Beginning in the Spring of 1990 and continuing thru 1994, Lindgren funnel traps were baited with a commercial pheromone lure (Phero Tech Inc., Delta, BC, Canada) and rebaited biweekly at four different locations on the Hobcaw forest located near Georgetown, South Carolina. Two pheromone traps were placed in pine stands on the west side of the forest where damage was primarily from the wind and two traps were placed on the east side within one kilometer of the forest-marsh interface where damage was from wind plus salt water inundation of root systems (Figure I). In 1992 one of the traps on the west side was not maintained and thus data from only three traps was included for that year. The traps were located approximately two miles apart. They were monitored for a period of six to eight weeks each Spring (from March to May). Insects were collected every 6 to I4 days and counts were made of SPB and Clerid beetles.

SPB percent was calculated for each trap and for all traps combined each year in the method described by Billings (I 988). SPB per trap per day and Clerids per trap per day were also calculated each year. The overall mean values for SPB/trap/day and clerids/trap/day were computed by dividing the total trap count for the respective beetles by the total number of trap days in the same year. The overall percent SPB and the overall mean SPB/trap/day for each year were then used in conjunction with a dichotomous key called "Guide for forecasting southern pine beetle infestation trends based on early season pheromone trap data" which was developed during a regional study using the same technique (Billings 1988).

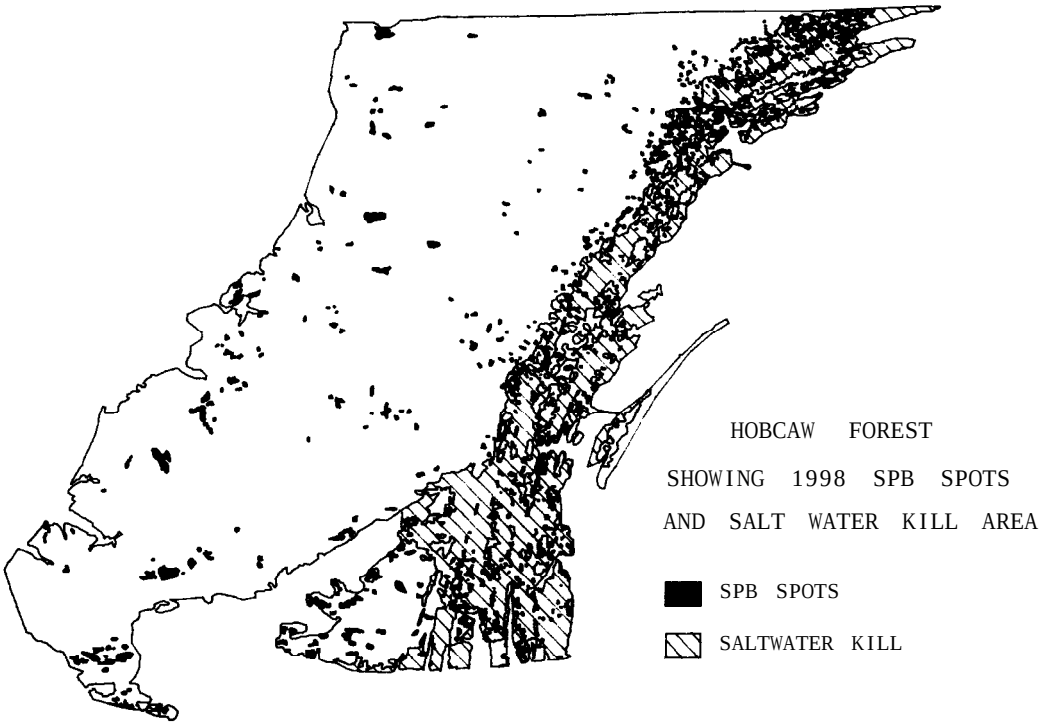

Figure I -Outline of Hobcaw Forest showing location of the 1990 SPB spots and their spatial relation to the salt kill area.

Each fall from 1990 through 1992 a set of low altitude color infa-red photos was taken of the entire forest. The scale of these photos was approximately one inch to 550 feet. The fall 1990 set was registered to a base map to the forest in the UTM coordinate system and areas of the forest killed by bark beetles were mapped. In 1990 the area of the forest killed by the combined action of salt water inundation and bark beetles was also mapped. Pine tree mortaiii in this latter area was the result of salt water, ips beetles, or SPB , but it was impractical to distinguish between these agents on the photos so this large single area of approximately 1300 acres was not counted as SPB killed. However, it may have been a reservoir for numerous patches of dead pine trees which were located throughout the remaining area of the forest, and were infested by SPB (figure 1). During the 1990 growing season the forest was flown for aerial detection of SPB spots and mapped spots were ground checked with salvage control in mind.

The 1991 and 1992 photos were registered to a base map with improved spatial information in the S.C. state plane coordinate system. In 1991 a detection flight was made in the same month that the photos were taken, this allowed a second opportunity to compare mapped spots found during direct aerial detection to those identified and mapped from the color IR photos. The 1992 SPB spots were identified and mapped solely from the color IR photos.

In 1993, fall photos were not taken due to mechanical difficulties. However, the state of South Carolina made flights in the late tinter and early spring of 1994 to take high quality photos of the entire state. Since these photos were taken after the 1993 growing season was ended and before the 1994 began they provided the opportunity to map spots from the 1993 growing season. The spring 1994 NAAP photos were registered to the base map of the forest in the S.C. state plane coordinate system and spots were detected and mapped in a similar to the previous sets.

RESULTS

In the Spring of 1990 the overall SPB percent in the traps was greater than 98% and the overall mean SPB/trap/day was above 45 (figure 2). These two values indicated the SPB population was building to outbreak proportions with few predators to restrain them as indicated by an overall clerids/trap/day value of 0.81. By the end of the growing season 317 spots were mapped outside the salt water kill area of the forest (figure 1). However spot growth was stow as indicated by the fact that only 20 percent were spots of more than 50 trees. The trap counts and dichotomous key (Billings, 1988) accurately indicated a build up of SPB on the forest.

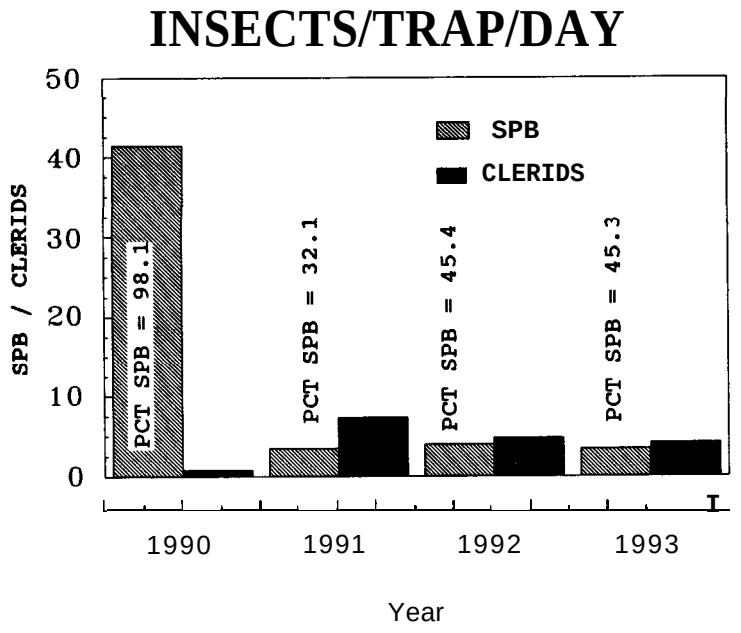

Figure 2-Graph showing the average SPB/trap/day and Clerids/trap/day captured from 1990 thru 1993. Also shows the ratio of SPB to Clerids expressed as a percent.

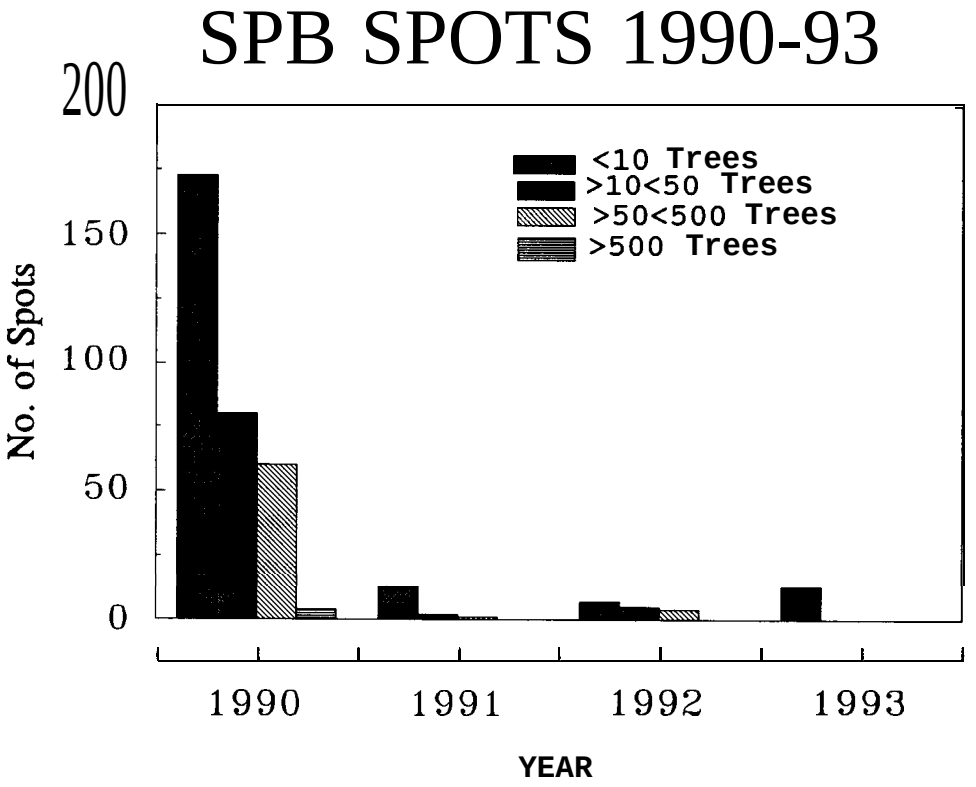

Figure 3-Graph showing the number of SPB spots mapped in each size class (by number of trees in the spot) for each year corresponding to the trap data in figure 2.

One year later in the Spring of 1991 trap counts indicated the situation had completely reversed. The SPB overall percent trapped had dropped to just over 32 percent and the average SPB/trap/day value was 3.45 (figure 2) while clerids/trap/day were more than double at 7.31. The key forecasted SPB infestation levels to be low. At the end of the 1991 growing season only 16 spots were mapped with one (0.05 percent) larger than 50 trees (figure 3).

In the spring of 1992 the overall percent SPB trapped rose above 40 to 45.4, but the SPB/trap/day remained low at 3.95 which still predicted the infestation level to be low. The ratio of SPB/trap/day in 1992 to SPB/trap/day in 1991 was 1. 15, another indication that the infestation level would remain similar to the previous year (Billings 1988). At the end of the 1992 growing season 16 new spots were mapped from the photos. However the 1992 spots had spread a little more than the 1991 spots as indicated by the fact that 25 percent had more than 50 infested trees.

In 1993 the percent SPB trapped was 45.27 (figure 2). This value was very close to that of the previous year. The SPB/trap/day count was also close to the same, showing a very small decline. The ratio of these counts was only 0.87. All indications for 1993 were for SPB infestations to remain low. At the end of the 1993 growing season, only 13 spots were mapped and none were greater than 10 trees in size. A significant decline in the outbreak level over the previous three years.

In the spring of 1994 the percent SPB trapped dropped to 3.11 and the per day average to less than one (0.19). These numbers indicate the SPB are near the bottom of the expected population cycle. The expectation of a SPB outbreak was very low and there was little need for surveillance flights.

CONCLUSIONS

The pheromone traps provided a reliable method of predicting SPB build-up and afforded several months of

advance *notice to prepare for* salvage *operations.* Figures 2 and 3 show a consistent relationship between the trapped insects and the number of spots for each successive growing season. Thii data provided useful guide to planning surveillance flights in each of the past five growing seasons. For example, trap data for the 1994 growing season suggested there was little need for surveillance flights, because the percent SPB, the SPB/trap/day, and the ratio to the previous year were very low. This does not mean surveillance flights can be eliminated all years because they are traditionally part of any salvage or control program and needed to obtain spot locations and set treatment priorities. However, the trap technique for predicting SPB outbreak potential in a season might result in reduced flights, or in some years, no flights at all.

Regardless of the survey methods, rapid response to SPB infestations is still the best method for reducing short-term losses. Neither will survey methods replace sound silvicultural practices. A sustained forest management program is also needed to reduce the longer term risk of outbreak.

Data in thii study was insufficient to evaluate the application of trap data to long-term trends in SPB/clerid populations. This data represents, at best, only one cycle in the rise and fall of the SPB population on the Hobcaw Forest. A number of such cycles would be needed to detect patterns, even if all other pertinent forest conditions (e.g. age class distribution, densities, and species mix) remained constant

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INFLUENCE OF OAK CONTROL AND PINE GROWTH ON FUSIFORM RUST INCIDENCE IN YOUNG SLASH AND LOBLOLLY PINE PLANTATIONS'

R. A. Schmidt, J. E. Allen, R. P. Belanger and T Miller[2]

Abstract—Fusiform rust is the most wtdespread and damaging disease of siash and loblolly pine in the southeastem United States. Planting genetiilly rust-resistant pines has significantly reduced rust incktence in the southeast. However, in perennially high-rust-hazard areas, combining disease resistance with other strategies, e.g., inoculum management (oak control), might provlde addiiil gains in young pine plantations, or inoculum **management** might provide an altematii control strategy when **rust-**resistant pines are not available.

The influence of oak (the alternate host) control and pine growth on fusiform rust incidence on **rust-susceptible** slash and loblolly pines was evaluated at age **five** years at seven high-rust-incidence locations in the Coastal **Plain** of FL, GA and MS. Rust-susceptible oaks were reduced or eliminated In a g-acre treatment block and the surrounding **500-feet** border zone of an oak-free (OF) area; oaks were not controlled in an adjacent, but otherwise similar oak-present (OP) area. The treatment block accommodated a 2X2X3 randomiied complete block, **split-split** plot design (three replications) including: 2 pine species (slash and Molly); two family mixtures (rust-resistant and rust-susceptible); and three cultural treatments (control [no treatment], fertilizer + herbicii and fertilizer + herbicide + fungicide). Numbers of oak stems were estimated (on-site oaks) on the OP and OF areas at all locations and in the surrounding region **(3/4** mile radius) of the OF area (off-site oaks).

On-site oaks were abundant on **the** treatment block **(80** stems/acre) and border zone **(106** stems/acre) of the OP areas and greatly reduced on the treatment **block** (0.9 stems/acre) and border zone **(20** stems/acre) of the OF areas. Off-site oaks averaged **3545** stems among locations. At four of seven **locations,** rust **incidence** was **significantly** greater on the OF areas compared with the OP areas and among all **locations,** average rust incidence on pine was greater **(Pr>F** = 0.06) on the OF areas (51.4 percent) than on the OP areas (49.0 percent). Greater rust incktence was associated with greater pine height; most often greater **pine** height occwed on the OF areas as compared to the OP areas. **Fertilizer** and herbkii **significantly** increased pins height at age **five** years but were associated with an increase in rust incidence at only one of seven locations.

Greatly reducing rust-susceptible oak stems in the treatment blocks and in a surrounding **500-feet** border did **not reduce rust incidence** on **rust-susceptible** slash or **loblolly** pine in the treatment block. Inoculum to Infect **pine** came from beyond the **500-feet** border zone. Greater pine height, associated **with** reduced competitii from oaks, apparently contributed to the greater rust incidence on pine in the OF areas.

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WHAT'S RUST HAZARD PREDICTION WORTH? A BIOECONOMIC SIMULATION OF RESISTANT SEEDLING ALLOCATION ACROSS THE SOUTH'

John M. Pye, John E. Wagner, Thomas P. Holmes and Frederick W. Cubbage[2]

Abstract: Being able to place fusiform rust-resistant seedlings into areas at greatest risk could be worth Southern pine plantation owners up to twelve million dollars per year, with most of that value ultimately coming from loblolly (*Pinus taeda* L.) plantations. These conclusions come from a set of simulations designed to evaluate the economic benefits of rust hazard information. The evaluation simulated the planting, growth, harvesting and merchandizing of loblolly and slash (*Pinus elliottii* Engelm.) plantations Southwide. Aggregate soil expectation values were calculated under two alternative methods of resistant seedling allocation, reflecting either no information or perfect information on areas at risk. The difference between them indicates the maximum value of hazard information.

INTRODUCTION

Fusiform rust is generally recognized as the most damaging disease of southern pines. Research has identified families of loblolly and slash pine with improved genetic resistance to the disease and industry is producing resistant seedlings in increasing numbers. However, the value of planting resistant seedlings depends on the landowner's ability to place resistant seedlings into areas at high risk of infection. Past practices of surveying nearby stands for infection may be becoming less effective as greater planting of resistant seedlings across the landscape prevents unambiguously attributing the absence of infection to low spore loadings. Also, high risk areas may not be spatially constant over time (Lenhart et a/. 1994), compounding the problem of predicting risk.

This study estimated the value of optimally targeting resistant seedlings given the number of resistant seedlings expected to be produced in the next several decades. The study encompassed plantations of both loblolly and slash across the South established between the years 1970 and 2020. The analysis builds on a broader benefit:cost appraisal of fusiform rust research recently conducted by the authors (report in review).

METHODS

We drew on three principal sources of information to simulate the influence of site hazard information on regional plantation values:

1. simulated impacts of rust on stand rotation value.
2. empirical distributions of plantation conditions.
3. a questionnaire survey of resistant seedling production and gains in resistance.

Stand simulations linked volume outputs from loblolly and slash yield models (Hafley and Smith 1989; Burgan, Bailey, and Brooks 1989) to custom routines which merchandized stems and selected the economically optimal rotation age. Infected stems were utilized efficiently-cankered portions were pulped and remaining wood used to its highest value. Simulations were run separately for each combination of species (slash and loblolly), site qualii (low, medium and high), and early rust infection level (0,10...100). Stand value was calculated as soil expectation value (SEV), defined as the net present value (NPV) of a rotation plus the NPV of all subsequent rotations, discounted back to the original planting date. Constant 1992 product prices and a 4 percent discount rate were assumed. Only even-aged management was evaluated.

Data on Southwide plantation conditions were obtained from the Southeastern and Southern Forest Experiment Stations' Forest Inventory and Analysis (FIA) surveys, based in Asheville, NC and Starkville, MS respectively. Plot records for loblolly and slash pine plantations less than ten years old were summarized to provide area distributions corresponding to the conditions employed in the stand simulations. Plots were confined to those sampled prior to 1987 to

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represent conditions prior to improved genetic resistance. Acreage estimates were adjusted to account for past and projected planting rates.

We surveyed loblolly and slash seedling producers with the assistance of the tree improvement cooperatives at NC State University, University of Florida, and Texas A&M University to obtain estimates of fusiform-resistant seedling production and the gains in resistance achieved by those seedlings. Historical and projected figures were requested to span activities from 1970 through 2020.

Acres in a particular condition class were multiplied by the corresponding SEV for that set of conditions. Genetic resistance was simulated as a reduction in early infection rate for acres receiving resistant seedlings, with the amount of reduction depending on the gains in resistance reported for that species and year. Values were summed across plantation conditions for each planting simulation year from 1970 to 2020.

We used two schemes to allocate resistant seedlings to the various plantation conditions:

1. uniform targeting- resistant seedlings were assigned without regard to fusiform infection levels, simulating allocation in the absence of risk information.
2. optimal targeting- resistant seedlings were assigned first to those plantation conditions where improved resistance would be most valuable, using hindsight to simulate allocation under perfect information.

The difference in Southwide plantation values under these two targeting scenarios represents the value of site hazard information given that years expected planting activity, production of resistant seedlings, and gains in resistance.

RESULTS

Stand level simulations showed that high levels of fusiform rust lowered stand value more in slash pine than loblolly (Figure 1). However, slash pine stands with low infection levels returned somewhat higher stand values than stands with no rust, presumably due to thinning effects.

The distribution of conditions for young plantations (Figure 2) showed that most plantations fell into the lower site quality classes. Infection was more frequent on higher quality sites, as noted elsewhere (eg. Borders and Bailey 1986). Stands with infections of 50 percent or more accounted for about seven percent of each species' area.

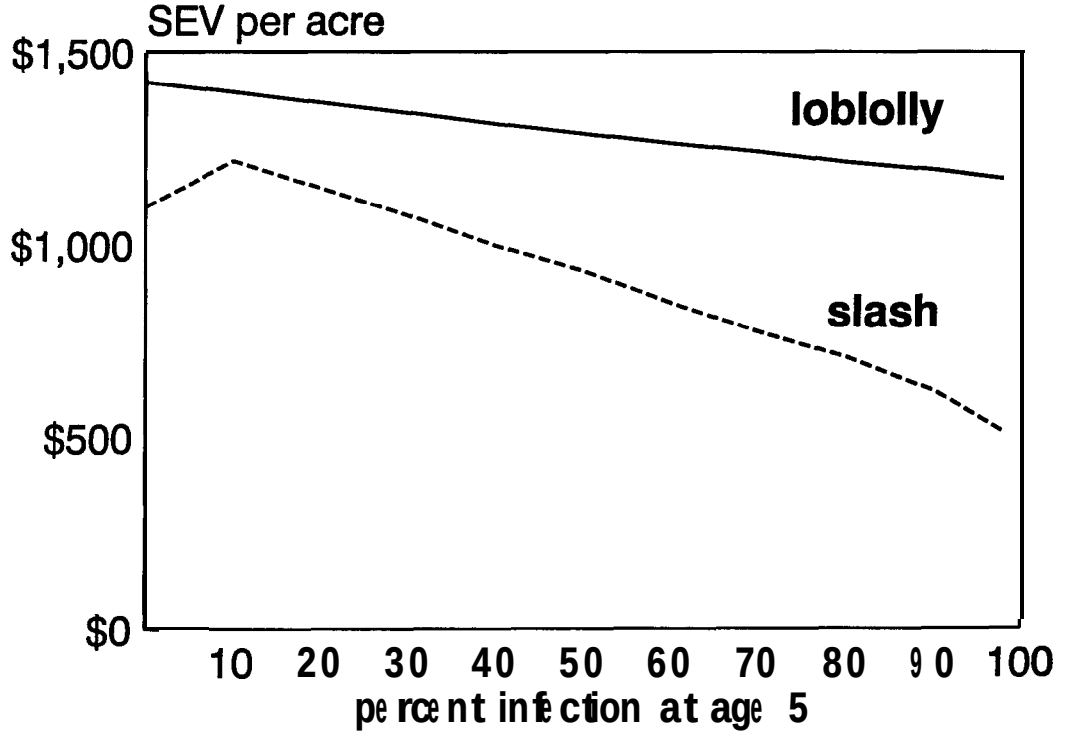

Figure I-Soil expectation value for loblolly and slash pine plantations for a range of initial (age 5) fusiform rust infection levels. Simulations assumed economically optimal rotation lengths and medium quality sites (SI 65 for loblolly and 60 for slash, base age 25).

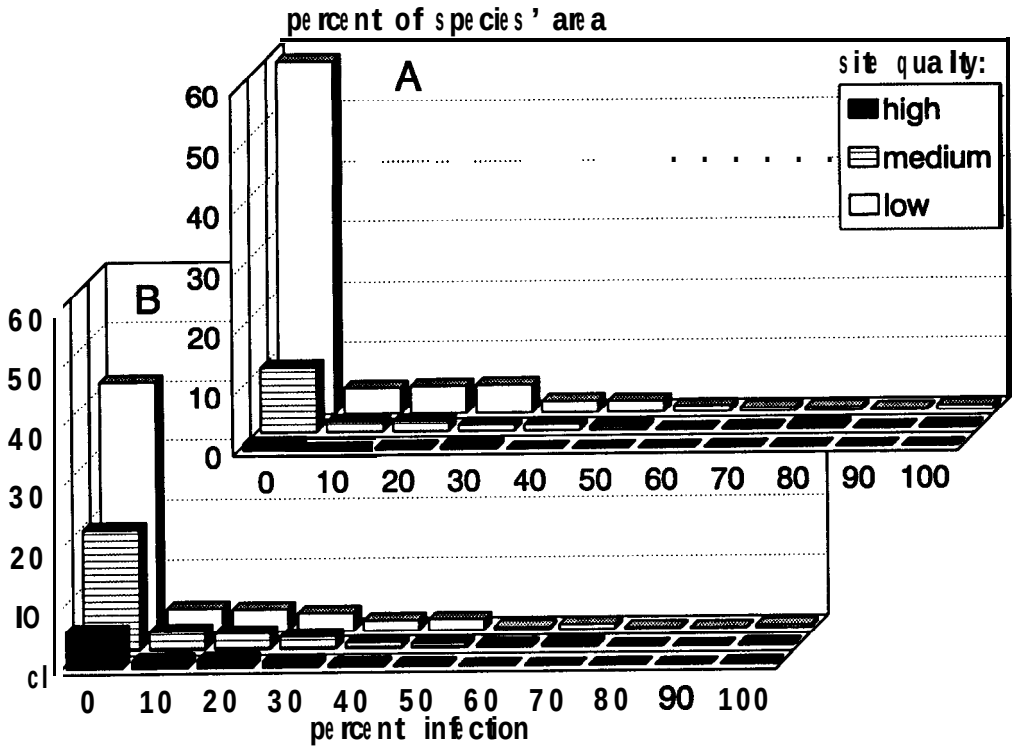

Figure 2--Percent of each species' young plantation area for slash (A) and loblolly (B), by site quality and infection **level**. Data drawn from **FIA** plots surveyed Southwide between 1968 and 1986.

Estimates from the industry survey indicated a continuing shii of production toward resistant lines over the survey period (Figure 3). Slash's share of resistant seedlings **is** anticipated to become three-fold greater than **loblolly's,** with resistance gains half again greater than those achieved in **loblolly**.

Aggregate plantation values under both allocation scenarios varied by a factor of two over the period studied due to variations in planting **activity** (Figure 4). Aggregate values under the two scenarios were identical in the **1970's** when resistance improvements were minimal but separated gradually until their relative **difference** ultimately reached 1.3 percent of aggregate plantation values.

The **difference** between the two scenarios is shown in Figure 5 and represents the absolute value of hazard information. Such information is at present worth between ten and twelve million dollars annually, rising from only three million in the late **1970's**. The annual value of hazard information will oscillate over the next decade in response to changes in planting **activity** and genetic resistance, but by 2005 will **settle** to about nine million dollars.

Hazard information was initially most valuable for slash, which saw earlier improvements in resistance. In the future, as the proportion of resistant slash pine seedlings increases, targeting will become less critical for this species. For **loblolly,** greater Southwide acreage and a lesser amount of resistant seedling production will mean that **loblolly** will ultimately account for three quarters of the total value of hazard information.

DISCUSSION

The value of being able to target resistant seedlings optimally will vary over time as planting rates change and the full effects of resistance technology unfold. In the long run it is worth about nine million dollars a year. Given its small value relative to total plantation values timber prices should remain unaffected. Thus the principal beneficiaries of hazard information will be timber producers, especially those in high infection areas.

The contrast valued here represents extremes, comparing no information on hazard with perfect information. The industry at present must operate somewhere between these extremes. Knowing where between these extremes would be useful for setting future research priorities, but quantitative information on region-wide predictive **abilities** is not available.

Qualitative information indicates continuing sources of uncertainty. Forest managers have available to them

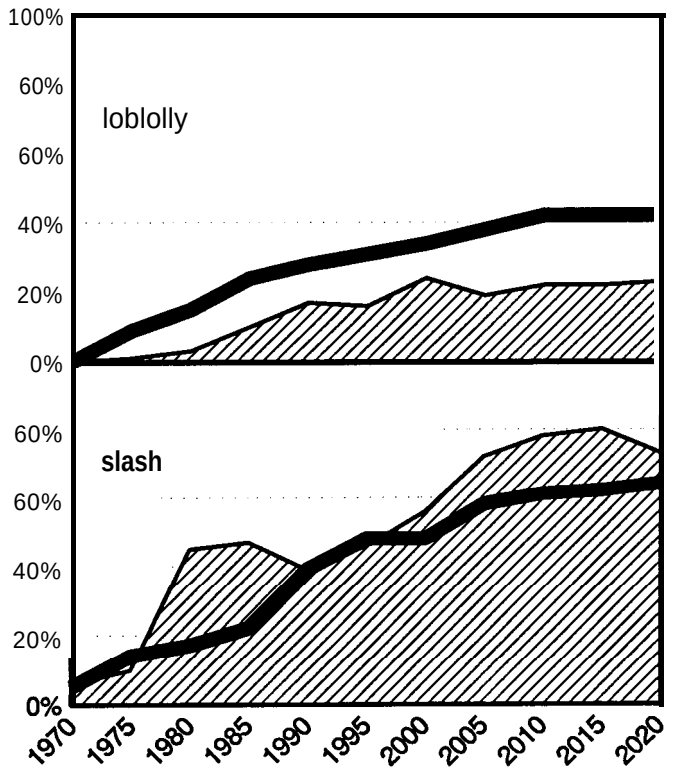

Figure 3--Industry-estimated production of fusiform rust-resistant loblolly and slash pine seedlings over time, expressed as a percentage of each species' total seedling production (hatched areas), and percentage gains in resistance among those resistant seedlings (lines).

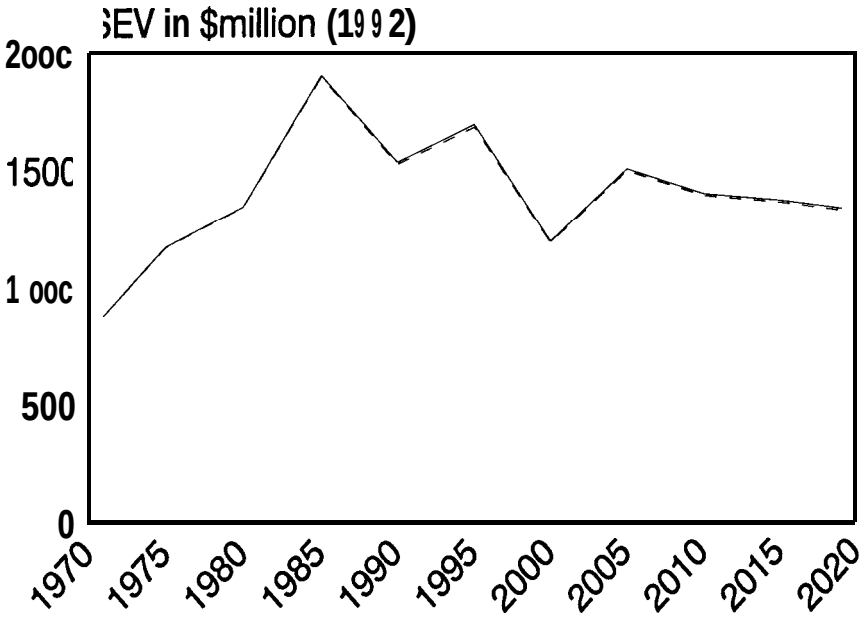

Figure 4-Southwide plantation soil expectation values (SEV) for planting years 1970 to 2020. Solid line indicates aggregate values when rust-resistant seedlings are allocated using perfect information on infection hazards. This largely overlays the dashed line, which indicates aggregate values when resistant seedlings are allocated in the absence of such information.

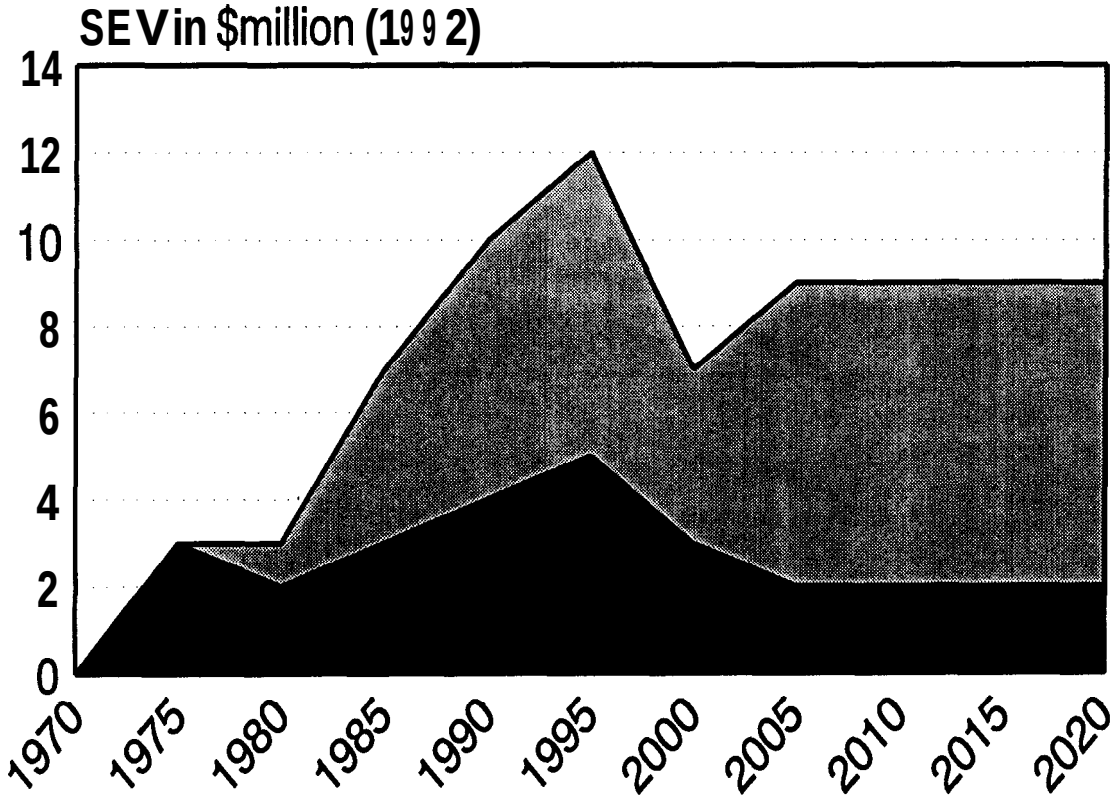

Figure 5--Difference between soil expectation value (SEV) of plantations under optimal versus uniform allocation of seedlings, partitioned into contributions from slash (dark fill) and loblolly (light fill) plantations.

the results of many studies on risk factors, including information on broad geographic areas at risk (Phelps 1977; Anderson et *al.* 1986) and the effects of other edaphic and managment factors (Powers and Rowan 1983; Froelich and Snow 1986; Borders and Bailey 1986). However, studies show considerable variability in rust incidence on annual and inter-stand scales (Schmidt et *al.* 1986; Lenhart et *al.* 1994), suggesting fundamental limitations to perfect knowledge in the face of variations in such factors as weather and pathogen genetics.

ACKNOWLEDGMENT

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TREE REGENERATION IN THE GEORGIA PIEDMONT FOLLOWING A TORNADO DISTURBANCE'

Timothy B. Harrington, Andrew A. Bluhm, and Kirk D. Howell[2]

Abstract-Tree regeneratii was studied in the second year after tornado damage to 3 mixed stands of pines and hardwoods in the Georgia Piedmont. Seeds of 8 species were sown December 1993 into 20 seed-predation exciosures representing various overstorydarnage levels. In 1994, emergence and size of seedlings, leaf-area index (LAI), and wit-water content (SWC) were measured at each exciosure. Species varied in their emergence (O-5 percent), height (5-14 cm), and diameter (I-3 mm). Correlations (p<0.10) existed between SWC and LAI (r=0.50), emergence of *Liquidambar styraciflua* L. and SWC (r=0.40), and heights of *Pinus taeda* L. or Quercus *nigra* L. and LAI (w0.52 and -0.54, respectively).

INTRODUCTION

Natural disturbances play an important role in the structural development of forest communities, and an understanding of their influence on tree regeneration is essential to successful silvicutture.

A disturbance causes temporary decreases in plant density and size that can release resources formerly monopolized by pre-disturbance vegetation (Bormann and Likens 1979). A disturbance also will alter the number, size, and type of microsites capable of being colonized by plants. In deciduous forests of the eastern U.S., wind is the primary agent of disturbance (Canham and Loucks 1984, Henry and Swan 1974, Lorimer 1977, Webb 1988), causing both small gaps (Runkle 1982, 1985) and large blowdowns (Bormann and Likens 1979; Foster 1988; Peterson and Pickett 1990, 1991; Putz and Shari 1991). Historically, the natural disturbance regime of southern Appalachian and northern Piedmont forests was dominated by the formation of small canopy gape from the death of one to several trees (Runkle 1982, Runkle and Yetter 1987).

Although it is likely that wind has played an important role in shaping the forests of the Georgia Piedmont, little or no research information exists on tree regeneration following a catastrophic wind disturbance, such as a tornado. Such information has potential application in the silvicutture of mixed pine and hardwood forests which often are composed of both early- and late-successional species. The objective of this research, therefore, was to identify how various levels of overstory damage from a tornado affect relationships between resource availability and regeneration performance of tree seedlings.

METHODS

On November 22, 1992, a class IV tornado (I-V scale of increasing intensity) created a linear path of destruction up to 0.8 km wide in the central-Georgia Piedmont. In summer 1993, 3 study sites (Eatonton, Round Oak, and Stanfordville, GA) were selected according to the following ciieria:

1. The pm-disturbance forest stand was composed of a loblolly pine (*Pinus taeda* L.) overstory with an understory of upland hardwoods.
2. Each stand was of natural origin following abandonment of farmland during 19251935, and has had little, if any, human disturbance since its origin.
3. A range of overstory-damage levels was present at each site.

Twenty microsites (6-8 per site), each having an undisturbed forest floor, were selected visually to represent various levels of overstory damage, ranging from no damage to gaps IO-20 m in diameter. Seeds of the following tree species common to the study sites were collected near Athens, GA (approximately 60 to 90 miles north of the study sites) during fall 1993 (exception: white-oak seeds were purchased from Jeane Seed, Inc., Quitman, LA):

1. mockernut hickory (*Carya tomentosa* [Poir] Nutt.)
2. sweetgum (*Liquidambar styraciflua* L.)
3. yellow-poplar (*Liriodendron tulipifera* L.)
4. loblolly pine (*Pinus taeda* L.)
5. black cherry (*Prunus serotina* Ehrh.)
6. white oak (*Quercus alba* L.)
7. water oak (*Quercus nigra* L.)
8. northern red oak (*Quercus rubra* L.)

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These species were selected because they were the primary overstory species in the pre-disturbance stands of the study sites, and because they are important sources of timber and wildlife habitat in mixed forests of the Piedmont

At each of the 20 microsites, a cohort of 50 (hickory and oaks) or 100 seeds (sweetgum, yellow-poplar, loblolly pine, and black cherry) were sown December 1993 into an exdosure. Each exclosure, constructed of wood lath and hardware cloth to prevent seed predation and seedling herbivory from mammals and birds, was of sufficient size (0.3-m height x 1.2-m width x 1.8-m length) to accommodate development of 1-year-old seedlings and to allow repetition of the experiment in 1995. To standardize for variation in depth of leaf titter among exdosures, current-year litter was removed before sowing and a fixed weight of it (600 g/m^2, dried previously in the laboratory) was replaced immediately after sowing.

In 1994, the following indices of species performance were measured: emergence (percent) in May, July, and September, and height (cm) and basal diameter (mm) of individual seedlings at the end of the growing season (September).

As a measure of overstory-damage level, and hence, light availability, leaf-area index (LAI, m^2 leaf area/m' ground area) at peak development (July) was measured in 1994 with an LAI-2000 plant canopy analyzer (Li-Cor, Lincoln, NB) at the top surface of each exclosure. Gravimetric soil-water content (SWC, percent) at 15-cm depth was measured monthly from March to September 1994 at each exclosure.

For each species, maximum emergence and mean height and diameter were calculated per exclosure. Relationships between availabilii of light and soil water and performance of individual species were identified with correlation coefficients (α=0.10).

RESULTS

Soil-water content (SWC) varied from 8 to 34 percent and differed liie among the three sites. Because 1994 had an unusually wet summer, soil-water content increased from May to July, and then remained relatively constant through September.

Leaf-area index (W) varied from 0.6 to 5.7 m^2/m^2, indicating that the exclosures represented microsites with a wide range of overstory-damage levels, and therefore, light availabiiiies. August soil-water content (SWC) was positively correlated (r=0.50) with LAI (Table 1).

Only 3 species had greater than 2 percent emergence: loblolly pine (5 percent), sweetgum (3 percent), and water oak (2 percent) (Table 2). Seedling height and diameter varied from 5 to 14 cm and from 1 to 3 mm, respectively. Species with the largest seed weights tended to have the largest seedlings.

Table l-Correlation coefficients (r), sample sizes (n), and significance levels (p) for relationships among leaf-area index (LAI), soil-water content (SWC), and species performance in microsites of various overstory-damage levels following a tornado in the Georgia Piedmont

Relationship	r	n	P
August SWC vs. July LAI	0.50	20	0.03
Sweetgum emergence vs. Sept. SWC	0.40	20	0.08
Loblolly pine height vs. July LAI	-0.52	13	0.07
Water oak height vs. July LAI	-0.54	11	0.09

For species with values of emergence exceeding 2 percent (lobloliy pine, sweetgum, and water oak), performance was correlated with resource availability (Table 1). Emergence of sweetgum was positively correlated (r=0.40) with September SWC, while heights of loblolly pine (r=-0.52) or water oak (r=-0.54) were negatively correlated with LAI.

DISCUSSION AND CONCLUSIONS

The tornado disturbance created understory microsites with a wide range of resource availabilities. LAI varied from 0.6 to 5.7 m^2/m^2 because of variation in levels of overstory damage. SWC was positively correlated with LAI, perhaps indicating that overstory damage increased evapotranspiration. In support of this hypothesis we observed that, at high levels of overstory damage, cover of herbaceous and vine species dominated the understory.

Of the 8 seeded species, loblolly pine, sweetgum, and water oak were those most likely to colonize the undisturbed forest floor after the tornado disturbance. Emergence of all other species was less than 2 percent. Performance of species with greater than 2 percent emergence was correlated with resource availability. Emergence of sweetgum was positively correlated with SWC, suggesting that its performance was best in areas with low to moderate levels of overstory damage (high SWC). However, we observed that variation in sweetgum emergence increased with SWC, indicating that other factors were limiting the species' performance at high SWC. Heights of loblolly pine or water oak were negatively correlated with LAI, suggesting that their performance was best at high levels of overstory damage (low LAI).

By creating microsites of various resource availabiliies, the tornado disturbance has provided opportunities for regeneration of both early- and late-successional tree species. It is diicult to predict which seedlings, if any,

Table 2-Average seed weight, emergence, height, diameter, and sample size (n) of 8 tree species seeded into microsites of various overstory-damage levels following a tornado in the Georgia Piedmont

Species	Weight/Seed (g)	Emergence (pct)	Height (cm)	Diameter (mm)	n^a
mockernut hickory	8.762	0.9	5.2	1.8	6
sweetgum	0.004	3.4	8.9	1.2	12
yellow-poplar	0.034	1.0	7.6	1.8	6
loblolly pine	0.025	5.0	14.2	1.1	13
black cherry	0.060	1.1	11.4	1.0	5
white oak	7.075	0.7	13.4	2.2	2
water oak	1.052	2.3	10.9	1.4	11
northern red oak	6.537	1.2	13.2	2.9	6

'For a given species, *n* is the number of exclosures with at least 1 seedling.

will reach the upper canopy, because light will become decreasingly available as the overstoty recovers. Long-term responses of overstory and understory trees are being studied to quantify effects of the tornado disturbance on structural diversity of these mixed pine and hardwood stands.

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EFFECTS OF A SEVERE ICE STORM ON MATURE LOBLOLLY PINE STANDS IN NORTH MISSISSIPPI'

Howard G. Halverson and James M. Guldin[2]

Abstract—On 9 February 1994, a severe winter storm deposited an estimated 7.5-l 2.5 cm of precipitation as ice across north Mississippi. Among the stands damaged in this storm we three old-field pine piantattons between 40 and 50 years of age. Thess stands had been scheduled for experimental cutting in the summer of 1 QQ4, and had received 1 W-percent inventories in the fail of 1993. We quantified the damage in the stands by repeating the inventory after the storm. Ice damage was assessed using six damage categories, including (1) no damage, (2) branch breakage, (3) bending, (4) breakage within the crown, (5) breakage below live crown, and (6) uprooting. Of the 1,577 tress on the three watersheds, only 241 (15 percent) were undamaged. Undamsgsd tress were primarily small pines snd hardwoods. The most severe forms of damage--broken stems snd uprooting--affected 76 percent of the trees. On a percentage basis, pines were more often and more seriously damaged than hardwoods, and large trees were more often damaged than small tress. We therefore expect hardwoods to incresss in importance ovsr the next 10 years.

INTRODUCTION

When freezing rain or sleet accumulates as ice in the crowns of trees, its weight causes physical damage ranging from minor branch loss to complete uprooting of the tree. Secondary damage can occur when wounds provide entries for insects and disease, or when heavy fuels contribute to the threat of fire. In this paper, we quantify the damage caused by a major ice storm in north Mississippi, and we place this information in an ecosystem context. Ice storms are not frequent events in north Mississippi, and there are no good quantitative evaluations of storm damage in the area in the literature.

Long-time residents tend to expect a 20- to 25-year interval between significant ice storms. Desplte this variability in local estimation of recurrence, a severe ice storm did occur in February 1994. Weather conditions prior to the storm were mild, with midday temperatures exceeding 20°C and lows near 16°C. On February 8, early warnings of an approaching ice storm were issued. In Oxford, MS, at 5:00 a.m. on February 9, the air temperature was 19°C. During the next hour the temperature dropped to 6°C and then continued to fall, reaching 0°C by 6:00 p.m. that evening. Precipitation also began to fall at 6:00 p.m. that day. Freezing rain fell for 24 hours and was followed by an additional 18 hours of fine mist or drizzle; most of this precipitation accumulated as ice in tree crowns. Ground-level temperatures during the precipitation hovered near the freezing point In all, the total precipitation was estimated to be between 7.5 and 12.5 cm, and ice deposits 20 cm thick were commonly observed.

The storm was unusual in two respects-ii was very severe, and it covered an unusually large area. Heavy damage extended from eastern Arkansas roughly 160 miles northeasterly through northern Mississippi; at its widest point, an area 100 miles wide extending from Memphis, TN, southward to Greenville, MS, bore the brunt of the storm.

Within this area, the weight of this accumulated ice resulted in extensive and severe damage to trees and power tines. The ice storm caused an estimated $1.3 billion timber loss in Mississippi, a state with an annual cut of approximately $700 million. Nearly 750,000 utilii customers lost power, some for as long as a month; estimates of damage to utiliies were about $500 million. This was the worst ice storm to strike Mississippi since 1951.

Storm-damaged stands included three small experimental watersheds on the Holly Springs National Forest east of Oxford, MS, in Lafayette County (sec. 7 & 18, T. 8 S., R. 2 W.). Vegetation on the watersheds consisted largely of old-field loblolly pine (*Pinus taeda* L.), some natural shortleaf pine (*Pinus echinata* Mill.), and a few hardwoods of various species. The watersheds were scheduled for partial cutting treatments in 1994 as part of a hydrology study; as

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such, in late 1993 a loo-percent inventory was conducted in each of the watersheds by species, size, and diameter class.

The treatments were deferred as a result of the ice storm. However, the existence of the preharvest inventory inspired a similar inventory after the storm in order to assess the damage the storm caused.

METHODS

Prestorm conditions and the cutting treatments that had been prescribed for each of the three watersheds in the study are listed in table 1. The preharvest inventory followed normal National Forest timber sale procedures, so volumes and all other variables are expressed in English units. Data were gathered for the following species and sizes: pine sawtimber by species and d.b.h., hardwood sawtimber by species and d.b.h., small pine roundwood by d.b.h., and small hardwood roundwood by d.b.h. For purposes of analysis, it was assumed that all trees tallied before the storm were undamaged. Tree diameters were measured with a diameter tape

Table 1. Prestorm conditions on the three watersheds

Condition and unit of measure	Pine 1	Pine 2	Pine 3
Area, acres	3.56	3.36	2.59
Trees, number	617	599	366
Sawtimber, pine, MBF[a]	52	76	44
Sawtimber, hardwood, MBF	1.0	0.5	0
Roundwood, pine, CCF[b]	26	18	12
Roundwood, hardwood, CCF	2	4	0
Topwood, pine, CCF	6	6	3
Proposed treatment	seed tree	control	shelter-wood

[a]MBF is thousands of board feet.
[b]CCF is hundreds of cubic feet of solid wood.

After the storm, trees were measured in the same way as before the storm. In addition, ice damage was assessed by assigning each tree one of six damage categories: (1) no damage, (2) loss of branches, (3) bending in excess of 45°, (4) bole breakage within the live crown, (5) bole breakage below the live crown, and (6) uprooting. Each tree was marked with biodegradable tape when measured to prevent either double counting or omission of individual trees. Poststorm surveys were taken in late March and early April 1994.

In scientific hindsight, the after-storm inventory could stand alone by simply assuming that all trees tallied were in good condition prior to the storm. The advantage of the loo-percent before-storm tally was primarily to assure that the after-storm tally accounted for all the trees present in the stand prior to the storm. Since the after-storm tally closely agreed to the before-storm tally (table 2), these results are based primarily on inferences made from the after-storm inventory data. These inferences were compared to the before-storm inventory to detect changes from the baseline condition.

Table 2. Comparison of 100 percent inventory, before and after the storm

Species and size group	Number of stems: Before storm	After storm
Shortleaf pine sawtimber	122	138
Loblolly pine sawtimber	844	890
Small pine roundwood	518	451
All pine	1484	1479
Sweetgum sawtimber	3	3
White oak sawtlmber	1	2
Southern red oak sawtimber	7	11
Small hardwood roundwood	93	82
All hardwood	104	98
All merchantable trees	1588	1577

Because the three experimental watersheds were small, the inventory from each was combined into one large data set Thus, analyses were based on 9.51 acres of inventory data. Damage was summarized for pine and hardwood and for pulpwood and sawtimber. In addition, changes in stand structure by l-inch d.b.h. classes were analyzed to more precisely assess differences in the pattern of damage by size. Data were summarized using spreadsheet software and analyzed statistically using nonparametric analysis of variance (SAS Institute 1990).

RESULTS AND DISCUSSION

The inventory before the storm compared reasonably well with that taken after the storm (table 2). In the before-storm inventory, 1,588 trees were tallied, of which 1,484 were pine and 104 hardwood. After the storm, 1,577 trees were tallied, of which 1479 were pine and 98 hardwood. The greatest differences were in assigning trees to the small roundwood category. Before the storm, 518 pines and 93 hardwoods were tallied as small roundwood; after the storm, the small roundwood tally included 451 pines and 82 hardwoods. The after-storm tally resulted in more trees being included in the sawtimber count, especially in the loblolly pine sawtimber component, which increased from 844 to 890 trees. This slight discrepancy is explained by the more arduous effort required to conduct the inventory after the storm; broken limbs and downed trees hindered access to and measurement of some of the trees. The close agreement between tallies taken before and after the

storm suggests that virtually no precision would have been lost by using only the data taken after the storm.

Before the ice storm, stocking averaged 167 trees per acre with a basal area of 143 ft^2 per acre in trees 3.6 inches in d.b.h. and larger. Pines accounted for 155 trees per acre, with a basal area of 137 ft^2 per acre. The diameter distributions of pines and hardwoods before the storm (fig. 1) are typical of even-aged stands. The bimodal pattern in the conifer component seen here has been reported for other pine stands found in the Interior Highlands (Guldin and others 1994).

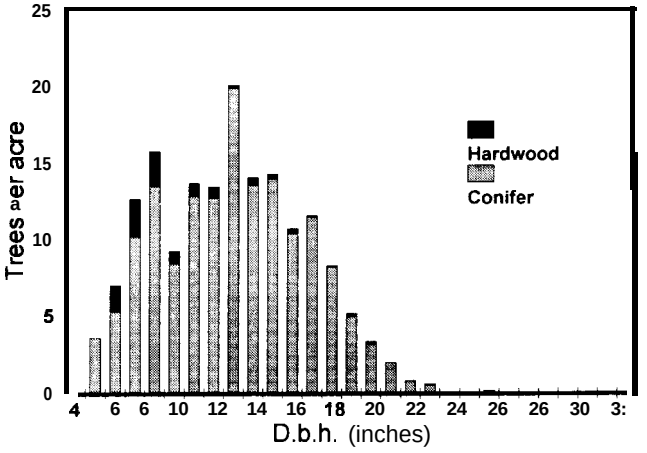


Figure 1.-- Stand structure of pines and hardwoods prior to the ice storm. Data based on composite of all three watersheds.

The ice storm damaged 85 percent of the trees in the three watersheds, and most of these were severely damaged. Only 25.3 trees per acre, or 16.6 ft^2 of basal area per acre, were undamaged. Uprooting or stem breakage in or below the live crown affected 75.6 percent of the trees, or 80.3 percent of the basal area, in the three watersheds.

Damage by Size Classes

An overview of damage classes indicates that trees in the smaller diameter classes were more likely to escape damage, and less likely to have stem breakage or uprooting, than the larger diameter classes (fig. 2). For example, in the 8-inch class, 39 percent of trees suffered only minor damage (no damage, bending, or branch breakage) whereas only 14 percent of the trees in the 18-inch class had minor damage. Further, for both pines and hardwoods, undamaged trees of pulpwood size outnumbered undamaged trees of sawtimber size (table 3). But some degree of damage was the rule rather than the exception across all species and size classes, and the damage was more likely to be major than minor.

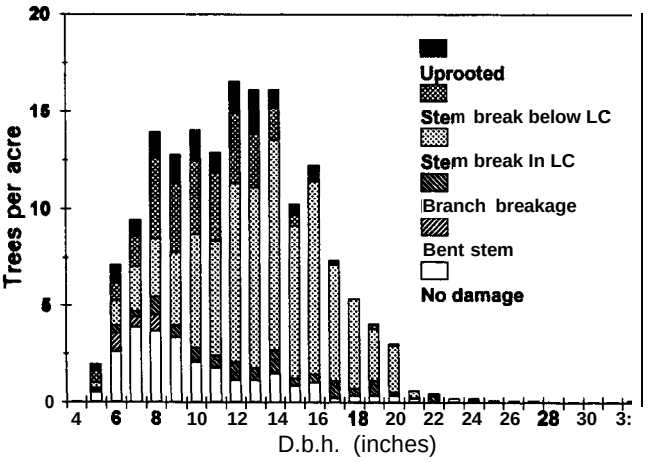


Figure 2.-- Distribution of damage classes across the three watersheds after the storm. Stand structure based on composite of all three watersheds. LC: live crown.

The quadratic mean diameter (Dq) of trees damaged in each category is a good indicator of the relationship between damage and size (table 3). For all trees, the ranking of the six damage classes by Dq indicates that small trees tended to bend, break low on the stem, become uprooted, or remain undamaged. Large trees tended to have branch breakage or stem breakage in the live crowns. We conclude that size confers some resistance to mortal effects, though the relationship is muddied by noting that the Dq of undamaged trees is slightly less than the average Dq for all trees.

Damage by Species Groups

Pines Versus Hardwoods.

Overall, only 12.1 percent of conifers escaped damage, whereas 63.3 percent of hardwoods were undamaged (table 3). From the 6- to 16-inch classes (the broadest range of contiguous classes that include both pines and hardwoods), pines show a consistently larger percentage of damage than hardwoods (fig. 3), and this pattern also characterizes other size classes where both pines and hardwoods are present.

The most common form of damage to conifers was stem breakage; 72 percent of all pines had broken stems (table 3). Stem breakage in the live crown was three times more prevalent than the second most common damage class, stem breakage below the live crown. Tree bending affected only 1.5 percent of the pines; the storm was sufficiently severe that pine stems were much more likely to break rather than simply bend. The distribution of damage by d.b.h. classes suggests that stem breakage below the live crown was more likely to occur in the smaller size classes, whereas

Table 3. Distribution of trees per acre and basal area per acre by damage classes after the ice storm, classified by species group and size group in each damage class

Species/size groups	No damage	Tree bent	Branch breakage	Stem breakage: Within live crown	Stem breakage: Below live crown	Tree uprooted	All classes
			Trees per acre				
Pine pulpwood	9.86	2.31	1.78	9.97	10.38	4.72	39.02
Pine sawtimber	8.92	0.10	6.82	75.11	16.26	8.92	116.12
All pines	18.78	2.41	8.60	85.07	26.64	13.64	155.15
Hardwood pulpwood	4.20	0.10	0.63	0.73	0.42	0.21	6.29
Hardwood sawtimber	2.31	0.00	1.15	0.31	0.10	0.10	3.99
All hardwoods	6.50	0.10	1.78	1.05	0.52	0.31	10.28
All pulpwood	14.06	2.41	2.41	10.70	10.80	4.93	45.32
All sawtimber	11.22	0.10	7.97	75.42	16.36	9.02	120.11
Ail trees	25.28	2.52	10.38	86.12	27.17	13.95	165.43
			Basal area, ft^2 per acre				
Pine pulpwood	3.18	0.61	0.59	3.41	3.57	1.53	12.88
Pine sawtimber	9.09	0.06	9.74	87.81	13.09	8.00	127.78
All pines	12.26	0.67	10.33	91.22	16.65	9.53	140.66
Hardwood pulpwood	1.21	0.02	0.20	0.23	0.13	0.05	1.84
Hardwood sawtimber	3.16	0.00	1.09	0.30	0.07	0.07	4.69
All hardwoods	4.37	0.02	1.29	0.52	0.20	0.12	6.52
All pulpwood	4.39	0.63	0.79	3.64	3.70	1.58	14.72
All sawtim ber	12.24	0.06	10.83	88.11	13.16	8.07	132.46
All trees	16.63	0.69	11.62	91.74	16.85	9.65	147.18
			Quadratic mean diameter (inches)				
All pines	10.94	7.13	14.84	14.02	10.71	11.32	12.89
All hardwoods	11.10	6.00	11.52	9.58	8.33	8.29	10.79
All trees	10.98	7.09	14.32	13.98	10.66	11.26	12.77

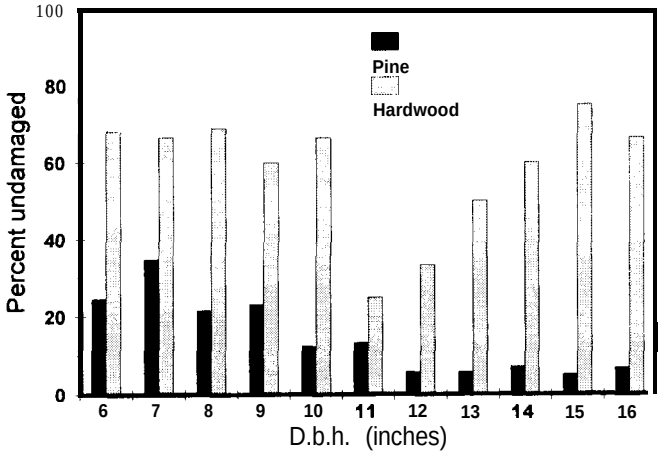
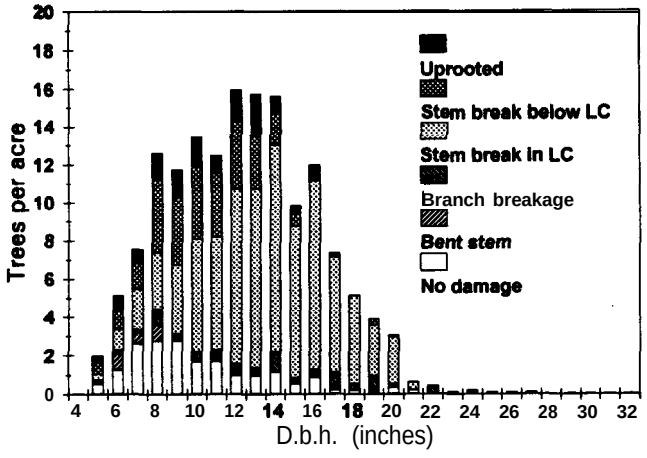


Figure 3.-- Percentage of damage in hardwoods vs. pines by diameter class. The diameter classes shown here contain a contiguous set of nonzero pine and hardwood data.



Fiiure 4.-- Distribution of damage across all diameter classes in the pine component of the three watersheds. LC: live crown.

stem breakage in the live crown was more typically associated with larger size classes (fig. 4).

In the hardwoods, the most prominent category was "no damage" (table 3). Like the pines, small hardwoods were most likely to escape damage. The kind of damage that hardwoods most often suffered was branch breakage, which affected 29 percent of the sawtimber and 10 percent of the pulpwood trees. Fifteen percent of the hardwood stems were broken, with breakage in the live crown roughly twice as common as breakage below the live crown (fig. 5). Stem breakage tended to occur in the smaller size classes of hardwoods. These data suggest that ice bent many small hardwoods to the point of stem breakage; some stems broke, others remained bent, and some probably returned to normal after the ice melted. In large hardwoods, whose stems were more resistant to bending, branch breakage was more common.

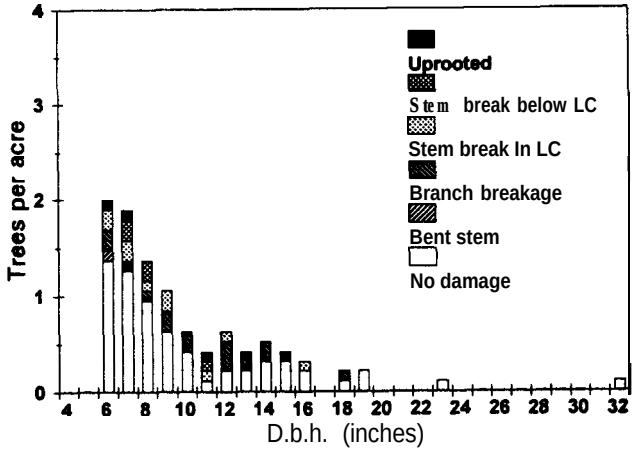


Figure 5.-- Distribution of damage across all diameter classes in the hardwood component of the three watersheds. LC: live crown.

Analysis of Dq trends by species group reinforces these species differences (table 3). In both pines and hardwoods, the damage class with the largest Dq was branch breakage. In the pine component, two damage classes-stem breakage in the live crown and branch breakage-had a Dq greater than the average. Similarly, in the hardwood component, two damage classes-undamaged trees and trees with branch breakage-exceeded the overall Dq.

Loblolly Pine Versus Shortleaf Pine.
Before the storm, loblolly pine sawtimber trees outnumbered shortleaf pine sawtimber trees by roughly seven to one in these watersheds. Loblolly accounted for 100.4 ft^2 per acre of basal area, and shortleaf for 16.7 ft^2 per acre. Distributions by d.b.h. class did not diier significantly for the two species (fig. 6).

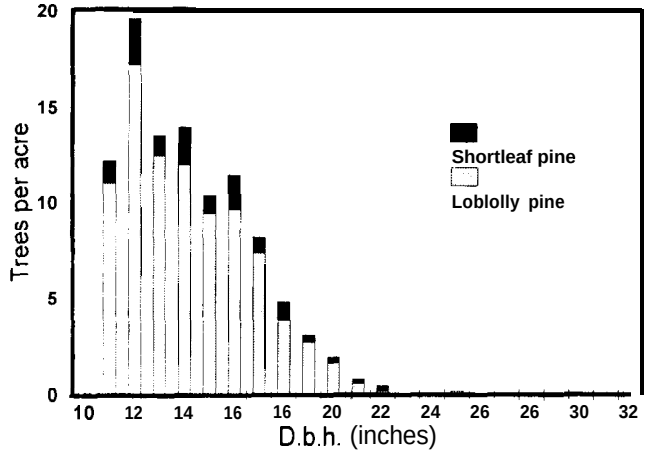


Figure 6.-- Stand structure for loblolly pine and shortleaf pine sawtimber prior to the storm. Data based on composite of all three watersheds.

After the storm, there was no significant difference in the proportion of trees from each species in any damage category, either in total or across the range of d.b.h. classes. From this, one can conclude that loblolly pine sawtimber and shortleaf pine sawtimber were affected similarly by this storm. These effects were primarily in the stem breakage category as discussed above (figs. 7 and 8).

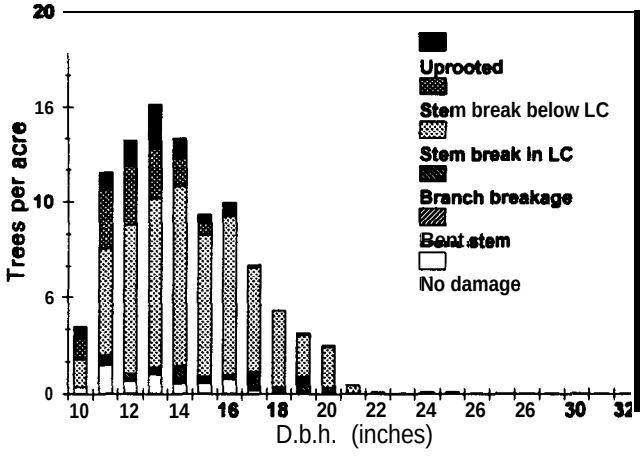


Figure 7.-- Distribution of damage classes in the loblolly pine sawtimber component after the storm. Stand structure based on composite of all three watersheds. LC: live crown.

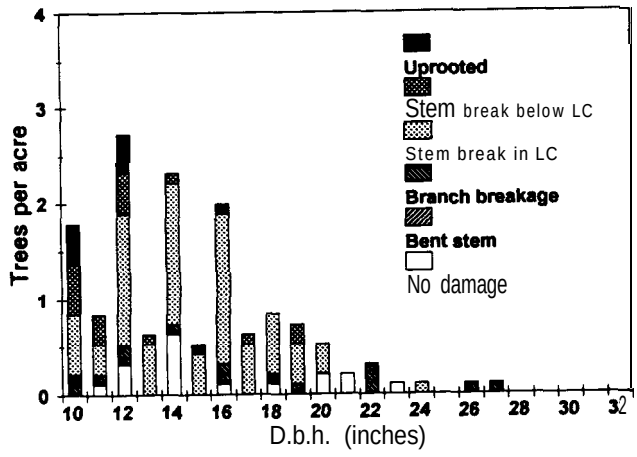


Figure 8.– Distribution of damage classes in the shortleaf pine sawtimber component after the storm. Stand structure based on composite of all three watersheds. LC: live crown.

CONCLUSIONS

To estimate the long-term ecological effects of the storm, we have made several assumptions about the prospects for trees in various damage classes. Basically, we assume that the trees that escaped damage, trees that were bent, and trees with broken branches will survive; we further assume that uprooted trees and trees with stems broken below the live crown will die. However, the fate of trees with stems broken below the live crown (the major type of damage in the study) is uncertain.

If one assumes that all trees with stem breakage in the live crown succumb, the storm will reduce stand stocking by roughly four-fifths. Trees per acre will decline from 165.4 trees per acre before the storm to 38.2 trees per acre after the storm. Basal area per acre will decline from 143.1 ft^2 per acre to 28.9 ft^2 per acre. The Dq will increase from 14.55 to 15.55 inches. These changes in stand structure are more from "below" than "above", and might resemble a natural version of the shelterwood reproduction cutting that had been silvicutturally prescribed initially.

Conversely, if one assumes that all the trees with stem breakage in the live crown survive, the storm will reduce the total trees per acre and basal area per acre by roughly one-quarter. Under this assumption, trees per acre will decline from 165.4 trees per acre before the storm to 124.3 trees per acre after the storm. Basal area per acre will decline from 143.1 to 120.7 ft^2 per acre. The Dq will be reduced from 14.55 inches before the storm to 13.74 inches afterward. Thus, losses will somewhat resemble a thinning from above. Considering the recovery of pines from previous storms in the area, this scenario is the more likely of the two.

Based on these data, we hypothesize that hardwoods will gain competitive advantage over the pines in two ways. First, a smaller proportion of hardwoods were damaged; among the most important ecological effects of the storm is that small hardwoods were released. Hardwood roundwood stems seem certain to increase in relative dominance in the stands. Second, the damage to large pines was more severe than the damage to large hardwoods. Large hardwoods, therefore, are likely to recover more quickly and be stronger competitors than large pines.

In these watersheds, pines will continue to be important simply because they outnumbered the hardwoods nearly 15 to 1 before the storm. Numbers of small hardwoods were low because these were old-field stands that were planted in pine, and hardwood control in the area has been aggressive over time. In stands of second-growth forest or where hardwood control has been less aggressive, the hardwood response may be more prominent.

The storm also created ecological opportunities for regeneration by exposing mineral soil where trees were uprooted. If the pine seed crop in the autumn of 1994 is large, these seedbeds may soon support plentiful pine regeneration. It will be interesting to monitor seed development in these residual pines, to determine whether the stress of the storm promotes or hinders cone and seed development. However, pine seedlings that become established in the autumn of 1994 will be at a competitive disadvantage relative to hardwood sprouts and released hardwood advance growth.

Because of the storms, we expect the importance of pines to decrease and the importance of hardwoods to increase over the next decade. On national forests and some nonindustrial private holdings, these changes may be acceptable. On industry land and nonindustrial private land managed for pine production, cultural intervention may be required to restore the dominance of pine.

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INFERRING CANOPY DISTURBANCES FROM DENDROECOLOGIAL DATA'

Gregory A. Reams[2]

Abstract-The use of tree rings to data the timing and extent of canopy disturbances is illustrated for baldcypress and red spruce. Past hurricanes strikes along the Louisiana coast are documented by ring-width variation of oktgrowth baldcypress. Influential data points in parameter estimation of a dendroclimatii model for baldcypress are associate with known hurrkanee strikes. For red spruce a parsimonious classification of ring-width growth patterns using functiil data analysis and cluster analysis is presented. Results from the red spruce analysis indites that numerous canopy disturbances throughout New England and New York occurred between the late-930s and 1950. These disturbances are more frequent and extensive than previously imagined.

INTRODUCTION

Over the last several decades there has been increased awareness that natural and human-caused disturbances of forests are more frequent and extensive than previously envisioned. There are numerous methods by which disturbances events can be chronicled and these methods are by their very nature dependent upon the type of disturbance being investigated. Lorimer (1985) provides an excellent discussion on reconstructing disturbances events using nondestructive techniques such as fire scars, soil mounds, canopy structure, diameter distribution, and the use of increment cores to establish age distributions and growth increment patterns.

With an increased emphasis for ecosystem management the development of methods to estimate the occurrence of canopy disturbances and resulting stand development trends in natural forests will be necessary. That natural and human caused canopy disturbances are influential drivers of stand development is a widely known principle to forest managers and scientist. Because initiation of sustained growth increase for a tree is usually the result of a major stand disturbance that reduces among-tree competition, dates of canopy disturbance can be inferred when a large proportion of trees show a synchronous increase in growth. Various types of ring-width growth patterns can suggest diierent disturbance histories for both individual trees and stands.

The purpose of this paper is to present recent developments useful for inferring canopy disturbances from growth increment patterns. Because low-frequency (long-term) and initially abrupt increases in radial growth are most often related to canopy disturbances the potential for reconstructing important disturbances over the life of a stand or least a subset of the stand is possible (Reams and Van Deusen 1993). However patterns of growth increment must be evaluated carefully because climatic anomalies can cause growth patterns that are superficially similar to release from competition (Lorimer 1985). Generally droughts and their corresponding narrow rings do not last more than 5 or 6 consecutive years in most of eastern North American (McIntyre and Schnur 1936, Cook and Jacoby 1977, Lorimer 1985). Because effects of climate on radial growth are usually much shorter term than canopy disturbances it is often possible to eliminate climate as a probable cause for synchronous increases in long-term radial growth.

The use of radial growth in estimating past disturbance histories is readily apparent to those familiar with growth response data from thinning experiments (Harrington and Karnig 1975, Barbour et al. 1992). It is recognized that some tree species do not make ideal candidates for reconstruction of canopy disturbance events because suppressed trees of midtolerant and intolerant species do not always respond to release (McGee 1981).

A key task in estimating occurrence of canopy disturbances is in characterizing and classifying ring-width growth patterns. Two methods for identification of canopy disturbances are presented. The first application involves the use of baldcypress (*Taxodium distichum* (L.) Rich) tree-ring data and regression diagnostics from a dendroclimatic model to identify canopy disturbances from hurricanes. The second method presents a parsimonious classification of ring-width growth patterns using functional data analysis and cluster analysis. How this second method can be used to date canopy disturbances is illustrated with red spruce (*Picea rubens* Sarg.) tree-ring data.

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METHODS

All studies presented share the trait common to all dendrochronological studies, that is, that every tree-ring series is reliably cross-dated. Cross dating is the process by which each ring in a tree-ring series is associated with the exact year of formation (Fritts 1976). This is possible because trees under similar climatic conditions show similar high-frequency (year to year) growth patterns (Douglas 1941). Rigorous cross dating leads to increased confidence in the dating of disturbance events.

Baldcypress and Red Spruce Data

Old-growth baldcypress trees are scattered individually and within small stands throughout many river basins and estuaries in the southeastern United States. After identifying candidate old-growth sites in southeastern Louisiana from remotely sensed images, tree-ring data were collected using standard increment core sampling techniques with a few minor modifications that greatly increased the temporal depth of our tree cores. Increment cores were extracted from the base of each tree at heights between 2 and 4.5 feet above the ground, depending on the soundness of the main stem. In prior studies involving old-growth baldcypress, researchers sampled above the well-known root buttress (Stahle et al. 1988). Trees from our study sites show little to no buttressing, but exhibited heartrot (and therefore hollowness) that increased with sampling heights. The heartrot is caused by the fungus, *Stereum taxodi*, and is prevalent in old-growth baldcypress. The fungus gains entrance in the crown and slowly works downward, frequently destroying heartwood to the base of the tree (Wilhite and Toliier 1990). By sampling as close to ground level as possible instead of dbh it was often possible to add hundreds of annual ring-widths.

The baldcypress tree-ring data represent 19 old-growth trees ranging from 400 to 1280 years old. These trees are scattered individuals and small stands located within the Tangipahoa River basin in southeastern Louisiana. Annual increments of each tree core were measured to within 0.001 mm and crossdated using graphical and statistical procedures available in DYNACLIM (Van Deusen 1990).

Red spruce tree rings from a number of different studies throughout the range of species were obtained. High-elevation samples from New York (Whiteface Mt. and Lake Arnold), Vermont (Mt. Mansfield), and New Hampshire (Mt. Washington) were originally used in studies by Johnson and Siccama (1983) and Johnson et al. (1988). Increment cores used in these studies are from dominant and codominant trees within the canopy. The number of tree cores per site range from 37 to 78.

Dendroclimatic Model and Regression Diagnostics for Baldcypress

To evaluate the existence of a hurricane signal in baldcypress ring-width series the following logic was employed. Ring widths from 19 old-growth (>400 yr) baldcypress were measured, crossdated and standardized using the inverse-hypersine transformation:

$$r(i) = \ln(r(i) + \sqrt{[r(i)^2 + 1]})$$

where r(i) is ring-width. A climate-tree growth model based on the standardized ring-widths was fit using OLS analysis. A regression diagnostic that provides information about influential data points and leverage points was investigated. If the regression diagnostic indicated that certain years had large residuals or leverage points then investigate whether these years were associated with known hurricane strikes. Previous studies have shown that standardized ring-widths of baldcypress are positivety correlated with June PDSI (Palmer Drought Severity Index) and spring precipitation on a wide regional basis (Stahle and Cleaveland 1992). Numerous OLS models using monthly average temperature, precipitation and PDSI since 1895-l 991 were fit to the standardized ring-width data. Like previous studies, June PDSI was consistently the single most influential variable. The regression model for coastal Louisiana is: Y= 0.003965 + 0.06067 (June PDSI). Although the regression is significant at the p=0.003 level, the model R^2 of 0.10 is unimpressive. Reasons for the low R^2 will become evident in the results and discussions section.

The regression diagnostic statistic COVRATIO was evaluated for the above regression model. The COVRATIO statistic is based on the ratio of the covariance matrix with all the data, with the covariance matrix that results when the ith observation (row) is deleted (Belsley et al. 1980). Since the two matrices diier only by the inclusion of the ith row in the sum of squares and cross products, values of this ratio near unity can be taken to indicate that the two covariance matrices are close, and the estimated coefficients are insensitive to deletion of the observation. Values furthest removed from unity indicate that they influence the estimated coefficients and therefore warrant further investigation.

Cluster and Functional Data Analysis for Red Spruce

A second-degree orthogonal polynomial of the form

$$y = b_0 f_0(x) + b_1 f_1(x) + b_2 f_2(x_2),$$

where the $f_i(x_i)$ are the orthogonal polynomials in x of the ith degree, was fit to the last 41 years (1940-81) of radial growth for the high-elevation red spruce tree

rings. The coefficients were then used as input to a clustering algorithm in a search for common growth patterns at each site.

Various types of ring-width growth patterns can suggest different histories for both individual trees and stands (Lorimer 1985). Clustering routines that employee partitioning methods are particularly useful when characterization of the data is desired. Partitioning methods *construct* k clusters, with k given by the user. Not all values of k lead to "natural" clusterings, so it is recommended that several values of k be selected; the k *that* retains a clustering which appears to give rise to the most meaningful interpretation should be used. it is also possible to choose k based on numerical criterion. Experience indicates that k suggested by a numerical criterion and that by ocular estimation are often the same (Reams and Van Deusen 1993).

The clustering program, based on the algorithm PAM (partitioning around medoids) searches for k representative objects among the objects of the data set. In the PAM algorithm, the representative objects are medoids of the clusters (Kaufmann and Rousseeuw 1987). After finding a set of k representative objects, the k clusters are constructed by assigning each object of the data set to the nearest representative object. To achieve "good" clustering, the representative objects must be chosen so that they are centrally located in the clusters they define. In this way the average distance of the representative object to all others in the cluster is minimized. For this reason, such an optimal representative object is called the medoid of its cluster (Kaufmann and Rousseeuw 1990).

In this type of analysis it is important to remember that the basic observed response is a growth curve rather than the original radial growth data. Such an analysis is commonly referred to as functional data analysis (FDA) in the statistical literature (Ramsay and Dalzell 1991) and offers a more natural analysis of growth trend information than would be provided by analyzing the actual yearly data points.

RESULTS AND DISCUSSION

Baldcypress

The COVRATIO residuals indicate that 1916, 1970 and the late 1940s are influential data points (Figure 1). All of these years followed known hurricane strikes (Figure 2). Other influential data points such as 1905 and the mid-l 950s appear to be associated with drought (negative June PDSI values).

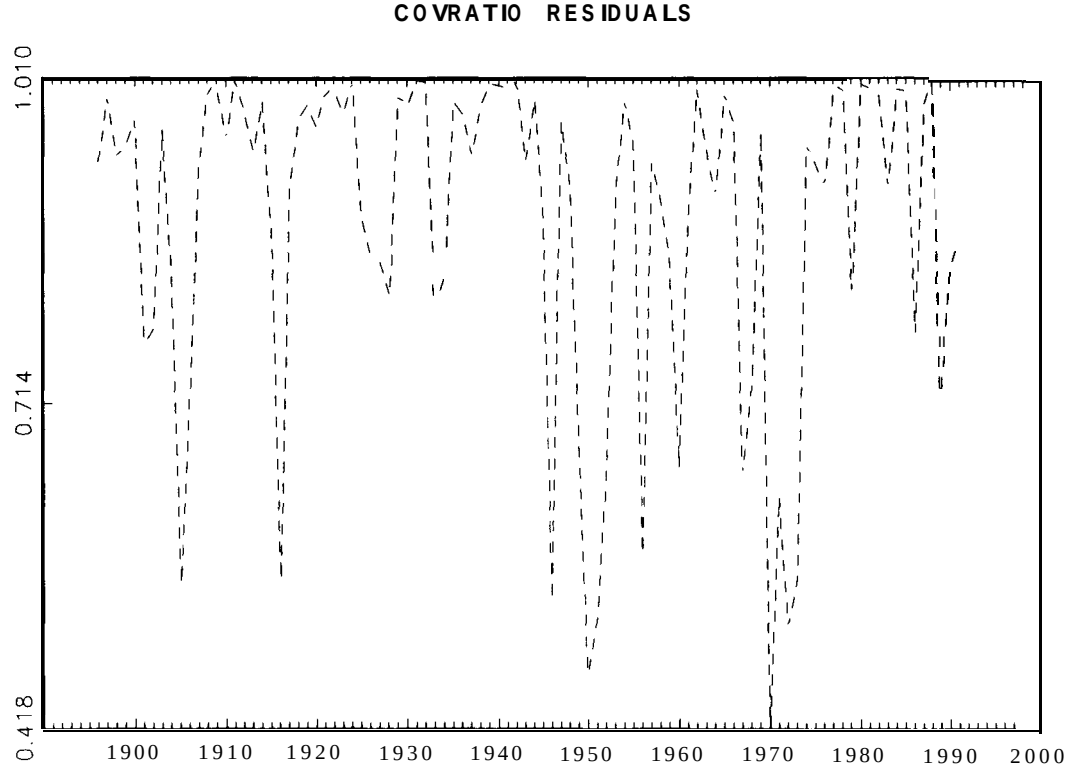

Figure I-COVRATIO residuals from the baldcypress dendroclimatic model. Values furthest from unity are data points that heavily influence estimated coefficients. Residuals for the year 1916, 1970, and the late 1940s all coincide with known hurricanes.

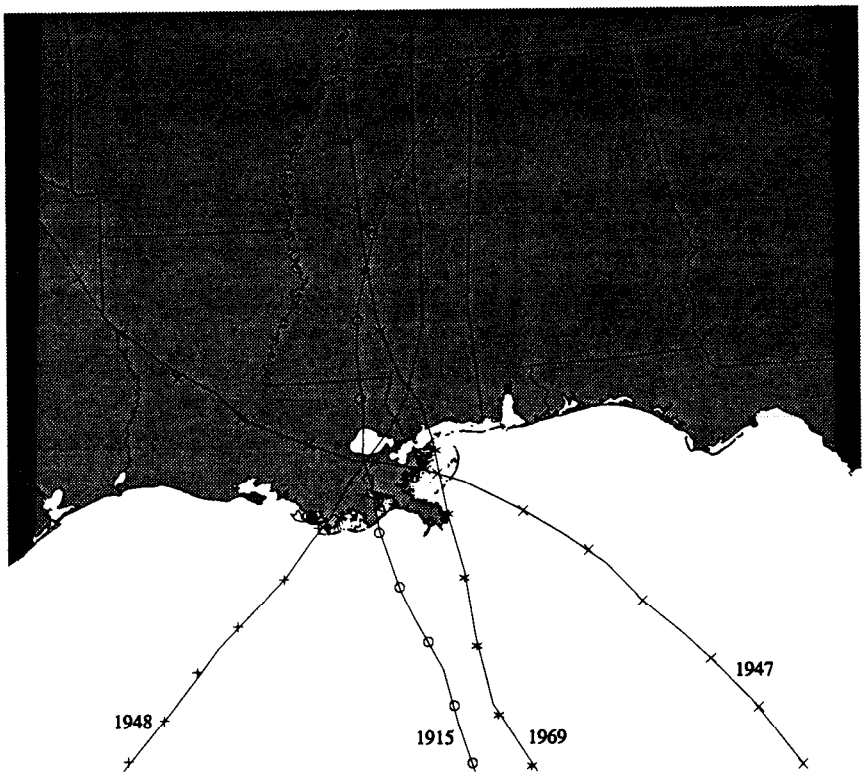

Figure 2-Paths of hurricanes in the vicinity of New Orleans since 1915.

From the COVRATIO regression diagnostic it appears that the most influential data points are associated with summer drought and hurricanes. Both phenomena result in small annual rings, the possible mechanisms for reduced ring widths associated with the drought signal in baldcypress have been discussed by Stahle and Cleaveland (1992). A possible mechanism for small rings following a hurricane is the reduction in foliage through lose of small and large branches. Francis and Gillespie (I 993) related maximum wind gust speeds during Hurricane Hugo to tree damage. They found that large trees were at greater risk than smaller trees and that crown and bole damage began at speeds of about 60 km/h, and increased rapidly with gust speed to about 130 km/h. Personal observations of baldcypresa condition following Hurricane Andrew in July-August of 1992 in southern Louisiana were similar to findings by Francis and Gillespie (I 993) in that larger/older cypress lost individual large branches, while smaller/younger cypress are relatively undamaged. Loope et al. (I 994) also report that nearly all old-growth baldcypress (>300 years) from Corkscrew Swamp in southwestern Florida have lost upper portions of stems and major branches as a result of recent (Hurricane Andrew, 1992) and past hurricanes.

Red Spruce

The majority of mountain sites are represented by two clusters (Figure 3). From Figure 3 it is clear that between 29% (Mount Mansfield, medium elevation) and 68% (Whlteface Mountain, medium elevation) of the trees show a growth increase in the 1940s followed by a growth decrease in the 1960s for all sites. Across all mountains sites approximately 46% of the trees show a large increase in growth in the 1940s followed by a decrease in the 1960s (row 1, Figure 3). Another 45% of the trees are classified as showing a generally decreasing rate of growth over the last 40 years (row 2, Figure 3). Several sites (Figure 3, Whiteface Mountain high and low, Mount Mansfield low) have a cluster of trees that have generally increased growth over the last 40 years. A concave up growth pattern is evident for a cluster of trees (32%) at the medium elevation on Whlteface Mountain.

Dates of canopy disturbances can be inferred when a large proportion (cluster) of trees show a synchronous release from suppression or rapid growth over 1 or 2 decades (Lorimer 1985). Results from the cluster analysis for high-elevation red spruce indicate that approximately 46% of the trees show a large increase in growth in the 1940s followed by a decrease starting in about 1960 (row I, Figure 3). Initiation of sustained

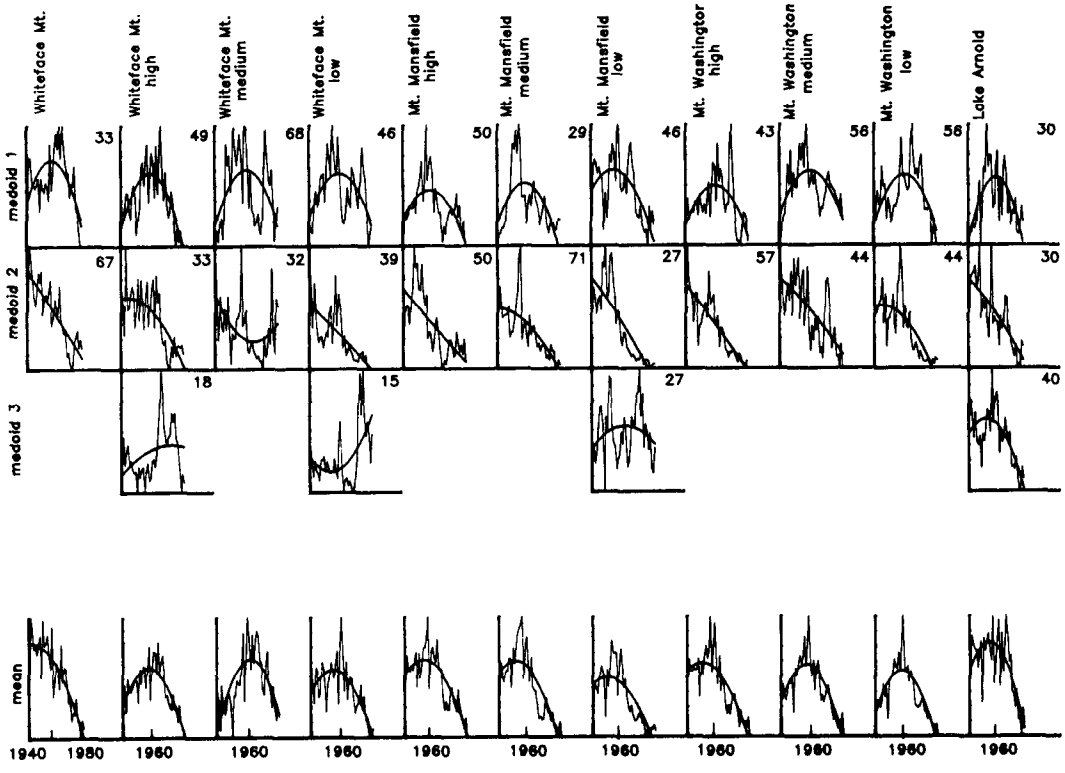

Figure 3-Medoids of clusters based on radial growth patterns (1940-1981) for high-elevation red spruce sites. The number in the upper right corner is the percentage of trees assigned to that cluster.

growth increase are usually the result of a major stand disturbance that reduces among tree competition. Studies of accelerated growth following release from competition indicate that, in general, the response is quicker and more striking in shade-tolerant species such as red spruce (Baker 1950). These results indicate that a large canopy disturbance likely occurred throughout the region in the late 1930s through the 1940s.

The 1940s growth increase seen throughout the northeast is coincident with a number of documented region-wide disturbance events that occurred between the late 1930s and 1950. in particular, the 1938 hurricane stands as one of the greatest single events in the meteorological history of the region. The storm caused widespread forest blowdown throughout the interior of New England, affecting 10 x 10^6 to 14 x 10^6 acres over seven states (Reams and Van Deusen 1993). Wind speeds atop Mount Washington gusted to 162 mph with a sustained speed of 136 mph. The hurricane passed equidistant between Mount Mansfield and Whiteface Mountain. in addition to wind damage and logging, a region-wide birch dieback epidemic and beech bark disease removed significant hardwood competition in mixed spruce-hardwood stands, thus giving greater occupancy of the site to residual trees. Nash et al. (1951) estimated that 67% of the birch in Maine had died, with about 15% of the remaining birch in a dying condition. Damage in the Adirondacks of New York was not as severe, where approximately 25% of the white birch died; however, mortality was usually greater on mountain slopes (Millers et al. 1989). Beech bark disease cause significant mortality throughout the northeast (e.g. 24% in New Hampshire and 50% in Maine) starting in the 1940s (Millers et al. 1989).

CONCLUSION

Canopy disturbance signals from hurricanes and other natural disturbances are recorded by individual tree ring-width variation and can be detected by a number of statistical methods. Regression diagnostics indicate that the most influential data points effecting baldcypress dendrociimatic parameter estimation are those years associated with hurricane strikes. Although it appears that the hurricane and drought signal in baldcypress are nearly identical there is one notable difference in that there is a large increase in high-frequency variation associated with hurricanes that is not present during drought periods. Crown damage to these old-growth cypress appears to be the most

likely mechanism by which passing hurricanes are recorded.

The identification of a region-wide increase in red spruce tree growth in the early 1940s-1960 indicates that natural disturbances such as hurricanes and disease are not only frequent but even more extensive than previously imagined. As a result of major stand disturbances and therefore reductions in among-tree competition, red spruce growth appears to have increased during the 1940s for nearly 50% of all red spruce trees throughout New England and New York.

That canopy disturbances are influential drivers of current stand characteristics and future stand development is a widely known principle to forest managers and scientist, Because initiation of sustained growth increase for a tree is usually the result of a major stand disturbance that reduces among-tree competition, dates of canopy disturbance can be inferred when a large proportion of trees show a synchronous increase in growth. Because various types of ring-width growth patterns suggest different disturbance histories for both individual trees and stands the two methods presented can be valuable tools in assisting researchers and foresters in chronicling the attainment of current and future stand characteristics.

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GROWTH AND SURVIVAL PREDICTION FOR HARDWOODS IN THE MINOR STREAM BOTTOMS OF MISSISSIPPI'

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Abstract—Remeasurement data from permanent plots located in the minor stream bottoms of Mississippi were used to develop growth and survival prediction equations for bottomland hardwood species on an individual tree basis. The basal ares growth prediction equations were fit using weighted multiple linear regression. Survival was predicted for the stand, agsin using weighted multiple regression, and partitioned by diameter class and species using conditional probability.

INTRODUCTION

Bottomland hardwoods are an important resource to the timber industry in the South. However, relatively little effort has been directed toward modelling the growth and yield of such species. Makeshift sources of yield information regarding bottomland forests have included silvicultural and/or management studies (e.g., Putnam et al. 1960), as well as continuous forest inventory records maintained by some industries. More recent information in the form of variable density yield tables (McClure and Knight 1984, Franco 1988) is also available. Finally, estimates of growth have been produced for broad species groups from plots located across the southern coastal plain (Roeder and Gardner 1984, Mengel and Roise 1990). The only example of an individual tree model designed specifically for bottomland hardwoods was produced by Kenney (1983) using a very limited data set.

OBJECTIVE

The objective of this study was to develop a distance independent individual tree growth and yield model for bottomland hardwoods in the minor stream bottoms of Mississippi. Targeted species, or species groups, were sweetgum, *Liquidambar styraciflua* L., and the red oak group (including cherrybark oak, *Quercus pagoda* Raf., water oak, Q. *nigra* L., willow oak, Q. *phellos* L., and shumard oak, Q. *shumardii* Buckl.).

METHODS

Data

The plots for this study (a total of 150) were installed from September 1981 to July 1982. The plots were placed in undisturbed, unmanaged, even-aged red oak-sweetgum stands found in minor stream bottoms which had the following characteristics (Franco 1988): (1)sweetgum and red oak species were to have accounted for a minimum of 75 percent of the plot basal area; (2)the required minimum basal area for either the red oaks or sweetgum on the plot was 20 percent; (3) minimum plot basal area of 60 square feet; (4)minimum plot size of 0.1 acre (no maximum plot size was established; however, each plot had to contain at least 50 trees); and (5) minimum stand age was 20 years (no maximum age was established).

The following data were recorded for each tree in the plots: species, dbh, crown class, tree grade, damage codes and magnetic azimuth and distance from plot center. During the remeasurement period, August 1992 to May 1993, 39 plots were eliminated due to cutting or other disturbance. For each tree within the remaining 111 plots, the original tree attributes were remeasured and the following additional data were recorded: mortality, ingrowth trees (trees which became ≥3.5 inches dbh over the last 11 years), tree heights of a randomly selected subset of trees (10 oaks, 5 sweetgum, and 7 "others"), and age and height of several dominant trees for each plot (to check site index). For a more detailed description of the original and remeasurement data see Franco (1988) and Perkins (1994).

Growth Prediction

Basal area growth for individual trees was predicted with multiple linear regression, using weighted least squares methodology to correct problems with the heteroscedasticity of residuals. Both individual and combinatorial tree and stand variables were considered for these models, respectively.

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Mortality Prediction

A three stage approach to mortality prediction was developed: (1) estimation of overall mortality (trees per acre) during a given time period; (2) allocation of mortalii by diameter class; and (3) distribution of mortalii among species, within diameter class. Overall mortalii was predicted using multiple regression. Weighting was necessary to alleviate problems with heteroscedastic residual patterns. The occurrence of mortalii by diameter class was then examined. Although other approaches were tried, the simple and effective technique of apportioning mortality by the average percent across all plots was adopted. Finally, mortality within each diameter class was allocated among species using conditional probability and Bayes' Theorem.

RESULTS

Growth Prediction

Table 1 presents the coefficients for the basal area growth prediction equations. One regression equation was developed for each of the following species or species groups: cherrybark oak (CB), water oak (WT), willow oak (WL), shumard oak (SH), sweetgum (SG), and the white oak group (WH), which consisted of white oak, Q. *alba* L., and swamp chestnut oak, Q. *michauxii* Nutt.. Because weighted regression was used, indices of fit were calculated rather than multiple R^2 values. Index values ranged from 0.5096 for water oak, to 0.7380 for the white oak group.

Mortality Prediction

The regression equation to predict expected overall mortalii for a time period of 11 years (the length of the remeasurement period in this study) was

$$WA = -31.2916 - 1.5303 \left(\frac{TPA}{AVDBH} \right) + 0.48477\ TPA \quad [1]$$

where,

MPA = mortality per acre (#trees)
TPA = trees per acre
AVDBH = average dbh of the stand

The index of fit for the regression was 0.5584.

Table 1 -Coefficients for the prediction of basal area growth by species, and the associated index of tit for each model.

	Species[a]					
Variable[b]	CB	WT	WL	SH	WH	SG
INT	.06668	.04110	.01958	-.00329	.16701	-.03835
AVBA		.14889				.02698
BAT			.22176	.24546		
DBH	.03063	.02096			.05316	
LDBH	-.08797				-.28114	.12769
IOAGE			1.76262			
OAGE	-4.26E-4	-.00391		-9.91E-4	7.10E-4	
SI	-4.58E-4	3.93E-4				
RABASE	.07977	.11439	.08861	.02419	.03173	.04254
RBASE		-18.0017	-17.9916			6.86664
TPA	-6.98E-5	-2.15E-4	-2.37E-4			-3.73E-5
IFIT	.7298	.5096	.6887	.7316	.7380	.5470

'Species codes:
CB = cherrybark oak
SH = shumard oak
WL = willow oak
SG = sweetgum
WH = white oak group
WT = water oak

"Variable codes:
INT=intercept
AVBA=basal area per acre/trees per acre
BAT=basal area per tree
DBH=initial tree diameter
LDBH=natural log of DBH
IOAGE=1/initial age of stand
OAGE=initial age of the stand
SI=site index
RABASE=BAT/AVBA
RBASE=BAT/basal area per acre
IFIT= index of fit

The predicted mortality (trees per acre) was distributed by diameter dass using the percentages shown in Table 2. These percentages were generated by averaging across all plots. Species were grouped as red oak (water, willow, cherrybark, and shumard), sweetgum, other hardwoods (commercial species other than red oaks), or non-commercial. Finally, the partitioning of mortality by species group within a given diameter class was accomplished through the use of the average ratios of mortality to occurrence shown in Table 3. The only exception to the use of average ratios was the red oak group. The average ratio used for red oak changed by diameter class as follows: 2.11: 1 for the 4-7 inch classes; 1.39: 1 for the 8-l 1 inch classes; and 1.08:1 for the 12 inch and greater classes.

Table 2-Average percent mortality attributed to each diameter class, across all plots.

Diameter Class	Percent Mortality
4"	37.70
5"	19.87
6"	14.75
7"	8.20
8"	5.74
9"	2.87
10"	2.11
11"	1.48
12"	1.24
>12"	6.24

Table 3. Ratios of mortality to occurrence by species, within diameter class.

Diameter Class	Species			
	NC	OH	RO	SG
4"	0.48:1	0.82:1	1.74:1	1.04:1
5"	0.54:1	1.05:1	2.39:1	0.81:1
6"	0.89:1	1.05:1	2.01:1	0.71:1
7"	0.58:1	0.72:1	2.32:1	0.63:1
8"	1.67:1	0.92:1	1.38:1	0.86:1
9"	5.20:1[b]	1.63:1	1.34:1	0.67:1
10"	0.00:1	1.60:1	1.54:1	0.46:1
11"	M[c]	0.79:1	1.31:1	0.72:1
12"	M	0.98:1	1.17:1	0.67: 1
>12"	1.40:1	1.73:1	0.99:1	0.86:1
Average	0.79:1	1.13:1	1.62:1[d]	0.74:1

Species group codes: RO = red oaks
SG = sweetgum
NC = noncommercial species
OH = other hardwoods

All the mortality due to loblolly (ratio not used).
M = missing case. No observations for these cells.
Average replaced by several.

These ratios, when multiplied by the percent occurrence, produced the conditional probability of mortality given that a tree falls into a particular species group. Bayes' Theorem was then used to estimate the conditional probability that trees of a given species group would die, given a certain level of expected mortality.

Example Mortality Calculation

Assuming that using equation 1 for a particular stand, we can expect a total of 100 trees per acre to die over a set period of time. Also assume that the percent occurrence by species group (from a tree list) were as follows: 30% SG, 10% RO, 20% OH, and 40% OH. Looking at a single diameter class, the S-inch class, we can expect 19.67% of the total mortalii, or approximately 20 trees out of the expected 100 to die (from Table 2). To allocate these 20 trees by species we then make use of the ratios in Table 3. Specifically, for sweetgum, the calculation would be as follows:

$$P(SG|m) = \frac{(.3)[(.3)(.74)]}{(.3)[(.3)(.74)]+(.1)[(.1)(2.11)]+(.2)[(.2)(1.13)]+(.4)[(.4)(.79)}$$

$$= 0.2568$$

Therefore, 25.68% of the 20 trees in the 5-inch class, or approximately 5 trees, would be assigned to sweetgum. This calculation would be repeated for each species group that occurred in the class, and for every diameter class, until the expected overall mortalii was assigned to the tree list.

The results of this study represent the foundation for future growth and yield work with bottomland hardwoods. Well researched and documented growth and yield systems are critical to the improvement of bottomland hardwood management and decision-making. Further research efforts will be directed toward expanding the range of sites and species mixes, and extending the models to managed hardwood stands.

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A SITE INDEX EQUATION FOR DIRECT-SEEDED SLASH PINES IN LOUISIANA'

Q. V. Cao, V. C. Baldwin, and R. E. Lohrey'

Abstract-Remeasurement data from 157 permanent plots were used to construct a site index equation for direct-seeded stash pines (*Pinus elliottii* var. *elliottii* Engelm.). These 0.1 -acre plots were established in stands throughout Louisiana. Candiite models were base-age invariant so that the base age (or index age) could be changed anytime without having to refit the equations. Models were evaluated based on their performances in projecting stand height over time, in terms of mean difference (between observed and prediied height), mean absolute difference, and fit index (similar to R^2). Coefficients and site index curves from the final model are presented and discussed.

INTRODUCTION

Site index equations are used to estimate the potential of an area to produce timber and also used to project stand height over time. Site index curves and/or equations have been published for slash pine (*Pinus elliottii* var. *elliottii* Engelm.) natural stands (USDA Forest Service 1929, Schumacher and Coile 1960, Bennett 1970, Farrar 1973) and plantations (Bennett et al. 1959, Coile and Schumacher 1964, Bailey et al. 1973, Bailey et al. 1982, Border et al. 1984, Zarnoch and Feduccia 1984, Lenhart et al. 1986).

Lohrey (1987) constructed site index curves for direct-seeded slash pine stands, using an equation form considered by McGee and Clutter (1967). The objective of this study was to evaluate Lohrey's (1987) equation and other site index models in order to develop an appropriate equation to predict stand height for direct-seeded slash pines.

DATA

Data were from O.l-acre permanent plots established in direct-seeded slash pine stands throughout Louisiana. Available for this study were 157 plots with more than one measurement each, ranging from ages 8 to 28 (Table 1). Precommercial thinning had been applied at age 3 or 4 years to 62 of the 157 plots, but no plots were thinned at older ages. More detail about this data set can be found in Lohrey (1987). Table 2 shows the distribution of 655 height-age observations by age and site index. There were a total of 498 growth periods.

In order to select an appropriate site index model for this data set, the data were randomly separated into a fit data set (77 plots) for estimation of regression coefficients and a validation data set (80 plots) for evaluation of the models in predicting stand height.

Table 1. Distribution of 157 plots by measurement age

No. of Plots	Measurement Ages
1	8, 11, 14, 17
10	8, 11, 14, 17, 20
7	8, 11, 14, 17, 20, 23
18	8, 11, 14, 19
35	8, 12, 17, 22, 27
18	8, 13, 18, 23
1	8, 17, 22, 27
3	9, 13, 18
13	9, 13, 18, 23, 28
9	9, 15
3	9, 15, 20
21	10, 15, 25
18	11, 14, 17, 22

MODELS CONSIDERED

Table 3 lists seven site index models that were included in the analysis. All of these models are base-age invariant, i.e. the base age can be changed without refitting the equations. Some of these models originated from height-age equations of the form H = f(A). These models were developed by Schumacher (1939), Chapman-Richards (Chapman 1961 and Richards 1959), Bailey and Clutter (1974), and Lohrey (1987). The rest of the site index models, derived from differential equations, were those by Clutter and Lenhart (1968), Amateis and Burkhart (1985), and a new model modified from Clutter and Lenhart's (1968) equation. The letter a included in the equation numbers (e.g., eq. la) corresponds to the original equations. Coefficients of the site index equations were

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Table 2. Distribution of height-age observations by age and site index

Age (years) from seed	Site index in feet (base age 25 years) [a]						
	≤35	3645	46-55	56-65	66-75	≥76	Total
	No. of observations						
8-10	0	2	15	53	67	2	139
11-12	5	10	5	43	26	0	89
13-14	5	12	16	20	35	0	88
15-16	0	0	0	1	30	2	33
17-18	5	12	18	43	28	0	106
1 g-20	0	0	0	12	25	1	38
21-22	5	10	5	32	2	0	54
23-24	0	2	11	8	17	0	38
25-26	0	0	0	1	20	0	21
27-28	0	2	13	32	2	0	49
Total	20	50	83	245	252	5	655

[a] Site index for each plot was interpolated from observed height values. if the last measurement of a plot was at an age below 25 years, its site index was predicted from Lohrey's (1987) site index equation.

Tabie 3. List of site index models included in the analysis

Model	No.	Equation [a]
Schumacher (1939)	I a	$ln(H) = b_0 + b_1/A$
	Ib	$H_2 = H_1 \exp\{b_1 (1/A_2 - 1/A_1)\}$
Lohrey (1987)	2a	$\ln(H) = b_0 + b_1/A + b_2/A^2$
	26	$H_2 = H_1 \exp\{b_1 (1/A_2 - 1/A_1) + b_2 (1/A_2^2 - 1/A_1^2)\}$
Chapman-Richards	3a	$H = b_0 [1 - \exp(b_1 A)]^{b_2}$
	3 6	$H_2 = H_1 \{[1 - \exp(b_1 A_2)] / [1 - \exp(b_1 A_1)]\}^{b_2}$
Bailey and Clutter (1974)	4a	$\ln(H) = b_0 + b_1 A^{b_2}\}$
	46	$H_2 = \exp\{b_1 + [ln(H_1) - b_1] (A_2/A_1)^{b_2}\}$
Clutter and Lenhart (1968)	5a	$dyldx = co + c_1 y + c_2 x$
	5b	$H_2 = \exp\{b_1 + b_2/A_2 + [ln(H_1) - b_1 - b_2/A_1] \exp[b_3 (1/A_2 - 1/A_1)]\}$
Amateis and Burkhart (1985)	6a	$dy/dx = b_1 y + b_2 y/x$
	6b	$H_2 = \exp\{ln(H_1) (A_1/A_2)^{b_2} \exp[b_1 (1/A_2 - 1/A_1)]\}$
New model	7a	$dyldx = c_0 + c_1 y + c_2 \exp(c_3 x)$
	7b	$H_2 = \exp\{b_1 + 4 \exp(b_3/A_2) + [ln(H_1) - b_1 - 4 \exp(b_3/A_1)] \exp[b_4 (1/A_2 - 1/A_1)]\}$

[a] where H = average height of the dominants and codominants at age A,
$Y = ln(H)$,
$x = 1/A$,
H_1 = average height of the dominants and codominants at age A_1.

obtained through formulation of height growth equations (or difference equations), denoted by the letter *b* in the equation number (e.g., eq. *b).* Cao (1993) reported superior estimation of coefficients from height growth equations as compared to other formulations.

DEVELOPMENT OF A NEW MODEL

The differential equation proposed by Clutter and Lenhart (1968) has the form:

$$dy/dx = c_0 + c_1 y + c_2 x \quad (5a)$$

where y = ln(H),
H = average height of the dominants and codominants in feet,
x = 1/A,
A = stand age from seed in years, and
c_i = coefficients.

The last term of equation (5a) can be modified as follows:

$$dy/dx = c_0 + c_1 y + c_2 exp(c_3 x) \quad (7a)$$

Equation (7a) resulted in the following height growth equation:

$$H_2 = \exp\{ b_1 + b_2 \exp(b_3/A_2) + [\ln(H_1) - b_1 - b_2 \exp(b_3/A_1)] exp[b_4 (1/A_2 - 1/A_1)] \} \quad (7b)$$

where H, and A_i are stand height and age, respectively, at time i.

MODEL EVALUATION

Coefficients of the seven site index equations were obtained from consecutive height-age pairs from the tit data set. Then the performances of these models were evaluated using the validation data set. All possible combinations of projection lengths from A, to A_2 from the validation data set were divided into three groups: 3-5 years, (b) 6-10 years, and (c) 1 l-l 9 years. Stand height H_2 at age A_2 was predicted from height H, at age A, using each of the seven site index models. The height prediction abilities of the site index models were evaluated based on the following three criteria:

Fit index: similar to R^2.

$$FI = 1 - \{\Sigma (H_i - Hp_i)^2 / \Sigma (H_i - H_{avg})^2\}$$

Mean difference

$$MD = \Sigma (H_i - Hp_i) / n$$

Mean absolute *difference:*

$$MAD = \Sigma |H_i - Hp_i| / n$$

where H, and Hp_i are the observed and predicted height of the ith stand, respectively, H_{avg} is the average stand height, and the summation sign includes i from 1 to n.

RESULTS AND DISCUSSION

Parameter estimates for the site index models were obtained from 243 growth periods of the fit data set (Table 4). Table 5 shows evaluation statistics computed for each model based on the validation data set. Ail models predicted height well for short-term projection periods (3-5 years) but their performance declined when the projection length increased (1 l-19 years).

Table 4. Parameter estimates for site index models for direct-seeded slash pine stands

Model	b_1	b_2	b_3	b_4
Schumacher (1939)	-14.28512			
Lohrey (1987)	-19.53314	32.50328		
Chapman-Richards	-0.07174	1.85264		
Bailey and Clutter (1974)	5.28422	-0.63893		
Clutter and Lenhart (1968)	4.27504	-22.34150	7.49727	
Amateis and Burkhart (1985)	-3.62265	-0.02661		
New model	4.50058	1.36852	-26.44333	8.05336

Table 5. Evaluation statistics for the site index models for direct-seeded stash pines

Model	Projection length 3-5 yrs (n=238)			Projection length 6-l 0 yrs (n=238)			Projection length 1 l-l 9 yrs (n=238)		
	FI (%)	MD (ft)	MAD (ft)	FI (%)	MD (ft)	MAD (ft)	FI (%)	MD (ft)	MAD (ft)
Schumacher (1939)	95.87	0.19	1.84	79.47	-0.18	3.75	29.20	2.30	6.28
Lohrey (1987)	96.80	-0.01	1.57	84.43	-0.76	3.16	44.41	1.68	5.27
Chapman-Richards	96.65	0.004	1.63	84.19	-0.81	3.19	44.01	1.77	5.27
Bailey and Clutter (1974)	97.58	-0.39	1.44	91.57	-1.01	2.33	78.27	-0.68	3.10
Clutter and Lenhart (1968)	97.78	-0.29	1.35	91.72	-0.99	2.31	79.89	-0.24	3.03
Amateis and Burkhart (1985)	95.46	0.23	1.88	74.46	-6.42	3.99	-19.45	3.46	7.84
New model	97.97	-0.34	1.30	93.12	-0.81	2.12	80.94	-0.49	2.90

Note: FI = fit index; MD = mean difference; MAD = mean absolute difference.

In general, anamorphic site index curves (Schumacher, Lohrey, and Chapman-Richards) did not perform as well as their polymorphic counterparts. A notable exception is Amateis and Burkhart's (1985) model, which is polymorphic. This model provided extremely poor height prediction for long-term projection periods. On the other hand, the new polymorphic site index model seemed to be most appropriate for this data set, ranking first in terms of fit index and mean absolute difference for all three projection lengths.

FINAL MODEL

Coefficients for the new model (equation 7b) were again obtained from the combined data of all 157 plots. Replacing H_1, A_1, H_2, and A_2 of equation (7b) with S, I, H, and A, respectively, the final site index equation for direct-seeded stash pine stands is:

$$H = exp\{4.41163 + 1.34011\ exp(-22.93305/A) + [ln(S) - 4.41163 - 1.34011\ exp(-22.93305/I)]\ exp[8.04187\ (1/A - 1/I)]\} \quad (8)$$

Fit index = 97.98%; $s_{y.x}$ = 1.82 ft; avg H = 45.48 ft; n = 498.

where H is average height in feet of the dominants and codominants in the stand at age A, and S is site index in feet at base age I. Site index curves generated from this equation were presented in Figure 1.

Equation (8) can be rearranged to predict site index from observed stand height:

$$S = exp\{4.41163 + 1.34011\ exp(-22.93305/I) + [ln(H) - 4.41163 - 1.34011\ exp(-22.93305/A)]\ exp[-8.04187\ (1/A - 1/I)]\} \quad (9)$$

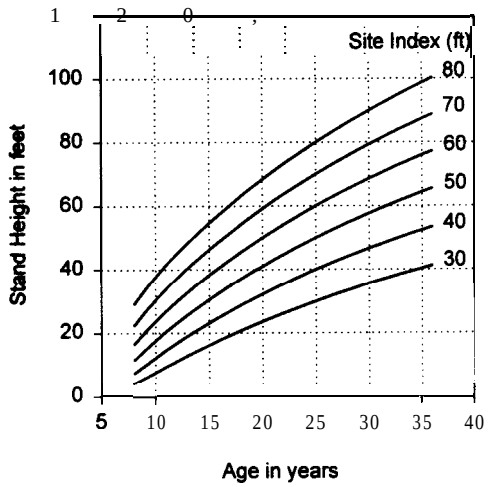

Figure 1. Siie index curves (base age 25 years) for direct-seeded stash pine stands

SUMMARY

Seven base-age invariant site index models were evaluated based on their ability to project stand height for short-, medium-, and long-term projection periods. A new site index model provided superior height prediction compared to the rest of the models, especially for long-term projection. Site index curves were then constructed from this model for direct-seeded slash pine stands.

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AN INDEX OF COMPETITION BASED ON RELATIVE CROWN POSITION AND SIZE'

Dwight D. O'Neal, Allan E. Houston, Edward R. Buckner, and James S. Meadows'

Abstract—A new competitkn index, the Crown Position Index (CPI) was evaluated using a 41-year-old, well stocked, upland hardwood stand in southwestern Tennessee. CPI was based on relatiie crown positkn and crown size as expressed by crown projectiis and relatii heights of crop trees and their competitors. Comparisons were made among CPI, ths Hegyi (1974) index, and a value of Direct Sunlight from the Sii (DSS). Correlations of each measure of competition with 1 and 2 year crop tree diimeter growth ware used as criteria for analysls. The highest r-values were calculated using DSS followed by the Hegyi index and CPI respectively.

INTRODUCTION

Indices that effectively quantify competition among individual trees are elusive concepts. Common density measurements such as basal area are useful for estimating total stand growth but are usually not effective for evaluating the growth response of individual trees to various treatments (Moore et. al. 1973 and Biging and Dobbertin 1992). The need to evaluate factors influencing individual tree growth is especially important with the increasing interest of culturing individual "crop trees" (Hehman and Nyland 1991).

EXISTING INDICES

Holmes and Reed (1991) recognized 3 types of competition indices: (1) influence zone overlap indices, (2) growing space indices, and (3) size ratio indices. Size ratio indices, derived from relative tree size and intertree distance comparisons, are computationally the simplest form of competition index. Several authors (Daniels 1976, Daniels et al. 1986, Lorimer 1983 Holmes and Reed 1991) using a range of species, reported that size ratio indices performed as well or better than the more complex influence zone overlap and growing space indices. The one index that was most consistent was the Hegyi (I 974) index.

Hegyi's original (1974) competition index for jack pine (*Pinus banksiana* Lamb.) was calculated as follows:

$$CI_i = \sum_{j=1}^{n} (D_j/D_i)/DIST_{ij}$$

where CI, = competition index of subject tree i

D, = diameter at breast height (d.b.h.) of subject tree I

D_j = d.b.h. of competitor tree j

$DIST_{ij}$ = distance between subject tree I and competitor j

N = number of competitors.

Hegyl(lQ74) originally defined N to include all trees within a 1 O-foot radius of the subject tree. Daniels and Burkhart (1975) modified the index incorporating a diameter-distance relationship to select competitors. Daniels (1976) found that higher correlations with diameter growth were achieved when the index included more competitor trees (i.e. using a lower basal area factor). Using a basal area factor of 10, Daniels (1976) obtained a correlation coefficient (r) of -0.415 between the index and diameter growth in managed loblolly pine plantations.

The Hegyi index assumes that the relative d.b.h. and distance between the subject and competitor tree reflects their competitive interaction. However, the degree of competition among individuals at a given stocking level depends on crown characteristics (Perry 1985). For example, two trees could have the same d.b.h. and be the same distance from the subject tree, but have crowns that are very different in their influence on the subject tree. The crown of one tree may not project towards the subject tree at all, while the other may overtop the subject tree. While the difference in competitive influence is apparent, indices based solely on d.b.h. and intertree distance would give identical competition values. Incorporating crown characteristics in a competition index should strengthen lts performance, especially when measuring the degree of

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competitive release for a subject tree when only one of two equal diameter trees is removed.

A possible measure of competition that incorporates crown characteristics is the Direct Sunlight from the Side (DSS) value used in a Point System for Hardwood Crown Classes developed by Meadows et al. (unpublished)'. DSS provides a numerical rating (ranging from O-to-IO) of the amount of sunlight from the sides reaching the upper 50 percent of a tree's crown. An open grown tree would receive a DSS point value of 10 (i.e. 100 percent of the upper half of the crown is receiving direct sunlight from the side). If only 50 percent of the tree's crown is receiving direct sunlight from the side then it would receive a DSS value of 5. DSS requires no direct measurement of competing trees.

CROWN POSITION INDEX

The two crown characteristics that may best describe a tree's competitive status are crown position (both horizontally and vertically) and crown size. Foresters make thinning decisions partially based on these 2 factors as well as stem qualii. A competition index based on the measurement of these criteria would incorporate traditional judgement in the evaluation of tree competition.

The Crown Position Index (CPI) evaluated in this study incorporates these variables. It is calculated as follows:

$$CI_i = \sum_{j=1}^{n} ((CP_j + MCR)/D_{ij})(CP_j/MCR)((HT_j - D_{ij})/HT_i)$$

where CI_i = competition index of subject tree i
CP_j = crown projection of competitor j measures in a straight line towards subject tree I
MCR = mean crown radius of subject tree I
D_{ij} = distance between subject tree i and competitor j
HT_i = total height of subject tree i
HT_j = total height of competitor j
N = number of competitors, as determined by a IO BAF prism point taken 2 feet west of the crop tree.

OBJECTIVE

The objective of this study was to evaluate CPI as a measure of competition for upland hardwood crop trees. Specifically, the study compared CPI, the Hegyi index and DSS.

'Meadows, James S., Hodges, John D., Burkhardt, E.C. and Johnson, Robert L [In preparation]. Numerical Rating System to Distinguish Crown Classes of Southern Hardwood Trees. (unpublished manuscript).

STUDY AREA

The study was conducted on Ames Plantation, a research unlt of The University of Tennessee Agricultural Experiment Station, located in southwestern Tennessee. Topography was gently rolling (5 to 20 percent slopes), with soils that were well drained (primarily of the Lexington and Smithdale series). These soils were well suited to upland oaks with an average site index (base age 50 years) of 75 to 85 feet (Flowers 1960).

The study stand was well stocked (average basal area per acre of 120 square feet) and even-aged (41 years old) with a small component of larger, older trees. The primary overstory species were white oak (*Quercus alba* L.), southern red oak (Q. *falcata* Michx.), scarlet oak (Q. *coccinea* Muenchh.), black oak (Q. *velutina*), black cherry (*Prunus serotina* Ehrh.), hickory (*Carya spp.*), red maple (*Acer rubrum* L.) and black tupelo (*Nyssa sylvatica* Marsh.).

METHODS

A randomized complete block design containing 5 blocks each with 2 replicates was used in the study. Each replicate contained 36 cells (35- by 35- feet) and was surrounded by a 35-foot non-treated buffer zone. Treatments were a control and a crop tree release.

The trees in each cell were evaluated and where criteria were met, a single crop tree was selected. The tree that exhibited the greatest potential for attaining the highest value at maturity was selected. Selection was based primarily on stem qualii, crown position, and species, wlth white oak being the most desirable. When possible black oak was selected as the crop tree if no desirable white oak were available. Other acceptable species included southern red oak, scarlet oak and black cherry. Baseline data were taken in the winter of 1992-I 993. A summary of the crop tree data is given in Table 1.

Table l-Average d.b.h. (inches), total height (feet), and number of crop trees selected in a 41-year-old upland hardwood stand in southwest Tennessee.

Crop Tree Species	N	Average D.b.h.	Average Total Heiaht
white oak	445	9.9	65
southern red oak	101	9.9	64

Crop trees were released in March of 1993. Each crop tree was released on at least 3, and preferably 4, sides. Any tree (except adjacent crop trees) that was impeding the expansion of the crop tree's crown was felled. Crop tree d.b.h. was remeasured in January 1994 and October 1994. DSS was also remeasured in October 1994.

Crop tree diameter growth was assumed to reflect competitive influence. Correlation coefficients (r) were calculated between diameter growth and each measure of competition. Both 1 year and cumulative 2 year diameter growth were tested. For the control treatment, index values (CPI and Hegyi) were calculated using the baseline data (initial competition). For the release treatment, index values represent the amount of competition removed (i.e. initial competition - competition removed = residual competition). Correlations of diameter growth with DSS for both control and release treatments were made using the values measured in October 1994. Only white oak and southern red oak were tested as small sample size precluded testing other species.

RESULTS AND DISCUSSION

Correlations of 1 year growth in the control treatments with the Hegyi index (r = -0.484) and DSS (r = 0.479) were significant for southern red oak (Table 2). For white oak only DSS had a significant correlation with 1 year growth (r = 0.436). Correlations with 2 year growth were significant for all measures of competition for both white and southern red oak in control treatments. Correlation coefficients with 2 year white oak diameter growth were r = -0.210, r = -0.242, and r = 0.544 for CPI, Hegyi and DSS respectively. Correlation coefficients with 2 year southern red oak diameter growth were r = -0.484, r = -0.514, and r = 0.623 for CPI, Hegyi and DSS respectively. Negative r-values for CPI and Hegyi indices indicate that as values of competition increased diameter growth decreased. Positive r-values for DSS demonstrate that d.b.h. growth increased with increasing side light.

Table 2-Correlation analysis of 1 and cumulative 2 year diameter growth of crop trees in the control treatment with the Crown Position Index (CPI), the Hegyi index and Direct Sunlight from the Side (DSS).

	r-values			
Comoetition	white oak		southern red oak	
Measure	Year 1	Year 2	Year 1	Year 2
CPI	-0.191	-0.210'	-0.345	-0.484*
Hegyi Index	-0.133	-0.242'	-0.484'	-0.514'
DSS	0.436**	0.544"	0.479"	0.623"

* P < 0.05
** P < 0.01

These results are consistent with the findings of Holmes and Reed (1991). The correlation between d.b.h. and crown size appears to be strong enough to allow d.b.h. alone to consistently reflect competitive status in even-aged stands. Crown projection may be overemphasized in CPI as it failed to account for significantly more variation in d.b.h. growth than did the Hegyi index. More definitive guidelines for measuring crown projection should improve CPI. For example, crown projection in the lower portion of a competing crown could have less influence on a subject tree than crown projections in the upper crown. Selecting competitors based on a height-distance relationship as reported by Biging and Dobbertin (1992) might also improve CPI.

Although CPI did not perform better than the Hegyi index it is still apparent that crown characteristics are important when evaluating competition as demonstrated by the correlations between diameter growth and DSS. DSS measures crown positlon as affected by all above ground competition for light, a recognized biological factor influencing individual tree growth. From a practical standpoint DSS is more efficient than either index since only 1 measurement of the subject tree is needed versus arduous measurement of several competing trees. Also DSS emulates a field forester's subjective assessments more closely than CPI. Foresters are trained to evaluate competition in terms of relative crown position. DSS is a quantitative measure of a subject tree's position relative to its immediate competitors.

None of the 3 measures of competition were significantly correlated with diameter growth of released crop trees. A better evaluation will be possible when the crop trees have had more time to fully respond to the release treatments.

CONCLUSIONS

All 3 measures of competition correlated significantly with 2 year diameter growth for both white and southern red oak. Relative crown position as expressed by CPI did not provide a more effective measure of competition than did relative d.b.h. as expressed by the Hegyi index. However, some measure of crown position, such as DSS, was shown to be a better evaluation of competition than using d.b.h. as a surrogate for actual crown characteristics.

ACKNOWLEDGMENTS

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FACTORS AFFECTING CROWN DIMENSIONS IN UNEVEN-AGED LOBLOLLY PINE STANDS'

Paul A. Murphy and Michael G. Shelton[2]

Abstract-Eighty one plots were installed in southern Arkansas and northern Louisiana to investigate the dynamics and growth of uneven-aged loblolly pine, *Pinus taeda* L., stands. Plots were remeasured 5 years after installation. Crown width and crown length were regressed against tree and stand variables. The most powerful explanatory variables for crown width were d.b.h. and total height; the best for predicting crown length were d.b.h., total height, and site index.

INTRODUCTION

Since tree crowns support photosynthesis and transpiration, their size is an important indicator of a tree's ability to survive and grow. Collectively, tree crowns in a stand determine site occupancy and affect the abilii of subordinate vegetation to grow and develop. Crown dimensions have many practical applications, such as construction of competition indices, components of growth and yield models, and as linkages to biological process models. They have been used in remote sensing applications and may have a role in the use of geographical information systems (GIS) for forestry applications. A potential recent application is the use of crown dimensions in calculating fractal dimensions of tree crowns (Zeide and Pfeifer 1991).

Crown width has been the dimension of most interest. An early application was the use of crown width in aerial photogrammetry. Minor (1951) reported on stem-crown relations for the southern pines for use in determining stand volumes from aerial photographs; Baldwin (1982) is a more recent application. Concern for developing measures of stocking that overcome the shortcomings of basal area has also prompted the development of crown width models; some examples are crown competition factor (Krajicek and others 1961), stocking equations (Gingrich 1967), and application of crown competition factor to loblolly pine (*Pinus taeda* L.) plantations (Strub and others 1975). Francis (1986) studied the relationship of crown width with respect to crown class and d.b.h. for several bottomland hardwood species. Smith and others (1992) analyzed crown and basal area relationships of open-grown southern pine species. Guldin (1987) used crown area-d.b.h. relationships to ecologically derive structures in uneven-aged loblolly-shortleaf (*P. echinata* Mill.) pine stands. In addiion, Grano (1957) observed that cone production in loblolly pine trees was strongly related to crown size.

Comprehensive studies of the relationships between crown dimensions and other stand, site, and tree variables have been quite limited. Minckler and Gingrich (1970) investigated crown width-d.b.h. relationships in upland oak (*Quercus* spp.) stands; they found them to be similar to those for open-grown trees and independent of site, crown class, and species. As a part of linking an individual-tree loblolly plantation growth model to a biological process model, Baldwin and others (1993) modeled crown radius as a function of d.b.h., crown length, site index, surviving trees per acre, and number of trees planted, plus an indicator variable for physiographic region. Larocque and Marshall (1994) investigated the effects of spacings and ages as well as tree variables on crown width and length for red pine (*Pinus* resinosa Ait.).

Despite the utility of crown dimension relationships, the lack of information for uneven-aged loblolly pine stands is particularly acute. The only available data are from Guldin (1987), and his equation was developed from only 31 trees in one 40-acre stand in southern Arkansas. We present data from a regional study of uneven-aged loblolly pine stands.

METHODS

Treatment Variables

Uneven-aged stand structures are typically defined in terms of (1) basal area, (2) maximum diameter, and (3) a quotient, termed "q." This quotient is the ratio of the number of trees in a diameter class to the next larger diameter class. For example, if there are 12 trees per acre in the 12-inch class and 10 trees per acre in the 13-inch class, the q value would be 1.2. The quotient is also affected by diameter class width: a q value of 1.2 for l-inch classes would become 1.44 for 2-inch classes. Several guides have been published on how to use these three variables to describe stand structure (Brender 1973, Moser 1976, Murphy and Farrar 1982).

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The effects of basal area, maximum diameter, and site qualii on growth and development of uneven-aged loblolly pine stands are being investigated in our study. Although "q" is one of the principal variables used to define uneven-aged stand structure, experience has shown it to be the least amenable to management, at least initially. Therefore, the other variables were selected in thii first effort and q was fixed. A q of 1.2 was used for thii study; Reynolds (1959, 1969) and Reynolds and others (1984) have observed and used this value in several decades of uneven-aged management of loblolly-shortleaf pine stands.

For treatments, we chose target basal areas of 40, 60, and 80 ft^2 per acre in trees larger than 3.5 inches d. b. h.; target maximum diameters of 12, 16, and 20 inches d.b.h.; and site index ranges of less than 81, 81 to 90, and 91 feet and above (loblolly pine base age 50). Basal areas are kept lower than in even-aged stands to favor the development of pine reproduction. Reynolds (1959) recommended cutting when stand basal area reaches 75 ft^2 per acre to allow pine regeneration to develop. Uneven-aged loblolly pine stands, therefore, should probably not be much above this level at any time during a cutting cycle. A slightly higher basal area (80 ft^2) was chosen to investigate its long-term effects on loblolly pine growth and regeneration. The lowest basal area treatment level of 40 ft^2 probably represents the lower acceptable density limit for management Lower densities approach understocked conditions for uneven-aged stands, and growth is being lost without any concomitant gain in regeneration.

Maximum d.b.h. is somewhat akin to rotation age in even-aged stands. Selection of a larger maximum d.b.h. represents a longer term investment than a smaller maximum d.b.h. A residual maximum d.b.h. of 20 inches probably represents an upper limit for both economic and product-size goals. A 12-inch maximum d.b.h. represents a lower limit for an adequate seed source. The site index classes of this study adequately capture the range of site qualii that is encountered in the West Gulf Coastal Plain. Each treatment combination was replicated three times, and there are 81 plots in all.

Field Installation and Measurements

Candidate stands for plot installation had to have at least 70 percent of the basal area in loblolly pine; no evidence of cutting within the last 10 yearn; no evidence of catastrophic loss from insects, disease, weather, or fire; and a site index that did not vary more than 10 feet over the plot area. Stands that exhibited a reveme J-shaped stand structure were preferred if available.

The stands represented a gamut of conditions: some already exhibited a reverse J-shaped stand structure, while others had a mound-shaped structure more typical of even-aged stands. Most stands had more than one plot installed in them. All 81 study plots are on the Coastal Plain in southern Arkansas and northern Louisiana (fig. 1). Plots were assigned to a residual basal area and maximum d.b.h. treatment as randomly as possible.

Figure l-Locations of the 81 plots of the regional uneven-aged loblolly pine study. Multiple plots occur at locations.

Square 1 .6-acre gross plots included an interior square 0.5-acre net plot. Before harvest, all loblolly pine trees greater than 3.5 inches d.b.h. were inventoried by l-inch d.b.h. classes separately for the 0.5-acre net plot and 1 .l-acre isolation strip. Plots were then marked for harvest to attain their assigned residual structure as defined by residual basal area, maximum d.b.h., and a "q" of 1.2 for l-inch d.b.h. classes. Any shortleaf pines occurring in the plots were cut. All hardwoods with a groundline diameter of 1 inch or larger were injected with herbicide prior to harvest, if possible, but no later than the first growing season after treatment. Plot installation and harvest occurred over a 3-year period beginning in the fall of 1983. All cutting was completed during the early part of the dormant season of each year, and about one-third of the plots were established each year.

After harvesting, all residual loblolly pine trees larger than 3.5 inches d.b.h. on the net plot were numbered, mapped, and measured. D.b.h. was measured to the nearest 0.1 inch using a tape. A d.b.h. mark was painted on each tree to ensure consistency in subsequent measurements. Total height and height to the crown base were measured to the nearest foot on a sample of 20 percent of the trees in each l-inch d.b.h. class. Fiie to 10 height-sample trees suitable for site index calculation were selected for age determination by increment coring. Candidate trees had to show no evidence of past suppression as indicated by ring widths and growth patterns to be used for site index

computation. Site index was computed with the function by Farrar (1973).

The plots were remeasured after 5 years of growth. The same measurements, except tree age, were taken on both surviving trees and ingrowth trees. In addition, crown widths were measured on all height measurement trees. Measurements were taken at the maximum and minimum crown widths to the nearest foot. Measurements were usually at right angles to one another.

Data Summary and Analysis

This analysis was confined to remeasurement data for two reasons: (1) crown widths were not measured during plot installation, and (2) the trees needed a few years to respond to the treatments. The following variables were calculated and expanded to a per-acre basis when appropriate for trees 3.5 inches in d.b.h. and larger at remeasurement: (1) basal area per acre, (2) maximum diameter, (3) site index (loblolly pine, base age 50 years), (4) quadratic mean diameter, and (5) basal area per acre in trees equal to and larger than the subject tree (includes the subject tree). The tree variables d.b.h. and total height were also used in the analysis.

Means and ranges for the data are presented in table 1. The maximum basal area was about 120 ft^2 per acre. This density was from a treatment with a maximum d.b.h. of 12 inches and a residual basal area of 80 ft^2 per acre after cutting. Even though the residual basal area was high, the relatively young trees that remained after treatment grew very rapidly.

Table l-Descriptive statistics for tree, stand, and site variables from a regional, uneven-aged loblolly pine study

Variable'	Mean	Minimum	Maximum
Crown width (feet)	18	4	42
Crown length (feet)	28	2	64
D.b.h. (inches)	10.5	3.5	23.4
Total height (feet)	66	24	112
Basal area larger (ft^2 per acre)	49.0	1.7	119.4
Quadratic mean d.b.h. (inches)	10.4	6.5	15.5
Stand basal area (ft^2 per acre)	75.9	38.5	119.6
Siie index (feet at 50 years)	83	56	97

[a] Tree variables (crown diameter, crown length, d.b.h., and height) are based on 2,340 sample trees; stand and site variables (basal area larger, quadratic mean d.b.h., stand basal area, and site index) are based on data from 81 0.5-acre plots. AU values were measured 5 years after basal area and maximum d.b.h. treatments were imposed.

Crown width and length were plotted with independent variables to detect possible relationships and determine their pattern. Linear regression was selected for analysis, because most relationships were linear or could be appropriately transformed. In addition, thii modeling approach is highly tractable. An initial set of promising variables was chosen, and a preliminary regression analysis was conducted. Residual plots were also used to detect anomalous observations and to test model adequacy. Extraneous variables were eliminated, and reduced models were fitted by ordinary least squares. The method of seemingly unrelated regressions (SAS Institute 1988) was used to account for any correlated errors between the crown width and crown length equations, and least squares with the Gentleman-Giiens orthogonal transformation (SAS Institute 1990) was utilized to mitigate the effects of ill-conditioned data because tree diameters and tree heights were highly correlated. However, neither of these two alternate methods was better than the ordinary least squares estimation; therefore, the ordinary least squares estimates were accepted.

RESULTS AND DISCUSSION

The final variables selected to predict crown width were d.b.h. and total height; for crown length, the square root of d.b.h., total height, and site index were used. The parameter estimates and associated standard errors are given in table 2. The root mean square errors were 2.8 and 5.5 feet, and the R-squares were 0.86 and 0.72 for crown width and crown length, respectively.

Table 2-Parameter estimates and standard errors for linear regressions of crown width and crown length for lobloliy pine trees in uneven-aged stands.

Dependent variable	Independent variable	Parameter estimate	Standard error
Crown width (ft)	Intercept	4.55476	0.24830
	D.b.h. (in)	1 .98753	0.02419
	Total height (ft)	-0.11667	0.00615
Crown length (ft)	Intercept	-10.71498	1.43368
	Square root of d.b.h. (in)	12.61980	0.34536
	Total height (ft)	0.04750	0.01689
	Site index (ft)	-0.04402	0.01645

The negative coefficient for total height in the crown width equation may seem surprising, but earlier studies (Briegleb 1952, Ilvessalo 1950, Smith and Bailey 1964) have also shown this relationship. More recently, Larocque and Marshall (1994) had the same results in a study of stand development of red pine plantations in Ontario, Canada. Additional evidence for the negative effects of height on crown features exist in the biomass

prediction equations for loblolly pine trees from even-aged stands of Nelson and Switzer (1975) and Baldwin (1987). Both studies show a negative coefficient for the height variable in equations predicting crown biomass. The negative effects of height on crown features mean that, for a given diameter, a shorter tree will have a larger and heavier crown than a taller tree. Explanation of this relationship requires some degree of speculation and is more easily visualized in even-aged than in uneven-aged stands. This relationship may reflect the fact that height is affected less by lateral competition than is d.b.h. and apparently crown width. That is why height rather than d.b.h. is used as an index of site qualii. In addition, tree height may be a better indicator than d.b.h. of tree age in uneven-aged stands.

Several explanations can be proposed for the lack of substantial effects of stand-level variables on crown diameter and length: (1) d.b.h. and height have collectively accounted for most of the explainable variation, (2) basal area and maximum d.b.h. treatments had been imposed for only 5 years, and more time may be needed to detect a response, (3) pine basal area was reduced to some degree in even the highest treatment (80 ft^2 per acre), and (4) hardwood-competition control was imposed on all treatments. Since pretreatment conditions were not measured, their effects could not be investigated.

The negative effect of site index on crown length was also surprising. There is no corroboration in the literature, because nobody has apparently looked at this relationship. Though significant, the effects of site index are relatively small. A 1 O-foot increase in site index results in only a 0.4-foot decrease in crown length.

Figure 2 shows predicted crown widths for different d.b.h. ranges and height classes. It also compares our results with those for another uneven-aged pine stand (Guldin 1987) and for open-grown loblolly pine trees (Smith and others 1992). As expected, the equations from our study and Guldin's are below the one for open-grown trees. However, crown diameters from Guldin's equation are only about 2 feet lower that those for open-grown trees, and values from our study are 2 to 5 feet lower than those of open-grown trees. The predictions from our study also fall below Guldin's, with comparable values only for the upper diameters.

Figure 3 shows estimates for crown length by different d.b.h. ranges and height classes for a given site index of 83 feet, the average for the data set. Although height has a small but perceptible effect, most of the change in crown length is attributable to d.b.h. A 40-foot increase in height results in an increase in crown length of only 1.5 feet.

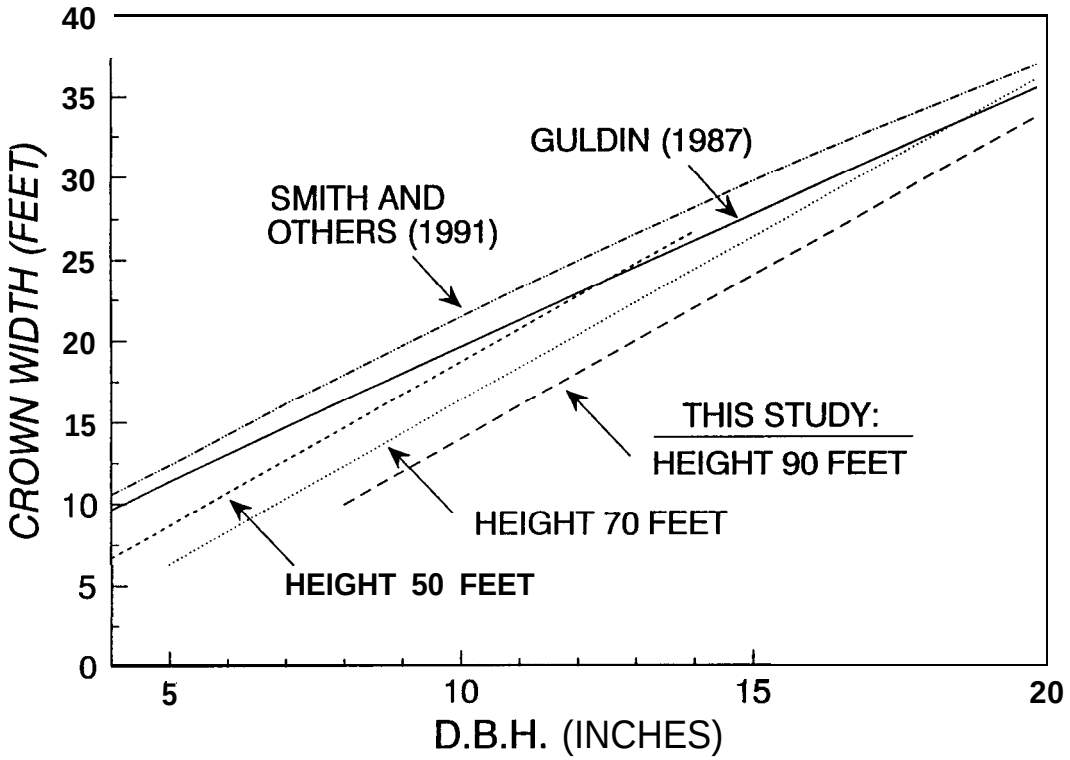

Figure 2.-Calculated values for crown width from this study compared to those from an uneven-aged loblolly-shortleaf pine stand (Guldin 1987) and from open-grown loblolly pine trees (Smith and others 1991). Guldin's (1987) crown area equation was transformed to give crown diameter.

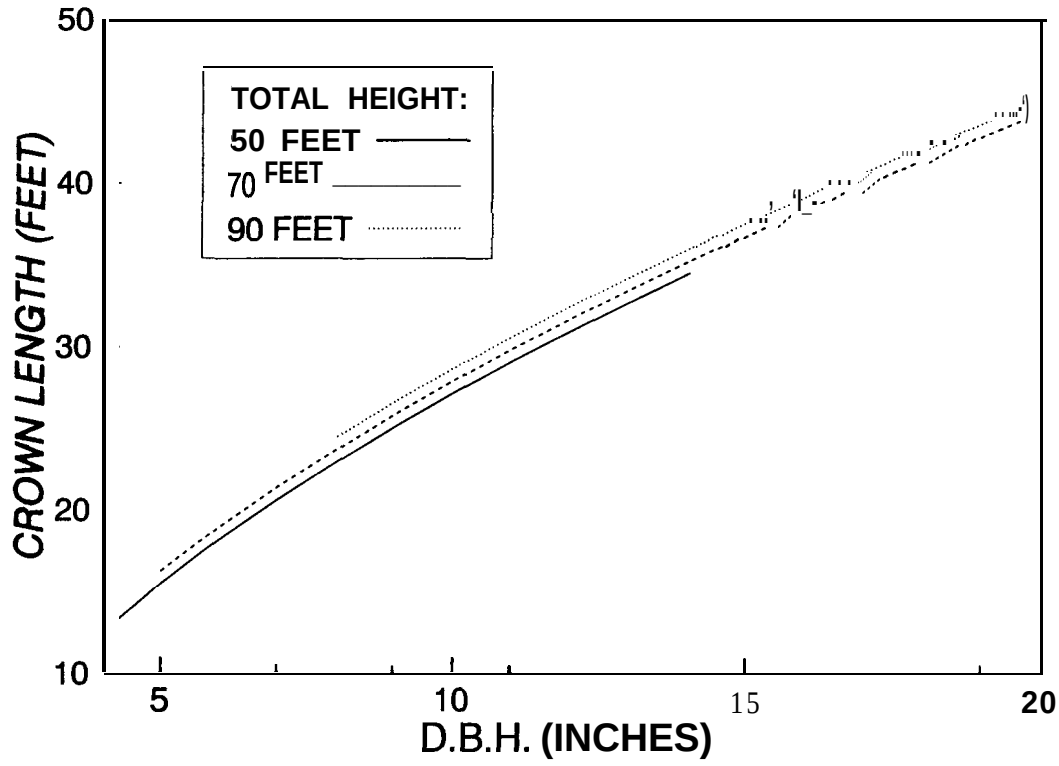

Figure 3--Calculated values for crown length for loblolly pine trees from uneven-aged stands.

The crown width and crown length equations developed here have a wide range of potential applications. A major finding was that tree characteristics alone were generally adequate for modeling crown width, and only tree variables plus site index were needed for crown length. A practical consequence is that use of the equations will be simpler, because only tree d.b.h., tree height, and site index are needed.

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A WEIGHTED LEAST SQUARES DIAMETER MOMENT RECOVERY SYSTEM FOR CUT OVER SITE PREPARED LOBLOLLY PINE PLANTATIONS'

Thomas G. Matney and Keith L. Belli[2]

Abstract-Ths components and structure of a thinned/unthinned growth snd yield simulator for planted loblolly pine (*Pinus taeda* L.) on cutover site-prepared land devakped by the MSU Growth and Yield Cooperative are dedescribed. Prior to the first thinning, a three-parameter Wbbull diameter distributkn mcoverysysternsupportedonstand minimum, and arithmetic, and quadratk mean diameters la empkyed. At the first thinning, or if an initial tree list is supplied as input, a parameter-free least squares adjustment dii moment recovery system is applii to allocate mortality and diameter growth to the elements of the tree list. Because thinning from below can be considered essentially equivalent to heavy competition mortality, the parameter-free mortality allocation procedure is adapted for allocating thinned trees to the before thinning tree list. Copies of a PC-compatible implementation of the model can be obtained by writing to the authors.

INTRODUCTION

Loblolly pine (*Pinus taeda* L.) is the backbone of southern forest products industries. In order to estimate future wood supplies, these industries must have reliable growth and yield predictors for their new generation of loblolly pine stands planted on cutover site-prepared land. In response to this need, cooperative arrangements between universities and forest products industries have been formed to generate growth and yield data bases for these new-generation plantations. This paper describes the thinned stand, growth and yield simulator produced by a cooperative of seven forest products industries and Mississippi State University, Department of Forestry, in the Mississippi Agricultural and Forestry Experiment Station that was established in 1982 to develop a data base for thinned loblolly pine stands in the Mid Gulf South.*

Conceptually, the simulator presented is a combination of a three-parameter Wiebull diameter breast height (dbh.) distribution recovery system (Matney and Sullivan 1982; Matney, Sullivan, and Ledbetter 1986) and a recently developed weighted constrained least squares dbh moment recovery system. Prior to the first thinning, diameter distributions are approximated by recovering the parameters of a three-parameter Wiebull probability distribution so that the distribution's expected arithmetic and quadratic mean dbhs are equal to predicted. At the first thinning, a tree list" to represent the stand is randomly generated from the Wiebull distribution. After generation of the tree list, any specified thinning is applied to the list, and weighted constrained least squares procedures are employed to allocate mortality and diameter growth to the elements of the tree list. The mortality allocation least squares procedure specifies an allocation function that minimizes the weighted sum of squared differences between tree list elements before and after mortality, subject to constraints on the adjusted tree list that (1) the total number of trees per unit area represented in the tree list equals the predicted total number of trees per unit area surviving to time $t_1 = t_0 +$ At, and (2) the arithmetic and quadratic mean dbhs (first- and second-order dbh moments) equal predicted for those trees at time t_0 that will survive to time t_1. Similarly, the least squares diameter growth recovery procedure generates a tree diameter growth allocation function by minimizing the weighted sum of squares differences between tree list dbh elements at times t_0 and t_1 subject to the constraints that the adjusted tree fist have arithmetic- and quadratic-mean dbhs equal to their t, projected values.

In both least-squares models, a weighing function is used to control the magnitude of the growth/mortality allocation assigned to each tree list element. Elements of a list with higher weights relative to other list elements receive relatively smaller adjustment Also, by controlling the shape of the weighing function, the shape of the allocation function is determined, and thus mortality and growth allocation functions can be obtained approximating a desired shape.

Because thinning from below tend to remove potential mortality trees, the least squares mortality model is easily modiied for performing thinning from below.

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This adaptation is made by requiring the after thinning tree list have total numbers of trees per unit area, and arithmetic and quadratic mean dbhs equal to estimated after-thin values. Row thinnings are performed by reducing the number of trees represented by each list element by the percentage of removed trees, basasl area, or volume. Lower diameter-limit thinnings are performed by eliminating all trees from the list having dbh less than or equal to the threshold dbh. Row-low and lower diameter limit-low thinning are modeled by first doing the row- or diameter-limit thinning and then the thinning from below.

DATA

Data for the study were from 258 permanent sample plots remeasured on a three-year cycle beginning in 1982. Figure 1 shows the geographic distribution of the 258 sample plots. All of the sample plots were located in cutover site-prepared loblolly pine plantations with every effort being made to cover a wide range of stand conditions. Tables 1 and 2 show the distribution of plots by age, site index, and stand density.

Two hundred forty-two (242) of the installed rectangular plots were approximately 1/4 and 16 were approximately l/l 0 acre. On each plot, every planted pine and any natural pine or hardwood extending into the main canopy were tagged and measured. The measurements taken were:

1. dbh to the nearest l/l 0th inch,
2. total tree height to the nearest foot,
3. height to the base of the live crown to the nearest foot,
4. tree damage and disease (e.g., broken top, forked, rust),
5. quality class (e.g., straight, sweep, crook), and
6. rectangular coordinates of tree locations at plot installation.

Beginning in 1986, thinning were applied to a subset of the plots. An approximately equal number of plots received thinning from below, row thinning, and a combination of row and below thinning. The intensity of the thinning ranged within types from a 25 percent basal area reduction (light thinning) to a 50 percent basal area reduction (heavy thinning). No stands were reduced below 65 square feet of basal area per acre.

UNTHINNED STAND RECOVERY MODEL

Growth and yield model users typically apply a model to solve two basic problems. One is to investigate the product volume (revenue) distribution flow under a specified management regime given potential land productivity (site index) and expected numbers of trees surviving establishment The other is to estimate future product flows of a stand from a stand table prepared from a inventory data. To accommodate the first of these uses, a three-parameter Wiebull distribution recovery system supported on minimum and arithmetic, and quadratic mean dbhs was developed from the data for estimating stand diameter distributions until the first thinning.

Table 1- Distribution of sample plot measurements by age, and surviving trees per acre. In the table, N_{ut} denotes the number of unthinned measurements and N_{th} denotes the number of thinned measurements.

Age	N_{ut} or N_{th}	Surviving number of trees per acre									
		150	250	350	450	550	650	750	850	>900	All
<5	N_{ut}	0	0	1	1	2	4	0	0	4	12
	N_{th}	0	0	0	0	0	0	0	0	0	0
5-l 0	N_{ut}	0	5	8	21	37	26	16	6	32	151
	N_{th}	0	1	1	0	0	1	0	0	0	3
10-15	N_{ut}	0	1	5	18	37	34	27	14	21	157
	N_{th}	1	7	12	9	5	3	1	0	0	38
15-20	N_{ut}	0	3	11	29	13	12	10	6	1	85
	N_{th}	1	18	16	12	4	0	2	0	0	53
20-25	N_{ut}	0	4	13	16	5	3	3	0	0	44
	N_{th}	8	20	14	1	0	2	0	0	0	45
25-30	N_{ut}	0	4	9	5	2	0	0	0	0	20
	N_{th}	7	5	1	1	0	0	0	0	0	14
>30	N_{ut}	0	0	1	1	0	0	0	0	0	2
	N_{th}	7	7	0	0	0	0		0	0	14
All	N_{ut}	0	17	48	91	96	79		56	26	58	471
	N_{th}	24	58	44	23	9	6	3	0	0	167

Table 2– Distribution of sample plot measurements by age and site index (base age 25). The numbers in this table diier in total from those in Table 1 because only the site index before thinning is induded.

Age	Siie index (feet)				
	<50	50-60	60-70	>70	All
<5	4	7	29	0	12
5-10	28	72	70	22	151
10-15	10	61		16	157
15-20	13	22	30	14	79
20-25	3	20	28	11	62
25-30	2	12	13	2	20
30	0	10	4	0	14
All	60	204	175	65	504

Several growth and yield modelers have found that a three-parameter Wiebuil distribution parameter recovery system supported on diameter moments or diameter order statistics (percentiles), provide very close approximations to observed distributions in pine plantations (Matney, Sullivan, and Ledbetter 1086; Matney and Sullivan 1082; Zarnoch et al. 1000). The procedure is computationaly efficient and easy to implement because precise and accurate equations to predict diameter percentiles or diameter moments can be quickly developed from a growth and yield data base.

If D_{min}, $\overline{D}$, and $\overline{Q}$ denote respectively, the predicted(known) minimum, arithmetic mean, and quadratic mean dbhs of a stand, and if a, b, and c, denote respectively, the location, scale, and shape parameters of a three-parameter Wiebull distribution for representing the stand's dbh distribution, $\overline{D}$, and $(\overline{Q})^2$ can be equated to their Wiebull distribution expected values; and the resulting two nonlinear equations generated solved for parameters b and c when parameter a is known. The two nonlinear equations generated are:

$$\overline{D} = a + b\Gamma_1 \quad (1)$$

$$\overline{Q}^2 = a^2 + 2ab\Gamma_1 + b^2\Gamma_2 \quad (2)$$

where Γ_k is the gamma function value of 1 + k/c.

To solve the two nonlinear equations for the parameters b and c given that the parameter a is known, Equation 1 is first solved for parameter b to yield that

$$b = \frac{\overline{D} - a}{\Gamma_1}. \quad (3)$$

Next Equation 3 is substituted for b in Equation 2, to produce a nonlinear equation solvable for parameter c when a is known:

$$a^2 + 2a(\overline{D} - a) + \frac{(\overline{D} - a)^2\Gamma_2}{\Gamma_1^2} - \overline{Q}^2 = 0 \quad (4)$$

The value of parameter c satisfying Equation 4, can be found using a bisection or secant fixed point iteration (Conte and deBoor 1072; Burden, Faires, and Reynolds 1080). After a value is found for parameter c, it can be substituted for parameter c in Equation 3 to find parameter b.

Kolmogorov's goodness of fit test (Conover 1071) showed that for parameter a, values chosen between $0.25D_{min}$ and $0.92D_{min}$ allowed no discrimination between the distributions of the test statistics. This occurred because the high correlation between the a parameter and the b and c parameters compensated for a parameter values within the range of $0.25D_{min}$ and $0.92D_{min}$. Small values for the a parameter produced better tree number estimates in the small diameter classes while tending to overestimate tree numbers in the larger diameter classes. Large values for the a parameter provided better tree number estimates for the larger diameter classes while underestimating the tree numbers in the smaller diameter classes. Consequently, to define a particular value, the Kolmogorov test statistics were calculated conditionally on the data above the seventy-fifth diameter percentile to refine tree number estimates in the larger diameter classes. The value of the a parameter having the lowest average Kolmogorov test statistic was $0.65D_{min}$. It should be noted that no significant differences with the Kolmogorov test were observed at the .05 level.

MORTALITY/THINNED TREE ALLOCATION MODEL

Once the simulator generates a tree list from a Wiebull distribution or a tree list is specified as input, any trees removed by thinning from below and any trees dying before the end of the next projection period must be removed from the list A logical way to characterize the process of thinning from below is to require that the after thinning tree list have numbers of trees per unit area, and arithmetic , and quadratic mean dbhs equal to predicted or known values. Likewise, to characterize the process of mortality between two time periods it is logical to require the initial tree list be adjusted to have numbers of trees per unit area, and arithmetic mean, and quadratic mean dbhs equal to their predicted after mortality values.

A convenient and controllable way of removing (allocating) thinned/mortality trees to the tree list elements and to impose any required logical restrictions on the adjusted is to use a weighted constrained least squares model that minimizes the weighted sum of squared difference between list number elements before thin/mortality and after thin/mortality numbers per unit area. The logical

constraints imposed on the solution being that the after thin/mortality numbers of trees per unit area, and arithmetic, and quadratic mean dbhs equal their predicted or known values. Control of the magnitude of the thinned/mortality tree allocations to each list elements is exercised by assigning weights to the list elements based on their size or relative position in the list. Mathematically for both thinned and mortalii tree allocation, the least squares model, using Lagrangian multipliers (Whittle 1971), can be expressed as:

$$\left\{\sum_{i=1}^{i=n} W_i(S_i - s_i)^2 + 2\lambda\left(\sum_{i=1}^{i=n} S_i - TS_1\right) + 2\delta\left[\sum_{i=1}^{i=n} S_i d_i - (TS_1)\bar{d}\right]\right. \quad (5)$$

where

n is the number of trees in the tree list before mortality allocation;
d, is the diameter at breast height (dbh) of the ith tree;
s_i is the number of trees per unit area represented by the ith tree before thinning/mortality;
S, is the number of trees per unit area represented by the ith tree after adjustment for thinninglmortalii;
W_i is the weight assigned to the ith list element;
TS_1 is the total number of trees per unit area after-thin after mortalii ,
$\bar{d}$ is the arithmetic-mean dbh of all trees after thinninglmortalii;
$\bar{q}$ is the quadratic-mean dbh of all trees after thinning/mortal& and
A, δ, and γ are Lagrangian multipliers to be determined by the constraints that:

a. numbers of trees per unit area equal to projected,

$$TS_1 = \sum_{i=1}^{i=n} S_i,$$

b. arithmetic mean stand dbh equal to predicted,

$$\bar{d} = \frac{\sum_{i=1}^{i=n} S_i d_i}{\sum_{i=1}^{i=n} S_i} = \frac{\sum_{i=1}^{i=n} S_i d_i}{TS_1}, \text{ and}$$

c. quadratic mean dbh equal to predicted,

$$\bar{q}^2 = \frac{\sum_{i=1}^{i=n} S_i d_i^2}{\sum_{i=1}^{i=n} S_i} = \frac{\sum_{i=1}^{i=n} S_i d_i^2}{TS_1}.$$

The S_i values that minimize Equation 5 are found by taking the partial derivative of the equation with respect to S, , equating it to 0, and solving the resulting equation for S, . That is:

$$\frac{\delta L}{\delta S_i} = 2W_i(S_i - s_i) + 2\delta d_i + 2\gamma d_i^2 = 0,$$

and thus,

$$S_i = s_i - \frac{\lambda + \delta d_i + \gamma d_i^2}{W_i} \quad (6)$$

The constant Lagrangian multipliers A, δ, and γ are determined from Equation 6 by imposing each of the required constraints on the equation. This results in the following simultaneous system of three linear equations that can be easily for A, δ, and γ using standard linear equation solution procedures.

$$\left[\sum_{i=1}^{i=n} W_i^{-1}\right]\lambda + \left[\sum_{i=1}^{i=n} d_i W_i^{-1}\right]\delta + \left[\sum_{i=1}^{i=n} d_i^2 W_i^{-1}\right]\gamma = TS_0 - TS_1$$

$$\left[\sum_{i=1}^{i=n} d_i W_i^{-1}\right]\lambda + \left[\sum_{i=1}^{i=n} d_i^2 W_i^{-1}\right]\delta + \left[\sum_{i=1}^{i=n} d_i^3 W_i^{-1}\right]\gamma = \sum_{i=1}^{i=n} s_i d_i - (TS_1)\bar{d}$$

$$\left[\sum_{i=1}^{i=n} d_i^2 W_i^{-1}\right]\lambda + \left[\sum_{i=1}^{i=n} d_i^3 W_i^{-1}\right]\delta + \left[\sum_{i=1}^{i=n} d_i^4 W_i^{-1}\right]\gamma = \sum_{i=1}^{i=n} s_i d_i^2 - (TS_1)\bar{q}^2$$

where

$TS_0 = \sum_{i=1}^{i=n} s_i$ is the number of trees per unit area present before thinning/mortality.

The amount of adjustment given to a tree list element is controlled by its assigned weight, W,. List elements assigned large weights relative to other list elements receive relatively small adjustment of

$$\frac{A + \delta d_i + \gamma d_i^2}{W_i}.$$

Thus, for both thinned and mortality tree allocations, the assigned weights should decrease with increasing dbh so proportionally more adjustment will occur in the smaller diameter classes then in the larger diameter classes.

In order to determine a suitable weighing function, we assumed the general form

$$W_i = \frac{1}{s_i d_i^p}$$

where p is a parameter to be chosen so that the average value of the Kolmogorov goodness of fit test statistic is minimized for all possible applicable distributions in the data base . On thii parameter selection criteria, the p values of 2.3 and 3.9, respectively, were found to be the best for thinned and mortalii tree allocation. No significant differences between the predicted and observed after-thin/mortality dbh distributions by either Chiiquare or the Kolmogorov goodness of fit test were found at the .05 level.

TREE LIST DIAMETER GROWTH MODEL

After removing thinned and mortalii trees from a tree list, the diameter elements of the tree list must be grown to the end of the projection period. The predictability of future aggregate stand arithmetic and quadratic mean dbhs for both thinned and unthinned' stands make these quantities suitable for characterizing the future tree list Hence, given predicted or known future arithmetic $\bar{D}$ and quadratic $\bar{Q}$ mean dbhs, growth must be allocated to the initial tree list so that the resulting list has arithmetic and quadratic mean dbhs equal to $\bar{D}$ and $\bar{Q}$, respectively.

One way of deriving the required growth allocation function is to minimize the weighted sum of squared differences between present and future list dbh's subject to the constraints that the arithmetic and quadratic mean dbh. of the future list equal $\bar{D}$ and $\bar{Q}$, respectively. Again, using Lagrangian multipliers, this model can be mathematically expressed as:

$$\underset{D_{i's}}{\text{Min}}\ L(D_{i's},\lambda,\delta) = \underset{D_{i's}}{\text{Min}} \left\{ \sum_{i=1}^{i=n} W_i S_i (D_i - d_i)^2 + 2\lambda \left[\sum_{i=1}^{i=n} S_i D_i - (TS_1)\bar{D} \right] + \delta \left[\sum_{i=1}^{i=n} S_i D_i^2 - (TS_1)\bar{Q}^2 \right] \right\} \quad (7)$$

where
D_i is the estimated future dbh of the ith tree list element;
$\bar{D}$ is the predicted future arithmetic-mean stand dbh;
$\bar{Q}$ is the predicted future quadratic-mean stand dbh; and
A and δ are Lagrangian multiplier constants to be determined so that the estimated list has

a. arithmetic-mean stand dbh equal to predicted,

$$\sum_{i=1}^{i=n} S_i D_i = (TS_1)\bar{D}, \text{ and}$$

b. quadratic-mean stand dbh equal to predicted,

$$\sum_{i=1}^{i=n} S_i D_i^2 = (TS_1)\bar{Q}^2.$$

The $D_{i's}$ satisfying the least squares model are determined by taking the partial derivative of Equation 7 with respect to D_i setting the result equal to 0 and solving for D_i

$$\frac{\delta L}{\delta D_i} = 2W_i S_i (D_i - d_i) + 2\lambda S_i + 2\delta S_i D_i = 0, \text{ and}$$

thus,

$$D_i = \frac{W_i d_i - \lambda}{\delta + W_i}. \quad (8)$$

To solve for the Lagrangian multipliers, the two constraints are imposed on Equation 8 to produce the following two nonlinear equations solvable for A and δ

$$\sum_{i=1}^{i=n} S_i \left(\frac{W_i d_i - \lambda}{\delta + W_i} \right) = (TS_1)\bar{D} \quad (9a)$$

$$\sum_{i=1}^{i=n} S_i \left(\frac{W_i d_i - \lambda}{\delta + W_i} \right)^2 = (TS_1)\bar{Q}^2 \quad (9b)$$

Since the regression of future diameter on initial diameter for short projection intervals (10 or less years) usually is well approximated by a straight-line model, a logical choice for the weight W_i is 1. With $W_i = 1$, equation 8 becomes

$$D_i = a + bd_i$$

where the intercept a is

$$\frac{-1}{\delta + 1}, \text{ and}$$

the slope b is

$$\frac{1}{\delta + 1}.$$

Newton's iteration for solving systems of nonlinear equations (Burden, Faires, and Reynolds 1981) can be used to soke Equations 9a and 9b for A and δ. Newton's iteration for solving the equations is illustrated in Matney, Farrar, and Belli (1990).

STAND-LEVEL PARAMETER PREDICTION EQUATIONS

Implementation of the described system of models required that a large number of stand-level prediction equations be developed from the data. These required equations are summarized in Table 3. In the table, Equations 1, and 2 estimate site index from age and average height of dominant and codominant trees, and average height of dominant and codominant trees from age and site index, respectively. The minimum, and arithmetic, and quadratic mean dbh prediction equations for unthinned stands are provided by Equations 3, 6, and 9. In the case that an unthinned stand tree list is input, Equations 4, and 7 are used to project stand arithmetic and quadratic mean dbh s. Equations 5, and 8 are used after thinning to obtain projected stand arithmetic and quadratic mean dbhs. Equations 11, and 12 estimate the numbers of trees per acre (T_r) and arithmetic mean dbh of the residual stand after thinning from below given a specified residual stand basal area (B_r). The r esidual stand's quadratic mean dbh is computed as

$$\bar{Q}_r = \sqrt{\left(\frac{576}{\pi}\right)\frac{B_r}{T_r}}$$

where T_r is the residual number of trees per acre after thinning.

Estimates of the basal area per acre and arithmetic mean dbh at time 0 after mortalii allocation are estimated from Equations 13, and 14.

Table 3– Component equations of the cutover site-prepared loblolly pine plantation thinned stand model. See the variable legend at the end of the table for variable definitions.

Base aae 25 site index (si) and **averaae heiaht of dominant and codominant trees (hd):**

$$si = (hd)e^{6.32\left(\frac{1}{\sqrt{a}} - \frac{1}{\sqrt{25}}\right)}$$

$n = 256\ r^2 = n/a\ s_{y.x} = n/a$ (1)

$$hd = (si)e^{-6.32\left(\frac{1}{\sqrt{a}} - \frac{1}{\sqrt{25}}\right)}$$

$n = 256\ r^2 = n/a\ s_{y.x} = nla$ (2)

Unthinned stand arithmetic-mean dbh fad]:

Given a, hd, and ts:

$$\bar{d} = 105.389(ts)^{-0.21780}\, e^{\frac{-9.1647}{\sqrt{hd}} + 0.006827a}$$

$n = 458\ r^2 = .981\ s_{y.x} = 0.083$ (3)

Given a_0, a,, hd, and $\bar{D}_0$:

$$\bar{d}_1 = \bar{d}_0\left\{1 + (a_1 - a_0)e^{\left[10.779 - 0.20758a_0 - 0.25177\frac{hd_0}{a_0} + 96.21717\frac{1}{a_0} - 64.77313\frac{1}{\sqrt{a_0}}\right]}\right\}$$

$n = 235\ r^2 = .972\ s_{y.x} = 0.087$ (4)

Thinned stand arithmetic-mean dbh:

$$\bar{d}_1 = \bar{d}_0\left\{1 + (a_1 - a_0)e^{\left[9.83166 - 0.194a_0 - 0.23555\frac{hd_0}{a_0} + 90.026791\frac{1}{a_0} - 60.60578\frac{1}{\sqrt{a_0}}\right]}\right\}$$

$n = 203\ r^2 = .956\ s_{y.x} = 0.096$ (5)

Unthinned stand quadratic mean dbh:

Given a, hd, and ts:

$$\bar{q} = 109.086ts^{0.23399}e^{\left(-8.6470\frac{1}{\sqrt{(hd)}} + 0.0051778a\right)}$$

$n = 418\ r^2 = .990\ s_{y.x} = 0.085$ (6)

Table 3--Continued

Given a_1, a_1, hd, and $\bar{q}_0$:

$$\bar{q}_1 = \bar{q}_0\left\{1 + (a_1 - a_0)e^{\left[7.46305 - 0.16520\,a_0 - 0.26178\left(\frac{hd_0}{a_0}\right) + \frac{75.21620}{a_0} - \frac{48.85020}{\sqrt{a_0}}\right]}\right\}$$

$n = 235\ i^2 = .983\ s_{y.x} = O.OQl$ (7)

Thinned stand quadratic mean dbh:

$$\bar{q}_1 = \bar{q}_0\left\{1 + (a_1 - a_0)e^{\left[6.50637 - 0.15110\,a_0 - 0.23944\left(\frac{hd_0}{a_0}\right) + \frac{68.79537}{a_0} - \frac{44.68011}{\sqrt{a_0}}\right]}\right\}$$

$n = 203\ i^2 = .962\ s_{y.x} = 0.101$ (8)

Unthinned stand minimum dbh:

$$d_{min} = 0.258\,\bar{d}^{0.33108}$$

$n = 418\ i^2 = .920\ s_{y.x} = 0.98$ (9)

Total tree heiahk:

$$h_t = 5.602\,(hd)^{1.0021}\,e^{-1.76969\left(\frac{\bar{q}}{d}\right)^{\frac{1}{4}}}$$

$n = 10000\ i^2 = .993\ s_{y.x} = 0.82$ (10)

Trees per acre remaining after **thinning** from below to a **specified** residual basal area **per** acre:

$$\frac{t_{at}}{t_{bt}} = \left\{1 - \left[1 - \frac{b_{at}}{b_{bt}}\right]^{0.516096}\right\}^{0.781906}$$

$n = 87\ \ i^2 = .951\ \ s_{y.x} = .0433$ (11)

Arithmetic-stand dbh after thinning from below:

$$\frac{\bar{d}_{at}}{\bar{d}_{bt}} = \left(\frac{t_{bt}}{t_{at}}\right)\left\{1 - \left[1 - \frac{b_{at}}{b_{bt}}\right]^{0.770311}\right\}^{0.911238}$$

$n = 87\ i^2 = .972\ s_{y.x} = .0196$ (12)

Basal area **per** acre after mortality tree allocation:

$$\frac{b_{am}}{b_{bm}} = \left\{1 - \left[1 - \frac{t_{am}}{t_{bm}}\right]^{1.166633}\right\}^{0.697098}$$

$n = 158\ i^2 = .954\ s_{y.x} = .0116$ (13)

Arithmetic-stand dbh at time 0 after removal of mortality trees:

$$\frac{\bar{d}_{am}}{\bar{d}_{bm}} = \left(\frac{t_{bm}}{t_{am}}\right)\left\{1 - \left[1 - \frac{t_{am}}{t_{bm}}\right]^{1.107949}\right\}^{0.85329}$$

$n = 158\ i^2 = .950\ s_{y.x} = .008$ (14)

Table 3--Continued

Survival oredictionsystem:

First year survival percent:

$$p_{fy} = 100\left[1 - e^{-0.03636(si)}\right] \quad (15)$$

Proportion of mortality after first years to onset of competition:

$$p_{sy} = (P_m) \quad (16)$$

$$p_m = e^{-0.03636(si)}$$

Onset of competition inequality:

$$\frac{\pi ts}{4}(0.0 + 0.0290a)si^2 \geq 43560 \quad (17)$$

Annual mortality until time of first thinning:

$$m = 0.00634(ts)\left(\frac{hd}{a}\right)^{\frac{2}{3}} \quad (18)$$

Annual mortality following thinning:

$$m_{at} = (0.92)(0.00634)(ts)\left(\frac{\bar{q}_{bt}}{\bar{q}_{at}}\right)\left(\frac{hd}{a}\right)^{\frac{2}{3}} \quad (19)$$

Legend

a = **current stand age**
a_0 = **initial** stand age
a_1 = future stand age
b = current pine basal **area** per acre
b_0 = initial pine basal **area** per **acre**
b_1 = future pine basal area per acre
b_{at} = basal **area per acre after thinning**
b_{bt} = **basal area per acre before thinning**
b_{am} = **basal area per acre after mortalii tree removal**
b_{bm} = **basal area** per acre before **mortality** tree removal
d = diameter breast height (dbh)
d_{min} = unthinner stand minimum dbh
$\bar{d}$ = current stand arithmetic-mean dbh
$\bar{d}_0$ = initial stand arithmetic-mean dbh
$\bar{d}_1$ = future stand arithmetic-mean dbh
$\bar{d}_{am}$ = arithmetic-mean dbh after mortality tree removal
$\bar{d}_{bm}$ = arithmetic-mean dbh before mortality tree removal
= arithmetic-mean dbh **after** thinning
4_{bt} = arithmetic-mean dbh before thinning
e = the base (2.7182818) of the natural logarithm.
hd = average height of dominants and codominant s
h, = total tree height
i^2 = index of fit
m = unthinned per acre annual mortalii after onset of crown competition
m_{at} = annual per acre mortalii after thinning
n = number of observations
n/a = not applicable
P_{fy} = first year survival percentage
P_{sy} = proportion dying per year after the first year and before the onset of competition
$\bar{q}$ = current stand quadratic mean dbh
$\bar{q}_0$ = initial stand quadratic mean dbh
$\bar{q}_1$ = future stand quadratic mean dbh
$\bar{q}_{am}$ = quadratic-mean dbh after mortalii tree removal
$\bar{q}_{bm}$ = quadratic-mean dbh before mortalii tree removal
$\bar{q}_{at}$ = quadratic-mean dbh after thinning
$\bar{q}_{bt}$ = quadratic-mean dbh before thinning
r^2 = R-square
si = base age 25 site index
$s_{y.x}$ = standard error of estimate
t_0 = initial number of surviving trees per acre
t_1 = future number of surviving trees per acre
t_{am} = number of trees per acre after mortailty
t_{bm} = number of trees per acre before mortality
t_{at} = number of trees per acre after thinning
t_{bt} = number of trees per acre before thinning
ts = number surviving trees per acre
π = 3.14159

The units of measure for diameters, heights, and basal **areas are inches, feet, and square feet, respectively.** Tree numbers are per acre.

STAND LEVEL SURVIVAL ESTIMATION

Survival curves are generated from a system of equations that attempt to mimic the actual mortalii process of plantations. First-year seedling survival percentage (p_{fy}) tends to be site-qualii sensitive and is estimated by the equation form

$$p_{fy} = 100[1 - e^{-\alpha(si)}]$$

where si is base age 25 site index, a is a parameter to be estimated, and constant e is the base of the natural logarithm.

After the initial seedling mortalii has occurred and until a significant level of crown competition develops to cause mortalii, the proportion of trees dying per year can be allocated with a declining geometric progression whose term represents the proportion of trees dying between age a and age a + 1. That is:

$$p_{sy} = (p_m)$$

where p_{sy} is the proportion of trees dying between age a to age a + 1, a is stand age, and p_m is the geometric

progression term. Like p_{fy}, p_m is related weakly to site index and is approximated by the equation

$$p_m = e^{b(si)}$$

where b is a parameter to be estimated.

At the age when significant crown competition begins, and thereafter for unthinned stands, the number of trees dying per year is estimated from the differential

$$m = k(ts)\left(\frac{hd}{a}\right)^g$$

where m is the number of trees dying in the time interval a to a + 1, ts is the number of trees surviving at age a, hd is the average height of dominant and codominant trees at age a, and k and g are parameters to be estimated. The model states that after the onset of competition, mortaiii is proportional to the numbers of trees surviving times the mean annual increment of the average height of dominant and codominant trees raised to a power. Mean annual height increment is related strongly to site qualii and stand density and is highly correlated with mortaiii.

The age at which significant crown competition occurs is estimated by finding the age a at which the following inequality is satisfied:

$$\frac{\pi ts}{4}(\alpha + \beta a)si^2 \geq \lambda$$

where a, β, and A are parameters to be estimated. in the inequality, the term [a + βa]si can be considered to represent the average diameter of the circle of crown influence around individual trees, and thus the left-hand side of the inequality represents the total area of influence circles in a stand at age a with the right-hand constant A equaiiing the level at which crown competition becomes significant.

To estimate ail of the parameters of the survival system, a computer program was written to minimize the sum of squared differences between observed and predicted surviving trees per acre. Because of the way the system parameters were estimated, the component equations are not true regression equations but are rather a device to simulate the process of competition mortalii.

Stand mortality after thinning is erratic and is not correlated highly with stand parameters. Mortality in the period following thinning was most related to the expected rate of mortality of an unthinned stand with the numbers of trees per acre reduced by the ratio of mean stand diameter before thinning to mean stand diameter after thinning. That is:

$$m_{at} = \delta k(ts)\left(\frac{\bar{q}_{bt}}{\bar{q}_{at}}\right)\left(\frac{hd}{a}\right)^g$$

where m_{at} is the number of trees dying between age a and a + 1, $\bar{q}_{bt}$ is the quadratic mean dbh before thinning, $\bar{q}_{at}$ is the root mean dbh after thinning, δ is a parameter to be estimated from the data, and k, g, ts, and h d are as previously defined.

INDIVIDUAL TREE VOLUME PREDICTION EQUATIONS

Tree volumes are calculated using the stem profile equations for cutover loblolly pine trees described by Ledbetter, Matney, and Sullivan (1986).

DISCUSSION

The least squares models presented for thinned stands is a parameter-free diameter distribution recovery system. Because the models do not assume any underlying probability distribution after thinning, they afford a high degree of flexibility for modeling thinned stand diameter distributions and other stands not having diameter distributions closely approximated by a parametric probability model.

While the least squares adjustment procedures are not founded on biological arguments, they produce tree growth/survival equations that follow known biologically sound relationships. This is because the procedures minimize the weighted distance between initial and future diameters/numbers of trees. Thus, by choosing a biologically reasonable weighing function, it is possible to generate tree growth and mortality

allocation equations that are almost as good as the same equation fitted to the raw data by regression.

Overall, the simulator developed from the models presented centered well on the observed data. The data were, however, collected over a wide geographical range and incorporate the operational variations among companies. Key components of the model most disturbed by this variation are the survival function and the site index function. Users of the model should modify these components to reflect their specific conditions. Other components in the model (diameter and volume) should be pulled in line by the site index and survival function. A PC compatible FORTRAN 77 program available from the authors allows the user easily modify the survival function and site index equation.

ENDNOTES

*The corporations joining the cooperative in 1982 were Crown Zellerbach, Masonite, Potlatch, International Paper, Hammermill, American Can, and Container. Companies joining the cooperative after 1982 were Scott Paper Company, James River, and International Paper Company. The cooperative has been inactive since 1990.

"A tree list is a list of diameters and the numbers of trees per unit area represented by each diameter in the tree list.

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RAPIDLY RESTORING LARGE-DIAMETER LONGLEAF PINE ECOSYSTEMS AT A LOW COST: A PRELIMINARY APPRAISAL'

R. L. Busby, C. E. Thomas, R. E. Lohrey, and K. H. NLê [2]

Abstract-The bngleaf pine *(Pinus palustris* Mill.) ecosystem once dominated the Coastal Plain of the South, but difficulties in regenerating the species led to Its replacement with other southern pines. Improved regeneration techniques make bngleaf pine plantations biologiilly and economically feasible. An analyses of data from six plots of a large 50-year-old thinning study in the Natii Forests of East Texas yields land expectation values (LEVs) of $2.307, $667, and $136 per acre for longleaf plantations at real discount rates of 3, 5, and 7 percent, respectively. Restoring large-diameter bngleaf ecosystems by planting and thinning stands heavily through age 65 yields LEVs of $1,559, $392, and $–18 for the same discount rates, even though 40 ft² of basal area are left unharvested at age 65. This approach is feasible, and it is cheaper and faster than trying to restore ecosystems without timber harvest.

INTRODUCTION

Longleaf pine (*Pinus palustris* Mill.) once dominated the forests of the South's Coastal Plain. It provided the timber for establishment of the timber industry there. Unfortunately, problems with regeneration led to the decline of the species in southern commercial forests, even on favorable sites. Currently, longleaf pine occupies less than 5 percent of its original acreage. However, the longleaf ecosystem is important to many associated species. For example, an old-growth, low-density longleaf forest can be ideal habitat for the red-cockaded woodpecker (*Picoides borealis),* an endangered species (Lennartz 1985). Because of the unique characteristics of the longleaf ecosystem, there has been increasing interest in its restoration.

After a long period of decline, loss of longleaf acreage appears to have slowed; it now occupies about 3.5 million acres (Kelly and Bechtold 1989). Regeneration techniques for hastening the passage through the grass stage have been developed (Croker and Boyer 1975; Mann 1989). And Barnett (1992) reported that high seedling survival can be obtained with: *(1) well-*prepared, competition-free sites, (2) healthy, top-quality, fresh planting stock, (3) meticulous care of stock from lifting to planting, (4) precision planting, and (5) proper post-planting care.

One option for restoring the parklike stands of large trees that once typitied the ecosystem is by planting longleaf pine8 and thinning the stands frequently and heavily. Thii approach will provide stands of large-diameter trees rather quickly, and the products removed in thinning can be sold to defray part of the cost of ecosystem restoration.

In this paper, we examine the economics of that approach. We analyze the economics of longleaf pine plantations both as a commercial forestry investment and as a strategy for restoring old-growth longleaf ecosystems. We focus on the potential commercial returns that can be obtained during the restoration process.

MATERIALS AND METHODS

Economic Evaluation

The investment criterion 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 perpetually managing an area in longleaf pine production. Revenues occur when products are harvested and costs are incurred when the site is brought into production and whenever the area is treated. The formula for LEV is:

$$LEV = \sum_{t=0}^{\infty} \frac{R_t - C_t}{(1 + i)^t}, \qquad (1)$$

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.

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All costs and prices were expressed in 1994 dollars; values were assumed to increase only at the rate of inflation. The discount rate used was the real (after inflation) discount rate. Taxes were not included in this analysis.

Stumpage prices

Stumpage prices from the State of Texas were compiled from Timber Mart-South (various). The product prices (averages for 1992, 1993, and the first three quarters of 1994) were:

Poles, $343/M bd. ft., Scribner,
Sawtimber, $216/M bd. ft., Scribner,
Chip-n-saw, $48/cord, and
Pulpwood, $21/cord.

Stumpage prices changes were assumed to parallel changes in the inflation rate over time. This assumption is conservative, given the large increases in sawtimber stumpage prices forecast by Haynes and Adams (1992).

Costs

Current establishment costs were estimated from Belli and others (1 gg3). intensive mechanical site preparation (shearing, raking, and piling) which is required, costs $127/acre. Planting costs are $38/acre plus $0.15/containerized seedling. Thinnings and cruising the harvests cost $12 and $4/acre, respectively. The annualized cost of periodically (2-4 years) burning the site, and protecting and maintaining the property is $5/acre.

Modeling commercial longleaf production

In the model of commercial timber management, the assumption is that all stands are intensively site prepared and planted with 800 containerized seedlings/acre. Thinnings to basal areas 40 to 140 ft^2/acre were examined. Commercial thinnings were assumed to occur every 5 years beginning at age 25 if more than the target basal area were present at that age. The model allowed final harvest to occur from ages 25 to 65 at 5-year intervals. For each plot, an optimal management regime was chosen to maximize LEV. Analysis of a diierent thinning schedules (e.g., every 10 years) or a diierent regeneration systems was impossible since a full growth and yield model was not available. Instead, historical plot data were used.

Modeling longleaf pine ecosystem restoration

Restoration of large-diameter longleaf pine was assumed to require the same starting inputs as commercial plantation management. The assumption was that the land would be converted to longleaf from loblolly or slash pine management. The option was to accelerate restoration through using intensive management Commercial thinnings were assumed to occur every 5 years beginning at age 25 and ending at age 45, if the target basal area was exceeded. The final entry at age 65 is a partial harvest to 40 ft^2/acre of basal area. Because of the intensive thinning and the nature of longleaf pine, the crown ratio for each of the trees will be high enough to respond to the intensive cut Thii management regime should favor species, such as the red-cockaded woodpecker, that require relatively low-density stands. From age 65, no commercial forestry entries were planned. The goal of management is to provide large-diameter, old-growth longleaf. Additional cuttings might be beneficial, but their timing is uncertain, and the potential value of such harvests was ignored in this analysis.

The opportunity cost of ecosystem restoration consists of (1) the reduced harvest at age 65, (2) harvesting at age 65 when another harvest age may be optimal, and (3) the loss of the stand for future rotations. Thii cost was estimated by subtracting the present value of the ecosystem restoration management strategy from the optimal commercial management strategy.

Plot data

Data for these analyses were collected in thinned longleaf pine plantations in the National Forests of east Texas. All plantations were established 50 years ago on cutover forest sites. Measurement data are available up to age 45. 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 0.25-acre plots were first measured at 25 years old and showed no evidence of severe insect or disease damage.

Trees

At 5-year intervals, the d.b.h. of each tree 0.8inch or larger d.b.h. was measured with a steel diameter tape to the nearest 0.1 inch. Trees were remeasured at 5-year intervals. More than 2,000 individual tree age-d.b.h. measurements were taken. Total height was measured on sample trees in all l-inch-diameter classes. Height equations, based on age and d. b. h., were developed from 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 (Thomas and others in press). These trees had been selected for thinning or from isolation strips around the measured plots. The thinned stands in the felled tree study, had been repeatedly cut to residual basal areas of 40 to 140 ft^2/acre for at least 15 years before the sample trees were felled. Only sound trees that did not fork were selected for measurements. Some of the sample trees were in intermediate and suppressed crown positions, but the sample also included some high-quality fast-growing trees that ordinarily would have been left to grow.

Treatments

Data used are from the median volume plots as a subset of the original thinned plantation study. We selected a single block that included six plots, one representing each thinning level from the original data set. Residual density levels of 40 to 140 ft^2/acre were established in these plots. Most plots were thinned at age 25, after the initial 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 thinned at 5-year intervals to maintain the target basal area assigned to them. Trees with 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 dasses 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.

Projections

These east Texas thinned plantations have measurements up to age 45. We are developing a growth model to project the trees' basal area and volume to age 65. The basic model is an individual tree distance independent model related to the TWIGS approach (Belcher 1982). For simplicity we report a few statistics about the projected basal area growth, and heights that were used in the taper modal for the economic study. The equation for 5-year basal area growth is:

$$bagr_5 = b_0+b_1*(Ba_i)+b_2*(PBAL_i)+b_3*(Age)+ b_4*(BAS)+b_5*(Ba_i*PBAL_i) \quad (2)$$

where Ba_i is the initial basal area of the individual tree, PBAL is the proportion of basal area larger than the subject tree in the plot, BAS is the total basal area smaller than the given tree and Age is the plantation age. The equation r^2 is 0.73 and the root mean square error is 0.029. Mean basal area growth per tree is 0.086 ft^2.

We also modeled heights for the trees; 2,396 tree measurements were used to develop the equations. The model was a non-linear multiple regression involving age and diameter. The prediction equation is

$$HT=exp(b_0+b_1/dbh+b_2/age+b_3*(age*dbh)) \quad (3)$$

The final model statistic (in untransformed space) gave a fit statistic of 0.89 and an overall root mean square error of 4.05 ft. We also examined heights and predictions in a selection of the thinning treatment levels for bias and variation at the treatment level.

Product Yields

A computer model was developed to simulate merchandising of the longleaf stands. Dynamic programming subroutines from MERCHOP (Busby and Ward 1989) were adapted for longleaf by using a taper function for Texas longleaf (Thomas and others in press). The products, the diameter and length constraints, and the expected defect for each product are listed in table 1.

Table 1. Product size and defect assumptions used in the analysis.

Product	Top diameter	Product length	Defect
	(Inches)	(Feet)	(Percent)
Poles	6.00-16.00	35.00-90.00	30
Sawtimber	9.50-24.00	8.00-16.00	10
Chip-n-saw	6.00-12.00	6.00-16.00	10
Pulpwood	3.50-12.00	5.00	0

Table 1 shows that the amount of defect in these stands of longleaf was very low. In our example plots, it was assumed that 70 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 have yielded good production of poles and sawtimber.

RESULTS AND DISCUSSION

Commercial timber management produced high LEVs on the study sites. The high cost of site preparation was adequately compensated for by high-value thinnings and final harvests. At a 5-percent real discount rate, LEVs averaged $667/acre (Table 2). The range for the six study sites was from $569/acre to $848/acre. The combination of commercial thinnings every 5 years and the production of high-value poles resulted in optimal rotations of 40 to 45 years, which are fairly long compared to those for plantation of other southern pine species.

Table 2.-Average land expectation values (LEVs) of commercial and restoration regimes calculated at 3-, 5-, and 7-percent real discount rates.

Management regime	LEV at 3%	LEV at 5%	LEV at 7%
	(Dollars per acre)		
Commercial	2307	667	136
Restoration	1559	392	-18
Difference	749	275	154

As the real interest rate declined, commercial timber LEVs increased and the length of the optimal stand rotation increased. At a 3-percent real discount rate,

the LEV ranged from $1,854/acre to $2,635/acre and averaged $2,307/acre. Optimal rotations ranged from 45 to 85 years. Conversely, higher interest rates produced lower LEVs. The average LEV at a 7-percent real diiount rate dropped to only $136/acre, with a range from $73/acre to $237/acre. Optimal rotation ages ranged from 35 to 40 years.

Restoration regimes also produced significant LEVs (table 2). At a 5-percent discount rate, the restoration regimes produced an average LEV of $392/acre, and a range of $260/acre to $582/acre. Discounted revenues from commercial thinnings at ages 25 to 45 and a partial final removal at age 65 were sufficient to pay for the high cost of stand establishment and associated management costs through the years. Note that costs and revenues are only calculated through age 65. Additional costs and returns from these stands are uncertain and are ignored in this analysis. There remains on the tract a 65-year-old stand of longleaf that has a basal area of 40 ft^2/acre and a median d.b.h. of between 13.8 and 19.9 inches, depending upon the thinning regime chosen (table 3). The longleaf stands may eventually be regenerated, but not for many years. Additional harvests may be permitted, but timber production is not assumed to be the management objective.

Changes in the assumed real interest rate also has a major impact on LEVs for the restoration regimes. At a 3-percent discount rate, LEVs range from $1 ,I 17/acre to $1,863/acre and average $1,559/acre. At a 7-percent discount rate, the average LEV drops to $1 B/acre, with a range from $143/acre to $99/acre.

Despite positive LEVs for many scenarios; large-diameter longleaf pine restoration is not free. Opportunity costs are high because the value of commercial production of longleaf pine is high. At the 5-percent real discount rate, the average difference between the commercial timber LEV and the restoration LEV is $275/acre, which represents a 41-percent reduction in LEV. Low interest rates cause the opportunity costs to expand. At the 3-percent real discount rate, the opportunity cost is $749/acre, but that is only 32 percent of the commercial value of the stand. Since the LEVs of both the commercial timber and restoration regimes are low at the 7-percent real discount rate, the opportunity costs are low. The opportunity costs at the 7-percent rate average only $154/acre, but the LEV changes from positive to negative, and over 113 percent of the commercial value of the tract is lost.

Two keys to the loss are: (I) loss of profitable second rotation, and (2) loss of the harvest of the 40 ft^2/acre of basal area in the residual stand. The longleaf restoration projects no income from harvests after the removal of all but 40 ft^2/acre of basal area at age 65. This low level of residual stand may simulate a shelterwood cut in which the overstory is never removed. In fact, trees eventually may also be cut out of that overstory if basal areas increase beyond the desired targets. But additional costs for management after age 65 are also excluded from the analysis. The net impact of these exclusions is unknown.

CONCLUSION

Although these results are based upon a small data set, LEVs are significant despite high assumed stand establishment costs. We were able to envision scenarios in which commercial restoration of longleaf pine could be profitable. Although it involves significant opportunity costs, large-diameter longleaf restoration can provide positive present values. The commercial thinnings pay for the large-diameter longleaf restoration. This option could lead to significant longleaf restoration at a minimum of cost. It also fills the ecological niche of old-growth longleaf fairly rapidly. Thus, it may be argued that managing longleaf plantations will produce largediameter, healthy trees faster and with greater certainty than will natural regeneration using scattered longleaf remnants.

Table 3.-Measured and predicted median longleaf diameter breast height. Thinning target basal area

	Stand age (Years)								
	25	30	35	40	45	50	55	60	65
	Measured					Predicted			
(Fe/acre)	(Inches)								
40	5.3	8.4	10.9	12.2	13.9	15.3	16.8	18.3	19.9
60	5.7	8.0	9.5	11.6	13.0	14.5	15.8	17.1	18.6
80	6.0	7.8	9.3	IO.6	12.1	13.4	14.5	15.6	16.8
100	6.5	7.9	9.4	10.3	II.5	12.1	13.0	13.9	14.8
120	6.3	7.0	8.7	9.5	10.4	II.6	12.3	13.1	13.9
140	6.0	6.5	7.7	9.3	10.7	II.6	12.4	13.1	13.8

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PROJECTED ECONOMIC RETURNS TO SIX SITE-PREPARATION TREATMENTS FOR LOBLOLLY PINE IN THE GEORGIA PIEDMONT'

Coleman W. Dangerfield, Jr., and M. Boyd Edwards'

Abstract--Tree stand growth (DBH, height, and stems per acre) for six site-preparation treatments were measured at age 10 years on a Georgia piedmont site. Stand growth was projected to clear-cut at age 30 years. Variables examined are growth differences observed at year 10, modeled to year 30. Estimated are: effects of hardwood competition on relative site index and projected wood-flows, net present worth of each site-preparation treatment, and changes in internal rate of return by treatment. Implications are appreciated for the relative value (cost and return) of the level of site-preparation intensity on forest profitability.

INTRODUCTION

It is commonly believed that unwanted competitor species growing in a plantation of desired crop trees have a negative effect on crop trees. A study by Glover and Zutter (1993), examining alternative site preparation methods, found that small increases in the density of hardwood early in the life of the stand had a considerable negative effect on 27 year pine survival and basal area. The amount of hardwood also had a negative effect on mean pine diameter and total height, but these effects decreased at later ages with increasing pine mortality and intra-species competitive pressure when the pines were left un-thinned.

OBJECTIVES

The objectives of this study are to compare the modeled wood-flows and financial performance of six site-preparation treatments on loblolly pine plantations in the Georgia Piedmont Wood-flow comparisons are based on total cord equivalents per acre. Financial comparisons are made with net present worth, internal rate of return, and equal annual equivalent returns.

Net present worth is calculated with revenues discounted to present year less costs discounted to present year at the discount rate. A net present worth value greater than zero indicates that at least the discount rate is being earned on the investment.

Internal rate of return is the interest rate at which discounted revenues equal discounted costs. It assumes that all intermediate revenues are reinvested into the project. The project is considered profitable if the internal rate of return exceeds the discount rate.

Annual equivalent value is the net present worth expressed as an annuity over the planning horizon, computed at the discount rate. Annual equivalent value is a useful measure for comparing investments over unequal time periods.

METHODS

This analysis utilizes a designed experimental study by Edwards (1993) located on an 84 acre tract (34 ha.) in the lower Piedmont of Georgia, at the Hitchiti Experimental Forest. The original stand of loblolly pine was harvested in 1981 and replanted with improved loblolly pine seedlings in early 1982 on a spacing of 6 x 10 ft. or 726 trees per acre (1.8 x 3 m, or 1,794 trees per ha.). Site index for the study area is 80 ft. (24.4 m) at base age 50 years (60 feet (18.3 m) at 25 years).

The six site preparation treatments were randomly assigned to the treatment plots. Listed in order of increasing intensity the treatments are:

1. Clear-cut only (check) -- No site preparation cost.
2. Chain saw-Ail residual trees greater than 1 inch DBH (2.54 cm) were removed by chain saw in August 1981. Site preparation cost = $30 per acre ($74 per ha.).
3. Shear and chop -- Shearing was performed by a KG-blade mounted on a D7-sized tractor in September 1981. Chopping was done with a single pass of a single-drum chopper in September-November 1981. No prescribed burning was performed on treatments 3 and 4 due to unsuitable weather conditions. Site preparation cost = $120 per acre ($296 per ha.).

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4. Shear, chop, and herbicide -- In addition to the shearing and chopping of treatment 30.5 cc Velpar Gridball(TM)[1] pellets (hexazinone) with 10 pct. a.i. were applied in a 1.9 x 1.9 ft. (0.58 x 0.58 m) grid at the rate of 25 lb. per acre (28 Kg per ha.) in March 1982. Site preparation cost = $200 per acre ($494 per ha.).

Note: Initial survival in treatment 4 was significantly reduced because about 3 inches of rain fell in a short period immediately after herbicide application and allowed for rapid distribution of a large quantity of hexazinone. This untimely event caused 35 pct. of the planted pines to die in this treatment 4. This herbicide action also provided approximately 80 p&control of the herbaceous and woody plants after the first growing season. Replacement pines were planted the following winter so that treatment 4 could remain part of the original study. The practice of inter-planting has long been of questionable merit Wakely (1968) found that by age 9 years inter-planted trees were on average, 2.25 inches (5.72 cm) in diameter and 8.5 feet (2.6 m) in height less than the original trees.

It could be argued that treatment 4 should be dropped to make this study look better. However, it is felt that more knowledge is to be gained by keeping things in the study that were tried and did not, and discussing those issued within a proper context. This work deals with unstable biological processes where a wrong turn in the weather can push aside the best laid plans.

5. Shear, root rake, burn, and disk -- Shearing and root raking into windrows was carried out in September 1981. Consuming burns of the windrows were achieved in October 1981. Remaining debris and ash were scattered over the plot with a dozer blade, then the plots were disked with an offset harrow to a depth of 6 to 8 inches (15 to 20 cm) in October 1981. Siie preparation cost = $150 per acre ($370 per ha.).

6. Shear, root rake, burn, disk, fertilize, and herbicide -- Site preparation was the same as described in treatment 5, plus ammonium nitrate (34-O-O) was applied by hand at the rate of 300 lb. per acre (336 Kg per ha.) in March 1983, and Oust(TM) weed killer, containing 75 pct. sulfometuron methyl, was applied at a rate of 8 oz. per acre (0.65 liters per ha.) in April 1982. Site preparation cost = $210 per acre ($519 per ha.).

[1]Use of trade names is for the reader's information and convenience and does not constitute offiial endowment or approval by the U.S. Department of Agriculture to the exclusion of any other suitable product.

The plots in the original study by Edwards (1993) were measured at the end of the tenth growing season with results shown in Table 1.

For the current study, treatment results were simulated from planting to age ten to approximate the data reported in Table 1 for trees surviving per acre, DBH, height, and basal area. Wood-flow projections and economic analyses were modeled using YIELDplus version 4.0 by Hepp (1994) with growth simulator parameters for site index, volume, weight, survival, and height-by-DBH diameter distribution set for south-wide conditions to broaden applicability of the study. Amateis and Burkhart (1981) concluded that no logical and consistent trends in regional variabilii could be distinguished from their south-wide database after examining the behavior of prediction equations for three stand characteristics (basal area, total volume, and heightdiameter relationships). Hasenauer et al. (1994) concluded that there were significant differences in the potential density within a given site index among the Gulf Coastal Plain and the Piedmont and the Gulf Coastal Plain and the Atlantic Coastal Plain but not between the Atlantic Coastal Plain and the Piedmont

Glover and Zutter (1993) cite growth modeling difficulties for weed competition in pines when examining differences in height at a young stand age after alternative site preparation treatments. They indicate that height differences should be combined with DBH, survival, and basal area data when modeling future tree growth. Further, they find that when left unthinned, high pine density adversely affects average DBH by age 22 years.

Initial stand stocking was adjusted in the modeled scenarios to allow surviving trees per acre, at age 10 years, to equal the treatment plot data. Initial modeled stocking for treatments l-6 were 741, 755, 815, 895, 906, and 873 trees per acre, respectively (1,830, 1,865, 2,013, 2,211, 2,238, and 2,156 trees per ha.).

To simulate weed competition, and other factors. impacting growth to age 10 years, site index was adjusted from 60 feet (18.3 m) at 25 years, to allow average survival, basal area, height, DBH, and volume to conform to the measured treatments. Site indexes modeled for treatments l-6 were 30, 37, 55, 53, 63, and 66 feet at 25 years, respectively (9.1, 11.3, 16.8, 16.2, 19.2, and 20.1 m at 25 years). Survival, basal area, average DBH, and average volume consistently matched average data from each treatment However average height, weighted by the number of trees within each diameter class, was consistently four to five feet below the measured treatments.

Table 1 .--Loblolly pine mean survival, height, DBH, volume, and basal area, per acre after 10 growing seasons (1992), by treatment, in the Georgia Piedmont.

Treatment'	Survival (pct.)	Height (feet)	DBH (in.)	Volume (cu. ft.)	Basal area (sq. ft.)
1	72c[2]	20.8c	2.4c	296.0	22.0b
2	76bc	24.2bc	2.8c	412.6c	27.8b
3	84abc	28.1ab	3.9ab	879.8b	56.9a
4	Slab	23.9c	3.7b	863.5b	59.3a
5	94a	29.3a	4.4ab	1158.7ab	74.8a
6	Slab	31.2a	4.6a	1286.7a	79.2a

[1] 1 = Clearcut only; 2 = Chain saw; 3 = Shear and chop; 4 = Shear, chop, and herbicide; 5 = Shear, windrow, burn, and disk; 6 = Shear, wlndrow, burn, disk, fertilize, and herbicide.
[2] Results within columns followed by the same letter are not significantly diierent (P = 0.05).

An alternative strategy to calculate average stand height was suggested by Todd E. Hepp[1] where-by average height per treatment was calculated by weighting DBH groups by basal area instead of by number of trees. This alternative strategy gave more weight to the taller trees and increased average height of the modeled plots almost equal to those of the measured plots.

It is recognized that site indexes of 30 and 37 are outside of normal parameters set up by Hepp (1994) for YIELDplus v. 4.0. Weed competition, while not listed directly, was consistently heavy before site preparation, across the study area.

At this point the modeling procedure was congruent with the treatment data at two points, at planting and at ten years of age, and provided a basis for extending the modeling age toward financial maturity.

Each treatment was then modeled, using parameters established up to 10 years, to final harvest (30 years) where total cord equivalent wood-flow, Table 2, and financial performance, tabie 3, were evaluated. Site index, volume, survival, diameter distribution, and height/DBH relationship were modeled on a South-wide basis.

A thirty year rotation was chosen for all treatments to provide equal time periods for comparison. It may be possible to improve the wood-flow and financial performance of individual treatments where rotation length is varied by treatment Thii option is deferred for future analysis.

The option of thinning at age 20 years was maintained to reduce the effects considered separate from weed competition: those of increasing pine mortality and intra-species competitive pressure found by Glover and Zutter (1990) by age 22 years without thinning. Treatment 1 did not produce sufficient wood-flow during the 30 year rotation to justify a thinning operation before clearcut. Treatments 2-6 were given an even thinning at age 20 years with a residual basal area after thinning depending on total growth available and the adjusted site index.

Prices modeled were state-wide averages for the preceding four-quarter period as reported by the U.S. Forest Service in Forest Farmer (1983) inflated at 4 pct. per year, table 3. The 4 pct. inflation is intended to be slightly above the general inflation rate of 3.5 to 3.75 pct. per year to yield a real price inflation rate of 0.5 to 0.25 pct. A discount rate of 8.0 pct. was chosen to represent a conservative, alternative investment rate. Planting costs were charged at $50 per acre ($123.50 per ha.) for hand planting. Site preparation charges were varied by treatment as reported by Moak, et.al. (1983). Management was charged at $1 per acre ($2.47 per ha.) per year for treatments 3-6. Harvest costs were 10 pct. of revenues for thinnings and 8 pct. for clear-cuts. Results are reported before taxes. Other variables such as ad valorem property taxes, federal tax effects, hunting leases, and pine straw harvests were omitted from the assumptions because they would be common to each scenario and would add no real new information to the comparative study.

RESULTS

Wood-flow, expressed in total cord equivalents per acre, of the modeled treatments l-6 were 7, 16, 38, 36, 51, and 55, respectively, table 2. These results match and extend the trends established by the original treatment plots through year 10. The interrelated, negative effects of competition on survival, height, DBH, and basal area were incorporated into the modeling process.

'Telephone consultation with the author on Tuesday, October 4, 1994.

Table 2. Wood-flow summary report of modeled results per acre for six site preparation treatments, Georgia Piedmont. Trees planted in 1982 and harvested in 2012, 30 years.

Treatment Number[2]	Site Index)	Height feet	Harvested component' Basal Area	Number Stems	MBF Scribner	Net Cords	Total Cords
1	30	34	57	362	0.00	7.06	7.06
2	37	42	99	437	0.32	15.33	16.40
3	55	63	153	471	3.01	29.77	37.66
4	53	61	153	505	2.36	29.57	35.89
5	63	72	184	497	5.91	36.05	50.80
6	66	76	191	481	7.41	36.45	54.65

[1] Pulpwood top diameter: 4"; Cords = Cuft/[77.1 + 1.4(dbh)]; Max. Cuft/cord: 110; Min. pulpwood dbh: 4.5"; Min. saw-timber dbh: 10.0" Site Index: SOUTHWIDE Cuft Volume: SOUTHWIDE, Weight: SOUTHWIDE, Survival: SOUTHWIDE, Diameter Distribution & Ht-dbh: SOUTHWIDE
[2] 1 = Clearcut only; 2 = Chain saw 3 = Shear and chop; 4 = Shear, chop, and herbicide; 5 = Shear, windrow, burn, and disk; 6 = Shear, windrow, burn, disk, fertilize, and herbicide.
[3] Site index is expressed as average height in feet of dominant and co-dominant trees at age 25 years.
The inclusion of a thinning at year 20 generally improved wood-flow of modeled treatments 2-6 compared to the check, treatment 1. Harvests of the treatments 1-6, without a thinning option, yielded wood-flows of 7, 13, 35, 34, 49, and 52 total cord equivalents per acre, respectively.

Table 3. Financial summary report of modeled results per acre for six site preparation treatments, Georgia Piedmont. Trees planted in 1982 and harvested in 2012, 30 years. Discount rate 8%. Results reported before tax, adjusted for inflation.

PRODUCT NAME	DBH-RANGE LOW	HIGH	STUMPAGE PRICES ---SAWLOG--- $/MBF	INF%	PULP-TOP-CULL $/CORD	INF%
PULPWOOD	5	9	.oo	.o	19.50	4.0
CHIP-N-SAW	10	12	.00	.o	35.80	4.0
SAW-TIMBER	13	19	130.00	4.0	15.00	4.0

	Site Preparation Treatments' 1	2	3	4	5	6
IRR[2]	7.2%	9.4%	11.1%	10.2%	10.5%	10.4%
AEV'	$-1	$3	$14	$10	$18	$21
NPW'	$-10	$36	$155	$114	$206	$234
Return to Treatment	$0	$46	$165	$124	$216	$244
Cost of Treatment	$0	$30	$120	$200	$150	$210
Net return to Treatment	$0	$16	$45	$-76	$66	$34

[1] 1 = Clearcut only; 2 = Chain saw; 3 = Shear and chop; 4 = Shear, chop, and herbicide; 5 = Shear, windrow, burn, and disk; 6 = Shear, windrow, burn, disk, fertilize, and herbicide.
[2] Internal rate of return.
[3] Annual equivalent value.
[4] Net present 1 worth.

Treatment 4 yielded total relative wood-flow less than expected for the level of intensity of site preparation. It is assumed that this decrease was due, in part, to excessive tree seedling mortality (35 pct.) and associated stunting of remaining seedlings from damage experienced after heavy rainfall shortly after herbicide application. In addition, inter-planted trees in treatment 4 likely failed to catch up to growth of the original planting. Again, the real value of this treatment may be the implications it has for the effect of herbicide/heavy rain interaction on survival, and the effectiveness of inter-planting rather than for its comparative effects of site preparation wood-flow and financial performance.

In their site preparation study, Glover and Zutter (1993) found pine basal area of prepared sites 10 to 20 times higher than the untreated check when all sites were left un-thinned to age 27 years. The untreated check grew substantial volumes of non-target tree species. Also, mean DBH of treated sites was double that of the untreated check. Pine survival in the treated plots was 2.5 to 5 times the number of trees found in the check. Further, average total height was 26 pct. higher for the treated sites than the untreated check. Note, no thinnings were performed in the Glover and Zutter (1993) study.

Analysis of financial performance of the modeled treatments, l-6, indicates that as site preparation intensity (cost) increases, financial performance increases also, table 3. The removal of competing vegetation, allowing increased survival and improved tree growth (height, DBH, volume, and basal area), are major factors in the relatively improved modeled performance of the successively intensive, site preparation treatments. Given modeling assumptions, t he addiion of a thinning operation for treatments 2-6 contribute to the increased profitability by moving cash-flows forward in time and by opening up the stand to reduce tree crowding and allow improved later tree growth. In addition, higher product prices for chip-and-saw and saw-timber earned by the scenarios producing more of these products boosted those financial performances.

NPW and AEV of the forestry investment generally increases with increases in site preparation intensity (with the exception of treatment 4). This means that more total returns (total revenues) per acre are being earned with more intense site preparation (higher costs and better weed control).

IRR, as a measure of financial performance, shows that the average efficiency of invested capital increases up through treatment 3 (1 1. 1 pct.), then begins to drop between treatments 3 and 5. This means that the average total returns are increasing for each additional dollar invested in site preparation. These total average returns per dollar of input begin to decrease after treatment 3.

Net financial returns (bottom line of table 3) steadily increase with increases in site preparation up to treatment 5 (Treatment 4 is considered affected by herbicide damage and inter-planting, and the relatively high total cost of site preparation of $200 per acre compared to $150 for treatment 5.). Treatment 6, while yielding the highest NPW ($234) has a lower net return to site preparation ($34) than does treatment 5 ($66). This decreasing net return to site preparation for treatment 6 is reflected in the associated decreasing IRR (10.4 pct.) compared to the IRR for treatment 5 (10.5 pct.).

CONCLUSIONS

In the Georgia Piedmont, for an average site index of 60 feet (18.3 m) at 25 years, with heavy herbaceous and woody weed competition, increasing site preparation intensity (cost) increases total cord equivalent wood-flow in a 30 year rotation.

The inclusion in the modeling process of consideration for tree survival, DBH, height, basal area, and total volume should improve estimates of future wood-flow.

The addition of a thinning option at age 20 years appears important to allow wood-flows to match practical experience. These increasing wood-flows yield increases in financial performance. Therefore, for the site preparation treatments 26, favorable returns could be expected (i.e. net present worth > $0 at the 8 pct. discount rate chosen).

Treatment 3 provides the highest rate of average returns (11 .1pct.) to capital invested in site preparation. Investment could continue to increase as long as IRR is above the discount rate.

Treatment 6 earns the most total revenue per acre, as shown by NPW, $234, but at the expense of decreased investment efficiency (10.4 pct.).

IMPLICATIONS

Reliability of modeling effects on pine growth and profitability, of weed competition controlled by varying levels of intensity and expense of site preparation, is uncertain at present. Inclusion of consideration for measurements of survival, height, diameter, basal area, total volume, and thinning when setting model parameters for future growth should improve results. As the Edwards (1993) study matures, modeling techniques should improve to yield results to match realii.

Wood-flow and financial performance of forestry enterprises can be greatly improved with site preparation efforts to control competing vegetation. However, limits of investment in site preparation can be

reached beyond which the rate of improvements in performance begin to decline.

To further the discussion, increasing tree growing costs per acre (per hectare) without increasing total wood-flow would necessarily shorten the rotation age. However, increased production costs, with an associated increased financial performance, may shorten, lengthen, or not effect the optimum rotation age. Additional analysis is required to solve this issue.

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LOBLOLLY PINE PLANTATION PROFITABILITY: SUCCESSIVE PULPWOOD VS. MULTIPLE-PRODUCT ROTATIONS'

Coleman W. Dangerfield, Jr., and David J. Moorhead[2]

Abstract-Planted loblolly pine rotations interact with the **reality** of financial maturity and market areas **and with the concept of sustainability. A comparison is made between two, short (20 yr.) pulpwood rotations** and a single, multiple+product (40 yr.) rotatii. **Variables examined** are market areas (price) and **soil productivity** (site index). Estimated are: **wood-flow projections,** net present **worth,** internal rate **of return, and equal annual equivalent returns. Implications** are **associated** for the time **preference** of **money as impacted** by **factors** of productii and marketing beyond the **control** of **most non-industrial private** forest **landowners.** These factors are the natural resource (land) and the **developed** resource (markets).

INTRODUCTION

Non-industrial private forest landowners in the southeast United States have experienced increased demand and prices for pine **stumpage** in recent years (Timber-Mart South 1994). As **stumpage** value increases, particularly for pulpwood, landowners are reevaluating plantation management intensity and rotation length. One common consideration has been the choice between longer rotations producing higher value chip-n-saw and sawtimber size **stumpage** verses shorter rotations for pulpwood production. Many landowners observe the intensive short rotation pulp production "models" used on some forest industry land and question if they should emulate this management option on their lands. Pine pulpwood rotations of 20 years are possible in southeast Georgia, while longer rotations of 35 to 40 years produce pulpwood along with chipn-saw and **sawlog** dimension treas. Periodic thinnings in longer rotations can be used to maintain optimum stocking levels and generate income prior to final harvest.

OBJECTIVES

The objectives of this paper are to compare the **wood-**flow and financial performance of two successive pine pulpwood plantations with one multiple-product rotation. Wood-flow comparisons are based on total cord equivalents per acre. Financial comparisons are made with net present worth, internal rate of return, and equal annual equivalent returns.

Net present worth is calculated with revenues discounted to present year less costs discounted to present year at the discount rate. A net present worth value greater than zero indicates that at least the discount rate is being earned on the investment.

Internal rate of return is the interest rate at which discounted revenues equal discounted costs. It assumes that all intermediate revenues are reinvested into the project. The project is considered profitable if the internal rate of return exceeds the discount rate.

Annual equivalent value is the net present worth expressed as an annuity over the planning horizon, computed at the discount rate. Annual equivalent value is a useful measure for comparing investments over unequal time periods.

METHODS

Wood-flow projections and economic analyses are modeled using **YIELDplus** version 4.0 by Hepp (1994). An average site index of 65 feet at 25 years is assumed for a cut-over **loblolly** pine plantation in Georgia, planted in 1994. The pulpwood scenario chosen was two, successive **20-year** rotations to represent a common industry model (Table 1). The second pulpwood rotation was modeled to yield equivalent wood-flow to the first pulpwood rotation. The single, multiple-product rotation of 40 years was **utilized** for comparison to represent a viable alternative to short rotation forestry and to provide an investment analysis comparison over equal time periods (Table 1).

Prices modeled were statewide averages for the preceding four-quarter period from Timber-Mart South (1994) inflated at 4 percent per year (Table 2). The 4 percent inflation is intended to be slightly above the general inflation rate of 3.5 to 3.75 percent per year to yield a real price inflation rate of 0.5 to 0.25 percent. A discount rate of 8.0 percent was chosen to represent a conservative, alternative investment rate. Site preparation and planting costs totaled $100 per acre,

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Table 1. Woodflow summary report of modeled results for two cutover loblolly pine plantation scenarios planted in 1994: 1) two successive, 20-year pulpwood rotations; and 2) one multiple-product, 40-year rotation, Georgia. Site index = 65 feet at 25 years, 650 trees per ace surviving at year 0.'

1) Two, successive pulpwood rotations					RESIDUAL COMPONENT-					VESTED COMPONENT-				
HARVEST NUMBER	YEAR	AGE	HEIGHT	PAI CORDS	THINNING METHOD	BASAL AREA	NUMBER STEMS	MBDFT SCRIBNER	NET CORDS	TOTAL CORDS	BASAL AREA	NUMBER STEMS	MBDFT SCRIBNER	NET CORDS	TOTAL CORDS
1	2014	20	54	1.5	N/A	FINAL HARVEST					127	430	.79	27.68	29.99
1	2034	29	54	1.5	N/A	FINAL HARVEST					254	860		27.68	29.90
						TOTALS/ACRE							1.58	55.36	59.80

2)One, multipl- product 40-year rotation					RESIDUAL COMPONENT-					VESTED COMPONENT-				
HARVEST NUMBER	YEAR	AGE	HEIGHT	PAI CORDS	THINNING METHOD	BASAL AREA	NUMBER STEMS	MBDFT SCRIBNER	NET CORDS	TOTAL CORDS	BASAL AREA	NUMBER STEMS	MBDFT SCRIBNER	NET CORDS	TOTAL CORDS
1	2011	17	47	1.4	EVEN	75	300	.00	15.15	15.15	40	161	.00	a.07	a.07
2	2018	24	63	2.2	LOW	75	133	2.82	14.00	21.28	35	462	.00	9.02	9.02
3	2025	31	77	1.7	LOW	70	73	8.01	4.26	23.35	31	63	2.65	3.64	10.27
4	2934	49	92	1.4	N/A	FINAL HARVEST					95		15.34	3.04	35.56
						TOTAL/ACRE					201	402	17.99	23.77	82.91

'Pulpwood top diameter: 4"; Cords = Cuft/[77.1 + 1.4(dbh)]; Max. Cuft/cord: 110; Min. Pulpwood dbh: 4.5"; Min. Sawtimber dbh: 10.0"; Site index: SOUTHWIDE Cuft Volume: SOUTHWIDE, Weight: SOUTHWIDE, Survival: SOUTHWIDE, Diameter istribution & Ht-dbh: SOUTHWIDE

Table 2. Financial summary report of modeled results for two cut-over loblolly pine plantation scenarios planted in 1994: 1) two successive, 20-year pulpwood rotations; and, 2) one multiple-product, 40-year rotation, Georgia. Site index = 65 feet at 25 years, 650 trees per acre surviving at year 0, discount rate 8%, planning horizon 1994-2034, before tax, adjusted for inflation.

PRODUCT NAME	STUMPAGE PRICES DBH-RANGE LOW	HIGH	---SAWLOG--- $/MBF	INF%	PULP-TOP-CULL $/CORD	INF%
PULPWOOD	5	9	.00	.0	30.00	4.0
CHIP-N-SAW	10	12	.00	.0	55.00	4.0
SAWTIMBER	13	19	200.00	4.0	20.00	4.0
BIG SAWTBR	20	27	250.00	4.0	20.00	4.0

	1) Two, successive pulpwood rotations	2) One, multiple-product 40 year rotation
NET PRESENT WORTH	$357.05	$843.99
INTERNAL RATE OF RETURN	14.0%	15.0%
ANNUAL EQUIVALENT VALUE	$29.94	$70.78

per rotation. Management was charged at $2 per acre per year. Fire protection was estimated at $5 per acre, on five year intervals. Harvest costs were 10 percent of revenues for thinnings and 8 percent for clearcuts. Results are reported before taxes.

Early growth reductions were found by Haywood (1994) for successive short rotation loblolly and slash pine in central Louisiana. Reasons for these growth declines in the second rotation were not identified. Differences between rotations in rainfall patterns, logging damage, or competition were termed unlikely responsible. It was suggested by Haywood that nutrition may have been a factor in the height reduction of the second rotation compared to the first, up to the seven years covered by the study. For comparative purposes with the financial performance of the current study, an alternative scenario was modeled where the wood-flow of the second pulpwood rotation was reduced 10 percent from the first rotation with the level of inputs held constant.

Allen et al. (1991) details that competing herbaceous and woody weeds are likely responsible for decreased pine growth during a second, successive pulpwood rotation studied in North Carolina. Further asserted is that with increased inputs of weed control, the second rotation wood-flow can equal that of the first. In the current study, to measure the effect of those assumptions on financial performance, an additional alternative scenario was modeled with the level of wood-flow for the second, successive pulpwood rotation held equal to the first rotation while the level of costs for planting and site preparation were increased 10, 20, 30, and 40 percent.

RESULTS

Wood-flow of the successive pulpwood rotations totaled almost 80 total cord equivalents per acre (Table 1). This compared to the total yield of just under 63 cord equivalents for the muttiple-product rotation. Even though the total cord equivalent wood-flows of the two modeled scenarios were relatively equal, the single, 40-year multiple-product rotation produced over 23 cords of pulpwood, plus higher valued products in the amounts of 19 cords of chip-n-saw, and 32 MBF of sawtimber. Pulpwood accounts for just over 37 percent of the total volume harvested from the multiple-product stand.

Financial performance of the single, 40-year, multiple-product rotation was clearly superior to the two successive, 20-year pulpwood rotations (Table 2). The addiion of the second planting cost in year 20 was a major factor in the relatively poorer performance of the successive pulpwood rotations. In addiion, higher product prices for chip-n-saw and sawtimber earned by the multiple-product rotation boosted that financial performance.

A price sensitivii analysis was also estimated for the two scenarios (pulpwood and multiple-product). The two successive, pulpwood rotations would perform financially equal (net present worth and annual equivalent value) to the single 40-year rotation when pulpwood prices increases approximately 85 percent, from $30 to $55 per cord (equivalent to the current chip-n-saw price), with pulpwood, chipn-saw, and sawtimber prices of the multiple-product rotation held constant. Alternatively, profitability of the single 40-year rotation would be reduced equal to that of the pulpwood rotations when chip-n-saw prices decreased 45 percent, from $55 to $30 per cord and with sawtimber prices decreased over 62 percent, from $200 to $75 per MBF, with pulpwood prices held constant for both scenarios.

When wood-flow of the second successive pulpwood rotation is reduced 10 percent, and inputs are held constant, as found by Haywood (1994), several results occur: net present worth of the total investment over the 40 year period drops $18.30 per acre; internal rate of return drops 0.1 percent; and annual equivalent value drops $1.53 per acre.

Alternatively, when site preparation and planting costs for the second, successive pulpwood rotation are raised to control increased weed competition, with wood-flow held constant, as reported by Allen et al. (1991), less effect on profitability is shown. The above costs must be increased 40 percent, up to $140 per acre, before profitability is decreased approximate to the amount experienced by decreasing yield 10 percent.

CONCLUSIONS/IMPLICATIONS

For an average site index of 65 feet at 25 years, a single, multiple-product 40-year rotation yields approximately the same total cord equivalent wood-flow as two, successive 20-year pulpwood rotations for loblolly pine plantations (Table 1). However, the multiple-product rotation contains higher valued products of chip-n-saw and sawtimber in addition to the reduced volume of pulpwood.

In the market area examined (Georgia state average prices 1993-94), the single 40-year multiple-product rotation clearly out-performs financially the two successive 20-year pulpwood rotations with measures of net present worth, internal rate of return, and annual equivalent value (Table 2).

The successive pulpwood rotations provide several advantages. The planning horizon is shorter and more focused, and harvest and marketing are less complicated. In addition, if assumptions or conditions change during the first pulpwood rotation, the grower can elect to change goals and practices, and extend the planning horizon beyond 20 years.

Disadvantages include that pulpwood rotations require more frequent site disturbance with additional planting costs and operations experienced. Thus, soil loss through erosion may be greater. Also, plant and wildlife diversity may be decreased. Opportunities for adding enterprises such as hunting leases and pine straw harvests to pulpwood production may be diminished.

The single, 40-year multiple-product rotation has advantages in addition to superior financial performance. As mentioned, more opportunities exist to include multiple-use enterprises such as hunting leases/activities, pine straw harvest hiking and camping, wildlife observation, livestock grazing, etc. with growing trees. Also, if assumptions or conditions change during the first part of the rotation, the grower can elect to shorten the planning horizon to less than 40 years.

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Site Productivity

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CLEARCUTTING AND SHEARING ON A SALINE SOIL IN EAST TEXAS: IMPACTS ON SOIL PHYSICAL PROPERTIES'

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Abstract-Soil samples, or in-situ measeurments, were collected at seven occasions and at six depths to study the impact of **three** forest condiiions on soil **physical** properties of a **saline soil in E. Texas. Soil bulk density, % of silt plus clay at the surface horizons, soil water content, soil water retention, and depth to groundwater increased following intensive site preparation. Differences in these properties between the commercial clearcutting and undisturbed forest were small. The wet soil condiiions created in the intensive preparation site are not likely to be responsible for the failure of artificial pine regeneration. In areas where site preparation may cause standing water on the surface, all plants and stumps should be left intact after marketable timber is removed.**

INTRODUCTION

Commercial clearcutting is the most common type of forest disturbance in **East** Texas **(McWilliams** and Lord, 1988). Following clearcutting, sites are usually mechanically prepared for forest regeneration by chopping, shearing, piling, bedding or some combination of these activities. Because of the intensity of site disturbance, these **activities** have caused concern about their impacts on soil physical (Lal and Cummings, 1979; Gent et al., 1983 **)** and chemical properties (Mroz et al., 1985; Snyder and **Harter, 1985),** nutrient losses (Clayton and Kennedy, 1985; **Muda** et al., 1989) and erosion problems (Beasley and Granillo, 1988; Chang et al., 1982; Miller, 1984; Riekerk, 1983).

There are more than 120,000 hectares (ha) of somewhat poorly drained, upland saline soils in central East Texas (between Sam **Rayburn** Reservoir in the NE and Lake Livingston in the SW). The soils contain a high concentration of aeolian sediments derived from volcanic ash and deposited over impervious **mudstone** high in pyroclastic sediments. Vegetation is dominated by mature **loblolly** (P. ***taeda*)** and **shortleaf** (P. *echinata)* pines with scattered hardwood species. After clearcutting the forest, artificial pine regeneration on these soils is extremely **difficult** (three attempts in some areas). Examination of scattered pine seedlings naturally regenerated in **clearcut** sites show J-shaped root-systems at about **15** cm below the surface with **little** lateral-root development. **It** is not clear if the poor root systems and mortality of pine seedlings are due to high water tables caused by the removal of vegetation, salt concentrations toxic to seedlings, nutrient imbalance near the surface, or combinations of all three.

A project was initiated in 1988 to study the effects of forest harvesting and site preparation on soil physical and chemical properties along with soil, water and element losses on a poorly drained saline soil in East Texas. Such information is essential in developing artificial regeneration techniques for southern pine species and for managing **nonpoint** sources of water pollution. Results of the research on sediment-loss and element movement have been reported by Chang et al. (1992) and **Sayok** et al. **(1993a** and **1993b);** the objective of this report is to discuss the results of the work related to soil physical properties.

METHODS AND PROCEDURES

Study Area

The study was conducted during the water **years** 1989 and 1990 in the Davy Crockett National Forest near Apple Springs, Texas, about 200 km north of Houston and 250 km southeast of Dallas. The area has a humid subtropical climate with prevailing winds from the southerly directions. Summer storms typically occur afternoon and are of high intensity, low frequency, and short duration. The normal (1951-80) annual precipitation and temperature at Lufkin Airport, about 22 km NE of the study area, is 1,054 mm and 19 **°C,** respectively. Precipitation recorded at the study site was 1,245 mm for the 1989 and 1,349 mm for the 1990 water years. Topography of the area is characteristized by gently rolling hills with **slopes ranging from 2-10%. The** soil of the study site is Fuller fine sandy loam, **a** member of the fine loamy siliceous, thermic family of Albic Glossic Natraqualfs. The saline nature of these soils was derived from volcanic ash blown from the Cook Mountain Formation during the Eocene Epoch and deposited on siltstones or

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mudstones. Ocean water inundated the area and compacted the volcanic ash, and silty materials were blown from the west to settle on top of the compacted ash.

Vegetation was dominated by loblolly pine and shortleaf pine with a mixture of post oak (Q. stellata), red oak (*Q. falcata*), white oak (*Q. alba*), Sweetgum (L. *styraciflua*), and hickories (*Carya spp.*). Merchantable trees ranged from 30 to 55 years of age in 1988 with an average height 28.5 m, DBH 25 cm, site index 27 m, and basal area 21.81 m^2 ha-'.

Treatment

Three treatments were employed in the study: 1) undisturbed forest with full crown closure as a control, 2) commercial clearcut with all merchantable timber removed, other vegetation left intact, and 3) clearcut, all vegetation removed, stumps sheared with V-blade D6 crawler tractor, and debris windrowed; vegetation was prevented from regrowth, by shearing, with no disturbance to the soil for two years. All treatments were randomly located within an area of 3.24 ha with each treatment separated by about 90 m and a small lst-order drainage ditch. They all had the same soil and comparable site condiions in terms of vegetation, slope, aspect and climatic characteristics. The size of each treatment plot was about 0.5 ha; the harvest was conducted on July 23-24, and shearing on August 26, 1988.

Soil Measurements

Soil physical properties examined in the study included texture, bulk density, moisture retention, hydraulic conductivity, moisture content, end depth to groundwater. Soil samples were collected using a Soilmoisture #200-A soil core sampler along three slope positions centrally located at each treatment site and at six different depths from surface (O-l 5, 15-45, 45-60, 60-85, 85-100, and 100-120 cm). These samples, taken about two months before (June 1988) and at five different times after treatments (September and December of 1988, February and July of 1989, and January 1990), were used for determinations of texture (Day, 1965), bulk density (Blake, 1965), soil moisture retention (Richards, 1965) and saturation hydraulic conductivity (Falling-Head Permeameter; Soiltest Inc., 1979) in the laboratory. The bulk density and hydraulic conductivity were run on undisturbed samples. Since the effect of logging and its associated activities on soil texture is generally confined within the surface 40 cm depth (Burger and Pritchett, 1984), only were samples collected at the O-l 5 and 15-45 cm depths two months before and five months after the treatment used in the soil texture study.

Weekly soil moisture contents at four soil depths were monitored using Campbell Pacific Nuclear (CPN) #503 Hydroprobe, a neutron scattering moderation device, through three access tubes installed in the soil of each plot to a depth of 0.90 m. At the beginning of the study, the rating curve of Hydroprobe furnished by CPN was recalibrated to reflect the concentration of soil hydrogen ions at the study site (Sayok, 1991). Three groundwater wells, each 2.0 m deep and 73 mm in diameter slitted PVC pipe, were installed in the center of each plot (5.53 m apart each other). Water table levels were measured weekly using a Soilmoisture handheld water-level indicator, Model K654A. These depths to groundwater table were later converted into elevations of groundwater table for comparisons.

Data Analysis

Data collected from these soil samples and field measurements were employed to show differences in soil physical properties among the three forest site conditions through simple comparisons of sample means, ranges, coefficients of variation, or graphical illustrations. Differences in soil properties were also examined through analysii of variance and Students t-test. Soil properties measured before treatments were used as references for each site. Since there were no replicates employed in this study, results of analyses could only be inferred to the study site. It was assumed that any differences in soil properties were attributable to the site treatment, other effects such as slope, aspect and climatic variations were negligible through careful selection of the study site and random arrangement of site treatments.

RESULTS

Soil Texture

Percent sand composition was the most affected by the treatment, especially in the sheared plot and in the surface 15 cm. Changes in silt and clay caused by the treatments were small (Table 1).

Clearcutting and shearing caused an increase in sift plus clay content (or a decrease in sand) about 9% in the O-15 cm and 5% in the 1545 cm depths , compared to 3% and 5% respectively of the clearcutting without site preparation. These changes in the clearcut plot, in view of the variation of soil texture in the undisturbed forest or among the three plots before treatments, seem to be within the range of site variation, but that in the sheared plot are somewhat substaintial. Apparently, the use of a D6 Caterpillar Crawler tractor in site preparation had a great mixing effect on soils in the surface 45 cm depth. The effect of site preparation on particle size distribution may consequently affect bulk density and soil water holding capacity. No statistical analysis was performed on these changes in the present study due to small sample size.

Bulk Density

Priot to treatments, average bulk density (BD) was 1.02 g cm^{-3} at the O-l 5 cm depth, and 1.43 g cm^{-3} at the 15-

Table I- Means and ranges (in parenthsis) of percent sand, silt, and day two months before and five Months after forest treatments on a saline soil near Apple Springs, Texas

Depth,	Undisturbed Forest		Commercial clearcut		Clearcut & sheared	
	Before	After	Before	After	Before	After
0-15 m						
Sand	78.1 (73.8-80.4)	81.3 (79.6-83.0)	82.3 (79.4-86.2)	79.0 (73.2-82.4)	80.3 (79.0-81.6)	71.6 (67.8-77.6)
Silt	13.1 (09.2-20.6)	13.6 (13.2-17.2)	14.9 (11.2-17.6)	15.8 (13.0-25.2)	18.0 (17.0-19.8)	24.7 (19.8-27.6)
Clay	8.8 (05.6-10.6)	5.1 (03.2-07.0)	2.8 (02.6-03.0)	5.2 (01.6-06.3)	1.7 (01.2-02.6)	3.7 (01.0-04.6)
15-45 cm						
Sand	79.3 (76.8-81.2)	76.3 (73.0-82.2)	82.5 (79.4-85.4)	77.7 (73.0-82.0)	78.1 (76.4-79.6)	72.7 (67.8-77.0)
Sitt	11.2 (08.0-15.4)	17.7 (13.0-20.8)	13.4 (10817.4)	17.0 (14825.0)	18.9 (17.6-20.4)	22.4 (19.0-27.6)
Clay	9.5 (03.6-14.0)	6.0 (04.2-07.2)	4.1 (03.2-05.4)	5.3 (00.8-05.8)	3.0 (02.8-03.2)	4.9 (01 .o-06.0)

45 cm depth of the three treatment sites with a greater site variation at the surface level (coefficient of variation 0.17 versus 0.07). These values are within the range for most soils in East Texas (Stransky, 1976). However, compared to Fuller soils in Angelina County (Dolezel, 1988), the BD at the study site (Trinity county) is lower by 0.53 and 0.19 g cm^{-3} for the O-l 5 and 15-45 cm depths, respectively.

After treatments, BD increased with severity of site disturbance, but was gradually reduced with depth and time. Two months after treatments, BD in the sheared plot increased as much as 50% (from 1 .00 to 1.50 g cm") at the O-l 5 cm depth, and only about 3% (from 1.49 to 1.53 g cm^{-3}) at the 15-45 cm depth. However, the increase in the clearcut plot was about 33% and 12% for the two respective depths. Eighteen months after treatment, BD in the surface 15 cm depth of the sheared and commercial cleared plots was still 0.46 and 0.23 g cm^{-3}, respectively, greater than that before the treatment (Figure 1).

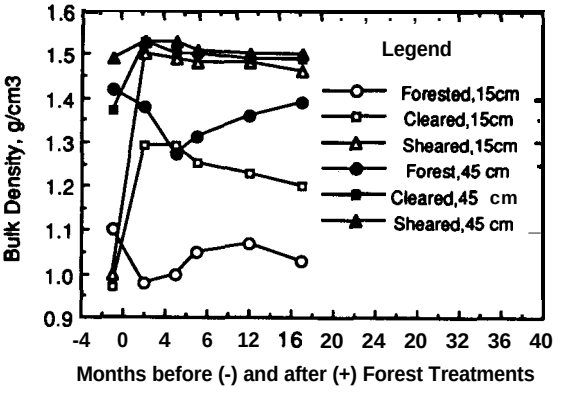

Figure 1 -- Changes in soil bulk density with time due to various forest treatments on Fuller soils near Apple Springs, Texas.

The rate of BD recovery depends upon soil texture, degree of disturbance, equipment, and climatic conditions. It has been reported to range from one year in a rubber-tired skidder operation on a relatively dry, coarse-textured soil in Minnesota (Mace, 1971) to 48 years on a landing site in Virginia Coastal Plain (Hatchall and Ralston, 1971). Assuming a constant BD decreasing rate in the study area, it would take about 15 and 5 years for the BD at the surface 15 cm depth of the sheared and cleared plots, in that order, to resume its pretreatment levels.

Studying the effect of soil compaction on loblolly-pine growth in a sandy loam soil, Mitchell et al.(1982) found that the root development could be mechanically impeded when BD exceeded 1.4g cm^{-3}. The present study showed that BD at both depths(O-15 and 15-45 cm) in the sheared plot and at the 15-45 cm depth in the cleared plot exceeded the 1.4 g cm^{-3} level. A tornado occurred on January 19, 1990 uprooted a large loblolly-pine in the study area. Soil BD under the uprooted tree ranged from 1.26 to 1.75 g cm". Of the 20 core samples collected at the depth (about 60 cm) where the downward growth of the root system was blocked, 1 1 had BD values equal to or greater than the 1.4 g cm" critical limit The roots were found to grow laterally at this depth.

Soil Water Retention

Due to differences in soil texture and organic matter content, the amount of water retained at a particular pressure (tension) varies considerably from one soil to another. Forest harvesting and site preparation reduce canopy coverage and disturb forest floor and surface soil which may cause a mixing effect on soil mechanical composition and enhance organic matter decomposition, consequently affecting soil water retention.

Under six diierent pressure conditions, the mean amounts of water, in g g^{-1}, retained in the soils of the three study plots collected five months after treatments are given in Figure 2. These means were calculated from nine soil samples collected at three slope positions. The results showed that water retention for soils at the surface and bottom levels of the sheared plot was greater than that of the forested and cleared plots when they were under the 33 kPa pressure, but the forested plot was greater than the cleared and sheared plots when the soils were under the pressure 100 kPa or greater. Soil water available to plants at the 15 cm depth was 0.11 g g^{-1} for the sheared plot, compared to 0.041 and 0.073 g g^{-1} for the undisturbed forest and cleared plots, respectively.

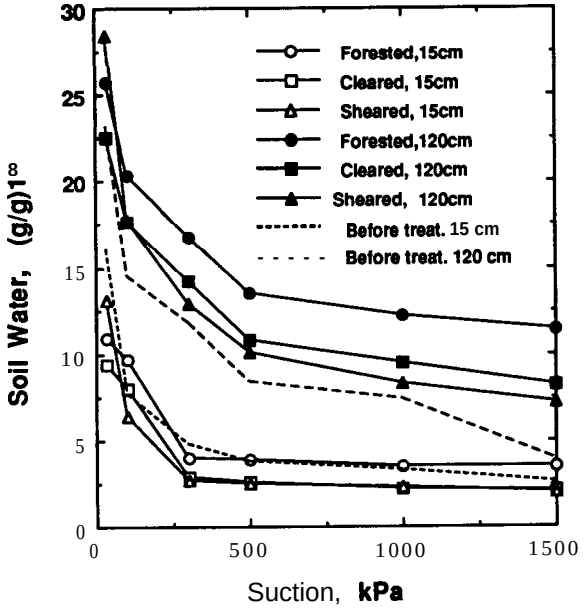

Figure 2 -- Soil water retention curves at the 15 and 20 cm depths of the Fuller soil before and five months after the treatment near Apple Springs, Texas.

At 33 kPa, water retention in the sheared plot was 0.130 g g^{-1} at the 15 cm depth versus 0.109 g g^{-1} and 0.094 g g^{-1} in the forested and cleared plots, respectively. At the 120 cm depth, water retention was 0.284 g g^{-1} in the sheared plot versus 0.257 and 0.226 g g^{-1}. As indicated in a previous section, clearcutting and shearing caused an increase in clay and silt content of almost 10% at the 15 cm depth (Table 1). In a companion study, Sayok (1991) also showed that there was a leaching of organic matter with time in the soil profile of the treatment plots. These might contribute to the greater moisture retention in the surface horizon of the sheared plot.

Soil Water

Soil water content (SWC) in the study area consistently increased with increasing degree of forest cover removal and with increasing depth below the surface. It was also higher in winter (November-April) than in summer (May-October) half-year. This trend reflects the great loss of soil water near the ground surface due to evapotranspiration.

The mean SWC of the whole soil profile (O-l 05 cm) during the first post-year period (October 1988 - September 1989) were 0.278, 0.309, and 0.349 g cm^{-3} for the undisturbed, clearcut, and sheared plots, respectively (Figure 3). In other words, the commercial clearcut and shearing treatments caused an increase in annual SWC for the whole soil profile by 0.031 (11%) and 0.071 g cm^{-3} (26%), respectively, as compared to the undisturbed forest plot. The effect was more

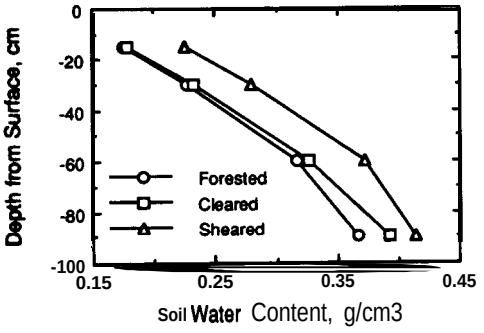

Figure 3 -- Mean soil water contents in the Fuller soil under three forest conditions in the Davy Crockett National Forest near Apple Springs, Texas.

significant for soil at surface levels and in the summer, based on Duncan's multiple range test at the 0.05 alpha level. For instance, summer SWC in the sheared plot at the 15 cm depth was greater than the undisturbed plot by 38% (0.070 g cm-'), but winter SWC at the surface level was greater by 28% (0.057 g cm-'). The maximum difference in daily SWC between the sheared and forest plots during the study period was about 0.172 g cm^{-3} (75%) observed at the 15 cm soil depth. Chang et al. (1983) reported differences in average SWC between sheared and forest plots on a Woodtell soil in Nacogdoches, Texas by as much as 0.135 g cm" (46%). The present study was conducted in a very wet period. Annual precipitation in the first post-treatment year (October 1988- September 1989)

at the study site was higher than the normal annual precipitation (1951-80) recorded at Lufkin, 22 km NE of the study area, by 1 gl mm (18%). The great amount of precipitation in the present study might cause the treatment effect on SWC to be less than that reported for the Woodtell soil.

Groundwater Table

Based on 101 weekly observations made between March 6, 1989 and February 251991, groundwater tables in the sheared plot were always the highest among the three treatments, followed by the clearcut and then undiirbed forest plots. The average groundwater elevation in the sheared plot was 29.16 m (shown as depth from surface), higher than the cleared and forest plots by 0.72 and 1.72 m, respectively. This trend persisted throughout the entire period, no matter if it was in a cold season or in a rain-recharged period. Apparently, thii is attributed to the differences in evapotranspiration caused by canopy density among treatments.

Expressing the occurrence of groundwater table as percentage of time that a given water table is equal to or greater than the indicated depths from surface, Figure 4 shows that these percentages decreased most rapidly at the forest site and most slowly in the sheared plot. During the summer half-year (May - October), for example, 18.7% of the time in the forest plot the groundwater table was 105 cm deep or less from the surface but it was 28.3% for the cleared plot and 31.4% for the sheared plot. The chances of having a high groundwater table were always greater in the sheared plot than that of cleared and forest plots, regardless of season of the year.

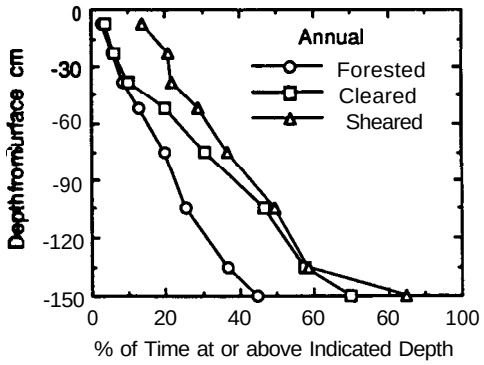

Figure 4 -- Average percent of time in March 1989 through February 1 ggl that the groundwater was equal to or above the indicated depths of three forest conditions near Apple Springs, Texas.

DISCUSSION AND CONCLUSIONS

The drainage in the Fuller soil is very slow although its texture is loamy sand in the surface horizon and fine sandy loam in the subsurface horizons. Laboratory analysis using soil samples collected before treatments showed the average saturated hydraulic conductivity to be 6.01 cm hr^{-1} at the O-15 cm depth, much slower than 71.01 and 17.70 cm hr^{-1} at the O-7.5 and 7.6-15.2 cm depths, respectively, reported for a soil of similar texture, Rains (typic Paleaquult, fine loamy, siliceous, thermic family), in the Lower Coastal Plain of North Carolina (Gent et al., 1 983; Figure 5). Apparently, other factors such as compaction, bulk density, soil structure, macropores, and salt concentrations might play an important role in affecting the hydraulic conductivity.

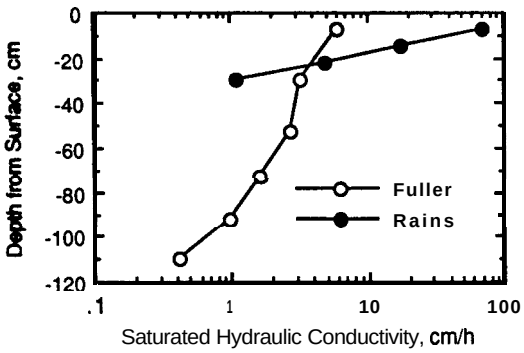

Figure 5 -- The saturated hydraulic conductivity for the Fuller and Rains soils.

Conventionlly, the saline soils in many agricultural areas is reclaimed by use of water drainage through the soil profile. Slow hydraulic conductivity precludes this approach in the study soil. Also, on the sheared plot all trees were cut, all stumps and shrubs were sheared, and all debris were raked into windrows. Not only was soil bulk density increased because of compaction and mixing effects of the mechanical operations, but the reduction in plant transpiration and interception also caused increases in soil water content, soil water retention, and height of groundwater table. During the two-year study period, 29% of the time the groundwater table in the sheared plot was within the surface 60 cm depth, while it was only 14% in the forested plot. Average soil water content at the 15 cm depth in the sheared plot was 0.226 g cm^{-3} for the two years period, or about about 0.15 g g^{-1}. Thii water is held in the soil equivalent to a force less than 33 kpa (field capacity; Figure 2).

Generally, loblolly pines grow well in upland soils as well as in floodplains, bottom-lands, or poor drainage sites (Baker and Langdon, 1990). Studies conducted in Georgia showed that one-year-old loblolly pine seedlings planted in 3.66 x 7.32 m in diked and ditched pots began to die 101 days after initiation of flooding to 10 cm depths. When flooded water was kept at the soil surface and at 10 cm depth above the surface, the

survival rates were 93% and 61 % at the end of 206 days, respectively (Walker et al., 1961). At the end of 579 days, the survial rates were still as high as 67% and 44% for the two respective innudated levels (Walker, 1962). Thus, waterlogged sites may make loblolly-pine regeneration impossible (Walker, 1980), but as long as seeds are germinated or seedlings are planted with buds above water, they should be able to survive flooding for one or two growing seasons. At that time, climatic conditions may change and groundwater level and soil water content may be lowered due to regrowth of vegetation, consequently creating a more favorable condition for seedling growth and development

Although clearcutting and site preparation created a site with a groundwater table close to the surface and a water content saturated or almost saturated, there was no standing water on the soil surface. Moreover, annual precipitation during the two study years was 191 (18%) and 295 (28%) mm greater than the normal. The groundwater table and soil water content should be lower in normal years. Thus, it is unlikely that the wet conditions normally encountered in the study area would cause the failures in artificial pine regeneration. Salt movement following clearcutting and site preparation may increase salt concentrations to levels that are toxic to seedlings; this hypothesis needs to be examined.

Clearcutting without site preparation did not significantly affect the soil physical properties. In areas such as valleys, flat terrains, or concave sites where forest clearcutting with site preparation may cause a standing water on the surface, all plants and stumps should be left intact after marketable timber is removed.

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EFFECTS OF HARVESTING METHODS ON SITE AND REGENERATION IN CYPRESS-TUPELO SWAMPS'

Emile S. Gardiner, John D. Hodges, and Stephen H. Schoenholtz[2]

Abstract-Two baldcypress-water tupelo stands, in the Mobile-Tensaw River Delta, were harvested in the winter of 1992 to test the hypothesis that mechanized felling increases site impact and reduces regeneration establishment relative to tradiiinal chainsawfelling. The sites differed by tidal influence, pre-harvest basal areas, and amount of preharvest understory vegetation. One year after harvest, soil hydraulic conductivity decreased 55 percent, but it did not differ between felling methods. There were about 3400 baldcypress or water tupelo stems per acre regardless of slte or felling method, but regeneration was significantly less on both sites where water was deepest. Over 80 percent of all stumps sprouted, and sprouting frequency was net influenced by felling method or stump diameter.

INTRODUCTION

Baldcypress, *Taxodium distichum* (L.) L.C. Rich., and water tupelo, Nyssa *aquatica* L, grow in association on floodplain sloughs and swamps from southeastern Virginia to southeasten Texas (Johnson 1990). The timber and fiber value of these species has made harvesting operations in these swampy habitats economical for well over a century (Brown and Montz 1986). Unfortunately, the first loggers were not concerned about the impact that their practices may have on the site and future stands. Early logging practices were often facilitated by road-building, channel construction, or dredging to position pull-boats needed to wench felled logs out of the swamp. Early logging practices often left ruts or ditches where logs were pulled out of the swamp during cable logging. Some of these pull-boat runs are still evident despite many years of alluvial deposition.

Current managers of forested wetlands are encouraged to critically evaluate their practices to ensure that activities do not impair wetland functions. As a result, harvesting practices in forested wetlands are being modified to reduce site impact during the removal cut. Minimal impact can be achieved by hand-felling trees and extracting logs from the site with a helicopter. Mechanized felling is attractive because it is economically efficient, and it improves worker safety. However, advancement of mechanized felling in wetlands has spawned problems with soil compaction and soil rutting, and machinery use is often restricted when soil is saturated. Recent advances in harvesting on wet sites involve harvesting machinery supported on wooden mats (Jackson and Stokes 1991). The mats displace the machine weight over a large surface area, hopefully reducing soil impact. Research in black water creek bottoms of south Alabama suggested that this type of operation could reduce site impact over traditional skidder operations (Lloyd et al. 1992). However, they reported that rootstock survial and biomass production may be reduced relative to chainaw felling. Aust et al. (1990) argued that quick establishment of vegetation following harvest is imperative to recovery of wetland functions. This study was initiated to test the hypothesis that feller harvesting increases site impact and reduces regeneration relative to chainsaw felling in cypress-tupelo swamps.

METHODS

The experiment was conducted on 2 baldcypress-water tupelo sites in the Mobile-Tensaw River delta of Alabama. Both sites contained ponds of low elevation relative to floodplain topography. Site 1 was the furthest upstream so it received the least amount of tidal influence. Thii site supported the highest pre-harvest basal area (about 230 square feet per acre), but the least amount of ground cover (about 20 percent). Site 2 was several miles downstream from Site 1. Preharvest basal area on this site was about 190 square feet per acre, and ground cover was estimated at about 60 percent. Soils on both sites were Typic Hydraquents.

Two blocks were delineated within each site or pond based on topography. Block 1 was closest to the river, and in the shallowest portion of the ponds. Block 2 was furthest from the river, and on the average in a deeper portion of the ponds. In each block, we installed 3 replications of 2 treatments in 2-acre experimental units. For the first treatment, all stems

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were felled with a chainsaw-head feller supported on wooden mats. Impact to site and regeneration wlth this treatment could potentially be realized from the machinery maneuvering on the site, felled trees, and/or feller damage to stumps. For the second treatment, or the operational control, all stems were hand-felled with chainsaws. Impact to the site and regeneration with traditional chainsaw felling would only be from sawyer foot traffic and felled trees. Each site was felled in the late fall of 1992, and all logs were removed from the site by a helicopter.

At each site, measurements of saturated hydraulic conductivity were taken to index site impact. This parameter was chosen as an index of site impact because it reflects alterations of bulk density, soil pore distribution and water movement Unfortunately, a different method of estimating hydraulic conductivity had to be used on each site, because Siie 1 was inundated during the sample period. Intact soil cores were collected at O-5 centimeter depth and the constant head method (Klute and Dirksen 1986) was used for Site 1 (20 samples for each treatment). The *In situ* auger hole technique (Amoozegar and Warrick 1986) was used on Site 2 (20 samples for each treatment). Therefore, the relative post-harvest change in saturated hydraulic conductivlty, calculated as the percent difference between harvested and an undisturbed reference area adjacent to each site, was used to compare sites.

In each 2-acre experimental unit 5, 0.01-acre regeneration sample plots were established and measured pre- and post-harvest. During both assessment periods, regeneration was evaluated in each 0.0%acre sample plot by recording species, height, and origin, either seedling or sprout, of all woody plants. Also, stump diameter and height of the dominant sprout were measured on all stumps. Regeneration density data were normalized with a log transformation, and Analysis of Variance was conducted on the pre- and post- harvest data. Simple linear regression was used to model the relationship between stump diameter and sprout height Tests were conducted at the 0.05 probability level.

RESULTS AND DISCUSSION

Saturated hydraulic conductivity was lowered about 55 percent relative to the undisturbed reference area on each site one year after harvest (Table 1). However, mechanical felling did not alter saturated hydraulic conductivity any more than chainsaw felling. Our findings agree with results reported by Aust and Lea (1992), who studied edaphii responses to logging practices on a nearby cypress-tupelo site in the Mobile-Tensaw River delta. They reported a signficant decrease in hydraulic conductivity after harvesting, especially where the site was traversed by a skidder. Soil disturbance under felled trees may account for the decreased hydraulic conductivity on plots where logs were extracted with a helicopter (Aust and Lea 1992).

Table 1. Relative change in saturated hydraulic conductivity by felling method for 2 baldcypress-water tupelo sites in the Mobile-Tensaw River delta, 1 year post-harvest

	Siie 1	Site 2
	---- Percent Change[a] ----	
Chainsaw	-47a[b]	-78a
Feller	-53a	-41a

[a] Percent change from undisturbed reference area.
[b] Means followed by the same letter are not significantly diierent (a = 0.05).

Across both sites, the pm-harvest regeneration inventory indicated about 160 baldcypress and water tupelo stems per acre (Table 2). One year after harvest, there were about 3400 stems per acre on each site (Table 2). About 93 percent of the regeneration was seedlings, while 7 percent originated from stump sprouts. Sii-one percent of the regeneration was baldcypress and the remaining 39 percent was water tupelo. Natural and artificial regeneration has been diicult to establish on some baldcypress-water tupelo sites because of altered hydrologic patterns, irregular seed distribution, or herbivory (Conner and Toliier 1990). First-year results from this study indicated baldcypress and water tupelo establishment was prevalent on both sites. Summer 1993 was relatively dry in the Mobile-Tensaw River delta, so perhaps this promoted germination and establishment of an apparently large baldcypress and water tupelo seed bank. Best germination of these species occurs during periods when water recedes and soils are exposed (Johnson 1990).

Carolina ash, *Fraxinus caroliniana* Mill., virginia-willow, *Itea virginica* L., and common winterberry, *Ilex verticillata* (L.) Gray, were the most common mid- and understory woody species on each site. Site 2 had the greatest density of these species both pra and post-harvest (Table 2). This may be linked to pm-harvest basal areas and resulting forest floor light levels (Marois and Ewell983). Site 2 had the lowest basal area, and a resultant thinner canopy which could allow more light to reach the forest floor. Contrary to the response by baldcypress and water tupelo regeneration, a large post-harvest increase in these understory species was not observed. For both sites, species other than baldcypress and water tupelo comprised 83 percent of woody plant regeneration pm-harvest, but only about 23 percent of the regeneration post-harvest. Other authors (Allen 1962, Kennedy 1982) have reported that black willow, *Salix nigra* Marsh, often invades and

Table 2. Regeneration (stems per acre ± standard error) by site, block, and felling method for 2 baldcypress-water tupelo sites in the Mobile-Tensaw River delta, preharvest and 1 year post-harvest

	Pre	Post	Pre	Post
	Site 1		Siie 2	
Group 1[a]	176.5 ± 21.9a[b]	3216.6 ± 395.1a	146.2 ± 26.8a	3562.7 ± 441.9a
Group 2	619.2 ± 72.3b	415.1 ± 40.4b	940.9 ± 121.9a	1577.9 ± 133.8a
	Block 1		Block 2	
Group 1	170.0 ± 33.5a	4258.3 ± 449.3a	160.0 ± 19.7a	2503.4 ± 34.9b
Group 2	650.0 ± 78.2a	1285.4 ± 149.6a	764.2 ± 96.2a	778.9 ± 96.7b
	Feller		Chainsaw	
Group 1	168.4 ± 23.0a	3252.5 ± 399.5a	154.5 ± 24.7a	3521.7 ± 437.0a
Group 2	713.3 ± 82.5a	1040.3 ± 124.8a	717.2 ± 103.9a	1014.5 ± 134.5a

[a] Group 1 refers to baldcypress and water tupelo regeneration while Group 2 refers to all other woody plant species.
[b] Means in a row followed by the same letter are not significantly diierent (a = 0.05). Only mean comparisons at the same sample period are valid.

establishes early dominance on harvested swamp sites. In this study, black willow regeneration accounted for only 1 percent of all stems on both sites one year after harvest.

There were no differences in the amount of baldcypress and water tupelo regeneration between blocks before harvest (Table 2). However, blocks in the deepest portion of the pond had significantly fewer stems per acre after harvest. Others (Conner and Toliver 1990) have reported poor establishment of baldcypress and water tupelo in deep-water swamps. Floodwater subsidence is critical for seed germination and seedling establishment of swamp species (Demaree 1932, DuBarry 1963, Shunk 1939). Though regeneration was less dense in deeper blocks, there were still over 2500 baldcypress or water tupelo seedlings per acre. The other woody species followed a similar pattern (Table 2). There was no density difference praharvest, but a slightly higher stem density in the shallowest portion of the ponds post-harvest

First-year results indicated that felling method did not influence regeneration (Table 2). The average seedling height was not affected by felling method and was 9.5 inches. Density of woody plant regeneration other than baldcypress and water tupelo was not influenced by harvesting method either (Table 2). Harvesting practices can reduce regeneration establishment through soil rutting or compaction (Lloyd et al. 1992). In this study, harvesting reduced saturated hydraulic conductivity, but this was apparently not detrimental to regeneration establishment.

One of our concerns was the sprouting abilii of stumps damaged by the feller. Lloyd et al. (1992) reported 46 percent mortalii of swamp blackgum, Nyssa *biflora* Walt., stumps 1 year post-harvest in black water creek bottoms of southern Alabama. In this study, about 82 percent of all stumps sprouted regardless of felling method. In addition, stump diameter did not influence sprouting frequency or height of sprouts (Data not shown). Kennedy (1982) also found no relationship between stump diameter and sprouting abilii of water tupelo in the Atchafalaya Basin of Louisiana. However, he did find that coppice regeneration was in decline by year 6 due to rotting stumps.

SUMMARY

The influence of 2 felling methods on site and regeneration was studied in 2 baldcypress-water tupelo ponds of the Mobile-Tensaw River delta. First-year results indicated saturated hydraulic conductivity, an index of site impact decreased post-harvest, but was not influenced by felling method. Regeneration establishment was good on both sites, and did not diier between felling methods. We did find a lower density of baldcypress and water tupelo stems in the deepest portion of the swamps, but there were still several hundred per acre. Density of midstory and understory woody species showed very little response to overstory removal. Successful regeneration can only be determined several years after establishment, but early establishment of baldcypress and water tupelo regeneration did not seem to be negatively influenced by mechanized felling. Future inventories will monitor regeneration survival and development on these sites.

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LOBLOLLY AND LONGLEAF PINE RESPONSES TO LITTER RAKING, PRESCRIBE BURNING AND NITROGEN FERTILIZATION'

Sharon M. Ross, William H. McKee and Michele Mims[2]

Abstrac-The objectives of this study were to evaluate the effects of prescribe burning and litter removal on soil nutrient levels and tree growth. An addiiil objective was to determine if nitrogen can be replaced with the application of fertilizer. There were no statistiilly significant changes in the soil nutrient levels or tree growth after six years, but there were significant changes in forest floor weights, nutrient levels, and tree mortality.

INTRODUCTION

Harvesting pine straw has increased in recent years because of its value for landscaping. There is concern that mineral nutrients are being removed from the site and that disruption of biological processes associated with organic matter litter mineralization are disrupted as a result. Since these consequences may affect long term site productivity, the development of optimum forest floor management practices is important.

McLeod et al. (1979 a,b) reported that forest floor removal disrupts the hydrologic and macronutrient cycles of 20 to 30 year old longleaf pines. They also concluded that tree growth was reduced the year following liier removal. By comparison, prescribed burning that consumes an appreciable portion of the forest floor does not result in a net loss of mineral soil nutrients. McKee (1 982), reported nitrogen tends to accumulate in the surface mineral soil on some sites following prescribed burns.

Considerable information has been developed on the components of nutrient pools and rates of liier decay, however, application of these principles to forest floor management has not been developed. Therefore, the objectives of this study were to evaluate the effects of prescribed burning, a silvicultural management practice, and litter removal on: (1) the growth of loblolly and longleaf pine; (2)nutrient pools in the forest floor and surface soil, and (3) determine if nitrogen applications will alter tree growth and/or forest floor properties.

MATERIALS AND METHODS

This study was located on the Savannah River Sie in Aiken County, South Carolina. The soil in the area is mapped as Fuquay fine sandy loam (Arenic Plinthic Paleudult, loamy siliceous, thermic). It is well drained with a 2 percent or less slope.

The stands were originally in agriculture and were planted or seeded to either loblolly or longleaf pine in the early 1950's. In 1971 the loblolly pine stand was clear-cut, sheared and root raked, then replanted with I-O loblolly pine with an approximate 1.80 by 3.04 meter spacing. The treatment plots were 0.16 hectares with some variation in size depending on site properties. The longleaf stand was thinned in the mid 70's with approximately half the stems removed. The plots in the longleaf stand were 0.19 hectares with 1.80 by 3.04 meter spacing.

The study consists of three replications for the loblolly stand and two replications for the longleaf stand in a randomized split plot design. There are three treatments imposed on the loblolly stand: 1) no treatment (control), 2) prescribed burn treatment in winter at three year intervals and 3) red straw (liier layer) raking treatment in winter at three year intervals. The longleaf stand received all the above treatments plus a total raking treatment in the winter at three year intervals. The split plot factor consists of no fertilizer or 100 kilograms of nitrogen as urea and 12 kilograms of phosphorus as triple super phosphate per hectare. For the raking treatment, pine straw was removed from the plots manually, making sure onty red straw was removed. For the total raking treatment all the red straw plus the fermentation and humus layer was removed to the mineral soil. Prescribed burns were cool winter backing fires where flames did not exceed a half meter above the ground. About 75 to 80 percent of the forest floor was consumed with these burns.

Tree diameters were measured at 1.37 meters above the ground. Basal area was computed as the sum of the stem cross sectional area on each measurement plot expanded to square meters per hectare.

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The forest floor was sampled prior to the treatments in 1987 and at 3 year intervals. Ten sample points (15.2 centimeters square) were collected and composited by plot. Forest floor material was separated into the litter layer and humus plus the fermentation layer. Two 15 centimeter mineral soil cores were extracted at each of ten forest floor sample points and the soil composited in 5 centimeter increments by plot The soils were air dried and sieved to < 2 mm. Forest floor samples were oven dried at 65°C and ground to pass a 1 .O mm mesh screen.

Total Kjeldahl nitrogen was measured on both forest floor and mineral soil samples (Nelson et al., 1973). Exchangeable bases were extracted from the soil with 1 N ammonium acetate at pH 7 (Thomas, 1982). Organic matter content for the soil was determined by the Walkley and Stack Method (Jackson, 1958). Soil pH was determined on a 1: 1 soil to water paste.

Statistical analysis was performed separately for the loblolly and longleaf components of the study. Response to treatment were tested by analysis of variance with significance at the 0.05 level. The tree growth data was analyzed with covariance using the initial stand (1987) values as the covariant.

RESULTS AND DISCUSSION

There were no treatment effects on loblolly or longleaf pine basal area over the seven years of observation. There were significant treatment differences in mortalii for the loblolly pine (Table 1). The red straw raked treatment had significantly lower mortalii than the control and the prescribed burn treatments. To date, we do not have an explanation for this observation but the difference in tree mortalii maybe related to differences in stand growth and competition.

The treatments have not significantly altered the chemical properties of the soil in the upper 15 centimeters (Table 2). Treatments had an affect on the physical properties of the forest floor after six years, although the response of the liier and humus layers were diierent within the treatments. Litter mass on the loblolly stand was about twice that of the longleaf stand as well as being two folds higher in nutrient levels (Table 3). The difference in the weight of the loblolly and the longleaf needle production and the amount of nutrients found in the foliage may reflect differences in the species and/or differences in the age of the stands. In contrast the mass and nutrients of the humus layer was higher on the longleaf than on the loblolly forest floor (Table 4). The heavier humus layer of the longleaf stand is attributed to stand age and a slower rate of decomposition. The lower nutrient level is also an indicator of a slow rate of decomposition.

Fertilization treatments (Table 3) did not alter the physical properties of the liier layer on the loblolly or the longieaf stand. Although the physical properties (weights and nutrients) were not significant, there was an observable response to the fertilization treatment by the longleaf stand. The fertilizer increased liier production from 1.98 to 3.47 metric tones and the weight of the nutrients increased by 85 percent for nitrogen, 236 percent for phosphorus, 43 percent for calcium and 57 percent for magnesium.

Forest floor treatments altered the response of the humus layer (fermentation plus humus) for both species (Table 4). The control plots for the loblolly stand contained more organic material than the prescribed burn humus layer. The rake plots were not significantly diierent than other forest floor treatments. Nitrogen content of the humus layer was higher on the control plots than prescribed burn plots with the raked plots not being diierent from the other treatments. Phosphorus levels were not affected by forest floor treatments and ranged from 25.9 to 48.3 kilograms per hectare. Potassium levels were 0.21 to 0.85 kilograms per hectare higher on the control and raked plots than the prescribed burn plots.

Table 1-Loblolly and longleaf pine stand initial and seven year measurements for basal areas and mortalii

Treatments	F	Basal area 1987	Basal area 1994	DA	Mortality
		Loblolly			
	kg/ha	------m/ha----			pct
Control	0	20.4	29.8	9.4	13.5'
	112	23.3	33.5	10.2	19.7'
Prescribed burn	0	25.5	34.4	8.9	14.5'
	112	23.3	34.1	10.8	12.2'
Red straw raked	0	22.3	33.3	11.0	4.8[b]
	112	19.8	32.3	12.5	4.1[b]
		Longleaf			
Control	0	39.0	33.3	-5.7	4.5
	112	29.2	34.9	5.7	5.5
Prescribed burn	0	25.6	29.0	3.4	10.5
	112	29.2	25.2	-4.0	24.0
Red straw raked	0	26.2	36.2	10.0	9.5
	112	23.7	33.2	9.5	7.0
Total raked	0	33.2	36.0	2.9	5.5
	112	29.3	33.8	4.5	6.0

Columns without letters are not significantly different at p<0.05 level.
F=fertilizer; DA=diierence in basal area

Table 2-Soil properties after two 3-year interval treatments

Treatments	F	Loblolly OM	Loblolly N	Loblolly Bases	Longleaf OM	Longleaf N	Longleaf Bases
	kg/ha	pct	pct	meq/100g	pct	pct	meq/100g
0-5 m							
Control	0	3.23	0.11	0.96	1.58	0.14	0.11
	112	2.85	0.17	1.27	1.92	0.12	0.09
Prescribed burn	0	3.40	0.16	1.30	2.03	0.14	0.23
	112	3.37	0.17	1.46	2.99	0.13	0.26
Red straw raked	0	3.45	0.15	0.73	2.03	0.13	0.15
	112	3.08	0.17	0.99	2.14	0.14	0.16
5-10 cm							
Control	0	1.98	0.13	0.37	1.37	0.11	0.06
	112	1.99	0.13	0.30	1.49	0.11	0.07
Prescribed burn	0	2.30	0.14	0.42	1.56	0.12	0.08
	112	2.71	0.15	0.27	1.58	0.12	0.09
Red straw raked	0	2.04	0.14	0.26	1.36	0.12	0.05
	112	2.19	0.14	0.33	1.51	0.12	0.08
Total raked	0	----	----	----	1.60	0.11	0.11
	112	----	----	----	1.85	0.12	0.06
10-15 cm							
Control	0	1.33	0.10	0.16	0.87	0.10	0.07
	112	1.37	0.11	0.15	0.92	0.11	0.06
Prescribed burn	0	1.27	0.11	0.23	1.24	0.11	0.06
	112	1.33	0.11	0.13	0.92	0.11	0.10
Red straw raked	0	1.47	0.10	0.16	1.28	0.10	0.20
	112	1.45	0.11	0.17	1.07	0.11	0.06
Total raked	0	----	----	----	1.00	0.10	0.80
	112	----	----	----	1.07	0.12	0.14

F=fertilizer; OM=organic matter; N=nitrogen

Table 3--Weights and nutrient levels in the forest floor for loblolly and longleaf pine litter after two treatment intervals

Treatment	F	LW	N	P	K	Ca	Mg
	kg/ha	Mg/ha	kg/ha				
Loblolly							
Control	0	6.52	36.4	12.7	0.84	19.9	4.8
	112	7.98	50.1	13.0	1.64	24.9	5.6
Prescribed burn	0	5.61	34.6	12.0	0.86	16.9	4.6
	112	5.43	30.6	13.6	0.69	16.7	4.5
Red straw raked	0	4.08	22.2	8.1	0.21	11.8	3.3
	112	5.27	31.7	22.6	0.44	14.7	4.0
Lonaleaf							
Control	0	2.39	9.1	1.12	0.21	7.77	0.15
	112	4.05	14.3	3.52	0.27	12.10	1.02
Prescribed burn	0	1.40	5.2	0.56	0.10	4.58	0.30
	112	3.69	15.3	5.64	0.26	11.47	0.82
Red straw raked	0	2.02	6.5	1.72	0.26	5.76	0.09
	112	3.29	13.7	3.65	0.22	9.73	0.08
Total Raked	0	2.09	8.8	0.82	0.17	6.20	1.20
	112	2.87	11.6	1.31	0.30	8.88	1.89

F=fertilizer; LW=litter weight

Table 4-Weight and nutrient levels in the forest floor for loblolly and longleaf pine humus after two treatment intervals

Treatment	F	HW	N	P	K	Ca	tvlg
	kg/ha	Mg/ha			kg/ha		
Loblolly							
Control	0	13.64'	108.8'	48.3	1.28'	37.0	5.6
	112	13.39'	111.0'	46.7	2.02.	41.0	5.7
Prescribed burn	0	10.23[b]	80.4[b]	34.4	1.95[b]	28.0	6.9
	112	7.06[b]	57.0[b]	25.9	0.92"	17.8	3.5
Red straw raked	0	13.26'	97.2'	41.8	2.02[a]	41.1	8.4
	112	11.62[ab]	Q6.8'	37.7	2.56'	27.2	5.7
Longleaf							
Control	0	59.74'	394.2[a]	24.53[ab]	9.41	157.14	30.24
	112	61.27'	403.2[a]	50.62[ab]	8.21	155.46	29.12
Prescribed burn	0	5.48[b]	35.8[b]	5.15[b]	0.40	16.24	2.24
	112	11.75[b]	70.6[b]	15.12[b]	1.74	43.57	6.05
Red litter raked	0	32.94'	197.1'	47.60'	0.48	76.72	14.45
	112	73.53'	460.3'	86.58'	0.87	218.85	39.87
Total raked	0	7.88[b]	49.3[b]	6.50[b]	0.48	19.49	2.46
	112	10.48[b]	67.2"	13.55"	0.87	33.49	4.82

Columns without letters are not significantly diierent at p<0.05 level.
F=fertilizer; HW=humus weight

The mass of the longleaf humus was not significantly affected by fertilizer treatments, although it increased for the fertilized plots. The weight of the humus for the forest floor control and red straw raked treatments were significantly greater than the weight of the humus that received the prescribed burn and total raked treatments. Nitrogen levels in the humus layer responded similarly to the organic weights, with the prescribed burn and the total raked treatments having less nitrogen than other treatments.

SUMMARY AND CONCLUSIONS

So far, results of this study have not shown a reduction or an increase in tree growth. It has shown that prescribe burning may enhance nutrient cycling creating an improved environment for tree growth. This has been shown by other studies (Hough 1981 and McKee 1982). McKevlin and McKee (1986) showed that seedling growth was greatly improved on soil taken from a site annually burned as compared to the same soil unburned. Litter raking decreased the nutrients in the foliage for both tree species. Fertilizer application replaced the nutrients in the foliage for each species as well as increasing the litter yield for the longleaf. Morris et al. (1991) also expressed concern over possible loss of site fertility due to litter raking and indicated that the application of fertilizer did appear to maintain soil fertility and increase litter yield. This study should be continued for two additional 3 year intervals.

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A PRELIMINARY WETLAND TRAFFICABILITY HAZARD INDEX BASED ON SOIL MOISTURE'

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Abstract—Wet weather timber harvesting is a common occurrence in the southeastern coastal plain during the winter and spring months when rainfall exceeds evapotranspiration. Harvesting operatii during these wet conditions may result in reduwd operation productivity, increased equipment wear, and have negative consequences for site hydrology and soil characteristics. At present, there is no suitabk on-site mechanism for predicting the degree of traffic that a site can withstand before excessive disturbances occur.

Three wet pine flats in the South Carolina coastal plain were characterized to develop a Hazard Rating Index based on soil physical properties. The Hazard Rating Index requires on-site measurement of soil moisture and soil strength. The current model requires addiil refinement, but the initial valiiation efforts indiie that use of such a model could reduce site impacts caused by wet weather harvesting.

INTRODUCTION

Wet pine flats are often difficult to harvest due to wet soil conditions throughout the winter and spring months. On non-drained sites, operation of harvesting equipment without soil rutting problems is limited to a 3 to 6 month period (Allen and Campbell 1988). The limited window of operabiii makes it necessary to conduct harvesting operations during wet conditions, which may cause soil rutting and puddling. Concerns relating to rutting and puddling include issues such as sustainable forest productivity, wetland carbon storage, water quality, wetland ecosystem processes, and Best Management Practices (BMP's)for wetlands.

Avoidance of rutting and puddling will require better planning and improved understanding of soil and site characteristics (Aust and others 1990). A relatively simple technique of evaluating soil and site characteristics would aid land managers in making informed, on-site decisions concerning site operability and potential site damage.

Understanding the relationship between soil physical properties and soil strength can give land managers detailed trafficability information for individual forest tracts. The use of penetration resistance has been commonly used to describe the soil physical status (Canarache 1990). Most efforts to indirectly estimate penetration resistance or trafficability have included measures of soil moisture and bulk density (Ayers and Perumprall982; Bennie and Botha 1986; Henderson and others 1988; Wells and Treesuwan 1978). This study was developed in order to resolve some of the site disturbance problems associated with forestry operations in wetlands. The overall objectives of this study are: 1. to characterize and model soil strength as a function of soil physical properties and site characteristics, and 2. to use the soil strength model to develop a Trafficability Hazard Rating that can be used on similar soils and sites.

METHODS

Three blocks (North Horseshoe, South Horseshoe, and Sycamore units) were located on coastal plain wet pine flats near Cottageville, SC. Each block contained 20 ha (48 acres) of bedded loblolly pine (*Pinus taeda*) plantations that were 1 Q-21 years old. Soils were poorly drained loams and sandy loams overlaying clay loam subsoils (aqualfs and aquults). Surface drainage was minimal due to the flat topography (0-2% slope) and water tables remain within 1/2 m of the soil surface for most of the year.

Measurement stations were located on a 40 m X 80 m grid (216 stations). Water table, soil moisture, and soil strength measurements were taken simultaneously at each measurement station. This set of dynamic measurements were taken at 5 different times throughout the wetting and drying cycle between January 1993 - December 1994. Static and dynamic parameters measured at each sampling station are provided in Table 1. Static properties were determined by soil horizon (A, E, and Bt), but analyses and interpretation in this paper will be limited to A-horizon data. A trafficabilii model has been developed using only the A horizon because any vehicular traffic will be in direct contact with the surface A horizon, contains

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the majority of plant roots, and the location of the A horizon allows for easy sampling.

Table 1. Measurements taken at each sampling station.

Parameter	Method	Reference
Water Table	PVC welts	
Soil Strength	Standard cone penetrometer	ASAE (1990)
Soil Moisture	Time Domain Reflectometry	Soilmoisture Equipment Corp. (1989)
Bulk Density	Soil cores	Blake and Hartge (1986)
Horizon Depth	Push tube	
particle size classifications	Bouyoucus	Gee and Bauder (1986).
Pore Space	Tension table	Danielson and Sutherland (1986)
Organic Matter	LECO carbon analyzer	Nelson and Sommers (1982).
Hydraulic Conductivii	constant head method	Klute and Dirksen (1986)
Liquid Limit / Plastic Limit	Atterberg test	Sowers (1965)

Dynamic soil properties were measured at 5 different periods, representing a range of wet to dry conditions. At each measurement location, penetrometer readings were taken every 5 cm to a depth of 50 cm. As a result 10800 penetrometer measurements were taken each with dynamic and static soil properties associated with it. Scatter plots interpretations of soil strength vs. soil and site properties were used to determine if relationships were linear or non-linear. When a soil property had a non-linear relationship with soil strength a transformation was made to produce a linear relationship. A stepwise backwards elimination procedure (Belsley and others 1980) was used to determine the soil and site characteristics which had the greatest influence on soil strength for the A, E, and Bt horizons. Multiple linear regression was used to describe soil strength as a function of dynamic and static properties.

RESULTS

Candidate models for the A horizon were determined using a stepwise regression procedure (Equation 1).

Equation 1

log (soil strength, kPa) = 3.50 - 0.00642(water table depth, cm) - 0.671 log (volumetric moisture content, %) + 0.221 (bulk density, Mg/m3)
(P value < 0.01, R^2 = 49.9)

Problems associated with collinearity were removed (Belsley and others 1980) and Equation 2 was developed. Equation 2 is similar to a model developed by Bennie and Botha (1986).

Equation 2

log(soil strength, kPa) = 5.21 + 0.0738(bulk density, Mg/m3) - 1.53 log(volumetric moisture content, %)
(P value < 0.01, R^2 = 52)

When the water table variable (WT) was eliminated from the regression equations because of mutticollinearity, the subsequent equations' R^2 decreased. However, measurements of volumetric water content using a TDR system are easier and more rapid (Drungil and others 1989) as compared to water table measurements.

Regression Equation 2 for the A horizon used soil moisture content and bulk density to estimate soil strength. Within the regression equation, moisture content and bulk density had P values of < 0.001 and 0.034 respectively. The elimination of bulk density resulted in Equation 3, which has a lower R^2 but increased field applicabilii.

Equation 3

log (soil strength, kPa) = 5.39 - 1.60 log(volumetric moisture content, %)
(P value < 0.01, R^2 = 54.5)

Figure 1 represents the trafficabilii hazard index based on the effect of volumetric moisture content (%) on soil strength (kPa). By using soil moisture and vehicle ground pressure it can be determined if site disturbance will occur. Vehicle contact ground pressures can be derived by dividing the weight of a machine by the total ground contact area as described by Wasterlund (1994). Many factors affect the ground pressure exerted by harvesting equipment, thus specific values for intended equipment should be used in the index. However, this does not take into account pressures generated by movement and uneven axle loads created during log handling (Greacen and Sands 1980). Pressures of up to five times the nominal contact pressures have been measured in the soil under the rear wheels of agricultural tractors (Greacen and Sands 1980). Greacen and Sands (1980) cited Farrell and Greacen (1966) identifying soils in equilibrium with a compacting load X, the penetrometer resistance is approximately 10 fold. For example, a vehicle applying a ground pressure of 250 kPa will eventually reach a equilibrium state of compaction with a penetrometer resistance of 2500 kPa. Two hazard ratings were derived based on the effects of movement on vehicle ground pressure. Static ground pressure was multiplied by 5 and 10 to estimate dynamic pressure applied by a vehicle. Ground pressures were calculated using the formula reported by Wasterlund (1994). The use of these two multipliers identifies a

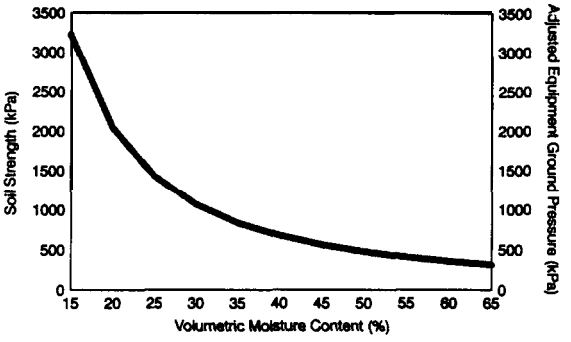

Figure 1. Trafficability Hazard Index

moisture zone at which machinery-site interactions are unpredictable. No site disturbance would bs expected for a moisture content below this zone and intensive site disturbance would be expected for moisture contents above the zone.

The following example demonstrates the use of the model. A soil has a volumetric moisture content of 21% and will be trafficked by a medium sized skidder (23000 Ibs) using 23 inch wide tires. The skidder being considered has a ground pressure of 223 kPa. The adjusted equipment ground pressure can be determined by continuing across the table, 2230 and 1115 kPa (with adjustments of 1 OX and 5X, respectively). Next these two values are found on the Y2 axis in Figure 1. Horizontal lines can be drawn from the adjusted equipment ground pressure value until the horizontal lines intersects the soil strength regression line. At the intersection, vertical lines can be drawn down to identify critical moisture contents on the X-axis. The moisture content between the two vertical lines represents a unpredictable zone with regards to site disturbance (moisture content between 19 - 28%). This is due to the adjustment of a static measurement to a dynamic measurement. The moisture content of the site falls just within the lower limit of this zone. If the site had a moisture content less than 19%, little site disturbance would be expected. A site with a moisture content greater than 28% would be expected to have intense site disturbance. At a moisture content of 21%, site disturbance would be expected to be limited; however, it would exists. At thii point the land manager can use equipment that applies less ground pressure or wait until the site becomes dryer.

DISCUSSION

Sites with high disturbance potentials can be avoided by having an understanding of major soil physical properties and processes that affect soil strength. By avoiding extensive site disturbance possible declines in productivity and public opposition to forest management in wetlands can also be avoided by land mangers. This study revealed very significant relationships between moisture content and site hydrology parameters and soil strength. However, the use of moisture content and water table depth as a base for a identification method vary in applicabilii. The measurement of water table depth across a large site would be too labor intensive and not economically feasible. However, the measurement of moisture content using time domain reflectometry offers a simple and economically sound alternative for measuring a significance soil strength parameter across large land holdings.

Soil strength, estimated by soil moisture can be compared to pressures applied to the soil by equipment to determine if equipment forces are greater than that of the soil. By using only the surface horizon measurements can be made quickly and economically. The moisture content was significant in explaining variations in soil strength; however, penetration resistance was also included in the index to aid in identification of sites susceptible to disturbance. Penetration resistance is also easily attainable by the use of a penetrometer which has been suggested for this purpose in many reports. The use of hazard indices such as the one reported in this study have the potential to limit site disturbance and lower site preparation costs. The use of the trafficability hazard index can give the land manager and logger additional site information. Additional validation and refinement of this hazard index will continue.

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RECOVERY STATUS OF A TUPELO - CYPRESS WETLAND SEVEN YEARS AFTER DISTURBANCE : SILVICULTURAL IMPLICATIONS'

Thomas W. Zaebst, W. Michael Aust, Stephen H. Schoenhottz, and ConneFristoe[2]

Abstract---A water tupelo, *Nyssa aquatica* L., - baldcypress, *Taxodium distichum* L. Rich., swamp located in the Mobile - Tensaw Rii Delta of Southwestern Alabama was harvested in 1986. Harvest treatments included i.clearcutting with helicopter log removal (HELI), ii. HELI followed by skidder simulation (SKID), and iii. HELI followed by rsmoval of all vegetation via glyphosate herbicide application (GLYPH). At age 7-yrs, total biomass, average densities, total heights, and diameters of SKID treatments were equal to or greater than those of the HELI treatment. Water tupelo responded more favorably to SKID treatment at the expense of carolina ash, *Fraxinus caroliniana* L., which was more abundant in HELI treatment. The GLYPH areas have basically become freshwater marshes. All treatments have significant groundflora components that have increased sediment accumulation 70 - 175 percent relative to an undisturbed reference area.

INTRODUCTION

Timber harvesting operations in forested wetlands have been increasingly scrutinized by the general public and by agencies authorized to implement the Federal Water Pollution Control Act (Tolliier 1993). Public and agency concerns about timber harvesting in forested wetlands have revolved around issues such as maintaining site productivity, water quality, site hydrology, and biodiiersity (Walbridge **1993),** yet little long-term research has been conducted in forested wetlands to address such issues (Lockaby et al. 1994).

The overall objective of this research project was to determine the effects of various levels of disturbance in a water tupelo, Nysse ***aquatica*** L., - baldcypress, ***Taxodium*** *distichum* L. Rich., wetland on indices of water qualii, plant **diversity,** and vertical **stratification.**

METHODS

Study Area

A productive (1 **00* steres/ha)** two-aged tupelo - cypress "gum pond" on the western bank of the **Tensaw** River (Baldwin Co., AL) was selected for the study. Age-classes resulted from previous **cable-**logging operations and the majority of the trees were **70-yrs-old** while scattered residual trees were **130+-yrs-**old (in 1986). The site floods annually, with the longest periods of inundation occurring during the winter and spring months when transpiration rates are low, although growing season floods are common. The soil is clayey, mixed, thermic Vertic Fluvaquent. Detailed site and stand descriptions are provided by Aust and Lea **(1991, 1992).**

Treatments

Three disturbance treatments were imposed on the study area and an undisturbed reference area was maintained immediately adjacent to the site (Fig. 1). All disturbance treatments were **clearcut** with chainsaw felling during fall, 1986 and all merchantable stems were removed via helicopter (HELI). This sequence of events comprised the helicopter treatment. The skidder simulation treatment (SKID) was achieved by trafficking approximately 50% of the area within treatment plots with a loaded cable skidder equipped with **34-inch-wide** tires. Average skidder rut depth exceeded 30 cm. The third treatment consisted of removal of all vegetative regrowth from helicopter treated areas during the growing seasons of 1987 and 1988 via backpack sprayer application of glyphosate herbicide (GLYPH).

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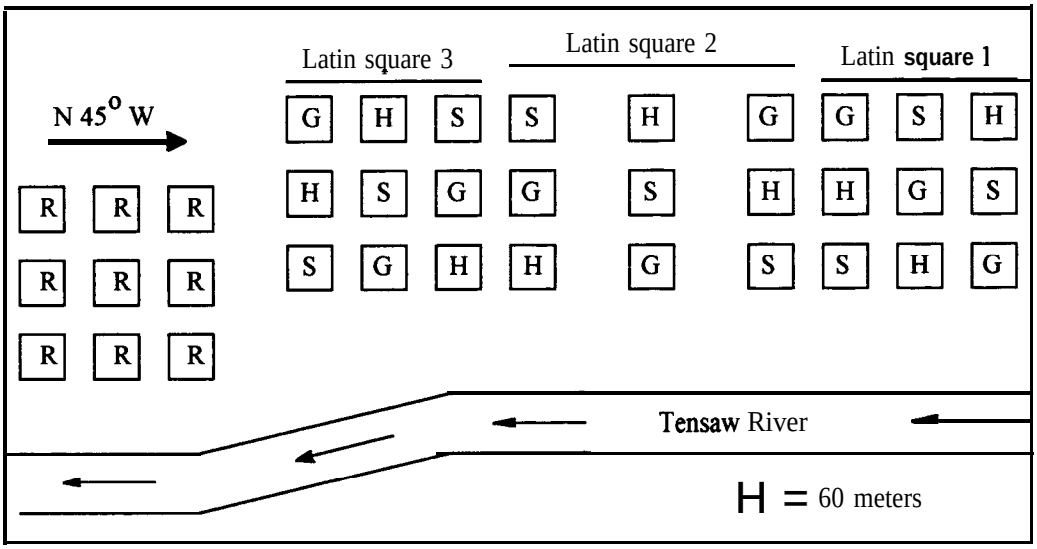

Figure l-Experimental design of the Tensaw River study area. R = Reference area G = Glyphosate treatment S = Skidder simulation treatment H = Helicopter harvested treatment

Field Measurements

Vegetation.

All vegetation measurements were completed in summer, 1993. Measurements were collected by vegetation strata, which were overstory (4.0" cm at dbh), lowerstory (< 3.9 cm at dbh), and groundflora (< 1.38 m in height).

Overstory data were collected from 0.013 ha (1/30 ac) circular sampling plots located in the center of each treatment plot. Data collected include species, total tree height and crown height (measured with. height pole), diameter at breast height, percent cover (spherical densiometer), vigor class (based on crown position, attachment to stump), stem origin (stump sprout or seedling), and number of stems per stump sprout Additionally, ten trees of each species and 2.5-cm diameter class were destructively sampled to determine the green weight of the bole, branches, and foliage. All destructive analysis occurred outside of the sampling areas. These green weights were used to develop equations for each species that used diameters and total heights to predict dry weight so that overstory biomass estimates could be obtained.

Lowerstory data were collected from 0.004 ha (1/100 ac) circular measurement plots located within the overstory measurement plots. Lower story data collection included species, total tree height, diameter at breast height, diameter at 40 cm and stem origin (stump sprout or seedling). Lowerstory dry weight biomass values for each species were obtained by using the formulas developed by Mader (1990).

Groundflora data were destructively sampled from four 0.5 m X 0.5 m square sampling frames that were located 20 m from treatment plot centers in the four cardinal directions. All vegetation shorter than 1.38 m was clipped, bagged, and transported to a weighing station. At the weighing station all clipped material was sorted and identified by species using Radford et al. (1981) as a taxonomic key and weighed (0.1 gram). Green weights were recorded and subsamples were collected for each species so that dry weight conversions could be accomplished after green samples were dried at 60 ° C.

Sediment Accumulation.

In 1986, nine sediment rods were installed in each treatment plot on a 20 m X 20 m grid system (Aust et al. 1991). These sediment rods were relocated in 1993 and the depth of erosion or deposition were measured in mm.

Experimental Design.

A latin square statistical design (Steel and Torrie 1980) was selected for the study because it was suspected that gradients might exist perpendicular and parallel to the river (Fig. 1). Each latin square was replicated

Table l-Average aboveground biomass (dry weight) of groundflora species at age 7-yrs. (letters represent results of Fisher's protected LSD test performed for species at alpha = 0.10)

Species	Treatment HELI	SKID	GLYPH
		—— (kg/ha) ——	
Ampelopsis cordata Rottboell			74
Asclepias perennis Walter	137	36	53
Boehmeria cylindrica (L.) Swartz			3
Boehmetia nivea (L.) Gaudin			101
Borrichia frutescens (L.) DC	11 a	89 a	821 b
Cepholanthus occidentalii L.	65		311
Commelina erecta L.	5	4	
Cyperus erythrorhizos Muhl.	I a	124 b	549 c
Echinodorus cordiioliup (L.) Grisebach	18	23	85
Fimbristylis vahlii (Lam.) Link		I a	206 b
Hymenocallis crassifolia Herbert	402 a	310 a	283 a
Hypericum hypercoides (L.) Crantz	78a	108a	267 b
Itea virainiana L.	2		1
Leemia virainica Willd.	54 a	163 b	48 a
Lindernia anaaallidea (Michaux) Pennell		24	160
Lobelia cardinalis L.	31a	36 a	98 b
Lycopus rubellus Moench	13	1	
Mikania scandens (L.) Willd.	2	6	11
Nyssa sylvatica var. biflora (Walter) Sargent	1	6	
Peltandra saaittaefolia (Michaux) Morong 3			
Peltandra virainica (L.) Kunth	4	67	
Polvaonum punctatum Elliott	1195 a	1103 a	842 a
Pontedaria cordata L.		1	233
Saaittaria montevidensis Cham. & Schlecht.	710 a	1573 a	5566 b
Salix niara Marshall	87		
Saururus cernus L.	75 a	194 b	68 a
Smilax lanceolata L.		14	
Smilax walteri Pumh	861 b	843b	96 a
Taxodium distichum (L.) Rich.	2	1	
Tradescantia ohiensis Raf.	1457 b	920 a	3155 c
All Species	5214 a	5647 b	13031 b

three times resulting in a total of nine treatment plots for each disturbance treatment. Analysis of variances were performed on data collected within the three 3 X 3 latin squares and treatment effects having p-values < 0.1 were separated via Fisher's protected LSD test. T-tests were used to compare disturbance treatment means to undisturbed reference means.

RESULTS AND DISCUSSION

During the first two growing seasons GLYPH had a dramatic effect on aboveground biomass of all vegetative strata (Tables 1 - 3). Essentially, GLYPH created an herbaceous dominated, freshwater marsh environment, with scattered water tupelo and black willow, *Salix nigra* Marshall, being the most important

Table 2-Average aboveground biomass (dry weight) of overstory species at age 7-yrs. (letters represent results of Fisher's protected LSD test performed for species at alpha = .10)

	Treatment		
Species	HELI	SKID	GLYPH
	----- (kg/ha) -----		
Fraxinus caroliniana L.	2277 b	676 a	
Fraxinus profunda Bush	b	742 b	12 a
Nyssa aquatica L.	18603b	36733 c	1430a
Salix niara Marshall	17238b	19409b	350a
Taxodium distichum (L.) Rich.	2577 a	2662 a	
All Species	41373b	60222 c	1792a

Table 3-Average aboveground biomass (dry weight) of lowerstory species at age 7-yrs. (letters represent results of Fisher's protected LSD test performed for species at alpha = 0.10)

	Treatment		
Species	HELI	SKID	GLYPH
	----- (kg/ha) -----		
Acer rubrum L.	10 a	15a	
Ceoholanthus occidentalis L.	1 a	3 b	1 a
Fraxinus caroliniana L.	126b	46a	
Itea virainiana L.	la	la	
Nyssa aquatica L.	18 b	21b	3a
Planara aquatica Walter ex J. F. Gmelin	la	la	
Populus deltoides Marshall	1 a	a	
Salix niara Marshall	8 a	13a	14 a
Taxodium distichum (L.) Rich.	8 b	7 b	2 a
All Species	174 c	108 b	2 0 a

overstory and lowerstory species in terms of density, growth, and biomass (Tables 2, 3).

The luxuriant groundtlora of the GLYPH had 2X and 3X greater groundflora biomass than the SKID and HELI treatments, respectively (Table 1). Three species comprised approximately 75% of GLYPH groundflora biomass: dotted smartweed *Polygonum punctatum* Elliott, giant arrowleaf, *Sagittaria montevidensis* Cham. 8 Schlecht, and spiderwort, *Tradescantia ohiensis* Raf., (Table 1).

Sediment accumulation was directly related to the groundflora vegetation at age 7-years (Table 4). The undisturbed reference area had the least quantity of groundflora biomass and sediment accumulation was lower there than in the disturbance treatments, where groundflora biomass was greater. The dense herbaceous groundflora in GLYPH trapped an average of 14.9 mm/yr of sediment.

Table 4-Average annual sediment accumulation (1988 -1993) at 7 years by treatment (letters represent results of t-tests performed between treatments at alpha = 0.10)

Treatment	Average Sediment	Average Groundflora
	(mm/yr)	(kg/ha)
Reference	5.4 a	1516 a
SKID	9.2 b	5202 b
HELI	11.6 b	5649 b
GLYPH	14.9 c	13121 c

At stand age two yrs, it was hypothesized that future vegetative growth of HELI would exceed that of SKID treatments because SKID had lower average values for saturated hydraulic conductivity and poorer soil aeration (Aust and Lea 1989). It was thought that the reduced water and air movement would reduce site productivity (Aust and Lea 1991), although both helicopter and skidder treatments had abundant woody and herbaceous regeneration (Mader 1990). Data collected 7 years after treatment did not support this hypothesis, indeed, average densities, total heights, diameters, and above ground biomass of SKID treatments were equal to or greater than those of the HELI treatment (Tables 1, 5-7). Two overstory species were most affected by the HELI and SKID treatments, water tupelo and Carolina ash. Measures of density, growth, and biomass indicated that water tupelo responded more favorably to SKID treatment at the expense of Carolina ash which was more abundant in HELI treatment. This phenomena is explained by the reduced soil aeration and increased soil moisture

Table 5-Average overstory species density at age 7-yrs. (letters represent results of Fisher's protected LSD test performed for species at alpha = 0.10)

	Treatment		
Species	HELI	SKID	GLYPH
	(trees I ha)		
Fraxinus caroliniana L.	930 b	305a	
Fraxinus profunda Bush	288b	32Qb	8 a
Nvssa aquatica L.	1046 b	1910 c	148 a
Salii niara Marshall	1153b	1153b	33a
Taxodium diitichum (L.) Rich.		132a	132a
All Species	354Qb	382Qb	189 a

Table 6--Average total height of overstory species at age 7-yrs. (letters represent results of Fisher's protected LSD test performed for species at alpha = 0.10)

	Treatment		
Species	HELI	SKID	GLYPH
	(m)		
Fraxinus caroliniana L.	6.9	6.7	
Fraxinus profunda Bush	5.4 b	5.9 b	1.5 a
Nvssa aauaticg L.	7.0 b	7.6 c	1.4 a
Salii niara Marshall	8.0 b	8.2 b	1.7 a
Taxodium distichum (L.) Rich.	3.9	2.9	
All Species	7.6 b	7.5 b	2.6 a

conditions created by the skidder treatment during the first two years of stand establishment and the flood tolerance of the species (Aust and Lea 1992). Water tupelo is more flood tolerant than Carolina ash and therefor had a competitive advantage in the more reduced conditions associated with skidding. In HELI treatment, water tupelo had less of an advantage and intraspecific competition became more pronounced. Overall, at age 7-years SKID actually has greater total above-ground biomass (65,979 kg/ha) than HELI (46,748 kg/ha) and SKID has a higher proportion of the most desirable timber species water tupelo (Table 8).

Table 7-Average diameters of overstory species at age 7-yrs. (letters represent results of Fisher's protected LSD test performed for species at alpha = 0.10)

	Treatment		
species	HELI	SKID	GLYPH
	(cm)		
Fraxinus caroliniana L.	4.7 a	4.7 a	
Fraxinus profunda Bush	4.0 a	4.2 a	
Nvssa aauaticg L.	6.6 b	7.6 c	4.9 a
Saiii nigra Marshall	6.6 b	7.1 b	4.6 a
Taxodium distichum (L.) Rich.	4.3 b	3.7 a	
All Species	6.2 b	6.9 b	4.8 a

CONCLUSIONS

The glyphosate treatment had the most pronounced effect on stratification and is proceeding through a successional sere currently dominated by herbaceous species. Black willow and water tupelo seedling are invading the area and this treatment will probably revert to a water tupelo dominated forest in time. However, this treatment does emphasize the importance of sprouting as a regeneration source for these gum ponds. Apparently the rapid initial growth of the sprouts is critical for survival in the presence of abundant herbaceous species. Interestingly, baldcypress did not become reestablished in the area, although the areas have flooded annually and floodwaters would be expected to transport viable seed.

Both helicopter and skidder-simulated treatments resulted in adequate stocking of acceptable overstory tree species and both will eventually result in stands similar to the original. However, the two areas are following slightly different patterns of succession. The helicopter treatment area overstory is more uniform in terms of species, Carolina ash, pumpkin ash, Fraxinus *profunda* Bush, water tupelo, black willow, and baldcypress were relatively uniform. Within skidder-simulation treatments, water tupelo was clearly the dominant overstory species. The more uniform distribution of species within the overstory of the helicopter treatment, coupled with a larger lowerstory component may have some advantages for certain wildlife species by providing more niches. From a

Table 8-Average aboveground biomass (dry weight) of all strata by species at age 7-yrs.

Species	Treatment		
	HELI	SKID	GLYPH
	(kg/ha)		
Acer rubrum L.	10	15	
Ampelopsis cordata Rottboell			74
Asclepias perennis Walter	137	36	53
Boehmeria cviindrica (L.) Swartz			3
Boehmeria nivea (L.) Gaudin			101
Borrichia frutescens (L.) DC	11	89	821
Cepholanthus occidentalis L.	66	3	312
Commelina erecta L.	5	4	
Cvperus ervthrorhiios Muhl.	1	124	549
Echinodorus cordiiolius (L.) Grisebach	18	23	85
Fimbristvlis vahlii (Lam.) Link		1	206
Fraxinus caroliniana L.	2403	722	
Fraxinus profunda Bush	678	742	12
Hvmenocallis crassifolia Herbert	402	310	283
Hypericum hvoercoides (L.) Crantz	78	108	267
Itea virainiana L.	3	1	1
Leersia virginica Willd.	54	163	48
Lindernia anaaallidea (Michaux) Pennell		24	160
Lobelia cardinalii L.	31	36	98
Lycopus rubellus Moench	13	1	
Mikania scandens (L.) Willd.	2	6	11
Nvssa aauatica L.	18621	36754	1433
Nvssa svivatica var. biflora (Walter) Sargent	1	6	
Peltandra saaittaefolia (Michaux) Morong	3		
Peltandra virginica (L.) Kunth	4	67	
Planara aauatica Walter ex J. F. Gmelin	1	1	
Polygonum ounctatum Elliott	1195	1103	842
Pontedaria cordata L.		1	233
Populus deltoides Marshall	1	1	
Sagittaria montevidensis Cham. & Schlecht.	710	1573	5566
Salix nigra Marshall	17333	19422	364
Saururus cernus L.	75	194	68
Smilax lanceolata L.		14	
Smilax walteri Pursh	861	843	96
Taxodium distichum (L.) Rich.	2587	2670	2
Tradescantia ohiensis Raf.	1457	920	3155
Total Biomass	46761	65977	14843
Total No. of Species	29	32	26

timber production viewpoint, the skidder-simulation treatment may produce more water tupelo by a shorter rotation age.

The results of thii study are interesting because they do not follow the conventional wisdom that skidding and associated rutting will result in poorer stand growth and reduced site productivity. However, much of the conventional wisdom is based upon upland studies, where soils do not have annual shrinking and swelling events coupled wlth annual additions of nutrient replenishment in the form of sediment. Also, in thii study, the desired species, water tupelo, was more flood tolerant than most of the other species. This study reemphasizes that species requirements and site characteristics will determine the desirability of a particular silvicultural practice and that short-term research results may not be indicative of future stand dynamics.

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SKID TRAIL AMELIORATION FOLLOWING TIMBER HARVESTS ON WET PINE FLATS IN SOUTH CAROLINA: TWO-YEAR RESULTS[1]

GA. Scheerer, W.M. Aust, JA. Burger, W.H. McKee, Jr.[2]

Abstract—Rutted skid trails caused by wet site timber harvesting have possible negative consequencea for site hydrology, soil physical and chemical properties, and long-term site productivity. Mechanical and chemical amendments have been recommended as possible ameliii treatments for rutted skid trails, yet, the effects of such treatmenta are untested. Therefore, mechanical and fertilization treatments were applied to six wet-pine-flata in the coastal plain of SC. All six sites had been rutted or compacted by wet-weather skidder aalvage operations. After two growing seasons, loblolly pine (*Pinus taeda*) seedling growth and survival were reduced in rutted and compacted skid trails, although aite preparation and fertilization dii partially reatore site productivity. The reduction of seedling growth and survival in skid trails is due to reduced soil macropore space and the resultant reductii in air and water movement.

INTRODUCTION

In the Southeast, wet pine flats are regarded as the some of the most productive pine plantation sites (Allen and Campbell, 1988), yet, these sltes are subject to site disturbance during harvesting operations because of their frequently saturated soils. Soil disturbances caused by harvesting may be categorized as compaction and rutting. Soil compaction is the physical compression of the soil mass under excessive pressure (Greacen and Sands, 1980), while soil rutting is the churning of a soil above its liquid limit to the point that it is broken into lts ultimate soil particles and flows outward and upward from applied pressure (Karr *et al.*, 1991). These disturbances may adversely impact survival and growth of planted seedlings by increasing bulk densities, decreasing soil porosity, water and air movement, and altering organic matter decomposition rates and contents (Reisinger et al., 1988).

Several site preparation techniques are utilized by forest managers to ameliorate these impacts, including bedding, disking, and fertilization (Edwards, 1990; Wilhite and McKee, 1986). However, the actual effectiveness of these treatments in restoring site productivity has not been established for wet pine flats. The objectives of this study were to determine to what extent disking, bedding, and fertilization can mitigate soil problems, both physical and chemical, and enhance seedling growth and survival. A previous study on the same sites determined to what extent rutting and compaction affected soil physical and chemical properties, prior to site preparation (Tippett, 1992).

METHODS AND PROCEDURES

The study was conducted on Coastal Plain wet-pine flats in the Francis Marion National Forest (Berkeley County, SC). A detailed description of the study site is provided by Tippett (1992). In October of 1989, Hurricane Hugo devastated the mature loblolly and longleaf (*Pinus palustris*) pine stands that occupied these sites (Jones et a/., 1991). Salvage operations resulted in widespread site disturbance because they occurred during an unusually wet fall.

The study sites were relatively flat (0-2% slope) and water tables on the study sites were high during the fall and winter. The residual overstory of the study sites was composed of five to twelve longleaf and loblolly pine trees per hectare that survived Hurricane Hugo (Tippett, 1992). Soil series of the study sites were Bethera (clayey, mixed, thermic Typic Paleaquults), Goldsboro (fine-loamy, siliceous, thermic Aquic Paleudults), Lynchburg (fine-loamy, siliceous, thermic Arenic Paleaquults), and Rains (fine-loamy, siliceous, thermic Typic Paleaquults) SCS, 1980).

Six sites (blocks) were studied. Three blocks were compacted and three were rutted by salvage logging

[1]Paper presented at the Eighth Biennial Southern Silvicultural Research Conference, Auburn, AL, Nov. l-3, 1994.

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during wet soil conditions. Rutted sites were identified by the presence of displaced soil having been moved outward from the tire track (a berm), an indication of the soil moisture content having exceeded its liquid limit at the time of trafficking. Compacted sites were identified by physical depression of the soil in the tire tracks without soil displacement. Each of the six study sites contained eight measurement plots that were 24.4 meters (80 feet) long and 7.6 meters (25 feet) wide (Figure 1). Four of the plots on each site contained rutting or compaction damage, and the other four contained undisturbed soils.

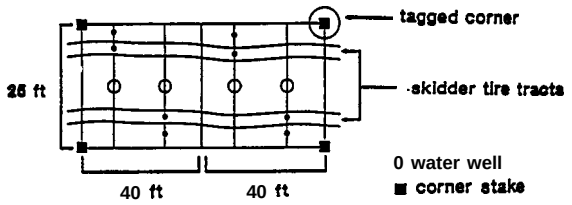

Figure 1. Diagram of trafficked treatment plot.

Four site preparation treatments were performed on each site: 1) diiked, 2) bedded, 3) disked + bedded, and 4) control (no treatment). Unfortunately, the control treatment was destroyed on four of the six sites by fire. Each treatment was installed on one trafficked and one non-trafficked plot per site (Tippett, 1992). The mechanical treatments were installed by a hired contractor. The fertilizer treatment consisted of 227 kg/ha of hand applied 1 O-10-1 0 fertilizer to half of each plot. Genetically-improved loblolly pine seedlings were planted on a 0.6 X 0.6 meter (2 X 2 foot) spacing on all study plots during the winter of 1992. Measured soil, site, and plant parameters are provided in Table 1.

The three compacted sites and three rutted sites were analyzed as two separate studies. The effects of trafficking (trafficked, non-trafficked), site preparation treatments (none, diiked, bedded, and disked and bedded), and fertiliiation (fertilized, unfertilized) were analyzed as a splii-split plot (Steele and Torrie, 1980). The control treatment plots were excluded because of the aforementioned fire damage. Only results from the rutted study are reported in this paper.

Table 1. Measured parameters and methods used in study.

Measured Parameter	Method	Citation
Saturated Hydraulic Conductivity	Constant-Head	Klute and Dirksen, 1986
Soil Bulk Density	Core	Blake and Hartge, 1986
Soil Porosity	Tension Table	Danielson and Sutherland, 1986
Soil Nitrogen	TKN	Bremner and Mulvaney, 1982
Soil P,K	Double-Acid Extraction / ICP	Bremner and Mulvaney, 1982
Soil Organic Matter	LECO Carbon Analyzer	Nelson and Sommers, 1982
Water Table Depth	Unlined Bore-Hole	Faulkner et a/., 1989
Topographic Elevation	Levelled-Line	Tippett, 1992
Competing Vegetation	Total Biomass	Slay et a/., 1987
Pine Seedling Survival	Census	
Pine Foliar Nitrogen	TKN	Isaac and Johnson, 1976
Pine Foliar P,K	Dry Ash	Isaac and Kerber, 1971
Pine Height Growth	Meter Stick	
Pine Diameter Growth	Digital Calipers	

RESULTS AND DISCUSSION

Pine Seedling Response

Rutting reduced second-year height growth, total volume, and survival rate of the rutted site pine seedlings (Table 2). Seedlings growing on the non-trafficked sites exhibited 43 percent greater height growth, 90 percent greater volume, and 9 percent better survival than those on the rutted sites.

Table 2. Rutting effects on two-year old pine seedlings.

Pine Seedling Parameter	Units	Disturbance Class	
		Non-trafficked	Rutted
2nd Year Height Growth	cm	49 (b)	34 (a)
Seedling Volume	cm'	219 (b)	115(a)
Seedling Survival	%	91 (b)	82 (a)* -

Difference in alphabetical notation across rows indicates a significant difference as determined by Fisher's protected LSD test.

Bedding resulted in 35 percent greater second-year height growth and 117 percent greater seedling volume than disking on the rutted sites; however, bedding + disking was no better than bedding alone (Table 3). Site preparation had no effect on pine seedling survival on the rutted sites after two years. However, it was noted that many seedlings growing in lower, wetter sites were in poor health, had not grown since planting, and may likely die in the next year or two. This phenomenon is explained by the small nutrient requirements and inherent hardiness of pine seedlings. The seedlings may be getting just enough resources for survival but not for any growth. The seedlings also may have been planted with just enough nutrient and energy reserves to last for two or three years in an unfavorable environment. This theory is supported by Wilhite and McKee (1986) who reported no site preparation effect on pine seedling survival five years after planting compared to Pritchett (1978) who reported a significant decrease in survival after eight years on similar sites.

Fertilization increased pine seedling height growth and volume by 54 and 125 percent, respectively, on the rutted sites. The fertilization did not, however, affect the survival rate of the seedlings growing on the rutted sites (Table 4).

There were no interactions between traffic, treatment, and fertilization for any of the pine seedling growth parameters. Of key interest is the non-interaction between site preparation and fertilization despite the main effect of each of these factors on the pine seedling responses. These results support the theory expressed by McKee and Wilhite (1986) that

Table 3. Site preparation effects on pine seedlings in the rutted study.

Parameter	Units	Site Preparation Treatment		
		Disked	Bedded	Disked & Bedded
2nd Year Height Growth	cm	34 (a)	46 (b)	45 (b)
Seedling Volume	cm'	98(a)	212(b)	193(b)
Seedling Survival	%	84	88	88* -

Difference in alphabetical notation across rows indicates a significant difference as determined by Fisher's protected LSD test.

Table 4. Average fertilization effects on the pine seedlings in the rutted study.

Parameter	Units	Fertilization Treatment	
		Fertilized	Unfertilized
2nd Year Height Growth	cm	50 (b)	33 (a)
Seedling Volume	cm^3	232 (b)	103 (a)
Seedling Survival	%	87	87" -

Difference in alphabetical notation across rows indicates a significant difference as determined by Fisher's protected LSD test.

fertilization may be an inexpensive alternative to mechanical site preparation on wet sites such as those in this study. However, for the greatest growth potential, both bedding and fertilization are necessary as fertilization did have an additive effect on the pine seedling height growth and volume (Figures 2 and 3).

Significant **Factors Influencing Pine Seedling Responses**

The residual effects of rutting, after two years and site preparation, were exhibited by the lower growth and survival rates of the pine seedlings growing on the rutted plots. Rutting effects were found on two soil properties related to water movement and supply, saturated hydraulic conductivity and water table depth (Table 5). The rutted sites had slower saturated

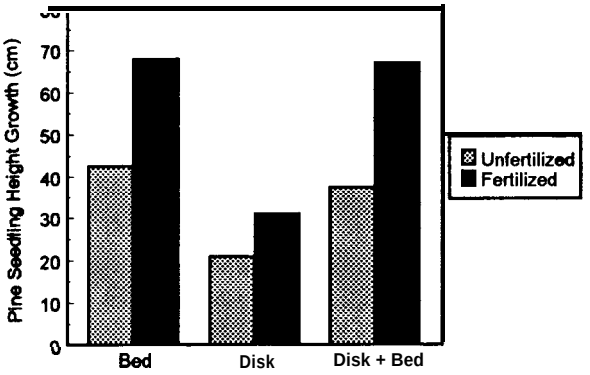

Figure 2. Additive effect of fertilization on rutted site pine seedling height growth.

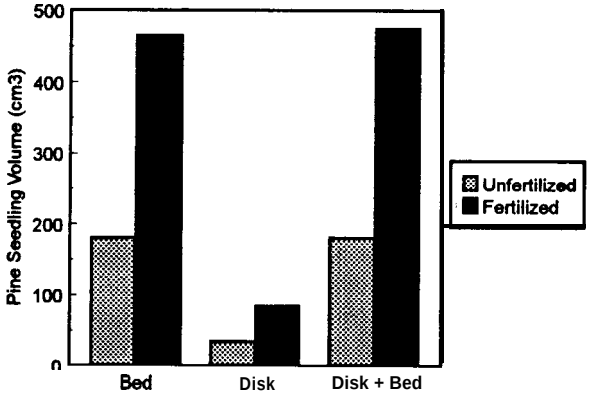

Figure 3. Additive effect of fertilization on rutted site pine seedling volume.

Table 5. Mean rutting effects on soil physical and chemical properties.

Soil Property	Units	Disturbance Class	
		Non-trafficked	Rutted
Saturated Hydraulic Conductivity	cm/hr	3.05 (b)	0.81 (a)
Water Table Depth	cm	-26 (b)	-16 (a)*

Difference in alphabetical notation across rows indicates a significant difference as determined by Fisher's protected LSD test.

hydraulic conductivities and higher water table depths three years after rutting and two years after site preparation. Both of these conditions can be detrimental to pine growth on these poorly drained lower coastal plain sites. The reduced hydraulic conductivity probably resulted in insufficient aeration to the seedling roots, thereby increasing mortality and decreasing growth (Kozlowski, 1986). A higher water table is also detrimental to pine seedling growth on poorly drained wetland sites. Aust et al. (1991) reported that rutting raised water tables on a wet pine flat in South Carolina by reducing drainage; this effect reduces the rooting zone oxygen supply and can drown seedling root systems.

The seedlings growing on the bedded and bedded + disked plots exhibited mean second-year height growths 1.5 times greater than the seedlings growing on the disked plots of the rutted sites. Very similar results were reported by Priichett (1978) for a study in Florida on eight-year-old slash pines; the trees growing on bedded sites were an average of 3.1 feet taller than the trees growing on disked sites. The seedlings growing on the bedded and disked + bedded plots also exhibited mean volumes three times greater than the seedlings growing on the disked plots.

These pine seedling responses to site preparation were attributed to water supply and movement because site preparation affected two of the measured soil parameters, saturated hydraulic conductivity and mean topographic profile height, both of which are related to soil water supply and movement (Table 6). On these poorly drained wet pine flats, pine seedling growth is often limited by high water tables (Piichett, 1978). The site preparation treatments that involved bedding proved superior to disking for pine seedling growth because they elevated the pine seedlings further above the water table and increased the drainage of excess water from the rooting zone, thereby increasing aeration and exploitable soil volume (Kozlowski, 1986).

The bedded + disked plots contained 75 percent more competing vegetation than the bedded or disked plots (Table 7). It is normally accepted that increased site preparation intensity results in decreased vegetative competition (Conde et al., 1983); however, the most intense treatment resulted in the most competition in this study. The combined advantages of finer tillage from the disking and greater elevation from the bedding may have caused this competing vegetation result. Competing vegetation did not have a detrimental effect

Table 6. Average site preparation effects on soil physical and chemical properties.

Soil Property	Units	Site Preparation Treatment		
		Disked	Bedded	Disked & Bedded
Topographic Profile Height	cm	+1 (a)	+16(b)	+15(b)
Saturated Hydraulic Conductivity	cm/hr	0.47 (a)	2.07 (b)	3.23 (b)' -

Difference in alphabetical notation across rows indicates a significant difference as determined by Fisher's protected LSD test.

Table 7. Average site preparation effects on competing vegetation and pine seedling foliar properties in the rutted study.

Vegetation Parameter	Units	Site Preparation Treatment		
		Disked	Bedded	Disked & Bedded
Competing Vegetation Biomass	kg/ha	485 (a)	449 (a)	774 (b)
	---------- Pine Seedlings ----------			
Foliar Phosphorous	g/kg	13.0 (b)	10.6 (a)	11.1 (ab)
Foliar Nitrogen	g/kg	13.7	13.6	13.4
Foliar Potassium	g/kg	46.8	44.3	47.0* -

Difference in alphabetical notation across rows indicates a significant difference as determined by Fisher's protected LSD test.

on pine seedling growth in the first two years as the treatment with the most competition also exhibited the highest pine seedling growth rates. Evidently, the two-year-old pine seedlings obtained sufficient resources despite the increased competition. Furthermore, it is possible that the increased competition actually aided the pine seedlings by taking up more water on these wet sites, thereby increasing aeration in the rooting zone of the pine seedlings and creating a more favorable growing environment. As the seedlings continue to grow, however, their nutrient requirements will increase, and the competing vegetation may have an adverse effect on pine growth. Weed control has been reported to increase pine height, volume, and survival after four to twenty years by many researchers (Creighton et al., 1986; Haywood, 1987; and Smethurst and Comerford, 1993).

The seedlings on the disked sites had the highest foliar phosphorous content followed by those on the disked + bedded sites and those on the bedded sites in decreasing order (Table 7). This result is exactly opposite of that reported by Wilhite and McKee (1986). The foliar phosphorous results show a dilution effect as all of the pine seedlings apparently received a sufficient phosphorous supply, but the bedded and disked + bedded seedlings grew better despite their lower phosphorous contents. Indeed, all treatments exhibited foliar phosphorous contents above the 0.10 g/kg critical value below which pine seedlings are phosphorous-deficient (Burger, 1993).

Fertilization increased both pine seedling height growth and total volume; therefore, the pine seedlings responded to an increased nutrient supply. The fertilizer had an additive effect to the site preparation effects which appeared to have more control over the pine seedling growth. Fertilization increased the surface soil phosphorous and potassium contents of the rutted sites by 33 and 26 percent, respectively (Table 8). This is an extremely important result on these inherently phosphorous-deficient sites. The fertilized plots also had higher soil potassium contents; however, such an increase was not found in the pine seedling foliage (Table 9).

Table 8. Average fertilization effects on the soil chemistry of the rutted study.

Parameter	Units	Fertilization Treatment	
		Fertilized	Unfertilized
Soil Phosphorous	g/kg	0.008 (b)	0.006 (a)
Soil Nitrogen	g/kg	0.402	0.383
Soil Potassium	g/kg	0.311 (b)	0.247 (a)* -

Difference in alphabetical notation across rows indicates a significant difference as determined by Fisher's protected LSD test.

Table 9. Average fertilization effects on the competing vegetation and pine seedling foliar properties in the rutted study.

Parameter	Units	Fertilization Treatment	
		Fertilized	Unfertilized
	---------- Pine Seedlings ----------		
Foliar Phosphorous	g/kg	11.8 (b)	10.7 (a)
Foliar Nitrogen	g/kg	13.8	13.6
Foliar Potassium	g/kg	46.9	46.6" -

Difference in alphabetical notation across rows indicates a significant difference as determined by Fisher's protected LSD test.

The greater soil phosphorous levels on the fertilized plots led to a higher foliar phosphorous content among the fertilized seedlings. Fertilization, however, had no effect on the mean pine seedling foliar nitrogen or potassium contents on the rutted sites (Table 9). The young pine seedlings were apparently receiving sufficient supplies of these two nutrients.

CONCLUSIONS

Rutting reduced pine seedling growth and survival despite the application of site preparation treatments. However, site preparation treatments did partially ameliorate rutting impacts that reduced seedling growth. The bed and disk + bed treatments increased second-year pine seedling height growth and volume as compared to the disk treatment. Water supply and movement were determined to be the major factors controlling the pine seedling growth. Seedlings grew better with increased drainage, aeration, and increased distance to the water table.

Fertilization increased pine seedling growth by increasing the available phosphorous supply. The fertilizer response is attributed to the increased phosphorous supply because the fertilized seedlings exhibited higher foliar phosphorous contents but not higher foliar nitrogen or potassium contents. Also, past studies have reported that fertilization of only phosphorous significantly increased pine growth on the South Carolina coastal plain (Buford and McKee, 1987). The fertilization had an additive effect to the site preparation treatments and, hence, should be used for optimum pine seedling growth.

Fertilization also increased the total biomass of competing vegetation. It is possible that fertilization of only phosphorous might result in the same pine seedling growth increases but less competing vegetation because many of the competing species are believed to be more responsive to an increased nitrogen supply (Jobidon, 1993). As suggested, however, the increased competition may actually be beneficial to young pine plantations on wet sites due to its abilii to transpire a much greater amount of water than the seedlings alone. This phenomenon may increase aeration in the rooting zone and, therefore, create a more favorable growing environment for the pine seedlings. Soil macro- and total porosity were also increased following site preparation. The increased porosities increased aeration and drainage in the rooting zone and increased pine seedling growth.

The overall conclusions of this study are that bedding and phosphorous fertilization appear to be the most effective site preparation treatments for the partial amelioration of rutting impacts on early pine seedling growth. None of these treatments, however, were completely effective.

Increasing drainage, aeration, and depth to water table are the keys to increasing pine seedling growth on wet and poorly drained sites. This conclusion is supported by past research that has reported increased seedling growth with increase seedling elevation above the water table on poorly drained coastal plain sites. Phosphorous fertilization appears to be a profitable treatment on these lower coastal plain sites as it had an additive effect on pine seedling growth. Fertilization also increased the total biomass of competing vegetation, mostly herbaceous, but this may be beneficial to young pine plantations on wet sites because of the greater water transpiration and aeration in the rooting zone. As a final note, disking appears to be a completely ineffective site preparation treatment on these lower coastal plain sites.

This study should have major impacts on lower coastal plain wetland site management decisions. Rutting impacts from wet weather harvesting can not be completely ameliorated in the first three years by bedding, disking, or fertilization, and such disturbances should be avoided when possible. This could be achieved by responsible harvest scheduling on wet

sites, i.e. during the driest period of the year. Specialized wet-site harvesting equipment should also be used to minimize harvesting impacts on these sites. Finally, for the subsequent establishment of loblolly pine stands on these lower coastal plain sites, bedding and phosphorous fertilization are two site preparation techniques that should be considered; whereas, disking should not Also, herbicide treatments should possibly be delayed until year four or five as competing vegetation was not detrimental to pine seedling growth in the first two years, and it may actually have been beneficial due to increased water transpiration on these wet, poorly drained sites.

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THE EFFECT OF SITE DISTURBANCE ON NITROGEN AVAILABILITY IN OAK-HICKORY FORESTS OF VARYING PRODUCTIVITY

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Abstract-The temporal effects of forest floor removal and forest floor incorporation with the mineral soil an nitrogen availability were examined in three oak-hickory forests of varying productivity. Nitrogen (N) availability increased following disturbance. The temporal patterns of N availability were closely related to soil moisture and temperature. N availabilii and nitrate-N (NO_3) es a percentage of total N were greater at the highest productivity site and for the forest floor incorporation treatment.

INTRODUCTION

Forest management activities affect soil and forest floor processes which, in turn, affect the nutrient dynamics of the site. Frequent forest floor disturbances associated with selection harvests affect nitrogen availabilii and long term soil productivity. Many studies have examined the effect of intensive harvesting or site preparation on nutrient pools and cycling (Burger and Pritchett 1984, Fox et al. 1986, Masters 1993, Matson and Viiousek 1981, Viiousek and Matson 1985), but little information exists on the effects of management activities such as selection harvesting on nutrient cycling. Studies have demonstrated that nitrogen availability is affected by site disturbances principally because disturbances are associated with alterations in soil temperature (Matson and Vitousek 1981, Viiousek and Matson 1985), water availabilii (Matson and Viiousek 1981, Viiousek and Matson 1985), plant uptake (Johnson and Edwards 1979) and vegetative inhibitors (Rice and Pancholy 1974, Smith et al. 1968). The impacts of selection harvests are usually limited to forest floor and mineral soil disturbances and to small variations in microclimate due to changes in canopy structure, which influence incident radiation, temperature and water budgets. Forests harvested by the selection system are characterized by frequent entry and therefore frequent impacts on the nutrient and hydrologic characteristics of the site. Soil and site disturbances resulting from selection harvesting may have different impacts on nutrient availability and soil productivii when compared to clearcutting systems and intensive site preparation treatments. The objectives of this study were (1) to determine the affects of forest floor removal and incorporation with the mineral soil on ammonium and nitrate availability and (2) to compare the effects of forest floor disturbance on nitrogen availability on sites of inherently diierent productivity potential.

MATERIALS AND METHODS

Study Site Descriptions

Three study sites, typical of upland oak-hickory dominated forests of the Central Hardwood Forest region, were located in the state of Indiana. Study sites were characterized as second-growth oak-hickory dominated forests with no disturbance for at least 20 years. The oak-hickory species group comprised at least 75 percent of the basal area of each stand. The minor associated species that made up the remaining basal area differed among sites. The sites chosen represent a gradient of potential site productivity that range from a xeric, nutrient poor site to a mesic, nutrient rich site. Potential site productivity was based on previously determined N mineralization potential and water availability (Table 1).

The site representing high potential productivii, Nelson-Stokes (NS), is located in Putnam County in the Entrenched Valley Section of the Central Till Plain Natural Region (Homoya et al. 1985). The soil is a Russell silt loam (Fine-silty, mixed mesic, Typic Hapludalf) which developed from moderately thick loess deposits over glacial till (Soil Conservation Service 1981). White oak, *Quercus alba* L., northern red oak, Q. *rubra* L., various hickories, Carya spp., and other mesophytic species dominate the overstory, while

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sugar maple, *Acer saccharum* L., dominates the subcanopy (Table 2). The site index for whii oak on a base age of 50 years in approximatety 85-90 feet (Table 1).

Table I- Studv Site Characteristics

Site	Annual Leaf-fall (Kg/ha)	Annual N via leaf-fall (Kg/ha)	N Min. Potential (ug/g)
Nelson-Stokes	4890	43	58.6
SIPAC	5145	50	37.2
Jasper-Pulaski	3947	37	13.0

	Avail. Water (cm/cm)	Annual ppt. (cm)	Siie Index for White oak (base age 50)
Nelson-Stokes	0.23	107	85-90
SIPAC	0.19	107	65-70
Jasper-Pulaski	0.05	94	55-60

Table 2- Species composition of the three study sites. The first row (1) associated with each species provides its basal area (m^2/ha) and the second row (2) provides its relative dominance in each respective stand

Species	Nelson-Stokes	SIPAC	Jasper-Pulaski
White oak	20.6 [1]	22.0	15.2
	56.7 [2]	68.0	67.1
Black oak	0.0	0.2	6.4
	0.0	0.6	28.4
Northern red oak	3.5	2.4	0.0
	9.6	8.9	0.0
Hickory spp.	4.3	3.4	0.0
	11.9	10.6	0.0
Sugar maple	4.6	4.0	0.0
	12.7	12.3	0.0
American beech	0.3	0.0	0.0
	0.9	0.1	0.0
Tulip poplar	0.5	0.0	0.0
	1.3	0.0	0.0
Misc.	2.5	0.3	1.0
	6.9	1.0	4.5
Total Basal Area	36.3	32.3	22.6

The site representing moderate potential productivity is located in Duboii County at the Southern Indiana Purdue Agricultural Center (SIPAC), and is in the Crawford Upland Section of the Shawnee Hilts Natural Region (Homoya et al. 1985). The soil is a Wellston silt loam (Fine-silty, mixed mesic, Ultic Hapludalf) developed from moderately thick loess deposits over paleosols derived from weathered sandstone and siltstone (Soil Conservation Service 1980). The overstory vegetation is dominated by white oak, assorted hickories, and northern red oak, while sugar maple dominates the subcanopy (Table 2). The site index for white oak is approximately 65-70 (Table 1).

The site representing low potential productivity is located in Jasper County at the Jasper-Pulaski State Fiih and Wildlife Area (JP). JP is in the Kankakee Sand Section of the great Prairie Natural Region (Homoya et al. 1985). The soil is a Plainfield fine sand (Mixed mesic, Typic Udipsamment) derived from glacial outwash (Soil Conservation Service 1990). Both overstory and subcanopy vegetation is dominated by white oak and black oak, C?. *velutina* Lam. (Table 2). The site index for white oak is approximately 55-60 (Table 1).

Site Disturbance Treatments

At each site the three site disturbance treatments were (1) forest floor removal (REM), (2) forest floor incorporation with the mineral soil (INC) and (3) no disturbance (ND). For each treatment, four 2m X 2m plots were randomly located at each site. The REM treatment was installed by removing the liier, fermentation and easily identifiable humus layer above the mineral soil with a leaf rake. The humus mixed with the upper mineral soil was not removed to minimize mineral soil disturbance. For the INC treatment, the forest floor organic layers and the A, E and upper B horizons of the mineral soil were thoroughly incorporated with a garden tiller to a depth of approximately 20 cm.

Sampling

Each site was sampled for soil water potential, soil temperature, and N availabilii. Nitrogen availabilii was assessed at 60 day intervals beginning in December of 1993 which corresponded to sampling dates in April, June, August and October 1994. The length of the first sampling period was extended to 120 days because the soils were frozen during January, February, and early March and N mineralization was assumed to be minimal. Soil moisture and temperature sampling

occurred on approximate 21 day intervals from March 1994 through October 1994.

Miied-bed anion/cation exchange resins (Baker IONAC NM-60) were used to determine in-situ N availability. Three bags of O.Olmm nylon mesh material containing the equivalent of five grams of oven-dry resin were installed in each treatment plot, i.e., 12 samples per treatment per site, 36 in total. The resins were installed at a depth of approximately 10 cm by removing an undisturbed soil core 10 cm deep and 3 cm in diameter, placing the resin bag into the hole, and replacing the soil core and organic layers, where applicable. Installation of the resin bags for the succeeding sampling period occurred at the same time as the resin bags for the current sampling period were retreived. Prior to installation, each resin bag was soaked in 100 ml of 1 N NaCl per bag for one hour. N was extracted from each resin bag by shaking it in 100 ml of 2 N KCL for one hour (Binkley and Viiousek, 1989). Ammonium (NH,*) and nitrate (NO;) were determined from a 15 ml aliquot of the extract by steam distillation followed by titration with 0.01 N HCl (Keeney and Nelson 1982).

The water potential for each site was determined for the A horizon at 21 day intervals. Twelve samples of the A horizon (approximately 15-30 g each) were taken at random in the undisturbed forest soil at each site. Water potentials were determined by comparing the gravimetric moisture content of the field samples to previously determined soil moisture retention curves for the soils at each site. The mean water potential was determined for each site at each sampling period. The forest floor removal and incorporation treatment plots were not sampled due to the small plot size and the likelihood of water channeling into the holes created from sampling.

Soil temperature was determined for an integrated O-l 0 cm depth with a thermocouple soil probe on 21 day intervals at each site. For each sampling date, three measurements were taken in each of the treatment plots for 12 measurements per treatment, 36 in total. The mean temperature for each treatment at each site was determined.

Statistics

Comparisons of ammonium, nitrate, and total N availability were made across sampling periods, treatments, and sites. Significant differences between each of these factors were determined using Duncan's Multiple Range Test (SAS Institute, 1985). The significance level for all tests was 5 percent.

RESULTS AND DISCUSSION

Overall, the data suggest that, (1) nitrogen availabilii was enhanced by incorporating the forest floor with the mineral soil at the three sites studied. (2) The removal of the forest floor had variable affects on N availability. (3) Temporal changes in N availability were related to seasonal temperature and moisture patterns. (4) The variations in site productivity tended to influence the relative rates of ammonification and nitrification.

At all sites, the incorporation treatment resulted in significantly higher values of total N (NH_4^+ + NO;) relative to the control, principally because of elevated levels of NO;-N (Table 3). Ammonium availability was not significantly different between the incorporation treatment and the control. The increase in overall N availability and nitrification may be attributed to higher soil temperatures (Figures 1,2,3) and the accelerated decomposition of the forest floor material. These findings are in agreement with previous studies (Burger and Pritchett 1984, Fox et al. 1986, Matson and Viiousek 1981, Plymale et al. 1987, Robertson 1982, Viiousek and Matson 1985).

The affects of the removal treatment on nitrogen availability varied (Table 3). Nitrogen availability was significantly higher than the control at the NS site (high productivity) only. The overall increase in N accumulation may be the result of an increase in soil temperature during the first two time periods (December-April, April-June) (Figure 1). This increase may also be attributed to a reduction in N immobilization as suggested by Viiousek and Matson (1985). Since the N mineralized early in the season (December-April, April-June) would likely be from pre-existing organic N pools, the decrease in N mineralization in the later sampling periods (June-August, August-October) may have resulted from a depletion of these pools with no additional inputs from forest floor decomposition.

The temporal patterns of overall N availability were closely related to seasonal moisture and temperature fluctuations rather than to affects caused by differences in site or treatment (Table 4). These results agree with previous studies that found seasonal N mineralization and nitrification patterns to be more closely linked to soil temperature and moisture availability than to initial soil

Table 3. Effects of site (productivity) and forest floor treatment on nitrogen accumulation (mg), compared across treatments. The first column (*) denotes the treatment and the sampling period; (1) December-April, (2) April-June, (3) June-August, (4) August-October[a]

	Nelson-Stokes			SIPAC			Jasper-Pulaski		
	NH;	NO;	Total N	NH,'	NO;	Total N	NH;	NO;	Total N
*	---	mg	---	---	mg	---	---	mg	---
				Sampling Period 1					
ND[b]	0.13b	0.77a	0.90b	0.27b	0.86a	1.13a	0.27a	O.IOa	0.37a
REM	0.27a	1.07a	1.33a	0.39ab	0.50a	0.89a	0.20a	0.15a	0.34a
INC	0.17b	1.03a	1.21a	0.48a	0.49a	0.97a	0.32a	0.21 a	0.52a
				Sampling Period 2					
ND	0.14a	0.55b	0.70b	0.47a	0.95a	1.42a	0.20a	0.06a	0.26a
REM	0.38a	0.74b	1.13a	0.55a	0.75a	1.30a	0.21a	0.18a	0.38a
INC	0.23a	1.21a	1.44a	0.66a	1.12a	1.78a	0.19a	0.14a	0.34a
				Sampling Period 3					
ND	0.16a	0.48b	0.64b	0.21a	0.34b	0.54b	0.15ab	0.23b	0.38b
REM	0.22a	0.69b	0.91 b	0.08a	0.13b	0.21 b	0.05b	0.34b	0.39b
INC	0.27a	1.25a	1.53a	0.13a	1.19a	1.32a	0.30a	0.95a	1.25a
				Sampling Period 4					
ND	0.05ab	0.39b	0.44b	0.42a	0.43a	0.85a	0.03a	0.19a	0.22a
REM	0.04b	0.35b	0.39b	0.12b	0.16b	0.28b	0.02a	0.17a	0.19a
INC	0.11a	0.84a	0.95a	0.1 Ob	0.25ab	0.36b	0.03a	0.16a	0.19a
				Totals over all four sampling periods					
ND	0.48b	2.19b	2.68c	1.37a	2.58a	3.94ab	0.65a	0.58b	1.23b
REM	0.91a	2.85b	3.76b	1.14a	1.54b	2.68b	0.48a	0.84b	1.30b
INC	0.78ab	4.33a	5.13a	1.37a	3.05a	4.43a	0.84a	1.46a	2.30a

'Means in the same column in the same time period followed by the same letter are not significantly diierent at the 5 percent level using Duncan's Multiple Range Test.

[b]Treatments are ND, no disturbance; REM, forest floor removal; INC, forest floor incorporation.

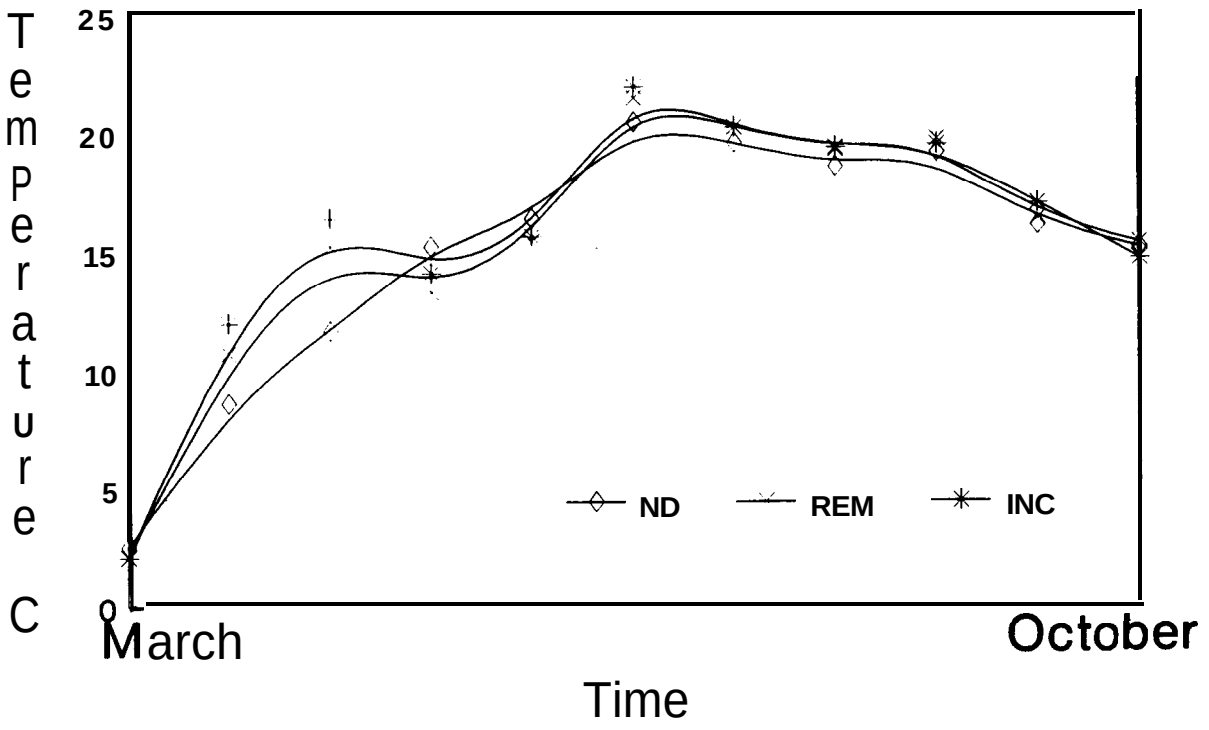

Figure l-Soil Temperatures at Nelson-Stokes, March-October, 1994.

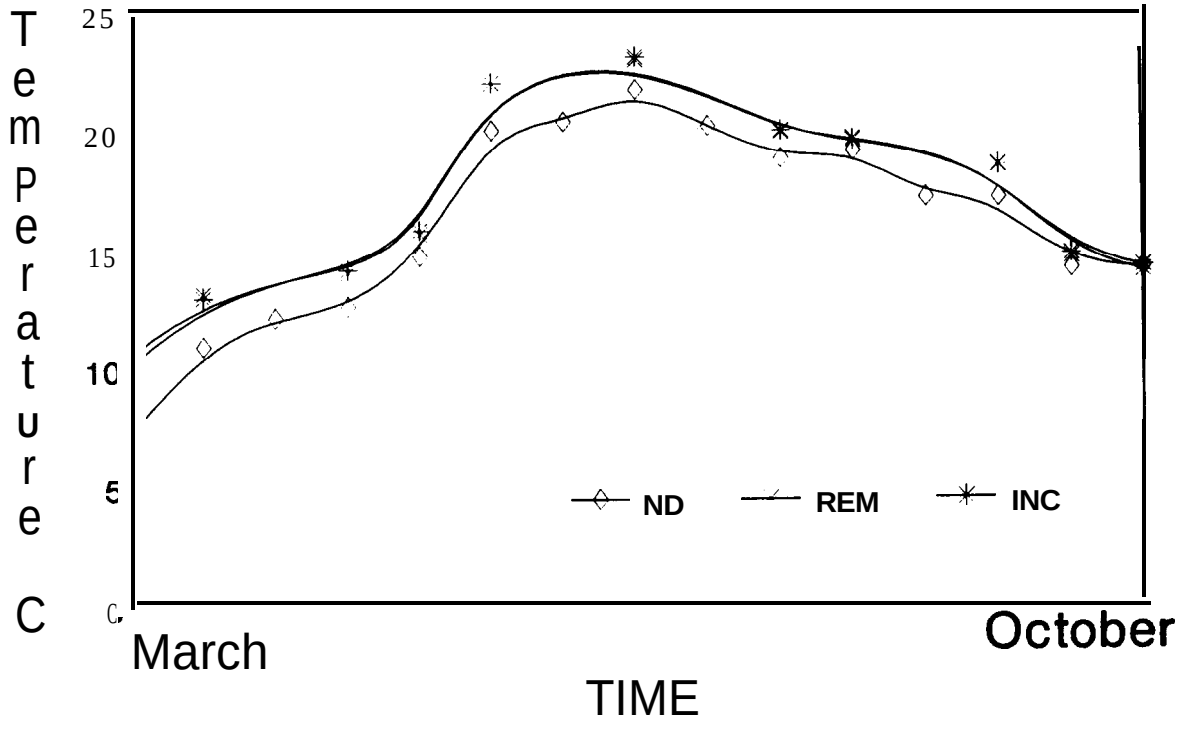

Figure 2-Soil Temperatures at SIPAC, March-October, 1994.

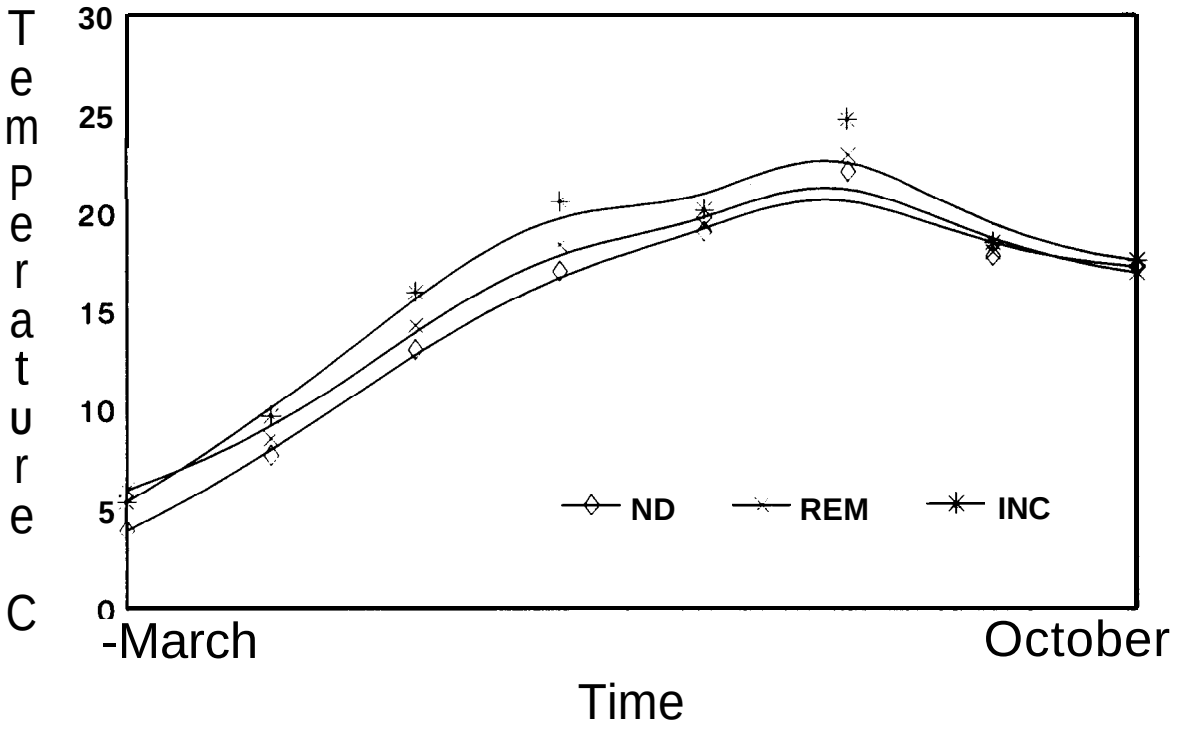

Figure 3-Soil Temperatures at Jasper-Pulaski, March-October 1994.

Table 4. Effects of site (productivity) and forest floor treatment on nitrogen accumulation (mg), compared across sampling periods. The first column (*) denotes the treatment and the sampling period; (1) December-April (2) April-June. (3) June-August (4) August-October

	Nelson-Stokes			SIPAC			Jasper-Pulaski		
	NH_4^+	NO_3^-	Total N	NH_4^+	NO_3^-	Total N	NH_4^+	NO_3^-	Total N
*	mg			mg			mg		
				No Disturbance					
1	0.13a	0.77a	0.90a	0.27a	0.86a	1.13ab	0.27a	0.10ab	0.37a
2	0.14a	0.55ab	0.70ab	0.47a	0.95a	1.42a	0.20ab	0.06c	0.26a
3	0.16a	0.48b	0.64ab	0.21a	0.34b	0.54b	0.15ab	0.23a	0.38a
4	0.05b	0.39b	0.44b	0.42a	0.43b	0.85ab	0.03b	0.19ab	0.22a
Total	0.48	2.19	2.68	1.37	2.58	3.94	0.65	0.58	1.23
				Removal					
1	0.27ab	1.07a	1.33a	0.39a	0.50b	0.89b	0.20a	0.15a	0.34a
2	0.38a	0.74ab	1.13a	0.55a	0.75a	1.30a	0.21a	0.18a	0.38a
3	0.22ab	0.69bc	0.91a	0.08b	0.13c	0.21c	0.05b	0.34a	0.39a
4	0.04b	0.35c	0.39b	0.12b	0.16c	0.28c	0.02b	0.17a	0.19a
Total	0.91	2.85	3.76	1.14	1.54	2.68	0.48	0.84	1.30
				Incorporation					
1	0.17bc	1.03ab	1.21bc	0.48a	0.49b	0.97b	0.32a	0.21b	0.52b
2	0.23ab	1.21a	1.44ab	0.66a	1.12a	1.78a	0.19ab	0.14b	0.34b
3	0.27a	1.25a	1.53a	0.13b	1.19a	1.32ab	0.30a	0.95a	1.25a
4	0.11c	0.84b	0.95c	0.10b	0.25b	0.36c	0.03b	0.16b	0.19b
Total	0.78	4.33	5.13	1.37	3.05	4.43	0.84	1.46	2.30

Means in the same column in the same treatment followed by the same letter are not significantly different at the 5 percent level using Duncan's Multiple Range Test.

chemistry (Plymale et al. 1987) and substrate quality (Viiousek and Matson 1985). The influence of moisture availabilii was evident at both SIPAC (moderate productivity) and NS (high productivity) sites (Figure 4), where a drought in late July and August may have reduced mineralization rates by decreasing microbial activity. Soil moisture stress was not a factor at the JP (low productivii) site during the course of this study (Figure 4). The period of highest N availability tended to occur during the periods of high soil temperatures. Since soil temperature peaked during different periods at diierent sites, the highest N production also occurred at different time periods (Figures 1, 2, 3).

Site, i.e., the site productivity class, significantly affected the rates of nitrification and ammonification (Table 5). Total N and NO;-N for the control treatment were significantly higher at SIPAC relative to both NS and JP, which were similar. Nitrification at the JP site (low productivity) was inhibited until sampling period three (June-August), when soil temperature was at its highest (Figure 3). Nitrification inhibition at JP was likely due to a low initial ammonium concentration and low soil pH (Donaldson and Henderson 1990, Robertson 1982).

This study indicates that disturbances such as those resulting from selection harvesting may affect nitrogen availability patterns in many of the same basic ways as more intensive site disturbances. Forest floor incorporation tends to increase the availability of nitrogen via increased soil temperature. Forest floor removal tends to increase the availability of nitrogen via increased soil temperature until the nitrogen reserves in the forest floor are depleted. Repeated forest floor removal may decrease the long-term availabilii of nitrogen. Sites with inherently high potential productivity may show increased nitriication following disturbances characterized by forest floor incorporation and show fewer long-term adverse affects following forest floor removal than sites with lower potential productivity.

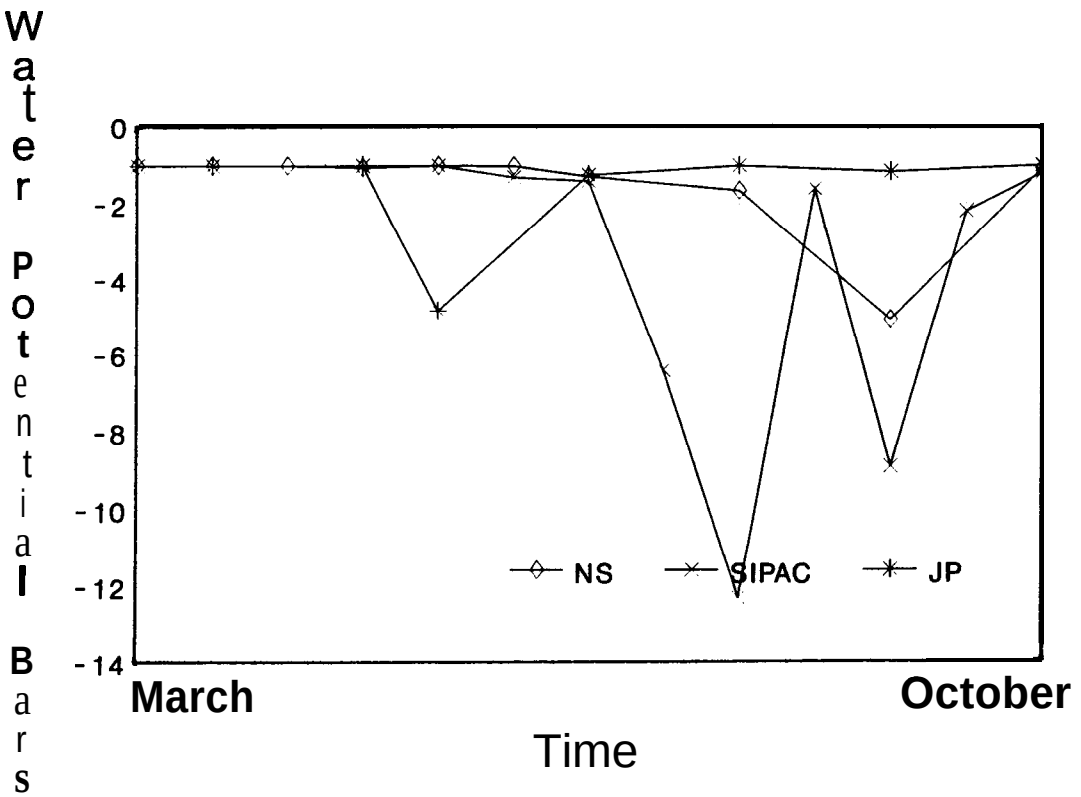

Figure 4-Soil Moisture Potentials for each site, March-October 1994.

Table 5. Effects of site (productivity) and forest floor treatment on nitrogen accumulation (mg), compared across sites'

Siie	NH4+ mg	NO3- ma	Total N ma
	No Disturbance		
NS[b]	0.48b	2.19a	2.68b
SI	1.37a	2.58a	3.94a
JP	.65b	.59b	1.23c
	Removal		
NS	O.Qla	2.85a	3.76aSI
	1.14a	1.54b	2.68b
JP	0.48b	0.84c	1.30c
	Incorporation		
NS	0.78a	4.33a	5.13a
SI	1.37a	3.05b	4.43a
JP	0.84b	1.46c	2.30b

'Means in the same column in the same treatment followed by the same letter are not significantly diierent at the 5 percent level using Duncan's Multiple Range Test.

[b]Sites are NS, Nelson-Stokes; SI, SIPAC; JP, Jasper-Pulaski.

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EVALUATION OF A NEW SYSTEM OF HUMUS CLASSIFICATION IN THE WINE SPRING CREEK WATERSHED OF THE NANTAHALA NATIONAL FOREST[1]

W. Henry McNab[2]

Abstract-A classification system of forest humus forms was tested over a range of environmental conditions in the southern Appalachian **Mountains** of western NC. **The new** system is easy to **understand,** can **be objectively and quickly applied,** and compares **favorably** to an **earlier classification** system. Using **this system,** humus forms were found to **be associated** with six **ecological** types.

INTRODUCTION

Humus, the layers of predominately organic matter that accumulate, decompose, and mix with mineral soil, is a product of **climate,** moisture regime, soil fauna, and vegetation of forest sites. Readily available for examination and characterization, humus may serve as an integrator of the physical and biological components of ecosystems. However, humus is seldom mentioned in ecological studies where the forest floor, soil, or vegetation are described. In one of the few recent studies, Moffat (1993) repotted that humus in the southern Appalachian Mountains of northeastern Georgia was **highly** correlated with site units, but he did not specify how it **was** classified.

Several humus **classification** systems have been proposed since the **early 1900's,** but none has gained wide acceptance. Most recently, Green and others (1993) developed **a classification** system based primarily on concepts reported in international literature. This system, believed to be applicable in all environments, provides an objective way to classify humus into three orders and 16 groups. Thii **relatively** new system has been tested throughout Canada and in parts of the United States, including the Appalachian Piedmont of South Carolina, but **little** has been reported on its use, applicability, and comparison with other humus **classifications**.

The primary objective of thii study was to test and evaluate the **classification** of humus forms developed by Green and others (1993) in a mountainous area of western North Carolina. Thii classification system was compared to the **classification** system of humus **types** developed for upland forested sites by Hoover and Lunt (1952). Although each system uses **different** terminology (ie. forms, types) when referring to humus, both describe the same organic and mineral layer of the forest floor. A secondary objective involved characterizing humus forms in the study area and determining their association with environmental conditions.

METHODS

The humus classification systems were tested in the Wine Spring Creek watershed, a 3,000 ha mountainous tract in the Nantahaia National Forest where altitudes range from about 900 m to 1640 m. Arborescent vegetation consists of cold-deciduous forests dominated by species of the genus *Quercus.* Shrub understories consist mainly of deciduous and evergreen species in the *Ericaceae* family. Preliminary vegetational relationships associated with **mesic,** dry, and **xeric** moisture regimes in this area are described by **McNab** and Browning (1993).

Fii plots were established during October 1994 in hardwood-dominated tree communities along roads and trails. Siies with two distinctive communities were not sampled: those dominated by Canada hemlock, *Tsuga canadensis* (L) Carr., and those with a dense understory of **rhododendron,** *Rhododendron sp.* **(L.). A** minimum of **five** plots were located in each community.

Data were collected from variable-radius field plots defined by **a** 1 O-factor prism. Plots were located subjectively to sample the range of prevalent

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environmental conditions and vegetational components. Each plot was classified into one of the six tentative ecological types' described by McNab and Browning (1993). Humus was classified as one of three orders in both systems of classification. The system developed by Green and others (1993) required measuring thickness of the F and H layers of the forest floor and determining the presence of fungal mycelia or soil meso fauna. The Hoover and Lunt (1952) classification system required determining the presence of the F and H layers. Both classification systems used Mull and Mor terms to designate humus associated with biologically active or inactive sites, respectively. The transition form of humus is termed Moder by Green and others (1993) and Duff Mull by Hoover and Lunt (1952). Problems encountered in applying the two systems were noted.

Two hypotheses were tested. The first was a test of the inter-classification agreement between the two systems and was evaluated with a kappa statistic (Landis and Kock 1977). The second test, which was an exploratory analysis because samples were not randomly selected, evaluated homogeneity of the distribution of humus forms among ecological types. Chiaquare, based on Fisher's exact test (SAS Institute, INC 1985), was used in this test of homogeneity.

RESULTS AND DISCUSSION

Evaluation of the Classification Systems

Both classification systems could be objectively applied, and Mor and Mull humus forms and types could be determined quickly. Identification of Moder forms and Duff Mull types required detailed examination because these orders occupied transition zones between Mors and Mulls. Both classification systems agreed on humus order for 94 percent of the samples (Table 1). The kappa statistic value (0.9039) suggested that agreement between the two classification systems was almost perfect

Relationship of Humus Forms With Ecological Types

In the system developed by Green and others (1993) humus form appeared to correlate to ecological type (Table 2), which was confirmed by the exploratory chi-square test Moders and Mors were associated with ecological types dominated by chestnut oak and scarlet oak, respectively. Mulls occurred over a range of ecological types, especially those associated with higher elevations. Relationships observed between humus forms and ecological types in the study area are consistent with two observations reported by Green and others (1993). They reported that (1) Mors were typically associated with dry sites where relatively little soil biological activity existed, and (2) Mulls were usually found on sites with a mesic moisture regime, where abundant soil fauna promoted mixing of organic material in the soil A-horizon.

Table 1 .–Classification of humus in the Wine Spring Creek watershed using methods described by Hoover and Lunt (1952) and Green and others (1993).

Humus type order*	Humus form order" Mull	Moder	Mor	All
	--- Number of plots ------			
Mull	19	0	0	19
Duff Mull	0	21	1	22
Mor	0	2	7	9
An	19	23	8	50

'Hoover and Lunt (1952)
"Green and others (1993)

Table 2.-Distribution of humus form orders by tentative ecological type in Wine Spring Creek watershed of the Nantahala National Forest

Tentative ecological type	Humus form order Mull	Moder	Mor	Total
	-Number of plots-----			
Northern hardwoods	5	0	0	5
Northern red oak	5	2	0	7
White oak	2	4	0	6
Yellow-poplar	5	3	0	8
Chestnut oak	2	12	1	15
Scarlet oak/pine	0	2	7	9
Total	19	23	8	50

Relationship of Humus Forms With Environmental Variables

A generalized model of the relationship between humus forms and both elevation and moisture gradient is shown in figure 1. Ecological types are positioned at their relative modal positions in relation to these gradients. At elevations, below about 1050 m, each humus form was associated with one of the three

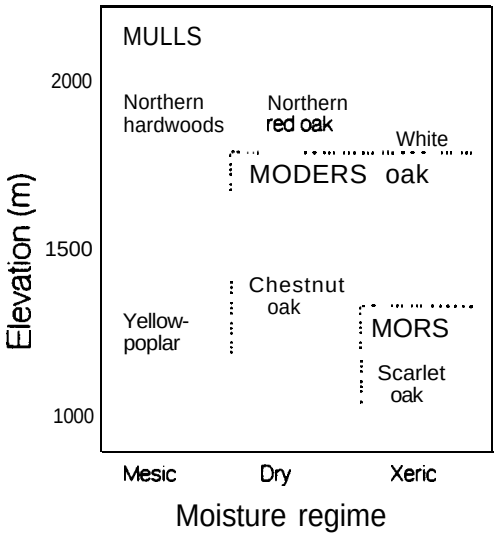

Figure 1 .-Relationship of humus forms with the modal positions of ecological types across elevation and moisture gradients in the Wine Spring Creek watershed of the Nantahala National Forest.

moisture regime classes. Between 1050 to 1350 m elevation, Moders tended to occupy landscape positions that Mors occupied at lower altitudes. Above 1350 m, Mulls extended over all perceived moisture regimes. Reduced annual soil moisture deficits and cooler temperatures could account for the increased biological activity associated with the presence of Moder and Mull humus orders at higher altitudes. Most soils above about 1400 m, regardless of slope position, have a thick surface horizon with high organic matter content (Personal communication S.Browning, August 1994).

Green and others (1993) suggested that site fertilii might be inferred from knowledge of humus forms. In British Columbia, for example, they reported that base saturation tended to be higher on sites with Mull humus forms. This is probably not the case in the southern Appalachian Mountains, however, where most soils are derived from rocks with highly acidic reaction and have relatively low base saturation.

CONCLUSIONS

The classification of humus forms developed by Green and others (1993) was easy to understand, could be objectively applied, and produced results consistent with those from an earlier classification system. A desirable and unique feature of this new system is its proclaimed applicability in all environmental conditions in North America. However, because this classification system is relatively new, it should be evaluated in other regions by testing and comparing to other traditional systems.

ACKNOWLEDGEMENTS

I thank Sara A. Browning, and other personnel of the Wayah Ranger District, Nantahala National Forest, for their cooperation in this study.

ENDNOTE

'An ecological type is a category of land having a unique combination of potential natural community, soil, landscape features, and climate; and differing from other ecological types in its ability to produce vegetation and respond to management. Tentative ecological types were identified in a reconnaissance investigation prior to a more complete study conducted in the summer of 1994 by S. Browining of the Wayah District of the Nantahala National Forest and S. Simon of the Supervisor's Office of National Forests in North Carolina.

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RECYCLING BARK BOILER ASH IN FORESTS: EFFECTS ON SURFACE AND GROUND WATER'

Thomas M. Williams, Charles A. Hollis and Bill R. Smith[2]

Abstract—An operational trial of bark boiier ash application to forest land was conducted near Georgetown SC. Ash from the Georgetown paper mill was applied at a rate of 5 tons /acre (9.7 Mg/ha) to two watersheds, one in the regeneration phase and one in a thinned 17 year - oid pine plantation. Two control watersheds were established as pairs with the treated watersheds.

in August - October 1991, 64 multi-depth ground water samplers were installed in the four watersheds. Pm-treatment (Nov. 1991) and monthly post-treatment (Dec. 1991 -May 1994) samples have been retrieved from these samplers. Samples were analyzed for Cl, NO,, PO, (ion chromatography) K, Ca, Mg, Zn, Al, (flame AA), and Cd, Cu, Cr, Ni (graphite furnace AA). in addition, Parshaii flumes and automatii stream samplers were installed on each watershed. Stream samples were taken at six hour intervals, filling one bottie per day, and analyzed for the same constituents.

No adverse effects of ash application were observed in either stream or ground water quality. Heavy metal concentratiis were well below drinking water standards. When applied in low rates and in appropriate landscape positiis, bark boiler ash had no detrimental impact on water quality.

INTRODUCTION

Since the energy crisis in the mid 1970's the paper industry has been very successful in replacing fossil fuels with wood residues (primarily bark) as fuel for power boilers. Replacing oil with wood residue has both cost and environmental benefits. However, using wood residues results in large quantities of ash and creates a solid waste problem. For example, the International Paper Georgetown Mill, while being over 90% energy self-sufficient, has produced 100 tons (78.7Mg) of ash per day since conversion to wood fuels in the late 1970's. The large quantity alone has an undesirable effect of filling landfill space quickly. Placing the material in a landfill also has the undesirable effect of concentrating small amounts of heavy metals found in bark at a single point.

A program to spread ash back onto forest land not only reduces the need for landfill space but also distributes elements back to the forest environment to compensate for harvesting removals. However, as an industrial waste, ash spreading is regulated under state solid waste and water quality programs. The research outlined here supplied water quality data on an operational ash spreading trial to state regulatory agencies with responsibilii for water quality and solid waste management The goal of this study was not to find a treatment effect but was to assure that the analysis would find any treatment effect that might cause violation of water qualii criteria (SCDHEC 1981).

METHODS

The operational trial was conducted in eastern Williamsburg County, SC (Lat. 35 Deg. 35 Min. N, Long. 79 Deg. 34 Min. W). A block (roughly 250 ac (100ha)) of clear-cut pine plantation and a similar block of recently thinned (1990) 17 year old pine plantation were chosen. Two watersheds were chosen in each block and an ash application area was chosen to completely enclose one watershed in each block.

Soils on the study site were primarily Eulonia (fine-loamy, siliceous, thermic, Aquic Hapludults), Emporia (fine-loamy, siliceous thermic Typic Hapiudults), Yemassee (fine-loamy, siliceous, thermic Aeric Ochraqualts), and Ogeechee (fine-loamy,

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siliceous, thermic Typic Ochraqualts) (Ward 1989). An on-site soil survey was conducted in each application area and ash was applied to all soils that were moderately well drained or better. Approximately 125 acres (50 ha) received ash in each block. Ash was applied at a rate of 5 tons/acre (9.7 Mg/ha). No ash was applied to poorly drained soils. Ash was applied to each area in December of 1990. Following ash application, the clear-cut areas were bedded and planted to pine.

Ground water was collected from 64 multi-level samplers (Williams and McCarthy 1991). These samplers allowed collection of information on piezometric potential at four depths and ground water samples at five depths. For this paper each sampler installation will be called a well for simplicity. Wells were placed in five transects of four welts in each treatment (ash) watershed and three transects of four wells in each control watershed. In each transect two wells were placed in the area receiving ash (or on soils eligible for ash in the control watersheds) and two wells in the area that received no ash. Samples were collected in November 1991, prior to treatment, and monthly from December 1991 through May 1994.

Surface water was collected by ISCO brand automatic samplers. Parshall flumes were placed at the outlet of each watershed and a sampler was placed in the stream just upstream of the pond created by flume installation. The sampler was programmed to pump a sample every six hours and fill a single sample bottle each day. Samples were removed from samplers weekly. Samplers were maintained continuously and pumped whether water was in the stream or not, assuring samples of intermittent flows. Surface samples were collected from January 1992 (the first flow after ash application) until April 1994.

Ground water samples were collected with a battery powered peristaltic pump. Each well was connected to the five head pump and run until all samplers produced over three sampler volumes, all pump lines were rinsed with sample, the sample bottles were rinsed with sample, and a 65 ml sample was collected. Pump lines were air purged between samples.

All samples were put in an ice chest and transported to the laboratory. Samples were refrigerated until analysis. Sample aliquots were analyzed for: NO_3, PO_4, and Cl, by ion chromatography; Ca, Mg, K, Zn by air-acetylene flame atomic absorption and Al by nitrous oxide-acetylene flame atomic absorption; and Cd, Cr, Cu, Ni by graphite furnace atomic absorption. Techniques were as described in Standard Methods for Analysis of Water and Waste Water 16th and 18th ediions (Greenberg et al. 1985, 1992).

RESULTS

Ground Water

Since the goal of the operational trial was to apply ash at a rate that did not result in ground water contamination, data analysis was challenged to assure that any effect of ash application was inconsequential. Data collection had two goals: The primary goal was to demonstrate that ground water beneath the areas of application did not exceed drinking water standards. The secondary goal was to demonstrate that ash application had no environmentally important impact on ground water qualii.

Table 1 lists the mean and upper 95% confidence limit for ground water concentrations in the wells within the two ash application areas. In all cases the mean and upper confidence limit are within the primary drinking water standard and often more than an order of magnitude below the standard. These means were calculated with data that were above the analytical limits of the analysis, all non-detectable samples were excluded, which inflates the means slightly. Nitrate and phosphate are not included in these tables as most values were non-detectable and a valid mean was not possible.

The sampling design allowed three methods to evaluate the effect of ash application. Differences between the control and applied watersheds could be evaluated before and after application in a normal paired watershed technique. However, there were too few pm-treatment samples taken for this technique to produce conclusive data. Alternatively, differences in elemental concentrations of wells in treated and control areas can be compared for the post- treatment period. Table 2 lists the differences between means of well concentrations in treated and control watersheds. For this comparison only wells that were in areas receiving ash were included in the treatment watershed means. In the control watersheds only wells in the same landscape position and on similar soils to the wells receiving ash were included in the analysis. The means for this analysis were also calculated excluding all non-detectable samples.

Table 1. Mean concentrations of elements in ground water. All elemental concentrations are in milligrams per liter, except Cd, Cr, Cu, and Ni which are in micro-grams per liter. UCL is the upper 99 percent confidence limit.

Element	Clear Cut Ash Mean	UCL	Clear-Cut Control Mean	UCL	Thinned Ash Mean	UCL	Thinned Control Mean	UCL
Al	4.71	6.92	0.55	0.82	4.13	7.52	1.37	2.27
Ca	3.30	3.79	0.44	0.55	1.15	1.33	4.27	4.84
Cd	0.16	0.39	0.053	0.064	0.15	0.18	0.087	0.144
Cr	2.30	3.20	25.7	64.6	19.0	43.1	0.80	1.00
cu	1.89	2.68	1.37	2.16	2.65	5.18	0.60	0.77
Cl	10.5	11.9	5.2	5.5	7.7	8.1	7.6	8.1
K	0.66	0.72	0.74	0.79	0.83	0.90	0.65	0.70
Mg	0.57	0.65	0.45	0.47	0.45	0.48	0.47	0.51
Zn	0.063	0.069	0.039	0.045	0.262	3.99	0.14	0.52

Table 2. Mean concentration increases of elements in ground water attributable to ash application. All elemental concentrations are in milligrams per liter, except Cd, Cr, Cu, and Ni which ar in micro-grams per liter. Predicted value is treatment watershed mean - control mean, negative values indicate control concentrations were larger than treatment. Maximum effect is the upper 99 percent confidence limit on the difference. ' - Difference is significant at 99 percent confidence

Element	Clear Cut Predicted Effect	Clear Cut Maximum Effect, 99 pct. Confidence	Thinned Predicted Effect	Thinned Maximum Effect, 99 pct. Confidence
Al	4.16'	6.38	2.76	6.15
Ca	2.81'	3.35	-3.12'	-1.79
Cd	0.10	0.33	0.06	0.09
Cr	-23.3	15.0	18.2	42.0
cu	0.52	1.31	2.00	4.58
Cl	5.33"	6.71	0.12	0.47
K	-0.08'	-0.02	0.18'	0.35
Mg	0.12'	0.18	-0.20	0.06
Zn	0.016'	0.017	0.22	3.95

In each transect in the treated areas two wells were included that did not receive ash. On each transect, one of these wells was dose to one of the two wells that did receive ash. For the third analysis, these two wells were considered as a paired comparison. For each transect month, and depth, the concentration in the well in the untreated area was subtracted from the concentration in the well in the treated area. Table 3 iii the mean difference between the paired wells. In this analysis non-detectable values in one or both wells were important. For example, if the wells in the control were generally non-detectable but had a few large values and the treatment wells had consistently high values the means might be similar. However, if a small value (1/2 the detection limit in this analysis) is assigned to each non-detectable value a difference will be recorded for each instance the treatment exceeds the control. Also the simultaneous presence of non-detectable values in both wells is a valid indication of no treatment effect that is included in this analysis.

Table 3. Mean concentration increases of elements in ground water attributable to ash application. AU elemental concentrations are in milligrams per titer, except Cd, Cr, Cu, and Ni which ar in micro-grams per iiier. Predicted value is the mean difference between paired samples in wells in treated areas and nearby untreated areas, negative values indicate control concentrations were larger than treatment Maximum effect is the upper 99.9 percent confidence limit on the difference. • - Diierence is significant at 99.9 percent confidence

Element	Clear Cut		Thinned	
	Predicted Effect	Maximum Effect 99.9 pct. Confidence	Predicted Effect	Maximum Effect 99.9 pct. Confidence
Al	-0.58	1.74	-0.40	-0.64
Ca	1.17"	1.96	-1.30'	-0.70
Cr	-0.45	2.48	1.64	4.31
cu	0.53	2.24	0.76	1.69
Cl	-1.13	1.87	-1.13	0.53
K	-0.064	0.022	-0.21'	-0.11
Mg	-0.0098	0.09	-0.188'	-0.11
Zn	0.0165'	0.022	-0.217	0.53

Surface Water

Each of these small watersheds flowed intermittently, generally from January through May. Mean concentrations of each stream and upper 95% confidence limits are listed in table 4. T-tests of individual elements do show significant differences between watersheds but there is no clear-consistent effect of ash treatment There was a clear increase of potassium concentrations on both clear-cut watersheds during the first year. However, this effect disappeared on clear cut - ash applied watershed in the second year and for the entire study only the clear-cut control watershed has significantly higher potassium concentration.

CONCLUSIONS

The data clearly show that ash application did not result in contamination of either streams or ground water on these two sites. Concentrations of all materials easily met primary drinking water standards. The stream data also show that there was no surface movement of ash into the streams. Stream concentrations are remarkably similar to ground water concentrations, suggesting that most of the stream water traveled through the upper forest soil horizon and possibly through the water table aquifer.

Table 4. Mean concentrations of elements in stream water. All elemental concentrations are in milligrams per liter, except Cd, Cr, Cu, and Ni which are in micro-grams per iiter. UCL is the upper 99 percent confidence limit.

Element	Clear Cut Ash		Clear-Cut Control		Thinned Ash		Thinned Control	
	Mean	UCL	Mean	UCL	Mean	UCL	Mean	UCL
Al	1.67	2.17	0.30	0.36	0.54	0.62	0.36	0.44
Ca	0.74	0.78	1.08	1.14	2.48	2.66	0.80	0.64
Cd	0.096	0.160	0.118	0.182	0.076	0.087	0.133	0.233
Cr	0.66	0.75	0.66	0.73	0.73	0.81	0.98	1.35
cu	1.14	1.38	2.87	3.47	1.37	1.54	1.13	1.39
Cl	6.99	7.30	7.43	10.1	8.81	9.19	7.43	7.84
K	0.69	0.77	1.25	1.49	0.69	0.76	0.39	0.31
Mg	0.66	0.67	0.83	0.88	0.83	0.90	0.54	0.50
Zn	0.008	0.013	0.013	0.016	0.012	0.017	0.009	0.014

Two factors of the ash application may have contributed to successful protection of water quality. The ash was not applied to wetland soil types. Careful soil mapping identified poorly drained soil types and ash application avoided these areas. This assured that ash would not be placed in the source area of stream flow and that water would percolate through the soil where ash was placed. Ash was also applied at a rate that was near the rate of elemental removal in forest harvest.

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SMALL MAMMAL SAFETY OF BARK BOILER ASH RECYCLING IN SOUTHEASTERN COASTAL PLAIN FORESTS

John R. Sweeney, Philip D. Jones and George P. Cobb'

Abstract-Small mammals inhabiting newiy regenerated and **17-yr-old thinned pine stands near Georgetown, S.C., were sampled over 1 year** and analyzed for **heavy** metal content to **monitor potentiii faunal impact of recycling bark boiler** ash on these sites. **Ash was applied at the rate of 10 metric tone/ha. Whoie body samples were analyzed for cadmium, copper, chromium, iead, nickel and zinc. Based on analyses of these samples, application of ash on these sites has not had a substantial impact on heavy metal whole body burdens of small mammals inhabiting these areas.**

INTRODUCTION

Recycling bark boiler ash through land-spreading apparently represents an environmentally responsibie alternative to land-filling because it may be beneficial to the forest ecosystem to which it is applied and it frees up limited land-fill space for non-recyclable materials. The purpose of this study was to determine the impact on small mammals of an operational program of recycling paper mill power boiler ash on pine ecosystems in coastal South Carolina. This project was a companion project to the studies reported earlier in this proceedings on the effects of recycling bark boiler ash on forest soil properties and vegetation (Hollis and Williams 1994) and on surface and groundwater (Williams et al. 1994).

METHODS

Small mammals were collected from four 40-ha study sites - a treatment and a control study site each established **in a** newly regenerated pine plantation and in a **17-yr-old,** thinned pine plantation - near Georgetown, South Carolina. Nineteen pitfall stations were placed on the four study areas, with three to seven stations per study area depending on the habitat potential of each area. Two hundred small mammal snap traps were also set on each study site per sampling period. Pitfall stations and snap traps were monitored daily for approximately 7 days on each study site per sampling period. Animals captured were euthanized and stored frozen until they were analyzed for heavy metal content

Bark boiler ash was applied to the treatment sites at the rate of 10 metric tons/ha in November 1991. Fauna were sampled immediately following ash application (winter 1991) and in spring, summer and fall 1992. Whole body samples were analyzed for cadmium, copper, chromium, lead, nickel and zinc.

Animals were acid digested and then analyzed by atomic absorbtion. Determination of biologically significant lead concentration required graphite furnace atomization. All other metals were atomized by an **air-** acetylene flame. Instrument response to each metal was calibrated with a four-point calibration curve. Samples were measured in triplicate and mean results computed. Detection limits were taken to be twice the blank response or a concentration producing an **absorbence** of 0.003, whichever was greater. Quantitation limits were defined as the concentration of the lowest calibration standard.

For statistical comparisons, values for samples that were below detection were set at one-half their quantitation value. Analysis of variance was used to test for significant **differences** between stand types, treatments, taxonomic groups, and seasons. Least square means for all logical, paired comparisons were then examined for those instances where analysis of variance indicated a **significant** effect. All tests were conducted at the 0.05 level of probabilii.

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RESULTS AND DISCUSSION

Forty-six carnivorous mammals, and 99 herbivorous mammals were collected from the four study sites and analyzed for heavy metal whole-body burdens. Carnivorous mammals were either the southern short-tailed shrew, *Blarina carolinensis* Bachman, (56% of captures) or the least shrew, *Cryptotis parva* Say, (44%). All but two of the herbivorous mammals were one of three species - the house mouse, *Mus musculus* Linnaeus, (36%) eastern harvest mouse, *Reithrodontomys humulis* Audubon and Bachman, (37%) or the hiipid cotton rat, *Sigmodon hispidus* Say and Ord, (24%).

Zinc, Lead, Copper and Nickel

Levels of zinc were too low to be measured accurately by the procedures used. Analysii of variance tests revealed no significant differences ($P > 0.05$) between stand types, treatments, taxonomic groups, and seasons for lead, copper and nickel. Whole body burdens for these metals averaged less than 1, 5 and 6 ppm, respectively (Table 1), and all were within ranges expected as background for wildlife (Hunter and Johnson 1982, Eiier 1988, Alberici et al. 1989).

Cadmium and Chromium

No significant differences were found in cadmium or chromium whole-body burdens of carnivorous mammals, which averaged 0.090 ppm ± 0.012 ppm (mean ± standard deviation) and 1.042 ppm ± 0.309 ppm, respectively.

Table 1. Mean whole-body burdens for lead, copper and nickel found in small mammals inhabiting newly regenerated and thinned pine stands near Georgetown, S.C., 1991-92

Taxonomic Category	No. of Observ.	Metal	Whole body Burden (ppm wet weight) Mean	Std. dev.
Carnivorous Mammals	46	Pb	0.700	0.172
		cu	4.016	0.568
		Ni	5.769	2.934
Herbivorous Mammals	79	Pb	0.196	0.061
		cu	2.935	0.299
		Ni	1.547	0.391

Seasonal Fluctuations.

Significant seasonal fluctuations were detected in whole-body burdens of cadmium and chromium for herbivorous mammals. In all but one case for cadmium, mean whole-body burdens of herbivorous mammals in winter and summer samples taken from the four study sites were approximately 3 to 18 times higher than their respective spring and fall sample means (Table 2).

Whole-body burdens of chromium for herbivorous mammals exhibited similar seasonal fluctuations in that winter and summer whole-body burdens were usually

Table 2. Mean whole-body burdens for cadmium found in herbivorous mammals inhabiting newly regenerated and thinned pine stands near Georgetown, S.C., 1991-92

Site	Stat.	Season Winter	Spring	Summer	Fall
Thinned Treatment	Mean				0.024
	SD				0.007
Thinned Control	Mean			0.295 A'	0.062 B
	SD			0.019	0.032
Clearcut Treatment	Mean	0.179 A	0.020 B	0.145 A	0.021 B
	SD	0.075	0.011	0.085	0.025
Clearcut Control	Mean	0.275 A	0.046 B	0.093 B	0.015 B
	SD	0.226	0.063	0.066	0.017

[a] Within each site, means followed by diierent letters are significantly different ($P < 0.05$).

Table 3. Mean whole-body burdens for chromium found in herbivorous mammals inhabiting newly regenerated and thinned pine stands near Georgetown, S.C., 1991-92

Site	Stat	Season			
		Winter	Spring	Summer	Fall
Thinned Treatment	Mean				0.953[a]
	SD				1.095
Thinned Control	Mean			1.319 A[b]	0.146 B
	SD			0.114	0.099
Clearcut Treatment	Mean	3.737 A	0.237 B	0 658 c	0.270 B
	SD	0.396	0.128	0.482	0.268
Clearcut Control	Mean	3.324 A	0.092 B	0.247 BC	0.559 C
	SD	0.788	0.084	0.294	0.650

[a] Underlined means within the same stand type are significantly different due to treatment ($P < 0.05$).
[b] Within each site, means followed by diierent letters are significantly diierent ($P < 0.05$).

higher than spring and fall levels (Table 3). Additionally, whole-body burdens of herbivorous mammals in the clearcut sites were high in the winter, averaging greater that 3 ppm, then dropped significantly during the rest of the year, averaging less than 1 ppm, with spring values being less than 0.25 ppm (Table 3).

There are several potential reasons for the seasonal fluctuations seen in the sample means of whole-body burdens for cadmium and chromium. Influx of juveniles into the populations sampled may have caused a decrease in mean whole-body burdens due to the shorter time juveniles had been exposed to environmental levels of these metals. This may explain some of the decline in spring levels. However, similar significant declines were seen in fall, and examination of body weights as indicators of age did not reveal any significant changes in age ratios of the samples from one season to another.

Emigration of new animals into the study site from adjacent areas is another possible cause of sample mean fluctuations. However, sampling intensity per trapping period was restricted to approximately 7 days in order to minimize depletion of the study populations, and thereby creating any increased opportunities for emigration into the study areas. Also, samples were taken only from the interiors of the study sites in order to avoid sampling fauna from adjacent areas.

Additionally, similar fluctuations were seen in both treatment and control sites. Therefore one would expect to see similar levels of metal concentrations in the adjacent areas.

The third potential cause of seasonal fluctuations is fluctuations in availabiliies of these heavy metals in the diets of the animals tested as a result of changes in food habits and or changes in concentrations of these metals in the foods eaten. This is the most plausible cause. However, what actually caused the change in availabilities of these metals is unknown.

Treatment Effects.

Of all the heavy metals tested, chromium is the only one for which significant differences were found in whole-body burdens of at least some small mammals inhabiting treated versus control study sites. Although analysis of variance tests revealed no significant differences due to treatment for any of the metals, examination of individual LS means indicated significant differences in chromium whole-body burdens of herbivorous mammals inhabiting treatment versus control sites in two cases. Summer whole-body burdens were 1 .9 times higher in the treated than in the control clearcut, and fall whole-body burdens were 6.5 times higher in the treated versus control thinned sites (Table 3). Sample sizes for the fall were very low (less than four animals per site) and the significant treatment effect was due to a single sample with a high whole-body burden of 1.727 ppm. On the other hand, sample sizes for the treatment and control clearcut stands in the summer were 24 and 21 animals, respectively. Therefore this measured difference apparently does represent a true phenomenon. However, there were

no other significant differences between samples taken from control versus treated sites for herbivorous mammals during the other seasons or for other taxonomic categories. Furthermore, concomitant research on soil properties and vegetation (Hollis and Williams 1994) and on surface and groundwater (Williams et al. 1994) indicated that differences in heavy metals were most likely due to inherent differences in individual study sites rather than due to treatment effects. In light of these findings, the observed differences in summer whole-body burdens for small mammals most likely were not a response to treatment.

CONCLUSIONS

Recycling of bark boiler ash in the pine plantations studied did not have an appreciable effect on whole body burdens of small mammals for the heavy metals tested - cadmium, copper, chromium, lead, nickel and zinc. The primary differences that were detected were seasonal fluctuations in both treatment and control plots, in wholebody burdens of cadmium and chromium for herbivorous mammals. In most cases, winter and summer whole-body burdens for these metals were higher than those in spring and fall. Forest recycling of mill ash at the rates applied in this study does not appear to deleteriously affect the fauna studied.

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GROWTH REDUCTIONS IN SHORT-ROTATION LOBLOLLY AND SLASH PINES IN CENTRAL LOUISIANA--10TH YEAR RESULTS'

James D. Haywood and Allan E. Tiarks[2]

Abstract--A 22-year-old loblolly (*Pinus taeda* L.) and slash pine (P. *elliottii* Engelm. vsr. *elliottii*) research plantation was clearcut and replanted with the same species to compare tree growth between the two rotations. Both pine species were more productive in the first than the second rotation through 10 growingseasons. Loblolly pine productivity was especially reduced on replanted plots that had been disked or disked and bedded 32 years earlier. However, reductiis in growth and yield occurred on all treatment plots for both species.

INTRODUCTION

We recently reported that second-rotation plantations of loblolly (*Pinustaeda* L.) and slash pines (P. *elliottii* Engelm. var. *elliottii*) on silt loam soils in central Louisiana were growing more slowly than those in the preceding generation (Haywood 1994). That report was based on height growth in 7-year-old stands that were only beginning the rapid growth period common for these species. We are now reporting on the development of these plantations after 10 growing seasons. The effects of repeated rotations on diameter, basal area, and stand yields are even more apparent.

METHODS

Study Area

The study area, in Rapides Parish, Louisiana, contains Beauregard (Plinthaquic Paleudult, fine-silty, siliceous, thermic) and Caddo (Typic Glossaqualfs, fine-silty, siliceous, thermic) silt loam soils (Haywood 1994). Natural stands of longleaf pine (*P. palustris* Mill.) and hardwoods were clearcut in the 1920's. A cover of grasses and scattered hardwoods developed and was maintained by periodic burning. Prior to pine planting, the area was burned to reduce the grass rough, and the woody vegetation was cut and removed.

Plot Establishment, Treatments, and Management

At the beginning of the first rotation, four blocks of six plots (treatments) each were established in a randomized complete block design. Blocking was based on surface drainage. Each of the 24 plots was 144 by 108 feet (0.36 acre), and contained 18 rows spaced 8 feet apart. Seedlings were planted 6 feet apart within rows.

Within blocks, the six plots were randomly assigned one of two species, loblolly or slash pine, and one of three site preparation treatments. Treatments were: (1) Burnonly-all plots were burned in 1960 to facilitate planting, (2) Burndisk-plots were treated with an offset disk harrow in the fall of 1960 and again in July 1961 to control established grass competition, and (3) Burn-disk-bed-after disking, the plots were double bedded in September 1961 by making two passes with a bedding harrow. Beds were spaced 8 feet apart, and the height from furrow-to-crest averaged 20 inches before settling; after 15 years, the beds were 10 inches tall. Graded, nursery-grown, bare-root, 1-O loblolly and slash pine seedlings were hand planted in rows on their respective plots in February 1962.

During the first rotation, grasses were the initial principal competitors with the pine trees. Some woody competitors were present, principally southern bayberry (*Myrica cerifere* L.). The loblolly pine plots were thinned to a basal area of 84 ft^2/acre and the slash pine plots to 78 ft^2/acre after the 13th growing season (Haywood 1983). By 1981, total outside-bark stemwood production averaged 4,780 ft^3/acre on the loblolly and 4,390 ft^3/acre on the slash pine plots.

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All plots were clearcut in August 1983, after 22 growing seasons. Logging equipment was not allowed on the plots, and tops and limbs were left in place. After harvest, the entire study area was prescribed burned to remove logging residue and facilitate planting. The burn-disk and bum-disk-bed plots were not retreated mechanically so the influence of the initial site preparation treatments could be evaluated during the second rotation.

In February 1984, the plots were hand planted the second time with graded, nurserygrown, bare-root, 1-O loblolly or slash pine seedlings. The seedlings were planted between stumps in the original planting rows.

During the second rotation, all plots were rotary mowed yearly between the rows of pine trees to control the size of woody competitors, and the debris left in place. Woody vegetation was cut down in the planted rows during the 9th growing season. Thii was done to keep woody plant competition from negatively affecting pine tree growth more than it did in the first rotation.

Measurements and Data Analysis

Ten rows of 10 trees each were measured in the center of each plot In the first rotation, tree measurements included total height, taken at ages 1 to 10, 13, 15, and 20 years, and diameter at breast height (d.b.h.), taken at ages 5 to 10, 13, 15, and 20 years. In the second rotation, tree measurements included total height, taken yearly, and d.b.h., taken yearly beginning at age 5 years. In both rotations, height poles were used to measure tree heights for at least the first seven growing seasons and diameter tapes were used to measure d.b.h. A clinometer was used to measure tree heights at age 10. The d.b.h. and height data were used to calculate outside bark total stem volumes for loblolly (Baldwin and Feduccia 1987) and slash (Lohrey 1985) pines.

Pine survival, height, d.b.h., basal area, and volume data were subjected to analysis of variance using a split-plot model with rotation as the main plot effect, site preparation as the subplot effect and four blocks (Probability > F-value=0.05) (Haywood 1994).

Precipitation data have been collected in the general area of the research plots since 1952. For the first 10 years of both rotations, the monthly total precipitation values were used to calculate winter/spring (January, February, March, April, May, and June) and total yearly precipitation. The winter/spring and total yearly precipitation data, which do not vary across blocks or treatments, were analyzed for differences between rotations (Haywood 1994). Also, a Kruskal-Wallis test was used to compare the distribution of winter/spring and total yearly precipitation during the first 10 years of each rotation (Probability > Chi-square=0.05).

On March 18, 1993, foliar samples were collected from five dominant and codominant trees per plot. The samples were taken in the upper one-third of the tree crowns. The samples were oven-dried at 158°F (70%) for 24 hours, weighed, and ground in a Wiley mill. After sulfuric acid/cupric sulfate digestion, nitrogen, phosphorus, and potassium were determined by ammonium probe, colorimetry, and atomic absorption spectrophotometry, respectively.

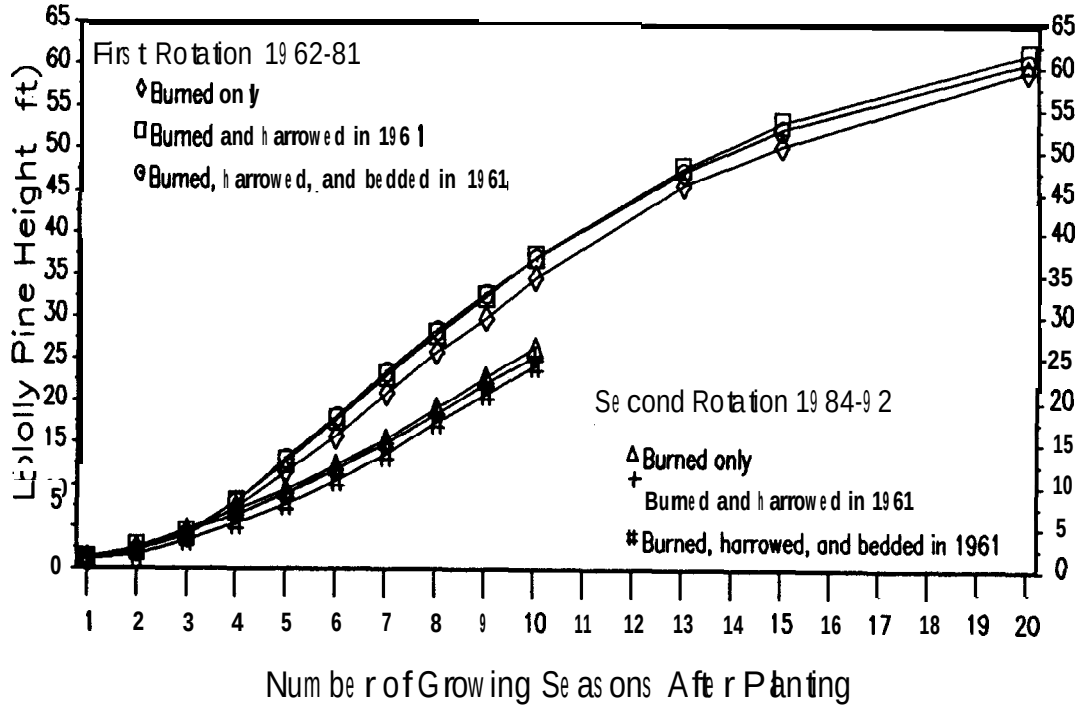
Treatment differences in 1993 concentrations of nitrogen, phosphorus, or potassium in the loblolly or slash pine foliage were identified through analysis of variance (Probability > F-value=0.05). Rotation was not a variable in these analyses.

We wanted to determine if nutrient concentrations in the living foliage were related to pine growth responses (dependent variables) during the second rotation. We therefore developed linear regression equations with the concentrations of nitrogen, phosphorus, and potassium in the living needles as the independent variables. The equation form was: pine growth variable=b_0+b_1(nutrient concentration).

RESULTS

Initially, the second-rotation pine seedlings were taller, but after four growing seasons, the first-rotation loblolly pines were 24 percent taller and the first-rotation slash pines were 18 percent taller on average than the second-rotation trees (figs. 1,2). Height differences continued to increase thereafter, with the height differences between the two rotations averaging 11 .O feet for loblolly and 3.5 feet for slash pine by age 10 (table 1).

Both pine species also had significantly greater diameter growth and yield in the first rotation than in the second (table 1). The first-rotation loblolly pine stands had averages of 1.1 inch greater d.b.h., 1.8 ft^3 more volume per tree, 48 ft^2 more basal area, and 1,280 ft^3 more volume per acre than the second-rotation stands. The first-rotation slash pine stands had averages of 0.5 inch greater d.b.h., 0.7 ft^3 more volume per tree, 121



Fiiure l-Height growth of planted **loblolly** pines in the first and second rotations on silt loam soils in **Louisiana.**

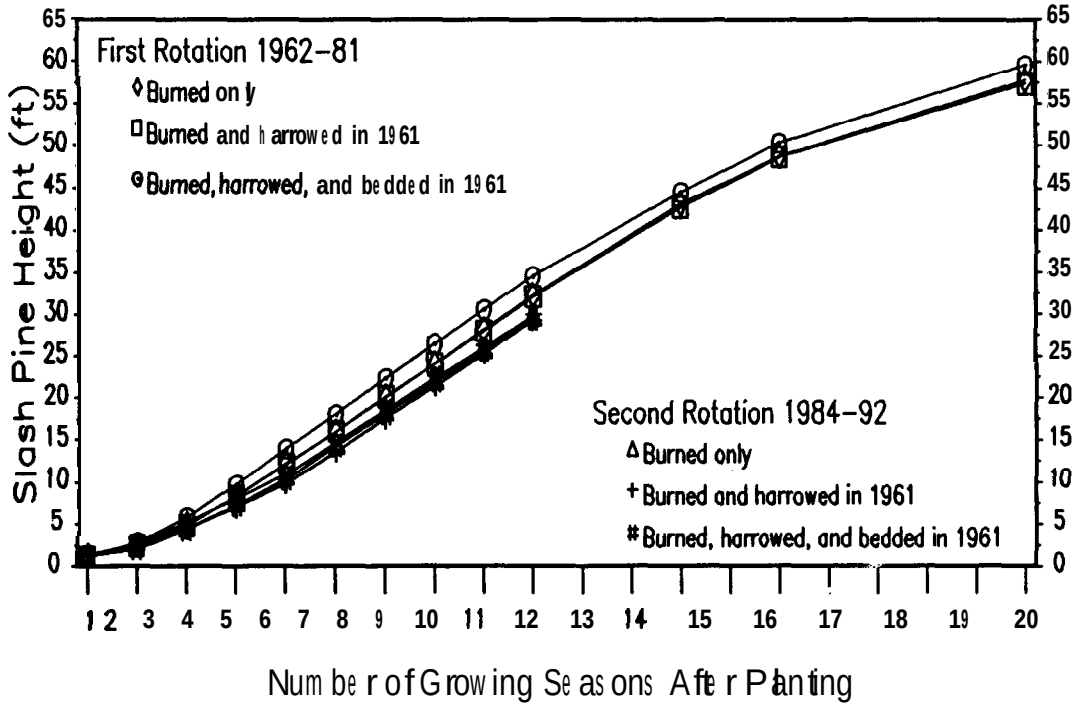


Figure 2-Height growth of planted slash pines in the first and second rotations on silt loam soils in Louisiana.

Table 1. **Mean total height, d.b.h., and outsidabark volume per tree and number of pine trees, basal area, and volume per acre in the first and second rotations** for 1 O-year-old loblolly and slash pine, and the probabilities of greater F-values based on the analyses of variance

Rotations and treatments	Species: Loblolly pine — Total height	dbh	Volume per tree	Number per acre	Basal area	Total volume	Slash pine — Total height	d.b.h.	Volume per tree	Number per acre	Basal area	Total volume
	feet	in	ft³	count	ft²/ac	ft³/ac		in.	ft³	count	ft²/ac	ft³/ac
First Rotation												
burn-only	34.8	5.3	2.93	660	103.5	1,912	32.2	5.1	2.63	731	105.5	1,913
burn-disk'	37.3	5.4	3.14	785	125.8	2,467	32.1	5.1	2.58	710	102.2	1,836
burn-disk-bed	37.2	5.3	3.06	806	126.3	2,465	34.6	5.3	2.93	753	116.2	2,212
	36.4	5.3	3.04	750	118.5	2,281	33.0	5.2	2.71	731	108.0	1,987
Second Rotation												
burn-only	26.5	4.3	1.58	747	79.6	1,174	29.9	4.7	2.06	647	78.8	1,328
burn-disk	25.4	4.2	1.43	701	71.3	996	29.3	4.7	2.07	583	71.8	1,190
burn-disk-bed	24.3	4.0	1.23	681	61.6	833	29.4	4.6	1.95	601	69.9	1.154
	25.4	4.2	1.41	710	70.8	1,001	29.5	4.7	2.03	610	73.5	1,224
Sources of variation	(probability > F-value)											
Rotation	0.0001	0.0011	0.0002	0.3626	0.0005	0.0003	0.0219	0.0185	0.0228	0.0692	0.0119	0.0116
Main effect error - mean square	.9656	.0498	.0342	8718.3	54.346	24684	3.6387	.0669	.1523	11394	235.72	113897
Treatment	.4520	.2592	.5071	.4527	.2079	.0719	.1881	.8907	.7074	.5903	.3215	.2934
Rotation by treatment interactions	.0040	.3250	.1688	.0256	.0004	.0001	.1374	.4244	.2685	.7126	.0777	.0844
Subplot effect error - mean square	1.2937	.0436	.0599	4957.8	57.244	21572	1.9564	.0576	.0899	6885.1	68.412	43384

'The disking and bedding treatments were only applied in the first rotation.

more trees per acre, 35 ft² more basal area, and 763 ft³ more volume per acre than the second-rotation stands.

Significant rotation-by-treatment interactions were evident on the loblolly pine plots for total height, number of trees, basal area, and volume per acre (table 1). During the first rotation, the loblolly pine trees on the two sets of mechanically prepared plots had 2.5 feet more height with 136 more trees, 23 ft² more basal area, and 554 ft³ more volume per acre than trees on the burn-only plots. In the second rotation, these relationships were reversed. The loblolly pines on the burn-only plots had 1.7 feet more height with 56 more trees, 13 ft² more basal area, and 260 ft³ more volume per acre than trees on the two sets of mechanically prepared plots.

No statistically significant rotation by treatment interactions were evident for slash pine. However, the bedded plots were the most productive in the first rotation, yielding 299 ft³/acre more volume than the burn-only plots at age 10 (table 1). In the second rotation, the burn-only plots were the most productive, yielding 174 ft³/acre more volume than the bedded plots.

During the first rotation, 70 tons of wood and bark containing 17 lbs P/acre were removed from the study area in intermediate and final harvests, but only about 2.2 lbs P/acre were added to the soil in atmospheric deposition (McClurkin and others 1987, Tiarks and Haywood 1993, Tiarks and others 1991, USDA Forest Service 1982). Foliage sampled from both species was deficient in phosphorus in the second rotation (Tiarks

1983, Tiarks and Shoulders 1982, Welts and Allen 1985) (table 2). Foliage nutrition of both loblolly and slash pine varied little among treatments, but loblolly pines on the bedded plots may have had a greater concentration of phosphorus than trees receiving the other two treatments. The concentrations of nitrogen, phosphorus, and potassium in loblolly pine were greater than the concentrations of these nutrients in slash pine, that result was expected (Tiarks and Shoulders 1982).

Table 2.-Nutrient concentrations in the foliage of loblolly and slash pines sampled in March 1993

Species and treatments	Nutrients		
	Nitroaen	Phosphorus	Potassium
	g/kg		
Loblolly pine			
burn-only	11.6	0.90	3.44
burn-disk'	12.3	.90	3.17
burn-disk-bed	12.5	.98	3.22
	12.1	.93	3.28
Slash pine			
burn-only	8.9	0.70	3.44
burn-disk	9.7	.70	3.30
burn-disk-bed	9.3	.68	3.21
	9.3	.69	3.32
Sources of variation	(probability > F-value)		
Loblolly pine			
Block	0.2481	0.4547	0.7129
Treatment	.7012	.1664	5737
Error Mean Square	2.5231	.00306	.13876
Slash pine			
Block	0.2604	0.8927	0.0955
Treatment	.4023	.8240	.7688
Error Mean Square	.60861	.00417	.19769

'The disking and bedding treatments were only applied in the first rotation.

It appeared pine growth and yield through 10 growing seasons of the second rotation might be associated with concentration of foliar nutrients. However, coefficients of multiple determination (R^2) were less than 25 percent for all of the linear regressions, regardless of pine species, dependent growth variable, or independent nutrient variable (data not shown).

Simple climatic models may help remove some of the variability associated with rotational growth differences (Allen and others 1991). The first year of both rotations had above-normal precipitation when compared to the 42-year average of 57.9 inches. However, average total yearly precipitation over the first 10 years of both rotations was below normal, with the first rotation averaging 54.1 inches/year, and the second rotation averaging 57.5 inches/year. There were no statistically significant differences in average yearly precipitation or in the distribution of yearly rainfall over the two 1 O-year periods.

The amount of precipitation during the winter/spring months averaged 30 inches over the last 42 years. Winter/spring precipitation was somewhat greater during the second rotation (31.4 inches) than the first rotation (26.2 inches) (Probability > F-value=0.1588), and there may have been some differences in the distribution of precipitation over the two lo-year periods (Probability > F-value=O. 1509). The first rotation had above-average winter/spring precipitation in the 1st, 5th, and 10th years, but the winter/spring precipitation was below normal in other years. The second rotation had above average winter/spring precipitation amounts in the 6th through 10th years, but winter/spring precipitation was below normal during the first 5 years.

DISCUSSION

Many potential factors may be involved in growth decline, and it often is not practical to measure all likely factors in hopes of identifying the correct ones. For example, we did not measure soil variables at the beginning of the first and second rotations, so we can only speculate about possible relationships between soil productivii and declines in pine growth and yield. However, even if soil data were available, the only way to prove the causes for decline in pine productivity would be to correct for potential deficiencies by imposing a complex of treatments. In the next rotation, we plan to replant the slash pine plots with loblolly pine and broadcast diammonium phosphate and potassium as a remedial treatment.

Growth decline is not always the consequence of human activities. Eriksson and Johansson (1993) reported that increased nitrogen deposition in Europe probably increased Norway spruce (*Piceaabies* (L.) Karst.) growth in the second of two consecutive rotations in Sweden. Nitrogen is normally a growth-limiting nutrient in most forest ecosystems in Sweden. Detrimental management practices in the broadleaf

forests that predated the first rotation of Norway spruce stands (protracted cattle grazing and utilization of woody debris as fuel) may have also contributed to the slow rate of stand development in their first rotation.

Silt loam forest soils in Louisiana are normally deficient in phosphorus, and intensive production of wood in short rotations may worsen such deficiencies (Dyck and Skinner 1990, Wells and Jorgensen 1977). From estimates of atmospheric deposition minus the amounts removed during harvests, we speculate that over 14 lbs P/acre were lost from this site during the first rotation.

Loblolly pine is known to be more sensitive to phosphorus deficiencies than slash pine on Aquuit and Udult soils in the lower West Gulf Coastal Plain (Tiarks and Shoulders 1982). The greater growth decline among loblolly than slash pines suggests, therefore, that phosphorus nutrition may be a factor. If this speculation is correct, phosphorus fettiliiation well might restore or increase yields (Allen 1987, Dyck and Skinner 1990, Tiarks 1 Q83).

Burning the logging residue prior to planting the second rotation may have adversely affected pine productivity. Squire and others (1985) recommended retention of pine liier and logging residue as sources of nutrients, organic matter, and mulch to maintain site productivity on infertile sandy soils in the next rotation. Retention of liier on planting sites has increased the growth of loblolly pine seedlings and saplings in other studies (unpublished data).

Despite yearly variation in precipitation, the cumulative height curves seemed to be unaffected by precipitation differences (figs. 1,2). Therefore, rainfall was probably adequate for tree growth every year.

CONCLUSIONS

Our study clearly demonstrates declining yields in successive rotations on fairly productive soils that yielded 230 ft^3/acre/year of pine volume during the first rotation (Haywood 1 983). Loblolly was more affected than slash pine. Aithough loblolly pine responded positively to mechanical site preparation in the first rotation, the reduction in growth on the same plots in the second rotation was significantly greater than that on burn-only plots.

Several obvious potential contributors to second-rotation growth decline do not seem important in this study; differences in precipitation patterns, logging damage, changes in competitive species, and the planting stock used in both rotations provided a wide range of genetic material.

We think that the loss of phosphorus is at least a partial reason for observed growth declines. The net removal of phosphorus and other nutrients could be reduced by lengthening the rotation or shredding and spreading bark, limbs, and tops over the site during harvests. Given the economic constraints faced by most landowners, fertilization seems like a more attractive aiternative or additional practice on similar sites where short rotation intensive management is preferred.

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GROWTH OF LOBLOLLY AND SLASH PINE SEEDLINGS ON SPODIC HORIZON MATERIAL[1]

John A. Stanturf and R. Donnie Bradshaw[2]

Abstract-Volume production under intensive management is greater for loblolly pine than slash pine. In south Georgia and north Florida, however, slash pine seems to equal or exceed loblolly pine growth on infertile Spodosols, especially when an indurated spodii horizon is within 50 cm of the soil surface. We compared loblolly end slash pine seedlings after growing six months in spodii horizon material (Bhl and Bh2 horizons) collected from four locations in south Georgia, plus a control of potting soil mixture. Overall, slash pine outgrew loblolly an spodic horizon material. Slash pine and loblolly pine seedlings grown on Bhl material were larger than those grown on Bh2 material.

INTRODUCTION

Since the 1980s, loblolly pine, *Pinus taeda* L., has been preferred by forest industry for plantation culture in the South. The switch from slash pine, *P. elliottii* Engelm., has doubled volume production (F.S. Broerman, pers. comm., 1990), due in part to the greater resistance of loblolly pine to mortality from fusiform rust On characteristically infertile coastal plain soils, loblolly pine appears more responsive to intensive management (Sarigumba 1978; Neary etal. 1990a). On some Spodosols, however, slash pine and loblolly pine grow equally well, or slash outperforms loblolly (Haines and Gooding 1983; Borders and Harrison 1989; Neary et al. 1990b).

While there are many factors accounting for observed differences in loblolly and slash pine growth on Spodosols, the physical and chemical nature of the spodic horizon probably plays a role. We observed better early growth in plantations of slash pine than loblolly pine on Spodosols that typically have a brittle, indurated Bhl horizon within 50 cm of the soil surface. Brittle layers are easily detected with a soil auger in the fieid, but are not mappable (Brandon et at. 1977). Brittle layers appear to be the result of filling of macropores by organic matter and silt-sized mineral fractions, and are not related to other chemical or physical differences (Brandon et al. 1977).

Another factor that could influence the competitive abilii of seedlings is their tolerance of the high concentrations of extractable aluminum found in Spodosols (Zelazny and Carlisle 1971), or their abilii to obtain sufficient phosphorus in the face of high Al levels. Williams (1982) showed that loblolly and slash pine seedlings were equally tolerant of high Al levels in solution culture, although she found family differences in slash pine tolerance. She did not test different loblolly pine families, however. Fox and Comet-ford *(1992)* found increased phosphatase activity in the rhizospheres of slash pine roots in the Bh horizons of two Spodosols, and organic P accounted for a large proportion of the total soluble P in the two soils. They concluded that at least some portion of the soluble organic-P was available to the seedlings.

We conducted a simple pot experiment in order to examine whether slash pine would outgrow loblolly pine on spodic horizon materials. We utilized material from the indurated Bhl and the non-indurated Bh2 horizons of the Mascotte series. We hypothesized that slash pine would outgrow loblolly pine on spodic material, and that growth would be less in material from the indurated horizon.

MATERIALS AND METHODS

Spodic Material

Spodic horizon material was collected from four locations on Union Camp land in southern Georgia and northern Florida. Locations are identified by forest names: from north to south, Sapelo, Satilla, Okefenokee, and Suwanee. All materials were

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collected from soils of the Mascotte series of somewhat poorly drained Ultic Haplohumods. The **Mascotte** soils have a spodic horizon underlain by an argillic horizon within 100 cm of the surface.

Material was collected from the Bhl and Bh2 horizons in pits dug after the soil was described. A pit was dug and the soil excavated from the surface until the Bhl was exposed. Thii material was removed, followed by the Bh2 material. Spodic horizons were differentiated by consistence. Material was sieved at field moisture to remove roots and placed in tubeling containers.

Chemical analyses of the spodic materials are given in Table 1. Organic matter content did not diier greatly between horizons at a location, but Al concentration was twice or greater in the Bh2 as compared to the Bhl. Phosphorus concentrations did not diier between horizons and all locations. The relatively high pH, especially of the Bh2 material is puzzling and may indicate calcareous material at depth.

Experimental Design

Improved families of stash (01-121) and loblolly (02-l 1) pines were planted in tubelingS containing material from each horizon from each forest, plus a control of sterilized potting soil. Seeds were stratified and placed in 21 tubelings of each horizon by forest combination. Seeds were planted by pressing them gently into the soil surface and covering with a thin layer of vermiculite to avoid desiccation. Germination rates for both species were 90 percent. Seedlings were grown in a greenhouse until outplanting size, approximately 6 months, and watered daily.

Plants were harvested, measured, dried, and weighed. Total length and root collar diameter were measured on green plants. Tops, tap roots, and lateral roots were weighed separately after drying. Top and root material from each treatment combination was cornposited and analyzed separately for Al.

Statistical Analysis

The mean of each location by treatment (species and soil) was considered the experimental unit. Seedling total length and root collar diameter; dry weights of tops, tap roots and lateral roots; and top and root Al concentrations were the variables tested. Treatment effects were tested at the 0.05 level of confidence and if found significant, means were compared by the LSMEANS option of the GLM program in SAS (SAS Institute 1989). Planned comparisons were slash versus loblolly growth on all media; pine growth on Bhl versus Bh2 material; inter- and intraspecific comparisons on Bhl and Bh2 material.

RESULTS

Length and Diameter

Slash pine seedlings were longer in all treatments than loblolly pine seedlings (Table 2). Growth in the spodic materials was significantly less than in the potting soil for both pines. Total length of slash pine was over 50 percent greater than loblolly pine on the Bhl and Bh2 materials. Total length of slash pine was significantly greater on the Bhl than the Bh2 material by 17 percent. Loblolly pine length, however, was not significantly different between the two spodic materials.

Table l-Chemical characteristics of Mascotte series spodic horizon materials from four locations.

Location	Horizon	Organic Matter percent	pH	P ppm	K ppm	Ca ppm	Mg ppm	Al ppm
Sapelo	Bhl	2.6	5.1	2.8	8	52	8	768
	Bh2	3.9	5.6	2.4	8	44	8	2640
Satilla	Bhl	5.5	4.7	4.0	8	188	40	1100
	Bh2	4.2	5.1	5.0	8	448	12	1920
Okefenokee	Bhl	3.1	5.4	5.2	4	8	40	920
	Bh2	3.0	5.3	4.0	4	16	40	1760
Suwanee	Bhl	1.8	5.2	2.0	4	16	4	568
	Bh2	1.7	5.3	3.0	8	12	8	1020

Table 2-Total length (cm) and root collar diameter (mm) of slash and loblolly pine seedlings; average of four locations.

Medium	Species	Total Length (cm)	Root Collar Diameter (mm)
Potting Soil	Slash	23.02	4.5
	Loblolly	18.75	4.1
Bhl	Slash	20.56	3.7
	Loblolly	13.16	3.2
Bh2	Slash	17.52	3.8
	Loblolly	11.68	2.9

Root collar diameters did not differ greatly across the treatments. Diameter of slash pine was significantly greater than loblolly pine on the Bh2 material (3.8 mm versus 2.9 mm). There were no other significant differences in root collar diameters between spodic materials.

Dry Weight

Top dry weight of stash and loblolly seedlings growing in all media are shown in Figure 1. Top weight of slash seedlings was significantly greater than loblolly in all comparisons (Table 3). Mean weight of slash pine growing in Bhl material was 1 .5g, as compared to

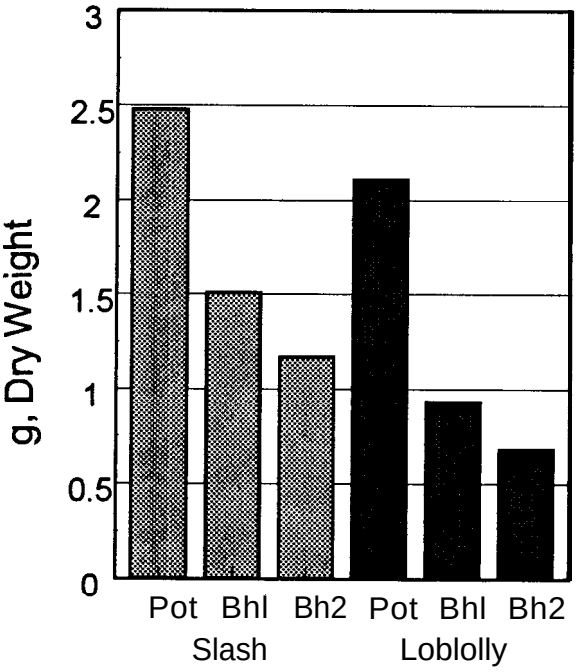

Figure I-Dry weight of seedling tops (grams)

Table 3-Significance levels' of planned comparisons between slash and loblolly pine growth on spodic materials.

Comparison	Total Length	Root Collar Diameter	Top wt.	Lateral Root wt.	Tap Root wt.
Slash vs. loblolly	***	**	***	***	***
Bhl vs. Bh2	***	ns	***	***	***
Slash vs. loblolly, Bhl	***	ns	***	***	***
Slash vs. loblolly, Bh2	***	**	***	***	***
Slash, Bhl vs. Bh2	**	ns	***	**	ns
Loblolly, Bhl vs. Bh2	ns	ns	***	**	ns

[1] Significance levels: *** = 0.001; ** = 0.05; ns = not significant.

loblolly pine top weight of 0.9g. The difference in the Bh2 material was also greater: slash pine averaged 1.2g and loblolly 0.7g. Both species had significantly heavier top weights (Table 3) growing in the Bhl material.

Differences in root dry weights were not as pronounced. Lateral root dry weights (Figure 2) were greater in Bhl than Bh2 material, and lateral roots of slash were significantly heavier than loblolly growing in both spodic materials (Figure 2, Table 3). Slash lateral root dry weight in Bhl material was 33 percent greater than loblolly (1.2g as compared to 0.9g).

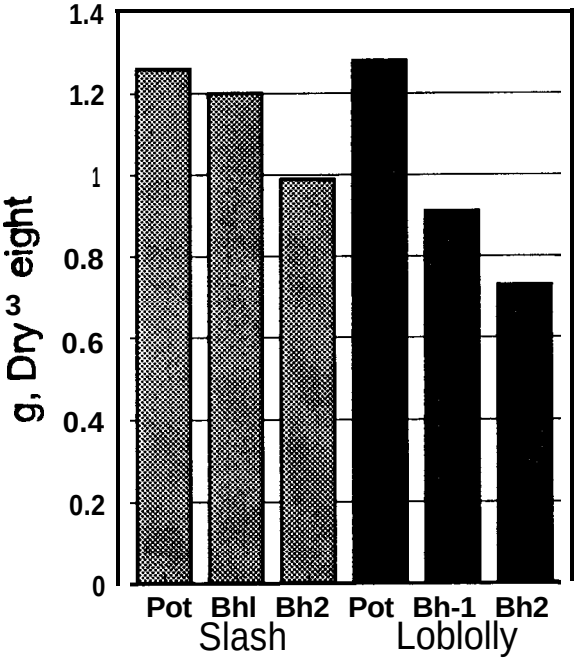

Figure 2-Dry weight of lateral roots (grams)

Tap root weights of slash pine and loblolly pine were significantly diierent in both Bhl and Bh2 material (Figure 3, Table 3). Slash pine tap root weights in the Bhl did not diier from the Bh2, and the same was true for loblolly pine tap roots.

Tissue Al Concentrations

Tissue aluminum concentrations are arrayed against soil Al concentrations in Figure 4. With the low initial value for potting soil as a reference, Figure 4 illustrates several points. In spodic materials with extractable Al values ranging from 500 to 2500 ppm, tissue Al

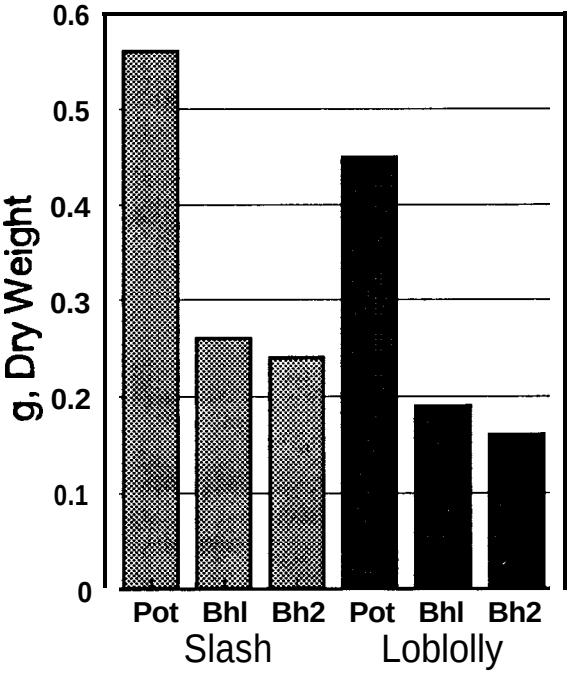

Figure 3--Dry weight of tap roots (grams)

concentrations of both species were fairly constant regardless of soil Al. Roots of both species had higher mean concentrations than tops, 4003 ppm versus 212 ppm. Aluminum concentrations in roots of loblolly pine and slash pine were not significantly different. Al concentrations in loblolly pine tops, however, were significantly greater than slash tops (250 ppm versus 175 ppm).

DISCUSSION

Slash pine grew better in spodic horiion material collected from Mascotte soils than loblolly pine. In general, growth was greater for each species in Bhl than Bh2 material. A notable exception was tap roots. Although tap root dry weight of slash pine was greater than loblolly pine in the Bhl and Bh2 material (Figure 3, Table 3), tap root dry weights were not significantly different between spodic materials for individual species. Thus, tap roots of slash pine averaged 0.26g and 0.24g and loblolly pine averaged 0.19g and 0.16g on Bhl and Bh2, respectively.

We hypothesized that growth would be reduced more on the indurated Bhl than the Bh2 material, but the reverse was true. Although the brittle "pan" of the Bhl was disrupted by excavating and sieving the material,

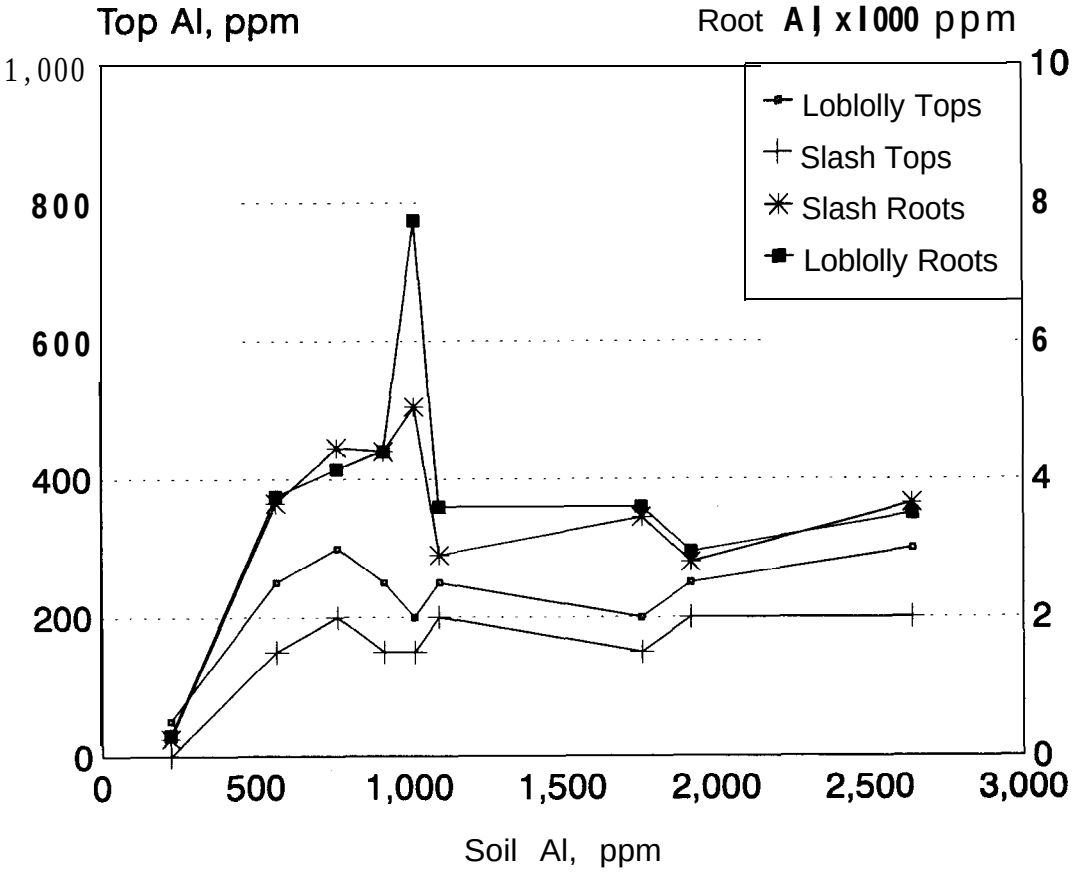

Figure 4--Aluminum concentration in soil versus tissue concentrations; note that the axis for tops is on the left, in ppm; the axis for roots on the right is times 1000, in ppm.

we observed the reforming of the induration in the tubelings over the course of the experiment If we had allowed the Bhl material to age in the tubelings before seeding, the physical characteristics of thii material perhaps would have been more important

Chemical differences between the spodic materials collected from four sites was minor in most respects, except that extractable Al was significantly greater in the Bh2 than the Bhl horizon. Extractable P ranged from 2.0 ppm to 5.2 ppm in the Bhl and from 2.4 ppm to 5.0 ppm in the Bh2 (Table 1). Thus, Al toxicity, P deficiency, or both could account for the reduced growth on the Bh2 material.

Aluminum in tissue was derived from the rooting media, as shown by the similarly low concentrations in seedlings grown in potting soil (the lowest value in Figure 4). Across the range of extractable Al concentrations exhibited by the spodic materials in this study, however, tissue Al concentrations were remarkably uniform. Although Al concentration was higher in tops of loblolly pine than slash pine, there is no simple relationship between spodic material Al levels and growth.

Results from this study suggest that spodic horizons play a significant role in early growth of planted pines. The exact nature of the physical and chemical characteristics that account for that role, however, awaits further study.

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MANAGEMENT OF LONGLEAF STANDS FOR PINE STRAW HARVESTING AND THE SUBSEQUENT INFLUENCE ON FOREST PRODUCTIVITY[1]

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Michael L. Elliott-Smith, and Henry A. Pearson[2]

Abstract-Pine straw harvesting can be highly profitable, but straw harvesting, which removes a portion of the forest floor, may ultimately reduce soil productivity. current pins straw harvesting practices were studied in 37-year-old stands of direct-seeded longleaf pine. Practices included fertilizer, fire, mechankal cutting of understory vegetation, and baling and removal of straw. Two annual straw harvests reduced longleaf pine growth over three growing seasons by 0.09 Inch d.b.h., 1.7 ft² basal area/acre, and 50 ft³ l.b./acre. Broadcasting 250 lbs/acre diammonium phosphate did not significantly increase longleaf pine diameter, height, basal area, or inside-bark volume growth over the 3-year period, but apparently fertilization was able to compensate for losses in wood volume caused by straw harvesting.

INTRODUCTION

Pine straw harvesting can be highly profitable. After age 12, average yields in loblolly pine (*Pinustaeda* L.) stands range from 3,740 to 5,255 lb of air-dried straw per acre per year (Bateman and Wilson 1961). Pine straw is worth from $10 to $131 per acre yearly to the landowner and $70 to 177 per acre in profits to the straw harvester (Mills and Robertson 1991, Morris and others 1992, Robertson 1992). As conditions become less favorable, income is reduced, but adding straw to timber and forage as products of management can increase profits substantially. In fact, the income from straw may exceed that from timber (Roise and others 1991).

Despite the immediate economic opportunities, repeatedly removing portions of the forest floor may ultimately reduce pine growth and yield (Jemison 1943, Ginter and others 1979). The loss of nutrients is considered the worst result from liier removal (Ballard and Will 1981). Therefore, the long-term detrimental effects of straw harvesting may be lessened by applying fertilizer and leaving sufficient liier and vegetation to reduce runoff and lessen compaction (Morris and others 1992, North Carolina State Forest Nutrition Cooperative 1992, Wood and others 1989).

Our study was designed to measure effects on pine nutrition and productivity of five practices associated with straw harvesting: (1) fertilizer application, (2) burning, (3) mechanical cutting, (4) raking, and (5) straw removal. This study is a cooperative effort among the Forest Service, Natural Resources Conservation Service, and Agricultural Research Service of the U. S. Department of Agriculture; the Louisiana Cooperative Extension Service; and the Louisiana Pine Straw Association.

METHODS

Study Site

The 100-acre study site is a gently rolling area in Rapides Parish, LA, with Ruston and Smithdale fine sandy loam soils (Typic Paleudults, fine-loamy, siliceous, thermic). The site supports a longleaf pine (*P. palustris* Mill.) stand that originated from direct seeding in 1956 and was 37 years old from seed in 1993. The site was continually prescribed burned as part of a range management program. Burning retarded development of woody vegetation in the understory. The whole stand was last burned in 1987.

Treatment Establishment

Four 3.2-acre research blocks were installed in the spring and early summer of 1990. Blocking was based on topographic and forest cover conditions. The diameters 4.5 feet above groundline (d.b.h.) of all pine

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trees on the blocks were measured to determine basal areas. Based on these initial data, some of the pine trees were selectively harvested in August 1990 to create more uniform basal areas within blocks. Also in August 1990, the understory vegetation was rotary mowed to create uniform understory conditions and to facilitate plot establishment

To examine several of the management practices associated with straw harvesting, we installed a randomized complete block split-plot design with the four blocks as replicates. In total, there are 32 0.38 acre subplots (4 blocks by 2 main plots by 4 subplots). The two main-plot treatments within each block were: (1) no fertilizer applied and (2) 250 lbs/acre (45 lbs N and 50 lbs P/acre) of diammonium phosphate (DAP) broadcast evenly over the entire main plot on April 23, 1991.

Management of the subplots for pine straw has been going on for over 3 years:

1. Control. No treatment after the subplots were thinned and mowed in 1990.
2. Winter burning only. The subplots were thinned and mowed in 1990, and burned in March 1991.
3. Winter burning **and straw harvesting.** In addition to treatment 2, the subplots were rotary mowed and straw was harvested in 1991 and 1992.
4. Summer burning and straw harvesting. The subplots were thinned and mowed in 1990, burned in August 1991, and rotary mowed in 1991 through 1993; straw was harvested in 1991 and 1992.

Burning was with strip head fires, which were monitored to determine their intensity (Alexander 1982, Deeming and others 1978, Hough lQ89, Smith and James 1978). One month after firing, the percentage of crown scorch was estimated for each pine tree on the burned subplots.

Appropriate subplots were rotary mowed in July. The straw was harvested by the standard commercial method in subplots 3 and 4. First, the straw was collected in windrows with a tractor mounted straight-bar rake. Large limbs and cones were removed, and the straw was mechanically baled. The bales were weighed and a subsample taken to determine moisture content so **actual** production values could be obtained.

Preliminary Measurements, Litter Traps, and Liier Sampling

An interior 0.23-acre area within each subplot was used for measurement and sampling purposes. In 1990, each longleaf pine tree over 4 inches d.b.h. was labeled with an aluminum tag and used as a sample tree. In January 1991 and 1994, d.b.h. and tree height were measured, and the inside-bark volume per tree was calculated using relationships of Baldwin and Saucier (1983).

Five 9.8-ft^2 liier traps were systematically located within each 0.23-acre measurement area for the monthly collection of liier samples. Liier samples were first collected in mid-October 1990. During each monthly sampling, the liier was separated into two classes: needles and debris. For nutrient analyses, soil samples were randomly collected in April 1990 and 1993 to a depth of 6 inches. Green needle samples were collected from the upper crowns of dominant longleaf pines in February 1994. Bulk density samples of the mineral soil were randomly taken in July 1994 to a depth of 4 inches.

The litter and green needle samples were oven dried at 70°C for 24 hours and weighed. The dried samples were ground in a Wiley Mill. After sulfuric acid/cupric sulfate digestion, nitrogen, phosphorus, and potassium content of the needle liier (November dates only) and green needles were determined by ammonium probe, colorimetry, and atomic absorption spectrophotometry, respectively. For the soil samples, phosphorus content was determined by the Bray P2 method and potassium content by extraction with 1 N ammonium acetate.

Data Analysis

Differences among treatments in pine straw liier weight, nutrient content, soil bulk density, and longleaf pine growth over three growing seasons and initial sizes of longleaf pines were subjected to analysis of variance for a randomized complete block split-plot design. Using essentially the same model, the final longleaf pine growth and yield data were examined by analysis of covariance, with the appropriate variable from the original data set as the covariate. Likewise, the April 1993 soil phosphorus concentration was subjected to analysis of covariance, with the concentration of phosphorus in April 1990 as the covariate.

The amounts of forest floor material removed from harvested subplots were compared by chi-square tests

of independence. To determine if nutrition concentrations in the living foliage could help explain pine growth differences (dependent variables), linear regression equations were developed with the concentrations of nitrogen, phosphorus, and potassium in the living needles as the independent variables: Pine growth variable=b_0+b_1(nutrient concentration).

RESULTS AND DISCUSSION

Burning Effects

For the March 1991 burn, fireline intensity averaged 63 BTU/sec/ft (218 kJ/s/m), which was above the expected range of 0 to 50 BTU/sec/ft (0 to 173 kJ/s/m) (Deeming and others 1978). Fireline intensity averaged 47 BTU/sec/ft (163 kJ/s/m) for the August 1991 burn. The March burn scorched 15 percent of the longleaf pine foliage; the August burn scorched only 2 percent.

Needle Fall Patterns

Falling longleaf pine needles were collected monthly from October 1990 to December 1993 (fig. 1). Our longleaf needle litter results are similar to Weigert and Monk's (1972), but less variable than Gresham's (1982). Only one of the imposed treatments significantly affected needle fall. The March 1991 burn and the associated scorch caused a sharp increase in needle fall in April 1991. As a result, between January and July 1991 about 400 lbs/acre more needles fell from subplots burned in March 1991 than from control and summer burned subplots (Probability > F-value=0.0712). Needle fall within and among treatments was highly variable from September through November 1992, possibly because Hurricane Andrew, which past through the area on August 26, 1992, resulted in some pine needle injury.

Drought can cause pine needles to fall 2 months earlier than normal (Hennessey and others 1992). Rainfall collected in 1993 near the research site was 14.6 inches in winter and 17.3 inches in spring. The winter value was near the 42-year averages of 14.8 inches, and the spring value was above the long-term average of 15.2 inches. The summer rainfall of 7.9 inches in 1993, however, was well below the 42-year average of 12.2 inches. The above normal-needle fall in September 1993 probably was associated with the late summer drought (Louisiana Office of State Climatology 1993) (fig. 1).

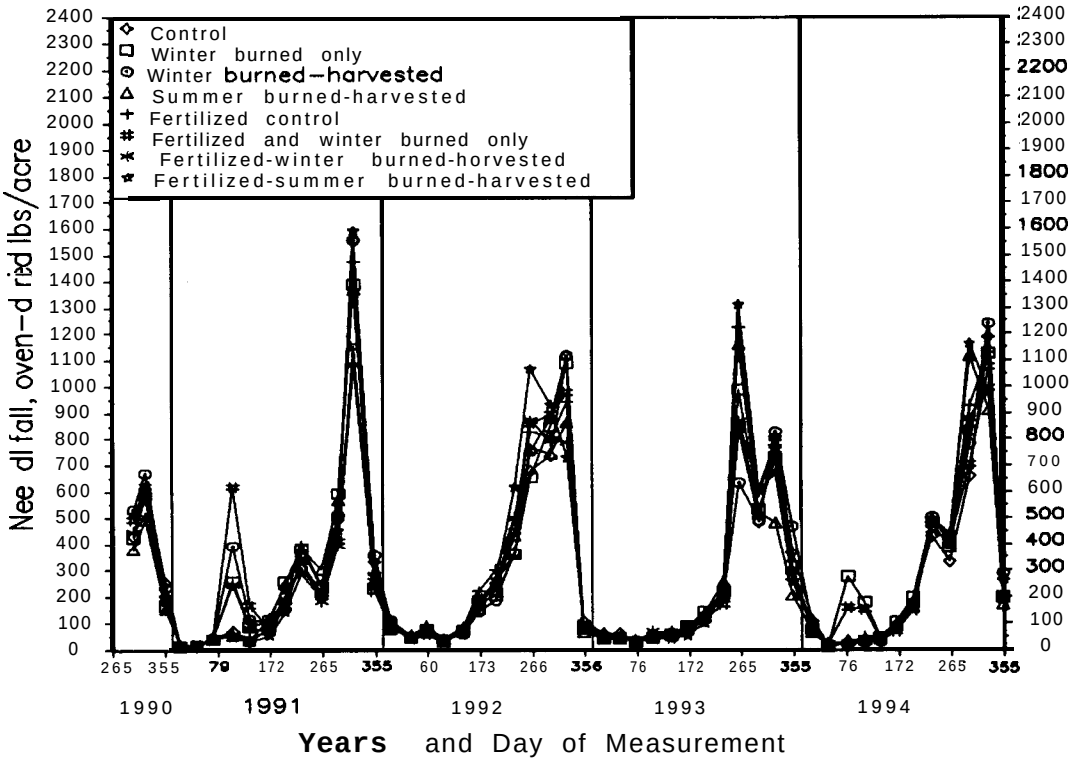

Figure l-Monthly needle fall from late 1990 through 1993 by treatment.

Harvesting the Forest Floor

In the first year, more forest litter was harvested from the two summer-burned subplots than from the two winter-burned subplots-5704 versus 4,889 lbs/acre (Probability > F-value=0.0840) (Table 1). There were no treatment effects in the second year of harvesting. More forest litter was harvested than was added on a yearly basis as litter fall, so older forest floor material was being removed during each harvest (data not shown).

Table I-Oven dried weight of forest floor harvested on the winter burned and harvested and summer burned and harvested subplots after two yearly harvests.

Main and subplot treatments	Year of harvest	
	First	Second
	Lbs/acre	Lbs/acre
No fertilizer		
Winter burned and straw harvested	4,784	4,573
Summer burned and straw harvested	5,988	4,884
Mean	5,388	4,829
Fertilized with 250 lbs/acre DAP		
Winter burned and straw harvested	4,553	4,878
Summer burned and straw harvested	5,420	4,499
Mean	4,988	4,888

Nutrient Concentrations in Soil, Pine Foliage, and Litter

Based on work with loblolly pine (Tiarks and Haywood 1988) and preliminary work in this study, phosphorus was believed to be the limiting nutrient on this forest site. Before fertilization, less phosphorus was available in soil on summer burned subplots than on winter burned subplots (Probability > F-value=0.0995), but there were no other significant differences among treatments (Table 2). Two years after fertilization, the concentration of available soil phosphorus was over 15 times as great on the fertilized plots as on the unfertilized plots. Thii increase in phosphorus was especially high on the fertilized subplots that had been burned in summer and harvested.

Fertilization also significantly increased the concentration of phosphorus in the needle litter and

Table 2-Available phosphorus concentration in the soil as determined by the Bray P2 method and total phosphorus concentration in the living longleaf pine needles

Main and subplot treatments	Phosphorus concentration in Soil		Liing foliage
	Apr 1990	Apr 1993	Feb 1994
	---g/kg---	-ma/kg-	
No fertilizer			
Control	1.70	1.03	0.753
Winter burned onty	1.73	0.73	.728
Winter burned-straw harvested	1.93	0.85	.688
Summer burned-straw harvested	1.53	0.83	.700
Mean	1.72	0.81	0.717
Fertilized with 250 Ibs DAP/acre			
Control	1.85	12.2	0.908
Winter burned only	1.88	15.3	.930
Winter burned-straw harvested	1.83	12.7	.865
Summer burned-straw harvested	1.80	21.3	.953
Mean	1.78	15.4	0.914

green needles. The concentration of phosphorus in the litter averaged 0.004 and 0.005 oz/lb (0.251 and 0.315 g/kg) on the unfertilized and fertilized plots, respectively. In February 1994, the concentration of phosphorus in the green needles averaged 0.012 oz/lb (0.72 g/kg) on the Unfertilized plots and 0.015 oz/lb (0.91 g/kg) on the fertilized plots (Table 2). However, the concentration in the foliage on the fertilized plots was still only marginally acceptable for optimal pine development (Tiarks and Shoulders 1982, Wells and Allen 1985).

Across all treatments, potassium concentrations averaged 0.048 milliequivalents (meq)/100g of soil and 0.058 oz/lb (3.8 g/kg) in the green needles. The concentration of soil potassium was greater on winter burned and harvested subplots (0.058 meq/100g) than on summer burned and harvested subplots (0.042 meq/100g) (Probability > F-value=0.1220). The concentration of foliar potassium, however, was less on the winter burned and harvested subplots (0.054 oz/lb or 3.4 g/kg) than on the summer burned and harvested subplots (0.081 oz/lb or 3.8 g/kg) (Probability > F-

value=0.0479). Foliar nitrogen did not diier among treatments and averaged 0.14 oz/lb (8.5 g/kg) across all treatments.

Soil Bulk Density

Pine straw harvesting significantly increased the bulk density of the mineral soil. Bulk density on the control and winter burned only plots averaged 0.048 lbs/in^3 (1.33 g/cm^3) in July 1994. On the two subplots where pine straw was harvested, bulk density averaged 0.051 lbs/in^3 (1.41 g/cm^3). Fertilization did not influence soil bulk density.

Longleaf Pine Growth and Yield

After 3 years of management, the 37-year-old longleaf pines averaged 11.8 inches in d.b.h., 71 ft in total height, 98 ft^2/acre in basal area, and 2,729 f&acre in wood volume inside bark (Table 3). Pine straw harvesting reduced stand productivity. Longleaf pine growth in diameter, basal area, and volume per acre were less on the winter burned and harvested subplots than on the winter burned only subplots on both the unfertilized and fertilized plots (Probability > F-value=0.0942, 0.1 191 , and 0.1309, respectively). Considering only the unfertilized plots, the two subplots that were harvested for pine straw produced 1.7 ft^2 less basal area and 50 ft^3 less wood volume per acre than the control and winter burned only subplots over the 3-year period (Table 3).

Broadcasting 250 lbs/acre diammonium phosphate did not significantly increase per-acre growth of longleaf pines in diameter, height, basal area, or inside-bark volume over the 3-year period (Table 3). This result supports our observation that phosphorus concentrations in the green needles were inadequate on the fertilized plots for optimum pine tree development However, effects of phosphorus application on tree growth are often not apparent for many years (Tiarks 1983). Potassium concentrations in soil and foliage indicate a deficiency of this nutrient, and we applied less nitrogen than others have recommended for managing pine stands for straw production (North Carolina State Forest Nutrition Cooperative 1992). In the past, however, maturing slash pine (P. *elliottii* Engelm. var. *elliottii*) stands in the West Gulf Coastal Plain have failed to respond to nitrogen fertilization (Shoulders and Tiarks 1990).

If only the harvested subplots were considered, however, it appeared that fertilizer application was able to compensate for the losses in wood volume caused by pine straw harvesting (Table 3). We thought that the 3-year growth differences among treatments might be associated with the concentration of phosphorus in the liing needles. However, the coefficients of multiple determination (R^2) were less than 24 percent for all of the linear regressions, with the R^2 value being only 6 percent when predicting longleaf pine volume production using the concentration of phosphorus as the independent variable.

CONCLUSIONS

Crown scorch caused the premature senescence of some needles, but the monthly trends in needle fall and the total annual amounts of needle fall were largely unaffected by management practices. Approximately 4,700 and 5,150 lbs/acre/year of oven dried forest floor material were harvested after winter and summer burning, respectively. After two rakings, most of the forest floor was removed. This outcome is common after burning and mechanical harvesting of straw. Straw harvesting also increased soil bulk density.

The productivity of the unfertilized 37-year-old longleaf stands was adversely affected by two straw harvestings over a 3-year period. Broadcasting diammonium phosphate increased phosphorus concentrations in the soil, living longleaf pine needles, and needle litter. However, even on the fertilized plots, the foliar concentration of phosphorus (0.015 oz/lb or 0.914 g/kg) may have been deficient, and broadcasting 250 lbs/acre diammonium phosphate did not significantly increase the growth and yield of longleaf pines. Still, if only the harvested subplots were considered, fertilization might be compensating for the losses in wood volume caused by straw harvesting. Under a management program, another fertilization treatment would be recommended.

Table 3–Number of surviving longleaf pines and preliminary and final longleaf pine d.b.h., total height, basal area, and inside-bark (i.b.) volume per acre; the data were collected in January 1991 and 1994, respectively.

Main and subplot treatments	January 1991					January1994				3-year growth difference			
	Number of pines	Total D.b.h.	Total heiahtarea	Basal	i.b. Vol.	D.b.h.	Total heioht	Basal area	i.b. Vol.	D.b.h.	Total heiaht	Basal area	i.b. vol.
	Trees/ac	Inches	Feet	Ft^2/ac	Ft^3/ac	Inches	Feet	Ft^2/ac	Ft^3/ac	Inches	Feet	Ft^2/ac	Ft^3/ac
No fertilizer													
control	135	10.7	70	86	2,418	11.3	74	95	2,752	.60	2.96	9.78	335.1
winterburnedonly	133	11.0	70	89	2,507	11.6	71	99	2,845	.60	2.85	9.80	337.3
winter burned-straw harvested	128	11.1	71	87	2,459	11.6	74	95	2,748	.51	2.82	8.12	289.1
summerburned straw harvested	121	11.4	70	87	2.429	11.9	73	95	2.712	.52	2.42	8.08	283.2
	129	11.0	70	87	2,453	11.6	73	96	2,764	.56	2.76	8.94	311.2
Fertilized with 250 lbs DAP/acre													
control	121	11.3	70	84	2,365	11.9	70	94	2,678	.59	2.88	9.14	312.5
winterburnedonty	133	10.9	70	86	2,413	11.5	71	96	2,742	.60	3.18	9.65	328.3
winter burned-straw harvested	130	10.9	69	87	2,424	11.5	70	96	2,741	.57	2.80	9.29	316.9
summer burned-straw hawested	132	10.8	67	85	2.286	11.5	67	95	2.613	.62	3.23	9.97	326.4
	129	11.0	69	86	2,372	11.6	70	95	2,693	.60	3.02	9.51	321.0
	ANALYSISOFVARIANCE (Probability > F-value)					ANALYSIS OF COVARIANCE (Probability > F-value)				ANALYSISOFVARIANCE (Probability > F-value)			
Block	.0075	.0267	.6545	.0001	.0066	.7867	.6376	.6759	.8207	.4412	.0322	.2608	.1752
Fertilizer	.9440	.5597	.3232	.0134	.1335	.2126	.3058	.2223	.2817	.2178	.2728	.3527	.5749
Main Error													
Mean Square	101.41	.1250	11.282	.4121	12,510	.1177	22.753	2.024	18,699	.0057	.2266	2.150	1,981
Subplot effects	.8404	.9558	.5283	.2140	.3562	.2548	.9792	.2442	.3613	.2957	.8679	.3921	.3371
Controlvs. others	.7922	.9448	.7014	.0902	.5781	.3427	.7880	.1475	.3419	.3670	.7018	.5509	.5107
Winter burned only vs. Winter burn-straw harvest	.6675	.8795	.9905	.4684	.7627	.0789	.7435	.1800	.1375	.0942	.5042	.1191	.1309
Winter burn-straw harvest vs. Summer burn-straw harvest	.6675	.7028	.2231	.5741	.1921	.3951	.8824	.3926	.4966	.3406	.9493	.6119	.9279
Fertilizer x Subplot[1]	.4314	.5527	.7987	.7742	.8242	.2301	.8261	.1694	.1737	.3881	.3852	.1891	.2927
1990-covariate						.0001	.1117	.0001	.0001				
Subplot Error													
Mean Square	222.9	.58762	7.2493	5.886	15,352	.0047	32.696	1.255	1,217	.0050	.3717	1.554	1,412

[1]The fertilizer main effect bysubploteffectinteraction.

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Ecophysiology/Genetics

Moderator:

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OZONE EFFECTS ON PRODUCTIVITY AND DIVERSITY OF AN EARLY SUCCESSIONAL FOREST COMMUNITY'

D.N. Barbo[2], A.H. Chappelka[2], and K.W. Stolte[3]

Abstract—Loblolly pine and an associated **early successional** forest community was exposed to **4 treatments of ozone.** The treatments were: **CF=carbon-filtered** air, **NF=non-filtered** air, **AA=ambient** air **and 2X=twice** AA air. Pine height and diameter, number of **understory** species, and percent-cover were **measured.** First-year results show the number of species were **significantly reduced** in 2X compared to CF. Pine **height** and **diameter** growth was greatest in NF and AA, and lowest in CF. Blackberry, although **severely** injured (visible), dominated the 2x **treatments.** Bahh **grass increased** in abundance and cover **with decreasing** ozone, **panicum grass increased** in abundance and cover with **increasing** ozone, and **andropogon was unaffected.**

INTRODUCTION

Tropospheric ozone, an important phytotoxic air pollutant, is currently increasing globally at a rate of l-2 percent per year (Mohnen et *al.* 1993), and is considered the most important phytotoxic gaseous pollutant in the eastern United States (US EPA 1986). The long range transport of ozone from urban-industrial regions to remote forested areas is well documented (Chevone, Skelly, Yang 1983), and ozone is implicated as a contributing **stress** factor in forest declines observed in Europe and North America (Tjoelker and Luxmoore 1991). The effects of ozone upon individual species are well known, but its influence upon native communities is not well documented. Duchelle et *al.* (1983) reported ambient ozone effects on biomass production of native vegetation growing in the Big Meadows area of the Shenandoah National Park, VA. Harward and Treshow (1975) reported visible injury and biomass reductions for many plant species found in the aspen community understories in the Rocky Mountains when exposed to elevated ozone. Ozone can cause visible injury to native forest tree and herbaceous species (US EPA 1986), and has been reported to cause damage at the ecosystem level in the San Bernadino Mountains of California (Miller 1983).

None of these studies investigate the alteration of competitive interactions between species, or the changes that may occur within a plant community due to ozone exposure. Research has shown numerous cases of decreased plant productivity and vigor due to ozone (Horsman et a/. 1980, Carter et al. 1992). Also, chemical substances can induce physiological stresses resulting in metabolic injury and, in some cases, loss of some function necessary for growth and/or maintenance (Weinstein and Birk 1989). These responses are likely to lead to shii in the competitive relationships among species (Weinstein and Birk 1989). The focus of this study is to investigate the effects of ozone on competitive interactions and to document the resultant community shifts that may occur due to interactive effects of ozone stress and competition in an early successional 'old-field" forest community in the Southeastern U.S..

OBJECTIVES

The specific objectives of this project are:

1. Determine the effect of ozone on **loblolly** pine (*Pinus taeda* L.) seedling growth and biomass production in an early successional 'old-field" forest community.
2. Measure changes over time (density, frequency, and abundance) in native early-successional forest vegetation in response to reduced, ambient, and above ambient ozone concentrations.
3. Determine the effect of ozone upon competitive interactions between species and the resulting effects upon diversity, productivity, and structure of an early successional "old-field" forest community.

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METHODOLOGY

Preparation of Experiment

Study Site.
The research site is located on the Auburn University (Alabama) campus and was occupied by longleaf pine, (*Pinus palustris* Miller), and loblolly pine forest for 50 years prior to clearing (1 986). Topography ranges from level to a 1-3 percent slope. The area is dominated by the Cowarts (Typic Kanhapladult) soil series. The soil is moderately well drained and has a site index for loblolly pine of 24 meters at age 50 years. Both the soil characteristics and site quality may be considered typical of pine sites in the Upper Coastal Plain of the Southeastern United States.

A study on acid deposition and ozone effects was completed on this site in 1990 (Chappelka et *al.* 1990). Open top chambers (Heagle et al. 1989) from the previous study have been left uncovered and fallow since its completion and a typical 'old-field" early successional community has grown into the chambers.

Chamber Selection.
The plant community within each of the 24 chambers was characterized in order to select and group the open-top chambers based upon their similarity. In September 1993, 15 percent of the area within each chamber was randomly sampled. Number of species and plants per species were counted and soil characteristics (pH, nutrient status, CEC) determined. Species counts and soil data were analyzed using principle component analyses to determine which variable accounted for the most variability between chambers. These variables were then used in a cluster analysis to place 4 chambers into a block based on the uniformity of the plant communities. Four blocks of 4 chambers each were created and treatments were randomly assigned within blocks.

Plant Culture.
The chambers are 4.8m. ht. x 4.5 m. diam. and open on the top to allow ambient rain to enter. In January 1994, all vegetation was cut to the ground. Loblolly pine (1-O "wild-type") were selected for uniform diameter and height; then 5 seedlings were planted at 1.6 meter spacing and 1 meter from the center of each chamber. The height and ground line diameter of each seedling was measured monthly. Six 0.2 square meter permanent plots were placed randomly within each chamber to measure 10 percent of the effective area within each chamber. Vegetation that grew within the permanent plots was monitored over the growing season for frequency, abundance, and cover. Plants were not watered or fertilized during the experiment.

Ozone Treatments.
Treatments consist of air with varying levels of ozone injected into the chambers: CF=carbon-filtered air (lowest ozone content), AA=ambient air (ozone levels vary diurnally), NF=non-filtered air(1 x AA), and 2X= 2 x AA. The AA treatment has no plastic cover on the chamber and no air is Mown into the chamber with fans. The purpose of the AA treatment is to test for chamber effects upon the experiment (control treatment). Treatments began on April 4, 1994 and were applied 12h d^{-1}, 7 d wk^{-1} between 0900-2059 h CST until Nov. 4, 1994. This simulates the pattern for maximum concentrations in the Auburn, Alabama area. Chamber fans were turned off at nights to allow natural dew formation within the chambers. Ozone concentrations were continuously monitored using a U.S. EPA approved monitor (Thermo Environ. Instr. Inc., Hopkinton, MA). Both the ozone monitor and calibrator were audited at least once per year.

Design and Measurement

Experimental Design.
The overall design of the experiment was a randomized complete block with 4 treatments and 4 blocks. The data will be analyzed using analysis of variance and repeated measures analysis.

Measurement
The height and diameter of each loblolly pine was measured monthly. The abundance of each old-field species that regenerated within the 6 permanent plots was recorded on a monthly basis (March-September) and biweekly in the spring (April & May) in order to capture the spring annuals. Percent canopy cover in each plot was measured monthly (May-November) using a modified point-frame method (Levy and Madden 1933). Total canopy cover and the canopy cover of the 5 most abundant species were measured: blackberry, (*Rubus* sps.), andropogon, *(Andropogon virginicus* L.), bahia grass, (*Paspalum notatum* Flugge.), panicum sps., (*Panicum* sps.), and loblolly pine, (*Pinus taeda* L.).

RESULTS
Data collection has been completed for 1994 (first growing season). The statistical analysis of the data

has not been completed, but some preliminary mathematical analyses were conducted. Results of the AA treatment are not presented in order to clarify the graphical data, but the AA treatment results generally were comparable to the NF treatment, indicating that the plastic covers did not greatly affect plant growth or response to ozone.

The 24 h ozone distribution by treatments and cumulative ozone exposure over time are illustrated in Figures 1 and 2, respectively. Treatment levels approximate target levels. The total ozone exposure (SUM O)(Lefohn et a/. 1991) over the growing season was approximately 75, 150, and 225 ppm-hr for the CF, NF, AA, and 2X treatments respectively. Loblolly pine height growth was greatest in all sampling periods in the NF treatment and lower in the CF and 2X treatments (Fig. 3). Diameter growth for lobloliy pine (Fig. 3) was greatest in the NF treatment for most dates, intermediate for the 2X treatment, and lowest in the CF treatment.

Mean number of species appear to be affected by ozone treatment (Fig. 4). A greater number of species were present in the CF than in any other treatment. Mean percent upper canopy cover of all species within each chamber (a measure of the top canopy layer) was greater in the CF and 2X treatments (Fig 5a) compared to the NF. Mean percent of total canopy (a measure of the percent cover for all canopy layers combined) is shown in Figure 5b, and the resutts are similar to the upper percent canopy cover.

Abundance of the 5 most common species was affected by ozone treatment. Blackberry was most abundant (canes per m^2) in the 2X treatment, less abundant in the NF treatment, and least abundant in the CF (Fig. 6a). Bahia grass was most abundant (shoots per m^2) in the CF and least abundant in 2X (Fig. 6b). Both narrow-leaved panicum, (*Panicum angustifolium* Ell.),(Fig. 6c) and roundseeded panicum, (*Panicum sphaerocarpon* Ell.),(data not shown) were most abundant (tillers per m^2) in the 2X and least abundant in the CF treatment. Andropogon did not appear to be affected by ozone treatment (Fig 6d).

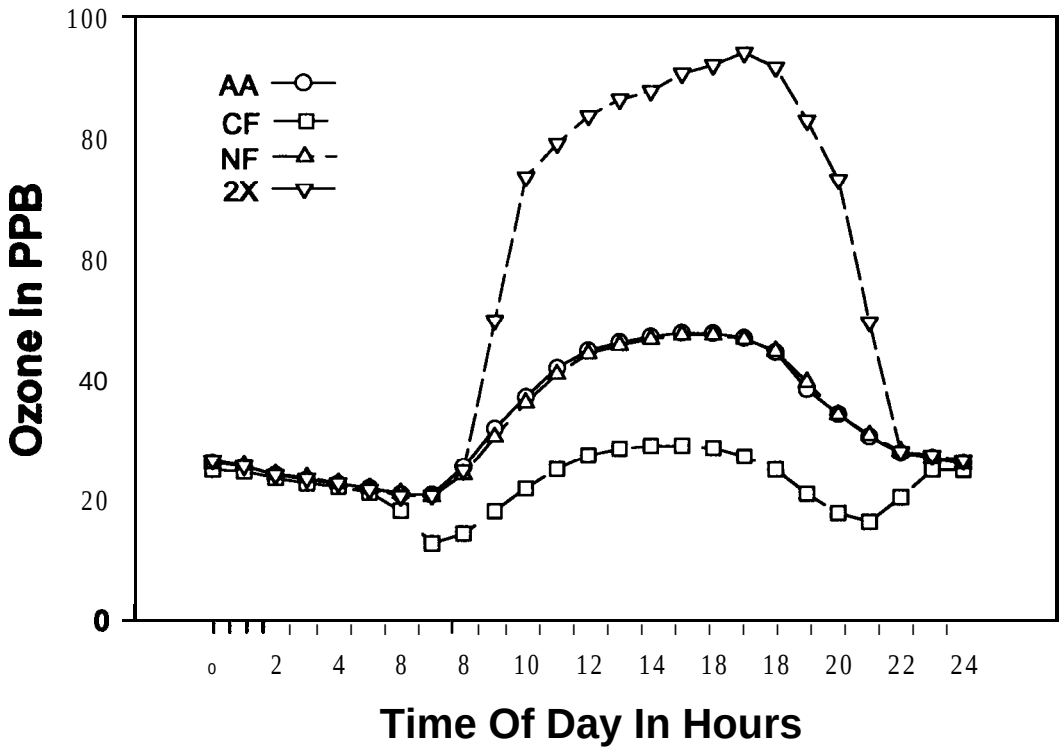

Figure 1. Ozone exposure over 24 hours for each treatment in parts per billion (ppb).

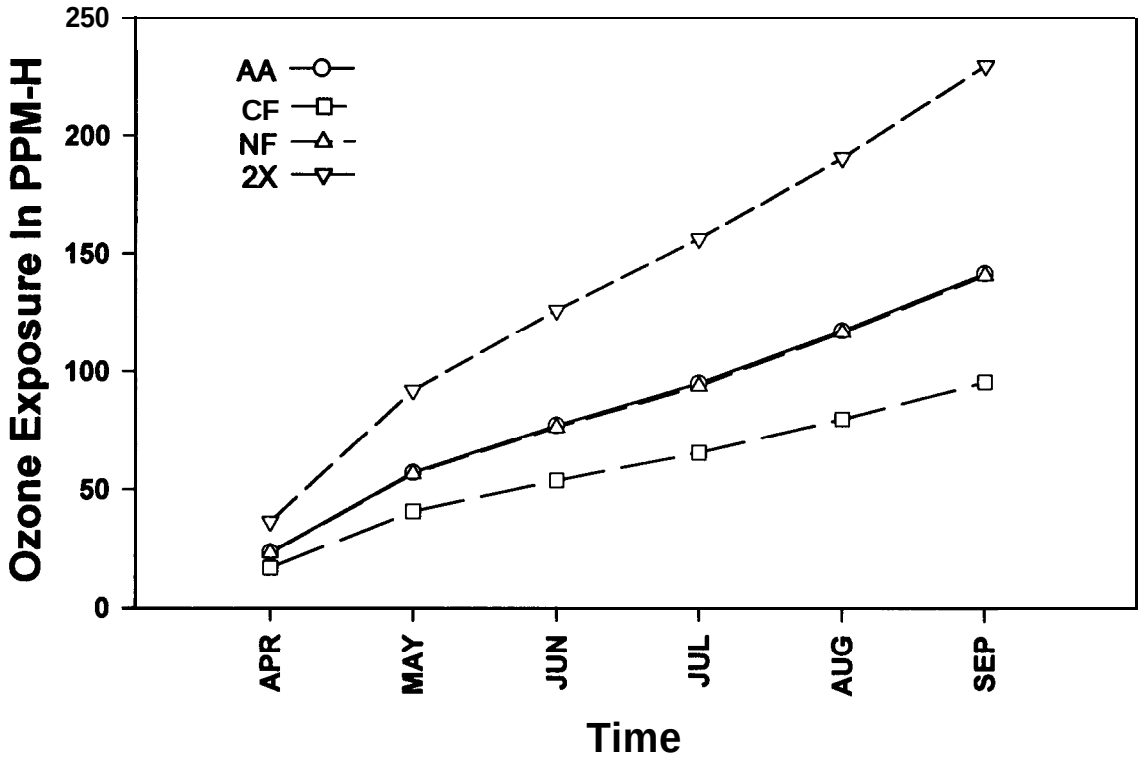

Figure 2. Cumulative ozone exposure over time for each treatment in parts per million hour.

DISCUSSION

At present the CF treatment can be characterized as having high percent cover, the greatest number of species, the least pine growth, high density of bahia grass, and the lowest density of blackberry and panicum. Conversely, the 2X treatment is characterized by high percent cover, lowest number of species, moderate pine growth, greatest density of blackberry, low density of bahia grass, and greatest density of panicum species. Competition for water and nutrients within the CF chambers may be more intense due to significantly greater number of species (compared to 2X) and greater percent cover. This competition may cause reduction in pine growth, and partially explains the low abundance of blackberry and both panicum species in the CF treatment. The reduced pine growth within the CF chamber contrasts with prior studies by Chappelka et *al.* (1990) who reported the greatest pine growth in the CF treatments and reduced within 2X treatments. However, in that study competing vegetation was eliminated and the seedlings were irrigated. Sensitivity of bahia grass to ozone exposure is unknown. Bahia grass is shade intolerant, yet it was most abundant in the CF ozone chambers where shading effects were high. This may indicate that bahia grass is very sensitive to ozone.

Conversely, there is an indication that an ozone x competition interaction is important in the 2X treatment. The 2X treatment is dominated by blackberry, however, blackberry is considered ozone sensitive with regard to visible injury (Chappelka and Wergowske 1994). One explanation for dominance of an ozone sensitive species in a high ozone environment would be release from competition. There were fewer species within the 2X treatment, which may be an indication of a reduction in competitive interaction in the high ozone environment. This decrease in competition may allow blackberry to achieve compensatory growth and counteract the ozone injury. The panicum sps. are probably not as sensitive to ozone (sensitivity is not known). However, panicum sps. did respond to reduced competition within the 2X treatment since it is shade intolerant. Reduced growth (ht. and dia.) of loblolly pine within the 2X treatment, when compared to the NF treatment, is consistent with previous studies.

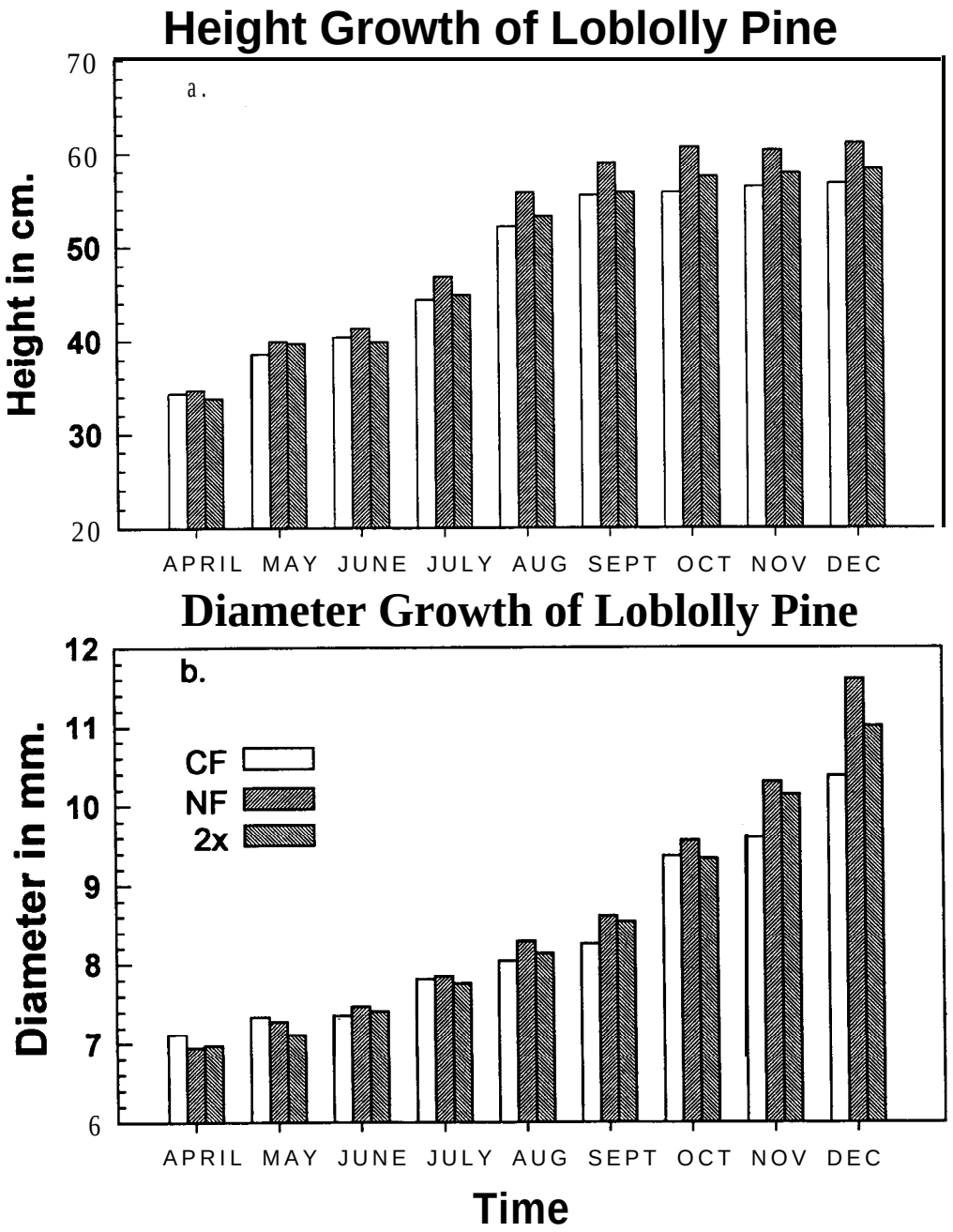

Figure 3. a) Loblolly pine height growth in cm over time. b) Loblolly pine diameter growth in mm over time.

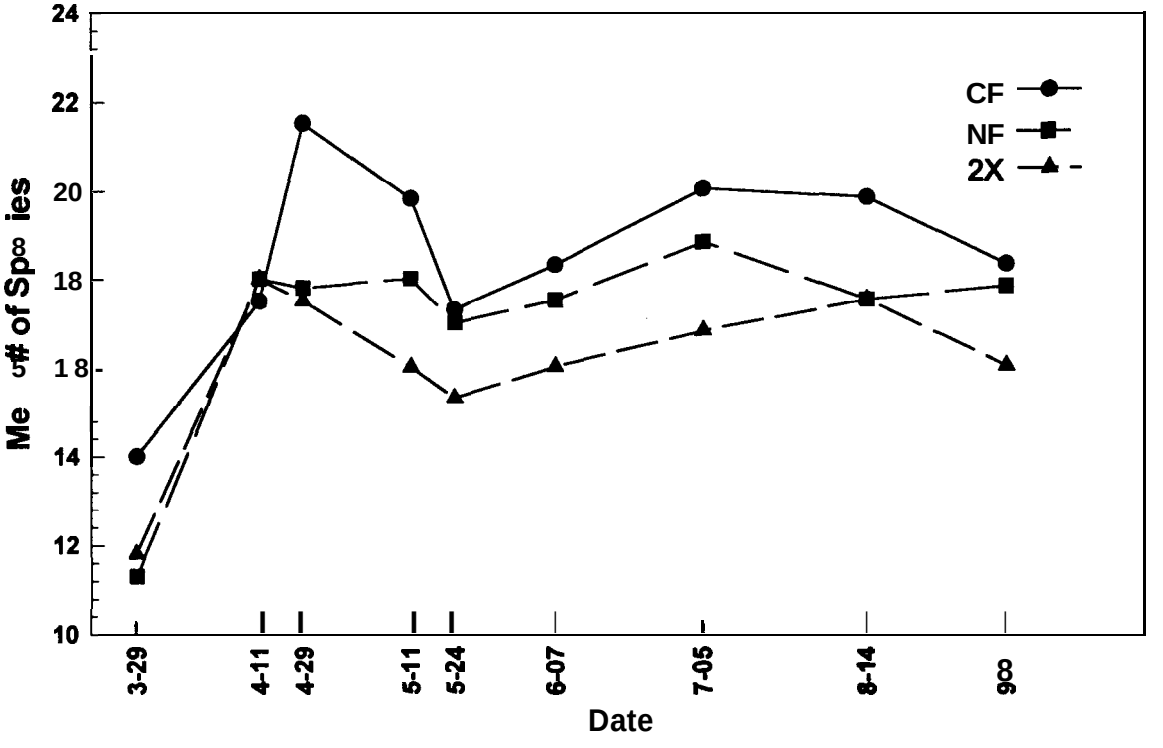

Figure 4. Mean number of species per treatment over time.

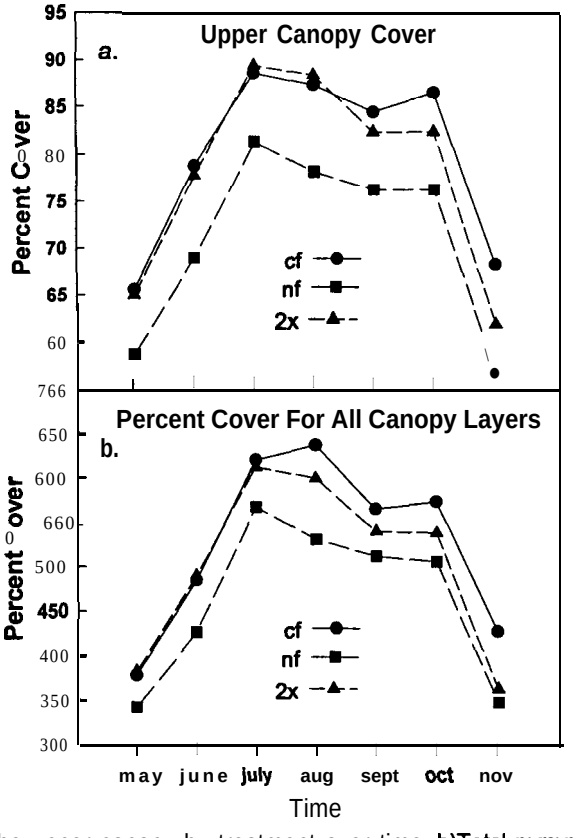

Figure 5. a) Percent cover of the upper canopy by treatment over time. b)Total percent cover (all canopy layers combined) by treatment over time.

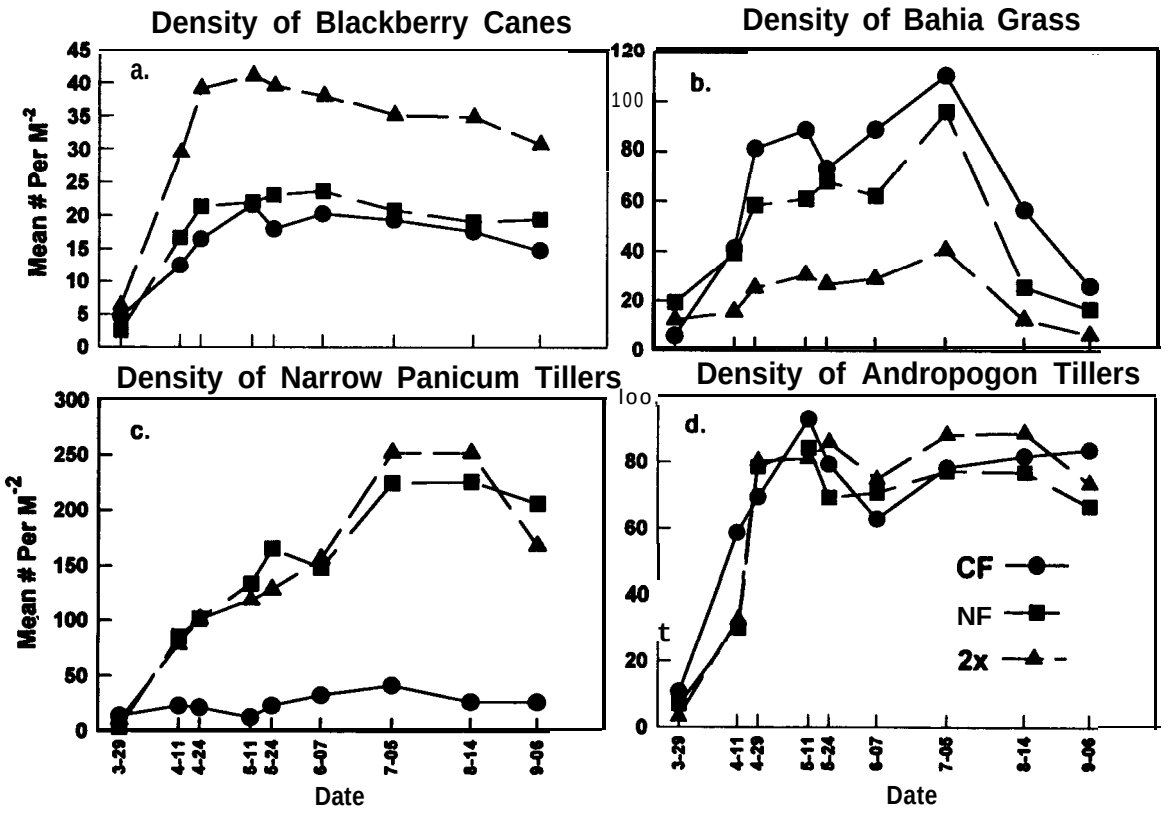

Figure 6 **a)** Number of blackberry canes per m^2 by treatment over time.
b) Number of bahia grass per m^2 by treatment over time.
c) Number of narrow panicum tillers per m^2 by treatment over time.
d) Number of andropogon tillers per m^2 by treatment over time.

Data will be collected over the course of the 1995 growing season and compared to the 1994 data. Changes in species diversity (indices), shifts in species composition and changes in abundance of individual species in response to ozone treatments and competition will be determined at that time.

CONCLUSIONS

Consideration must be given during data interpretation that the treatments will be applied for another growing season, and data analyses are preliminary. Effects observed in response to ozone treatments reported in this study may be very **different** next year. Resource allocation and storage may have been hindered within the 2X treatments which could cause the plants to overwinter **poorly** and subsequently result in reductions in productivity next year.

The different treatments appear to be altering the structure of these early successional "old-field" forest communities through modification of competitive relationships. Interactions may exist between the ozone treatments and intensity of competition within chambers. Although, plant competition is a very difficult to measure, this type of controlled mesocosm study is important in demonstrating how a forest community may react under these various ozone scenarios. Final results may indicate how **loblolly** pine productivity will be affected in an atmosphere where ozone levels are predicted to rise regionally and globally.

ACKNOWLEDGEMENTS

The authors would like to thank Efrem **Robbins** for his invaluable help in data collection and analysis. Also, Dr. Robert Boyd, Dr. Robert Jones, Dr. Mary Miller, and Dr. Greg Somers for assistance. Partial funding is provided by the USDA Forest Service Forest Health Monitoring Program.

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GROWTH AND PHYSIOLOGICAL CHARACTERISTICS OF PLANTED LOBLOLLY PINE AND RED MAPLE GROWN IN PURE AND MIXED STANDS'

John W. Groninger, Shepard M. Zedaker, John R. Seiler, Todd S. Fredericksen and Richard E. Kreh[2]

Abstract—Loblolly pine and red maple were grown for five years in pure stands and **50:50 mixtures** with tall fescue or under maintained weed-free conditions on the upper **Piedmont** of Virginia. By the end of the Afth growing season, relative size of both species was dependent on stand composition and herbaceous cover. **Although** red maple was more suppressed by tall fescue, high survival under these conditions will likely **allow** the eventual development of a larger red maple **component** in mixed stand as herbaceous vegetation continues to decline in conjunct&n with the development of an **overstory.**

INTRODUCTION

Recently, interest has increased in the management of pine-hardwood forests in the southeast (Cooper 1989). In addiion to **wildlife** and aesthetic benefits, these stands may provide landowners with greater market flexibilii by cultivating more product classes compared to traditional pine **monocultures. Stumpage** value of hardwoods has increased in recent years making mixed stand management more profitable. Also, planted hardwood species may act as nurse crops to **loblolly** pine, ***Pinus taeda*** L. by increasing **self-pruning** (Clatterbuck et al. **1985),** provided that pines do not become suppressed. Successful establishment of pine-hardwood mixtures requires the development of appropriate vegetation management strategies.

The objectives of **this** study were to quantify the effects of herbaceous vegetation and forest stand composition on physiology and growth of loblolly pine and red maple, ***Acer rubrum*** L. for the first **five** years following establishment from 1-O seedlings.

METHODS

The study was located at Virginia Tech's Reynolds Homestead Forest Resources Research Center in **Critz,** VA. The study site was an abandoned field and pasture prior to site preparation with glyphosate in Fall 1988. The soil is **a** Cecil clay loam (clayey, kaolinitic, thermic Typic hapludults) with slopes ranging from 2 to **20** percent. A number of competitive arrays (stand types) were established during March 1989 in a split-plot design with four replications (Fredericksen et al. 1991, 1993). Split plots consisted of two levels of weed control: weed free or closed ground cover. Weed free conditions were maintained through repeated application of glyphosate and closed ground cover was established by planting Kentucky-31 tall fescue *Festuca arundinacea* Schreb. at a rate of 28 kg/ha during the August immediately following tree planting. Loblolly pine and red maple (both 1-O stock) planted both in pure stands and **50:50** mixtures planted at a one by one meter spacing were subplots. Borders of subplots were trenched to one meter and trenches were lined with plastic sheets following the third growing season to prevent root interference between adjacent stands.

Total height and basal diameter were measured at the end of each growing season. Height to lowest **live** branch was measured following the second through **fifth** growing seasons. Stem volume index was calculated using total height and basal diameter in the equation for a cone. Gas exchange was measured monthly during June, July and August of the fourth and fifth growing season using a Li-Cor 6200 portable photosynthesis system (Li-Cor Inc., Lincoln, NE). Attached leaves for red maple and detached fascicles for loblolly pine from the upper third of the live crown were used in gas exchange measurements. Measurements were made under ambient light conditions iassociated with leaf growth environment.

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Midday water potentials were made in conjunction with gas exchange measurements using a pressure chamber. Gas exchange and midday water potential measurements were made on two trees per species, per stand.

RESULTS AND DISCUSSION

After 5 growing seasons, survival exceeded 95 percent for both species regardless of herbaceous cover or stand type. Height growth of both loblolly pine and red maple was suppressed by the presence of herbaceous vegetation throughout the study (Fig. 1). Differences in mean tree height due to herbaceous weed control was greatest (52 percent) after year three for loblolly pine and after year four (252 percent) for red maple compared to tall fescue plots.

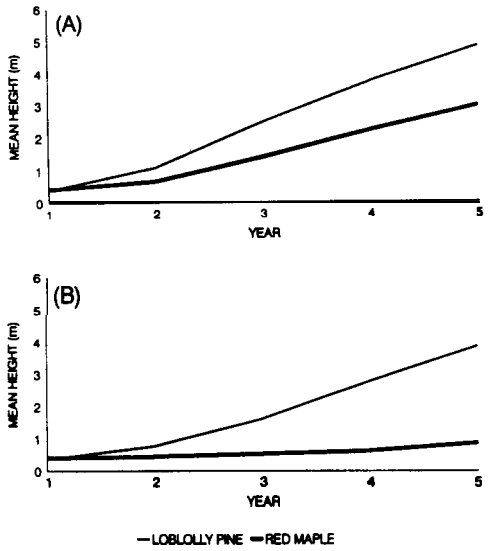

Figure 1- Mean total height for planted loblolly pine and red maple grown under maintained weed-free (A) and planted tall fescue (B) understories for 5 years on the Virginia Piedmont..

While loblolly pine was dominant in both herbaceous treatments throughout the study, the extent of pine domination over red maple, based on height differences between the species, peaked in weed-free stands following the third growing season and has been decreasing since that time. Although percent differences in height have been decreasing, the early growth gained under weed free conditions will continue to be evident in annual dry weight increment (Britt et al. 1990). Differences between pine and maple height have continued to increase in tall fescue plots through the duration of the study.

Stem volume index was significantly greater in weed-free versus tall fescue stands in both species from the second growing season onward (Fredericksen et al. 1991, 1993). Stem volume index was not affected by growth in pure stands or mixture for either species until the fifth growing season. Following the fifth growing season, loblolly pine grown in 50:50 mixtures with red maple were 31% larger than pines grown in pure stands regardless of herbaceous cover (Fig. 2). Larger stem volume in mixed stands are probably due to greater availability of resources for pine since adjacent maples tended to be smaller and less competitive than pines in the pure stands. For red maple, stem volume index response to growth in pure stands or mixture was dependent on herbaceous cover; mean weed-free stem volume index was 82 percent greater in pure stands under weed-free conditions while in tall fescue, maples grown in mixtures were 75 percent larger than those grown in pure stands. In tall fescue plots, pines appear to suppress herbaceous vegetation providing a more favorable microenvironment for maple in mixed stands (Fredericksen et al. 1993).

In previous studies, the presence of hardwood vegetation typically reduced pine yield (Miller et al. 1991, Perry et al. 1993). Comparison between previous studies and this one should be made with caution since hardwood seedlings are likely to be less competitive with pine compared with typical hardwood regeneration from stump and seedling sprouts. The results of this study suggest that competition from planted hardwoods is a function of tree size and density and the presence of planted hardwoods can enhance per tree loblolly pine stem volume if total tree density is not increased.

Ratio of tree height to diameter (HDR) was sensitive to herbaceous vegetation as well as growth in mixed or pure stands (Tables 1 and 2). Loblolly pine HDR was more strongly influenced by growth in monoculture versus mixture than by presence of herbaceous competition. In contrast, red maple was more strongly influenced by herbaceous competition during the second and third growing seasons. This relationship shifted over time with HDR of weed-free stands becoming greater suggesting that competition from trees became more important than herbaceous

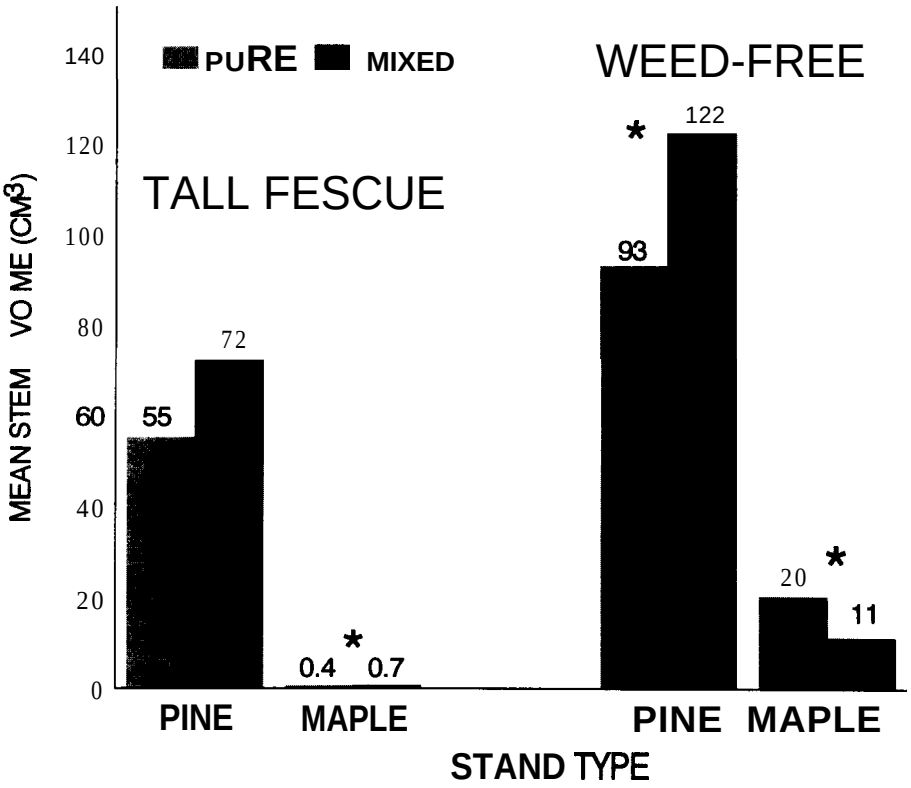

Figure 2-- Stem volume index after 5 growing season for planted loblolly pine and red maple grown in pure stands or 50:50 replacement mixtures in tall fescue or maintained weed-free understories on the Virginia Piedmont. Significant differences between pairs of means within species and herbaceous cover are indicated with an asterisk.

Table 1. Mean height:diameter ratios for loblolly pine and red maple across stand type grown under maintained weed-free conditions or with planted tall fescue for 5 years on the Virginia Piedmont. Means within species and year followed by the same letter are not significantly different at $p < 0.05$.

	Loblolly Pine		Red Maple	
Year	Weed-free	Tall fescue	Weed-free	Tall fescue
1	0.363 A	0.375 A	0.760 A	0.777 A
2	0.430 A	0.500 A	0.560 B	0.677 A
3	0.513 A	0.547 A	0.640 B	0.764 A
4	0.502 A	0.489 A	0.753 A	0.724 A
5	0.555 A	0.538 A	0.785 A	0,709 B

Table 2. Mean height:diameter ratios for loblolly pine and red maple across herbaceous treatment grown in pure stands and 50:50 replacement mixtures on the Virginia Piedmont for 5 years. Means within species and year followed by the same letter are not significantly different at $p < 0.05$.

	Loblolly Pine		Red Maple	
Year	Pure	Mixed	Pure	Mixed
1	0.372 A	0.367 A	0.706 A	0.759 A
2	0.491 A	0.448 A	0.638 A	0.599 A
3	0.550 A	0.505 B	0.710 A	0.694 A
4	0.526 A	0.465 B	0.722 A	0.755 A
5	0.577 A	0.516 B	0.690 A	0.810 B

vegetation by the end of the fifth growing season. Competition in mixed stands became more intense than pure stands for maples according to this index. HDR may be a useful index of competitive stress based on the observation that diameter is impacted by competition while height is impacted to a considerably lesser extent (Lanner 1985, Holbrook and Pub 1989, Knowe 1991, Perry et al. 1993). However, as competition intensifies during crown closure, greater allocation of resources to height at the expense of diameter may allow an individual to maintain a favorable status for light capture (Holbrook and Putz 1989).

Shifts in the importance of competition from herbaceous to woody species was also reflected by changes in live crown ratios (LCR) in loblolly pine (Table 3). Loblolly pine grown in weed-free stands maintained higher LCR during the third growing season. This relationship had shifted during the fifth growing season presumably due to greater lower branch mortality caused by the development of more dense canopies and greater crown competition in weed-free stands. In contrast, red maple LCR remained higher in weed-free stands from the second growing season onward. LCR was significantly higher in mixed versus pine monocultures during the fourth and fifth growing seasons (Table 4). In contrast, red maple grown in monocultures had a higher LCR than those from mixed stands during the fifth growing season suggesting greater competitive influence from pine than from itself. LCR is typically used as an index to determine stand responsiveness to thinning. Even though the stands in the study reported here had considerably higher LCR's than stands typically considered for thinning, this measure may be appropriate for tracking changes in vigor among a species growing under different competitive regimes.

Data collected during the fourth growing season showed net photosynthesis was significantly higher in loblolly pine on tall fescue plots during the June measurement but no further significant trends were present during subsequent measurements (Table 5).

Red maple net photosynthesis was significantly higher on weed-free versus tall fescue plots during the June and July measurement of the fourth growing season but no trends were observed after that time.

Water potential differences between treatments did not appear to be biologically significant during the fourth and fifth growing season. In contrast, herbaceous cover had a significant effect on midday water potentials for both species during the third growing season (Fredericksen et al. 1993) The influence of herbaceous weed control on tree water potential decreases once trees develop root systems able to extract water from greater depths than herbaceous vegetation (Green et al. 1989, Sands and Nambiar 1984).

Table 3. Mean live crown ratios for loblolly pine and red maple across stand type grown for 5 years under maintained weed-free conditions or with planted tall fescue on the Virginia Piedmont. Means within species and year followed by the same letter are not significantly different at $p < 0.05$.

	Loblolly Pine		Red Maple	
Year	Weed-free	Tall fescue	Weed-free	Tall fescue
2	0.868 A	0.814 A	0.799 A	0.623 B
3	0.914 A	0.876 B	0.805 A	0.707 B
4	0.803 A	0.848 A	0.895 A	0.674 B5
	0.639 B	0.706 A	0.895 A	0.638 B

Table 4 .Mean live crown ratios for loblolly pine and red maple across herbaceous treatment grown for five years in pure stands and 50:50 replacement mixtures on the Virginia Piedmont. Means within species and year followed by the same letter are not significantly different at $p < 0.05$.

	Loblolly Pine		Red Maple	
Year	Pure	Mixed	Pure	Mixed
2	0.818 A	0.864 A	0.686 A	0.735 A
3	0.885 A	0.906 A	0.783 A	0.809 A
4	0.777 B	0.874 A	0.792 A	0.776 A
5	0.618 B	0.726 A	0.795 A	0.739 B

Table 5. Net photosynthesis ($\mu mol\ m^{-2}\ s^{-2}$) for upper crowns of planted loblolly pine and red maple grown in weed-free and tall fescue understories on the Virginia Piedmont during the fourth and fifth growing season. Means followed by the same letter are not significantly diierent ($p < 0.05$) between weed-free and tall fescue stands for a species within the same month and year.

	Loblolly Pine		Red Made	
Month, Year	Weed-free	Tall fescue	Weed-free	Tall fescue
June, 1992	4.6 A	4.8 A	7.1 A	5.2 B
July, 1992	2.8 A	1.6 B	3.5 A	2.0 B
August, 1992	3.2 A	3.4 A	5.3 A	5.9 A
June, 1993	4.7 A	4.7 A	6.4 A	5.2 A
July, 1993	4.1 A	3.9 A	6.4 A	5.0 A
August, 1993	4.1 A	3.7 A	5.5 A	5.7 A

CONCLUSIONS

While stand dynamics during the first 2 growing seasons appeared to be governed by herbaceous interference and inherent growth characteristics of the two tree species (Fredericksen et al. 1991), inter and intraspecific competition between trees became more important following the third growing season. Once crown closure occurred, stand species composition become increasingly important Presence or absence of herbaceous vegetation decreased in importance over time but size differences established by herbaceous treatments prior to crown closure continued to be manifested throughout the study.

Changes in the role of woody and herbaceous vegetation in competitive relationships over time are likely accompanied by a shift in importance from competition for water to competition for nutrients (Nambiar and Sands 1993). The timing and actual nature of competitive interactions discussed here should be applied onty to stands where both loblolly pine and red maple are estabiiihed from seedlings. Typically, red maple is regenerated by stump or seedling sprouts which exhibit much more rapid growth rates and are more strongly competitive than planted 1-O seedlings used in this study.

MANAGEMENT IMPLICATIONS

Fiih year results of this study strongly suggest that establishment of compatible mixed stands of loblolly pine and red maple from seedlings is possible on Upper Piedmont sites similar to those described here. Because early growth of red maple is more sensitive to herbaceous vegetation than loblolly pine, the relative dominance of red maple could be regulated through the intensity of herbaceous weed control during early stand development The persistence of red maple under the planted tall fescue ground cover, especially when grown in mixture with loblolly pine, suggests that this species will become more important as herbaceous cover declines.

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TREE SHELTER ALTERATION OF SEEDLING MICROENVIRONMENT'

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Abstract-Tree shelters are used to protect and accelerate the growth of seedlings. The mechanism governing seedling performance in tree shelters is not clearly established, but is apparently related to microclimate changes.

To determine the microclimatic variables associated with increased growth in tree shelters, red oak (*Quercus rubra*) and Norway maple (*Acer platanoides*) seedlings were planted in either TUBEX® tree shelters, in shelters with supplemental holes to permit air exchange, or without tree shelters. Seedling microenvironmental parameters were measured throughout the second growing season.

Tree shelters lowered light levels, increased temperatures and relative humidii, and slightly decreased CO_2 levels. Seedling growth was greatest for both species in solid shelters, and reduced somewhat in modified shelters. Of the variables measured, relative humidity best explained growth patterns.

INTRODUCTION

Tree shelters are used to protect seedlings and increase early growth rates in urban plantings and in the seedling establishment phase of regeneration. Increased growth within tree shelters has been observed for several species of oaks (Potter, 1988; Minter et a/., 1992; Kittredge et *al.*, 1992; Lantagne et a/., 1990; Tuley, 1985), and cherry (Frearson and Weiss, 1987). However, several species do not exhibit increased growth rates when placed in tree shelters, including birches (*Betula* spp.), yellow poplar (*Liriodendron tulipifera*) (personal observation) and American sycamore (*Platanus occidentalis*) (Torbert and Johnson, 1993) and chestnut oak (McConnell, 1992).

Species response to tree shelters is likely related to the altered seedling microenvironment within the shelters. For example, some species may not be able to survive the low light levels within shelters. Additionally, low CO_2 levels may develop within shelters due to mid-day photosynthetic depletion, limiting carbon uptake. Low carbon dioxide levels could easily be improved by modifying shelters with small holes to provide ventilation.

The present study was undertaken to quantify the growth response of northern red oak and Norway maple to standard and modified (with holes) tree shelters and to characterize tree shelter microenvironments.

METHODS

The study was conducted on a mowed field located at the Virginia Polytechnic Institute and State University Horticulture Farm near Blacksburg, Virginia on a Groseclose series soil (clayey, mixed, mesic Typic Hapludut). In April 1993 three seedlings each of both I-O northern red oak and Norway maple were randomly planted in each of six blocks. Within each block, one seedling of each species was randomly selected to be grown within unmodified Tubex® tree shelters, within a tree shelter that had been modified by drilling 0.25 inch holes five cm apart, or without a tree sheiter. Wire mesh was used to prevent rodent damage. In addition, one empty standard and one empty modified shelter were placed in each block to determine shelter effects without seedling modification. Herbaceous vegetation was controlled through mowing and periodic applications of glyphosate.

Diurnal measurements of microclimatic variables were taken at two week intervals from May 16 through September 5 of the second growing season. Measurements began at 8 a.m. and were taken every

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two hours, ending at 6 p.m. Carbon dioxide, relative humidity, temperature, and photosynthetically active radiation (PAR) within the tubes were measured through 2.54 x 2.54 cm closable flaps that were cut into the sides of the shelters at 35 and 70 cm above the soil surface. In addition, ambient measures were measured once within each block at each sampling time. Carbon dioxide concentrations were measured with a Li-Cor Lii 6200 Portable Photosynthesis System. Light levels were measured with a Li-Cor Li-185B quantum sensor. Temperatures and relative humidities were measured with a Solomat MPM 2000 temperature/ relative humidity meter.

Near the end of the growing season, the aboveground portion of each plant was harvested. Height, leaf dry weight, and total aboveground dry matter were determined.

All analyses were conducted separately for each of the six sampling times on each sampling date using analysis of variance, with the measurements averaged across sampling heights for analysis. Ambient measures were not compared statistically with tree shelter data.

RESULTS

Maples grown in standard shelters averaged 47% taller than those grown in modified shelters and 257% taller than those grown without shelters (Table 1). Maple dry weight showed a similar, but less pronounced response to growth in the shelters. Oak seedlings did not respond to the shelters as strongly as maple seedlings. Seedlings were 10% and 87% taller in standard shelters compared to modified and no shelters, respectively. Total dry weight of oaks did not diier between treatments (Table 1).

Table I-Mean total height and dry weight at the end of the second growing season of seedlings grown in standard, modified, or no tree shelters (n=6)

	Height (cm)		Weight(g)	
Shelter type	Maple	Oak	Maple	Oak
Standard	132a	43a	45a	8a
Modified	90 b	39 a	24b	8a
None	37 c	23 b	22b	6a
P-value	0.0001	0.0352	0.0163	0.6327

[a] Numbers within a column followed by the same letter are not significantly different at alpha = 0.05.

On a typical mid-summer day (July 12), standard tree shelters without seedlings had relative humidities that were slightly greater than ambient humidity (67 vs. 65%), had greatly reduced light levels (214 vs. 819 µmol/m2sec-1), increased temperatures (28.4 vs. 26.5°C), and slightly increased CO_2 levels (361 vs. 344 ppm).

It was determined that elevated CO, within the shelters was caused by soil respiration. The placing of plastic bag barriers between the soil and the bottom of the shelters resulted in CO_2 concentrations in empty solid shelters equal to ambient concentrations. High CO_2 concentrations within shelters have been noted by several researchers. The elevated CO_2 levels observed in empty shelters in this experiment were roughly equivalent to levels found by Mayhead and Jones (1991), and for shelters that were not sealed into the soil, as noted by Frearson and Weiss (1987). Carbon dioxide concentrations in modified shelters were equal to ambient conditions.

Throughout the study, modified tree shelters (with or without seedlings) had CO, concentrations that were equal to ambient values, indicating unimpeded gas exchange in these shelters (Figure 1). Standard shelters with seedlings often depleted CO, below ambient concentrations, especially at mid-day. A significant CO_2 interaction was often observed, with standard shelters containing seedlings being drawn down well below ambient CO_2 concentrations, and those without seedlings maintaining increased CO_2 levels. Modified shelters had CO, concentrations near ambient values, with or without seedlings (Figure 2).

Temperatures did not differ significantly between standard and modified shelters (less than 1°C). Light levels did not differ between standard and modified shelters.

Relative humidity values were strongly affected by the presence of holes in the tree shelters (Figure 3). Standard shelters generally had significantly higher relative humidities (36%) than modified shelters, which were higher than ambient values. A significant interaction was observed, with empty standard shelters having relative humidities close to ambient, and standard shelters with trees having relative humidities approaching 10% higher than ambient (Figure 4).

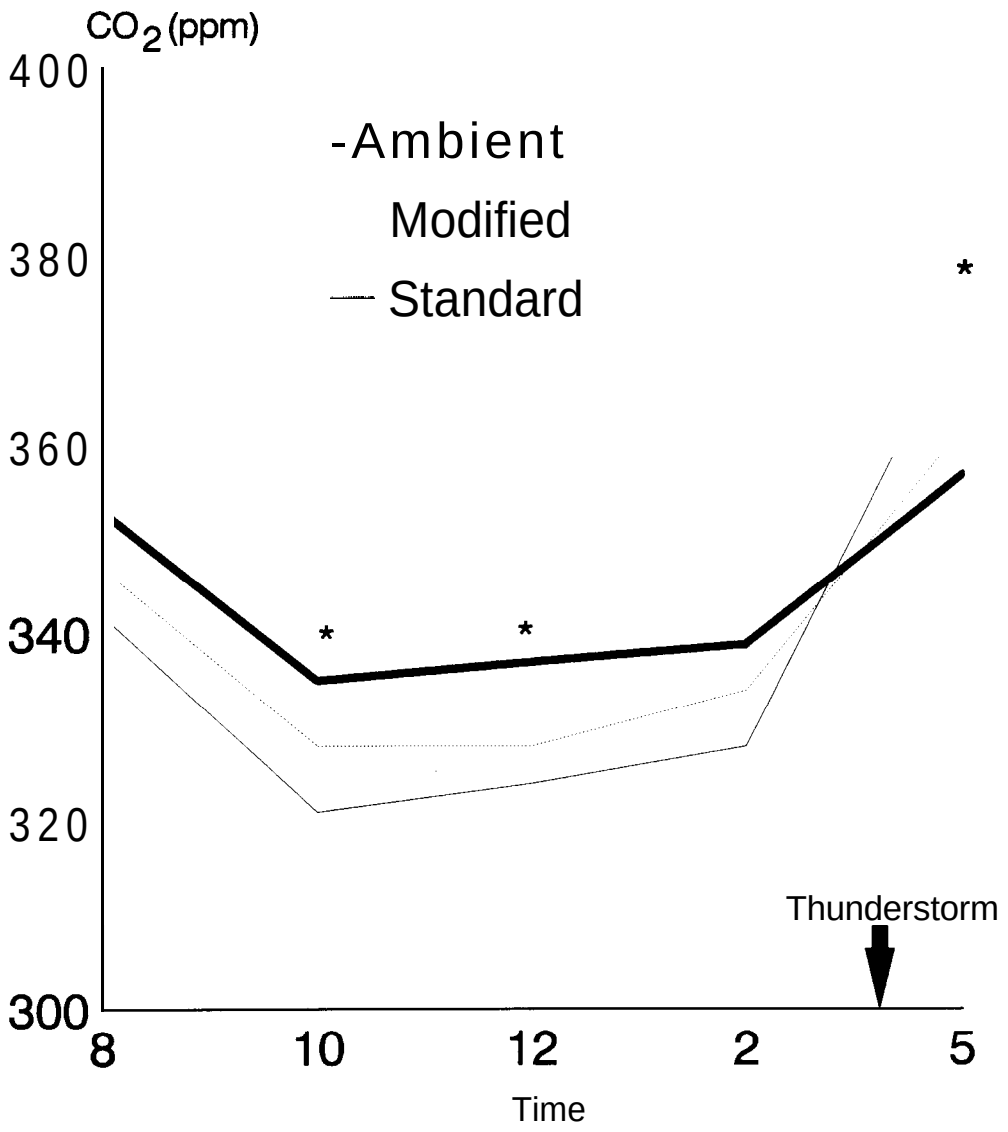

Figure l-Diurnal CO_2 concentrations recorded on a typical mid-summer sampling date for solid tree shelters, shelters with holes and ambient values. Shelters were either empty or contained maple or oak seedlings. • indicates modified and standard shelters were significntly different (alpha = 0.05).

DISCUSSION

Many authors indicate that increased CO, levels result in increased growth rates in forest trees, at least in the early stages of tree growth (Eamus and Jarvis, 1989). With the increase in CO_2 concentrations in empty solid shelters, it is possible that a CO_2 fertilization effect may be the reason for the observed increased growth rates of seedlings in the solid shelters. However, within-shelter CO_2 levels were often drawn down to ambient or below, especially at mid-day. The largest and most vigorously growing trees were often observed to deplete CO_2 concentrations below 260 ppm. The CO_2 depletions that were observed over the course of this experiment were well above the compensation point and were probably not biologically meaningful.

Differences in relative humidity were observed between modiied and solid tree shelters throughout the study period. The decrease in relative humidity in modified shelters may have resulted in decreased growth in these shelters. Increased relative humidity within the

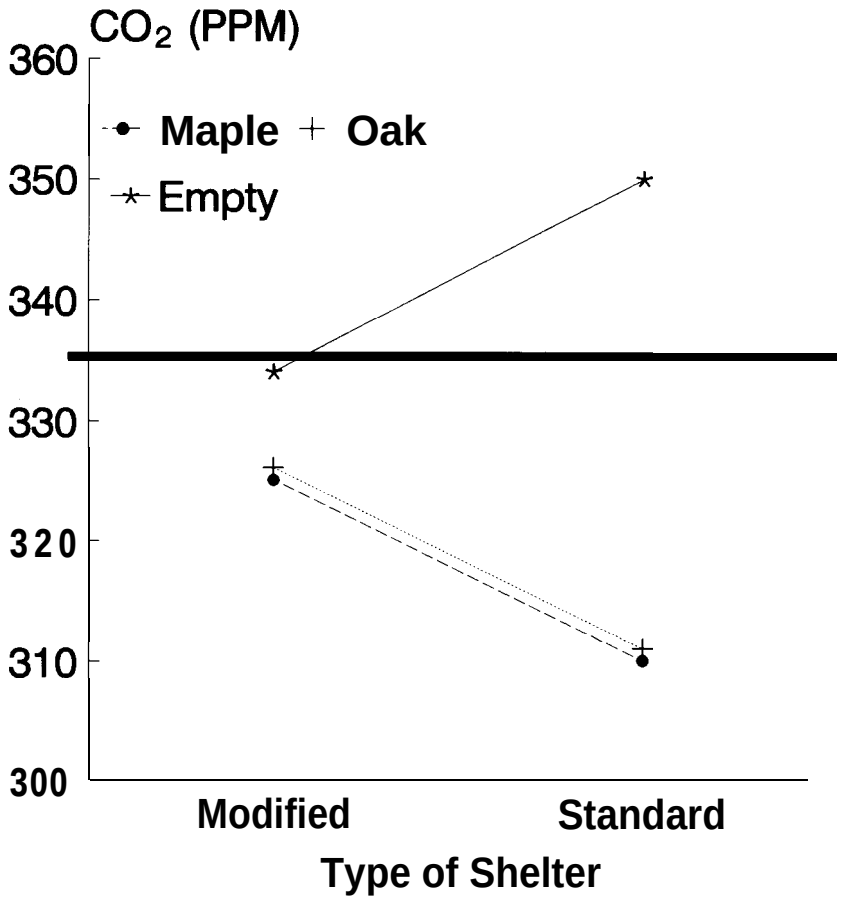

Figure 2-Carbon dioxide concentration mid-summer mid-day interaction between seedling type and microenvironment.

tree shelters would delay soil water depletion by decreasing water movement out of the seedlings, allowing for continued photosynthesis.

Modification of shelters by the addition of holes did result in the maintenance of CO_2 levels closer to ambient; however, the growth of both species was reduced. Clearly the somewhat lower mid-day CO_2 levels found in the standard shelters with seedlings did not reduce growth. It is likely that carbon fixation in the lower light and lower CO, of the standard shelters was reduced, but appears not to be a factor in the growth response.

The large light reduction in the shelters may have influenced seedling height growth by causing etiolation. Although the extent of light reduction by the shelters did not result in overall growth reductions in Norway maple and northern red oak, it is likely that shade intolerant species would have reduced growth under these conditions.

Wind was not measured, but may have been an important factor in seedling height growth reduction in shelters with holes and with trees grown without shelters. Potter (1988) suggested that wind reduction is a very important factor in the height growth increases associated with tree shelters.

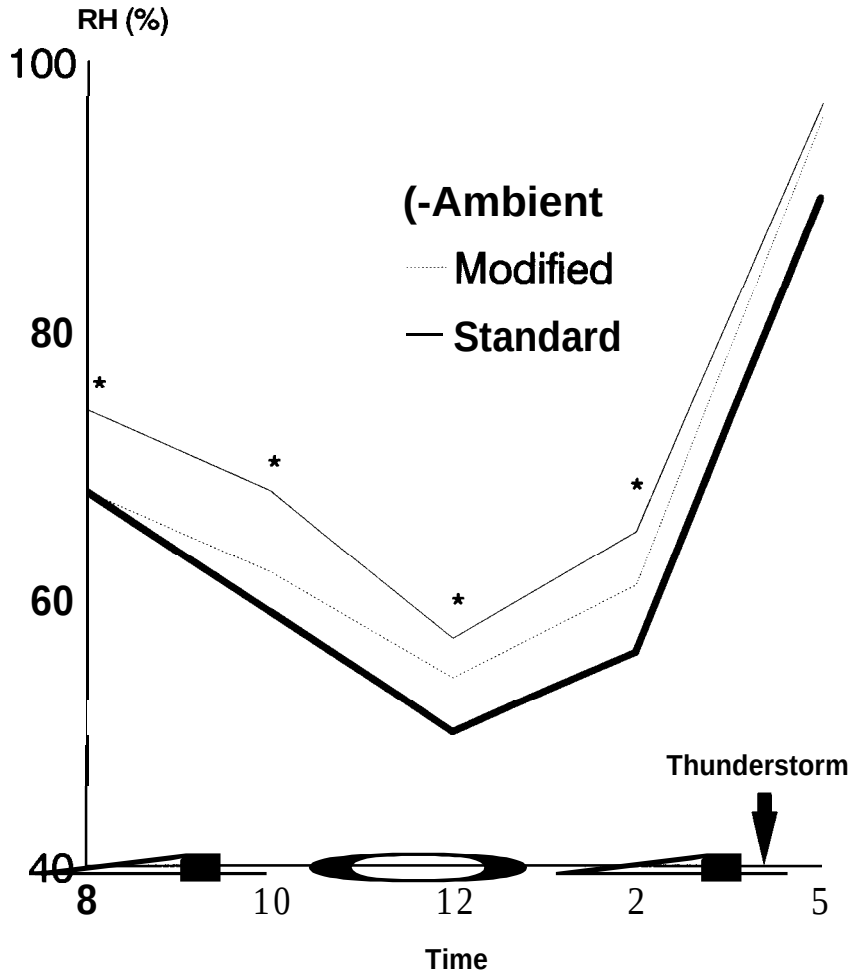

Figure 3-Diurnal relative humidity values recorded on a typical mid-summer sampling date for solid tree shelters, shelters with holes and ambient values. Shelters were either empty or contained maple or oak seedlings. • indicates modified and standard shelters were significntly diierent (alpha = 0.05).

CONCLUSIONS

The modification of tree shelters through the addiion of holes allowed for efficient gas exchange but decreased the growth advantages of standard shelters. Carbon dioxide concentrations, temperatures and light differences between standard and modified shelters did not explain the growth advantages of the standard shelters. Standard shelters had decreased CO_2 concentrations and similar temperature and light levels. Increased growth corresponded well with increased relative humidii values that were observed in the standard shelters. Increased humidii levels within tree shelters as well as factors not measured (such as wind reduction) may have influenced tree growth.

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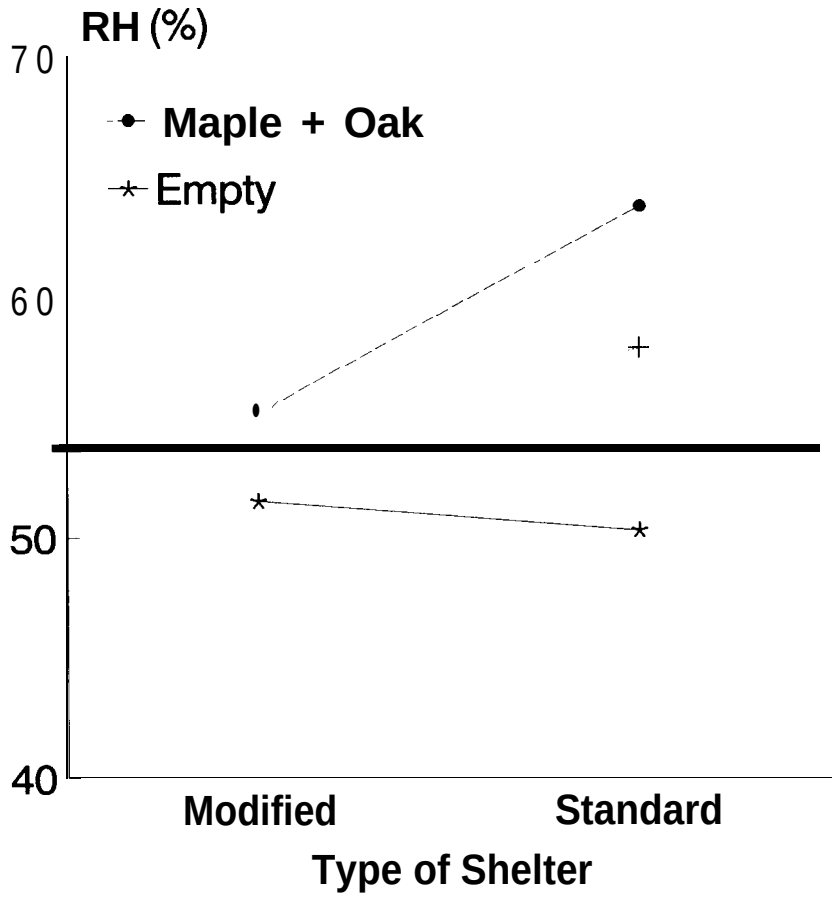

Figure 4-Relative humidity mid-summer mid-day interaction between seedling type and microenvironment.

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MORPHOLOGICAL AND PHYSIOLOGICAL DIFFERENCES BETWEEN ROOTED CUTTINGS OF ATLANTIC WHITE CEDAR GROWN IN CONTINUOUSLY FLOODED OR MOIST PEAT'

Martha R. McKevlin and Donal D. Hook[2]

Abstract-Rooted cuttings of Atlantic white cedar, *Chamaecyparis thyoides* (L.) B.S.P., were grown for two years in plastic pots containing either flooded or moist peat moss. Survival and growth were severely reduced by flooding. After one growing season, foliar Na concentrations doubled, whereas foliar Mn concentratiis decreased with flooding. After two growing seasons, foliar K and Na concentrations were increased and foliar Ca and Mg concentrations were decreased with flooding. Alcohol dehydrogenase actlvii of flooded root tips decreased with flooding, and oxygen uptake of flooded root tips was not significantly affected by flooding. Flooded stecklings that died before the end of the study had lower concentrations of Ca and higher concentrations of P in the foliage after one growing season than those that survtved two seasons of flooding.

INTRODUCTION

Atlantic whiie cedar, *Chamaecyparis thyoides* (L.) B.S.P., was once widely distributed from New Jersey to western Florida and was a dominant species in certain wetland ecosystems (Korstian and Brush 1931). Historically, it was an important timber species. Today, only remnant stands of the species may be found in scattered patches along its natural range. Why the distribution and stocking of the species has declined so dramatically across its entire range is unknown, but most explanations hinge on the paradoxical nature of the species.

Atlantic white cedar requires bare mineral soil and a lack of competition for regeneration. Catastrophic fire typically produces those conditions, however, such fires can destroy the seed bank and thereby favor competition (Buell and Cain 1943). Moore and Carter (1987) have reported that fire may be more important in limiting the occurrence of Atlantic white cedar than either moisture or organic matter content of soils.

Atlantic white cedar appears to require wet sites but not soil flooding. It has been found on sites with high water tables and with water standing in depressions for several consecutive months during winter and spring (Korstian and Brush 1931, Little 1950, Day 1984, Moore and Carter 1987). Korstian and Brush (1931) and Little (1950) reported, however, that growth of cedar on extremely wet sites was relatively poor. Buford and others (1991) also reported differences in height growth between rooted cuttings standing in water and those on drier microsites. Little (1950) reported that the best growth occurred in swamps with a relatively dry surface, a water table no greater than 4 to 5 inches below the surface, and water table fluctuations of a few inches.

Atlantic white cedar can be found on a variety of soils exhibiting a wide range of soil pH, texture, and organic matter content. Natural stands generally occur on sites composed of a peat surface soil with a sand or loamy mineral subsoil but also occur on peat or sandy surface soils with a clayey subsoil (Korstian and Brush 1931, Little 1950, Moore and Carter 1987, Day 1984, Levy 1987). These soils are generally acid but range in pH from 2.0 (Waksman 1943 as per Little 1950) to 7.5 (Clewell and Ward 1987). However, most sites are in the range of 4.0 to 5.5 pH units (Whigham and Richardson 1988, Day 1984, Hickman and Neuhauser 1977). Apparently, a species with extremely narrow tolerance on local sites, Atlantic white cedar is distributed over a wide climatic range-another paradox (Laderman 1989).

Because, very few autecological studies have been done on the species, physiological and ecological traits

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that would help define the natural tolerance of the species to site factors have not been adequately explored (Laderman 1989). The objectives of this study were to determine the effects of flooding stress on the survival and growth of rooted cuttings of Atlantic white cedar and to provide physiological information concerning the species and its relative flood tolerance.

MATERIALS AND METHODS

Plant Material

Atlantic white cedar stecklings (rooted cuttings) from the Weyerhaeuser Company nursery in Comfort, NC were produced from cuttings taken from wild seedlings on lands near New Bern, NC (Buford and others 1991). Prior to planting on July 31, 1989, stecklings were watered every three to five days, and fertilized once with 20-20-20 NPK liquid fertilizer.

Treatments

Stecklings were grown in plastic pots (25-cm diam) filled with a commercial sphagnum peat moss for two growing seasons. Pots were either continuously flooded to 2-3 cm above the soil surface or watered three times per week to maintain a moist but aerated root environment. Twenty stecklings were assigned to the flooded treatment and ten stecklings were assigned to the drained treatment. Pots were placed in a greenhouse on moveable benches that could be periodically rearranged to prevent positioning effects. No supplemental light was provided. All pots were initially saturated with tap water to thoroughly wet the peat. For the first year, all stecklings were mist fertilized twice weekly with equal amounts of 0.1 strength Hoagland's solution (Hoagland and Arnon 1950).

Measurements

Initial steckling heights ranged from 20-25 cm (Buford and others 1991). Monthly height measurements were taken starting in early November 1989, after a 3-month acclimation period. Stecklings were also observed for any changes in physiognomy such as production of adventitious roots, production of flowering structures, appearance of foliage, and hypertrophy of stems or lenticels.

During the summer of 1990, foliage samples were removed from all seedlings, including those that appeared to be highly stressed. After drying at 70°C for 24 hr, the foliage was analyzed for P content by colorimetry and for K, Ca, Mg, Na, Mn, and Fe content by atomic absorption spectrometry after dry ashing and uptake in 0.3 M HNO, (Jackson 1958). Small sample size prevented analysis for N concentration.

In early November 1990, ten of the flooded stecklings and 2 of the drained stecklings were randomly sampled in place for isozyme analysis of alcohol dehydrogenase (ADH) in root tissue. Actively growing root tips of intact plants were excavated from the peat, excised, and placed in liquid nitrogen. Alcohol dehydrogenase was extracted by grinding tissue in liquid nitrogen with PVPP using a Tris glycine buffer pH 7.0. Cellulose acetate gels were run for 15 min. at 200 V and stained for ADH.

In May 1991, soil redox potential (Eh) and pH were measured for each pot with a platinum electrode and calomel electrode, respectively. Platinum electrodes were constructed as described by Letey and Stolzy (1964). The value pe + pH was calculated as described in McKee and McKevlin (1993).

At the end of the second complete growing season (late August 1991), all stecklings were harvested by removing the intact plant from the plastic pot and rinsing away the peat with tap water. Plants were immediately dissected into roots and shoots. All actively growing white root tips were removed and placed in petri dishes on moist filter paper in preparation for either oxygen-uptake or ADH activity measurements. Oxygen uptake of three root tips per steckling was measured after 1, 2, and 5 min. using a Clark type oxygen electrode in a YSI biological monitoring chamber'. All remaining root tips per steckling were composited and frozen in liquid nitrogen for ADH activity. Alcohol dehydrogenase was extracted and activity measured using the method of Denslow and Hook (1986). The remaining root system was frozen for further analysis.

Shoot height and basal diameter was measured and all branches were removed from the stem. Branchlet tips of primarily green, succulent material were removed from the more woody branches and classified as foliage. Foliage projectional surface area was estimated using a LiCor leaf area meter. Component parts were dried at 70°C for 24 hr and weighed. Plant tissues were analyzed for N content by the method of

[1] Use of trade names does not constitute an endorsement by the USDA-Forest Service.

Nelson and Sommers (1973) and for P, K, Ca, Mg, Na, Mn, and Fe content as previously described.

Statistical Analysis

The experiment was conducted using a completely randomized design with 10 drained replicates and 20 flooded replicates. Two separate analyses of variance were performed to examine variation due to flooding and to determine variation associated with survivorship under flooded conditions. For each of the analyses, significance was determined at the 0.05 level unless otherwise noted. Pearson correlation coefficients were also calculated to determine relationships between physiological, morphological, and root environment characteristics.

First, differences due to flooding were analyzed. This analysis included measurements taken during the study prior to harvest (height, foliage nutrient content, and soil properties) and measurements taken at harvest (growth, biomass, and total nutrient content). There were 10 drained replicates but the number of flooded replicates varied between 20 and 12 depending on the number of survivors at the time the measurement was taken.

For the second analysis, data from flooded stecklings were analyzed to determine differences in nutrient content and root environment properties, which were measured prior to harvest, between stecklings that survived two years of continuous flooding and stecklings that died prior to harvest. This analysis was performed to provide some insight into what nutritional deficiencies or toxicities may have been associated with the eventual mortality of those flooded stecklings. There were 12 replicates for survivors and 8 replicates for non-survivors.

RESULTS AND DISCUSSION

General Observations

After one month (August 31, 1989), adventitious roots were observed forming on 63 percent of the stecklings. Sixty-five percent of the flooded and 60 percent of the drained stecklings produced one or more visible adventitious roots above the soil surface. Numbers of adventitious roots per steckling were not significantly different between flooded and drained treatments after one month of treatment. Values were 2.8 for drained and 3.3 for flooded stecklings. Mortality did not appear to be related to the lack of adventitious roots.

In March 1990, after seven months of treatment, male and female reproductive structures were observed on nine of the 20 flooded stecklings. Only flooded stecklings produced reproductive structures, and the majority appeared to be male. Of the nine stecklings that produced reproductive structures, six were dead by August 1991, after 24 months of treatment Of the three that survived until harvest, only one had produced adventitious roots one month after planting. By mid-summer of 1990, one of the two remaining stecklings had produced new adventitious roots, whereas the other had no visible new adventitious roots.

Production of reproductive structures by flooded stecklings may have been a stress response to the hypoxic conditions of the flooded peat. If that was the case in this situation, then apparently three of the severely stressed nine stecklings which produced reproductive structures were able to acclimate to the conditions and recover. Production of adventitious roots is often associated with acclimation to waterlogged soils (Hook and others 1970).

During the course of the experiment, differences in the appearance of the foliage from the flooded and drained stecklings were obvious. The foliage of the flooded stecklings appeared stubby and stunted with fewer branchlets. The flooded branchlets were cylindrical with curved tips. The drained steckling foliage appeared more delicate and lacy with many branchlets. Branchlets of drained stecklings were flatter and straighter than those of the flooded stecklings. Changes in the appearance of the foliage due to flooding are similar to the effects reported for ethylene production in other species (Kozlowski 1984).

The flooded stecklings also exhibited obvious stem hypertrophy (butt swell) which is commonly associated with flood tolerant species and attributable to ethylene production (Hook 1984). However, hypertropied lenticels did not occur as a result of flooding.

At harvest, differences in root system morphology and development were apparent. Under flooded conditions, the original roots present in the plug at planting were quite flaccid and appeared dead. Many new, short (6 cm average), thick, white, succulent, unbranched roots had originated from the stem and tap root of the flooded stecklings. These roots appeared to be of adventitious origin and to be actively growing. They formed a large root mat on the surface of the saturated peat and, after harvest, gave the appearance

of a white-bristled brush attached to the bottom of the shoot. These roots fit descriptions of soil water roots observed by others (Hook and others. 1970) and defined by Hook (1984). Root systems of stecklings from drained pots were fibrous and completely filled the plastic pot, which gave the impression that the drained stecklings were root-bound. Very few succulent white root tips were present in the drained pots.

Soil Properties

Soil redox potential values (Eh) averaged lower for flooded pots than for drained pots (Table 1). Values for pH were not significantly different. However, values for pe + pH, a more accurate measure of soil redox when pH values are not close to neutral, were significantly different. The low pe + pH value for the flooded pots indicates that the saturated peat within the pots was highly reduced and the root environment was extremely hypoxic (Gambrel1 and Patrick 1978). The organic nature of the peat and lack of minerals such as iron probably prevented the pH from approaching neutral which often occurs in the flooding of more mineral soils (McKee and McKevlin 1993).

Table I- Soil properties of flooded and drained pots after 22 months of continuous treatment

Soil Properties	Flooded	Drained
Eh (mV)	-315b	+419a
pH	4.63a	4.75a
pe+pH	3.42b	15.96a

Values followed by the same letter are not significantly different at the 0.05 level.

Survival and Growth

Survival of stecklings was 100 percent for the drained treatment but only 60 percent for the flooded treatment. After three months of treatment, flooded stecklings averaged 6 cm shorter than drained stecklings (Table 2). By harvest, surviving flooded stecklings averaged 13 cm shorter than drained stecklings. Root collar diameters at harvest were 3 mm greater for flooded than for drained stecklings indicating stem hypertrophy.

Total dry biomass of the flooded stecklings was only 39 percent that of drained stecklings (Table 2). Root dry biomass was 37 percent, branch dry biomass was 57 percent, and foliage dry biomass was 26 percent of drained steckling values. The significant difference in total biomass accumulation between drained and flooded stecklings was most attributable to decreases in foliage and root dry weight with flooding. Although larger, the ratio of shoot weight to root weight was not significantly influenced by flooding.

Table 2-- Height, diameter, and biomass of flooded and drained Atlantic white cedar stecklings after 2 years of continuous treatment

Characteristics	Flooded	Drained
Height after 3 months (cm)	30b	36a
Height after 24 months (cm)	44b	57a
Diameter (mm)	13a	10b
Foliage biomass (g)	3.32b	12.85a
Branch biomass (g)	1.34b	2.37a
Stem biomass (g)	4.28a	5.32a
Root biomass (g)	12.62b	34.13a
Total biomass (g)	21.57b	54.66a
Shoot:root ratio	0.83a	0.75a

Values followed by the same letter are not significantly different at the 0.05 level.

Projectional surface area of foliage from flooded stecklings was only 26 percent of that from drained stecklings (Table 3). Equal reductions in foliage biomass and area resulted in no significant effect on specific leaf area (SLA). On the other hand, both leaf weight ratio (LWR) and leaf area ratio (LAR) of stecklings were significantly less in the flooding treatment, indicating changes in biomass allocation due to flooding.

Table 3-- Foliage properties and biomass allocation patterns for flooded and drained Atlantic white cedar stecklings after 2 years of continuous treatment

Foliage Properties	Flooded	Drained
Projectional area (cm^2)	124b	482a
SLA (cm' g")	36.4a	37.2a
LWR (g g^{-1})	0.16b	0.25a
LAR ($cm^2 g^{-1}$)	6.0b	9.4a

Values followed by the same letter are not significantly different at the 0.05 level.

Nutrition

After one growing season, Na concentrations in the foliage more than doubted with flooding whereas, Mn concentrations dropped by over 60 percent (Figure 1). An increase in Na concentration in the foliage is often associated with the loss of selectivity in ion uptake by the roots (Kozlowski and Pallardy 1984). Once inside the stele, Na is transported via the transpiration stream to the foliage where it tends to accumulate. The decrease in Mn concentration was unexpected because Mn usually becomes more available to plants as it is reduced in the soil under flooded conditions. However, peat used in this study was low in Mn content and may have had a high affinity for absorbing Mn.

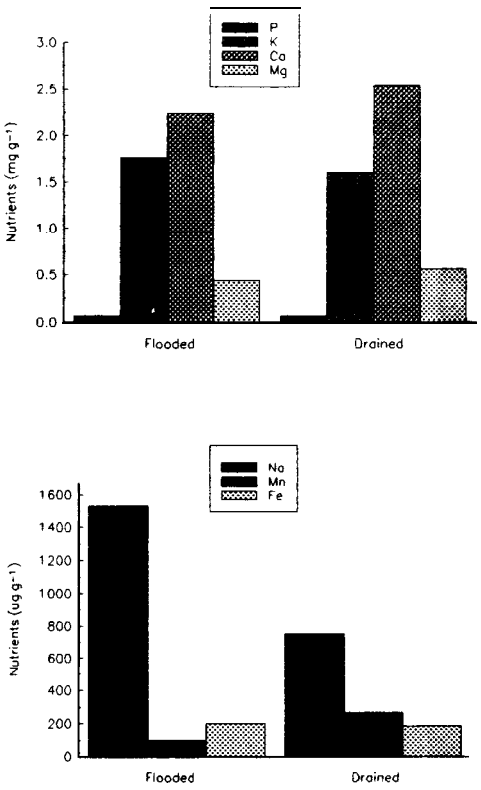

Figure 1-- Concentrations of selected nutrients in the foliage of flooded and drained Atlantic white cedar stecklings after 1 year of treatment. Bars with the same letter or no letter are not significantly diierent at the 0.05 level.

Flooding did not affect the concentration of P in the foliage, which was unexpected. Both flooded and drained steckling values were low relative to other plant species, but are similar to those reported by Whigham and Richardson (1988) for Atlantic white cedar. Work with loblolly pine, *Pinus taeda* (L), another wet site conifer, has shown that pine seedlings growing in flooded conditions often experience P deficiency in the foliage (Hook and others 1983, McKee and others 1984, McKevlin and others 1987). Swamp tupelo, Nyssa *sylvatica* var. *biflora* (Walt.) Sarg., which may co-occur with Atlantic white cedar, and water tupelo, *Nyssa aquatica* (L), have not shown foliar P deficiency when grown under waterlogged conditions (Hook and others 1983; McKevlin and others., in review).

After two growing seasons, the monovalent cations (K and Na) increased in the foliage with flooding, whereas the divalent cations, Ca and Mg, decreased with flooding (Table 4). Manganese concentrations decreased and Fe concentrations tended to increase ($p = 0.12$). Nutrient concentrations in the foliage are similar to those reported by Whigham and Richardson (1988). Patterns were similar for branch tissue, K and Na increased whereas Ca and Mg decreased. In stem tissue, Na increased and Ca decreased with flooding. Concentrations of N in stem tissue increased with flooding. In addition to being low, these N data are unusual because decreases in N concentration are commonly associated with flooding (Hook and others 1983, McKee and others 1984, McKevlin and others 1987, McKevlin and others, in review) even in hydrophytic species such as water tupelo. Root tissue tended to have lower concentrations of P and higher concentrations of Ca, however, neither were significantly different from drained steckling values ($p = 0.09$ and 0.06, respectively).

Physiology

Four of the 10 flooded stecklings yielded observable bands representing isozymes of ADH, whereas the other six flooded stecklings and the two drained stecklings yielded no visible bands with electrophoresis. Two of the four with ADH bands were dead by harvest and a third was near dead based on foliage and root conditions. Of the six flooded stecklings that produced no bands in November 1990, one was dead at harvest in August 1991 and one appeared near dead. These results suggest that the presence of isozymes of ADH after one year of flooding is not necessarily associated with the survival of Atlantic white cedar.

Table 4– Concentrations of selected nutrients in foliage, branches, stems, and roots of flooded and drained Atlantic white cedar stecklings after 2 years of continuous treatment

Nutrient	Flooded	Drained
Foliage -mg g^{-1}–		
N	0.625a	0.742a
P	0.052a	0.061a
K	0.891 a	0.531 b
Ca	1.43b	3.19a
Mg	0.258b	0.362a
Foliage -ug g^{-1}–		
Na	2371a	284b
Mn	676b	1615a
Fe	347a	95a
Branches -mg g^{-1}–		
N	0.239a	0.251a
P	0.019a	0.022a
K	0.343a	0.180a
Ca	0.924b	1.419a
Mg	0.048b	0.089a
Branches -ug g^{-1}–		
Na	1870a	717b
Mn	115a	179a
Fe	283a	101a
Stems -mg g^{-1}–		
N	0.266a	0.207b
P	0.017a	0.015a
K	0.154a	0.161a
Ca	0.554b	1.127a
Mg	0.048a	0.056a
Stems -ug g^{-1}–		
Na	1506a	532b
Mn	88a	83a
Fe	571 a	187a
Roots -mg g^{-1}–		
N	0.377a	0.341a
P	0.025a	0.096a
K	0.205a	0.247a
Ca	0.647a	0.558a
Mg	0.114a	0.111a
Roots -ug g^{-1}–		
Na	2115a	1812a
Mn	121a	128a
Fe	7055a	5348a

Values followed by the same letter are not significantly different at the 0.05 level.

Alcohol dehydrogenase activity (measured immediately after harvest) of flooded steckling root tips was lower than that of drained steckling root tips (Figure 2). These results suggest that increased ADH activity is not necessarily related to flooding tolerance over long periods of time, e.g. two years of continuous flooding. These results are somewhat confusing because anaerobic respiration is often associated with hypoxic soil conditions. However, most flood tolerant species produce well-aerated water roots after a period of acclimation to the hypoxic root environment, thus, reducing the requirement for anaerobic respiration. Anaerobic respiration has a high carbon requirement relative to energy output. Leaf area and biomass were significantly decreased with flooding, suggesting that photosynthates available for transport to the roots were also reduced. Stecklings that died may have exhausted their carbon supply via anaerobic respiration. Roots of mesophytes growing in well-drained soil conditions may possibly be more hypoxic within the endodermis than aerenchymatous water roots of hydrophytes growing in waterlogged conditions (Hook and McKevlin 1988).

Oxygen uptake rate by root tips from both flooded and drained treatments was not different for the first minute of the measurement period, indicating no loss of mitochondrial integrity for the flooded roots (Figure 2). However, after the second minute, O^2 uptake tended to increase in the drained root tips but remained fairly constant in the flooded root tips. Although drained root tip values for the last two time periods were basically double those of the flooded root tips, the differences were not significant at the 0.05 level. Differences in glucose availability could be responsible for the apparent differences in uptake rate between the two treatments.

These results indicate that flooded Atlantic white cedar root tips retained some degree of mitochondrial integrii and possessed the enzyme systems necessary to perform electron transfer in the Kreb's cycle (Vartapetian 1978). Therefore, aerobic respiration appears to be an important means of carbon metabolism in roots of flooded survivors. Although not measured directly in this study, Atlantic white cedar may be capable of some degree of oxygen transport to the roots, e.g. production of aerenchyma, sufficient to support aerobic respiration. However, seedlings may not respond in the same manner as rooted cuttings.

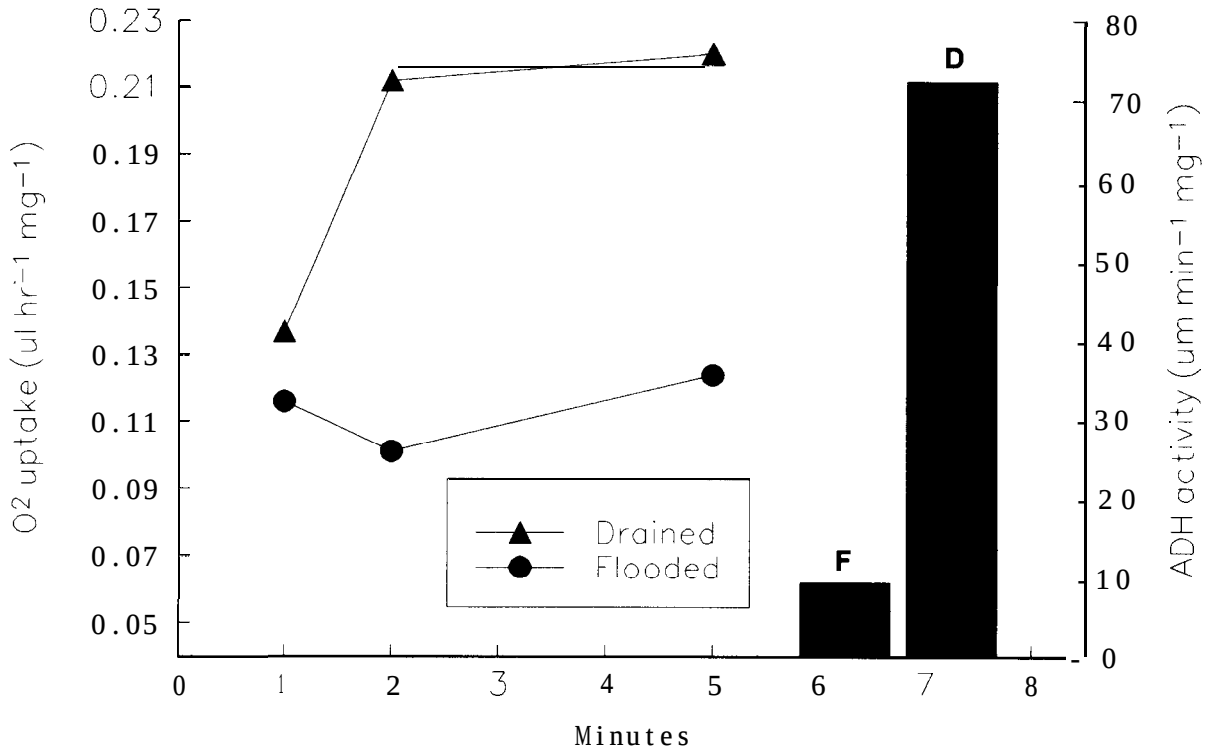

Figure 2– Oxygen uptake after 1, 2, and 5 minutes and alcohol dehydrogenase (ADH) activity of flooded and drained Atlantic white cedar steckling root tips both measured after 2 years of treatment.

Attributes of Survivors

To determine possible factors related to the death of stecklings under flooded conditions, values for those variables that were measured prior to the death of flooded stecklings were compared to values of the surviving flooded stecklings. Several significant differences were apparent.

Soil pH of the survivors' pots was lower than that of the non-survivors' pots. Values were 4.58 for the survivors and 4.83 for the non-survivors. Values for Eh and pe + pH, although lower for non-survivors, were not significantly different.

Mortality was weakly associated with low levels of Ca and Mn and high levels of P in the foliage measured prior to death (Figure 3). The correlation coefficients for survival versus foliage Ca and Mn concentrations were 0.49 and 0.47, respectively and were significant. The correlation coefficient for survival versus foliage P was negative and significant, r = -0.40. Recall that flooding decreased Ca and Mn concentrations in foliage but had no significant effect on P concentrations in the foliage after one year of treatment.

A decline in cation uptake and hydrogen ion extrusion by the roots of severely stressed stecklings could have contributed to the difference in pH values between pots of survivors and non-survivors. The decreased concentrations of Ca and Mn in the foliage of non-survivors also support the possibility of a decline in selective ion uptake.

Whigham and Richardson (1988) reported that Atlantic white cedar has a high Ca requirement in spite of its association with peaty soil and acidic conditions. Fire, an important factor in the ecology of Atlantic white cedar, is known to release nutrients bound in organic matter and may play a role in providing adequate Ca on organic soils (McKee 1982). Peats may be deficient in Mn, and even though Mn solubility increases under reduced conditions, anaerobic microorganisms may be utilizing what Mn is available under flooded conditions. The higher concentration of P in the foliage of

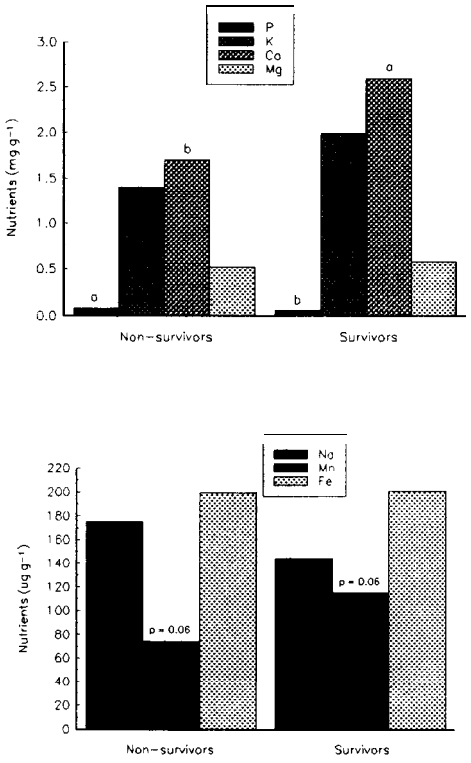

Figure 3-- Concentrations of selected nutrients in the foliage of flooded Atlantic white cedar stecklings after 1 year of flooding. Non-survivors did not survive the full 2 years of flooding whereas survivors were alive at the time of harvest after 2 years of flooding. Bars with the same letter or no letter are not significantly different at the 0.05 level.

stecklings that eventually died compared to survivors could have been related to the decline in growth resulting in the accumulation of P in the foliage.

No other variables measured prior to the death of flooded stecklings were significantly different between individuals that eventually died and individuals that survived. Apparently production of adventitious roots was not a factor in steckling survival, although survivors averaged more adventitious roots early on compared to those that eventually died, 3.6 compared to 2.9 roots per steckling.

SUMMARY

Results of this study indicate that Atlantic white cedar stecklings are moderately tolerant of flooded peat soils. However, continuous flooding of stecklings for two years resutted in significant stress response and a high percentage of mortality. Survivors appeared to be able to maintain aerobic respiration in root tissue possibly conserving the limited amount of photosynthate available from the greatly reduced foliage area of the shoot. In general, Atlantic white cedar appeared to have a high Ca requirement for survival under continuously flooded conditions and survivors were apparently able to maintain some degree of selective nutrient uptake. This requires significant inputs of energy which would also be intimately related to the maintenance of aerobic root respiration.

ACKNOWLEDGMENT

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SHADING AFFECTS DATE OF BUDBREAK IN NORTHERN RED, WHITE, AND SHUMARD OAK SEEDLINGS'

John Mullins, Charles McGee **and Edward Buckner**[2]

Abstract-During the spring of 1993 **budbreak** (initial elongation of the bud) was observed on 466 northern red, 367 whiie and **154** Shumard oak seedlings growing under 4 light levels - heavy, medium, and light shade and in full sunlight (30, 60, 70, and 100 percent of full sunlight, respectively). The average dates of bud break for the increasing light levels were: heavy shade- April 7; medium shade - April 9; light shade - April 11; and in the open (full sun) - April 14 . These findings indicate that bud-break patterns are significantly influenced by shading levels. Early bud-break under a canopy may help oak seedlings survive, however, when the canopy is removed, the buds continue to break early **which** may contribute to oak regeneration problems.

INTRODUCTION

Concern about problems in regenerating and growing oaks has been documented in forestry literature throughout the history of forest management in the U.S.(Clark 1993). Problems appear to be most acute on sites that supported high-quality oak stands prior to harvest. After studying 59 areas, Carvell and Tryon (1961) identified two important environmental factors affecting the presence or absence of oak regeneration: 1) the percent of sunlight reaching the forest floor, and 2) stand history during the previous 20 years. In general, advanced oak regeneration increases with increased light reaching the forest floor. Control of the understory in areas lacking advanced oak regeneration increased the establishment of oak seedlings and enhanced both their survival and vigor (Janzen and Hodges 1984).

The amount of light reaching the forest floor appears to be the critical factor influencing oak regeneration, affecting not only vigor and growth, but also phenology, and growth patterns (Hodges and Gardiner 1993). Stand management for oaks is not a problem where there is adequate advanced oak regeneration (Loftis 1993, Slander and Graney 1993, Smith 1993). In stands not having advanced oak regeneration successful management has been accomplished by underplanting oak seedlings and increasing the light to the forest floor (Tworkoski et al. 1986). McGee (1975, 1988) found that the date of budbreak was related to the levels of light seedlings received the previous season . Budbreak of seedlings released during the dormant season occurred up to 17 days earlier than that of seedlings that were in full sunlight the previous year. This pattern could place advanced oak reproduction at risk from late freezes.

METHODS

Acorns were collected in the fall of 1990 from northern red and white oak trees in East Tennessee and Shumard oaks in West Tennessee. White oak acorns were seeded in October, 1990 soon after collection; northern red and Shumard acorns were held in cool, moist storage until seeded on April 20, and May 10, 1991, respectively. Acorns were seeded into pots containing 0.012 cubic meter of a pine bark rooting medium. Water was provided by an automated dribble-ring irrigation system and each container was top dressed with 20 ml. Sierra 17-6-10 (plus minors) in May and July of both 1991 and 1992. During the winter months insulation board and leaf mulch were used to prevent the rooting medium from freezing.

Six shade houses and an adjacent open area provided space for 2 replications of 4 light levels (30%, 50%, and 70% of full sun and full sun). For each species, pots were randomly assigned to each of the 8 light-treatment locations. In November, 1991, the seedlings of each species at each treatment location were divided

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into 4 sub-groups which were randomly m-assigned, one to each of the 4 light levels for the 1992 growing season. This allowed one sub-group to stay in the same light level throughout the study while the other sub-groups were in a different light level the second growing season (1992).

During March, 1993,468 northern red oak, 357 white oak, and 154 Shumard oak seedlings were observed twice a week until budbreak activity was noted. At that time, observations of budbreak activii were made every other day until all trees had flushed. Data was analyzed using SAS GLM procedures (SAS 1985).

RESULTS

The average date of budbreak over all 3 species in 1993 for the 979 oak seedlings studied was April 10. Initial bud activity (budbreak) was first observed on April 5 in all 4 light levels. For seedlings grown in heavy and medium shade the previous season (1992) budbreak continued for 12 days (ending April 17); whereas for seedlings that grew under light shade and in full sun the previous season budbreak continued for 18 days (ending April 23). Differences in the average date of budbreak for seedlings grown the previous season under each of the 4 light levels tested was highly significant. These dates were: April 7 for heavy shade, April 9 for medium shade, April 11 for light shade, and April 14 for full sun.

For each species budbreak was first observed on April 5, and continued until April 23. There were significant differences among species in the average date of budbreak, which were April 9 for Shumard oak, April 10 for white oak, and April 11 for northern red oak (Table 1.).

The average date of budbreak for Shumard oak seedlings (April 9) was the earliest of the 3 oaks tested (Table 1.). Budbreak of seedlings grown under heavy shade the previous season (April 7) was significantly earlier than of those grown under light shade (April 8). For seedlings grown in full sunlight the previous season it was April 12, which was significantly later than Shumard seedlings in every other light level. There was no apparent effect of either mother tree or the 1991 light regime on the average date of budbreak in Shumard oak.

The average date of budbreak for white oak was April 10. There were significant differences in the average date of budbreak according to the light level the previous season (Table 1.). These were: April 7 for heavy shade, April 8 for medium shade, April 11 for light shade, and April 13 for full sun. There was no apparent mother tree effect on the date of budbreak. However the level of light in which the seedlings grew in 1991 appeared to effect 1993 budbreak. Seedlings grown in full sunlight and light shade during 1991 broke bud significantly earlier than seedlings grown under medium and heavy shade.

The average date of budbreak for northern red oak seedlings (April 11) was the latest of the 3 oaks tested. As with the other 2 oaks there were significant differences in the average date of bud break among seedlings grown in the different light levels the previous season (Table I), which were: April 8 for heavy shade, April 10 for medium shade, April 11 for light shade, and April 15 for full sun. There was no apparent effect of mother tree or the 1991 light regime on the average date of budbreak of northern red oak.

Table 1. Average date of budbreak by light level and species in 1993.

1992 Light Level	Shumard Oak		White Oak		Northern Red Oak	
	No.	Av. Date	No.	Av. Date	No.	Av. Date
Heavy Shade	39	April 7a[1/]	90	April 7a	112	April 8a
Med. Shade	37	April 8ab	91	April 8 b	113	April 10a
Light Shade	40	April 8 b	93	April 11 c	116	April 11 b
Full Sun	3 8	April 12 c	83	April 13 d	117	April 15 c
Tot./Mean	154 /	April 11 a[2/]	357 /	April 1 Ob	486 /	April 9c

[1/] Means within collums not followed by the same letter differ significantly (P< 0.001).
[2/] Overall means not followed by the same letter differ significantly (P< 0.001).

DISCUSSION AND CONCLUSIONS

The findings in this study support earlier claims that budbreak patterns in oaks vary significantly among light regimes and species. Seedlings grown in progressively higher levels of shade the previous year began growth progressively earlier than those grown in the open. The reason for this relationship is not clear.

Budbreak patterns have important ecological and managerial implications. Since oak seedlings shaded the previous season break bud up to a week earlier than open-grown oaks, they have a chance to grow and develop before the canopy leafs out and restricts their growth. This could be important to the survival of advanced oak regeneration. However, when a canopy is removed, as in a winter timber harvest, negative effects on oak regeneration can result. The released oak seedlings will break their buds early as if still in shade. This early budbreak, plus the removal of the protective canopy, increases exposure of advanced oak regeneration to spring frosts and freezes.

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THE PHYSIOLOGICAL DIVERSITY AND SIMILARITY OF TEN *QUERCUS* SPECIES[1]

S.S. Sung, M.N. Angelov, R.R. Doong, W.R. Harms, P.P. Kormanik and C.C. Black[2]

Abstract-Based on anatomical, photosynthetic, and biochemical data, the range of physiological differences and similarities was defined for ten Quercus species. There were no correlations between species' site adaptability, leaf anatomy and photosynthetic rate (A). For example, cherrybark oak, a mesic-hydrk type, and post oak, a xeric type, have the largest stomatal aperture among species examined; but the former has 55 percent higher maximum A than the latter. Northern red oak has twice as many stomata as Shumard oak and both species have similar stomatal aperture. Maximum A and photosynthetic active radiation at 50 percent maximum A (PAR,) of these species ranged between 6.3 and 19.6 μmol/m^2.s and between 160 and 360 μmol/m^2.s, respectively. Generally, seedling taproots have higher levels of soluble sugar and starch than stems. The highest levels of soluble sugar and starch in stems and roots occurred in July and November, respectively. Sucrose synthase was the dominant sucrose metabolizing enzyme activity and exhibited unique, characteristic seasonal patterns for roots and stems of northern red oak and cherrybark oak. It is concluded from these data that each oak species must be treated individually when incorporated into the management and restoration of ecosystems.

INTRODUCTION

To meet the demand for hardwood seedlings for the artificial regeneration and restoration of diverse ecosystems, we postulate that each tree species has unique traits and must be dealt with individually. For example, many Quercus species grow well only over a narrow range of sites with different soil moisture contents. Furthermore, relative terms such as shade intolerant and tolerant are often used to describe light requirements of these species (Burns and Honkala 1990). However, only a few studies reported the quantitative light requirements for photosynthesis for a limited number of oak species (Hanson and others 1988; Kleiner and others 1992; Kubiske and Abrams 1992; Weber and Gates 1990). The seasonal relationships between sucrose sources, such as photosynthetic and sucrose exporting leaves, and sinks, such as sucrose importing, growing, and reserve storing stems and roots, need to be established to further understand the biology of individual species. Performance of each species in the ecosystems can then be evaluated quantitatively. The objectives of this study were to grow ten oak species individually adapted to a range of soil water conditions from hydric to xeric under the same field conditions and to study some parameters that determine the dynamic source-sink relationships of these plants.

MATERIALS AND METHODS

Seedling Culture

Seedlings of 10 oak species, black (Quercus *velutina* Lam.), bur (Q. *macrocarpa* Michx.), cherrybark (Q. pagoda Raf.), chestnut (Q. *prinus* L.), northern red (Q. *rubra* L.), nuttall (Q. *nuttallii* Palmer), overcup (Q. *lyrata* Walt.), post (Q. *stellata* Wangenh.), Shumard (Q. *shumardii* Buckl.), and white oak (Q. *alba* L.), were grown according to a single nursery cultural protocol by Kormanik and others (1994) at the Georgia Forestry Commission's Flint River Nursery located near Montezuma, GA. The seedlings were lifted at the end of the first growing season and transplanted into the Institute of Tree Root Biology experimental nursery beds at Whitehall Nursery, Athens, GA in mid-January 1992.

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Leaf Anatomy And Photosynthesis

In July 1993, mature leaves of all species except chestnut and white oak were harvested and prepared for scanning electron microscopy (SEM) wlth a Philips 505 scanning electron microscope following Angelov and others (1993). A portable LiCor 6200 infrared gas analyzer was used to measure net photosynthetic rate (A) from recently mature attached leaves of all species during the summer 1993. Neutral density screens were rapidly placed over leaves to obtain photosynthetic light response curves. Photosynthetic active radiation at 50 percent of maximum A (PAR,) was determined from these light response curves. On July 2, 1993 a one-year-old northern red oak seedling, grown under similar nursery conditions as the other oak seedlings, was randomly selected and A was measured for all the leaves

Nonstructural Carbohydrate Contents

In July and November 1993 and March and May 1994, stems and taproots of all species except chestnut and white oak were harvested for nonstructural carbohydrate analysis using the extraction procedures by Angelov and others (1993). Soluble sugars, namely, sucrose, glucose, and fructose, were determined following van Handel (1968), Slein (1965), and Klotzch and Bergmeyer (1965), respectively. Extracted sample starch was first digested with amiloglucosidase at 55 ° C for 2 hours and glucose released was determined (Angelov and others 1993).

Sucrolytic Enzyme Activity

From April to December 1993, stem and taproot cambial and ray cells of northern red and cherrybark oak seedlings were sampled monthly for sucrolytic enzyme activity. Tissue sampling, enzyme extraction, and activity determination followed the procedures of Sung and others (1993). Activities of sucrose synthase (SS), acid invertase (AI), and neutral invertase (NI) were determined with a DU-70 spectrophotometer.

RESULTS AND DISCUSSION

Oak species generally are classified into groups reflecting site adaptability based on soil moisture content (Burns and Honkala 1990). Nuttall and overcup oaks are hydric type and cherrybark and Shumard oaks are mesic-hydric type. Black, northern red, and white oaks grow best on the mesic sites. Bur and chestnut oaks are xeric-mesic and post oak is a xeric species. Leaf anatomy, net photosynthesis, and nonstructural carbohydrate contents of different oak species were presented according to their tentative site adaptability.

Leaf Anatomy And Photosynthesis

Among the eight species examined, Shumard and northern red oaks had the smallest stomatal aperture and cherrybark and post oaks had the largest (Table 1). Shumard and post oaks had about 50 percent and 60 percent fewer stomata per unit leaf area as compared to those of northern red and cherrybark oaks, respectively. Nuttall oak, however, had similar stomatal aperture and density to those of black oak. No consistent relationships between stomatal aperture and density were observed. Furthermore, no correlations between species' site adaptability and its stomatal aperture and density existed (Table 1). This is the first report on stomatal aperture and density for all oak species studied except northern red oak. Kubiske and Abrams (1992) reported a 7-fold lower stomatal density in northern red oak than this study. Nonetheless, they did not find any differences in stomatal density between the mesic and xeric ecotypes of northern red oak seedlings.

Table l-Stomata1 aperture and density of mature *Quercus* leaves as determined from scanning electron microscopy

Site adaptability	Species	Stomatal aperture μm	Stomatal density mm^{-2}
Hydric	Nuttall	9.4	1228 ± 96
	Overcup	11.7	678 ± 53
Mesic-Hydric	Cherrybark	12.4	1580 ± 228
	Shumard	7.5	1357 ± 166
Mesic	Black	9.4	1034 ± 117
	Northern red	7.2	2600 ± 341
Xeric-Mesic	Bur	11.7	1443 ± 240
Xeric	Post	12.5	585 ± 37

Maximum A reported in Table 2 were similar in range to those reported earlier (Kleiner and others 1992; Kubiske and Abrams 1992; Weber and Gates 1990). Among the ten oak species, cherrybark oak was the most photosynthetically active species, followed by bur oak (Table 2). Nuttall oak was the least photosynthetically active species. Total photosynthate production potential (i.e., source strength) of a given species can be readily estimated from net

photosynthetic rate, leaf size, and leaf number. Table 2 also presents average leaf size and northern red and bur oaks had the largest leaves while nuttall and white oaks had the smallest. In an oak nursery study reported by Kormanik and others (1994), however, nuttall oak seedlings were among the top species with the greatest seedling height and root collar diameter. Although nuttall oak had the smallest leaf size and the lowest A, this species may compensate for its lower source strength, relative to other species of comparable seedling size, by producing more leaves.

Table 2 -Maximum net photosynthetic rate (Max A), photosynthetic active radiation at 50 percent of Max A (PAR,), and average leaf size of recently mature attached *Quercus*, *Liquidambar*, and *Acer* leaves

Site adaptability	Species	Max A	PAR,	Leaf size
		μmol/m^2.s	μmol/m^2.s	cm^2
Hydric	Nuttall oak	6.27	360	34
	Overcup oak	11.71	340	57
Mesic-Hydric	Cherrybark oak	19.75	200	75
	Shumard oak	10.25	160	70
Mesic	Black oak	12.88	360	85
	Northern red oak	13.61	250	132
	White oak (regular)	12.49	260	44
	White oak (lammas)	16.49	200	114
	Red maple	11.02	220	45
	Sweetgum	22.24	320	70
Xeric-Mesic	Bur oak	17.19	260	94
	Chestnut oak	11.55	260	81
Xeric	Post oak	12.60	230	47

Northern red oak seedlings can be more than twice as large in size as white oak seedlings under the same growth conditions (Kormanik and others 1994). Although A did not differ between them, average leaf size of northern red oak was three-fold greater than white oak leaf size (Table 2). However, some white oak seedlings developed one or two flushes of lammas shoots in summer and early fall. These lammas leaves had 30 percent higher A and 160 percent greater leaf size compared to non-lammas regular leaves. Therefore, white oak seedlings with lammas shoots were larger in size than those without lammas shoots (Kormanik and others 1995). Beerling and Chaloner (1993) did report that the lammas leaves of *Q. robur* trees were 50 percent smaller in leaf size than regular leaves. Whether other white oak species have lammas shoots and whether lammas leaves are larger than the regular leaves have not been studied.

In addiion to A, leaf size, and leaf number, another factor must be considered when estimating source strength of a given species. When all the leaves on a northern red oak seedling were measured for A on the same day, variations in A were observed (Fig. 1). The youngest three leaves in the last flush had similar A and leaf size as those of the oldest flush. Even when a leaf reached its full size, as the number 8 leaf of the third flush, its A was not the highest. Leaves of number 9, 15, and 17 were the most active in photosynthesis. Hanson and others (1988) also reported that northern red oak leaf A increased during development up to and beyond full leaf expansion. In this study, A was measured in early July. As reported by Koike (1987), A of the same *Acer mono* Maxim. leaves maintained 90 percent of the max A for two months and then decreased. Therefore, the developmental patterns of individual leaf A, such as the one shown in Figure 1, will change as seedlings continued to grow. This type of dynamic source strength needs to be defined for individual oak species.

Generally, the degree of oak species shade tolerance or intolerance has not been quantitatively determined. To further understand the meaning of shade tolerance, PAR_{50} values were calculated for each oak species and two other species grown at Whitehall Nursery: sweetgum (*Liquidambar styraciflua* L.), a shade intolerant species, and red maple (*Acer rubrum* L.), a shade tolerant species (Table 2). The usefulness of PAR_{50} value for quantifying shade tolerance can be demonstrated with the study of Koike (1987). The PAR_{50} values obtained from light curves were 160 and 260 μmol/m^2.s for shade tolerant *A. mono* and shade intolerant *Betula platyphylla* Sukatch. var. *japonica* Hara, respectively (Koike 1987). When compared to red maple leaves, the lower PAR, values of Shumard, cherrybark, and white oak lammas leaves indicated that these oak species can tolerate more shade than red maple. Leaves of nuttall, black, and overcup oak had higher PAR, values than sweetgum leaves and were probably more shade intolerant than sweetgum. White oak seedlings with lammas shoots can tolerate more shade than those without lammas shoots (Table 2). Finally, no differences were observed in the degree of

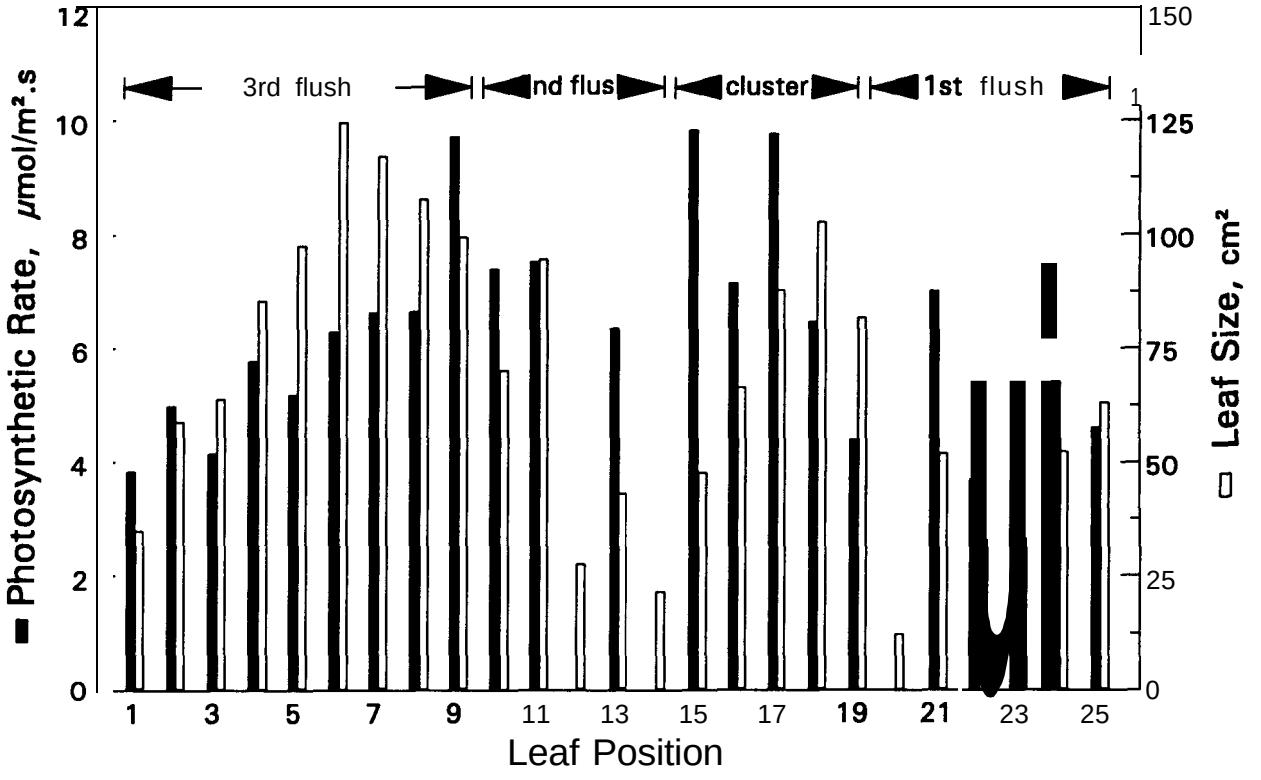

Figure l-Developmental patterns of photosynthetic rate and leaf size measured from a one-year-old northern red oak seedling on July 2, 1993. Leaf position numbers started basipetally from the shoot tip. Leaves 12, 14, and 20 were sessile and inaccessible for photosynthesis measurement.

shade tolerance, in terms of PAR_{50}, between white oak seedlings without lammas shoots and northern red oak.

Nonstructural Carbohydrate Contents

Generally, no differences in the nonstructural carbohydrate contents between species of different site adaptability were found throughout the sampling period (data not shown). Therefore, the nonstructural carbohydrate values from two hydric and two mesic-hydric species, from two mesic species, and from a xeric-mesic and a xeric species were grouped, averaged, and presented in Figure 2. Moreover, because no differences in glucose, fructose, and sucrose contents in all species were observed, these sugars were grouped as soluble sugar (Fig 2). Both the stems and roots of all species had a higher percent starch than soluble sugar (Fig 2a vs c; b vs d). Similar spatial and temporal patterns for the nonstructural carbohydrate contents were observed among all species analyzed. Roots contained more soluble sugar and starch than stems (Fig 2a vs b; c vs d). Stem and root samples collected in July and November 1993 had the highest levels of soluble sugar and starch, respectively. Decreases in root starch contents in spring were consistent. This may be the result of remobilizing starch reserves in stems and taproots to sustain renewed bud activity until newly expanded leaves become photoautotrophic.

Sucrolytic Enzyme Activity

This is the first study on the sucrolytic enzymes of oak seedlings. In stem and taproot cambial and ray tissues of northern red oak (Fig 3) and cherrybark oak (Fig 4) seedlings, sucrose synthase (SS) was the dominant sucrose cleavage activii. The other sucrose cleaving enzymes, namely acid invertase (AI) and neutral invertase (NI), were less than 10 percent of SS activity during most of the growing season (Fig 3, 4). Clear, unique seasonal patterns for stem and root SS activity existed in both species. However, the fluctuations in invertase activity were not seasonal. Generally, levels of SS activity in stems and roots of both species were low during the dormant period. Seedling SS activity increased as leaves became mature and exported

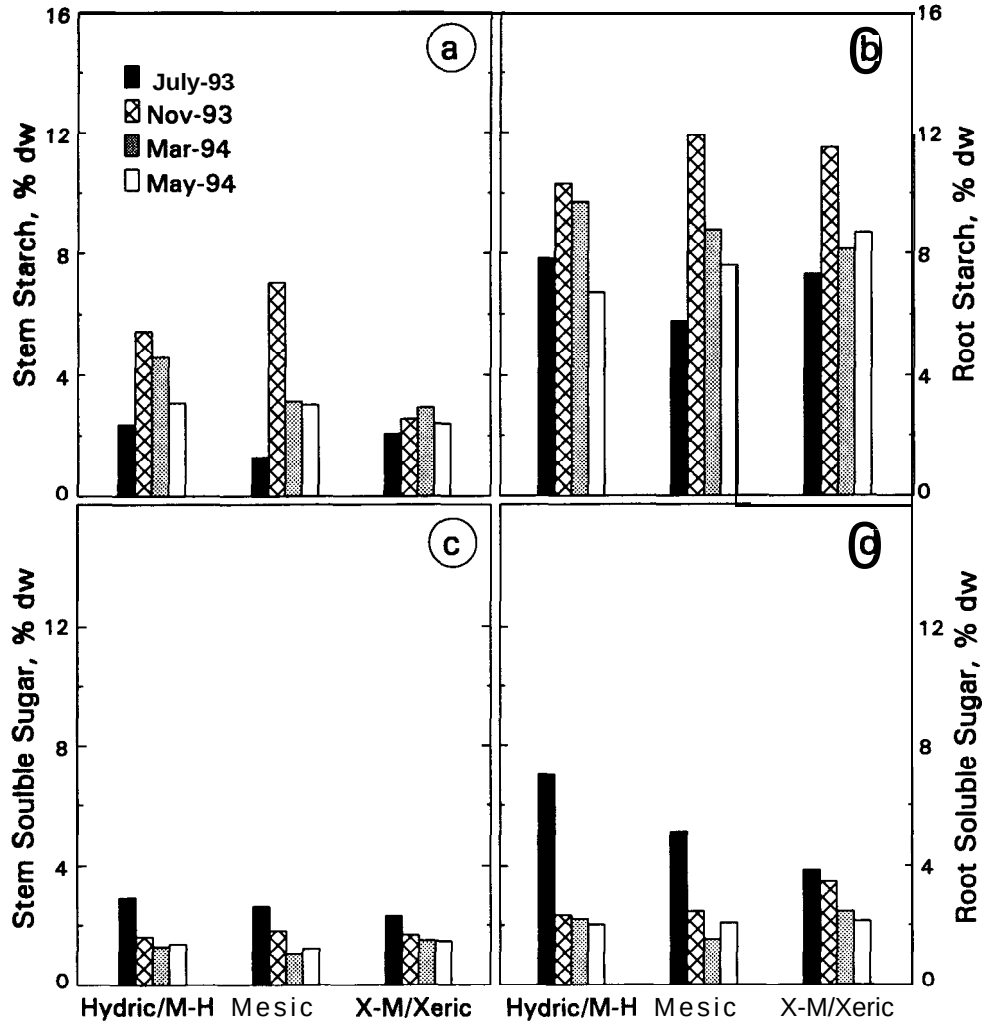

Figure 2-Seasonal seedling nonstructural carbohydrate contents, percent dry weight, of eight oak species. Hydric/Mesic-Hydric group included nuttall, overcup, cherrybark, and Shumard oak. Mesic species included black and northern red oak. Xeric-Mesic/Xeric group included bur and post oak. (a) stem starch, (b) root starch, (c) stem soluble sugar (sucrose plus glucose plus fructose), (d) root soluble sugar (sucrose plus glucose plus fructose).

photosynthates in spring. These results are consistent with those reported in studies of loblolly pine (Sung and others 1993) and sweetgum seedlings (Sung and others 1989a).

From early to mid-April, *stem SS* activity increased 1 and 3-fold, respectively, in northern red and cherrybark oaks (Fig 3a, 4a), and peak stem SS activity occurred in early May. Sharp decreases in stem SS activity occurred toward late September in northern red oak and mid-November in cherrybark oak. Compared to northern red oak, SS activity in cherrybark oak seedling stems was more active for a longer duration throughout the year (Fig 3a, 4a). Field observations indicated that cherrybark oak seedlings maintain green leaves for at least 6 weeks longer than northern red oak seedlings. These green leaves may continue to photosynthesize during winter when temperature allows, as do southern pine needles (Kuhns and Gjerstad 1991; Sung and others 1993).

Generally, root cambial and ray tissues had lower levels of SS activity than stems in both species (Fig 3a vs b; 4a vs b). Spring peak root SS activity of northern red oak occurred two weeks later than stem activity. On the other hand, cherrybark oak root and stem SS

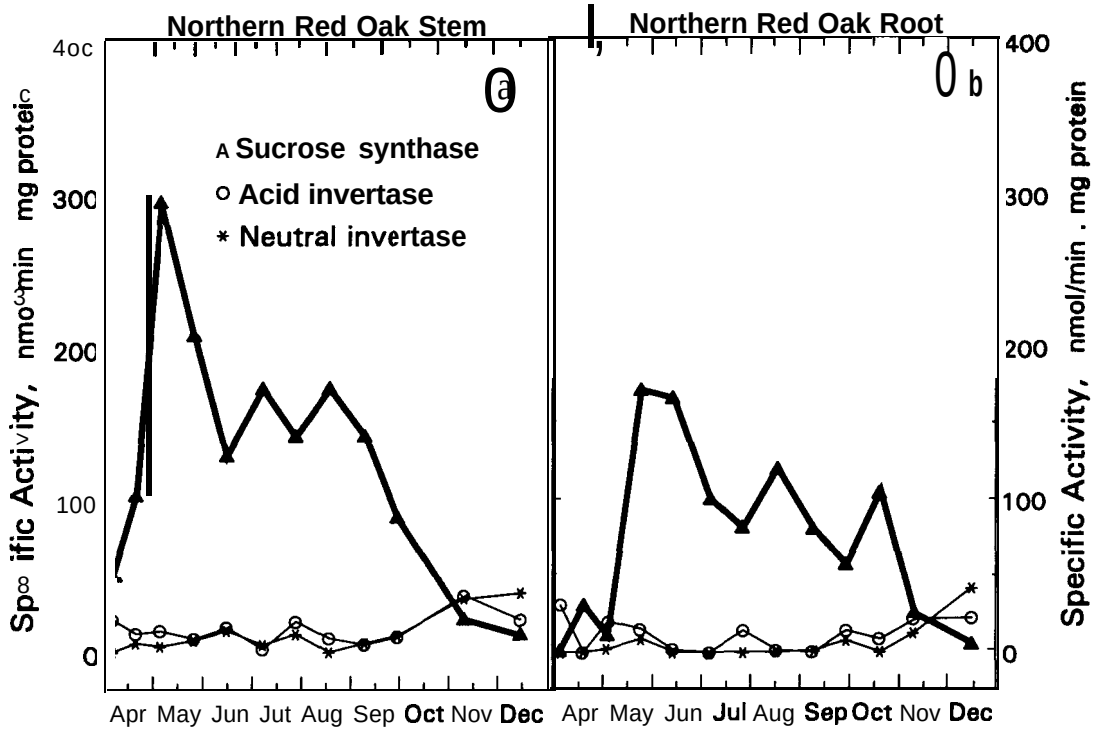

Figure 3-Seasonal activity patterns for sucrolytic enzymes in cambial and ray tissues of northern red oak seedling stems (a) and taproots (b).

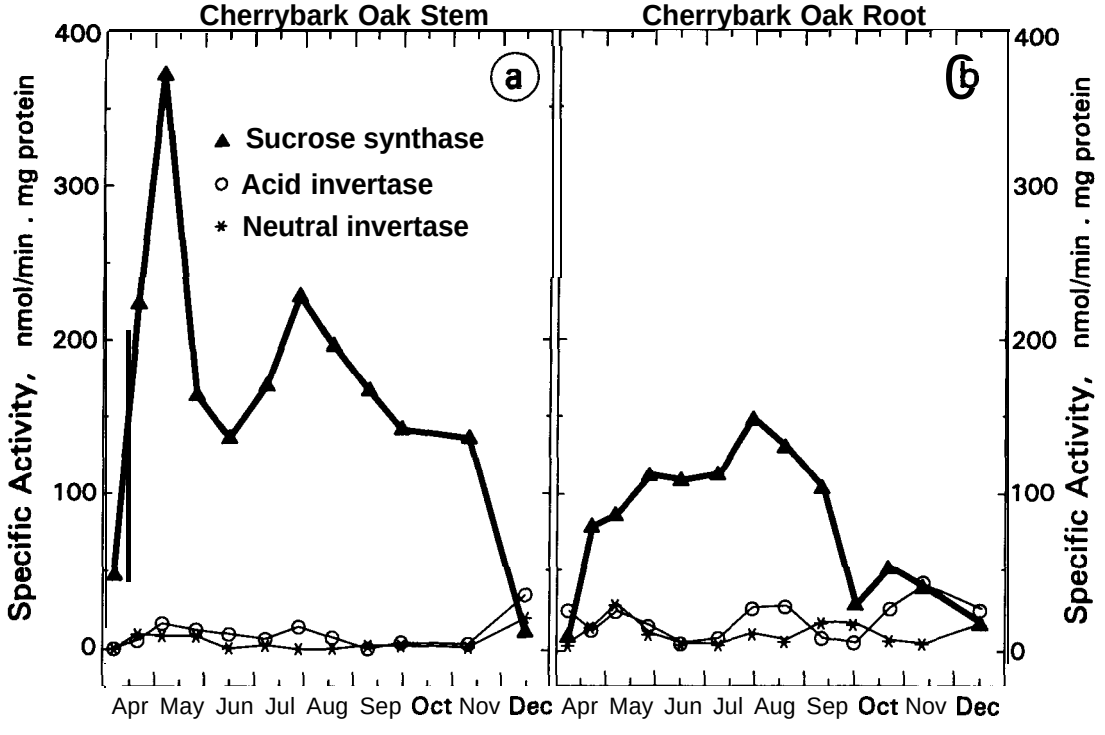

Figure 4--Seasonal activity patterns for sucrolytic enzymes in cambial and ray tissues of cherrybark oak seedling stems (a) and taproots (b).

activity increased 3-fold during the first two weeks of April (Fig 4). Cherrybark oak root SS activity resumed earlier in spring and decreased earlier in fall than that of northern red oak root (Fig 3b vs 4b).

To speculate that other oak species also have SS, Al, and NI to metabolize sucrose with SS as the dominant activity is reasonable. Each species, however, might have unique, characteristic seasonal and spatial patterns in SS activity. Sucrose synthase activity has been associated with growth, development, and reserve storage in plants (Sung and others 1989a, 1989b, 1993, 1994; Xu and others 1989). Thus, the temporal and spatial patterns of SS activity might be used to quantify sink strength in trees. When the ranges of dynamic source and sink strength are defined for each oak species, the biological position of the given species in the ecosystems, such as shade tolerance and site adaptability, can be redefined or explained.

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EFFECT OF APICAL MERISTEM CLIPPING ON CARBON ALLOCATION AND MORPHOLOGICAL DEVELOPMENT OF WHITE OAK SEEDLINGS[1]

P.P. Kormanik, S.S. Sung, T.L. Kormanik and S.J. Zarnoch[2]

Abstract-Seedlings from three open-pollinated half-sib white oak seedlots were clipped in mid-July and their development was compared to nonclipped controls after one growing season. In general when data were analyzed by family clipped seedlings were significantly less desirable in three to six of the eight variables tested. Numerically, in all families seedlots, the clipped seedlings were inferior to the controls. Regardless of clipping treatment, the growth variable that affected seedling development the most was the innate ability to develop lammas shoots. Seedlings that produced late season lammas shoots also produced the largest numbers for each of the eight variables tested.

INTRODUCTION

The range of white oak (*Quercus alba*) includes the entire eastern half of the United States because it can adapt to many climatic, edaphic and topographic conditions. It is one of the most commercially valuable oak timber species. White oak is also an important mast producer for wildlife such as squirrels, bluejays, crows, red-headed woodpeckers, deer, turkey, quail, mice, chipmunks, ducks, and raccoons (Rodgers 1990). Currently, white oak plays a major role in multiple use management and is usually included in other biodiversity and restoration ecology efforts.

Unfortunately, artificial regeneration of this valuable and adaptive species has been generally unsuccessful. Even though State nurseries have been providing white oak seedlings for over 50 years, successful plantings or plantations are difficult to find (Boyette 1980; Hill 1986; Kormanik and others 1989). In many instances, planting white oak is not recommended because attempts to artificially regenerate the species consistently fail (Russell 1971; Boyette 1980; Clausen 1983; Hill 1986). Most plantings fail because seedlings show poor growth and survival rates when they compete with herbaceous weeds and other woody, perennial plants. To assess the competitive ability of these seedlings, grading standards are needed. However, developing grading standards for the small white oak seedlings, which range from 25-30 cm in size, has been difficult.

At the Institute of Tree Root Biology (ITRB), we are developing a nursery fertility/management protocol for growing various species of oak and other hardwoods similar to the protocol for loblolly pine (Kormanik and others 1992). In one of the hardwood nursery trials at the Whitehall Experimental Nursery, deer browsed some of the white oak seedlings in mid-July. By mid-August we noted that browsing had affected the morphological development of the seedlings. We found a large variation in growth among the browsed seedlings; however, some of the browsed seedlings were 20 to 30 cm taller than adjacent nonbrowsed seedlings.

Normally, few axillary buds of white oak elongate in the nursery during the year of initiation except perhaps those at the terminal end of the initial flush. This strong apical control on axillary buds (Brown and others 1967) is evident even when cultural treatments result in five flushes instead of the three flushes typical in white oak seedlings. Browsing, however, resulted in rapid axillary bud elongation and lammas-like shoot development in some seedlings in late July. This shoot development is not usually observed on white oak seedlings until mid-August. We were unable to obtain reliable estimates of root and stem development of the browsed seedlings because (1) the number of seedlings affected was limited and (2) the seedlings were from a mixed seedlot

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and obvious seed source differences were apparent within the nursery beds.

The objectives of this study were to determine the effect of clipping on (1) seedling height, root collar diameters (RCD) and number of elongated axillary buds; (2) total weight and weight of component parts of seedlings; and (3) root/stem morphology of seedlings.

METHODS

White oak acorns were collected daily from three different mother trees from seedlots 2, 3, and 4 in Clarke County, Georgia, during October-November 1992. The acorns were immediately placed in water and those that floated were discarded. Acorns that sank and showed no evidence of weevil or other damage were placed in plastic bags and stored at 2 to 4 °C until sown.

In late December 1992, acorns were sown in a single raised nursery bed described in detail earlier (Kormanik 1986; Kormanik and others 1990). Based on soil sample analyses from A&L Laboratories, Memphis, TN, the soils were amended with the appropriate fertilizers to obtain the following levels of P, K, Ca, Mg, Cu, Zn, and B, respectively 80, 80, 500, 50, 2.5, 5, and 0.8 ppm, and a pH of 5.8. In other nursery studies these levels had been shown to be appropriate for many species of hardwood including white oak (Kormanik and others 1993; 1994).

Nitrogen, applied as NH_4NO_3 at rates equivalent to 1345 kg/ha (1200 lb/acre) began in mid-May and continued at 10 day intervals until mid-September. Four diierent rates were used in the 11 applications. The first two applications were at a rate equivalent to 28 kg/ha (25 lb/acre), the third at 56 kg/ha (50 lb/acre), the next six applications were at 168 kg/ha (150 lb/acre) and the final two at 112 kg/ha (100 lb/acre). If needed, seedlings were watered daily until the first growth flush was essentially complete for all seedlots and some seedlings were beginning their second flush. At this point, seedlings received water when moisture tensionmeters registered 30-50 centibars at a depth of 15 to 20 cm. During excessively hot periods, watering occurred at 30 centibars, while during cooler periods, watering was delayed until 50 centibars.

Sixteen continuous rows were assigned to each half-sib mother tree seedlot with 13 acorns placed in each row. This resulted in effective seedling density of 54 to 57/m^2. Within each half-sib seedlot one row of each of the seven pairs of rows was randomly chosen to be clipped. The remaining row in each pair became the nonclipped control row. Clipping was completed on July 13, 1993, and consisted of cutting approximately 3 to 5 cm off the current flush. The clipping was internodal and just above either a developed or immature axillary bud. In mid-December 1993, the seedlings were lifted and heights, RCD, first-order lateral root (FOLR) numbers, stem, and root green weights, lammas shoot development and seedling survival rates were obtained.

In this study, each seedlot was treated as a separate experiment. The experiments were analyzed as randomized block designs where the treatments were nonclipped and clipped. Since there were only two treatments, this analysis was equivalent to a paired t-test. Blocks were defined as adjacent pairs of rows in the nursery bed to which the two treatments were assigned at random, one to each row. The experimental unit was a row and the response variables were defined as row means based on thirteen seedlings. Similarly, survival percent and lammas shoot percent were computed on a row basis. Multiple embryos in about 10 to 15 percent of the acorns complicated survival data. Usually the largest seedling was maintained and measured when multiple embryo clusters occurred. Treatment differences were tested at the 0.05 probability level using PROC GLM (SAS Institute 1988).

RESULTS AND DISCUSSION

In this study, the clipping treatment and the innate ability of individual seedlings to develop lammas shoots affected seedling development and survival. Lammas shoot development was the most significant biological response and may be the most important factor in the artificial regeneration of white oak.

Effects of Clipping on Seedling Development

Clipping significantly affected seedling development in some half-sib mother tree seedlots for specific measured variables. However, because the overall responses were sometimes marginal and variable, they may not be of practical significance. Table 1 shows the sample means for clipped and nonclipped white oak seedlings for the eight variables and the associated P values from the analysis of variance. Half-sib seedlot differences in how clipping affected the variables were significant. However, the number of variables significantly different varied by family; the progeny from mother tree 4 were the most consistent. Numbers and

Table l-Effects of clipping on growth, survival, and P-values for white oak seedlings from three open-pollinated half-sib seedlots

	RCD mm	Hgt cm	FOLR' No.	Top wgt g	Root wgt g	Total wgt g	Survival pct	Lammas shoot pct
				Family 2[b]				
Nonclipped	5.48	30.8	3.02	18.7	43.0	61.8	81.3	37.7
Clipped	5.17	27.7	2.00	14.4	33.1	47.5	73.6	15.6
P-value'	0.257	0.185	0.123	0.084	0.042	0.051	0.086	0.009
				Family 3[b]				
Nonclipped	5.68	29.2	4.21	16.4	37.2	53.6	71.4	37.5
Clipped	4.61	27.0	1.94	12.1	26.4	38.5	63.7	8.9
P-value'	0.090	0.465	0.043	0.150	0.086	0.101	0.449	0.001
				Family 4[d]				
Nonclipped	7.34	53.6	5.51	29.9	49.1	79.0	96.2	69.1
Clipped	6.15	47.4	2.95	19.5	32.6	52.1	91.0	54.1
P-value[c]	0.005	0.059	0.013	0.006	0.002	0.002	0.235	0.179

[a] FOLR = first-order lateral root.
[b] Based on 7 blocks.
[c] The p-value obtained from testing the hypothesis that nonclipped and clipped means are equal.
[d] Based on 6 blocks.

proximal diameters of FOLR ≥1 mm were used to assess potential competitiveness of white oak seedlings (Kormanik and others 1989). Clipping reduced numbers of FOLR exceeding this minimum diameter which in turn, reduced root weights by approximately 30 percent.

Like deer browsing, clipping resulted in the release of axillary buds, usually immediately below the severed internode. The degree of elongation of these stimulated shoots varied considerably, both within and among half-sib mother tree seedlots. Several weeks passed before the axillary buds were released from their quiescent condition. During this period, the nonclipped seedlings continued to undergo sequential flushes so commonly observed in oak seedlings in nurseries. Even with continued flushing, the overall mean sizes of seedlings (table 1), except those from half-sib seedlot 4 were no larger than normally reported (Boyette 1980; Hill 1986). Past and ongoing research at this location indicates that the time period when FOLR development of nonclipped seedlings accelerates is between flushes 3 and 4 and 4 and 5. Although the study design did not allow for periodic seedling excavation to follow seasonal FOLR development, the lag period between clipping and axillary bud elongation suggests a wound response in terms of carbon sink relationships. We believe that root growth was restricted while carbon was shunted to repair clipping damage to the stem.

When the study was terminated, the clipped seedlings with no significant elongation had few, if any, FOLR that were ≥1 mm in diameter and had poorly developed root system. However, clipping was not the cause of poor root development. We found that nonclipped seedlings exhibiting poor growth were similar to the smaller clipped seedlings in both stem size and root system morphological development. Seedlings wlth undersirable growth and development had a significant impact on the mean growth variable shown in table 1. Unsatisfactory nursery development of open-pollinated half-sib progeny of white oak below a variables mean value has been shown to be accompanied by poor development of FOLR. Unfortunately, a high percentage of white oak seedlings from specific mother trees may be so affected (Kormanik and others 1989). Many of these inconsistencies were observed in the

past and can now be explained, in part, by lammas shoot development recorded in this study.

Effect of Lammas Shoots on Seedling Development

The response of white oak seedlings to the clipping treatment was of minor significance compared to normal lammas shoot development. It is well known that white oak seedlings tend to develop lammas shoots in late summer and early fall (Busgen and Munch 1929; Zimmermann and Brown 1971; Kramer and Kozlowksi 1979). In our nurseries studies, with white oak when either or both fourth and fifth flushes occur, these flushes can readily be classified as "lammas" rather than "proleptic" shoots (Kramer and Kozlowski 1979). Characteristically, these lammas shoots produce leaves that may be 3- to 7-fold larger in surface area than leaves produced earlier in the growing season. In the past, we have paid liie attention to lammas shoots of white oak except to note their presence (Kormanik and others 1989; 1993).

Lammas shoot development is believed to be under genetic control (Cannell and Last 1976; Kramer and Kozlowski 1979). Our study supports this theory because 38 to 69 percent of the nonclipped seedlings produced lammas shoots. Moreover, in seedlots 2 and 3 clipping significantly reduced lammas shoot development. We found lammas shoots always developed from the terminal bud and the shoots from axillary buds released by clipping rarely exhibited typical lammas growth characteristics.

Mean values of the growth variables for clipped and nonclipped seedlings by lammas shoot development show the impact of lammas shoots on stem and root development (table 2). Because lammas shoot growth was a dichotomous response variable (yes or no) and was not an independent experimental variable, we felt that formal statistical tests for differences were inappropriate and might be misleading.

All individuals with lammas shoots were superior in all seedling development characteristics (table 2). Most pronounced differences occurred in FOLR numbers and weight of component seedling parts. These growth responses related to lammas shoot development help to explain early FOLR development patterns in white oak (Kormanik and others 1989; 1993). Normally, diameter growth of FOLR accelerates in late summer or early fall. This acceleration coincides closely with lammas shoot development with white oak seedlings in this study.

Table 2-Effect of lammas shoot development on growth of clipped and nonclipped white oak seedlings

Family	Treat-ment[a]	Shoot[b] growth	RCD mm	Hgt cm	FOLR[c] No.	Top wgt g	Root wgt g	Total wgt g
2	1	0	4.7	24.7	1.4	11.7	28.1	39.8
	1	1	7.7	43.9	5.2	28.0	58.2	86.2
2	0	0	3.9	19.6	0.7	6.5	21.5	28.0
	0	1	8.0	48.1	6.5	37.4	76.2	113.5
3	1	0	4.4	24.9	1.5	10.2	23.6	33.8
	1	1	7.4	48.4	6.8	32.4	56.5	88.9
3	0	0	4.6	20.2	1.9	8.7	24.2	32.8
	0	1	7.3	43.2	7.6	29.0	57.1	86.0
4	1	0	4.5	33.6	0.7	8.9	18.8	27.7
	1	1	7.5	58.8	4.9	28.2	44.3	72.5
4	0	0	5.6	34.0	1.8	9.8	30.0	39.9
	0	1	8.0	62.1	7.1	38.7	57.1	95.9

[a] 1 = clipped; 0 = control.
[b] 1 = lammas shoot; 0 = NO lammas shoot.
[c] FOLR = first-order lateral root.

Table 3-Characteristics for leaves grown on normal shoot and lammas shoot of white oak seedlings.

Leaf type	Leaf area cm^2	Photosynthesis rate $umol/m^2.sec$	Total leaf photosynthesis $nmol/leaf.sec\ mg/cm^2$	Leaf specific weight
Mature normal	23	14.1	32.4	0.6
Mature normal	51	14.5	74.0	9.2
Mature lammas	132	14.6	192.7	11.6
Mature lammas	140	13.5	189.0	9.3

Seedlings exhibiting lammas shoot development were taller and had higher numbers of FOLR regardless of clipping treatment This observation parallels earlier observations where seedlings with six or more FOLR were two times taller and had RCDs twice as large as those with less than six FOLR. Earlier research had shown even greater variation among root and stem weights where 4- to 7-fold differences in root and stem weight were associated with greater numbers of FOLR (Kormanik and others 1989; 1990). The largest seedlings in all studies frequently had two consecutive lammas shoot episodes.

Based on these data (tables 1 and 2), a direct genetic correlation between FOLR development and lammas shoots with this species appears to exist. Our research supports the hypothesis that the most dominant and codominant oak trees in the forest were those that were able to make rapid juvenile growth (Korstain 1927). This permitted them to get ahead of the herbaceous competition that is encountered after overstory harvesting. Therefore, the innate ability to produce lammas shoots may be significant in white oak seedling establishment. How long seedlings have the potential to produce lammas shoots is unknown. Even a lammas shoot development period of only 3 to 4 years, may contribute to seedling success.

We also measured photosynthesis and found that photosynthetic rates per unit leaf area are the same for the large lammas shoots/leaves and the smaller leaves produced earlier in the summer. The advantage of lammas leaves lies in their greater total leaf area that contributes significantly more carbon for seedling development (table 3).

We have also observed in several ongoing research studies at the ITRB that seedlings that develop lammas shoots the first year may also develop lammas shoots in the second growing season. When grown under proper nursery cultural conditions, transplanted white oak that developed lammas shoots the first and second years, attained heights from 1.7 to 1.8 m after the second growing season.

CONCLUSION

Clipping whiie oak seedlings does not improve seedling qualii and is not recommended for improving seedling size or quality. Although lammas shoot development in nursery stock production has not been studies extensively, this innate trait may be important in early selection of competitive individual seedlings for outplanting. Clipping can significantly reduce the development of lammas shoots. When clipped seedlings develop lammas shoots, total height and RCD are comparable, but weight of other component parts of seedlings may be significantly reduced.

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TALLOWTREE (*Sapium sebiferum* L.) ALLELOPATHY AFFECTS LOBLOLLY PINE SEED GERMINATION AND SEEDLING GROWTH[1]

Charles A. Gresham[2]

Abstract-No regeneration was found in areas of a two-story loblolly pine stand that contained tallowtree (*Sapium sebiferum* L). To test for allelopathic interactions and tannic acid being the allelochem, loblolly pine seed germination and seedling growth was monitored in greenhouse experiments involving leaf leachate solutions and planting media treatments. Aqueous extracts of dry tallowtree and frozen leaves each reduced seed germination and seedling growth. Tannic acid solutions had few significant effects. Seed sown in soil from tallowtree areas had less germination, but the surviving seedlings grew the same as seedlings growing in soil from non-tallowtree areas. Aqueous leachates of dry tallowtree leaves reduced germination and root biomass of seed sown in non-tallow forest soil.

INTRODUCTION

A **naturally regenerated, two-story loblolly pine (*Pinus taeda* L.) stand** in South Carolina's lower Coastal Plain resulted from a 1959 high-grade cut. Those trees not cut then form the present overstory strata and seed and/or seedlings in place released by the high-grade cut form the present midstory. Below the **midstory** is an understory of Southern bayberry (*Myrica cerifera* L.) and tallowtree (*Sapium sebiferum* (L.) Roxb.). While inventorying this stand it was noticed **that those sections that contained tallowtree** in the understory did not have **a** loblolly pine midstory, even though there were overstory trees above the tallowtree. However, other sections that did not have tallowtree in the understory had a well stocked loblolly pine midstory. What could cause this relation? The overstory pines were present throughout the stand, thus all sections probably had the same seedfall. The soil type was the same throughout the stand, **as** was the microtopography, which rules out excessive or limiting soil moisture or nutrients. Tallowtree density was not sufficiently high to reason that shade **was a** significant factor.

Allelopathy is defined as "any direct or indirect harmful effect by one plant (including microorganisms) on another through the production of chemical compounds that escape into the environment' (Rice 1974). Allelopathic relations between loblolly pine and broomsedge (*Andropogon virginicus* L.) (Priester and Pennington 1978), old field herbs (Hollis et al. 1982), fescue (*Festuca arendinacea* L.) (Wheeler and Young 1979), and giant foxtail (*Setaria faberii* Herrm.)(Gilmore 1980,1985) are known. However allelopathy involving tallowtree has not been reported.

I applied several aqueous extracts of tallowtree leaves to loblolly pine seed in both potting media and forest soil and measured seed germination and seedling growth. This was done in three greenhouse experiments to test the hypothesis that tallowtree produces allelochems which will inhibit seed germination and seedling growth of loblolly pine in both potting media and forest soil. Another objective was to determine if the active ingredient of the allelochem was tannic acid. This objective was investigated because tallowtree leaves are known (Cameron and LaPoint 1978) to contain tannic acids.

MATERIALS AND METHODS

In the first greenhouse experiment, five treatment solutions were each applied to eight families of loblolly pine seed in a standard peat moss, vermiculite, pearlite potting media. Treatment solutions were: throughfall collected from a near-by pure tallowtree stand, a pine needle solution made by soaking 100 air-dry grams of pine needles per liter of rainfall, a frozen leaf solution made by soaking 200 grams of green tallowtree leaves per liter of rainfall, and a dry leaf solution made by

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soaking 100 air-dry grams of tallowtree leaves per liier of solution. All soaking was done at air temperature overnight and all solutions were filtered through 1 mm mesh screen. Rainfall was used as a control solution. Two seeds were placed in a 'Leach' tube that had been filled with potting media and 10 tubes were prepared per seed family for each treatment solution. Three replicates were prepared and placed in a heated, ventilated fiberglass greenhouse. Tubes were watered with treatment solutions for 10 weeks when seedling measurements were made.

The second greenhouse experiment used solutions made with commercial tannic acid and rainwater made to the same tannic acid concentrations as the solutions in the first experiment. Eight loblolly pine seed families (not the same as the first) were used in a design similar to that of the first experiment.

The third greenhouse experiment used a frozen leaf, dry leaf and a rainfall control solutions like the first experiment with the same eight families as the second experiment. However forest soil from the tallowtree section of the two-story stand, from the non-tallowtree section and from the border between the two sections were used as the potting media. The rainfall control, frozen leaf and dry leaf solutions were used with soil from the non-tallowtree section to test for the effect of treatment solution. Rainfall was used with tallowtree section soil, soil from the border area, and soil from the non-tallowtree section to test the effect of soil. Rainfall with non-tallowtree soil was the control in both tests.

RESULTS AND DISCUSSION

Seed germination, and seedling height and total weight were reduced in treatments with the frozen leaf and dry leaf solutions (Table 1) using an artificial potting media. However the throughfall and pine needle solutions did not significantly reduce these parameters as compared to the rainfall control (Table 1). Therefore, the allelochem was extracted at a sufficiently strong concentration in the frozen leaf and dry leaf solutions to affect seed germination and seedling growth, and was either not in or not enough was extracted in the throughfall and pine needle solutions to have a significant affect.

Treatment solutions made with tannic acid to the same tannic acid concentration as the artificial pine and artificial frozen leaf solutions increased seedling height above that of the rainfall control. The tannic acid dry leaf solution did decrease seedling height, top weight and total weight below that of the rainfall control but total weight was the same as the tannic acid frozen leaf solution treatment. Seed germination was the same for all treatments. Because some tannic acid solutions did have both stimulation and depression effects on loblolly pine seedling growth, its role as the responsible allelochem was not confirmed.

Although the dry leaf solution treatment did not significantly reduce total and top weights in forest soil media (Table 2), these weights were less than those weights with the control solutions. The dry leaf solution did significantly reduce root weight below that of the

Table 1--Loblolly pine seedling size and survival by treatment solution. Numbers in the same column followed by the same letter are not significantly different at the α=10 percent level.

Treatment Solution	Height (cm)	Top Wt. (gms)	Total Wt. (gms)	Root Wt. (gms)	Rt/shoot ratio	Survival (percent)
Control	5.8a	0.19a	0.20a	0.04a	0.23a	88.6a
Throughfall	5.5a	0.16ac	0.18a	0.04a	0.24a	91.3a
Needle	5.1a	0.15bc	0.17a	0.04a	0.23a	85.0a
Frozen leaf	2.6b	0.08d	0.06b	0.02b	0.21 a	62.5b
Dry leaf	2.9b	0.66d	0.06b	0.02b	0.31 b	52.9b

Table 2--Loblolly pine seedling size and survival by solution and soil type treatment. Numbers in the same column with the same letter are not significantly different at the α=10 percent level.

Treatment		Top Wt.	Total Wt.	Root Wt.	Rt./Shoot	Survival
Solution	soil	(gms)	(gms)	(gms)	ratio	(percent)
Rainfall	Pine	0.03a	0.04a	0.01 a	0.52a	37.5ac
Rainfall	Tallow	0.03a	0.04a	0.0 b	0.53a	16.3bd
Frozen leaf	Pine	0.03a	0.04a	0.0 b	0.53a	46.7c
Dry leaf	Pine	0.02a	0.03a	0.01 bc	0.47a	24.6ad

control. Also seed sown in soil from the tallowtree section had significantly less germination than any treatment except that of the dry leaf solution.

These experiments indicate that tallowtree allelochems can be extracted in cold water and such solutions reduce loblolly pine seed germination and seedling growth. This occurred with both potting media and forest soil. Also the allelochem is present in forest soil below tallowtees in sufficient concentration to affect loblolly pine seed germination and seedling growth.

This research reemphasizes the fact that allelopathy is not an isolated phenomena found in botanical studies but is one of several means by which plants compete with other species. More greenhouse and soil studies are needed to better define the allelochem and its occurrence in the field.

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Ecophysiology/Genetics

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ROOT-ZONE TEMPERATURE AND WATER AVAILABILITY AFFECT EARLY ROOT GROWTH OF PLANTED LONGLEAF PINE

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Abstract- Longleaf pine seedlings from three seed sources were exposed to three root-zone temperatures and three levels of water availability for 28 days. Root growth declined as temperature and water availability decreased. Root growth differed by seed source. Results suggest that subtle changes in the regeneration environment may influence early root growth of longleaf pine and that root proliferation may very by seed source.

INTRODUCTION

Since 1800, the area occupied by longleaf pine, *Pinus palustris* Mill., in the South has decrease from 60 million acres to less than 5 million acres (Sirmon and Dennington 1989). Sensitivity to competition for light; susceptibility to brown-spot disease, caused by *Mycosphaerella deamessii* Barr,; and a prolonged grass stage have prevented longleaf pine from becoming a species of choice for artificial regeneration (Barnett and Dennington 1992; Barnett and others 1990; Guldin 1982; Loveless and others 1989; Sirmon and Dennington 1989).

Longleaf pine establishment is improved by planting high-quality seedlings and by using optimum site preparation methods (Boyer 1985; Loveless and others 1989). The size and root morphology of planted longleaf pine seedlings are major determinants of establishment success (Hatchell 1987; Hatchell and Muse 1990; Lauer 1987; White 1981). The key characteristic used to quantify seedling size is root collar diameter, which should be at least 1.1 cm (Lauer 1987; White 1981). Longleaf pine planting guidelines also recommend a minimum quantity of primary lateral and fibrous roots (Hatchell 1987; Hatchell and Muse 1990).

Unfortunately, the establishment success of operationally-planted longleaf pine seedlings remains low. For example, first-year survival of longleaf pine planted on National Forest System land in the 1991-92 planting season was 66 percent; whereas that of loblolly and slash pine were 83 and 81 percent, respectively (Hessell994). Furthermore, a survey of 75 percent of the land in Louisiana that was regenerated with longleaf pine during the 1992-93 planting season indicated that first-year survival was only 44 percent; whereas, that of loblolly and slash pine were both 79 percent (State of Louisiana 1994).

The proliferation of primary lateral roots and new root tips by *Pinus* species is strongly influenced by root-zone temperature, water availability and their interaction (Andersen and others 1986; Brissette and Chambers 1992; Carlson 1986; Nambiar and others 1979). Furthermore, seed source influences the root system morphology within *Pinus* species (Carlson 1986; Hallgren and others 1993; Nambiar and others 1982; Sword and Brissette 1993). The unique stem and root system morphology of longleaf pine (Brown 1964), as well as the responsiveness of this species' root system to lateral root pruning in the nursery (Hatchell 1987; Shoulders 1963), suggests that the longleaf pine root system may be very sensitive to environmental and genetic stimuli and their interaction.

This experiment was conducted as our initial effort to study the new root growth of longleaf pine in response to root zone temperature, water availability, and seed source. Observations were made with container-grown seedlings and provide a basis for future investigation of root system response to environment and seed source, and the impact of this response on longleaf pine establishment.

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MATERIALS AND METHODS

Container-grown longleaf pine seedlings were produced outdoors using the recommendations of Barnett and Brissette (1986). Six-month-old seedlings of uniform size were chosen, stem diameters were measured at the root collar, the growth medium was washed from root systems, and new roots (≥ 5 mm) were excised.

Seedlings were planted in the seedling growth system described by Sword and Brissette (1993) in which water baths were used to maintain three root-zone temperatures: 13, 18, and 23 "C. This IO-degree range is representative of the soil temperature (15 cm) in central Louisiana during winter and early spring (figure 1). Within water baths, three water availability treatments were applied using the method of Brissette and Chambers (1992). Atmospheric temperature was maintained at 20 °C and seedlings received ambient light.

This experiment was done first in December 1993 and repeated in January 1994, using a splii plot, randomized block design. Initiation of halves of each repetition were staggered by 1 week. Week of initiation represented blocks in the experimental design. Root-zone temperature (13, 18, and 23 "C) was the whole-plot treatment. Water stress and seed source were subplot treatments and were randomly assigned to seedling planting locations within whole plots. Water stress treatments were a well-watered condition, mild water stress, and moderate water stress. Seed sources were bulk collections from seed orchards in Florida and Mississippi, and a general forest area in north Alabama.

Twenty-eight days after planting, the predawn xylem water potential (UJ,) of one mature needle from the mid-shoot area of each seedling was measured in a pressure chamber (PMS Instrument Co., Corvallis, OR). Sand was washed from root systems. New roots, defined as white or light in color and at least 5 mm long, *were* excised and counted. The excised roots were darkly stained and their projected surface area was measured with a Delta-T area meter (Decagon Devices, Inc., Pullman, WA). The older portion of each root system was dried for 48 hours at 70 °C and weighed.

Stem diameters were subjected to an analysis of variance. With stem diameter as a covariate, all other variables were subjected to an analysis of covariance. Unless noted otherwise, main and interaction effects were considered significant at $P \leq 0.05$. Treatment means were compared using the Least Significant Difference test at $P \leq 0.05$.

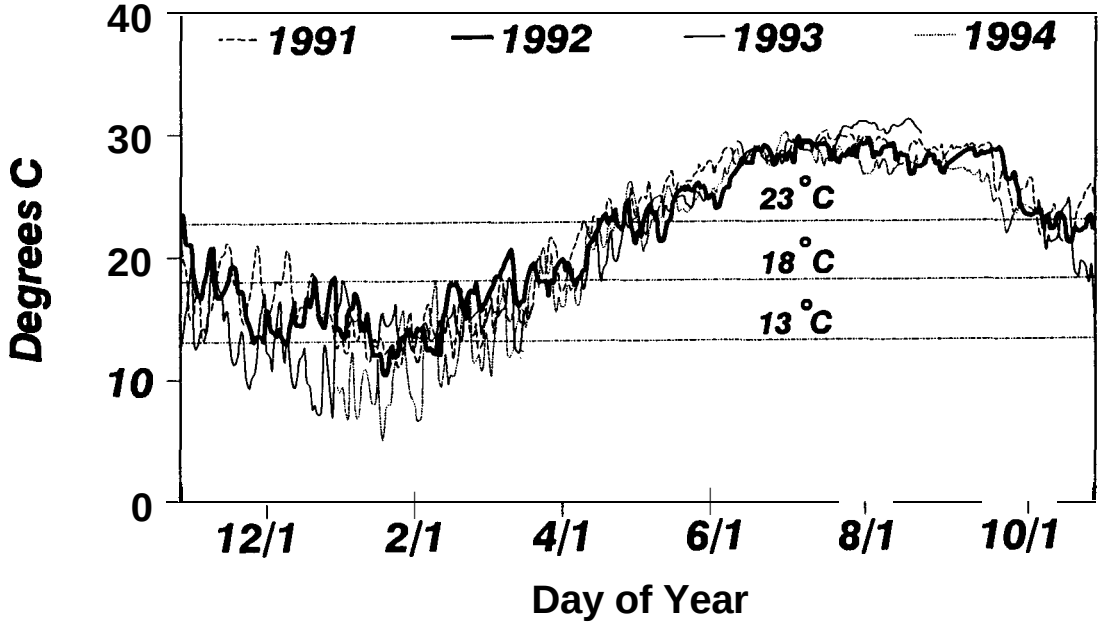

Figure l-Daily 12:00 pm soil temperature (15 cm) at an open-field location on the Palustris Experimental Forest, Rapides Parish, Louisiana, between January 1991 and September 1994.

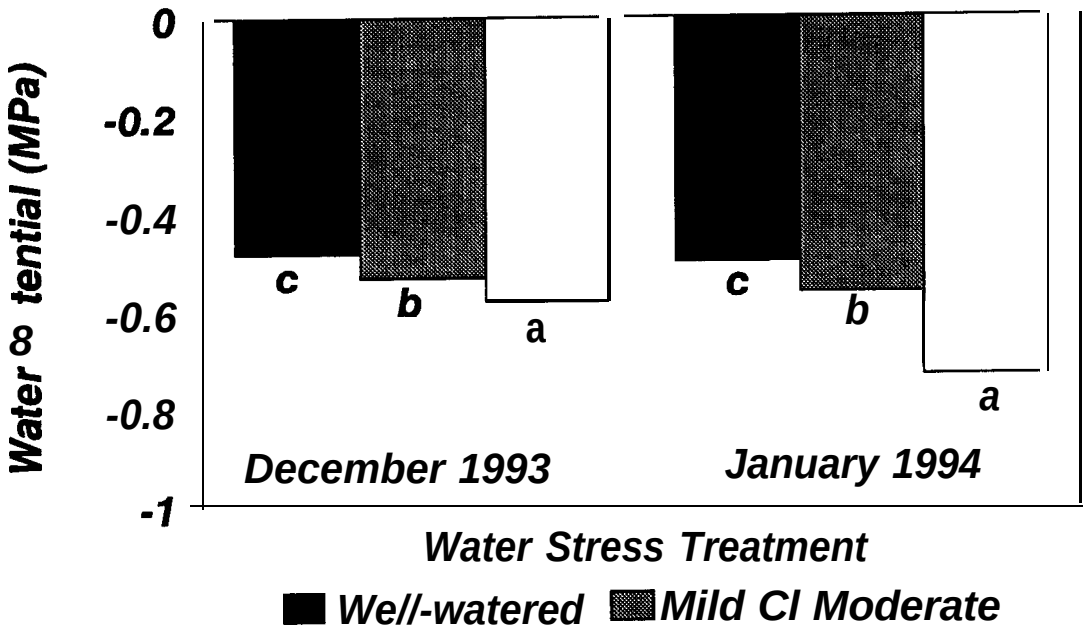

Figure 2-Mean predawn needle xylem water potential, adjusted by initial stem diameter, of container-grown longleaf pine seedlings after exposure to water stress treatments for 28 days. In each repetition, means associated with different letters are significantly different at $P \leq 0.05$ by the LSD test.

RESULTS

In both repetitions, water stress significantly reduced Ψ_{pd} after 28 days (table 1). In December, mild and moderate water stress resulted in 0.05 and 0.1 MPa decreases, respectively, in Ψ_{pd}; whereas, in January, decreases of 0.06 and 0.23 MPa, respectively, were found (figure 2). In December, number of new roots was significantly decreased by mild and moderate water stress (23 and 30 percent, respectively) (figure 3). In January, number of new roots was significantly decreased by moderate water stress (35 percent). New root projected surface area was similarly affected (figure 4).

Root growth was significantly affected by the 1 O-degree root-zone temperature range in this study (table 1). In December and January, an increase in root-zone temperature from 13 to 18 °C caused approximately 6- and 12-fold increases in number and projected surface area of new roots, respectively (figures 5 and 6). Elevation of the root-zone temperature from 18 to 23 °C caused approximately 1.8-fold increases in both the number and projected surface area of new roots in both repetitions.

In January, number of new roots was significantly affected by an interaction between water stress and root-zone temperature (table 1). At 13 °C, water stress did not affect number of new roots; however, at 18 °C, moderate water stress reduced number of new roots when compared to the well-watered condition (figure 7). At 23 °C, number of new roots was less under moderate water stress when compared to both the well-watered condition and mild water stress. Although not significant, a similar trend was observed with new root surface area in January. In December, number of new roots and new root projected surface area were not significantly affected by an interaction between water stress and root-zone temperature.

Seed source significantly affected new root growth (table 1). In both repetitions, the north Alabama source had significantly more new roots than the Florida and Mississippi sources (table 2). In December, the north Alabama source had a significantly larger new root projected surface area than the Florida and Mississippi sources; and in January, had a significantly larger new root projected surface area than the Mississippi source.

Table 1. Analysis of covariance for evaluation of the effects of root-zone temperature, water availability, and seed source on longleaf pine seedling root characteristics using a split plot, randomized block design with initial stem diameter as a covariate[a]

Source of Variation	Variable											
	Predawn Needle WP, (Mpa)			Old root dry weight (g)			New roots (#)			New root area index (cm_2)		
	df	MS	Pr>F	df	MS	Pr>F	df	MS	Pr>F	df	MS	Pr>F
December 1993 replicate												
diameter	1	0.476	0.3100	1	4.055	0.0001	1	338.8	0.3490	1	2134.3	0.3373
block	1	1.331	0.7883	1	1.587	0.0106	1	5181.1	0.1473	1	30371.7	0.1754
temperature (T)	2	7.576	0.6519	2	0.001	0.9263	2	68741.8	0.0139	2	410144.1	0.0171
block x T	2	14.186	0.0001	2	0.017	0.6721	2	972.3	0.0819	2	7146.7	0.0470
water availability (W)	2	23.463	0.0001	2	0.349	0.0200	2	4316.4	0.0018	2	14610.7	0.0397
seed source (S)	2	10.844	0.0016	2	0.452	0.0077	2	5189.5	0.0007	2	31692.5	0.0021
W x S	4	4.880	0.0151	4	0.113	0.2340	4	393.1	0.5653	4	2173.2	0.7004
W x T	4	2.332	0.1556	4	0.016	0.9254	4	1178.3	0.0924	4	4229.3	0.3924
S x T	4	1.599	0.3144	4	0.076	0.4241	4	1577.4	0.0374	4	6609.1	0.1887
W x S x T	8	1.060	0.5830	8	0.033	0.8885	8	245.3	0.8648	8	919.2	0.9807
block x W x S x T	24	1.273	0.4807	24	0.075	0.0184	24	521.3	0.1291	24	3947.2	0.0231
sampling error	265	1.286		268	0.043		268	384.9		268	2310.2	
January 1994 replicate												
diameter	1	11.039	0.0134	1	7.070	0.0046	1	281.5	0.4197	1	576.1	0.6207
block	1	148.502	0.0040	1	1.047	0.3237	1	96.4	0.6778	1	4927.6	0.5409
temperature (T)	2	30.347	0.0195	2	1.663	0.2719	2	101455.7	0.0041	2	526267.0	0.0172
block x T	2	0.604	0.7127	2	0.621	0.4893	2	416.0	0.3823	2	9224.9	0.0208
water availability (W)	2	158.968	0.0001	2	2.514	0.1083	2	6183.6	0.0024	2	20555.5	0.0146
seed source (S)	2	3.376	0.4415	2	2.354	0.1234	2	3763.9	0.0180	2	15393.2	0.0369
W x S	4	0.212	0.9944	4	0.571	0.6978	4	114.5	0.9634	4	1111.9	0.8917
W x T	4	11.662	0.0421	4	1.275	0.3213	4	2601.8	0.0274	4	7533.0	0.1507
S x T	4	4.207	0.4004	4	1.592	0.2208	4	1659.0	0.1117	4	10193.7	0.0681
W x S x T	8	1.221	0.9563	8	0.875	0.5695	8	263.0	0.9443	8	1124.1	0.9672
block x W x S x T	24	3.990	0.0011	24	1.030	0.2525	24	788.5	0.0120	24	4054.3	0.0209
sampling error	269	1.781		268	0.867		268	431.0		268	2346.9	

[a] "block x T" is the error term for whole plot effects. "block x W x S x T" is the error term for subplot effects.

Immediately prior to the start of each repetition, stem diameter was significantly affected by seed source (table 3). Specifically, the stem diameter of the Mississippi source was significantly larger than that of the north Alabama and Florida sources (table 2). After the December repetition, dry weights of the old portion of seedling root systems of the Mississippi and north Alabama sources were significantly larger than that of the Florida source. A similar, but not significant trend was observed after the January repetition.

An interaction between seed source and root-zone temperature significantly affected number of new roots (table 1). In December, at 13 and 18 °C, number of new roots was not affected by seed source; however, at 23 °C, the north Alabama and Florida sources had more new roots than the Mississippi source (figure 8). A similar but not significant trend was observed with new root projected surface area in December. In January, this interaction affected new root projected surface area ($P = 0.0681$). Specifically, at 13 and 18 °C, new root projected surface area was not affected

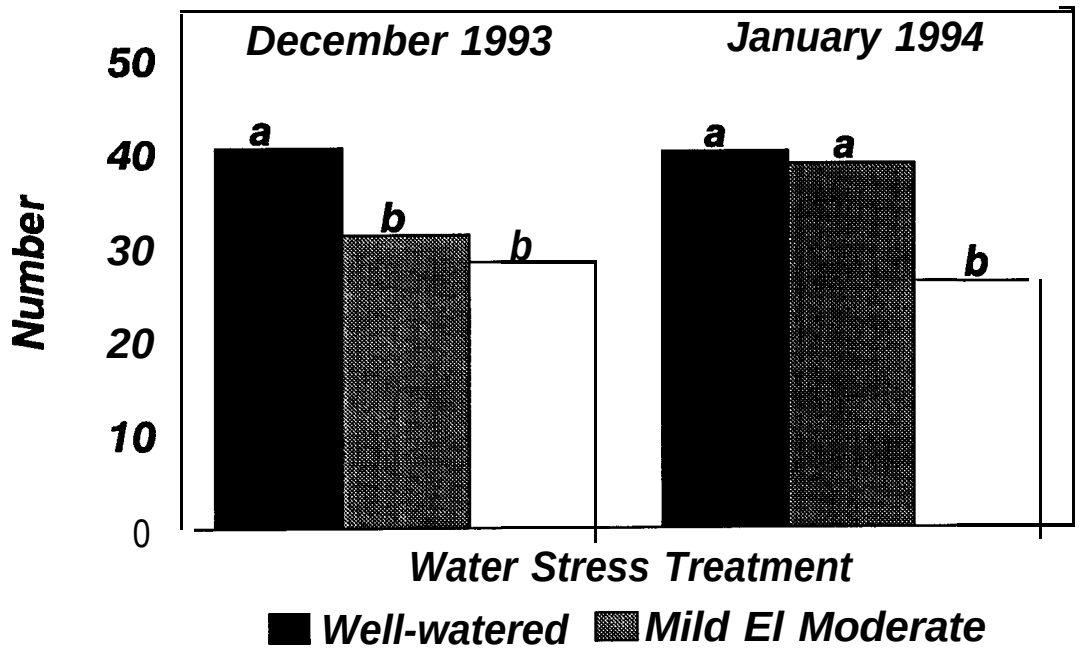

Figure 3--Mean number of new roots, adjusted by initial stem diameter, of container-grown longleaf pine seedlings after exposure to water stress treatments for 28 days. In each repetition, means associated with different letters are significantly different at $P \leq 0.05$ by the LSD test,

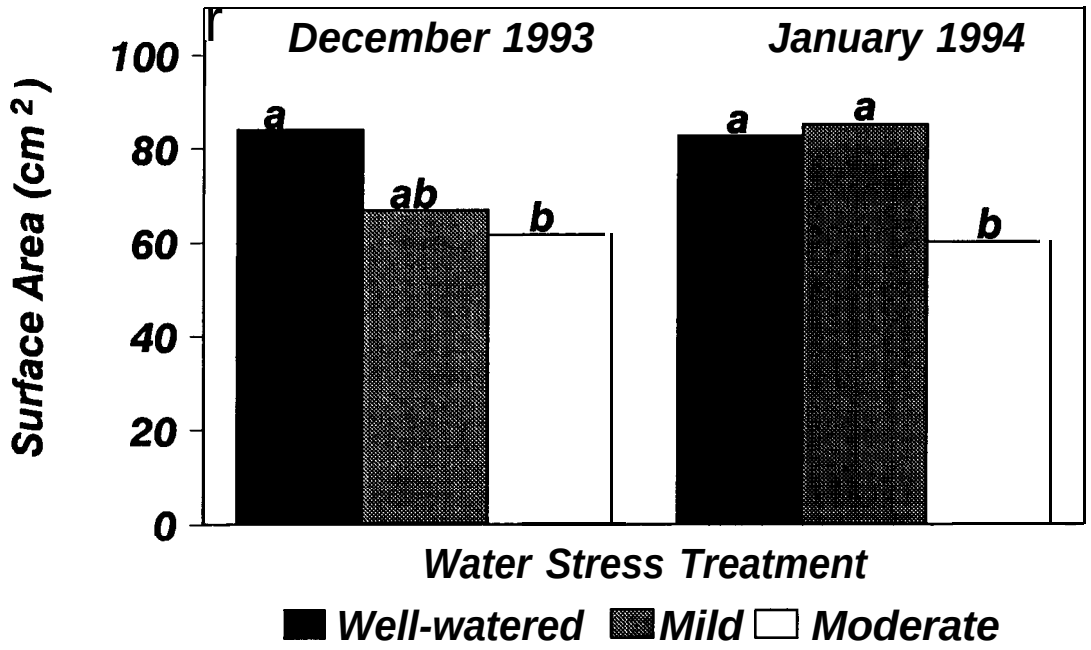

Figure 4--Mean new root projected surface area, adjusted by initial stem diameter, of container-grown longleaf pine seedlings after exposure to water stress treatments for 28 days. In each repetition, means associated with different letters are significantly different at $P \leq 0.05$ by the LSD test.

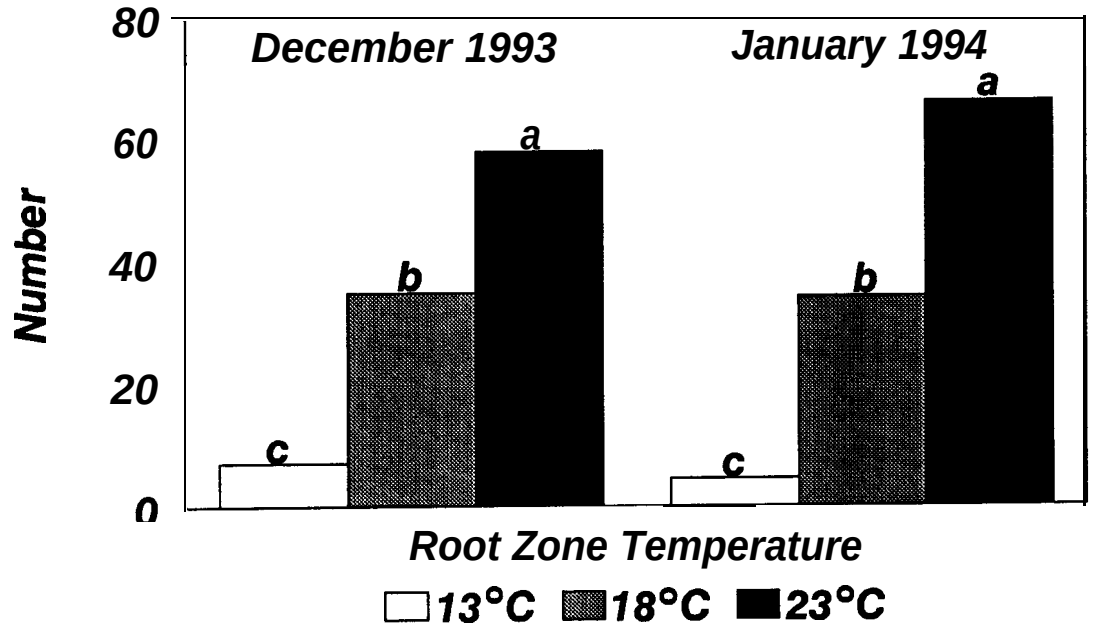

Figure 5--Mean number of new roots, adjusted by initial stem diameter, of container-grown longleaf pine seedlings after exposure to three root-zone temperatures for 28 days. In each repetition, means associated with different letters are significantly different at $P \leq 0.05$ by the LSD test.

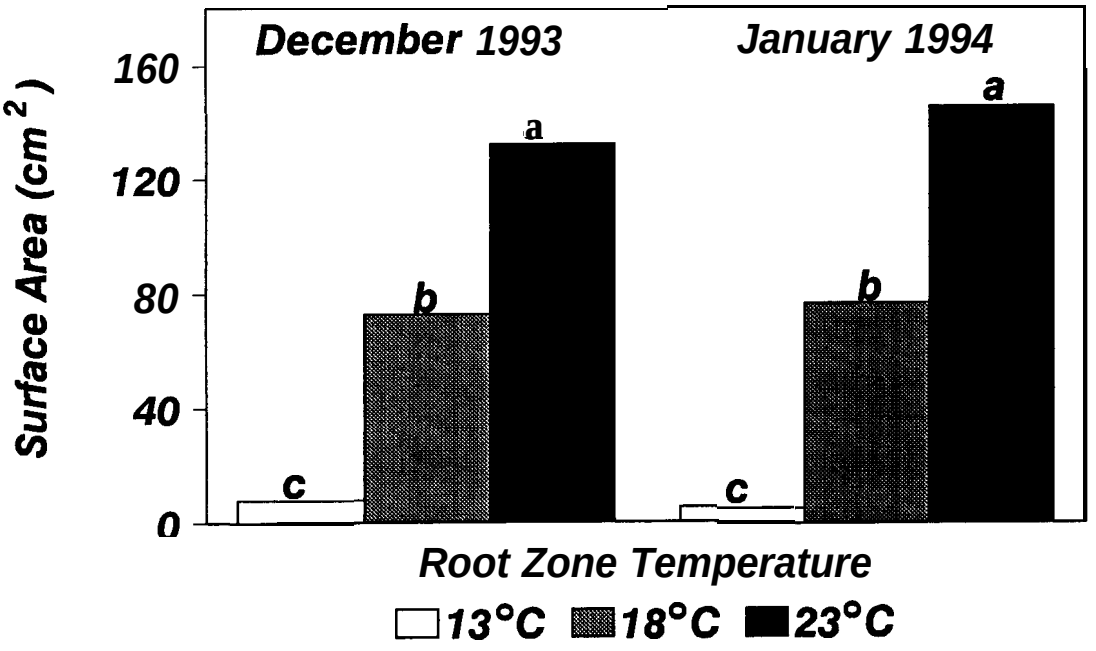

Figure 6-Mean new root projected surface area, adjusted by initial stem diameter, of container-grown longleaf pine seedlings after exposure to three root-zone temperatures for 28 days. In each repetition, means associated with different letters are significantly different at $P \leq 0.05$ by the LSD test.

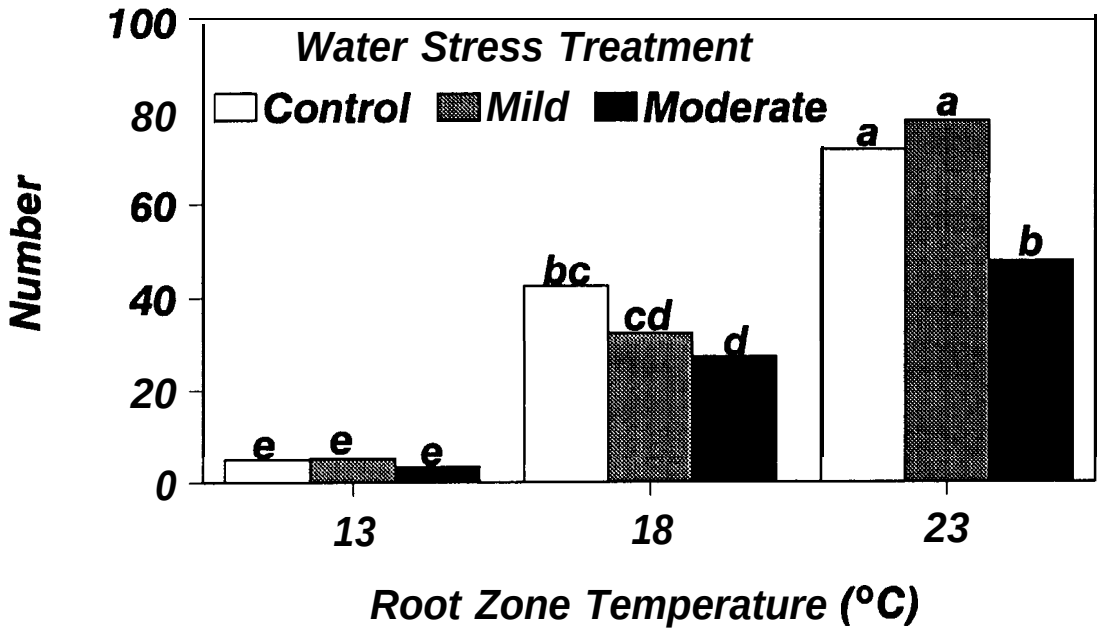

Figure 7-Mean number of new roots, adjusted by initial stem diameter, of container-grown longleaf pine seedlings after exposure to root-zone temperature and water stress treatments for 28 days in January 1994. Means associated with different letters are significantly different at P ≤ 0.05 by the LSD test.

Table 2-Mean initial stem diameter and adjusted means' of root characteristics of three seed sources of container-grown longleaf pine seedlings after exposure to three root-zone temperatures for 28 days in December 1993 and January 1994

Repetition and seed source	Stem diameter (mm)	New roots (#)	New root surface area (cm^2)	Old root dry wt. (g)
December 1993				
North Alabama	5.8 b[b]	40.6 a	90.4 a	1.09 a
Florida	5.9 b	32.8 b	66.4 b	0.98 b
Mississippi	6.3 a	26.1 c	55.6 b	1.10 a
January 1994				
North Alabama	7.7 b	41.7 a	89.7 a	1.54 a
Florida	7.8 b	32.2 b	72.2 ab	1.44 a
Mississippi	8.4 a	30.4 b	65.7 b	1.75 a

[a] Mean root characteristics adjusted by initial stem diameter.

[b] Within repetitions and columns, means associated with different letters are significantly different at P ≤ 0.05 by the LSD test.

Table 3-Analysis of variance for evaluation of the effect of seed source on longleaf pine seedling stem diameter using a completely random design

Source of Variation	df	MS	Pr>F
-December 1993 replicate--			
week (W)	1	3.4434	0.0076
seed source (S)	2	7.7413	0.0001
w x s	2	0.1882	0.6741
sampling error	317	0.4766	
-January 1994 replicate-------			
week (W)	1	12.2349	0.0001
seed source (S)	2	12.9559	0.0001
w x s	2	3.2398	0.0123
sampling error	317	0.7266	

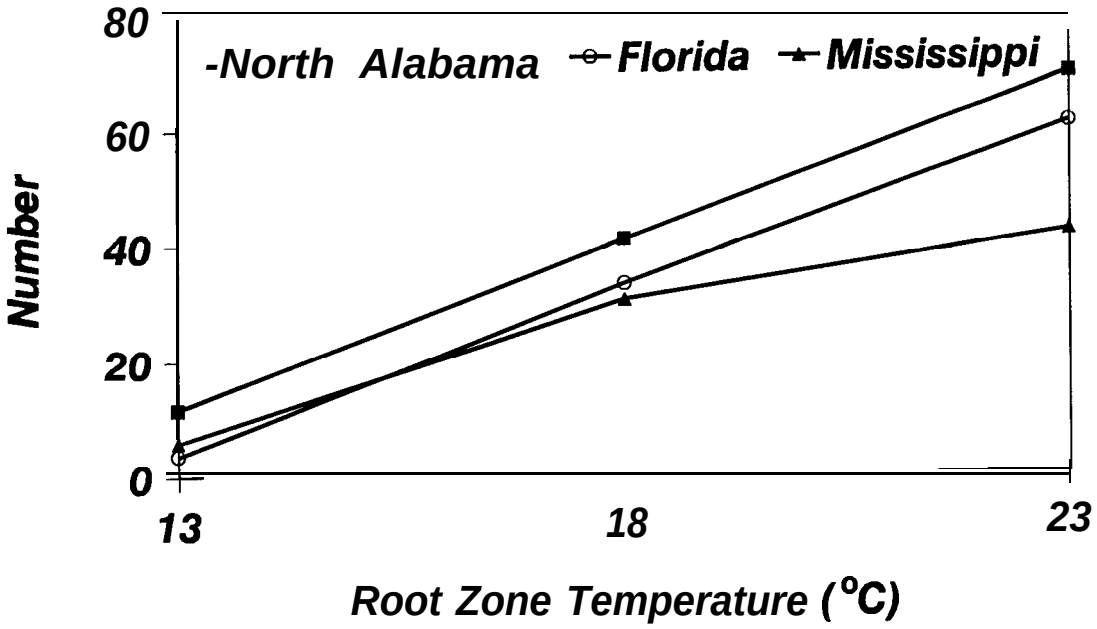

Figure 8--Mean number of new roots, adjusted by initial stem diameter, of three seed sources of container-grown longleaf pine seedlings after exposure to three root-zone temperatures for 28 days in December 1993. At 23°C, new root initiation of north Alabama and Florida sources was significantly greater than that of the Mississippi source by the LSD test ($P \leq 0.05$).

by seed source; however, at 23 °C, that of the north Alabama source was greater than that of the Florida and Mississippi sources. A similar but not significant trend was observed with number of new roots in January.

DISCUSSION

The new root growth of transplanted longleaf pine seedlings was 1.8-fold greater at 23 °C than at 18 "C. Nambiar and others (1979) found a 1.3-fold increase in the new root length of Monterey pine, *Pinus* radiata D. Don, seedlings in response to an increase in root-zone temperature from 15 to 20 °C, 32 days after transplanting. Similarly, Andersen and others (1986) found that an increase in root-zone temperature from 16 to 20 °C caused a 1.4-fold increase in the new root length of transplanted red pine, *Pinus resinosa* Ait., seedlings.

We also found that reduced water availability decreased longleaf pine root growth after transplanting. Furthermore, results from the January repetition indicated that the negative effect of water stress became more pronounced as root-zone temperature increased. Similarly, Brissette and Chambers (1992) reported that the positive response of root growth to increased soil temperature was reduced as water became more limiting to shortleaf pine, *Pinus echinata* Mill., seedlings.

Seedling establishment was not evaluated in the present study. Therefore, we cannot develop relationships between our results and the field performance of planted longleaf pine. However, successful seedling establishment is dependent on the development of a network of new roots after planting (Brissette and Chambers 1992; Carlson 1986; Johnsor and Cline 1991). Furthermore, the root-zone temperature and water availability treatments imposed in our study were representative of possible soil conditions during winter and spring in central Louisiana. Since our results characterize initial root responses to the soil environment after planting, they provide a sound basis for making hypotheses about relationships between the root-zone environment, root growth, and field performance of planted longleaf pine.

Root growth was strongly stimulated by an increase in root-zone temperature; however, this positive response was sensitive to water stress. Water availabilii is a key factor affecting southern pine seedling survival after planting (Gholz and Boring 1991; McGrath and Duryea 1994). Perhaps manipulation of the regeneration environment to maximize soil temperature immediately after planting would increase early root growth. Any gain in new root growth during winter and early spring could reduce the negative effect of early or gradual decreases in water availabiiii as the growing season progressed.

Walker and McLaughlin (1989) found that a black, perforated polyethylene mulch applied at the base of loblolly pine seedlings caused a 5 °C increase in spring soil temperature at 5 cm. Site preparation methods that elevate soil temperature in the root zone of planted longleaf pine may accelerate root growth in late winter and early spring.

In the present study, root growth of longleaf pine was affected by seed source. Similarly, other investigations have demonstrated that root growth of pine species differs by genotype (Carlson 1986; Hallgren and others 1993; Nambiar and others 1982). This information suggests that seed source may influence the root growth of longleaf pine seedlings immediately after planting.

We found that at 13 and 18 °C, root growth did not differ by seed source; however, at 23 °C, root growth of the Mississippi source was less than that of the north Alabama source. Since the duration of this experiment was short and field performance was not evaluated, conclusions about the adequacy of early root growth after planting these seed sources cannot be made. However, our information does suggest that seed sources may differ in the rapidness of their root growth response to increases in temperature as the soil warms in spring.

A positive relationship exists between the root collar diameter and root system size of southern pine seedlings (Hatchell 1987; Hatchell and Muse 1990; Johnson and others 1985). However, negative correlations between the stem diameter and root system fibrosity of longleaf pine seedlings have been reported (Hatchell 1987; Hatchell and Muse 1990). In the present study, we found that the Mississippi source had a larger stem diameter, but less new root growth, when compared to the north Alabama source. The new root initiation of seed sources in thii study may be related to their adaption to different planting zones. However, just as carbon partitioning between the shoot and root system of loblolly pine seedlings was found to diier by seed source (Bongarten and Teskey 1987), our results suggest it is possible that carbon partitioning between the tap and fibrous roots of longleaf pine may diier by seed source.

Our results indicate that the new root growth of container-grown longleaf pine is sensitive to subtle shifts in soil temperature and water availability immediately after planting. Furthermore, negative effects of water stress may become more pronounced as root-zone temperature increases. Further research is warranted to determine if soil temperature in the regeneration environment can be manipulated to stimulate early root growth before water limitations occur during the growing season. Our results also suggest that seed source affects longleaf pine root growth responses to changes in soil environments. The aggressiveness of early root growth after planting, and the field performance of longleaf pine seed sources should be evaluated. Moreover, the effect of seed source on carbon partitioning between tap and fibrous roots should be studied.

ACKNOWLEDGMENTS

The author thanks Dr. John C. Brissette for designing the seedling growth system used to impose root-zone temperature and water availability treatments, and Dan Andries, John McGilvray, and Chuck Stangle for their technical assistance.

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VULNERABILITY OF LOBLOLLY PINE ROOTS TO ENVIRONMENTAL AND MICROBIAL STRESSES'

C.H. Walkinshaw?

Abstract-During secondary root development in loblolly pine (*Pinus taeda* L.), shedding of cortical cells precedes diameter growth and causes a temporary exposure of cells and intercellular spaces to soil mlcroflora. In central Louisiana, approximately 62 percent of the roots were shedding their cortex in September. To understand this activity, I observed characteristics that express root growth **in relation to stress. These characteristics included the condition and attachment of the cortex and the presence or absence of old cortex, dead and still attached, and new periderm. These variables were tabulated for 10 to 20 roots per tree and 10 trees at a location. Numerous microorganisms grow in the masses of shed cells and may infect the root. Thus, the process of shedding in loblolly pine roots appears to stimulate microbial growth in the rhiiosphere.**

INTRODUCTION

Secondary growth **in roots** of trees causes major changes in root tissue morphology. Most of the cortical cells are shed and invaded by microorganisms, and new cells are formed to protect the remaining cortical cells (Esau 1953, Leshem 1974, Rogers 1968). Although root elongation has received attention in loblolly pines (*Pinus taeda* L.), secondary root growth is unexplored. Measurements of metabolism of pine roots in the process of shedding cortical cells probably are strongly affected by activity of microorganisms that are colonizing dying cells.

The objective of this study was to define root condition of loblolly pines in IO- to 40-year-old plantations. More than 2400 roots of various sizes were fixed, sectioned, and stained. Results from these observations suggest that secondary growth of loblolly pine roots is highly complex and that the roots are vulnerable to microbial invasion when secondary growth is initiated.

MATERIALS AND METHODS

Roots for this research were collected from July 1991 to June 1994 from healthy loblolly pine trees in the J.K. Johnson Tract of the Palustris Experimental Forest, USDA Forest Service, in central Louisiana and in the Homochiio National Forest in south central Mississippi. Roots were sampled at depths of 2 to 20 cm, separated from the soil, and fixed immediately in formalin/acetic acid/alcohol for 2 to 4 weeks (Sass 1951). Fixative was replaced by soaking in several changes of 70-percent ethyl alcohol. Roots were cut in the middle of their length, and one 5- by 8-mm long specimen from each root was dehydrated, embedded in paraffin, and cut into cross sections 5 to 10 microns thick. For each tree, 10 to 20 specimens were processed, and 10 trees were sampled per plantation. A total of 1780 roots were sectioned from Louisiana and 622 from Mississippi. Mycorrhizal roots were not included in this study.

Different sections of roots received different staining schedules (Hass 1980, Walkinshaw 1992). The hematoxylin-eosin stain, the Papanicolaou procedure, and the periodic acid-schiff reaction procedures were applied to all specimens. Giemsa stain, toluine blue, Congo red, Grocttt's methenamine-silver stain, and a stain of fast green, rose bengal, and acridine red were applied to some specimens that were shedding.

Stained sections of paraffin-embedded specimens were observed microscopically with a Carl Zeiss Photomicroscope II at magnifications of 100 to 500 diameters. Polariied light was used to differentiate tannins and primary cell walls from secondary cell walls, sclereid cells, and starch granules (Walkinshaw 1992).

Shedding of cortical tissues was observed in duplicate or triplicate root sections for two staining schedules.

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The occurrence of observed cortex variables was expressed as a proportion for each tree and location.

RESULTS

The two most useful staining schedules for root specimens were the hematoxylin-eosin and the Papanicolaou procedure. The former differentiated live and dead roots, while the latter separated primary and secondary growth of xylem and phloem tissues. The periodic acid-schiff reaction readily stained starch granules and was the best way to estimate starch content.

The diameters of roots that were shedding their cortex ranged from less than 1 mm to over 2.5 cm. For 10 trees sampled in June 1993, the range in the percentage of roots shedding their cortex was 35 to 60 and the mean was 48 $\pm$ 0.8 percent. The highest mean was 62 percent for the September sample. Only 25 percent of the roots collected over the year in Louisiana with the cortex shed were protected by outer cortical (new bark) cells.

Roots that were entering into secondary growth for the first time shed their cortical cells inward to the endodermis. In time, residual cortical cells formed an intact epidermis. The process of shedding appeared to minimize displacement of residual cells.

Roots that underwent one or more periods of secondary growth varied in their retention of bark cells. The majority of these roots shed all of their bark cells, but many retained a layer. An annual accumulation of layers of bark cells was not observed.

Loblolly pine roots appeared to be vulnerable to various pathogens during the shedding of cortical cells. In all samples, exposed residual cells had only primary walls. These cells contained large numbers of starch grains and prominant nuclei. Plasmodesmata and other wall components routinely appeared damaged.

Residual cells appeared to be protected after shedding by the synthesis of bark cells. The formation of these bark cells paralleled the sequence reported for stems of slash pine in Walkinshaw (1992). The thick-walled bark cells were filled with tannin and accumulated in layers 1 to 20 cells wide.

Microorganisms (mainly fungi) grew in large colonies within shedding cortical cells. Development of colonies coincided with disappearance of starch grains in shed cells. Cells were devoid of recognizable organelles at shedding. From 1 to 10 percent of the roots from 40-year-old trees had fungi that penetrated the endodermis after cortical cells were shed. These organisms completely disrupted internal root tissues. Hyphae were numerous, and the root cambium was dead.

Tannin in roots appeared to accumulate in response to microorganisms and to wounding. Large numbers of cells filled with tannin were seen in the phloem outside the cambium, on either side of emerging root tips, within the xylem tissue, and in the bark cells. Tannin was observed in all areas of cell disruption.

DISCUSSION

From my observations of roots of loblolly pines, I conclude that secondary root development is significantly affected by anatomical and microbiological events. During shedding of the cortex, so many dying cells and microbial cells are present that measurements of respiration and other enzymatic activities are nearly impossible. Adaptation of histochemical techniques for enzymatic assays might be more satisfactory than assays on intact roots or homogenates.

Histological observations were made on many roots sampled from 10- to 40-year old loblolly pines. Secondary root growth appeared to be highest in September during 1993. The shedding process was identical at the different sites in Louisiana and Mississippi, but variation in pathogenic flora occurred among locations. Overall, this variation was from 1 to 10 percent. These percentages do not include infected roots that were dying at the time of sampling.

Disappearance of starch grains in cells of the cortex before shedding was remarkable. The starch appeared to be mobilized to other tissues because microbial growth was highly localized in the outer cortex. Cells inside the endodermis had abundant starch granules. The other root tissues had typical starch granules during the shedding phase. The quantity of starch in the cortical cells that would soon be shed was large initially. The loss of this starch by mobilization, microbial action, and hydrolytic processes of dying cells represents a large amount of carbon energy.

The most effective protection of root cells appeared to be tannin deposition after shedding of cortical cells. Tannin, in combination with the cellulose:lignin complex of bark cells appears to protect the roots in the manner

I described for pine stems (Walkinshaw 1978, Walkinshaw 1992). Moreover, the accumulation of tannin around wounds and emerging root tips appears to reduce vulnerability of roots to wounds, desiccation, and microbes.

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ROOT GROWTH POTENTIAL AND FIELD SURVIVAL OF CONTAINER LOBLOLLY PINE SEEDLINGS FALL FERTILIZED WITH NITROGEN[1]

Hans M. Williams and David B. South[2]

Abstract-Two studies investigated the effects of fall nitrogen fertilizer applications on the root growth potential (RGP) and field performance of container loblolly pine seedlings (*Pinus* taeda L.). The seedlings were sampled at 4 chilling levels ranging from 100 to 580 hours (0 to 8" C). Seedlings propagated for the first study may have had a hidden nutrient deficiency and therefore the fall diammonium phosphate (DAP) application at rates of 202 kg Nha and 87 kg N/ha increased RGP 43% and 32%, respectively. The growing season mineral fertilizer application rate was increased in the second study which may explain why fall nitrogen applications at 202 kg N/ha did not increase RGP. In general, RGP Increased as exposure to chilling hours increased. Fall fertilization increased total seedling weight. Analysis of covarlance indicated that RGP may be a function of total seedling weight and not a direct response to fertilizer treatment or chilling level. For the first study, survival was not significantly affected by the fall DAP treatments.

INTRODUCTION

The majority of studies concerning the effects of fall nitrogen applications have concentrated on the northern forest tree species (Anderson and Gessel 1966, Benzian et al. 1974, Thompson 1982, van den Driessche 1985, 1988, Margolis and Waring 1986a, 1986b). The influences of fall nitrogen applications have not been extensively studied for loblolly pine (*Pinus taeda* L.). Earlier observations for loblolly pine suggest that fall nitrogen applications had a detrimental effect on outplanting performance (Ursic 1956, Gilmore et al. 1959, Shoulders 1959). Poor performance might be the result of altering the bud dormancy cycle. For loblolly pine, several studies have investigated the relationship between bud dormancy, storability, root growth potential (RGP) and outplanting performance (Garber 1983, Boyer and South 1985, Larsen et al. 1986, Dewald and Feret 1988).

RGP is considered to be an important measure of seedling quality (Riichie 1985). As bud dormancy is released by chilling, increases in RGP have been observed for loblolly pine (Rhea 1977, Johnson and Barnett 1985, Carlson 1985, Larsen et al. 1986). Few studies have reported the influence of nursery cultural practices on the interrelationship between the chilling requirement and other seedling processes. Therefore, the effects of fall nitrogen fertilization on RGP as it relates to chilling level were examined on container-grown loblolly pine seedlings.

MATERIALS AND METHODS

1984-85 Study

Seed from two half-sibling seed lots of loblolly pine (*Pinus* taeda L.) were sown in 144 cm^3 plastic cone containers filled with a coarse sand. Seed sources were from geographically different locations. The ortet of the northern family (No. 0208) was from Virginia (approx. 36.90°N lat. 76.95°W long.) while a southern ortet (No. 0056) was from Georgia (approx. 32.07°N lat. 81.54°W long.). Containers (98) were held in plastic trays which covered a 0.186 square meter area. Seedlings were grown outside at Auburn, Alabama.

Seedlings were sprayed with a Captan spray preceding germination for damping-off control. During the growing season, the seedlings were fertilized every two weeks beginning on May 21, 1984 alternating applications of a 20-20-20 ($N-P_2O_5-K_2O$) and a 15-30-15 fertilizer. Six applications were made supplying 170 kg/ha/year of nitrogen. The seedlings were watered approximately every other day until the end of August

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when watering was reduced. Both water and fertilizer were withheld promoting bud-set and hardening-off.

The study was conducted as a randomized complete block split plot design with four replications. Whole plots consisted of three levels of a fall application of diammonium phosphate (DAP) fertilizer treatment, while family represented the subplots. DAP was applied with a water can at levels equivalent to 0 (control), 67, and 202 kg N/ha over two application dates of September 28, 1984 and October 5, 1984.

Chilling hours, defined as the number of hours seedlings experienced temperatures between 0 and 8°C, were monitored using a digital temperature recorder. The temperature recorder was placed in a weather box located at seedling height. When chilling levels reached approximately 100, 250, 400, and 550 hours (Table I), seedlings were sampled from each replication for each treatment and family (subplot). The variables measured were root growth potential and field survival and height growth.

Table 1. Sampling dates and associated chilling hours (0-8° C) for the 1984-85 and 1985-86 root growth potential and outplanting experiments.

Sampling Date	Proposed Chilling Hours	Actual Chilling Hours
	— 1984-85 Fall N Study —	
November 13, 1984	100	97
November 29, 1984	250	238
January 6, 1985	400	406
January 19, 1985	550	559
	— 1985-86 Fall N Study —	
December 10, 1985	100	99
December 29, 1985	250	254
January 11, 1986	400	397
January 30, 1986	550	569

Root Growth Potential

Root growth potential (RGP) for unstored and stored seedlings was measured using a hydroponic method described by Ritchie (1984). RGP testing was conducted in a heated, glass greenhouse. Photoperiod was extended to 16 hr using 300 W incandescent light bulbs. Ten seedlings from each subplot were randomly sampled at each chilling level. Five seedlings were placed in 49 liter plastic bags and the bags placed in cold storage at 4°C for a IO-week period. The other five seedlings were tested immediately. Following a 30-day test period, seedlings were removed from the RGP test and placed in cold storage until root counts could be made. RGP was determined as the number of new roots (white roots) greater than or equal to 1 cm in length. Following the 1 O-week storage period, RGP was determined in a similar manner for the stored seedlings.

Field Performance

Twenty seedlings from each subplot were randomly sampled at each chilling level for outplanting. Ten of the seedlings were inserted in 49 liter plastic bags and the bags placed in cold storage at 4°C for 10 weeks. The remaining 10 seedlings were outplanted immediately. The outplanting site was located approximately 16 km north of Auburn, Alabama. Soil at the site was classified as a Gwinnett sandy loam (United States Department of Agriculture 1981). Seedlings were removed from their containers and planted in rows on a spacing of 61 cm by 91 cm using a dibble bar. Following planting, initial height and ground-line diameter were recorded. Stored seedlings were outplanted in a similar manner 10 weeks later. Subsequent measurements included first and second year height and survival.

1985-86 Study

A second study continued the examination of RGP response to late-season nitrogen application. The same two loblolly pine families reported previously were used in this study. Seed were sown in the plastic cone containers filled with a peat-perlite-vermiculite-pine bark mixture. For control of fusiform rust (*Cronartium quercuum* f. sp. *fusiforme*), seeds and seedlings were treated with triadimefon. Also, seedlings were sprayed periodically with malathion to control aphids. During the growing season, the seedlings were fertilized once a week beginning on May 11, 1985 applying similar fertilizer types used in the 1984-85 study. By August 31, about 155.3 mg N had been applied to each seedling. Seedlings were watered every other day until August. Fertilization was stopped and watering was reduced in August to promote bud-set and hardening-off.

The study design was a randomized complete block split-plot with four replications. Whole plots consisted of the fertilizer treatments and the subplots were the families. Fertilizer treatments consisted of comparisons between DAP, ammonium nitrate (AN), and a control.

DAP and AN were applied on November 3, 1985 at a rate equivalent to 202 kg N/ha. Seedlings for RGP were sampled at the same chilling levels stated for the 1984-85 study (Table 1).

Data Analysis

For each study, analysis of variance for a randomized complete block split-plot design was conducted using Statistical Analysis System procedures (Statistical Analysis System 1987). The main effects of fertilizer treatment, family, and storage were considered fixed. Analysis for the main effect of chilling level was handled as a split-plot in space and time (Steel and Torrie 1980). Plot means were used as the observations for all studies. Analysis of covariance was done to aid in RGP data interpretation. Where appropriate, simple correlation coefficients were calculated to identify relationships between certain variables. Differences within main effects and their interactions will be discussed as significant at the $\leq$ 5% level of probability.

RESULTS

1984-85 Study

Application of the DAP fertilizer did not significantly alter the nitrogen (N) concentration of foliage (avg.=0.70%) and roots (avg.=0.43%) for seedlings sampled in January. Stems of fall fertilized seedlings had higher N concentrations (0.41%) than the control seedlings (0.33%).

The main effects of fall fertilizer treatment, family, chilling level, and storage each had a significant influence on RGP (Table 2). RGP was enhanced 43 and 32 percent over the control when treated with 202 and 67 kg N/ha, respectively. Georgia seedlings produced an average of 12 more new roots per seedling than Virginia seedlings. An increase of about four new roots per seedling occurred with each addition of 150 chilling hours. Ten weeks of storage reduced RGP by about 9 percent.

Any significant interactions between main effects were small, usually involving fewer than 5 new roots. An exception is the chilling by storage interaction (P>F=0.0003). Storage reduced RGP by 54 percent at the 100 chilling hour level (Table 3). At 250 hours and greater, RGP was improved or remained unchanged with the 10 weeks of storage.

Table 2. Seedling biomass and root growth potential (RGP) of seedlings tested for RGP, 1984-85 Fall N study.

Treatment	Original Root Collar Diameter (cm)		Total Oven-Dry Weight (mm)		Root Growth Potential (g)		Root Growth Potential (#)	
Nitrogen Level[1]								
Control	17.8	ns	3.5	ns	2.05	***	29	***[2]
67 kg N/ha	17.8		3.7		2.45		43	
202 kg N/ha	17.6		3.8		2.53		51	
Family								
Virginia	15.6	***	3.6	ns	2.16	***	35	*
Georgia	19.8		3.7		2.52		47	
Chilling Level[3]								
100	17.7	ns	3.6	*	2.11	***	35	*
250	17.2		3.7		2.29		39	
400	18.1		3.7		2.40		43	
550	18.0		3.8		2.51		48	
Storage (10 wk)								
No	18.0		3.6	ns	2.27	*	43	*
Yes	17.7		3.7		2.40		39	

[1] Nitrogen levels were applied over two application dates of September 9 and October 5, 1984 using Diammonium Phosphate.

[2] ns, ●, *, **, *** = not significant, and significant at the 5%, 1% and 0.1% probability level, respectively.

[3] Chilling Level = the number of hours the seedlings experienced temperatures between 0 to 8° C before sampling.

The fertilizer treatments increased seedling oven-dry weight (Table 2). The Georgia seedlings were heavier than the Virginia seedlings. At each higher level of chilling, seedlings sampled for RGP were heavier. When compared with other oven-dry weight measures, total seedling oven-dry weight had the highest simple correlation coefficient with RGP (r=0.7685; P>t=0.0001; n=180). An analysis of covariance, with total seedling oven-dry weight as the covariate, was conducted to determine if the main effect results were a function of seedling size or a physiological response altering RGP. While their significance levels were greatly reduced, adjusting RGP for total weight showed that only the main effects of fertilizer treatment (P>F=0.0433) and storage (P>F=0.0079) remained significant. The analysis of covariance indicated that the chilling by storage interaction was not significant (P>F=0.3034).

Table 3. Root growth potential of seedlings sampled at four chilling hour levels in relation to no storage or 10 weeks of storage.

Chilling Hour Level[2]	Root Growth Potential[1]	
(0 - 8" C)	No Storage	Storage
	— 1984-85 Study —	
100	48	22
250	38	39
400	39	46
550	48	48
	— 1985-86 Study —	
100	60	59
250	53	35
400	76	36
550	92	42

[1] Root Growth Potential = The number of new, unsuberized roots greater than 1 cm in length.
[2] The chilling hour by storage treatment interaction for both studies is significant at the 0.1% probability level.

First-year field growth and survival was not significantly affected by the fertilizer treatments (Table 4). The Georgia seedlings had greater growth and survival than the Virginia seedlings. Chilling level did not significantly influence first-year growth, but, as chilling level increased, survival increased. Storage reduced survival by 8 percent. Significant family and storage effects were still evident the second year after outplanting. Also, a small increase in second-year height growth was observed for the fertilized seedlings.

Any significant interactions between main effects represented small differences in height growth or survival. The exception was the first-year chilling by storage interaction. First-year survival was reduced 24 percent and 9 percent by storage when seedlings received 100 and 250 chilling hours, respectively (Table 5). Survival was slightly improved or remained unchanged with storage for seedlings receiving 400 and 550 chilling hours.

1985-86 Study

Fall N applications did not significantly increase N concentrations in foliage (avg.=1.03%), stems (avg.=0.47%), and roots (avg.=0.53%) of seedlings

Table 4. First-year and second-year field survival and height growth for the 1984-85 Fall N study.

Treatment	First Year			Second Year		
	Total Ht. (cm)	Height Growth (cm)	Survival (pct)	Total Ht (cm)	Height Growth (cm)	Survival (pct)
Nitroaen Level[1]						
Control	30 ns	12 ns	75 ns	61 •	30 •	72 ns[2]
67 kg N/ha	31	13	76	63	32	74
202 kg N/ha	32	14	79	67	35	77
Family						
Virginia	28 ***	12 "	72 ***	58 ***	29 **	70 **
Georgia	34	14	82	70	36	78
Chillina Level[3]						
100	30 •	12 ns	64 **	60 ns	31 ns	61 ns
250	31	13	78	63	33	76
400	32	13	82	65	33	80
550	32	14	83	66	34	80
Storaae (10 wks)						
No	31 ns	13ns	81 ***	66 **	34 **	77 **
Yes	31	12	73	62	31	72

[1] Nitrogen Levels were applied to seedlings over two application dates of September 28 and October 5, 1984 using Diammonium Phosphate.
[2] ns, ● , **, *** = not significant, and significant at the 5%, 1% and 0.1% probability level, respectively.

Table 5. First year outplanting survival of seedlings sampled at four chilling hour levels in relation to no storage or 10 weeks of storage for the 1984-85 Fall N study.

Chilling Hour Level[1] (0 - 8° C)	Percent Survival	
	No Storage	Storage
100	76	52
250	83	74
400	80	84
550	83	83

[1] The chilling hour level by storage interaction is significant at the 5% probability level.

sampled in January. Fertilizer treatments did not significantly affect seedling weight or RGP (Table 6). The Georgia seedlings were heavier and had higher RGP than the Virginia seedlings. RGP decreased by 28 percent from 100 to 250 chilling hours. All chilling levels above 250 hours showed increases in RGP. Storage reduced RGP by 39 percent. The signficant chilling by storage interaction (P>F=0.0001) showed that storage did not reduce RGP when seedlings were sampled at 100 chilling hours, but storage did reduce RGP when sampling occurred after longer periods of chilling (Table 3).

High correlation coefficients between RGP and total seedling oven-dry weight (r=0.6122; P>t=0.0001; N=192) again necessitated the use of analysis of covariance. The main effects of chilling and storage remained significant. Also, the chilling by storage interaction remained significant (P>F=0.0001). The Georgia seedlings appear to have a higher RGP than the Virginia seedlings because of their larger size.

DISCUSSION

The enhanced RGP of seedlings fall fertilized in the first study may be explained by increases in seedling size and the poor seedling nutrient status. Loblolly pine continues adding shoot and root weight after height growth has stopped in the fall (May 1984). The Georgia seedlings were heavier than the Virginia seedlings. Seedlings sampled at each higher chilling level had greater total oven-dry weights. Analysis of covariance indicated that the family and chilling effect on RGP was confounded by total seedling oven-dry weight. Covariate analysis did not remove the

Table 6. Seedling biomass and root growth potential (RGP) of seedlings tested for RGP, 1985-86 Fall N study.

Treatment	Original Height (cm)	Root Collar Diameter (mm)	Total Oven-Dry Weight (g)	Root Growth Potential (#)
N Fertilizer[1]				
Control	41 ns[2]	5.8 ns	6.48 ns	54 ns
AN	41	5.8	6.63	60
DAP	41	5.8	6.65	58
Family				
Virginia	37 "	5.8 "	6.16 "	50 "
Georgia	45	5.9	7.01	65
Chilling Level[3]				
100	41 ***	5.8 ***	6.22 ***	60 "
250	39	5.6	5.87	43
400	41	5.9	6.74	58
550	43	6.1	7.50	67
Storage (10 wks)				
No	41 ns	5.8 ***	6.62 ns	71 ***
Yes	41	5.9	6.55	43

[1] AN = Ammonium Nitrate, DAP = Diammonium Phosphate; Application rate was 202 kg N/ha applied on November 3, 1985.
[2] ns, ●, **, *** = not significant, and significant at the 5%, 1% and 0.1% probability level, respectively.
[3] Chilling Level = the number of hours the seedlings experienced temperatures between 0 to 8° C before sampling.

significant chilling effect for the second study. However, the apparent relationship between the lower weight for seedlings sampled at the 250-hour level and their lower RGP casts doubt on the significant chilling effect.

Fall fertilization of Douglas-fir (*Psuedotsuga menziesii* (Mirb.) Franco) has improved RGP (van den Driessche 1985). Improving the nutrient content of the seedlings in the first study would be expected to improve RGP. The improved seedling N concentration in the second study may have resulted in the lack of a fall fertilizer effect on RGP.

It is hypothesized that the ability of seedlings to withstand storage is improved after fulfillment of the chilling requirement for winter bud rest (Garber and

Mexal 1980). The chilling experienced by the seedlings appeared effective in reducing the days-to-budbreak (Williams and South 1992). For the first study, RGP and field survival was not affected by long-term storage after 250 or more chilling hours. However, the analysis of covariance, with total oven-dry weight as the covariate, removed the significant chilling by storage interaction for RGP. Perhaps, the larger seedlings sampled at the higher chilling levels withstand long-term storage better than the smaller seedlings. The opposite result was observed for the second study. RGP was reduced by long-term storage for seedlings experiencing 250 or more chilling hours. Storage may reduce RGP regardless of the terminal bud rest status as influenced by chilling (Carlson 1985). In addition, chilling requirements for storage may diier from the amounts necessary for winter rest release (Boyer and South 1985).

Fall N fertilization improved the size and weight of the container seedlings without significantly altering the bud dormancy cycle (Williams and South 1992). Fall N fertilization may prove more beneficial for seedlings with known or hidden nutrient deficiencies. Any gains in RGP as a result of increasing seedling size may be negated by cold storage regardless of when the seedlings are liied. Future research should concentrate on the type, timing and amounts of fall mineral fertilization. In addition, future investigations should study the relationship between growing season bareroot cultural practices and fall mineral fertilization.

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THE IMPORTANCE OF SELECTION GAIN IN WALNUT AGROFORESTRY MANAGEMENT'

H.E. Garrett, E.F. Loewenstein, J.E. Jones and G Rink[2]

Abstract-Slack walnut nut production is a viable source of income for landowners involved in black walnut management. An evaluation of nut production in 934 juvenile trees, over a 7-year period, revealed that SO percent of the trees studied produced an average of 100 or fewer nuts/tree/year between the ages of 7 and 15 while only 2 percent produced more than 200. Through selection gain, using nut production records as a guide for thinning, a highly significant increase in nut production can be realiied over plantations thinned without the benefit of nut production information.

INTRODUCTION

Agroforestry, an intensive land-management system that optimizes the benefits from the biological interactions created when trees and/or shrubs are deliberately combined with crops and/or livestock, is rapidly coming of age in the U.S. (Garrett et al. 1994). Both production and conservation benefits accrue as a result of its adoption. Within domestic agroforestry, five distinct systems have evolved: alley cropping, windbreaks, riparian vegetative buffer strips, siivopasturing, and forest farming. Each has its region of emphasis but potential application exists throughout the entire temperate zone.

Within Missouri, a great deal of research and emphasis has been placed on alley cropping and in particular on establishing practices conducive to maximizing the economic gain from planting black walnut (*Juglans nigra* L.) in alley cropping practices (Kurtz et al. 1984, Kincaid et al. 1981). Early work on black walnut alley cropping (Garrett and Kurtz 1981, Garrett and Kurtz 1988) clearly demonstrated the economic benefits of sacrificing some wood production in favor of enhancing fruit production through the maintenance of large crowns. The purpose of this paper is to demonstrate the value of using selection gain as a means of increasing fruit production and, ultimately, the profitability of walnut alley cropping.

METHODOLOGY

The School of Natural Resources at the University of Missouri-Columbia and the U.S. Forest Service at Carbondale, Illinois in concert with Hammons Products Company of Stockton, Missouri have initiated studies to assess the variation in the nut-bearing characteristics of black walnut trees. Nut production from 934 juvenile trees grown under alley cropping management has been monitored on an annual basis since 1983. Seedlings were established on an upland site in 1975 at a spacing of approximately 6 x 12-meters. Planting stock was purchased from the Missouri Department of Conservation nursery in Licking, Missouri and is representative of a wild population. Soils within the planted area are of the Bolivar series and are ultic hapludalfs derived from acid sandstone which are moderately deep and well-drained.

Weed control has been accomplished throughout the life of the planting by applying 5Q of Roundup and Simazine 4L in 235ℓ of solution per treated hectare. Application is accomplished by banding in widths of approximately 1.5m along both sides of a row of trees. Harvesting of nuts is achieved by hand. Following release from a tree, nuts are picked up, counted, stored in onion sacks and identified by tree number. Husks are removed on a per tree basis by running the nuts through a mechanical huller. Following the removal of the husk, nuts are weighed and the weights recorded by tree number.

RESULTS AND DISCUSSION

Alley cropping management with black walnut dictates initial plantings of tree rows at wide spacings to accommodate the needs of companion crops grown in

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the alley ways. Such wide spacings also accommodate the development of large, relatively uninhibited crowns which are so important for fruit production. Studies in our program have clearly demonstrated the value of nut production in maximizing the economic gain from walnut management (Garrett and Kurtz 1988). Unfortunately, to date little research emphasis has been placed on selecting heavy bearing cultivars. Furthermore, few practitioners understand the importance of carefully monitoring and maintaining records on nut production which can later be used as a tool for securing selection gain through thinning.

The importance of landowners maintaining good nut production records is clearly demonstrated in Figure 1. Out of 934 trees representing a wild population (seedlings were from nuts picked up in the wild and are representative of most seedlings used in establishing plantations throughout the eastern half of the U.S.), 41 had borne no fruit by age 15. Eighty percent of the 934 trees produced an average of only 100 or fewer nuts per year from age 7 through 15. An additional 18 percent of the trees produced between 100 and 200 per year. Only 2 percent of the trees sampled averaged producing more than 200 nuts per year. Of these, three averaged more than 300. The importance of conducting thinnings based on good nut production data becomes obvious when a comparison is made in the dollar value per hectare of the best producers compared to the mean of the population. If an individual owned 3.5 hectares and wished to plant it on a 3 x 12-meter spacing, as in this study, he would order 931 trees (266 trees/ha). Assuming that the 934 trees monitored in this study are representative of the seedlings that would be received, from age 7 through 15 they would produce an average 1.25 kg of

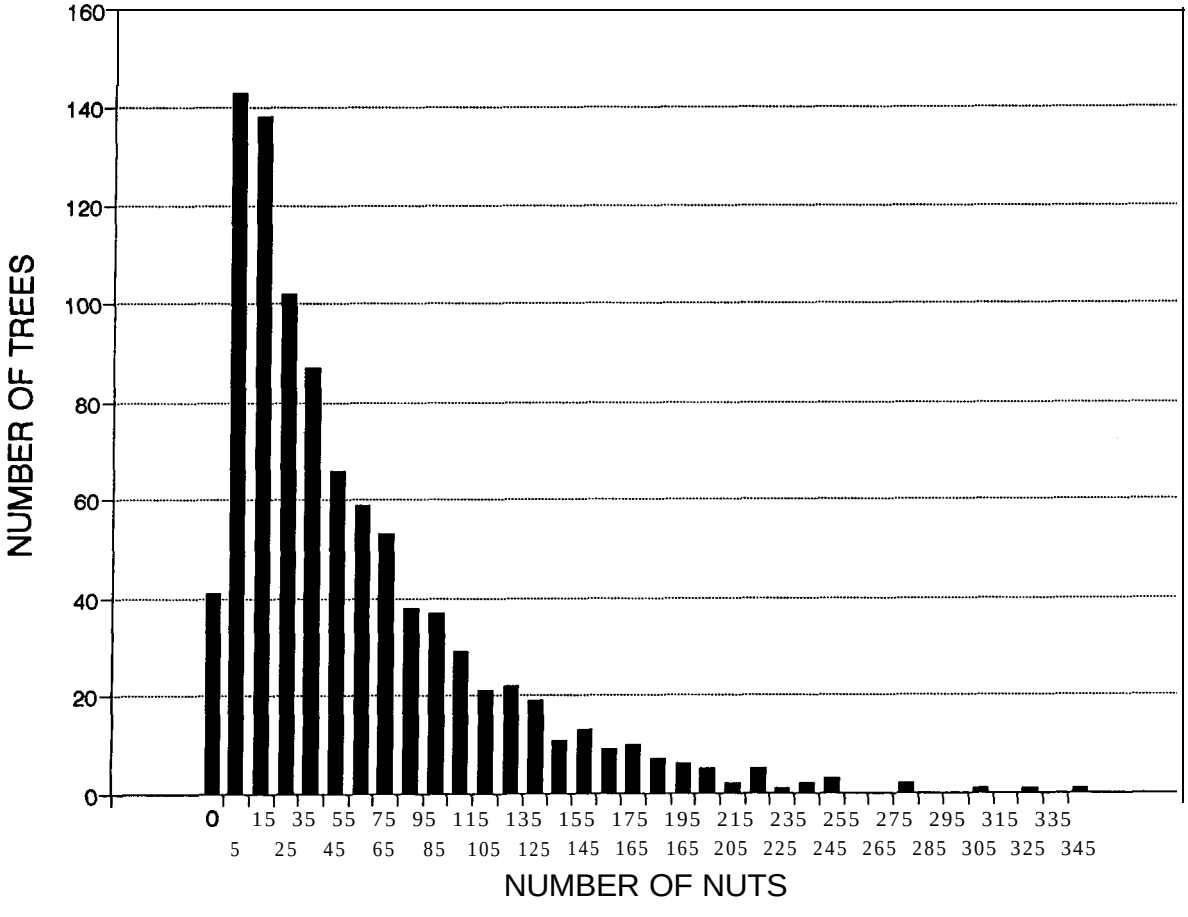

Figure l-Average nut production for 934 juvenile walnut trees grown under alley cropping management on an upland site. Nut production represents an average of nuts harvested from 1983 to 1990.

nuts/tree/year. In our study the average number of green nuts per kg (husk removed) equalled 60 and the average tree produced 75 nuts&ear (age 7-15). Assuming a value of $0.27/kg (this is a low average since as much as $0.44/kg has been paid on a contract basis for plantation-grown nuts), these 266 trees/ha would yield nuts with a value of approximately $90. If the 3.5 ha plantation occupied a good bottomland site, at 15 years it is approaching the age for thinning if nut production is being emphasized. A 15-year old walnut plantation (3 x 12m) on a high quality site in our study had an average height of 13m with an average diameter greater than 18 cm. Assuming the owner elects to thin the plantation to 70 trees/ha (approximately a 12 x 12m spacing which corresponds to our recommendations), the probability of his increasing the ratio of good to poor nut producers is poor unless he has maintained annual nut production records. More than 80 percent of the 931 trees he used to establish his 3.5 ha will have produced fewer than 100 nuts per year by age 15. Assuming random distribution, the 138 trees which have averaged producing more than 100 nuts/tree/year have the same probability of being removed as the poor producers which outnumber them almost 7 to 1. One might, therefore, assume that no improvement (selection gain) in nut production on a per tree basis will be realized from thinning under these conditions. Assuming that a production rate of 1.25 kg/tree/year is maintained, with only 70 trees/ha following the thinning, nut production value in year 16 would equal $23.62/ha (70 trees x 1.25 kg/tree x $0.27/kg).

In contrast, if a landowner maintained good nut production records and could retain the best 245 trees distributed across the 3.5 ha (70 trees/ha x 3.5 ha), an increase of 63 percent (2.04 kg/tree vs 1.25 kg/tree) in nut production would be realized. Seventy trees per hectare averaging 2.04 kg of nuts/tree would yield approximately 143 kgs of nuts in year 16 if we assume no increase in nut production immediately following thinning. Assuming a value of $0.27/kg, the 245 trees (70/ha x 3.5 ha) retained on the basis of nut production over the preceding 8 years (7-15), would yield $38.61/ha for a gain of $14.99/ha over the plantation thinned without the benefit of nut production data. Moreover, trees that have demonstrated a genetic capacity (heavy and regular bearers) for nut production between ages 7 and 15 may yield better with age than trees that showed lower potentials for fruiting during these same years. If this assumption holds, the percentage gain in nut production realized through selection will increase with the age of the planting as will the dollar value of the nut crops produced.

Walnut nut production is regulated by genetics and, therefore, varies significantly within a wild population. However, though the maintenance of annual nut production records, landowners can greatly improve their average yields by discriminating against poor producers during thinning (selection gain). Until genetically proven stock is available at a price affordable by the average landowner, selection gain offers the best opportunity for a landowner to increase nut yields and dollar value per hectare in walnut alley cropping plantings.

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A CLONAL COTTONWOOD TRIAL AFTER 21 YEARS'

J.C.G. Goelz and M.L. Monroe'

Abstract-Thirteen select clones of eastern cottonwood were planted in 1972 to provide information wncerning their growth and survival. Five of these clones were later identified as superior clones. More recent measurements taken in this plantation indicate that four of the five recommended clones are now among the five worst clones at thii location. Thus early selections may not indiite true growth potential for a clone. At age 21, Stoneville clone 124 had the greatest basal area and volume, but had poor log grade. Based on volume and log grade, the best clones at age 21 were Stoneville clones 63, 70, 71, and 72.

Much of the early work in genetics and biology of eastern cottonwood (*Populus deltoides* Bartr. ex Marsh) was conducted by scientists of the Southern Hardwoods Laboratory at Stoneville, Mississippi. In 1970, fourteen clones were selected for midsouth timber production (Mohn, and others 1970). In 1972, five of these clones passed a second stage of selection; these clones were widely disseminated as improved stock, and the other clones were to be eliminated from nurseries (Craig 1972, letter on file with authors). By 1974, these so-called "blue-tag" clones received the highest level of registration within the state of Mississippi (Land, 1974). Cooper and Ferguson (1979) and Cooper (1982, unpublished manuscript on file with authors) subsequently indicated that the blue-tag clones were outperformed by other clones, and they suggested that selection should be delayed until the clones had achieved approximately half of rotation age.

The objective of this paper is to report on the growth of thirteen of the original Stoneville clones, including the five blue-tag clones, at age 21 **at a site in Mississippi.** As quality sawlog production is **a primary aim** of the **land manager, diierences** in log grade among clones are important.

MATERIALS AND METHODS

Study Site

An 800 acre cottonwood plantation was planted in 1972 at Hookers Ridge. Hookers Ridge is about 20 miles north of Vicksburg, Mississippi, on the Mississippi Delta and is on the protected side of the levee. Thirteen of the Stoneville clones were planted: 63, 66, 67, 70, 71, 72, 74, 75, 81, 91, 92, 109, and 124. Clones 66, 67, 74, 92 and 109 are the so-called blue-tag clones. The plantation was divided into blocks, and within each block there were two-row plots of each clone. Each row contained 150 to 170 trees. Three of the blocks were randomly selected for measurement. A road ran approximately along the center of the plantation, coinciding with a soil-type boundary between Commerce and Tunica soils. Commerce soils are loamy throughout and among the best soils for cottonwood. Tunica soils diier from Commerce soils by having a clay cap of approximately two feet thickness. Although Tunica soils are good cottonwood sites, they are generally considered to be inferior to Commerce soils. The plantation was thinned three times, (mid 1970's, in 1981, and 1990). Both row and selective thinnings were conducted. Mortality due to thinning could not be distinguished from natural mortality. Some clones were removed from some blocks by the thinning. Thus, the design became unbalanced. One of the measured blocks was left unthinned.

Measurements

Measurements were made at ages 1, 2, 16, and 21. Twenty percent of the trees were measured-trees at two adjacent planting spots, followed by eight spots that were skipped. Height and diameter at breast height (d.b.h.) were recorded at ages 2, 16, and 21. Volume of individual trees was estimated from height and d.b.h. using weighted regression equations

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described by Krinard (1988). At ages 1, 2, and 21, the total number of living trees within each row was recorded. Because number of trees was not recorded at age 16, stand level variables (basal area, volume/acre) could not be determined at that age. At age 21, grade of the lower 16' log was recorded, using standard hardwood log grade rules.

Analysis

As removal of some clones from some blocks caused the design to become unbalanced, a regression approach, rather than an analysis of variance approach, was used in data analysis. Dummy variables were created for blocks, clones, and soil type. Model selection involved eliminating nonsignificant variables. The procedure used in model selection was basically backward elimination, where nonsignificant variables are removed one by one, starting with the least significant predictor, until only significant variables are left. Variables removed early in this process are added back into the equation if they become significant following the removal of other variables. Diameter at age 16 was used as an additional covariate to predict diameter at age 21. The coefficient for diameter at age 16 was allowed to be unique for each clone. During model building, tests for commonality of parameters among clones were made. Height growth data from ages 2, 16, and 21 were fit to a Weibull-equation, with each parameter of the Weibull expanded as a function of clones, blocks, and soil types. The model-building procedure described above provides good descrimination of the better and poorest clones. For survival and grade data, contingency tables were created and significant differences among clones were tested by comparing X^2 and G^2 to χ^2. An a of 0.05 was used for all tests.

RESULTS

Diameter at Age 21

The equation for average diameter at breast height (averaged over all trees in a row) is:

D = 17.006 + 0.762*B3 + 1.472*Soil - 5.175*C109 - 3.547*C74,91 - 2.374*C66,67,92 - 0.638*C70 + 1.092*C75.81

where

D represents diameter at breast height at age 21, in inches.

B3 is a dummy variable representing block 3,

Soil is a dummy variable representing different soil types, with a 1 representing Commerce soil, as identified in reference to the road running down the middle of the plantation. 0 would represent Tunica soil, or south of the road.

Cl09 is a dummy variable for clone 109.

C74,91 is a dummy variable for clones 74 and 91.

C66,67,92 is a dummy variable for clones 66,67, and 92.

C70 is a dummy variable for clone 70.

C75,81 is a dummy variable for clones 75 and 81.

The adjusted R^2 for the equation is ,907, with standard error of the estimate equal to 0.598 inches.

Dummy variables representing clones 63, 71, 72 and 124 were not significant; this group could be considered to be the "average" group for d.b.h. at age 21. Clones 75 and 81 averaged over one inch more in d.b.h. than that average group. Clone 70 was slightly smaller in d.b.h. than the average group. Clones 66, 67, and 92 had diameters that were 2.4 inches smaller than the average group. Clones 74 and 91 were 3.5 inches smaller than the average group. Clone 109 had the smallest diameters of all clones.

Trees per Acre at Age 21

The equation for trees per acre at age 21 is:

TPA = 50.259 - 12.688'83 + 5.655*Soil - 10.219*C75,81 - 36.415*C109

Where, TPA represents trees per acre. The adjusted R^2 for the equation is .546, with a standard error of the estimate equal to 8.3 trees per acre. Although clones 75 and 81 had the greatest diameters at age 21, they also have fewer trees per acre. Thus the greater diameter may be due to lower stand density rather than any inherent superiority in capacity to grow. Although clone 109 had low average diameter, it also has low density. The other ten clones were lumped together with regard to trees per acre. The three thinnings within the stand lessened early differences among clones in trees per acre.

Diameter Growth from Ages 16 to 21.

Diameter growth of individual trees from ages 16 to 21 was predicted as a function of dummy variables for blocks and clones with diameter at age 16 used as a covariate. The relationship between growth and initial diameter was linear. The adjusted R^2 of the equation was ,655 and standard error of the estimate was .386. The results of the equation are graphed in figure 1, for

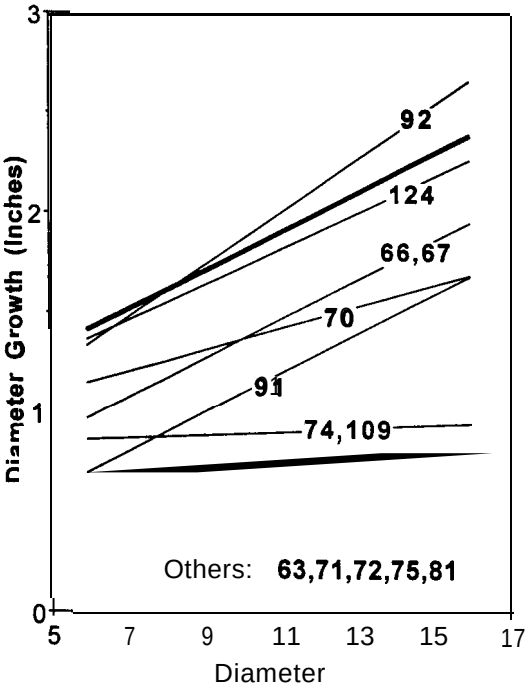

Figure 1. Diameter growth as a function of initial diameter. Lines are labeled by clones. Thickened lii represents five clones for which the regression equation did not include clone-specific parameters.

the second block. There are only minor differences in the intercept among blocks. Initial diameter is a significant covariate. There is a relatively large group of clones exhibiting good diameter growth, clones 63, 71, 71, 75, and 81. Clone 124 is only slightly below that group. Clones 66, 67 and 70 grew more slowly. Clone 91 was next, and clones 74 and 109 were considerably inferior. Clone 92 expressed diameter growth that was among the best, after adjusting for the covariate of initial diameter. However, clone 92 was shown to have among the smallest diameters at age 21, and in the absence of the covariate, clone 92 does have low raw diameter growth rates. Although the line for clone 92 is higher than the tine for clone 124, most of the trees for clone 92 had an initial diameter towards the lower end of the graph while most of the trees for clone 124 had initial diameters toward the higher end of the graph. There are two explanations for the apparent superiority for clone 92. The initial small size of clone 92 may be due to past incidence of disease or insects, and the clone may be recovering. Alternatively, a tree of a given diameter for clone 92 will be in a better crown position than a tree of the same diameter for a done with a greater average diameter. For example a tree with a diameter of 9 inches at age 16 for clone 92 might be a codominant tree, while a 9 inch diameter tree for a different clone may be in an inferior crown position. Although dones 75 and 81 had the largest diameter trees at age 21, they were clustered with dones 63, 71 and 72 with regard to diameter growth between ages 18 and 21. This might support the interpretation that the larger diameters of clones 75 and 81 were due to lower density rather than an inherently superior capacity to grow.

Height Growth to Age 21

For each plot, average height of the tallest 50 percent of the trees was calculated at ages 2, 16, and 21. An expanded Weibull function was fit to this data. The general form of the Weibull height-growth model is:

$$H = A(1-\exp(B(Age)^C))$$

where,

H represents height,
Age reflects plantation age, and
A,B, and C are parameters.

A represents the asymptote of the equation. B is a rate parameter, and C is a shape parameter. Each of the parameters was expanded as a function of dummy variables representing clones, blocks, and soil types. After eliminating non-significant variables, the resulting equations for each parameter are:

$$A = 134.749 + 8.987*B2 + 30.026'83 - 29.489*C109 - 19.456*C74 - 13.734*C91,92 - 2.590*C81 + 4.912 \cdot C66,70,71 + 20.656*C72$$

$$B = -0.106 + 0.018*B3 - 0.020*Soil + 0.013*C72$$

$$C = 0.943 - 0.069*B3 - 0.040*Soil$$

Where variables are as previously defined. The corrected R^2 is .996. The standard error of the estimate is 2.823 ft. The curves for the equation are plotted in figure 2. Although the dummy variables for most clones enter into the equation for the asymptote, only one clone, clone 72, contributes to parameters B or C. This means that the curves for all other clones are proportional, they only differ with regard to the maximum height. Clone 72 has the greatest asymptote as well as having a larger rate parameter. Thus clone 72 is diverging from the other clones. Clones 66, 70 and 71 express the next best height growth. Dummy variables for clones 63, 67, 75 and 124 do not enter the

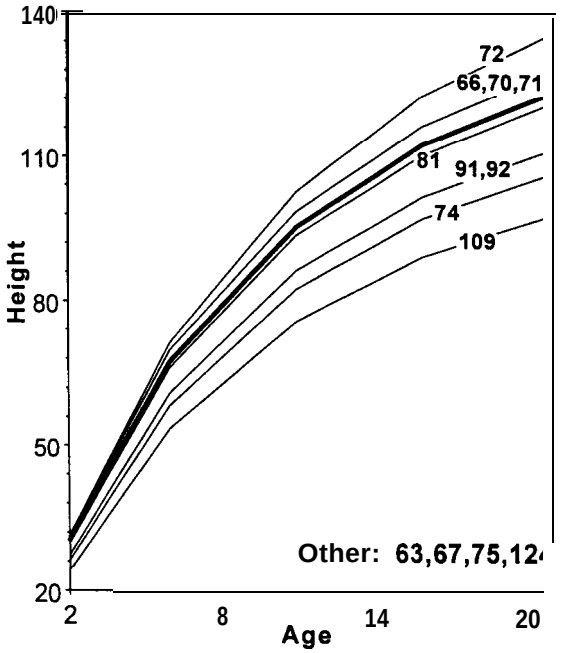

Figure 2. Height over age curves. Lines are labeled by clones. Thickened line represents four clones for which the regression equation did not include clone-specific parameters.

equation: they represent a group of clones with good height growth rates. Clone 81 has growth that is slightly less than that group. Clones 91 and 92 and clones 74 and 109 exhibit poor height growth. The dummy variable for soil type only enters the equation in the rate and shape parameters; it does not enter the asymptote parameter. This means that the two soil types have identical maximum heights. The Commerce soil produces taller trees than the Tunica soil, however, the difference in height among soil types has decreased between ages 2 and 21, both in proportional terms and in absolute differences. If the model can be extrapolated, in the future the difference will become negligible.

Basal Area per Acre at Age 21

The equation to predict basal area per acre at age 21 is:

BA = 93.474 - 10.084*B3 - 74.584*C109 - 23.874 • C67,74,91,92 + 15.832*C124

Where BA represents basal area per acre. The adjusted R^2 is .579. The standard error of the estimate is 14.237 ft^2/acre. Clone 124 had the greatest amount of basal area at age 21. Clone 109 had the lowest basal area. Clones 67, 74, 91 and 92, as a group, had almost 24 ft^2/acre less than the average group, comprised of the remaining clones, 63, 66, 70, 71, 72, 75 and 81.

Volume per Acre at Age 21

The equation to predict cubic foot volume per acre at age 21 is:

Volume = 3210.4 + 313.6*Soil + 626.6*B2 - 3410.4 • C109 - 2056.8*C74 - 1203.5*C67,91,92 + 578.5*C124

Where Volume represents cubic foot volume per acre. Volume per acre for the large "average" group, consisting of clones 63, 66, 70, 71, 72, 75 and 81, is over 3200 ft^3/acre. The Commerce soil produces over 300 ft^3/acre more than the Tunica soil. Clone 109 produced very little volume. The parameter for clone 109 would indicate that negative volume would be obtained for Tunica soils, except in block 2. The only data for clone 109 came from block 2. Clone 74 also produced little volume. Clones 67, 91, and 92 were also inferior to the average group, with regard to volume. Clone 124 produced over 575 ft^3/acre more than the average group. Thus with regard to volume at age 21, clone 124 is clearly superior, while clones 109, 74, 67, 91 and 92 do poorly. Baker and Broadfoot (1979) indicate volumes, at age 20, of 4300 ft^3/acre for high site class plantations. Thus, volume growth at this site is less than indicated by the yield tables of Baker and Broadfoot (1979).

Survival between ages 16 and 21

Although significant differences were found among clones with respect to survival between ages 16 and 21, only two clones had more than one tree die-clones 74 and 109. This provides further information to substantiate the inferiority of those two clones.

Log grade at age 21

Significant differences were found among clones with respect to log grade. Proportion of trees by clone and grade are graphed in figure 3. No grade one logs (the best grade) occurred for any clone; pruning may have been initiated one year too late. Five clones had more than 15 percent of trees with grade two logs; these are clones 63, 67, 70, 71 and 72. Clones 124, 75 and 81 had a small amount of grade two logs. No other clones had any grade two logs.

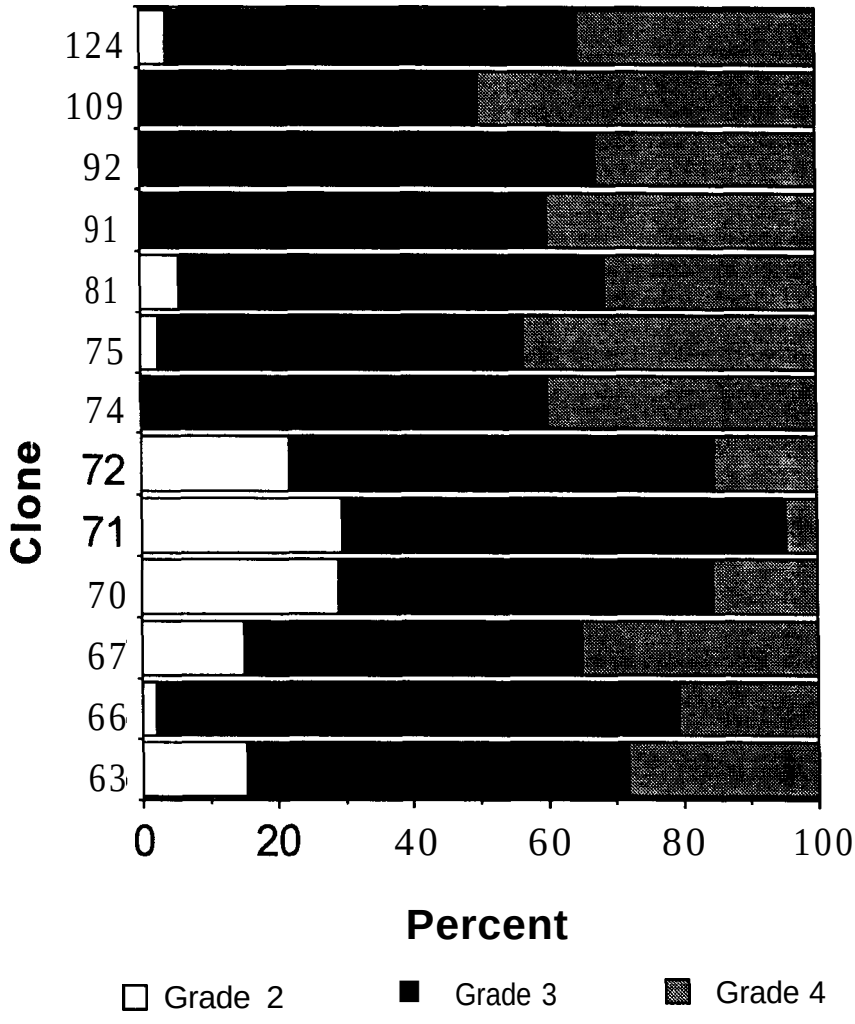

Figure 3. Grade of lower 16 foot log for each clone, represented as a percent of all trees of that clone. Grade 4 represents local use, or construction grade logs.

SUMMARY AND RECOMMENDATIONS

Although this study became unbalanced, and other factors, primarily inabilii to discriminate mortality from thinning, lessen the importance of individual contrasts among clones, consistency among many of the individual tree and whole stand measurements provides strong evidence for the superiorii and inferiority of particular clones. Among the five clones identified as superior in 1972: (1) Four were among the five worst growers with respect to volume at age 21. Only clone 66 was at least average; (2) Three of those four worst growers also had low log grade; only clone 67 had good grade; (3) Clones 74, 92 and 109 were unacceptable in regard to growth and grade. The blue-tag clones should no longer be considered to represent superior planting stock. Although they may outperform wild populations on some sites, they are inferior to other select clones.

Clone 124 produced the greatest volume, however, log grade was relatively low. Clone 124 is known to have deep crowns with large branches. While this may improve volume production, it detracts from production of quality sawlogs. With early pruning, clone 124 may be suitable for quality sawlog production. It may be suitable for biomass production. Clone 124 was idenfied by Cooper (1982, manuscript on file with authors) as being a superior clone, although he indicated that it was not appropriate for clay soils.

Based on total volume production and considering grade, the best clones are 63, 70, 71, and 72. They

are superior to the blue-tag clones in regard to growth of individual trees, of stand-level growth and grade. Clones 70 and 72 were previously identified by Cooper and Ferguson (1979) as superior dones. Clones 70, 71 and 72 are all open-pollinated progeny of a single female tree; thus they are at least half-siblings. Clone 63 is an open-pollinated progeny of a different female tree occurring at the same site in Mississippi as the mother tree of 70, 71 and 72. Thus, clone 63 may be related to clones 70, 71, and 72.

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SEED TRANSFER AND GENECOLOGY IN SHORTLEAF PINE'

R.C. Schmidtling'

Abstract- Tree heights in a 25-year-old provenance test of shortleaf pine (*Pinus echinata* Mill.) were related to temperature variables with polynomial regression models. The most important climatic variable associated with north-south variation was average annual minimum temperature at the seed source. Results of different plantings were combined by expressing growth as a percent deviation from the local source, and by expressing temperature at the source as a deviation from that of the planting site. The analyses show that moving seed sources northward from areas with minimum temperatures 7° F warmer than the planting site result in the maximum gain over local sources. Moving seed sources northward more than 15° F results in less growth than that of the local source. In general, western seed sources grew slightly better than eaetem seed sources.

INTRODUCTION

When choosing seed for afforestation, foresters generally follow the rule that local seed sources are best. This conservative approach is certainly best in the absence of reliable data on the performance of other seed sources. It cannot always be assumed, however, that local sources will perform the best (Namkoong 1969). Provenance tests have shown that the local source does not always achieve the highest yield (Wells 1983).

For more than 200 years, foresters have used provenance tests or seed source studies to determine the best source of seed for afforestation, and to study genetic differences in response to changes in climate and site (Langlet 1971). A major factor in the performance of a seed source in a particular location is the difference in climate between the planting slte and the seed source. Seeds moved a modest distance northward often out-perform seeds from the local source (Wells and Wakeley 1966). If moved too far to the north, however, they suffer cold damage and do not perform as well as the local source. If moved to the south, they also do not perform as well as the local source. These results suggest a curvilinear relationship between growth and climatic differences between seed source and the planting location.

Differences in temperature are certainly important, and yearly average minimum temperature at the source (Figure 1) was the best variable found to predict effects of seed transfer in loblolly pine (*Pinus taeda* L.) (Schmidtling 1994). In the present study, results of the Southwide Southern Pine Seed Source Study (SSPSSS) were used to explore the genecology and to predict the effects of seed movement on the growth of shortieaf pine.

MATERIALS AND METHODS

In the shortleaf phase of the SSPSSS, seeds from 16 sources were planted at many locations across the natural range of that species (Figure 1). Data from the 19 plantings that survived to age 25 were used in the analysis.

Plots representing single seed sources contained 11 rows of 11 trees at 6- by 6-foot (1.8 m X 1.8 m) spacing. These plots were replicated four times. Trees from five or six sources were planted at each site. Wells and Wakeley (1970) completely described the study.

Climatic and other location data, in addition to those in Wells and Wakeley (1970), were obtained from USDA Forest Service (1969), USDA Agricultural Research Service (1990), and NOAA(1991).

In an initial examination, each of the 19 plantings was analyzed separately. Mean heights and plot volumes of the provenances were used as dependent variables. Independent variables included each seed source's latitude, mean temperature, yearly average minimum temperature, precipitation, frost-free period, and the

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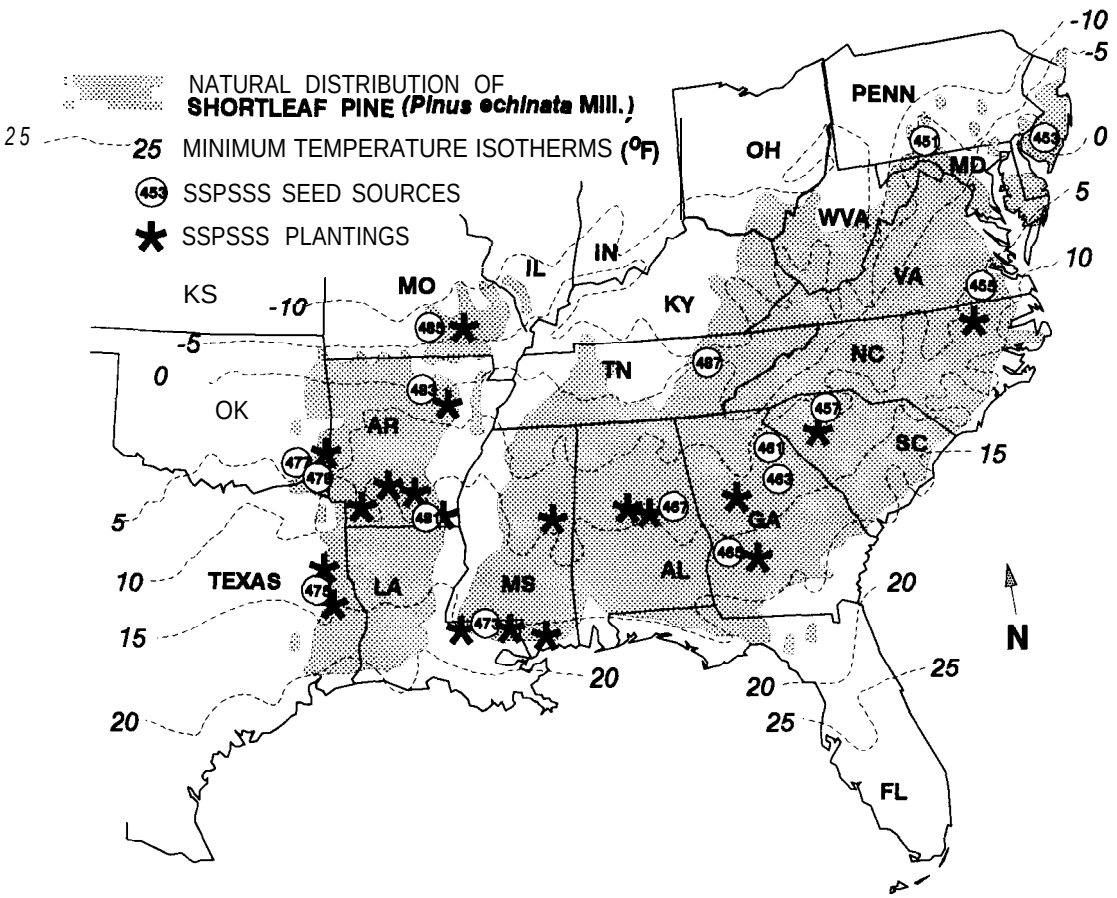

Figure 1. Natural distribution of shortleaf pine (*Pinus echinata* Mill.) in the Southeastern United States and locations of seed sources and plantings of the Southwide Southern Pine Seed Source Study (SSPSSS). Mean annual minimum temperature isotherms are from USDA Agricultural Research Service (1990).

squares of these. The variables were included in step wise multiple regressions to determine the most important variables. Overall, mean temperature and minimum temperature are probably the most useful, apparently because they integrate the effects of latitude, elevation, and maritime effects into a single variable. It also is important, however, to know what other variables are affecting growth.

In the regression analysis of combined data, the percent deviation in height from the local source was the dependent variable. Independent variables were the differences between the location and the seed source for latitude, minimum temperature, mean temperature, frost-free period and rainfall, and the squares and cross-products of these variables.

Differences between eastern and western sources, geographically defined by the Mississippi River Valley (Figure 1), were examined using techniques described by Neter and Wasserman (1974) for testing differences between regression lines. In this procedure, a reduced model (1) of the polynomial regression is compared sequentially with models (2), (3), and (4) containing terms for east/west effects, by a straight-forward F-test of the reduction in error sum of squares. Model (1) computes a common polynomial regression line for all the data. Model (2) is equivalent to computing separate regression lines where eastern and western sources differ in intercept (β_0), Model (3) is equivalent to computing lines having different coefficients for β_0 and β_1, and Model (4) is equivalent to computing lines where β_0, β_1 and β_2, differ for eastern and western

sources. The reduced polynomial model is:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i1}^2 + \epsilon_i \quad (1)$$

The model allowing for east/west differences in intercept is:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2}^2 + \beta_3 X_{i3} + \epsilon_i \quad (2)$$

The model allowing for east/west differences in intercept (β_0) and slope (β_1) is:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2}^2 + \beta_3 X_{i3}\, \beta_4 X_{i3} X_{i1} + \epsilon_i \quad (3)$$

The model allowing for east/west differences in intercept (β_0), slope (β_1) and curvature (β_2) is:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2}^2 + \beta_3 X_{i3}\ \beta_4 X_{i3} X_{i1} + \beta_5 X_{i3} X_{i2}^2 + \epsilon_i \quad (4)$$

where:

$\beta_0, \beta_1, \ldots \beta_5$ = Parameters fitted by the regression procedure

Y_i = Height (or volume) for observation i

X_{i1} = Most important dependent variable at the source for provenance i

X_{i1}^2 = Square of this dependent variable at the source for provenance i

$X_{i3} = \begin{cases} 1 & \text{if observation from west of the Mississippi River} \\ 0 & \text{if observation from east of the Mississippi River} \end{cases}$

ϵ_i = residual.

RESULTS AND DISCUSSION

In the original analysis of the SSPSSS, there was a strong interaction between planting location and seed source (Wells and Wakeley 1970). Their analysis showed that the relative performance of the seed sources depended on the planting location. This result is common, and even expected, in seed source studies, and is evident when comparing height growth with temperature in Figures 2a-c.

Consistently, the best single predictor for height growth was average annual minimum temperatures at the seed source. From 30 to 82 percent of the variation in height at age 20 years was explained by a linear or quadratic relationship with minimum temperature at the seed source. Latitude, mean temperature, frost-free season, and the squares of these variables also were significantly related to height in individual analyses. The effect of rainfall failed to achieve statistical significance, because rainfall does not vary much across the shortleaf pine range.

The relationship between height and minimum temperature at the source was nearly linear in the most southern plantings (Figure 2a). The sources from areas with the highest minimum temperature, those from the southern-most collection points, were the tallest, up to 41 feet, and those from area of the lowest minimum temperature averaged only around 32 feet. The climate in this southern planting was not cold enough to adversely affect the growth of any source.

A curvilinear relationship between minimum temperature at the source and growth is apparent in a mid-latitude planting (Figure 2b). The linear regression with minimum temperature explained 32 percent of the variation in height; adding the square of minimum temperature improved the fit to 63 percent. The sources with the tallest trees at age 25 were those that were collected from areas with minimum temperatures somewhat above that of the planting location-those from south of the planting location. Seed sources from climates colder than the planting location, as well as those from climates much warmer than the planting location did not grow as well as the local stock.

The curvilinear relationship also can be seen in a plot of height versus minimum temperatures in one of the northern plantings (Figure 2c). A linear fit with minimum temperature at the seed source explained 37 percent of the variation; addition of minimum temperature squared improved the fit to 81 percent. In this planting, the poor performance of sources from far south of the planting site is more evident than in the mid-latitude planting (Figure 2b).

Diierences in site index present diicult problems in combining data from different locations. Mátyás and Yeatman (1992) included the height of the local source as one of their independent variables, to compensate for these differences. Generally, high r^2 values are obtained with this method because of the auto-correlation. This approach was tried in the present study, but more interpretable results were obtained by first expressing growth as a percent deviation from the local source, and then combining the data from the different plantings.

The definition of the "local source" is often problematical, and in the case of the SSPSSS, exact local sources do not exist for many of the plantings.

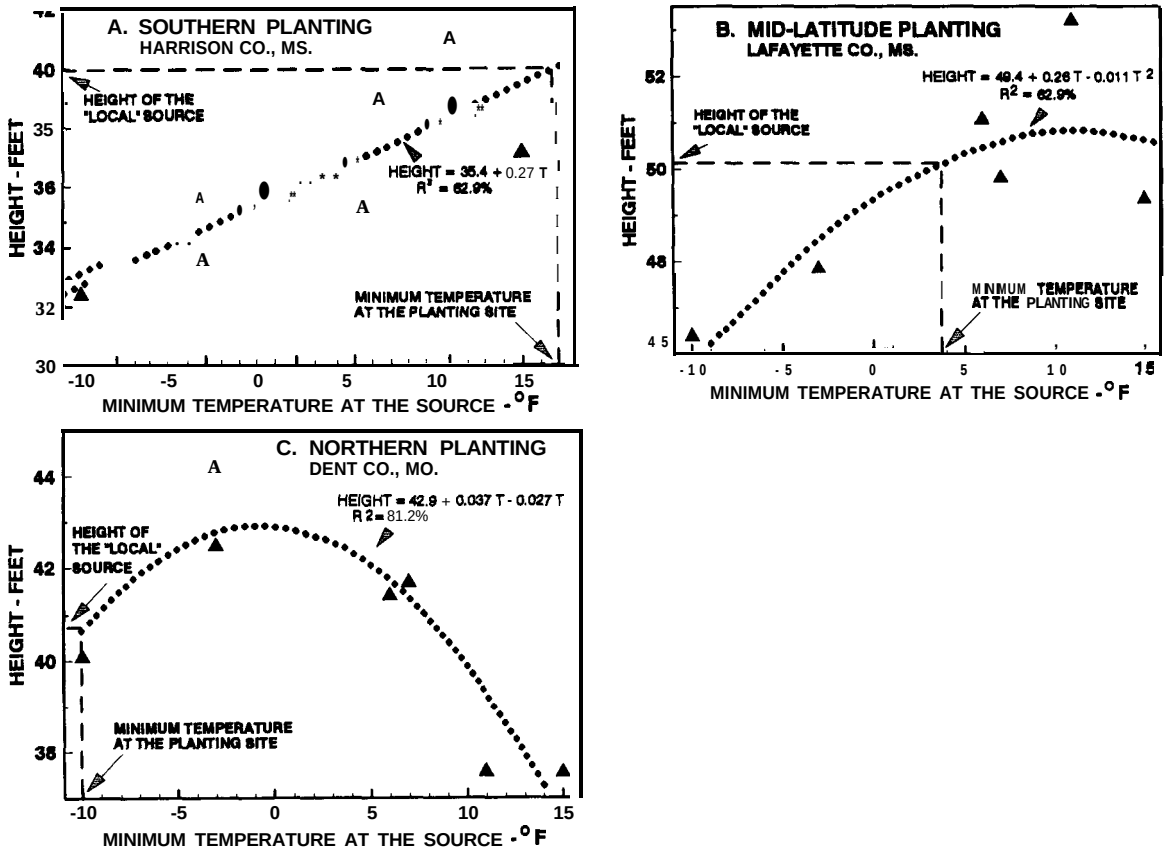

Figure 2. Height at age 25 versus yearly average minimum temperature at the seed source for three selected plantings representing southern (A), central (B), and northern (C) responses.

There may be one or more sources from nearby areas that could be used. In this analysis, the height of the "local" source was determined by regression (Figure 2a-c). As Mátyás and Yeatman (1992) have pointed out, the height of the local source is not known without error. Using a regression model to determine this height may result in less error than using any one particular source.

When combining studies from different locations, the differences in latitude, temperature, precipitation, etc., between the planting location and the seed source are probabiy more important than the absolute values of these variables. Giertych (1977) used "latitude displacement" to combine seed source data from several nurseries. In developing their seed transfer model in jack pine (*Pinus banksiana* Lamb.), Mátyás and Yeatman (1992) used the difference in latitude and the difference in heat sums between the planting location and the seed source to define "ecological distance."

Minimum temperature difference and minimum temperature difference squared were the most important variables when the data from the 19 plantings were combined (Figure 3). This combination accounted for 48 percent of the variation in height deviation from the local source. Latitude difference squared was also significantly related to height deviation in the multiple regression, but accounted for only an additional 2.5 percent of the variation. Photoperiodic effects are certainly important in loblolly pine (Perry and others 1966), but were not very meaningful in thii study after effects of temperature were accounted for.

Logically, the curve computed using deviations in height from the "local" source in the combined data should pass through the intercept, if the height of the

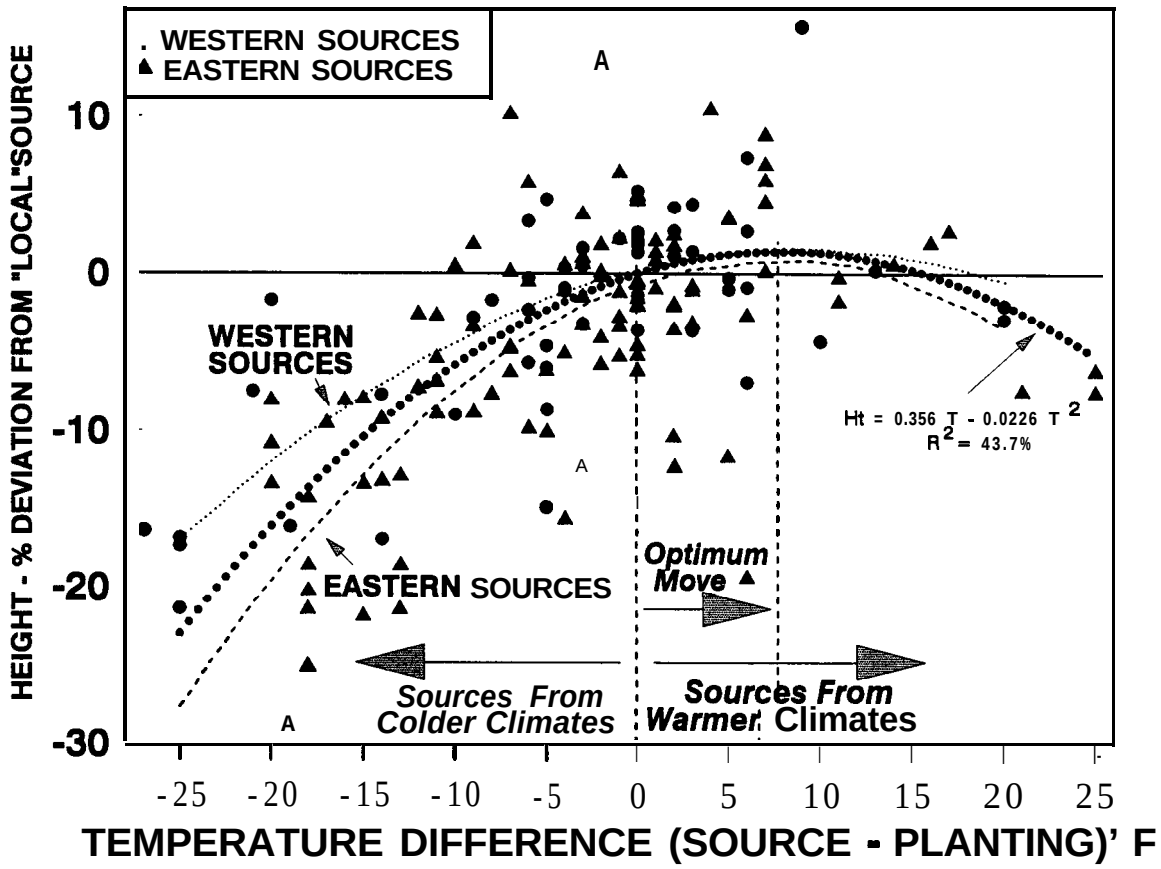

Figure 3. Height at age 25 versus minimum temperature for the combined data. On the vertical axis, heights are expressed as deviations from the local source. On the horiiontal axis yearly average minimum temperatures are expressed as differences between the seed source minimum temperature and the planting location minimum temperature.

"local" source as computed is a reasonable estimate for purposes of combining the data from several plantings. The intercept did not vary significantly from zero (P = 0.55), indicating that the method used here for determining the height of the "local" source appears to be reasonable.

The analyses that are summarized in Figure 3 show that moving seed sources northward from areas with minimum temperatures of 7 °F warmer than the planting site result in the maximum gain over local sources. Moving seed sources southward or northward more than 15 °F results in less growth than that of the local source.

The regression analyses showed a significant difference between eastern and western sources in intercept ($F_{1,161}$=6.43, P<0.04), slope ($F_{1,160}$=4.25, P<0.05), but not in curvature ($F_{1,159}$=3.32, P>0.06). In loblolly pine, western sources are slower growing (Wells and Wakeley 1966). The opposite appears to be true in shortleaf pine. Separate curves computed for height growth in Figure 3 show that western sources of shortleaf pine grow better than eastern sources, especially at the extremes of seed transfer. This result may be due to introgression with loblolly pine in the western part of the range since loblolly grows faster than shortleaf pine.

CONCLUSIONS

Provenance tests are often analyzed planting by planting, to determine which seed source is best at a given planting location. That approach is a simple way to deal with the strong and complex interactions between seed source and planting site. The approach described here provides an overall picture. Growth

variables are related to climatic factors at the seed source by regression. Performance in different plantings is combined by expressing growth as a percent deviation from the local source. Temperature or other climatic factors at the source are expressed as deviations from conditions of the planting site. The result is a general picture of the effects of seed transfer.

ACKNOWLEDGMENTS

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Regeneration

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REFORESTATION ON NON-INDUSTRIAL PRIVATE FORESTLAND IN EAST TEXAS FROM 19834993: FACTORS ASSOCIATED WITH FIRST-YEAR SEEDLING SURVIVAL'

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Abstract-Of the 12 million acres of commercial forestland in East Texas, 61 percent is owned by the non-industrial private sector. From 1963 through 1993, pine reforestation on non-industrial private forestland (NIPF) ranged from 17 to 31 thousand acres per year. Cost-sharing was involved on 67 percent of the acres planted. Annual first-year seedling survival ranged from 64 to 76 percent and averaged 64 percent over the 1 l-year period. First-year survival declined slightly as planting season progressed. While hand planting accounted for 67 percent of the acres planted, machine planting averaged about 4 percentage points greater in survival. Average survival was 68, 64, and 54 percent on good, average, and poor sites, respectively. Tracts receiving herbaceous weed control averaged 13 percentage points greater in survival than tracts where no weed control was used. Survival was significantly correlated with accumulated negative values of precipitation minus potential evapotranspiration during the growing season.

INTRODUCTION

Because of continuing population growth and the consequent reduction in the forestry land base, and because of increasing pressure on National Forests to manage for values other than timber, non-industrial private forestland (NIPF) will be increasingly relied upon to supply the nation with wood fiber. However, poor regeneration of pine on NIPF has been identified as a major cause of a reduction in pine forests and growth in the South (USDA Forest Service 1988, McWilliams 1989).

Of the 12 million acres of commercial forestland in East Texas, 61 percent is owned by the non-industrial private sector (Miller and Hartsell 1992). It is on these lands that the greatest potential lies in alleviating a future deficit in timber supply. It is therefore crucial that forest resource professionals encourage effective reforestation on NIPF and identify those factors associated with mortality and successful seedling establishment.

This paper relates first-year seedling survival on NIPF in East Texas from 1983 through 1993 to silvicultural, site, and climatic factors.

METHODS

Beginning in 1983, records were kept on first-year seedling survival of operational pine plantings administered by the Texas Forest Service (TFS) in East Texas. Table 1 lists the variables recorded each year. Survival was determined from number of trees planted and number surviving on O.Ol-acre plots established during or shortly after planting. Plots were systematically distributed over each planted area at a rate of 1 plot per acre for tracts of smaller than 35 acres, down to 1 plot per 3 acres for tracts larger than 90 acres. Number of trees planted was determined at plot establishment as part of a tree planting inspection program. Plots were revisited at the end of the first growing season and surviving trees were counted. Survival was summariied by the various variables. All survival means are weighted by acres planted. Analysis of variance or simple linear regression analysis was conducted on each main effect. All analyses were weighted by acres. Arcsine transformation of survival data was used for all analyses except survival by month of planting and survival by accumulated negative values of P-PET (described below) for the growing season.

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Table I-Variables recorded by year from 1983 through 1993

Variable	Year 83	84	85	86	87	88	89	90	91	92	93
County	+	+	+	+	+	+	+	+	+	+	+
Acres	+	+	+	+	+	+	+	+	+	+	+
Cost share program	+	+	+	+	+	+	+	+	+	+	+
Trees planted [a]	+	+	+	+	+	+	+	+	+	+	+
Trees surviving [a]	+	+	+	+	+	+	+	+	+	+	+
Date planted	+	+		+	+	+	+	+	+	+	+
Planting method [b]		+		+		+	+	+	+	+	+
Herbaceous weed control [c]						+	+	+	+	+	+
Site quality [d]								+	+	+	+
Seedling type [e]								+	+	+	+

[a] Number per acre
[b] Machine or hand
[c] Yes or no
[d] Good, average, or poor
[e] Species or genetic line

An attempt was made to relate a climatic factor to survival by correlating first-year survival to the accumulated negative values of precipitation minus potential evapotranspiration during the growing season. Potential evapotranspiration (PET) was calculated using Thornthwalte's method (1948). Following this method, an unadjusted potential evapotranspiration is calculated from mean monthly temperature according to the equation

$$e = 1.6\,(10t/I)^a$$

where e is the unadjusted monthly potential evapotranspiration in cm, t is the mean monthly temperature in °C, I is the heat index, and a is a coefficient determined from the heat index. The heat index, I, is the sum of 12 monthly values of temperature index (i) given by

$$i = (r/5)7.514$$

Coefficient a is obtained from the empirical equation

$$a = 0.000000675\,I^3 - 0.0000771\,I^2 + 0.49239$$

The above potential evapotranspiration equation gives values for months of 30 days and 12 hours each. Since number of days in a month varies and daylength varies with season and latitude, unadjusted rates must be reduced or increased by a factor that varies with month and latitude. This correction factor ranged from 0.86 to I .22.

Monthly precipitation and temperature data were obtained from 28 weather observing sites throughout East Texas supervised by National Oceanic and Atmospheric Administration/National Weather Service. A value for each TFS District was obtained by averaging the three most appropriate stations within or nearest the District. TFS Districts generally comprise from 1 to 3 counties. In some cases only two stations were included. Differences between precipitation and potential evapotranspiration (P-PET) were determined for each District. A negative value of P-PET indicates the amount by which precipitation fails to supply the potential water need of a vegetation covered area.

An overall weighted average of P-PET for East Texas for each month was obtained by averaging District values as weighted by number of acres planted in each respective District. Negative values from April through September were summed to provide an accumulated negative P-PET value, which is similar to Thornthwaite and Mather's (I 957) accumulated potential water loss. A Pearson correlation coefficient was then computed between these accumulated negative P-PET values and overall seedling survival for East Texas each year.

RESULTS AND DISCUSSION

Although twice as much timberland classified as pine or oak-pine forest type exists in the Southeast region of East Texas than in the Northeast region, non-industrial private timberland is concentrated in Northeast Texas (Figure 1)(McWilliams and Lord 1988, Miller and Hartsell 1992). There are two reasons for this. First,

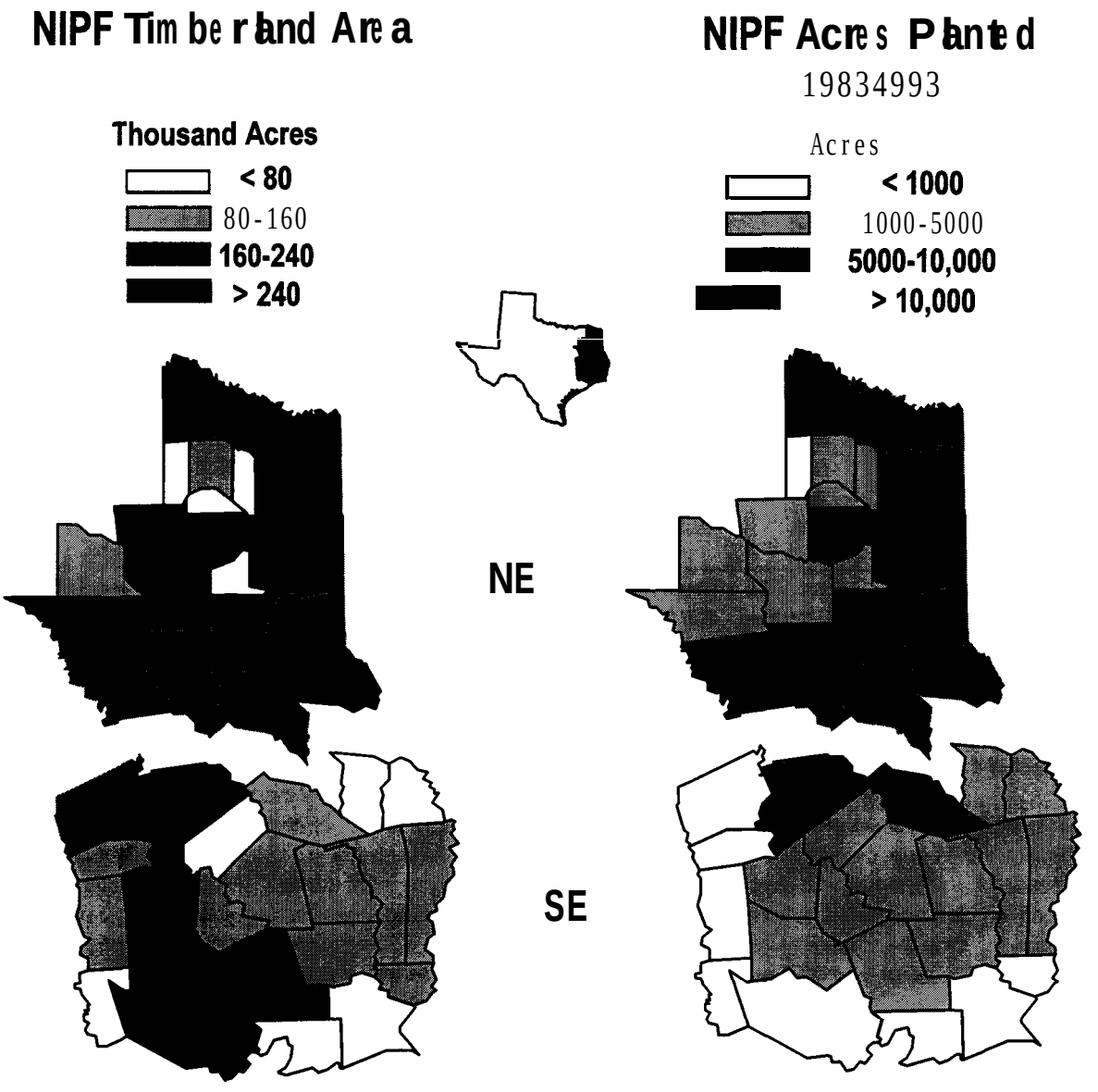

Figure l-Number of acres of non-industrial timberland and number of acres planted from 1983 through 1993 by county in East Texas.

forest industry timberland occurs primarily on the more productive sites that are found in the southeastern part of East Texas. One-third of timberland in Texas is owned by forest industry. Second, the four National Forests in Texas are located in the Southeast region. Because of these ownership patterns, 80 percent of the acres planted on NIPF lands from 1983 through 1993 has been in Northeast Texas (Figure 1).

Reforestation since 1983 has ranged from a low of 16,638 acres in 1983 to 30,663 acres in 1993 (Table 2). The low in 1987 was probably associated with low timber prices existing during 1985 and 1986. Sawtimber sold for an average of $125/mbf Doyle during that two-year period.

These values and all other values reported here include only reforestation on NIPF where the Texas Forest Service administered the planting. Additional reforestation on NIPF occurs in which the TFS is not involved and no accurate number is available for that,

Table 2-Acres planted by cost share program and average first-year survival from 1983 through 1993

Year	Cost share program[a]							
	FIP	TRe	CRP[b]	ACP[b]	SIP	None	TOTAL	Survival
	1000 acres							%
83	14.8	9.3	0	0.2		4.3	28.5	73.2
84	8.5	7.3	+	+		4.2	20.0	58.9
85	11.0	8.5	+	+		3.2	22.5	54.0
86	10.9	9.0	0	0.0		2.2	22.1	64.7
87	7.8	5.6	2.1	0.1		1.0	16.6	60.3
88	8.3	7.7	3.8	0.3	-	1.1	21.3	57.1
89	10.4	6.4	1.3	0.1	-	2.2	20.5	75.6
90	10.6	8.4	3.7	0.2		2.7	25.5	58.0
91	11.7	6.3	1.3	0.3		3.0	21.1	67.2
92	13.8	6.6	2.3	0.6		5.3	28.6	72.5
93	13.3	8.1	0.8	0.6	2.6	5.3	30.7	60.3
TOTAL	121.2	83.2	15.3	2.4	2.6	34.4	259.1	63.7

[a] FIP = Forestry Incentives Program, TRe = Texas Reforestation Foundation, CRP = Conservation Reserve Program, ACP = Agricultural Conservation Program, SIP = Stewardship Incentive Program
[b] "+" indicates acreage lumped with FIP data

However, a best guess is that the TFS is involved in 75 to 80 percent of the NIPF reforestation in East Texas.

First-year seedling survival ranged from 54.0 to 75.6 percent during the 1 l-year period. The high which occurred in 1989 is associated with good rainfail, in terms of both amount and distribution throughout that growing season. Over the 1 l-year period, average survival, weighted by acres, was 63.7 percent.

The importance that cost sharing has in reforestation of NIPF is evident from the data (Table 2). Eighty-seven percent of the acres planted were cost-shared (77 percent of planting cases). The most important program has been the federally-funded Forestry Incentives Program (FIP). This program has accounted for 54 percent of the cost-shared acres. The second most important program has been the Texas Reforestation Foundation (Barron 1983). This privately funded program accounted for 37 percent of the cost-shared acres. The relatively few acres planted under the Conservation Reserve Program is due to the lack of cropland present in East Texas. Most all of the openland planted is marginal pastureland, which is not eligible for participation in this program.

Three of every four acres were planted in February or March (Table 3). Ideally, plantings should be accomplished before March. However, because the same tree planting vendors plant both NIPF and industry lands, most of industry's plantings are completed before vendors move to NIPF since industry's contracts are larger and thus more lucrative. When averaged over the 1983-to-1993 period, survival showed a slight general decline as planting season progressed. Using linear regression weighted by acres, this decline was significant (P=0.0001) with an approximately 4-percentage-point decline per month. However, plantings in December through February were essentially the same, and most of the decline came with plantings accomplished in March and April. Wakeley (1954) also noted a decline in survival for March and April plantings. Lower survival of late-season planted seedlings may result from inadequate root growth before budbreak and the onset of droughty conditions in the spring and summer (Long 1991).

Information on method of planting was available for all years except 1983, 1985, and 1987 (Table 4). During the period, about twice as many acres were hand planted as were machine planted. Tracts that were machine planted averaged 4 percentage points greater in survival than hand-planted tracts. Using analysis of variance weighted by acres across all plantings, this difference was significant (P=0.0001). McNab and Brendemuehl(l983) found that seedling survival rates

Table 3-First-year seedling survival and acres planted by month of planting in East Texas from 1983 through 1993

Year	1000 acres planted					Percent survival					Regression [1]	
	Dec	Jan	Feb	Mar	Apr	Dec	Jan	Feb	Mar	Apr	B_1	P value
83	0.8	2.6	8.1	11.3	2.0	77.7	72.5	77.4	72.6	59.2	-3.49	0.0001
84	0.1	1.8	4.9	6.1	1.3	82.1	56.2	61.6	57.3	52.2	-2.21	0.1651
85									-	-		
86	0.1	2.3	2.2	4.0	0.2	28.2	69.9	72.8	60.0	57.2	-4.81	0.0020
87	0.2	2.1	2.2	4.4	0.8	76.8	64.9	60.8	54.2	47.3	-5.96	0.0001
88	0.2	3.8	6.5	9.5	0.6	43.9	60.0	61.9	53.2	52.7	-3.24	0.0135
89	0.9	4.4	5.4	7.6	0.7	79.2	75.1	77.5	74.4	64.4	-1.48	0.0739
90	0.8	4.5	7.7	9.9	0.5	40.6	62.4	61.8	54.5	61.1	-1.29	0.2273
91	0.2	2.8	6.6	11.1	0.3	78.6	74.8	75.2	61.3	50.7	-8.51	0.0001
92	2.6	6.8	10.0	7.7	0.0	87.4	78.6	71.8	64.1	-	-7.52	0.0001
93	1.8	6.0	9.2	9.6	0.3	55.1	64.8	61.5	58.0	66.3	-1.09	0.2231
83-93	7.8	37.1	62.8	81.3	6.7	70.5	68.8	68.5	61.4	56.6	-3.84	0.0001

[1]Simple linear regression weighted by acres where B_1 is slope and P value is significance level.

Table 4-First-year survival and acres planted by hand or machine in East Texas from 1983 through 1993

Year	1000 acres planted		Percent survival		
	Hand	Machine	Hand	Machine	P value
83		-			
84	7.0	7.2	62.0	54.8	0.0186
85					
86	5.7	2.1	65.5	66.7	0.1527
87			-		-
88	12.2	8.4	55.7	59.0	0.4190
89	13.3	5.8	74.2	77.6	0.0150
90	15.2	8.4	53.9	65.7	0.0001
91	16.2	4.9	65.0	75.8	0.0001
92	18.5	8.8	70.8	76.8	0.0001
93	21.0	7.4	58.7	64.9	0.1807
83-93	109.1	53.0	63.1	67.2	0.0001

were 20 percent lower with hand than machine planting in a comparison done in Florida. Higher survival with machine planting may be associated with more uniformity in the depth of the planting hole, better seedling placement, and better soil packing (South and Mexal1984, Long 1991). Without close supervision, hand planters often do not sufficiently pack the seedlings and thus root-to-soil contact is not maximized. Shiver et *al.* (1990) found that loosely packed seedlings had significantly poorer survival than seedlings planted firmly.

Herbaceous weed control on NIPF began to be used operationally in East Texas in 1987. Data are available for 1988 through 1993 planting seasons (Table 5). Herbaceous weed control has steadily increased each year and has been applied on 14 percent of the acres planted. Tracts on which herbaceous weed control was used averaged 13.0 percentage points greater in survival than tracts where no weed control was used (P=0.0001). Percentage point differences have ranged from 6.3 in 1988 to 20.2 in 1991. Herbaceous weed control throughout the South has proven effective in

Table 5--First-year seedling **survival** and acres planted by presence of herbaceous weed control (HWC) in East Texas for 1988 through 1993

Year	1000 acres planted None	HWC	Percent survival None	HWC	Pvalue
88	19.2	1.3	56.7	63.0	0.1466
89	17.5	1.6	74.8	80.4	0.0274
90	17.5	1.8	58.3	71.0	0.0003
91	18.1	3.0	64.6	84.8	0.0001
92	20.8	6.5	69.4	83.0	0.0001
93	24.2	4.1	59.3	66.1	0.0011
88-93	117.4	18.4	63.6	76.6	0.0001

increasing survival of newly planted loblolly pines **(Metcalfe** 1986). By decreasing the competition for soil moisture, planted seedlings are given the **opportunity** to establish root systems before commonly experienced dry periods occur in summer.

Beginning in 1990, TFS foresters began supplying information on site **quality.** As expected, survival increased as site quality increased (Table 6). Survival on good **quality** sites averaged 67.6 percent compared to 54.3 percent on poor quality sites. Linear regression weighted by acres revealed this to be a significant linear effect **(P=0.0001).** An analysis of variance was conducted on data for years 1990 through 1993 and included year, weed control, method of planting, site quality, and interactions in the model. All main effects were highly significant **(P<0.003)** except weed control which was significant at the **p=0.035** level. Only one interaction was significant-planting method by site **quality.** Further regression analysis showed that with hand planting there was a significant **(p=0.0001)** increase in survival as site qualii improved. However, with machine planting, this relationship was not expressed **(p=0.26).**

Since 1990, most loblolly pine, ***Pinus taeda* L.,** planted has been from three improved genetic lines produced **at** Indian Mound State Tree Nursery -- Southeast **Texas** (Superior), Northeast Texas, and Drought-Hardy **(Table 7).** The remaining 12 percent of improved loblolly was obtained from industry nurseries in **East Texas. Differences** in survival among the seedling sources is perhaps best evaluated by site quality. On good sites, there was essentially no difference in survival among the various seedlings sources. However, as site quality

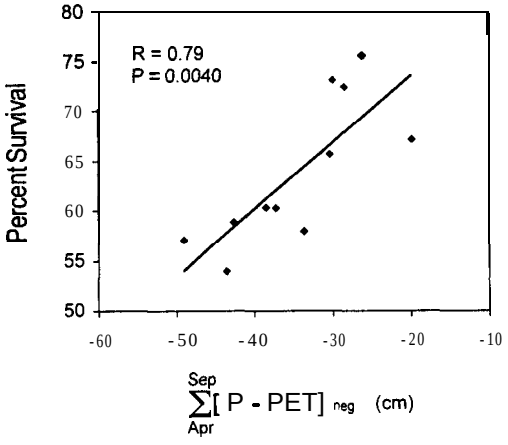

Figure 2-Correlation between first-year seedling survival and accumulated negative values of precipitation minus potential evapotranspiration during the growing season in East Texas from 1983 through 1993.

Table 6-First-year seedling survival and acres planted by site quality in East Texas from 1990 through 1993

Year	1000 acres planted Poor	Average	Good	Percent survival Poor	Average	Good	P value *
90	2.5	10.5	10.6	43.7	58.8	60.9	0.0001
91	2.1	10.2	8.8	50.8	69.5	69.3	0.0049
92	2.0	14.0	11.4	67.3	70.3	76.6	0.0001
93	2.6	14.0	11.2	58.2	58.5	63.7	0.0069
90-93	9.1	48.7	42.0	54.3	64.2	67.6	0.0001

*Significance level for simple linear regression for survival on site quality weighted by acres.

Table 7-First-year seedling survival and acres planted by improved loblolly pine seedling source' and site qualii for East Texas from 1990 through 1993

					1000 acres planted				
	Percent survival[b]								
Year	NE	SE	DH	Ind.	NE	SE	DH	Ind.	P value
Poor sites									
90	0.5	0.4	1.4	0.2	44.1	34.2	48.8	19.6	0.1001
91	0.6	0.4	0.7	0.0	52.7 a	25.7 b	60.5 a	36.0 ab	0.0002
92	0.4	0.1	1.4	-	57.1	42.0	69.4	-	0.1114
93	0.8	0.3	0.8	0.4	73.1 a	57.6 ab	52.4 b	53.7 b	0.0032
90-93	2.3	1.2	4.4	0.6	58.8 a	38.1 b	57.5 a	38.9 b	0.0001
Average sites									
90	1.7	2.2	5.6	1.0	54.8	62.6	59.5	53.1	0.1071
91	3.6	2.3	3.0	1.3	72.6 a	53.6 b	75.5 a	74.7 a	0.0001
92	4.6	3.4	4.3	1.6	72.9	61.1	75.6	68.9	0.0001
93	6.1	2.5	2.0	1.9	62.2 a	62.3 ab	52.4 bc	54.4 bc	0.0112
90-93	16.0	10.4	14.9	5.8	66.9 a	60.0 c	66.3 ab	62.0 bc	0.0001
Good sites									
90	4.4	3.4	2.1	0.6	59.9 a	62.9 a	66.9 a	34.5 b	0.0001
91	1.6	4.4	1.6	1.1	64.3	70.5	68.1	77.2	0.0955
92	4.0	4.5	1.4	1.5	82.7 a	72.1 b	68.7 b	81.5 a	0.0001
93	4.1	3.3	0.5	2.6	61.7	64.3	72.4	63.5	0.2889
90-93	14.1	15.6	5.6	5.7	67.2	67.9	68.2	67.7	0.9845
All sites									
90	6.5	6.1	9.0	1.8	57.4 a	60.8 a	59.5 a	44.0 b	0.0002
91	5.9	7.1	5.4	2.3	68.1 a	62.5 b	71.3 a	75.2 a	0.0013
92	9.0	8.0	7.1	3.0	76.6 a	67.1 c	72.9 b	75.8 ab	0.0001
93	11.0	6.0	3.4	4.8	62.9 ab	63.1 a	55.0 b	59.4 ab	0.0105
90-93	32.4	27.2	24.9	12.0	66.4 a	63.6 b	65.2 b	63.9 b	0.0001

'NE = Northeast Texas loblolly, SE = Southeast Texas loblolly (Superior), DH = Drought-Hardy loblolly, Ind. = loblolly from industry nurseries

[b] Where P value (significance level) is less than 0.05 for a row, survival values followed by common letters indicate no significant difference.

decreased, differences began to be apparent. On poor sites, Northeast Texas and Drought-Hardy loblolly seedlings survived significantly better than either Southeast Texas loblolly or improved loblolly produced by industry nurseries. This points to the importance of matching the most appropriate "species" or genetic line to site. In terms of first-year survival, this may be especially important on poor-quality sites.

First-year seedling survival was significantly correlated with accumulated negative values of precipitation minus potential evapotranspiration during the growing season (April-September) (Figure 2). This correlation exhibited a Pearson coefficient of R=0.79 (P=0.0040). Working in Minnesota, Cleland and Johnson (1986) found a similar correlation between first-year survival and growing-season water deficit, expressed as the difference between precipitation and potential evapotranspiration from May through August. Obviously, the less heat and water stress planted seedlings experience during the growing season, the greater we can expect survival to be.

CONCLUSIONS

Many factors affect first-year seedling survival. Success of plantings depends upon proper care and planting of seedlings, site qualii, and presence of adequate soil moisture during the growing season, Understanding

how these factors affect survival can improve development and refinement of reforestation guidelines.

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ANALYSIS OF REGENERATION ON DISTURBED FORESTED WETLANDS'

William B. Steele*, Donal D. Hook[2], James G. Williams[2], James D. Benson[2], William H. McKee, Jr.', and Dan Niquette'

Abstract-Composition and stratification of 18 disturbed forested wetland sites were surveyed from 1990 through 1992 in the Savannah River floodplain near Aiken, South Carolina. Species and diameter at breast height were recorded for all woody species at each site. The hydrology of all sites had been altered by a hydroelectric dam on the Savannah River and/or logged at various periods in the past and were in various stages of recovery. Other sites had been impacted by thermal water effluent. Preliminary analysis showed that canopy cover was highly variable within and among sites. Therefore, spatial techniques (GIS) were used to map and segregate plots within and among sites into overstory cover classes for further analysis. Eight of the most prevalent species were analyzed for importance values. Within creekbottoms, Importance values varied by species, disturbance (logging vs thermal), overstory class, and disturbance x overstory class interaction. In the floodplain, the importance value varied only by species and species x overstory class interaction. With logging disturbance, the importance value varied only by species. However, with thermal effluent, importance value varied by species, overstory class, species x overstory class, and type x overstory class. Generally, importance values were highest under a full canopy but the degree of difference was most notable in the creekbottom. This data demonstrates need for caution in interpreting causes of failure on disturbed wetlands without a thorough analysis of stand and hydrology conditions.

INTRODUCTION

In past decades, wetland forests of the Savannah River Site (SRS) near Aiken, South Carolina were impacted by thermal water effluent from nuclear reactors. Some impacted sites did not regenerate with desirable vegetation fifteen years after reactors were shut down and those that did regenerate were of different species composition and stocking than the parent stand or similar undisturbed areas (Muzika, Gladden, and Haddock, 1987). Disturbances were due to thermal effluent and increased flooding from reactors which impacted soils, hydroperiod, and stream morphology (Scott et al, 1985). Many of the sampled sites had been logged at various times in the past, impacted by hydroelectric dams, and impounded by railroad systems and/or beaver activity. The areas of the SRS most impacted by thermal effluent were near the confluences of Four Mile, Pen Branch, and Steele Creeks with the floodplain of the Savannah River (Figure 1).

Since the sites had not adequately regenerated to desirable forest stands by 1990, there was a need to restore these sites to functional forested wetlands meet government regulations. However, it was unclear as to what species might be the best choice for restoration efforts on highly impacted sites. Consequently, several sites in the floodplain and creekbottoms with varied histories of disturbances were surveyed for woody species stocking and composition in an attempt to identify suitable species for various types of disturbances. Site data were collected to determine some of the traits associated with regeneration success and failure (Hook and McKee 1992).

Study Area

Eighteen sites on or near the SRS were selected for evaluation (Figure 1). Twelve sites along the Savannah River floodplain and adjacent tributaries were sampled in 1990 and 1991 (sites A-M). Eight of these sites (A,

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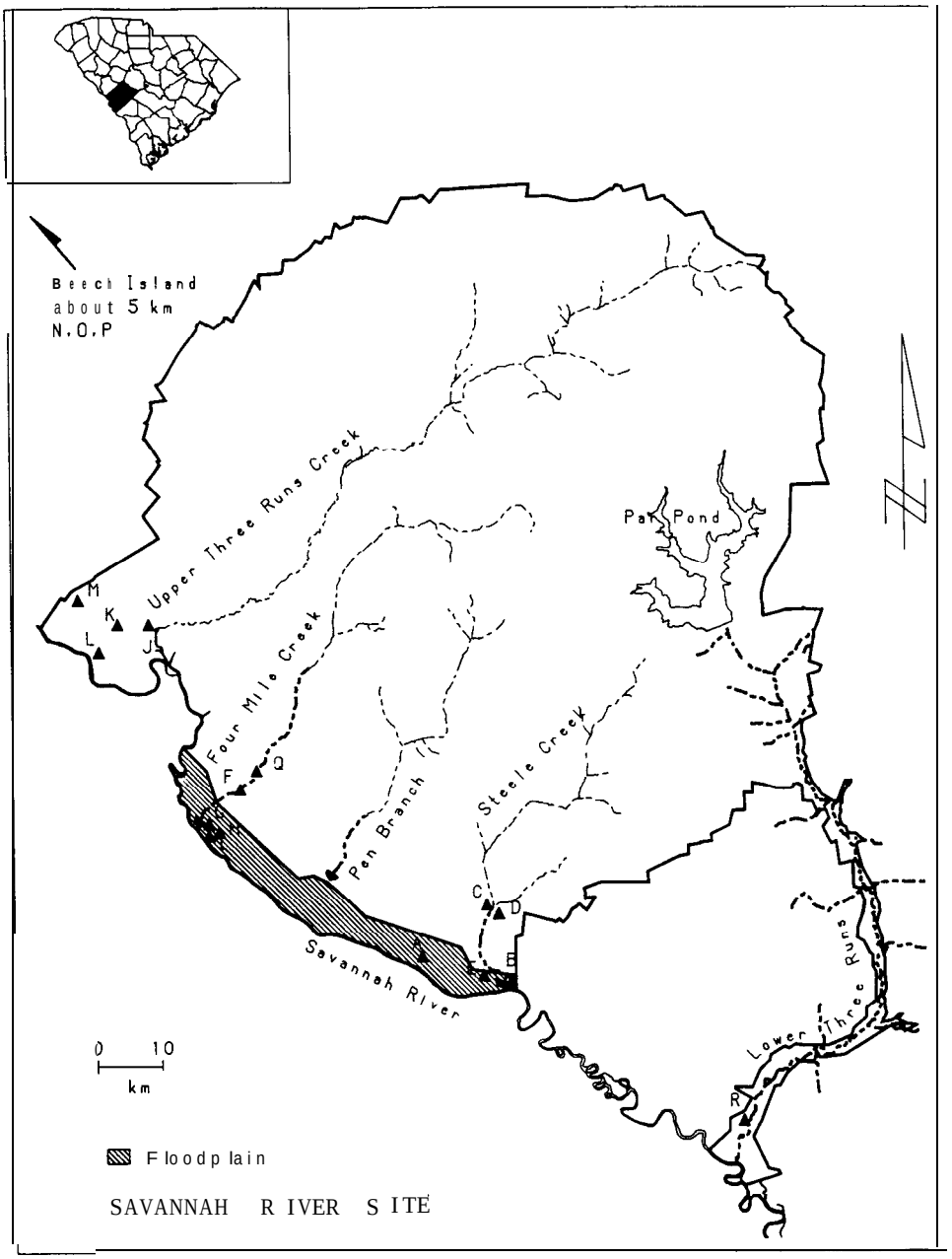

Figure 1. Location map of the Savannah River Siie and the Savannah River floodplain. Approximate sample site locations are indicated by capital letters from A to R. The sections of Four Mile, Pen Branch, and Steele Creeks and Savannah River floodplain impacted by thermal effluent during the past are indicated by cross hatch marks.

B, E, F, G, H, I, & L) were located in the Savannah River floodplain, including one site on Stave Island (A). Five sites (C, D, J, K, 8 M) were located in creekbottoms near the Savannah River (Figure 1). Two sites (C & D) were established just upstream from the confluence of Steele Creek and Meyers Branch. All sites except J, K, L, 8 M had been impacted by varying degrees of thermal effluent. Three sites (J, K, & M) were above all thermal effluent from the SRS. Five additional sites were surveyed in the spring and summer of 1992. Three sites (N, 0, & P) were located in the Savannah River floodplain on Beech Island about 5 km above the SRS. A section of Four Mile Creek on SRS was chosen that had a history of impact from reactor flows from 1955 until 1985 (Cl). Also, a site (R) on Lower Three Runs Creek was sampled about one

mile above the confluence of Lower Three Runs Creek and the Savannah River. The latter site received reactor flows from 1954 until Parr Pond was constructed in 1958. It and the sites at Beech Island were mature stands with essentially closed canopies.

METHODS

Thirty-four to forty-one plots (7.163 m radius; 0.016 ha) were established at each site at 30 meter intervals along transects. Distances between transects varied from 30 to 90 meters. Transects ran perpendicular to the drainage. Transects started in the floodplain and continued until the drainage was crossed, type changes occurred, or the upland was encountered. Plots along transects were discarded when elevation or topography caused a noticeable change in type from the rest of the transect. Species of all living woody vegetation greater than 1.37 meters in height were recorded. Diameter at 1.37 m was recorded to the nearest 0.1 centimeter. Height of several dominant and codominant trees was also measured. Three independent readings of each increment core were averaged to arrive at the reported age due to indistinct nature of false rings found in water tupelo (*Nyssa aquatica*) and baldcypress (*Taxodium distichum*) and advanced decay in some of the trees.

Analyses

The data was separated into three diameter classes (O-5.0 cm, 5.1 - 25.0 cm, and >25.0 cm) and analyzed separately. From these data, relative density (#stems per species/ha divided by total number stems per ha) and basal area (m^2 per species/ha divided by total basal area per ha) were calculated for each species by diameter class at each site. The O-5.0 cm class was used as an indicator of woody species regeneration success.

Importance values were calculated by summing the relative density and relative dominance for each species in each diameter class, a variation of the method used by Curtis and McIntosh (1951).

Canopy densities within the overstory (>25 cm diameter class) were established by basal area found within each canopy class. The overstory basal area considered to be a closed canopy for this study was based on a fully stocked stand of mature tupelo (Putnam, et al 1960). Overstory canopies were classified as closed, partial, and open by basal area (data not shown).

The eighteen sites were also classified as either floodplain or creekbottom site types and impacted by logging or by thermal effluent. Three classes were used in the analysis; species (eight), disturbance (logging or thermal), and overstory classes (closed, partial, and open). Although more than 80 woody species were found on these 18 sites, only eight species occurred with sufficient abundance to be analyzed statistically. Analysis of variance were run for each type (creekbottom or floodplain) and disturbance class independently. Ail significant variables were tested by Duncan's multiple range test at 0.05 level.

Soils Characteristics

Chastain series were the most prevalent soils at the Four Mile Creek site. Lower Three Runs Creek was occupied primarily by the Dorovan series. The Beech Island sites were primarily of the Chastain series with small inclusions of Shellbluff series at sites I and Ill. Site II had an inclusion of the Chewacla series. The Dorovan and Chastain series are hydric soils, whereas the Shellbluff series is not (Soil Survey Staff, 1991). Duration of flooding and height of the water table at Beech Island appeared to have been increased due to the influence of beaver impoundments.

RESULTS AND CONCLUSIONS

The effects of canopy cover on regeneration were assessed by cover classes of >40 m^2/ha, 20-39 m^2/ha, and O-l 9 m^2/ha basal area that were established by GIS techniques.

Of the eight species tested for regeneration potential (O.O-to-5.0 cm diameter class; Table 1), Carolina ash (*Fraxinus caroliniana)* had the highest or one of the highest importance values under every condition tested (Table 2) and red maple (*Acer rubrum*) was third highest under three class conditions and fourth on the other class. In contrast, water oak (*Quercus nigra*) and sweetgum *(Liquidambar styraciflua*) had the lowest importance values in all classes. Water tupelo (Nyssa *aquatica*) had the second highest importance value in the creekbottom and tied Carolina ash for highest in the floodplain.

The importance value of baldcypress *(Taxodium distichum*) was nearly constant among the creekbottom, floodplain, logged, and thermal areas. It generally had a low importance value (35-40 out of a possible 200), rating just above sweetgum.

Table 1: Eight species with sufficient abundance on all sites to allow statistical tests for importance values.

Common Name	Scientific Name
Baldcypress	*Taxodium distichum*
Carolina ash	*Fraxinus caroliniana*
Ironwood	*Carpinus caroliniana*
Red maple	*Acer rubrum*
Sweetgum	*Liquidamber styraciflua*
Sourwood	*Oxydendrum arboreum*
Water oak	*Quercus nigra*
Water tupelo	*Nyssa aquatica*

Table 2. Importance values for species by site type and disturbance classes.

	Importance Value			
	CLASS*			
Species"	Creekbottom	Floodplain	Logged	Thermal Effluent
CA	93a	82a	82a	92a
WT	71b	47bc	63b	44dc
RMA	65b	57b	60bc	76ab
IW	64b	82a	64b	83a
SW	54bc	49bc	42cd	60bc
BC	40cd	35cd	36cd	37de
SG	27d	39bcd	24d	37de
WAO	17d	27d	25d	21e

• Importance values were rank highest to lowest on the creekbottom site, hence the other categories show values mixed within a column. Values with a common letter in a column were not significantly different at the 0.05 level.
"Species: CA = Carolina ash; WT = water tupelo; RMA = red maple; IW = ironwood; SW = sourwood; BC = baldcypress; SG = sweetgum; WAO = water oak.

In the creekbottom, the overall (averaged over the eight species) importance value was significantly higher under closed (85a) and partial (61a) canopies, than in open (48b; values with common letter were not significant at the 0.05 level) areas. Also, when the sites were analyzed separately by disturbance, importance values were higher under closed and partial canopies. than open areas with thermal disturbance but not with logging (Table 3). This was somewhat surprising. These differences may be the result of unmeasured thermal effluent effects on the sites rather than differences in competition for light and nutrients among these canopy classes. On the logged sites, there were no differences in importance values among canopy classes.

Table 3. Interaction between disturbance and canopy cover classes.

Disturbance	Canopy Cover	Importance Value*
Logged	Closed	54a
Logged	Partial	57a
Logged	Open	58a
Thermal	Closed	103a
Thermal	Partial	85a
Thermal	Open	39b

• values within a disturbance class with the common letters are not significantly different at the 0.05 level.

DISCUSSION

The importance values, of the eight most abundant species on these 18 sites, were related to the geomorphology of the site, type of disturbance, and degree of canopy cover. Carolina ash regeneration had the highest importance value on every site type and disturbance type. However, this species is never a dominant species in mature stands. One can not help but wonder if this species (that is so ubiquitous on all sites as regeneration but not at maturity) plays an important ecological role in the natural regeneration of these forest types. Does it serve as a nurse tree or play some other ecological role?

Based on field experience on these sites, it appears that the lower importance values on open sites on thermal effluent impacted areas is more of a function of site disturbance than canopy cover per se. Generally on highly impacted sites, the areas had continuously standing water and/or highly disturbed soils. The combination usually resulted in such alterations in hydrology and soils that desirable woody species could not adequately occupy the site. Thus, for the SRS and other highly impacted sites, the use of aerial photographs and GIS to map for degrees of

disturbance may greatly improve restoration success. In this manner, restoration efforts can be targeted by degree of anticipated diiculty. Less intensive action could be planned for low impacted areas and more intensive methods for highly impacted areas. Such efforts should make restoration not only more effective but also less costly in the long run.

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HARDWOOD REGENERATION ON THE LOESSIAL HILLS AFTER HARVESTING FOR UNEVEN-AGED MANAGEMENT'

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

Abstract-In 1991, study plots were harvested to four different residual diameter distributions. Generally, for all species, the more extreme overstory removals promoted regeneration establishment while the treatment with the least overstory removal tended to provide less regeneration than the uncut controls. For oak species, most of the seedlings present in 1993 were those occurring in 1992. Survival of oaks from 1992 to 1993 exceeded SO percent for all species. Yellow-poplars present in 1993 were primarily seedlings established since the inventory in 1992. Abundance in the overstory was a significant factor In predicting oak but not yellow-poplar regeneration. Diversity did not differ significantly across treatments, but diiersity increased from 1992 to 1993 on the most heavily cut plots.

INTRODUCTION

The loessial hills occur in a band east of the lower Mississippi River Valley. The soil parent material consists largely of wind-blown silt deposited at the end of the most recent ice age. The soils are productive, but prone to erosion. Some of the most productive hardwood stands in North America occur on loessial hills (Johnson 1958). Most of the current stands arose after abandonment of agricultural land. Uneven-aged management is often preferred there because it maintains a continuous high forest and reduces the risk of erosion that could occur in large clearcuts. However, cherrybark and shumard oak (Scientific and common names of most tree species mentioned in this article are provided in table 1.) are among the most valuable components of stands on the loessial hills, and single tree selection system, as it is commonly applied, does not promote regeneration of oak species (Clatterbuck and Meadows 1993; Sander and Graney 1993). The primary emphasis of the current study was to assess tree growth and stem qualii for different residual diameter distributions, but we also observed regeneration after cutting to the prescribed diameter distributions. Development of regeneration in 1992 and 1993 is described in this paper.

METHODS

The study area is near Redwood, MS, on land managed by Anderson-Tuliy Co. (ATCO). Like most of the forest in the area, the stand probably was established after agricultural land abandonment between 1860 and 1925. A stand adjacent to the study area contains considerable eastern redcedar and honey locust (*Gleditsia triacanthos* L.), species that indicate previous use as pasture. The treated stand had received selection harvests in the past. Trees of all sizes were present, but the smaller size classes included relatively few stems of desirable species.

In addition to a control, four treatments were imposed. Each is based on a different guide for achieving a residual diameter distribution (figure 1). (1) The Putnam guide (Putnam, Furnival and McKnight 1960) is a rotated sigmoid curve with a residual basal area of 68 square feet per acre. (2) The ATCO guide is a generalized approach to achieving desired stocking over relatively large areas rather than on an area the size of our research plots (0.5 acre measurement plot). It corresponds to a negative exponential curve with a basal area of 94 square feet, a "q" factor of 1.4, and a maximum diameter class of 36 inches. The main distinction between these two guides is for trees smaller than 16 inches d.b.h. The ATCO guide maintains many more small trees than the Putnam guide. The other two guides differ considerably from the first two. They reflect results of optimal stand structure studies derived for northern hardwoods, but with some larger diameter trees. The third guide (75BA) is an extreme rotated sigmoid with a residual basal area of 75; this guide includes a high density of 10 to 20 inch d. b. h. trees, with a maximum diameter class of 26 inches.

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Table I-Species observed on regeneration plots.

Scientific name	Common name
Preferred species	
Fraxinus americana L.	white ash
Liriodendron tulipifera L.	yellow-poplar
Pinus taeda L.	loblolly pine
Prunus serotina Ehrh.	black cherry
Quercus falcata var. *pagodaefolia* Ell.	cherrybark oak
Quarcus alba L.	white oak
Quarcus michauxii Nutt.	swamp chestnut oak
Quercus shumardii Buckl.	Shumard oak
Other commercial species	
Acer barbatum Michx.	Florida maple
Acer rubrum L.	red maple
Carya, spp. Nutt.	hickories
Diospyros *virginiana* L.	persimmon
Fagus grandifolia Ehrh.	american beech
Juniperus virginiana L.	eastern redcedar
Liquidambar styraciflua L.	sweetgum
Magnolia grandiflora L.	southern magnolia
Nyssa *syhratica* var. *sylvatica* Marsh.	blackgum
Platanus occidentalis L.	sycamore
Quercus falcata Michx.	southern red oak
Quercus muehlenbergii Engelm.	chinkapin oak
Quercus nigra L.	water oak
Quercus *phellos* L.	willow oak
Sassafras albidum (Nutt.) Nees	sassafras
Tilia caroliniana Mill.	Carolina basswood
Ulmus, spp. L.	elms

The fourth guide (45BA) has a maximum diameter class of 18 inches and a residual basal area of 45. The shape is similar to the results of Hansen and Nyiand (1987) in that the "q" factor become6 progressively greater from the larger to the smaller diameter classes.

Tree class (modiied from Putnam, Furnival and McKnight 1980) was assigned during the pm-harvest measurements. Tree class represent6 a cutting priority. Cutting stock was marked before cull stock, which was marked before reserve growing stock, which was marked before preferred growing stock. In some instance6 cutting stock was removed from an already deficient diameter class; this would be compensated

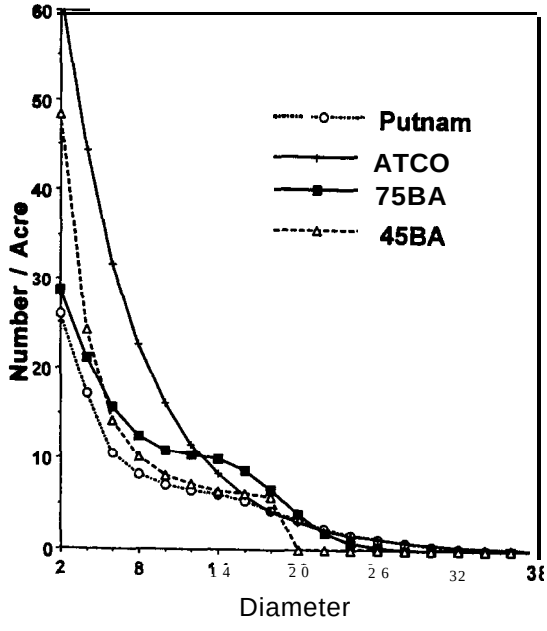

Figure I-Target diameter distributions for the four treatments.

for by leaving a surplus of reserve or preferred tree6 within an adjacent diameter class. When marking the stand, all diameter classes were treated. Small stems of undesirabie specie6 were deadened. Although stands were marked as close to the desired distribution as possible, deficiencies in the initial diameter distribution remained after the harvest. Some tree6 were inadvertantly killed during the logging operation.

The study area was harvested during the late summer of 1991. Each treatment was applied to three 1.6 acre plots. All trees with a d.b.h. of 1 .O inch or more were tallied within a 0.5acre measurement plot within each treatment plot. Regeneration was measured on four O.Ol-acre subplots within each measurement plot at two times-spring of 1992 and spring of 1993. Regeneration was assigned to one of three height classes: (1) less than 1 ft; (2) 1 ft to 3 ft; and (3) over 3 ft. Larger trees tagged during measurement of the 0.5-acre plot were recorded when they fell within the regeneration subplots. Only commercial timber specie6 were recorded on the regeneration plots; a list of species is presented in table 1. For some of the analysis, species were clustered into groups. Group 1 is the preferred red oaks (cherrybark and Shumard). Group 2 is all other red oaks. Group 3 is preferred white oaks (white oak and swamp chestnut oak). Group 4 is other white oaks. Group 5 represent6

yellow-poplar. Group 6 represents loblolly pine. Group 7 includes the rest of the preferred species (white ash and black cherry), and group 8 includes all other commercial species.

In addition to analyzing numbers of stems in different classes, we used the system of Johnson (1980) to assign regeneration points to each plot. Each stem in size class one counts one point, each stem in class two counts two points, and each stem in class three counts three points. A O.Ol-acre plot is considered stocked if it has 12 or more points. We also calculated Shannon's diversity index for each plot, averaging numbers for the four subplots within each plot.

Analysis

Number of Stems.

Individal one-way ANOVAs were done for each species group in each measurement year; numbers of stems were transformed to their square roots to stabilize variance, and a was set at 0.05.

Change in Stem Numbers 1992-1993

The model selected to predict number occurring in 1993 was :

$$N_2 = b_{00} + \sum_{i=1}^{4} b_{0i} D_i + b_{10} N_1 + \sum_{i=1}^{4} b_{1i} D_i N_1 + e$$

where N_2 is the number of regeneration stems per O.Ol-acre plot in 1993 in all size classes, b_{ij} are parameters, D_i are dummy variables signifying treatments, N_1 is the number in 1992, and e is an error term. As we expected N_2 to be distributed as a Poisson variable, where the variance is equal to the mean, we weighted inversely to the expected value of N_2 and fit the equation by nonlinear least squares. As nonlinear regression may take very long to converge when there are numerous nonsignificant parameters, we built up to equation [1]. Initially, the parameters b_{00}, all b_{0i} and b_{10} were included. Nonsignificant parameters were deleted, starting with the least significant, until all remaining parameters were significant. Then the four b_{1i} parameters were added into the equation, and nonsignificant parameters were deleted. Previously deleted parameters were added back into the equation if they became significant following deletion of some other parameter. This process was done individually for species groups 1,2,3,5,7,and 8.

Understory-Overstory Relationships.

Equation [1] was expanded to include both linear and power terms of the overstory basal area of the same species as the regeneration. Overstory included all trees of 1.0 inch or greater in d.b.h. The four subplots within a plot were aggregated for numbers of regeneration per 0.04 acre. We fit equations to estimate N_1 in fashion similar to that for estimating N_2. Model building and weighting were done as described in the previous section. This analysis was conducted individually for species groups 1,2,3, and 5.

Stocking.

Stocking was calculated in two ways. First all commercial species were counted towards stocking, as suggested by Johnson (1980). Second, only preferred species were included, with the exception of yellow-poplar and loblolly pine, and with the addition of non-select red oak species. Stocking was analyzed by a 5x2x2x2 contingency table, with five treatments, two levels of stocking, stocked or not stocked, two years of measurement, and two measurements of stocking-all species or preferred species. Treatment effects were tested by partitioning G^2, the likelihood-ratio statistic, or deviance, within nested loglinear models (Fienberg 1980).

Points.

Johnson's (1980) stocking assesment guide assigns different point values to different sizes of regeneration. The number of points on a plot provide a single estimate of the capacity of a plot to regenerate. Points were calculated in two ways. First, all commercial species were counted, as suggested by Johnson (1980). Second, only preferred species were included, except yellow-poplar and loblolly pine were excluded, and non-select red oak species were included. Average points among the four subplots were used as data. Individual one-way ANOVAs were done for each point estimate (all species and preferred species) in each measurement year for a total of four independent ANOVAs.

Diversity.

ANOVAs were conducted for diversity at 1992, 1993, and for the difference in diversity between 1992 and 1993.

RESULTS

Number of Stems

Treatments did not significantly affect reproduction numbers for any size class and species group in 1992 or 1993. The number per plot was highly variable and affected largely by factors other than the treatments. Ninety-five percent confidence intervals often included zero for most species and treatments. Across treatments, numbers of select red oaks ranged from 25 to 925 stems per acre in 1992 and from 0 to 800 per acre in 1993. Numbers of other red oaks ranged from 0 to 275 stems per acre in 1992 and from 25 to 300 stems per acre in 1993. Select white oak numbers ranged from 0 to 425 per acre in 1992 and from 0 to 575 stems per acre in 1993. Yellow-poplar numbers ranged from 0 to 125 in 1992, and from 25 to 1425 stems per acre in 1993. Across treatments, numbers per acre for select red oaks, other red oaks, select white oaks and yellow-poplar averaged 278, 108, 93, and 30 in 1992 and 200, 142, 95, and 253 in 1993, respectively.

Change in Stem Number 1992-1993

Final equations for each species group are presented in table 2. Fii indices vary from 0.81 for select red oaks, which is very high for regeneration data, to 0.17 for yellow-poplar. Most yellow-poplar regeneration in 1993 originated that year, while most select red oaks in 1993 were those which survived from 1992. Survival is apparently less variable than initiation of new seedlings. For all species and treatments, the b,, terms were between 0 and 1.0, thus strengthening the interpretation of the parameter as an expression of survival.

For all red oaks, and the white ash and black cherry group, number of seedlings in 1993 was reduced by the ATCO treatment, where the least amount of overstory was harvested. The three most severe harvest treatments increased the amount of white oak regeneration. Yellow-poplar had the greatest number of new seedlings initiated in 1993, and numbers of yellow-poplar seedlings increased as harvesting intensity increased. There were relatively few yellow-poplar seedlings in 1992. The cause of their absence is not known, but could be related to weather. Variation in seed abundance is an unlikely factor because yellow-poplar seed can survive for several years. The heaviest harvest treatment (BA45) increased the amount of regeneration of other commercial species (group 8); the second heaviest treatment (BA75) increased survival of those species.

Table 2-Equations predicting number of stems in 1993 as a function of number of stems in 1992 and dummy variables for treatments. Fit indices included as indicative of goodness of fit.

Select Red Oaks (Fit Index' = 0.81)

$N_2 = 0.764 - 0.764*ATCO + .732N_1$

Other Red Oaks (Fii Index = 0.26)

$N_2 = 1.168 + .930*N_1 - 0.885*ATCO*N_1$

Select White Oaks (Fit Index = 0.22)

$N_2 = 0.583*BA45 + 3.564*BA75 + 0.546*PUTN + 0.665*N_1$

Yellow-Poplar (Fii Index = 0.17)

$N_2 = 0.427 + 5.088*BA45 + 2.535*BA75 + 0.680*PUTN + 1.182*ATCO + 0.590*N_1$

White Ash and Black Cherry (Fit Index = 0.20)

$N_2 = 1.407 - 2.103*ATCO + 0.544*N_1$

Other Commercial Species (Fit Index = 0.37)

$N_2 = 4.076 + 6.206*BA45 + 0.352*N_1 + 0.295*BA75*N_1$

1 *Fit* index = $1 - \sum (y-\hat{y})^2 / \sum (y-\bar{y})^2$

Understory-Overstory Relationships

Final equations for predicting numbers per plot of select red and white oaks in 1992 and 1993 and an equation for predicting number of other red oaks in 1993 are presented in table 3. Equations for yellow-poplar and initial number for other red oaks are excluded because basal area of those species was not a significant predictor of regeneration. Fit indices vary greatly. They are quite high for predicting numbers of select red oaks and select white oaks in 1993, but they are negative for predicting numbers of select red oaks and other red oaks in 1993. Negative or low fit indices are not altogether surprising. Number of seedlings per plot is highly variable. The variability is related to mean number; we assumed numbers were distributed as a Poisson where mean equals the variance. When fit index is calculated from the unweighted data, a few large residuals can cause residual sums of squares in the unweighted units to explode, even though the weighted residuals are not outliers. Negative fit indices may merely reflect that weighting was essential and the fit index is not applicable, or they may indicate that the equation does not fit the data.

Table 3-Equations predicting number of stems in 1992 and 1993 as a function of basal area of overstory trees of the same species (BA), dummy variables for treatments and, when predicting number in 1993, number of stems in 1992. Fit indices included as indicative of goodness of fit.

Select Red Oaks
$N_1 = 0.77*BA$
(Fii index' negative)
$N_2 = 1.242 + 2.802*ATCO + 0.778*N_1$
$-0.337*ATCO*BA$
(Fit index = 0.890)
Other Red Oaks
$N_2 = 1.017*N_1 + .767*BA$
(Fii index negative)
Select White Oaks
$N_1 = 4\ 023*BA^{(0.346)}$
(Fit index = 0.158)
$N_2 = 0.609*N_1 + 0.347*BA$
(Fii index = 0.925)

1 *Fit* index = $1 - \sum (y-\hat{y})^2 / \sum (y-\bar{y})^2$

Notable among the equations is the absence of dummy variables for treatment effects in all but one equation. For numbers of select red oaks in 1993, the dummy variable for the ATCO treatment occurs twice. Overall, the ATCO treatment decreased the number of select red oaks. The coefficients of N, in the select red oak, other red oak and select white oak equations for predicting N_2 are not significantly different from the analogous parameters in table 2. As the equations of table 3 were based on data reflecting sums across four subplots and the equations of table 2 were based on data from the individual subplots, and thus the parameter estimates could potentially vary greatly, the interpretation of the parameter as a survival probability is strengthened. Although the coefficient of N_1 in the other red oak equation exceeds one, the confidence interval for the parameter is broad and includes one.

Stocking

Treatments did not significantly affect stocking (G^2 = 1.44, with 16 df-an extremely small value for G^2). When all species were included, only one plot was not stocked among all treatments and both years. When only preferred species were considered, stocking decreased between 1992 and 1993 for all treatments except BA45, the most severe harvest level, for which stocking increased (table 4).

Table 4-Number of stocked subplots for five treatments during 1992 and 1993. Stocked preferred indicates the plot was stocked considering only red oaks, select white oaks, white ash and black cherry.

	Treatment				
Stocking	Control	BA45	BA75	PUTNAM	ATCO
			1992		
Stocked	12	12	12	12	12
Not stocked	0	0	0	0	0
Stocked preferred	8	5	8	7	6
Not stocked preferred	4	7	4	5	6
			1993		
Stocked	11	12	12	12	12
Not stocked	1	0	0	0	0
Stocked preferred	7	8	7	6	5
Not stocked preferred	5	4	5	6	7

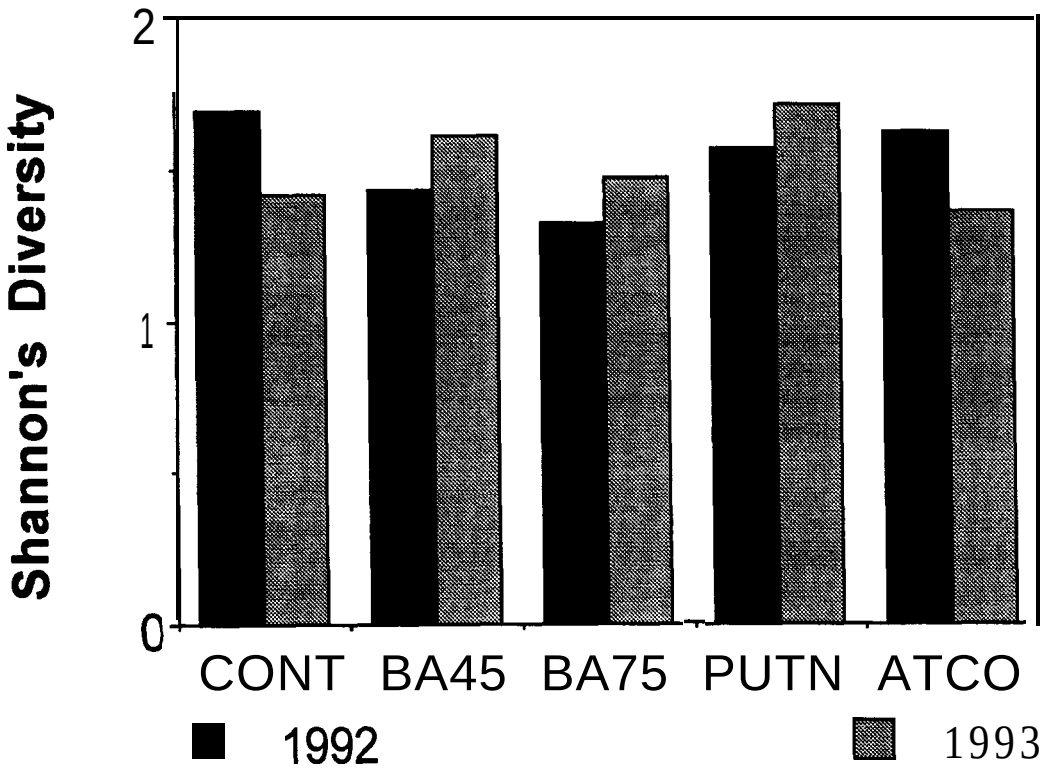

Figure 2-Average of Shannon's diversity index for each treatment in 1992 and 1993.

Points

There were no significant treatment effects for either method used to calculate points in either 1992 or 1993. The number per plot was highly variable and affected largely by factors other than the treatments.

Diversity

Although treatments did not significantly affect diversity in 1992 or 1993, the difference in diversity between 1992 and 1993 was significant at $a = 0.10$ level ($p=0.06$). Diversity tended to be higher in 1992 for the control and the ATCO treatment, the lightest harvest. In 1993, these two treatments had the lowest diversity (figure 2). Thus, diversity increased the most in the BA45, BA75 and PUTNAM treatments, while decreasing in the control treatment and staying about the same in the ATCO treatment. The disturbance caused by the heavier harvests seems to have reduced diversity temporarily, but this loss was rapidly overcome. Although only commercial species contributed to our diversity calculations, those species are probably the most indicative of diversity because the common understory species are ubiquitous.

SUMMARY AND DISCUSSION

Regeneration data are very variable and are strongly influenced by factors other than treatments. Several expressions of regeneration were not related to treatments, these included numbers observed in 1992 and 1993 as well as stocking. Treatments did influence the change in numbers between 1992 and 1993. Generally, for all species, the more extreme overstory removals promoted regeneration establishment, while the treatment with the least overstory removal tended to provide less regeneration than the uncut control. For oak species, most of the seedlings present in 1993 were survivors from 1992. Survival of oak species from 1992 to 1993 exceeded 60 percent for all species. Most yellow-poplar present in 1993 were established since the inventory in 1992. Abundance in the overstory was a significant factor in predicting regeneration for the oak species, but was not for yellow-poplar, whose seeds are disseminated more broadly. This result implies that oak must be a substantial portion of the overstory for the development of significant oak advance regeneration. After abundance of the overstory was factored into the

prediction equations, dummy variables for treatment effects were no longer significant.

The multiple approaches to analysis of the regeneration data uncovered several aspects of the dynamics of regeneration establishment. However, the variability of the data often overwhelms the effect of the treatments. In uneven-aged management, regeneration must establish regularly and that regeneration must eventually be recruited into the overstory. Although regeneration establishment was spotty, there seems to be a sufficient amount on most plots. The real test of the treatments will be whether desirable regeneration develops into saplings, poles and sawtimber.

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VARIATIONS IN THE FELL-AND-BURN SYSTEM TO REGENERATE PINE-HARDWOOD MIXTURES IN THE PIEDMONT[1]

Thomas A. Waldrop[2]

Abstract—Several variations of the fell-and-burn system we tested in the Piimont region. Results indicate that this system can successfully improve the value of low-quality hardwood stands by introducing a pine component. After four growing seasons, fell-and-bum treated stands, on poor- to medium-quality sites, were dominated by oaks and pines **of nearly equal height.** The precise timing **of felling residual stems, as prescribed by the fell-and-bum system, may be unnecessa ry because winter** and spring **felling produced similar results. Site preparation burning may be necessary to ensure pine survival. These bums controlled hardwood height growth, allowing** planted pines to **become** as tell as **hardwoods by the end of four growing seasons. Hardwoods in unburned treatment areas remained taller than pines and could suppress pins growth** and survival in **future growing seaaons.**

INTRODUCTION

Approximately 80 percent of the forested land of the southeast Piedmont is owned by individuals or family groups. These nonindustrial private forests (NIPF) are small (average about **10** acres) and most are cutover lands or old abandoned farms. In most instances, the timber is low qualii and grows in unmanaged pine-hardwood or hardwood stands **(McMinn 1983).** Demand for timber from the Piedmont region is increasing because of coastal timber losses from Hurricanes Hugo and Andrew and public demands to use National Forests for nontimber objectives. To meet these increasing demands, improved productivity on **NIPF** lands in the Piedmont has become a major goal.

Although **NIPF** landowners are not primarily interested in timber production, they are attracted to enhancing their income as long as their forest lands can provide other benefits. The abiiii to establish pine-hardwood mixtures for multiple uses would offer these landowners an alternative to expensive pine plantations established primarily for timber production.

An inexpensive regeneration system, which may be used as an aiternative to pine monoculture, **is** the felt-and-burn technique (Abercrombie and Sims 1986). Thii technique has been successful for converting **low-quality** hardwood stands to more productive **pine-**hardwood mixtures in the Southern Appalachian Mountains (Phillips and Abercromble 1987). Complete descriptions of the fell-and-burn technique are given by Phillips and Abercrombie (1987) and Waldrop and others (1989). **Briefly,** the technique involves a commercial **clearcut** followed by a spring felling of residual hardwood stems **(>** 5 feet in height) and a summer broadcast burn. These treatments are designed to control hardwood sprout growth so pines can be established without eliminating hardwoods. Pines are planted the following winter at a wide spacing (10 by 10 feet or more) to allow some hardwood dominance in the stand.

Several aspects of the fell-and burn technique need further study. **It** is anticipated that this technique will produce results in the upper southeastern Piedmont similar to those observed in the mountains. However, differences in climate, soils, topography, and rainfall may necessitate refinements to the technique (Waldrop and others **1989).** The short time periods for felling (May to June) and burning **(mid-July** to August) are major limitations of this technique. Felling at diierent times of the year or eliminating burning may resolve these limitations and problems. However, these variations of the fell-and-burn technique have not been tested.

Thii project represents the first attempt to study the **fell-**and-burn system on Piedmont sites. It examines the effects of the fell-and-burn system and three variations of that system on stand development through four post-harvest growing seasons.

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METHODS

Study sites are located on the Clemson University Experimental Forest in Pickens and Anderson Counties of South Carolina. These sites were chosen because they are similar in aspect, soil, and vegetation. All sites were classified as subxeric to xeric (Jones 1989) and occurred on south-facing slopes. Before harvesting in December 1987 and March 1988, major tree species included white oak (*Quercus alba* L.), southern red oak (C?. *falcata* Michaux.), post oak (Q. *stellata* Wangenh.), black oak (Q. *velutina* Lam.), scarlet oak (Q. *coccinea* Muenchh.) chestnut oak (Q. *prinus* L.), hickory (*Carya* sp.), and shortieaf pine (*Pinus echinata* Miller). Minor tree species included blackgum (*Nyssa sylvatica* Marshall), sourwood *(Oxydendron arboreum* (L.) DC.), dogwood (*Cornus florida* L.) and yellow-poplar (*Liriodendron tulipifera* L.). Slopes averaged 7 to 10 percent on all replications. All soils were described as Typic Hapludults.

Before harvest, 87 plots, 1/10th acre in size, were established in three replications of four treatments. The treatments included: 1) spring felling of residuals with summer broadcast burning (the fell-and-burn technique), 2) winter felling of residuals with summer broadcast burning, 3) spring felling of residuals with no burning, and 4) winter felling of residuals with no burning.

Phillips and Abercrombie (1987) suggested that sprout vigor would be reduced by felling residual hardwood stems in spring when carbohydrate reserves in root systems are typically low. Winter felling and spring felling were compared to determine if sprout height growth was reduced by spring felling. Chainsaw crews felled all residual stems over 5 feet tall. Winter felling was completed in early March 1988; spring felling was completed in June 1988.

Burning occurred on July 7, 1988, two days after a rainfall of 1/2 inch. Humidity at the time of burning was 50-60 percent, and wind speed was approximately 5 mph. Moisture content of lo-hour timelag fuels (0.25-l inch in diameter) was 12 percent at 10:00 A.M. and 9 to 10 percent after noon. Backing fires were started along the edges of the units until a sufficient blackened strip was attained. Strip-head fires were used to ignite the interior fuels.

Improved loblolly pine seedlings were hand planted by contract crews in all treatment areas during March 1989. Observations on the Sumter National Forest and the results of a previous study in the Piedmont (Nix and others 1989) indicated that pines outcompete and overtop hardwoods on fell-and-burn sites in 7 to 10 years. To reduce costs and allow favorable conditions for hardwood development, pines were planted at spacings of 15 by 15 feet (194 seedlings per acre) in this study.

In each treatment area, five to eight sample plots were established; each was 1 chain by 1 chain square (1/10 acre). Plot centers were generally 80 feet apart (leaving a 14-foot buffer between plot boundaries), but this distance varied by topography. Prior to harvest, the species, dbh, and height of each tree was recorded. Advance regeneration was tallied by species and origin (seedling or sprout). After harvest, regeneration data were collected at the end of the fourth growing season (1991). Measurements on hardwoods included: 1) number of seedlings and sprouts by species, 2) sprouts per stump, and 3) height of the dominant sprout on each stump. Treatment differences were compared with each variable for the common species or species groups including: oak, hickory, blackgum, other hardwoods, and all species combined. Survival and height of planted pines were measured for a 100-percent sample of each 2-acre treatment area.

RESULTS AND DISCUSSION

Broadcast burns were high-intensity with flames reaching heights of 10 to 15 feet where fuel loading was heavy. Fire behavior appeared to be affected by the season of felling. In winter-felled areas, limited loading of fine fuels produced fires that did not carry between slash piles. In spring-felled areas, dry leaves sewed as fuels to carry the fire. Spring felling tended to produce uniform burns across the entire study area, while winter felling produced a patchy burn pattern.

At the end of four growing seasons (1991), species composition was similar to preharvest stands and was largely unaffected by site preparation treatments. No significant differences between treatments occurred in the number of stems per acre for blackgum and pines (table 1). The total number of stems per acre ranged from 9,208 to 12,636. Burning significantly increased the number of stems per acre of hickories and other hardwoods.

The number of oak stems appeared to be significantly reduced by burning (table 1). Burned areas averaged less than 3,500 oak stems per acre, while unburned plots had over 5,000 oaks per acre. However, this

Table I-Species composition of regeneration at the end of the 1991 growing season (four seasons after harvest)

Treatment	Oaks'	Hickory	Blackgum	Other Hardwoods	Pines	Total
	Stems per acre					
Winter fell/no burn	5095 b[2]	904a	543a	4383a	297a	11,222a
Spring fell/no burn	4991 b	710a	178a	3005a	324a	9,208a
Winter fell/burn	2924a	1397 b	136a	6064 b	516a	11,037a
Spring fell/burn	4047ab	1615b	649a	5910 b	415a	12,636a

[1] Scarlet oak, southern red oak, white oak, post oak, black oak, chestnut oak.
[2] Means followed by the same letter within a column are not significantly different at the 0.05 level.

difference may be due to plot location rather than fire effects because burning tended to increase the number of sprouts per stump rather than decrease them (table 2). This effect was significant for the oak and all species groups. In addition, site preparation burning had no effect on the percentage of stumps that produced sprouts through the first four growing seasons (table 3).

By the end of four growing seasons, the dominant sprout in each clump averaged over 5 feet tall for all treatments (table 4). Sprouts in burned treatment areas were significantly shorter than in unburned areas for all species and groups. Sprouts which emerged the spring following harvest were top-killed by burning. New sprouts which emerged after burning had a shorter growing season and, therefore, less height growth than sprouts in unburned areas. Additional control of hardwood growth, which was thought to be provided by spring felling, was evident only in the other hardwood group. In this group, stems in unburned areas felled in spring were significantly shorter than those in unburned areas felled in winter.

Table 2-Mean number of sprouts produced by each stump by species and treatment at the end of the 1991 growing season (four growing seasons after harvest)

Treatment	Oaks'	Hickory	Blackgum	Other Hardwoods	All Species
Winter fell/no burn	4.6a[2]	3.5	2.8	6.0a	5.0a
Spring fell/no burn	4.8a	4.0	2.0	6.2a	4.9a
Winter fell/burn	5.9 b	3.5	4.6	8.3 b	6.5 b
Spring fell/burn	6.2 b	4.4	3.3	6.7a	6.0 b

[1] Scarlet oak, southern red oak, white oak, post oak, black oak, chestnut oak.
[2] Means followed by the same letter within a column are not significantly diierent at the 0.05 level.

Table 3--Percentage of stumps that survived and produced sprouts through the 1991 growing season (four growing seasons after harvest)

Treatment	Oaks'	Hickory	Blackgum	Other hardwoods
Winter fell/no burn	91.0	81.8	70.8	93.1
Spring fell/no burn	89.1	88.0	63.9	90.1
Winter fell/burn	88.9	90.4	57.9	96.6
Spring fell/burn	82.5	76.5	75.0	94.1

[1] Scarlet oak, southern red oak, white oak, post oak, black oak, chestnut oak.

Table 4-- Average height (feet) of the dominant sprout by species group and treatment at the end of the 1991 growing season (four growing seasons after harvest)

Treatment	Oaks'	Hickory	Blackgum	Other hardwoods	All species
Winter fell/no burn	11.0a[2]	6.9a	8.3a	ll.Oa	10.4a
Spring fell/no burn	11.2a	6.7a	7.2a	10.0 b	9.9a
Winter fell/burn	8.3 b	4.8 b	4.2 b	8.4 c	7.5 b
Spring fell/burn	8.7 b	4.0 b	3.5 b	8.2 c	7.6 b

[1] Scarlet oak, southern red oak, white oak, post oak, black oak, chestnut oak.
[2] Means followed by the same letter within a column are not significantly different at the 0.05 level.

Controlling hardwood height growth by burning may prove beneficial to the growth and survival of planted pines. In the Autumn of 1991, planted pines had grown for three growing seasons, while hardwoods had grown for all (unburned) or a portion (burned) of four growing seasons. Pines were nearly as tall as hardwoods in burned areas but remained shorter than hardwoods in unburned areas. Pine heights ranged from 7 to 8 feet (table 5), but heights were not significantly different between treatments. Mean height of hardwoods was 7.5 feet in burned areas but over IO feet in unburned areas (table 4).

Survival of planted pines was good, averaging approximately 65 percent (126 stems per acre) for all site preparation treatments (table 5). Most of the pines that survived through 1991 appeared healthy and may become a major component of the regenerated stand.

In all treatment areas, hardwood crowns had not closed over the pines, therefore, most pines were free to grow. As crowns close, however, hardwoods may overtop pines in unburned areas and pine mortality may increase.

CONCLUSIONS

This study indicates that the fell-and-burn system can be successfully used in the Piedmont region to establish a mixed stand of pines and hardwoods. Burning in July controlled hardwood sprout growth by reducing the length of the growing season, This effect remained apparent through four growing seasons. Almost 65 percent of planted loblolly pines (126 per acre) survived throughout the study period. Most of these pines had caught up with the hardwoods and will become a dominant component of the future stand. Oaks, which were taller and more numerous than other

Table &Survival and height of planted loblolly pine seedlings after the 1991 growing season (three growing seasons after planting)

Treatment	Percent Survival	Height (ft)
Winter fell/no burn	69.0	7.8
Spring fell/no burn	67.7	7.6
Winter fell/burn	68.6	7.4
Spring fell/burn	58.3	7.0

hardwood species will probably become a codominant species in the stand.

This study also indicates that some variations of the fell-and-burn technique may be used successfully. Winter felling of residual stems, followed by summer burning produced nearly identical stands to those regenerated by the fell-and-burn treatment (spring felling and summer burning). Winter felling did not control hardwood growth as well as spring felling. However, growth reductions from spring felling had no apparent effect on stand development. This result indicates that the precise timing of felling as prescribed by the fell-and-burn system may be unnecessary in some cases.

Successful establishment of pine-hardwood mixtures may be possible without site-preparation burning. However, these stands are too young to completely evaluate the success of planted pines. Through the 1991 growing season, pine survival and growth in unburned plots equalled that of burned plots, indicating that burning may not be necessary. However, pines in unburned plots remained 2 to 3 feet shorter than hardwoods after four growing seasons. If pines continue to grow rapidly in unburned areas, they should overtop hardwoods and become a dominant component of the stand. However, hardwood crowns might close first and pines would become suppressed. Stand development in all treatment areas will be measured for several years to determine the need for site preparation burning.

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OPENING SIZE AND SITE PREPARATION TECHNIQUES AFFECT REGENERATION SUCCESS FOR UNEVEN-AGED PINE-HARDWOOD MIXTURES'

Carol J. Perry and Thomas A. Waldrop[2]

Abstract-Uneven-aged management of pine-hardwood mixtures may provide desirable combinations of timber and nontimber resources if these mixtures can be regenerated in small openings. This study compares pine-hardwood regeneration between several combinations of opening size and site preparation treatments. Treatments included two opening sizes(1 /10 acre and 1/3 acre) and three types of site preparation treatments(chainsaw fell noncommercial-sized trees, fell noncommercial trees and apply herbicide, and no treatment). Eariy resuits indicate that a balance of hardwood control and available sunlight is required to ensure survival of planted pines. After two growing seasons, most pines were free to grow and had overtopped competing hardwoods. Hardwoods were most vigorous in the larger openings where no herbicide had been applied.

INTRODUCTION

The forest products industry has increasingly come to rely on the resources of the Southeast for fiber production. This is due, in part, to logging restrictions in the Pacific Northwest as well as mandates to establish nontimber objectives for National Forests in all regions. And because Hurricanes Hugo and Andrew destroyed much of the coastal timber resources, management of forested lands in the Piedmont has become extremely important.

Forested lands of hardwood or mixed pine-hardwood stands in the Piedmont Plateau and Appalachian Mountains of the Southeast cover about 26.8 million acres (Bechtold and Ruark 1988). Nonindustrial private forests (NIPF) comprise 72 percent of this acreage. These private forests average about ten acres, are owned by individuals or families, and are typically unmanaged. Many owners choose not to manage because they object to pine monocultures or they do not want to invest heavily in timber (McMinn 1983, Haymond 1988).

Pine-hardwood mixtures are gaining acceptance and new regeneration techniques are proving successful (Waldrop 1994). Productivity of low-quality hardwood stands can be improved economically while maintaining aesthetic values. Uneven-aged pine-hardwood management may prove to be attractive to nonindustrial private landowners as well as national forestlands. However, supporting research is limited.

Extensive research has been conducted using the fell-and-burn technique to regenerate even-aged pine-hardwood mixtures in the Appalachian Mountains (Phillips and Abercrombie 1987) and the Upper Southeastern Piedmont (Waldrop 1994). This project was established to test whether some of the same technology used in the fell-and-burn system could be applied in small openings to establish uneven-aged pine-hardwood mixtures.

Among the questions considered was whether amounts of sunlight, limited by smaller openings, are sufficient for pine establishment. Loblolly pine seedlings are shade tolerant when young, but require more light as they mature (Brender 1973). Another consideration was whether herbicide can successfully replace fire as a site preparation technique. Felling and burning, as described by Phillips and Abercrombie (1987) and Waldrop and others (1989) have proven successful in regenerating mixed pine-hardwood stands, but the use of herbicide to control hardwoods may be more desirable in small openings where the use of fire is not feasible.

Previous research on pine-hardwood regeneration mixtures in clearcuts indicates that loblolly pine

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seedlings tolerate shade and other forms of competition on medium- to poor-quality sites, and within 5 years overtop surrounding hardwood sprouts (Waldrop and others 1989, Evans 1990). Minckler and others (1973) found that young hardwoods closer to the edge of openings than a distance equal to the height of border trees are suppressed and grow slower than those closer to the center. These findings suggest that mixtures of loblolly pine and upland hardwoods may be regenerated successfully in small openings on medium to poor sites if the edge effect controls hardwood growth enough to allow pines to become established.

This paper documents an attempt to convert an uneven-aged poor-quality Piedmont hardwood stand to an uneven-aged pine-hardwood stand using small openings to create groups. Pine and hardwood regeneration and their relative growth rates through two growing seasons are reported.

METHODS

The study area is in the Upper Piedmont of South Carolina on a 27-acre tract of the Clemson University Experimental Forest in Pickens County. Slopes range from 6 to 10 percent with a uniform southwest exposure. Soils are severely eroded clay loams of the Cecil series. These soils have poor fertility because past land management practices led to erosion of topsoil (USDA Soil Conservation Service 1972). Site index at age 50 years is 70 ft for loblolly pine and approximately 60 ft for upland oaks.

Prior to 1974, the stand was an unmanaged oak-loblolly pine mixture with an average basal area of 100 ft^2/acre (75 percent hardwoods and 25 percent pine). During that year, all pines of commercial size were harvested. In 1989 patches of naturally regenerated loblolly pine occurred throughout the stand in small openings created by that harvest. This regeneration may indicate that loblolly pine seedlings can survive in small openings where indirect sunlight is provided by a southwestern exposure.

This all-aged hardwood stand had a variety of tree ages with some as high as 150 years, and a wide range of dbh classes. White oak (*Quercus alba* L.) was the most abundant overstory species, representing 41 percent of all stems and 30 percent of the basal area (Table 1). Other common overstory species were black oak (C?. *velutina* Lam.) and loblolly pine (P. taeda L.). Common understory species were dogwood (*Cornus florida* L.) and hickory (*Carya* sp.). Basal area was 73 ft^2/acre in 1989.

Prior to treatment installation, the diameters of all trees 2.5 inches dbh and larger were measured. Increment cores were extracted from a sample of 150 trees to examine age distribution. Sample trees were selected over the range of dbh classes and distributed throughout the stand. The relationship of age to dbh was determined with simple linear regression.

In December 1989, six treatment combinations were replicated three times in a randomized complete block design. Treatments included two opening sizes and three levels of hardwood control. Opening sizes of 1/3 and 1/10 acre were chosen because a relationship between opening size and the height of border trees had been reported by Minkler and Woerheide (1965). Circular openings of 1/3 acre have a diameter of approximately two tree heights (136 ft), while 1/1 O-acre plots (74 ft) have a diameter of approximately one tree height. Levels of hardwood control included: (1) chainsaw felling of residual stems over 6-ft tall; (2) chainsaw felling of residual stems plus application of Garlon™ 3A to all stumps; and (3) no control. Replicates were blocked across the slope (upper, middle, and lower) to remove site differences. Study plots were located away from patches of heavy pine regeneration to minimize variation. Analysis of variance and linear contrasts were used to test for treatment differences at the 0.05 level of confidence.

Trees were harvested on the 1/3 and 1/1 O-acre treatment plots. All trees over 4.5 inches dbh were felled and limbed on site by research crews. Logs were skidded from the plots by a commercial logger in February 1990. To minimize damage to standing trees, skidder operators used logging roads and skid trails established for the 1974 harvest.

Hardwood control treatments were installed in early March 1990, immediately after logging. All residual stems over 6 ft tall were felled by chainsaw in 12 of the 18 study plots (two opening sizes x three control treatments x three replications). Garlon 3A was applied to all hardwood stumps in half the plots where residuals were felled. The herbicide was applied at full strength with no water. Hardwood control was not attempted in the remaining six openings. Where residuals were not felled, the basal area of residual stems averaged 10.8 ft^2/acre. Genetically-improved loblolly pine seedlings

Table l-Mean number of stems and basal area per acre before harvest by species group and size class

Species group	Stem dbh class (inches) 2.5-5.4	5.5-9.4	>9.4	Total (percent)
	(stems/ac)			
Oaks				
White	56.3	11.6	14.6	82.5 (41)
Black	9.6	4.5	3.1	17.2 (9)
Scarlet	3.9	2.0	3.3	7.6 (4)
Post	1.8	2.6	4.2	8.7 (5)
Southern red	3.1	1.2	3.3	7.6 (4)
Misc.	0.1	0.1	0.0	0.3 (<1)
Total	74.9	22.1	28.6	125.5 (63)
Other hardwoods				
Yellow-poplar	1.5	0.6	1.2	3.3 (2)
Hickory	9.7	4.8	3.5	18.0 (9)
Dogwood	22.7	1.9	0.3	24.9 (12)
Misc.	10.8	2.3	0.4	13.6 (7)
Total	44.7	9.6	5.4	59.8 (30)
Pines				
Lobloliy	2.6	5.9	4.3	12.9 (6)
Shortleaf	1.2	0.0	0.0	1.3 (1)
Virginia	0.1	0.1	0.0	0.3 (<1)
Total	4.0	6.1	4.4	14.4 (7)
All species	123.7	37.8	38.3	199.8(100)
	-Basal area (ft^2/ac)-			
Oaks				
White	1.3	3.4	17.2	21.9 (30)
Black	0.2	0.8	4.3	5.3 (7)
Scarlet	0.3	0.6	4.7	5.6 (8)
Post	0.2	0.8	4.3	5.3 (7)
Southern red	0.3	0.3	4.7	5.3 (7)
Misc.	0.0	0.0	0.1	0.1 (<1)
Total	3.0	6.4	36.8	46.2 (63)
Other hardwood				
Yellow-poplar	0.1	0.2	2.2	2.5 (3)
Hickory	0.9	1.2	3.6	5.7 (8)
Dogwood	1.8	0.3	0.3	2.4 (3)
Misc.	1.0	4.8	1.6	7.3 (4)
Total	3.8	6.5	7.7	17.9 (25)
Pines				
Lobloliy	0.3	1.9	4.1	6.3 (9)
Shortleaf	2.4	0.0	0.0	2.5 (3)
Virginia	0.0	0.0	0.0	0.1 (<1)
Total	2.7	1.9	4.1	8.9 (12)
All species	9.5	14.8	48.7	73.0(100)

were planted by research crews in each opening at a spacing of 12 x 12 feet during the first week of March 1990.

The location of each planted pine was mapped to monitor the relationship of position within a plot to survival and growth. At the end of the first two growing seasons, each pine was tallied as alive or dead and total seedling height and the height at last year's node were measured. Growth was calculated as the difference between the two height measurements. The percentage of each seedling's crown directly covered by nearby vegetation was estimated. Categories included 0, l-25, 26-50, 51-75, and 76-100 percent covered. Seedlings were considered free to grow if no more than 75 percent of the crown nor the terminal bud were directly covered by competing vegetation. Cover by residual stems over 6 ft tall was not included in estimates of direct cover.

Species composition and growth of hardwood regeneration were measured in September 1990 and 1991. Circular O.OOl-acre sample plots were established in a systematic pattern in each opening. Fifty sample plots were created in 1/3-acre openings, while 15 plots were created in 1/1 O-acre openings. Both samples represent 15 percent of the opening size. All seedlings and sprouts were tallied by species. Height was measured to the nearest 0.1 ft. In sprout clumps, all sprouts were counted and height of the dominant sprout measured.

RESULTS AND DISCUSSION

Prior to harvest, the study stand had large numbers of small trees and small numbers of large trees (Table 1). To avoid high grading, single-tree selection based on diameter requires a close correlation between dbh and age. This did not occur in the study stand (r^2=0.42), where too few stems were in age classes younger than 70 years. Group selection was chosen over single-tree selection to ensure that trees of all dbh and age classes were harvested.

The occurrence of natural pine regeneration was sparse in the stand prior to harvest. Survival of planted pines at the end of the second growing season was fairly high in both opening sizes and with all levels of hardwood control (Table 2). Survival averaged 61 percent in 1/1 O-acre openings and 65 percent in 1/3-acre openings. However, the number of free to grow pines was significantly less in the 1/3-acre openings (85 percent) than in the 111 O-acre openings (95 percent). The lesser amount of direct sunlight received on the 1/1 O-acre openings may account for less hardwood and herbaceous growth, thereby reducing competition with planted pines.

Total height of planted pines was not affected by the level of hardwood control within each opening size (Table 2); however, the pines in the 1/3-acre openings were, on average, 9 inches taller than those in the l/l 0-acre openings. Second year growth did not diier significantly in any of the treatments except in the 1/3-acre plots where residuals were felled and 1/3-acre plots where residuals were felled and herbicide applied. Pines in these two treatments grew more than those in the remaining four treatments.

Mortality patterns of the planted pines appear to be affected by direct sunlight rather than edge effect.

Table 2-Mean height, growth, and portion free-to-grow for planted pines surviving one growing season

Treatment	Height	Growth	Free-to-Grow
	feet		- pct -
1/1 0-ac openings			
No understory control	2.7a	0.4a	97.1a
Residuals felled	2.2a	0.4a	95.2a
Residuals felled + herbicide	2.6a	0.5a	93.6a
1/3-ac openings			
No understory control	3.2b	0.5a	86.3b
Residuals felled	3.2b	0.6b	88.8b
Residuals felled + herbicide	3.4b	0.6b	80.4b

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

Table 3--Composition (stems/ac) of hardwood regeneration by treatment

Hardwood species	1/10-ac openings			1/3-ac openings		
	No control	Fell Only	Fell and herbicide	No control	Fell Only	Fell and herbicide
Black oak	600	1479	1378	1061	841	914
White oak	1711	1177	1400	1857	1640	3456
Misc. oaks	578	1422	556	959	512	542
Black cherry	364	534	533	395	858	642
Blackgum	270	711	578	510	968	690
Dogwood	1333	1822	800	1448	4717	1774
Hickory	1222	3978	1755	1244	3317	2069
Yellow-poplar	911	1466	3022	2659	3889	1452
Misc.	289	1600	622	1993	1577	1231
Total	7400	15200	11089	12680	19401	13588

Mortality primarily occurred in the centers and the Northwest corners of the plots in all treatments, where the strongest sunlight was reached the seedlings. The sunlight also promoted a very heavy growth of Rubus sp., which competed intensely with the pines.

Total numbers of hardwood sprouts and seedlings (Table 3) were significantly lower in 1/10-acre openings than in 1/3-acre openings. This may indicate that shading created by edge effect kept hardwood regeneration down. In both opening sizes, the no control plots exhibited less hardwood regeneration than the remaining two treatments, which was expected because the number of stumps was lower. In the remaining plots, less sprouting occurred in the openings receiving the felling and herbicide treatment than those receiving the felling treatment.

Vigor of hardwood regeneration was affected by both opening size and level of understory control. For the oak and other-hardwood categories, the number of sprouts per cut stump was greater in 1/3-acre openings than in 1/10-acre openings (Table 4). Within the 1/3-acre openings, sprouts per stump were most numerous where residuals were felled but no herbicide was applied. In plots where residuals were not felled, sprouts originated from the stumps of commercial-size trees, which were from older trees with reduced sprouting capability. In plots where residual stems were felled and herbicide was applied, the herbicide did not kill the entire stump and root system, but did reduce the number of sprouts produced. This pattern agrees with the results of Lewis and others (1984), who found that a winter application of Garlon 3A to the stumps of Piedmont hardwoods killed only a portion of the stumps but effectively controlled sprout growth.

Table 4-Mean number of sprouts per stump by treatment and species group

Treatment	Oaks	Other hardwoods	All hardwoods
1/10-ac openings			
No understory control	1.2a	2.5a	1.9a
Residuals felled	1.7a	2.4a	2.0a
Residuals felled + herbicide	1.8a	1.7a	1.7a
1/3-ac openings			
No understory control	2.2a	2.3a	2.3a
Residuals felled	3.3 b	4.0 b	3.7 b
Residuals felled + herbicide	2.4ab	2.7ab	2.4a

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

Height of the dominant sprout in each clump was affected by opening size for the other hardwoods and all-hardwood groups (Table 5). Sprouts 1/3-acre openings tended to be taller than those in smaller plots. This occurrence is probably a result of reduced competition from border trees, The difference was significant for the other hardwood and all-hardwood

species groups. This finding agrees with that of Minckler and Woerheide (1965) who showed that the vigor of hardwood regeneration increased with distance from the edge of the opening. The sprouts exhibiting the most height growth were in the 1/3-acre openings receiving both the fell and fell plus herbicide treatments. The 1/3-acre plots where no residuals were felled exhibited less height growth because residuals standing within the plot increased shade. No significant differences occurred in the oak category.

Table 5-Mean height (ft) of the dominant sprout per clump by treatment and species group

Treatment	Oak	Other hardwoods	All hardwoods
1/10-ac openings			
No understory control	1.7a	2.6a	2.5a
Residuals felled	2.1a	2.3a	2.2a
Residuals felled + herbicide	2.2a	2.4a	2.3a
1/3-ac openings			
No understory control	2.1a	2.7a	2.4a
Residuals felled	2.7a	3.3ab	3.2 b
Residuals felled + herbicide	2.9a	3.7 b	3.3 b

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

The relative growth rate of pines and hardwoods is shown in Figure 1. Both pines and hardwoods grew at a faster rate in the 1/3-acre openings than those in the 1/1 O-acre openings, because amounts of available sunlight were greater. Typically, hardwood growth is represented by a straight line after the first year but pine growth tends to follow a Sigmoid growth curve. In clearcuts, pine growth lags behind that of hardwoods for the first four to five growing seasons (Waldrop 1994). In this study, the planted pines overtopped the hardwoods after only two growing seasons. This may indicate that these particular hardwood species are as sensitive to shading as pines. It appears the hardwoods may be somewhat controlled by the edge effect which promotes more successful pine establishment.

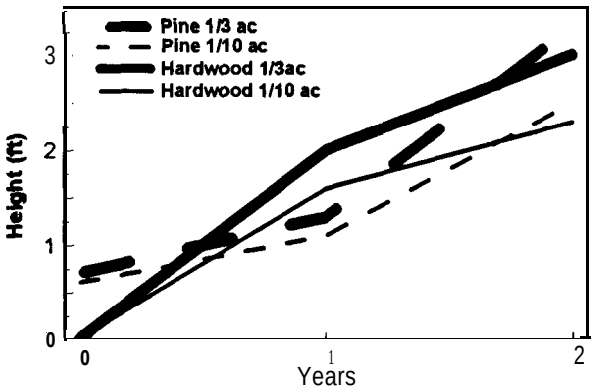

Figure l-Height growth of pines and hardwoods for two years by opening size

CONCLUSIONS

At the end of two growing seasons, in all of the treatment areas, survival of planted pine and growth of pines and hardwoods was adequate. The smaller 1/10-acre openings allowed some sunlight to reach the ground but the edge effect was substantial. Height growth was somewhat suppressed and applying herbicide did not provide additional benefits. Essentially no differences among the three treatments occurred in the 1/1 O-acre openings.

The larger 1/3-acre openings allowed more sunlight to reach the ground, and both hardwoods and pines grew better. Numbers of sprouts were very high in the 1/3-acre openings where no herbicide was applied, and herbicidal control of sprouts may prove necessary as the stand continues to develop. In larger opening sizes, a greater amount of control will be necessary for successful pine-hardwood regeneration. However, in both opening sizes, pine heights exceeded hardwood heights; therfore, pine will probably become a major component in this stand.

Little documentation of stand development with uneven-aged mixtures of pines and hardwoods exists. This stand will be monitored for several years to determine the best combination of opening size and level of hardwood control. Continued study of the long-range effects of competition from border trees in uneven-aged stands is needed.

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ESTABLISHMENT OF OAK REGENERATION IN GROUP SELECTION OPENINGS IN A RIVER FLOODPLAIN FOREST'

Michael S. Golden'

Abstract-A study of regeneration of bottomland tree species in group selection openings was established in an oak-dominated mixed hardwood stand in the floodplain of the Tombigbee River in western Alabama. Despite higher advance reproductii in the groups harvested in early fall, post-harvest reproduction densities in the fall-cut and the summer-cut openings were similar for both cherrybark and water oak. There was substantial post-harvest seedling establishment of oaks, and this was higher in groups harvested in the early summer, compared to those harvested in early fall. The post-harvest increases in summer-cut openings occurred during both of the first two seasons following harvest, and thus came both from delayed acorn germination and from seed dispersal from the surrounding uncut stand.

INTRODUCTION

Group selection is a silvicuttural technique that deserves a closer look for many ownerships and stand types. It is highly flexible. It can create and maintain an uneven-aged forest, even with intolerant species, provided that the groups are large enough. One standard textbook definition specifies that openings for group selection should be no more than two mature tree heights wide (Smith 1986). Thus, in mature southern bottomland forests, openings may, in some cases, be 75 meters (250 feet) or more in width, since trees may be 38 meters (125 feet) or more tall. This would allow circular or square openings of 0.6 hectares (1 1/2 acres) or so, and larger for long, narrow rectangles.

In harvesting, group selection overlaps and intergrades with small patch clearcutting. The major differences are the establishment of a cutting cycle and the typical area or volume regulation of true group selection systems. The small openings, set in a matrix of a larger stand, may appeal to many owners who would dislike the results of a complete clearcut. One maintains the look and feel of a forest, even though it may become somewhat uneven.

I am here reporting initial establishment results from a study that has aims of carefully documenting some of the results and effects of harvesting groups or patches that fall within the size range associated with group selection. Establishment is the first major hurdle in successful regeneration of desired species. Whatever happens later, without adequate initial establishment, there will not be a suitable stand.

STUDY SITE

The study was established in 1992 in a 30 hectare stand of oak-dominated mixed bottomland hardwoods in the floodplain of the Tombigbee River, in Choctaw County, Alabama. The property is owned and managed by James River Corporation. Most of the dominant canopy in the study area is composed of trees 35-40 meters tall, 65 to 75 years old. Breast-high diameters of 50-100 centimeters are common among the canopy oaks.

The area of the study is a mixture of low, well-drained ridges and moderately to somewhat poorly-drained flats. The dominant soils are of the Alamuchee and Mooreville series. Alamuchee soils are alluvial soils classed as fine-loamy, siliceous, thermic Fluventic Dystrochrepts that are deep, well-drained, and moderately permeable. Mooreville soils are alluvial soils classed as fine-loamy, siliceous, thermic Fluvaquenb Dystrocrepts that are deep, moderately well-drained, and moderately permeable (Harris 1989). Surface horizons are mostly loam to sitt loam. The ridges and better-drained flats have not been inundated by overbank flooding during the growing season since the study was installed. However, the lower flats have been

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covered with shallow water as late as May, and for short periods in June, following heavy rainfall.

STUDY DESIGN

Harvested openings (hereafter called "groups") of 0.32 hectare (0.8 acre), 40 by 80 meters, are the basic units of the study. This size falls within acceptable size limits for a selection method, since they approximate one tree height wide by two tree heights long (Smith 1986). Ten groups, centered among clusters of larger dominants and oriented generally east-west, were located in April of 1992. A minimum of 50 meters of uncut forest was maintained between all groups.

One purpose of the study is to test the effects of harvesting at diierent times of the year. Five groups were randomly selected and harvested in early June, 1992 ("summer-cut" groups), and the remaining five were harvested in early October, 1992 ("fall-cut' groups). These were operational commercial harvests conducted by loggers contracted by Linden Lumber Company of Linden, Alabama. Trees were felled by chainsaws, delimbed and topped where they fell, and pulled by grapple skidders to one of two centrally-located loading decks. Following the commercial harvests, all remaining trees in the openings that were larger than 5 centimeters dbh were felled.

DATA COLLECTION AND ANALYSIS

Prior to harvest, all trees in each group greater than 3 m tall were inventoried and their locations mapped. Species and dbh were recorded for each tree.

For inventory and long-term monitoring of reproduction, seven systematically-placed belt transects, each 2 meters wide and extending from side to side (40 meters) perpendicular to the long axis, were established in each group. These *were* segmented into 2 by 2 meter subplots, with 20 subplots in each transect within the group boundaries, for a total of 140 4 m^2 subplots within each group. The subplot corners were marked with wire pin flags, which were replaced by plastic pipe stakes after the harvests.

All non-vine woody species less than 3 meters tall were tallied by species and size class within each subplot in May and September of 1992, then again in September of 1993. Where multiple stems arose from a single rootstock, only the largest was counted. For "pre-harvest" estimates of reproduction, the May inventory data were used for the summer-cut (early June) groups, and the September, 1992, data were used for the fall-cut (early October) groups. September, 1992, and September, 1993, data provided "first" and "second post-harvest" estimates for the summer-cut groups. September, 1993, data provided the single post-harvest estimate for the fall-cut groups.

Mean pm-harvest and post-harvest densities were computed for each harvest treatment, using transects as the sample unit. This provided 35 observations for each harvest time (five groups with seven transects each). In order to identify and quantify post-harvest establishment from seed germination, the pre-harvest density was subtracted from the post-harvest density for each species in each subplot. A positive difference was a very clear indication of post-harvest germination. These positive differences were summed within transects and put on a per hectare basis for harvest treatments. This provided a conservative estimate of the number of seedlings established after the harvest for the groups of each treatment. Since there were two post-harvest inventories for the summer-cut groups, these germination increases were also determined separately for May to September, 1992, and September, 1992 to September, 1993.

Mean pre-harvest basal areas and pre- and post-harvest reproduction densities and density increases were compared between harvest treatments using the TTEST procedure of the Statistical Analysis System (SAS Institute 1988). Where variances were unequal, the Cochran and Cox approximate t-test (Cochran and Cox 1950) was used.

RESULTS AND DISCUSSION

Pre-harvest Trees

All of the groups were dominated by oaks. Cherrybark oak, *Quercus pagoda* Raf., was the most common and most abundant (Table I). It was present in the overstory of all ten of the groups, with a minimum basal area of 4.07 m^2 per hectare (17.7 ft^2 per acre) and a maximum of 21.8 m^2 per hectare (95.1 ft^2 per acre). Water oak, C?. *nigra* L., was also present in the overstories of all ten groups, but with smaller basal areas in most groups. Willow oak, Q. *phellos* L., was present in four of the summer-cut groups and three of the fall-cut. It strongly dominated (18.92 m^2 per hectare) one of the summer-cut groups that had a large, somewhat poorly drained flat. Swamp chestnut oak, *Q. michauxii* Nutt., was present in nine of the ten groups, but was never the leading dominant. Shumard oak, Q. *shumardii* Buckl., was a leading species (9 m^2

Table 1-Pre-harvest basal areas of tree species in the harvested groups, in m^2 per hectare. Means, standard errors, and extremes, in harvested groups, by harvest season treatments. Data for trees greater than 3 meters tall

Species'	Summer-cut n = 5				Fall-cut n = 5			
	Mean	± SE	Min.	Max.	Mean	± SE	Min.	Max.
Cherrybark oak	10.23	3.13	4.07	21.84	11.39	1.79	6.64	16.59
Willow oak	6.73	3.44	0.00	18.92	1.71	0.85	0.00	3.92
Sweetgum	4.55	1.02	3.01	8.51	5.21	2.20	1.68	13.50
Water oak	3.54	1.14	1.34	7.95	4.66	1.89	0.41	11.66
Swamp chestnut oak	1.65	0.69	0.09	3.89	2.19	0.93	0.00	4.94
Green ash	1.03	0.54	0.04	3.06	0.88	0.58	0.00	3.08
Sugarberry	0.85	0.63	0.23	1.84	0.77	0.81	0.00	1.73
Overcup oak	0.32	0.44	0.00	0.81	0.65	0.96	0.00	2.31
Shumard oak	0.00	0.00	0.00	0.00	2.08	3.96	0.00	2.31

[a] Other species not shown are: boxelder, *Acernegundo* L.; American hornbeam, *Carpinus caroliniana* Walt.; biiernut hickory; shagbark hickory; red hickory; mockernut hickory; persimmon, *Diospyrus virginiana* L.; two-winged silverbell, *Halesia diptera* Ellis; American holly, *Ilex opaca* Ait.; red mulberry, *Morus rubra* L.; black tupelo, Nyssa *sylvatica* Marsh.; swamp laurel oak, *Quercus laurifolia* Michx.; winged elm, *Ulmus alata* Michx.; American elm, *U. americana* L.; and possumhaw, *Ilex* decidua Walt.

per hectare) in one fall-cut group and present in another, but was absent from the other eight groups. Two other oaks, overcup, Q. *lyrata* Walt., and swamp laurel oak, Q. *laurifolia* Michx., were present but were scattered and in low numbers within the groups. Sweetgum, *Liquidambar styraciflua* L., was present in all groups, and exceeded 8.5 m^2 per hectare in two of them. Green ash, *Fraxinus pennsylvanica* Marsh., and sugarberry, *Celtis laevigata* Willd., were present in most of the groups, but were never among the dominant species. Shagbark, *Carya ovata* (Mill.) K. Koch, and bitternut, C. *cordiformis* (Wang.) K. Koch, were the most common hickories, although red, C. *ovalis* (Wang.) Sarg., and mockernut hickory, C. *tomentosa* (Poiret) Nutt., also occurred.

Reproduction

Reproduction (all trees less than 3 meters tall) density estimates from the pre- and post-harvest inventories are shown in Table 2. Pm-harvest inventories were taken in May, 1992, and September, 1992, for the summer-cut and fall-cut groups, respectively. The post-harvest densities are all from the September, 1993, inventory. Thus, the summer-cut post-harvest densities are at about 15 1/2 months after harvest, whereas the fall-cut are at about 11 1/2 months after harvest.

Pre-Harvest Densities.

Cherrybark oak and water oak pm-harvest reproduction densities averaged more than twice as high in the fall-cut groups as in the summer-cut (Table 2), and these differences were significant (0.05 level). Variation among groups was considerable. Cherrybark oak densities within individual groups ranged from 811 to 5346 per hectare for summer-cut and from 2047 to 9968 per hectare for fall-cut groups. Water oak pre-harvest densities were similar to those of cherrybark oak, both in numbers and in that the fall-cut groups averaged more than twice the seedling density of the summer-cut (5736 vs. 2389 per hectare). The willow oak pm-harvest reproduction averaged ten times as high in the summer-cut groups (significant at 0.01 level) compared to the fall-cut. The extremely high willow oak seedling densities were found primarily in low flats of two of the groups, where plot densities as high as 37 per m^2 were recorded.

Post-Harvest Densities.

The post-harvest (September, 1993) densities of cherrybark oak seedlings were very similar for the two harvest treatments, slightly more than 2000 per hectare (Table 2). However, since the preharvest density had been much higher for the fall-cut groups, the net

Table 2-Mean pre- and post-harvest reproduction densities and change for major oak species within the harvested groups, by harvest season treatment. Number per hectare for all seedlings and sprouts (rootstock count) less than 3 meters tall

Species	Pm-harvest		Post-harvest		Chanae	
	Summer-cut	Fall-cut	Summer-cut	Fall-cut	Summer-cut	Fall-cut
Cherrybark oak	2319	5086'	2086	2178	-232[b]	-2908
Willow oak	26012[b]	2549	6354[b]	918	-19659	-1631[b]
Water oak	2389	5736'	4250	3177	+1860[b]	-2559

'Significantly higher than for the other harvest time, 0.05 level of probability.
[b]Significantly higher than for the other harvest time, 0.01 level of probability.

reduction in density from preharvest levels was significantly less for the summer-cut groups, 232 per hectare compared to 2908 per hectare, or 10 percent vs. 57 percent reduction.

Willow oak seedling densities remained higher at the post-harvest inventory in the summer-cut groups, but they were reduced by 19659 per hectare, a 76 percent reduction, compared to 1631 per hectare for the fall-cut, a 64 percent reduction. The greater reductions for the summer-cut treatment is largely a result of the much higher initial densities, and the generally more concentrated distribution of willow oak seedlings. Skidding through dense patches of seedlings destroyed large numbers of them.

Water oak seedlings increased in the summer-cut openings by 1860 per hectare (a 78 percent increase), but they decreased by 2559 per hectare (45 percent) in the fall-cut groups, although a substantial density remained (3177 per hectare).

If no post-harvest seedling establishment had occurred, all oak species' reproduction densities could be expected to decrease. Logging damage, particularly during the concentrated skidding in the small openings, surely resulted in the destruction of many seedlings in every group. Unfortunately, since there were no inventories taken immediately after harvests, it is impossible from these data to determine if there were differences in the amount of losses directly attributable to the logging operations. The same crews, equipment, and loading areas were used for both harvests. Other factors, such as slash cover, herbivory (the white-tailed deer population is high), and competition from fast-growing vine and herbaceous species, also caused some mortality as well. There was no "ingrowth" affecting the density estimates, since even the smallest seedlings were counted in all inventories.

For the fall-cut groups, seedlings that germinated early in the growing season and were still alive at the September pm-harvest inventory could be expected to be of low vigor. Since these oaks are generally considered somewhat intolerant of shade, the typically dense shade at the forest floor during the summer would cause a deficit in carbohydrate production compared to respiration loss for most seedlings. Many of the understory seedlings at this time exhibited thin, damaged leaves and evidence of fungal attack. This state of low vigor may have increased seedling vulnerability to mortality from the logging, sudden increased exposure, and subsequent stresses of the new environment of the openings. They also had little time to recover before winter.

In contrast, seedlings of the summer-cut groups that had germinated in the spring generally appeared vigorous, probably due to their having not yet exhausted the carbohydrate reserves of the acorn. This apparent higher vigor at the time of harvest may have increased these seedlings' ability to survive logging damage and subsequent stresses when compared to that of the seedlings of the fall-cut groups. This could provide a partial explanation for the density change differences between the two treatments.

Additional explanation for the differences in seedling density changes among the treatments was provided by examination of the differences in post-harvest germination.

Table 3-Reproduction density increases in sampled subplots within the harvested groups, from pm-harvest to post-harvest measurement times, by harvest treatment and time period. Density per hectare for all sizes less than 3 meters tall. Only plots with increases during the specified period were included

Species	-Summer harvest groups----- Spring '92- fall '92	Fall '92- fall '93	Spring '92- fall '93	Fall harvest groups Fall '92 to fall '93
Cherrybark oak	1126	438	1068'	618
Willow oak	851	745	654[b]	161
Water oak	2636	918	2593[b]	407
All oaks	4627	2167	4357[b]	1843

"Significantly higher than the fall-cut post-harvest increase, 0.05 level of probability.
[b]Significantly higher than the fall-cut post-harvest increase, 0.01 level of probability.

Post-Harvest Germination and Seedling Establishment

Since the water oak densities increased in the summer-cut openings, clearly there was post-harvest germination for this species. When the pre- and post-harvest counts were compared for each individual subplot, it was clear that all three of the major oaks exhibited post-harvest establishment (Table 3) in both the summer and fall harvest treatments. For each subplot, only seedling increases that exceeded losses during the period were detectable. Thus the numbers shown in Table 3 should be underestimates of the actual number of seedlings that germinated after harvest.

Post-harvest seedling establishment, though still present in substantial numbers (1843 per hectare for all oaks combined), was significantly lower for all of the oaks in the fall-cut groups when compared to the summer-cut. The treatment difference was greatest for water oak, with an increase of 2593 compared to 407 per hectare for the summer-cut and the fall-cut groups, respectively.

Examination of the two seasons separately for the summer-cut groups revealed that post-harvest establishment occurred in substantial numbers for both the first (June through September) and second seasons (Table 3). Seedlings established during the 1992 summer (total of 4627 per hectare for all oaks) would have come from delayed germination of acorns of the 1991 seed crop. Those established during 1993 (total of 2167 per hectare for all oaks) would have originated from dissemination of acorns from the 1992 seedfall of the surrounding uncut forest.

No quantitative data on the size of the 1991 and 1992 acorn crops were taken. Casual observation led to the conclusion that both acorn crops were good. Since post-harvest establishment appears to have played an important role in the 1993 seedling densities, especially for the summer-cut groups, timing a group selection harvest to coincide with or follow a good seed crop would seem to be an important consideration in increasing reproduction densities of these oaks.

SUMMARY AND CONCLUSIONS

Despite higher advance reproduction in the groups harvested in early fall, post-harvest reproduction densities in the fall-cut and the summer-cut groups were similar for both cherrybark and water oak. This reflected both a higher loss of seedlings in logging and post-harvest mortality and a lower level of post-harvest establishment in the fall-cut openings.

A substantial amount of post-harvest germination and seedling establishment occurred for all oak species, most notably for water oak in the summer-cut openings. Post-harvest seedling establishment of all oaks was higher in the summer-cut groups. The post-harvest increases in summer-cut groups occurred during both of the first two seasons following harvest, and thus came both from delayed acorn germination

and from seed dispersal from the surrounding uncut stand. Timing the harvest to coincide with or follow a good seed crop should be an important consideration in applying group selection or patch clearcutting harvests.

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DROUGHT AND SURVIVAL OF LOBLOLLY PINE SEEDLINGS AFTER PLANTING[1]

Janusz Zwolinski, David B. South and Brad L. Barber[2]

Abstract--Palmer Drought Severity Index (PDSI) is an objective measure of monthly moisture conditions. Equations for prediiing post-planting survival of loblolly pine were developed for 2 regions of the southern United States. When using average yearly values over a period of 9 years (n=9), 70% of the variation in seedling survival could be accounted for with PDSI. As expected, survival decreased with decreasing PDSI values during droughts. However, to adequately predict survival for specific sites, factors such as seedling morphology and planting methods will need to be modelled. For example, PDSI values accounted for less than 8% of the variation in survival when using individual observations (n≥681).

INTRODUCTION

The term drought has not been universally defined. Most commonly, drought is defined as occuring after a certain number of consecutive days with precipitation below a specific level (Amidon et *al.* 1981; De Jager and Schulze 1977; Richardson and Kruger 1990). In climatology, atmospheric droughts are defined by mean monthly temperatures and total monthly precipitation (Chylarecki and Filipiak 1987). This method is most often used for climatic classification on a macro-regional scale and for explaining geo-distribution of plants (Walter 1975; 1985). Zwolinski (1992) showed, however, that available water in the soil did not always correspond with the atmospheric drought defined by temperature and precipitation, and the analysis of data on a monthly basis tends to obscure drought incidence for short-term observations. Neither of the above methods account for terrain, soil water retention and vegetation transpirational demands; therefore, they have limited applications in forest management.

For almost 30 years, Palmer Drought Severity Index (PDSI) has been used for both research and operational decisions across the United States (Anon 1985). The procedure uses both antecedent and current weather data (daily and monthly precipitation and maximum and minimum temperatures) (Palmer 1965). It includes Thornthwaite's water balance model to estimate evapotranspiration (Thornthwaite 1948). PDSI is calculated for each of the 344 state climatic divisions (geographic regions of "uniform" climate) and accounts for average geo-morphological and pedological characteristics of a particular region (Zahner and Grier 1990). Because of its complexity, it seems more appropriate to classify Palmer's index as a hydrological rather than meteorological method. Eleven moisture classes have been established to represent wet and dry periods as defined by PDSI (Table 1).

In forestry, PDSI has been used to explain differences in annual growth (Devall et a/. 1991; Jordan and Lockaby 1990; West et *al.* 1993; Zahner et *al.* 1989) and to reconstruct long-term climate changes using dendrochronology (Cook and Jacoby 1979; Stahle et *a/. 1988).* PDSI has also been used to model insect pest distribution (Michaels et a/. 1986) and to predict tree recruitment in naturally regenerated stands (Barden 1988). However, PDSI may show poor correlations with vegetative response where previous conditions have lasting impact on vegetation (Zahner and Grier 1990). Additional deficiencies of PDSI include: (i) not specific for a range of sites and soils within a region, (ii) all precipitation is included as rain in the model, (iii) evapotranspiration is calculated for level terrain with a complete vegetation cover, (iv) no runoff is allowed until soil saturation occurs.

Unlike regular mortality in older stands, different and often unrelated factors, such as stock quality, weather conditions, availability of water and nutrients, genetic attributes, pest attacks, and others may be responsible for mortality of trees after planting (Boyd 1977).

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Table l-Moisture classes based on Palmer Drought Severity Index (Anonymous 1985), and likelihood of occurance (pct) in Alabama and east Texas (data from 1895 to 1994)

PDSI	Class	Alabama (pct)	East Texas (pct)
> 3.99	Extremely wet	0	1
3.00 to 3.99	Very wet	4	4
2.00 to 2.99	Moderately wet	7	14
1.00 to 1.99	Slightly wet	11	9
0.50 to 0.99	Incipient wet spell	11	12
0.49 to -0.49	Near normal	33	25
-0.50 to -0.99	Incipient drought	5	7
-1.00 to -1.99	Mild drought	17	13
-2.00 to -2.99	Moderate drought	10	10
-3.00 to -3.99	Severe drought	1	3
< -3.99	Extreme drought	1	2

Integrated approaches towards modelling of post-planting mortality are rare (Zwolinski et *al*. 1994) and some do not include weather (Payandeh and Sutton 1989). In the southern United States, several attempts have been made to relate seedling mortality to climatological factors (Barnet et a/. 1984; Clealand and Johnson 1986; McKinley et a/. 1988). The following study was conducted to determine how much variation in post-planting survival of loblolly pine (*Pinus taeda* L.) can be attributed to PDSI.

METHODS

First-year survival records were obtained for 9 planting seasons (1983/84 to 1991/92). Data from the mid-South (Alabama, Mississippi and Tennessee) included survival figures from 690 locations. In east Texas, survival data were obtained from 3570 sites. The observations were stratified by planting year and month, and the following climatic division: Northern Valley and Upper Plains in Alabama, North Central, Northeast, Central and East Central in Mississippi, Middle and Western in Tennessee, East Texas and Upper Coast in Texas. PDSI values were obtained (via internet) from the National Climatic Data Center in Asheville, NC, for each of the climatic divisions and for each month from 1886 to 1994. PDSI means were calculated for the planting month and for 1 to 12 consecutive months after planting. The planting month index value and the 12 mean index values were allocated to each of the survival observations. For each region, linear regression was used to study the relationship between mean annual survival (response variable) and mean PDSI (explanatory variable) over the period extending from 0 to 12 months after planting. The "best' models were selected using maximum coefficient of determination (R^2) as a criterion (SAS 1985).

RESULTS AND DISCUSSION

A summary of the survival data for specific planting seasons is provided in table 2. This data shows lower overall survival of trees planted in east Texas (63%) as compared to the mid-South region (78%). The data also show that survival of 90 percent and higher could be achieved for any of the regions and planting seasons. After preliminary screening, quadratic functions were deemed most appropriate for the mid-South region and simple linear regressions for east Texas. Comparison of the regressions for sequential analysis showed that the best fit was defined for the mean PDSI which included the index value on planting month plus 6 consecutive months (Table 3). The equation for the mid-South region was: survival=85.66 + 3.38 (PDSI) - 1.80(PDSI)^2 ($n=9; R^2=0.73; p=0.02$). The equation for east Texas was: survival=60.71 + 3.49 (PDSI) ($n=9; R^2=0.71; p=0.004$).

These results suggest that the general relationship between PDSI and survival is not unique for different regions in the South. With a mean PDSI of -1 .OO (mild drought) during 6 months after planting the expected survival is 80 percent for the mid-South and 57 percent for east Texas. This difference may result from other factors such as site quality or seedling morphology, planting methods, or genetic attributes of planting stock (McKinley et *al*. 1988; Tuttle et a/. 1988; Valigura and Messina 1994). Another factor that may help to explain the lowe survival in Texas may be a difference between reforestation on industrial land and non-industrial private forestland. The survival data obtained from east Texas were from non-industrial private forestland while those obtained from the mid-South were for industrial Plantings. In general, industrial plantings probably receive more intensive site preparation since many non-industrial landowners are reluctant to spend much money for this practice. These variables will be important when predicting survival for an individual planting chance. For example, the PDSI accounts for only 4 to 8 percent of the variation in survival when all data points ($n \geq 681$) are used.

Table 2-Survival percentage (pct) and mean PDSI for February to August period, obtained from mid-South (AL, MS, TN) and east Texas regions during the years 1983/84 - 1991/92

Region	Planting season	Number of records	Survival (pct)			PDSI
			mean	range	standard deviation	
Mid-South	1983184	50	84	51-100	11.9	2.08
Mid-South	1984185	46	83	59- 99	10.9	-0.13
Mid-South	1985186	42	74	23- 97	19.8	-1.64
Mid-South	1986187	84	81	30-l 00	17.1	-1.32
Mid-South	1987188	124	69	13- 98	19.4	-2.15
Mid-South	1988189	137	81	27-100	12.7	2.90
Mid-South	1989190	92	77	3-100	15.6	2.53
Mid-South	1990191	68	86	50-l 00	10.2	2.76
Mid-South	1991192	47	87	58- 97	8.7	-0.40
Texas	1983184	363	57	o-1 00	26.7	-1.14
Texas	1984185	22	57	19- 90	17.8	-0.97
Texas	1985186	467	64	o-1 00	22.4	0.32
Texas	1986187	379	56	O-100	24.8	0.11
Texas	1987188	454	56	o-1 00	25.8	-1.49
Texas	1988189	411	75	O-l 00	18.1	1.61
Texas	1989190	483	62	4-100	21.5	1.39
Texas	1990191	471	68	o-1 00	22.8	2.72
Texas	1991192	520	72	0- l00	21.6	3.61

Table 3--Coefficient of determination (R^2) and significance of the regression (p) in the relationship between survival and Palmer Drought Severity Index defined for the planting month or a number of months following planting, separately for the mid-South and east Texas regions

Months after olantina	-Mid-South-		-East Texas-	
	R^2	p	R^2	p
0	0.61	0.058	0.34	0.102
1	0.64	0.047	0.40	0.066
2	0.62	0.053	0.50	0.033
3	0.56	0.083	0.59	0.016
4	0.62	0.054	0.66	0.008
5	0.71	0.025	0.71	0.005
6	0.73	0.020	0.71	0.004
7	0.66	0.041	0.69	0.006
8	0.54	0.097	0.64	0.010
9	0.41	0.202	0.59	0.016
10	0.29	0.360	0.55	0.022
11	0.20	0.522	0.54	0.025
12	0.12	0.668	0.54	0.025

Over the past century, the chance of a moderate to extreme drought (mean annual PDSI value for February to August period of less than -1.99) has been about 12 to 15 percent (Table 1). In Alabama, about nine droughts occurred within the 60-year period from 1895 to 1955. Similar droughts have not occurred during the last 4 decades. The worst February-August period since 1954 was in 1986 (PDSI=-1.91). In east Texas, droughts (PDSI<-1.99) have occured during 2 periods (Figure 1). From 1902 to 1925, there were 6 droughts followed by 25 years of relatively moderate rainfall. However, 9 drought years occurred during a 20-year period from 1951 to 1971. This was followed by 23 years of moderate climate.

Both Texas and Alabama have been fortunate in that no droughts (PDSI<-1.99) have occurred during years when more than 25,000 ha of land were planted (Figure 2). When another cycle of droughts occurs in the future, this may be the first time that droughts occur simultaneously with high planting rates. This could result in economic loss if regeneration managers fail to adopt better regeneration techniques.

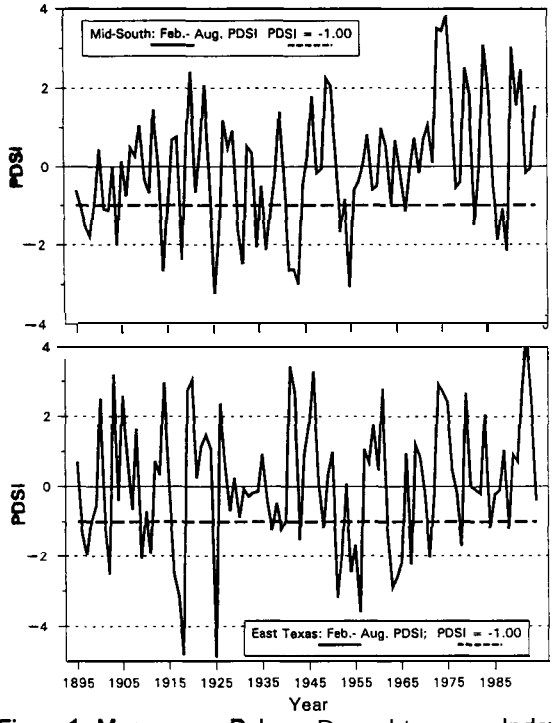

Figure 1--Mean annual Palmer Drought Severity Index for the months February-August, for the mid-South (top) and east Texas (bottom) regions of the southern United States during the years 18951994 (When PDSI is lower than -1 .OO then predicted mean annual survival is less than 80% and 57% for the mid-South and east Texas regions, respectively).

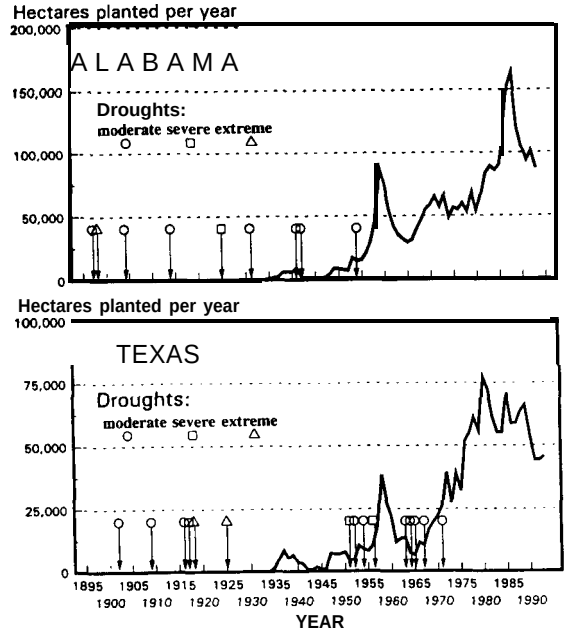

Figure 2-Planting rates for Alabama and Texas in comparison to dates of moderate (PDSI<-1.99), seven (PDSI<-2.99) and extreme (PDSI<-3.99) droughts.

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PLANTING PRODUCTION RATE, SURVIVAL, AND GROWTH OF BARE-ROOT OAK AND LOBLOLLY PINE SEEDLINGS SUBJECTED TO VARIOUS ROOT-HANDLING TREATMENTS'

Kirk D. Howell and Timothy B. Harrington[2]

Abstract-Regeneration efficiency is defined as an optimal balance between regeneration costs and seedling performance. In order to improve regeneration efficiency, root handling treatments (trimming, balling, and dug-hole planting) were applied to bare-root northern red and cherrybark oaks (from various nursery densities) and loblolly pine seedlings. Results Indicate that seedling weight of oak declined wlth high bed density, thereby increasing load-bearing potential for a planting technician. Planting production rate using the dug-hole method was 3 to 5 times that of the other treatments. Survival and first-year growth of pine was greater for the dug-hole method than for the other treatments.

INTRODUCTION

Artificial regeneration technology strives to minimize regeneration costs and maximize seedling performance - regeneration efficiency. An "ideotype" has been used to denote the "ideal" seedling (Mexal and South 1991); however, ideal seedling characteristics will vary according to user objectives. For example, a planter paid according to production rate desires small, easily planted seedlings; whereas, land managers stress seedling performance and often prefer large seedlings (South and Mexal 1984). Therefore, determining the ideotype in order to improve regeneration efficiency (the balance between competing objectives) becomes a necessary reality facing today's regeneration forester.

Commercial oak species of the southern U.S., such as cherrybark (*Quercus falcata* var. *pagodaefolia* Ell.) and northern red oaks (Q. *rubra* L.), are typically regenerated naturally through application of the shelterwood system (Loftis 1990). Artificial regeneration (i.e., planting) of oak is seldom considered because adequate seedling performance in the field is difficult to obtain (Boyette 1980). In addition, nursery technology of oak has yet to produce affordable stock that is easily planted and demonstrates strong seedling performance.

Over 1.2 billion seedlings of pine are planted each year in the southern U.S. (Duryea and Dougherty 1991). This massive reforestation effort has been successful because of past (Wakeley 1954) and more recent (Mexal and South 1991) technological improvements in seedling culture, transport, and planting. However, while research has proven that large seedlings sown at low bed densities improve seedling performance (South 1992), little research has attempted to evaluate the effects of root-handling (e.g. trimming and "balling" or root deformation) with respect to regeneration efficiency of loblolly pine (*Pinus taeda* L.).

OBJECTIVES

The objective of this study was to refine treatments which affect the components of regeneration efficiency, specifically:

1. minimization of regeneration costs, expressed as:
   a. quantity of seedlings carried per planting technician load.
   b. rate of planting.
2. maximization of seedling performance, expressed as:
   a. percent survival.
   b. incremental and total growth.

METHODS

Three species were tested in this study: cherrybark oak, northern red oak, and loblolly pine.

In December 1992, oak seeds were sown at densities of 100, 169, 256, 400, and 529 per m^2 in a tilled nursery bed at Whitehall Forest, University of Georgia, Athens, GA. In November 1993, seedlings were carefully lifted, undercut at a 30 cm point from the root

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collar, and placed in cold storage. In December 1993, northern red oak seedlings were planted on a site of about 100 ft^2 BA at Bent Creek Experimental Forest, Asheville, NC.; cherrybark oak seedlings were planted on a site of about 40 ft^2 BA managed by T&S Hardwoods, Inc., Milledgeville, GA.; and loblolly pine were planted on a clearcut site at Whitehall Forest, University of Georgia, Athens, GA.

Root-handling treatments were applied in the field at the time of planting to randomly selected seedlings as follows:
a) light pruning' (trimmed at the wispy/woody transition[2])
b) heavy pruning (trimmed to 9 cm from the root collar)
c) no pruning, balling (untrimmed with root deformation)
d) no pruning, no balling (untrimmed with no root deformation).

The experimental design for the oak study is a randomized complete block design, where seedlings from each of the 5 bed densities were subjected to 3 root-handling treatments with 4 replications per treatment and 4 seedlings per replication.

For the pine, seedlings were obtained from a typical bed density of 256 seedlings per m^2 (J. Brannan, Georgia Forestry Commission, Macon, GA, personal communication). A completely randomized design was used in which seedlings were subjected to 4 root-handling treatments with 10 replications per treatment and 10 seedlings per replication.

MEASUREMENTS

In order to determine the quantity of seedlings which can be practically carried into the field, an arbitrary value of 15 kg was set. This value was determined by calculating the average weight of 1000 loblolly pine seedlings. Weights (g/seedling) of 5 randomly selected oak, from each density, and 10 pine seedlings were measured to determine the quantity of seedlings carried. Planting rate (seconds per seedling) was measured during outplanting. Height (cm) and diameter (mm) measurements were taken at the time of planting (December 1993), and at the end of the following growing season (October 1994).

RESEARCHHYPOTHESES

Null hypotheses are that planting production rate, survival, and growth do not vary significantly (α=0.05) with:
- nursery bed density (for oak seedlings).
- root-handling treatments (for oak and pine seedlings).

Analysis of variance was used to test these null hypotheses, and a protected LSD test was used for pair-wise comparison of means.

RESULTS AND DISCUSSION

Quantity of seedlings per planting load (15 kg) increased with bed density of the oaks (Figure 1). The overall trend of data has a positive slope. This relationship suggests that smaller seedlings (sown at higher bed densities) will be lighter in weight, and thus allowing more seedlings to be carried per load.

Planting rate did not diier significantly ($p>0.05$) among bed densities for oak. However, planting rate by treatment (Figure 2) showed the dug-hole planting treatment to be the slowest method of planting, in that it took 3 times as long to plant for oak, and 5 times as long for pine, than the other planting treatments.

Survival, diameter and height did not diier significantly ($p>0.05$) among bed densities for oak. However, overall survival of northern red oak (98 percent) was better than that of cherrybark oak (64 percent), while surviving cherrybark oak seedlings were larger than those of northern red oak.

The root-handling treatments had no significant effects ($p>0.05$) on survival (Figure 3), diameter (Figure 4), and height (Figure 5) of each oak species.

Loblolly pine survival (Figure 3) did not diier significantly ($p>0.05$) among root-handling treatments, although treatment differences were similar to those observed for seedling size. Diameter and height of loblolly pine (Figure 4 and 5, respectively) were significantly ($p<0.05$) greater following the dug-hole method than for any of the other treatments.

SILVICULTURAL IMPLICATIONS

Since seedling performance did not diier among densities or treatments for the oaks, our results suggest that regeneration efficiency is maximized by:
- selecting seedlings sown at higher densities (small seedlings).
- using faster planting methods -- root pruning or balling.

Although the root-handling treatments did influence pine survival and size, the performance increase of the dug-hole method probably will not justify its much slower planting rate, and thus higher regeneration

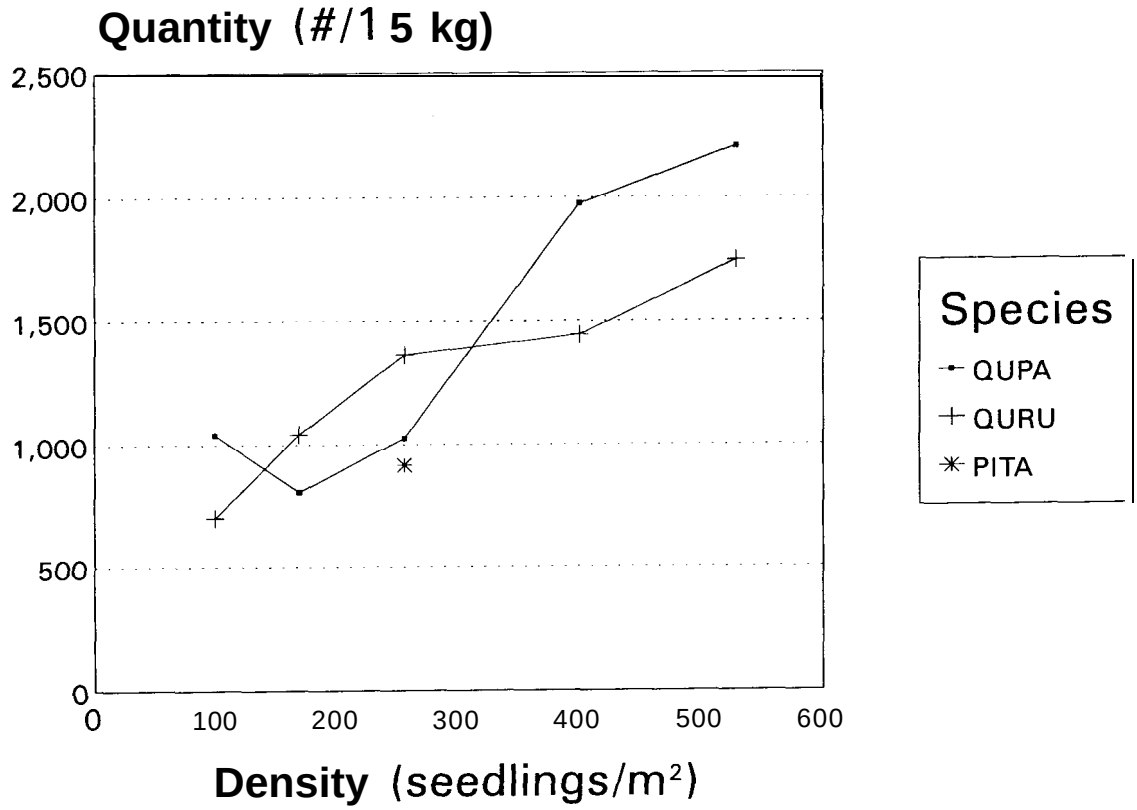

Figure l-Relationships of quantity of cherrybark oak (QUPA), northern red oak (QURU), and loblolly pine (PITA) seedlings equal to an arbitrary weight of 15 kg versus nursery bed density.

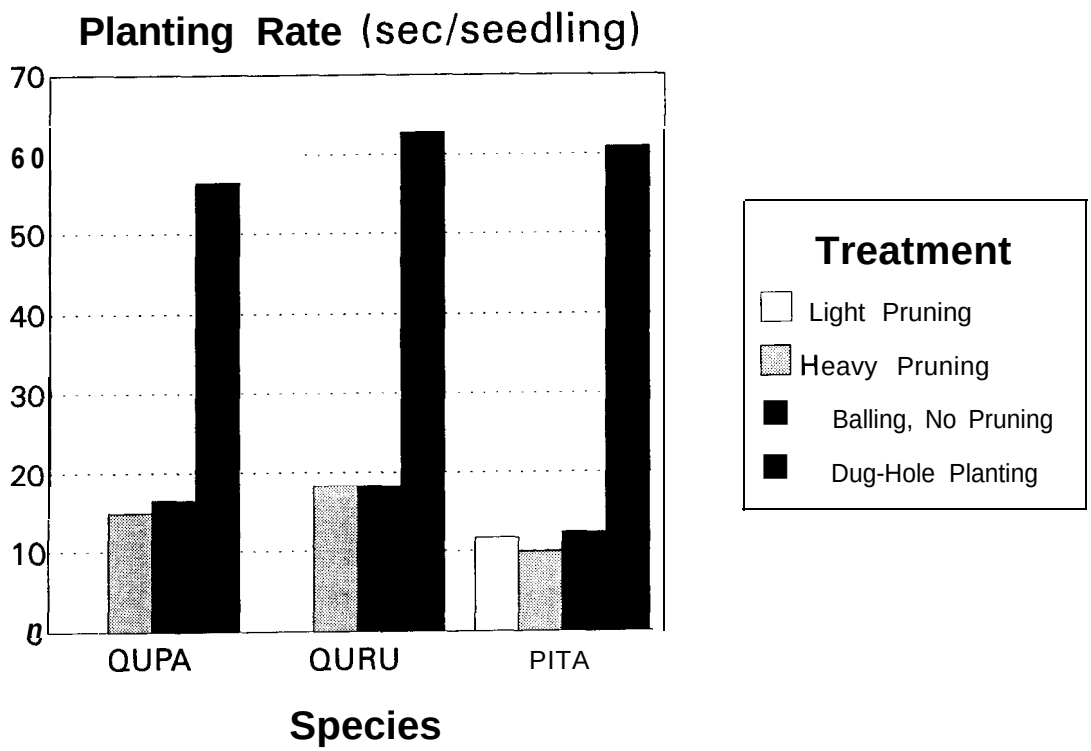

Figure 2-Planting rate of cherrybark oak (QUPA), northern red oak (QURU), and loblolly pine (PITA) seedlings by root-handling treatment.

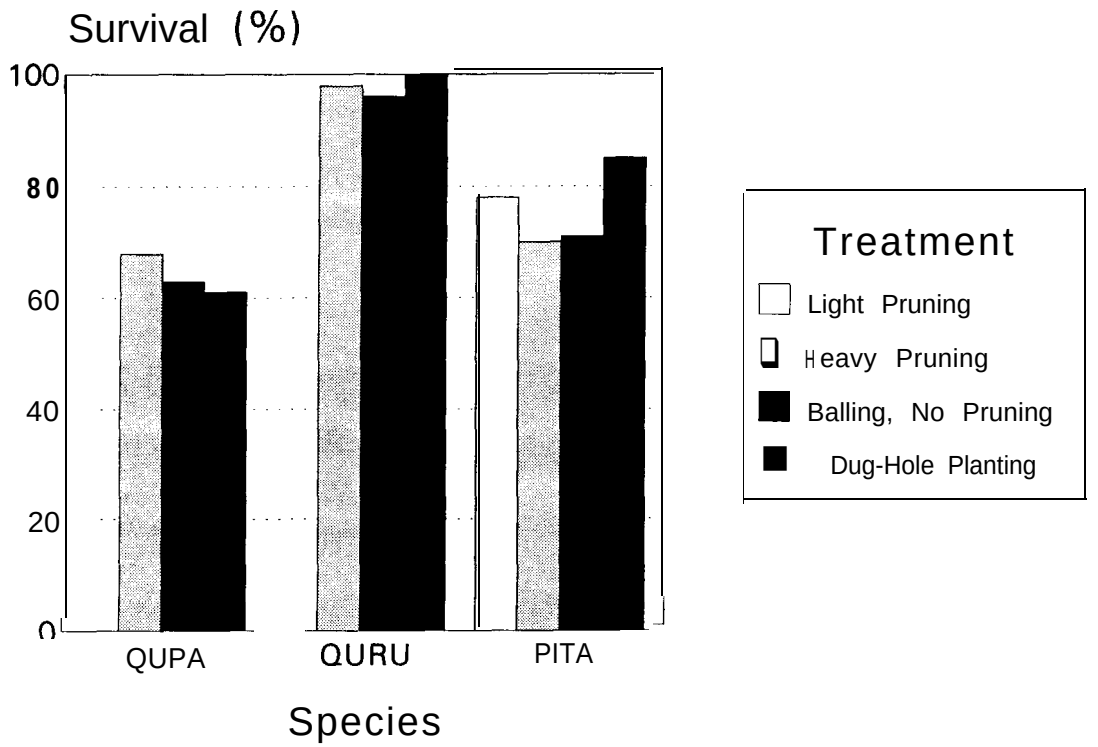

Figure 3-First-year survival of cherrybark oak (QUPA), northern red oak (QURU), and loblolly pine (PITA) seedlings by root-handling treatment.

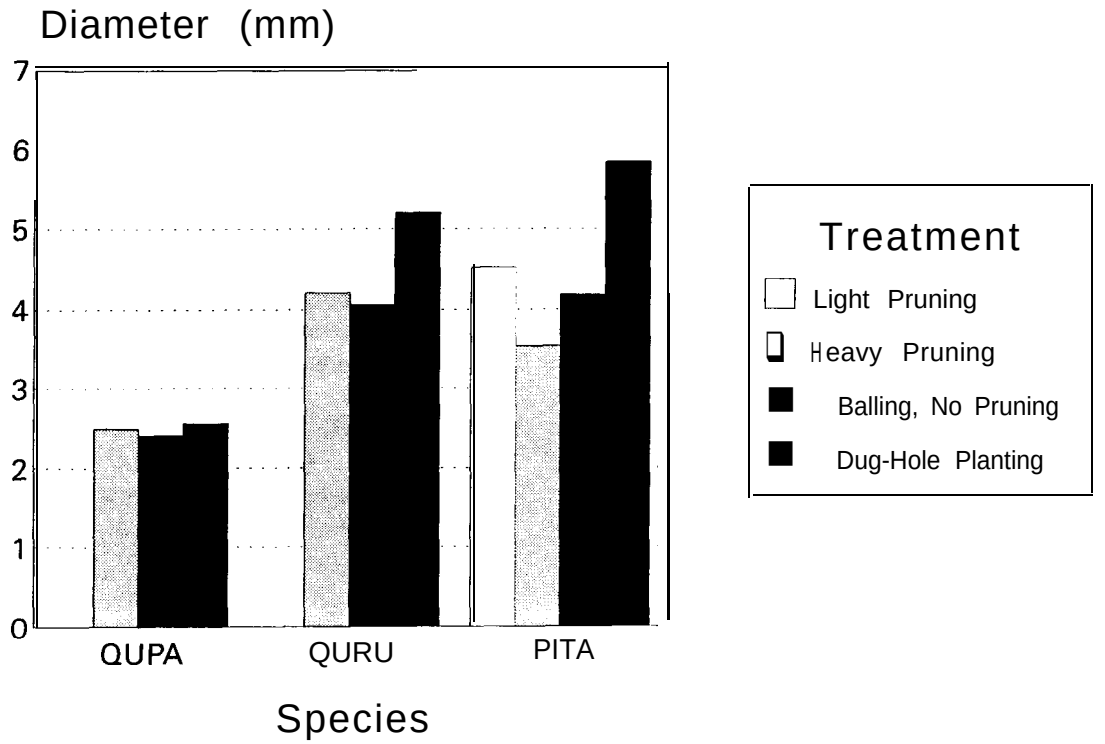

Figure 4-First-year diameter of cherrybark oak (QUPA), northern red oak (QURU), and loblolly pine (PITA) seedlings by root-handling treatment.

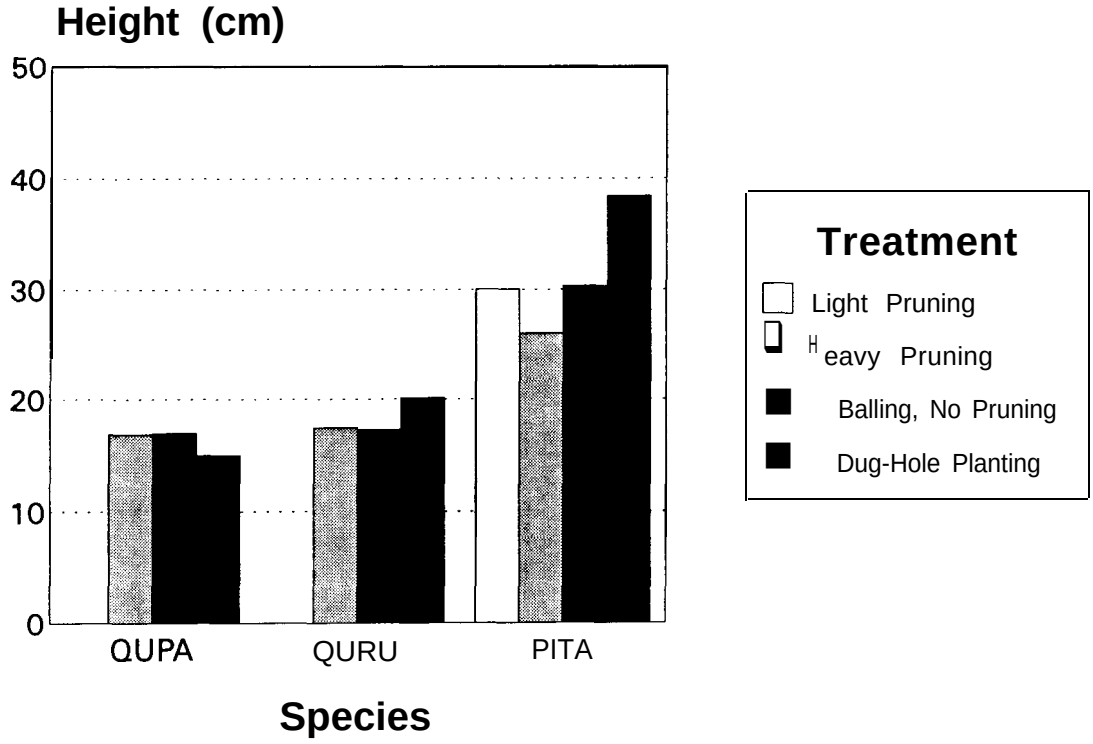

Figure 5-First-year height of cherrybark oak (QUPA), northern red oak (QURU), and loblolly pine (PITA) seedlings by root-handling treatment.

costs. Therefore, the planting method of lowest cost and highest performance (light pruning) is preferable.

CONCLUSION

It is no simple problem for today's forester to balance the two competing objectives of regeneration efficiency. Either the improvement in seedling performance without respect to regeneration costs, or reduction in costs without improvement in performance, may be easier to accomplish, but how great will be the realized benefits? Maximization of regeneration efficiency requires that the opposing components be considered with respect to the other, and that a balance can be found that is suitable for field application.

ACKNOWLEDGEMENT

The authors are grateful to the following organizations for their advice and in-kind assistance: USDA Forest Service, Southeastern Forest Experimental Station, Ashville, NC.; T&S Hardwoods, Inc., Milledgeville, GA.; Georgia Forestry Commission, Macon, GA.; Daniel B. Warnell, School of Forest Resources, University of Georgia, Athens, GA.; Louisiana Forest Seed Company, LeCompte, IA.; and Hicks Seed Company, Willow Springs, MO.

ENDNOTES

[1] The light pruning treatment was applied to loblolly pine only.

[2] The wispy/woody transition is the approximate point at which the diameter of the seedling's taproot equals 1 mm.

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BALDCYPRESS SEEDLINGS FOR PLANTING IN FLOODED SITES'

William H. Connef

Abstract-The push for wetland restoration to replace losses or mitigate disturbance requires that successful planting techniques be developed. Planting tree seedlings in wetlands generally occurs during the winter dormant season while the wetland may be flooded with several cm of water. The idea of pruning lateral roots from seedlings so that they can be planted by simply grasping the seedling at the root collar and pushing them into the soil was tested in this study. Pruned and unpruned seedlings were underplanted in two wetland forests and in six inch pots subjected to either permanent flooding or daily watering. Samples were collected at 0, 2, 4, 6, and 12 months to determine differences in height growth and in stem and root biomass. Potted seedlings grew better than underplanted seedlings, with daily watered seedlings showing slightly greater growth than permanently flooded seedlings. Underplanted seedlings grew least, and this may be a result of less light reaching the seedlings under a full canopy. Within each growing environment, there was no significant difference between pruned and unpruned seedlings in terms of final biomass values. Overall, pruned seedlings represent a fast and easy method of planting baldcypress seedlings in wet areas.

INTRODUCTION

The continued existence of forested wetlands is dependent upon the ability of the tree species to replace themselves through time. Normally, this is accomplished through seedling establishment via seed, but recent studies have shown that natural regeneration is limited due to water level changes in these forests (Sharitz and Lee 1985, Conner et al. 1986). Therefore, it is often necessary to plant seedlings in wetlands to ensure adequate stocking.

Baldcypress (*Taxodium distichum* (L.) Rich.) is very tolerant of flooded conditions (Hook 1984) and is ideally suited for planting in areas subject to prolonged flooding. Planting in standing water with dibbles or shovels, however, is difficult and time consuming. Using these tools, a hole must be opened in soft, often unconsolidated, mud and the root ball inserted to the proper depth and with the roots spread out naturally. Soil must then be firmly packed around the roots. All of this must be accomplished usually without being able to see the hole or the root mass under water. Conner and Flynn (1989) reported on a method for planting baldcypress seedlings whereby tap and lateral roots were trimmed and the seedling was simply pushed into the soil. Survival of these seedlings was 70% after three growing seasons. Unfortunately, there was no comparison made with unpruned seedlings to determine whether this method was better or worse than normal planting techniques. The objective of this experiment was to examine the growth, survival, and root development of pruned versus non-pruned baldcypress seedlings grown under flooded and watered conditions.

METHODS

One-year-old baldcypress seedlings were obtained from the South Carolina Forestry Commission in March 1992. Average height and diameter of the seedlings were 67 (±12) cm and 7.9 (i1.6) mm, respectively. On the day of planting, 288 seedlings were divided into 2 groups. The lateral roots of one group of seedlings were pruned to approximately 2.5 cm and the taproot pruned to 20 cm using anvil style garden clippers. The second group was left unpruned. Groups of 24 seedlings were assigned to one of six treatments: 1) pruned-flooded, 2) pruned-watered, 3) pruned-swamp, 4) unpruned-flooded, 5) unpruned-watered, or 6)unpruned-swamp. Each treatment was replicated once.

Flooded and watered seedlings were grown in 15 cm diameter by 20 cm high plastic pots filled with a mixture of 3 parts composted bark:1 part sand and a slow release fertilizer (Osmocote 14-14-14). Flooded treatment seedlings were placed in plastic pools 1.5 m wide and 30 cm deep. Water was added to the pool daily to maintain a constant water level approximately 10 cm above the soil surface of the potted seedlings. The water was completely replaced once a week to keep it from becoming stagnant. Watered seedlings were placed under a sprinkler system set to water once a day for 1 hour. Flooded and watered seedlings were grown under 30% reduction shadecloth. Swamp

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seedlings were underplanted in two baldcypress/water tupelo (*Nyssa aquatica* L.) wetlands on Hobcaw Barony near Georgetown, SC. Water levels in the two swamps were approximately 30 cm at time of planting and remained at that level during the course of the study.

Pruned seedlings were planted by holding the seedling at the root collar and pushing them into the soil of pots or natural wetland. Unpruned plants were planted in the pots by pouring the soil mixture around the root mass and with a shovel in the natural wetland. Eight seedlings (4/replication) were harvested at 0, 2, 4, 6, and 12 months. Heights were recorded, and the seedlings were separated into root, stem, and leaf components, dried to a constant weight, and weighed.

Height and biomass data were subjected to analysis of variance (ANOVA) and where treatment and location effects were significant, differences between means were tested using Fisher's Protected LSD (a = 0.05).

RESULTS AND DISCUSSION

Analysis of variance of mean height and biomass values after 12 months showed that each growing environment differed significantly (a = 0.05) in the following order (Figure 1): watered > flooded > underplanted. Within each growing environment, however, there was no significant difference between pruned and unpruned seedling values. Unpruned seedlings generally had slightly higher values than pruned seedlings, but this may not be significant in the long-term.

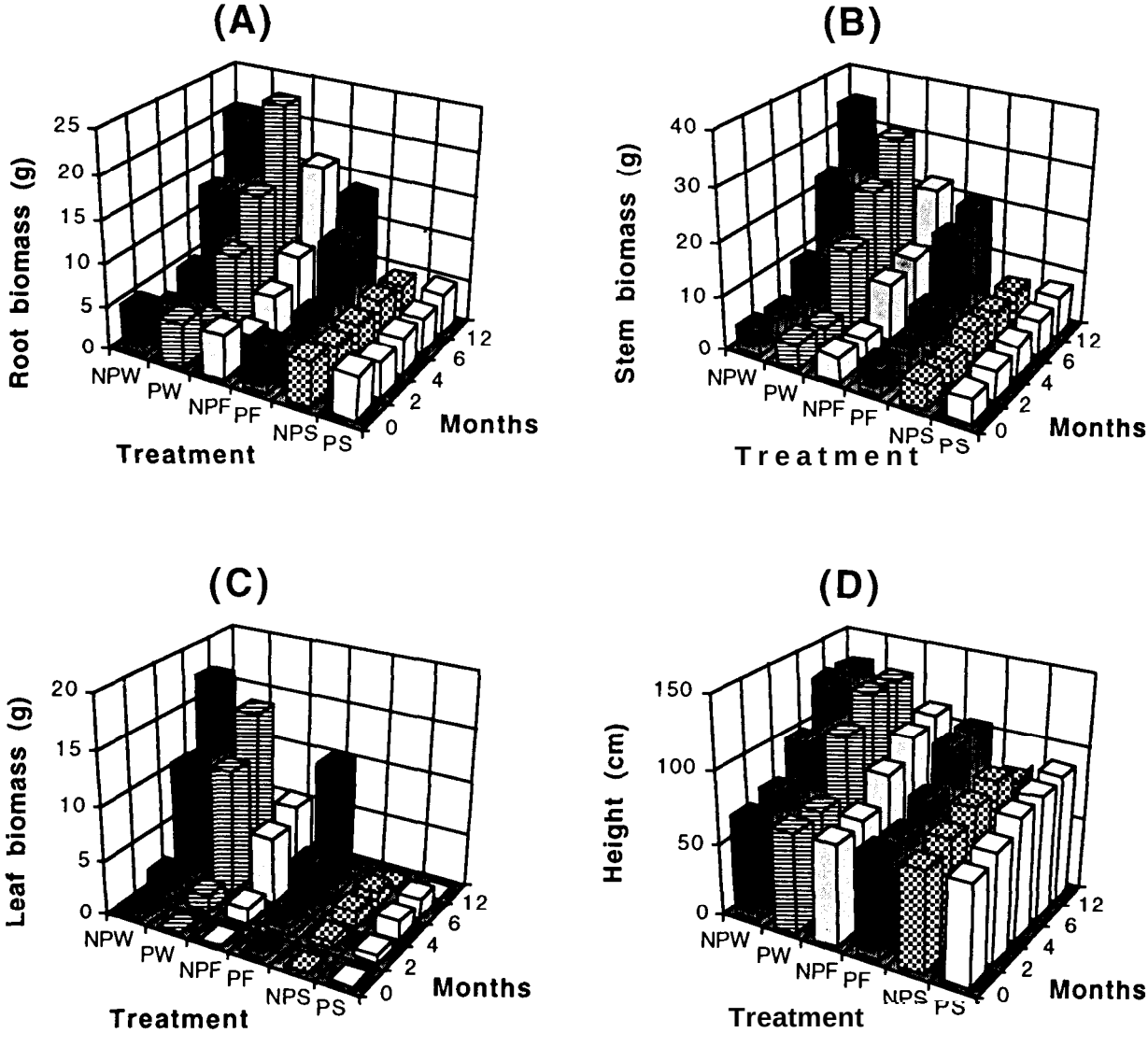

Figure l-Change in root biomass (A), stem biomass (B), leaf biomass (C), and height (D) for baldcypress seedlings during their first year of growth. P = root pruned, NP = unpruned, W = watered, F = flooded, S = swamp.

Baldcypress grows best under well-drained, moist conditions with plenty of light (Kennedy 1972, Williston et al. 1980, Chambers et al. 1987), and thii held true for both pruned and unpruned seedlings in this study. Pruning seemed to stimulate root growth of watered seedlings (Figure 1A) so that from month 4 to month 12, root biomass was slightly greater for pruned seedlings. Blake (1983) found that root pruning as much as 75% of the root area of white spruce (*Picea glauca* (Moench) Voss) had no effect on root area after 6 weeks, indicating that pruning substantially stimulated new root growth. At 4 months, stem biomass and height of watered-pruned seedlings were also greater than unpruned seedlings, but this did not last (Figure 1 B, D). Leaf biomass of watered seedlings increased rapidly (Fig. 1C) with little difference between pruned and unpruned seedlings. Since growth is a function of leaf area and net assimilation rate, Ledig and Perry (1969) suggest that an early and rapid increase in leaf area is important for increasing overall growth. Average heights of watered seedlings after 12 months were 131 cm (52 in) for unpruned and 128 cm (50 in) for pruned seedlings (Fig. 1 D).

Flooded baldcypress seedling had lower root, stem, and leaf biomass and increased in height less than watered seedlings (Fig. 1). As with watered seedlings, there were no significant differences between pruned and unpruned seedlings. Pruned seedlings were slightly lower in biomass and height. Only at month 6 did pruned seedlings exhibit higher root, stem, and leaf biomass (Fig. IA-C). Flooding of baldcypress seedlings can cause sharp decreases in photosynthetic rate (Pezeshki 1990) which would reduce growth of above- and belowground parts. This species has also been shown to produce new leaves once subjected to flooding that have improved conductance and greater capacity for photosynthesis (Pezeshki et al. 1986) which would lessen long-term effects of flooding. Final heights were 111 cm for unpruned seedlings and 105 cm for pruned seedlings.

Underplanted baldcypress seedlings grew the least in the study with almost no differences in biomass and height between pruned and unpruned seedlings and very little difference between beginning and end values. Pruned seedlings did exhibit slightly higher root and stem biomass at the end of 12 months and attained a height of 88 cm as compared to 80 cm for unpruned seedlings. Shading was probably the limiting factor to growth of underplanted seedlings. Both stands were relatively undisturbed baldcypress/water tupelo forests. During the peak of the growing season, only 4-9% of available sunlight reached the forest floors. Baldcypress is classed as intermediatety tolerant to shade, but grows best under full sunlight (Wenger 1984, Wilhite and Toliver 1990). In a Louisiana swamp, Conner and Flynn (1989) found that underplanted baldcypress grew well under flooded conditions if the canopy was open and sunlight reached the forest floor. In that two year study, shaded seedlings grew only 16 cm as compared to 47 cm in an open area. Conner (1993) found that the height growth of underplanted baldcypress seedlings growing under 58% versus 38% available sunlight was 8 cm greater during the first year and 22 cm greater the second year.

CONCLUSIONS

One-year-old baldcypress planting stock can be root pruned, thus making it easier to plant under flooded conditions. Root pruning does not seem to significantly affect growth, and in some cases may stimulate root growth which could be beneficial in the long run. With enough sunlight, pruned baldcypress seedlings could be used to revegetate disturbed swamp areas where natural regeneration has not occurred. The impacts of root pruning on long-term survival and growth are unknown and require further study.

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EVALUATING POTENTIAL OAK AND ASH REGENERATION ON MINOR BOTTOMS IN THE SOUTHEAST'

Christopher P. Hart, John D. Hodges, Keith Belli, and John Stanturf[2]

Abstract-The natural regeneration of oaks (*Quercus spp.*) on high quality productive sites is often difficult and failures are not uncommon even when the parent stand contains a large component of oak. in order for natural oak regemeration to be successful suitable advanced reproduction must be present before a final harvest cut is conducted. The objective of this study was to operationally evaluate, and modify if needed, a technique developed by R.L. Johnson which determines the adequacy of advanced hardwood regeneration. Specifically, this work tested the oak and ash (Fraxinus spp.) portion of Johnson's system. The results indiite that Johnson's system worked well for oak, with only a slight modification for advanced oak seedlings <1 ft tail. The results indicate that these seedlings should receive iesa credit than Johnson's system gave them. The results for ash indicate that Johnson's system may be too restrictive and that ash seedlings >1ft should receive more points than Johnson's system assigns to them.

INTRODUCTION

Regenerating oaks in hardwood stands following harvest cuts is often difficult. The percentage of oaks in the newly regenerating stand is frequently far less than what was present in the previous stand (Beck and Hooper 1986, Loftis 1988). Failure to regenerate red oak has been documented in both experimental and operational clearcuts (Beck and Hooper 1986, Loftis 1988, Johnson 1979, Kennedy 1989).

The problem of regenerating oaks is most evident on productive sites (Loftis 1988, Beck and Hopper 1986). Attempts to regenerate oaks on productive bottomlands have met with varying degrees of success, ranging from satisfactory numbers of oak being regenerated to almost the complete absence of oak in the new stand. Sander et al. (1976), Loftis (1982), Hodges (1987), Johnson (1979), and Beck (1970) have determined that advanced regeneration of oaks must be present in order to maintain oak in the new stand. Research has consistently shown that the amount of oak in the new stand depends directly upon advanced reproduction and stump sprouts.

Large advanced reproduction is the most reliable source for providing competitive stems in the new stand on high qualii sites (Loftis 1988, Sander 1972). Beck (1970) and Sander (1972) found that while some new seedlings may become established from seed following harvest, their inabilii to compete with already established fast growing competing vegetation renders them insignificant in the next stand.

Numbers and sizes of advanced reproduction combined with stump sprout potential have been incorporated into several systems in order to predict the potential oak regeneration of a stand. The rationale behind these evaluation systems has generally been that satisfactory oak reproduction will be achieved if the preharvest inventory of regeneration potential meets some minimum requirements, and the stand is harvested by a complete overstory removal and felling of all residual stems down to one or two inches dbh. Guidelines for evaluating the adequacy of oak regeneration can be applied based on oak site index. On upland sites a site index of 70 (base age 50) is often used, with sites falling below this level being classified as medium or low quality, less productive sites, and sites exceeding this level classified as highly productive sites. On bottomland sites a site index of 80 (base age 50) is more appropriate for a separation of site quality. The classification of sites using site index criterion is based on the fact that oak regeneration on lower quality sites has not been difficult (Johnson 1979, Clark 1970, Minckler and Jensen 1959). The large amount of competing vegetation present on productive uplands and bottomlands has made oak regeneration substantially more difficult, and thus it requires a different set of criteria for evaluation.

Guidelines for evaluating the adequacy of advanced reproduction on highly productive sites have been developed by Loftis (1970, 1982, 1988, 1990) and Johnson (1980). Loftis' work *on* productive upland sites in the southern Appalachians (site index 67 to 90,

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base age 50 for red oak) provides a set of probabilities that allows the silviculturist to predict, based on the given extant population of advanced oak regeneration, the number of stems that may attain a favorable competitive position in a new stand.

The only model designed to evaluate oak regeneration in the highly productive bottomlands of the South is that by Johnson (1980). Johnson cautions, though, that his system is preliminary and that more testing is needed prior to broad application of its use. Johnson's system makes use of 1/100th acre plots (radius 11.8 feet) in which all stems which may contribute to reproduction of the next stand are measured and tallied. Johnson's system then applies points to the various components based on the likelihood of contributing to the next stand. The primary objective of this research was to evaluate Johnson's technique as it applies to the oak and ash component of bottomland stands and test modifications which may make it more reliable.

METHODS

The stands to be evaluated were located in minor bottoms across the state of Mississippi. The minor bottom site type locations included seven areas on the Noxubee National Wildlife Refuge and one area on Scott Paper Company land in Wayne county, Mississippi, west of Waynesboro. The minor bottom site type is characterized by somewhat poorly drained soils on flood plains with moderate to slow permeability and medium to very high available water capacity. Slopes average zero to two percent and seldom exceed five percent. Soil texture ranges from silt loam to silty clay loam to silty clay. The soils are acid to very strongly acid with pH ranging from 5.3 to 4.5. The sites were subject to brief periods of flooding each year, mostly in the winter and early spring before the growing season. Site index (base age 50) for the red oaks occurring on the minor bottom site type has been estimated at 94-97 feet (USDA 1973, 1986).

All plots were established on a 2 X 2 or 2 X 3 chain grid to cover stand conditions from a known starting point. Plots were 1/100th acre in size with a radius of 11.8 feet. This plot size was used to coincide with Johnson's (1980) regeneration evaluation technique. At least 10 plots were installed per study site, depending on the size of the study area, for a total of 114 plots on the eight study areas. A 100 foot buffer was maintained from the border of the study area on all sites.

The basal area of trees greater than 4.5 inches dbh was determined with a 10 factor prism in order to characterize the parent stand. Up to three individuals corresponding to each size category from Johnson's system were selected and marked for permanent remeasure. During the preharvest inventory height was recorded to the nearest 1 .0 inch and the basal stem diameter was recorded. All oak and ash seedlings which were not marked for permanent remeasurement were banded with 3/4 inch diameter color-coded plastic rings according to height class prior to harvest (red bands = seedlings < 1 foot tall, white bands = seedlings 1-3 feet tall, and blue bands = seedlings >3 feet tall).

The regeneration potential of oak and ash was evaluated on each plot using Johnson's (1980) regeneration evaluation technique (Figure 1). Point values were assigned for seedlings in the following manner: one point for seedlings <1 foot tall, two points for seedlings 1-3 feet in height, and three points for seedlings >3 feet tall. For saplings and trees (dbh >1.5 inches) point values were assigned as follows: saplings 1.5 inches - 5.5 inches dbh received 3 points, 5.6 - 10.5 inches dbh trees received 2 points, 10.6 - 15.5 inches dbh trees received 1 point, and trees >15.6 inches dbh received 0 points. These point values are illustrated on Figure 1 which is taken from Johnson 1980. This study was designed to evaluate only the oak and ash segment of Johnson's system which corresponds to rows l-8 on Table 1.

A plot that received a total of 12 points from any combination of regeneration sources was considered to be adequately stocked using Johnson's technique. A good distribution of adequately stocked plots is required for successful regeneration.

Harvest of all study areas was conducted mid-summer through fall (July-October) of 1989 and 1990. With the exception of two areas on the Noxubee Wildlife Refuge where seed trees were left, all merchantable timber was harvested. Residual trees and saplings down to a size of 1.5 inches dbh were also felled either during the harvest operation or soon thereafter. In the plots, any remaining stems greater than 1.5 inches dbh and any stems within a distance of two times the stems' height were also removed.

Annual plot remeasurement was conducted at the end of the first, second, third, and fourth (where applicable) growing seasons following harvest. Measurements were taken between August 1 and November 1 of each year. Height and root collar measurements were taken for all oak and ash seedlings. A competitive position of overtopped (ot), medium competition (mc), or free to grow (ftg) for all desirable seedlings was recorded. Stump sprouts of desirable species were recorded as to origin, and the largest sprout was measured for height, root collar diameter, and competitive position. The presence of any new germinants of desirable species was also recorded.

The proportions of surviving oak and ash seedlings one year after harvest were calculated for each preharvest seedling height class. The proportion of oak and ash stumps reproducing a living sprout, one year after

Date _____
Plot Number _____
Location _____

REPRODUCTION INVENTORY

Circular 1/1 OO-acre pbt (11.8' radius)

Points per tree and number of trees by species and size class

	Height (feet)						DBH (inches)								
	4.0		1.0-2.9		3.0+		2 3		6-10		11-15		16-20		
Species	Pts.	No.	Pts.	No.	Pts.	No.	Pts.	No.	Pts.	No.	Pts.	No.	Pts.	No.	Total Pts.
Ash	1		2		3		3		3		2		1		
Red Oaks	1		2		3		3		2		1		0		
	1		2		3		3		2		1		0		
	1		2		3		3		2		1		0		
White Oaks	1		2		3		3		2		1		a		
	1		2		3		3		2		1		a		
Hickory	1		2		3		3		3		2		1		
Sweetgum	1		2		3		3		3		2		1		
Blackgum	1		2		3		3		3		2		1		
Elm	1		2		3		33		2		1		0		
Yellow-poplar	1		2		3		3		2		1		0		
Maple	1		2		3		3		2		2		0		
Sugarberry	1		2		3		3		21		1		0		
Persimmon	1		2		3		3		21		1		0		
Other	1		2		3		3		2		1		0		
	1		2		3		3		2		1		0		

Stocked - 12 points or more

Total points this pbt _____

Yellow-poplar or sycamore seed tree within 100 feet +6

Seedbed bare +2

Seedbed weedy -2

Figure 1. Reproduction inventory form.

harvest, was also calculated for each of Johnson's tree dbh size groupings.

The proportion of individuals from each of Johnson's oak and ash regeneration classes that produced a free to grow individual three years after harvest was calculated. The annual growth increment for ftg, mc, and ot trees was determined in order to determine whether seedlings assigned a ftg status actually had a competitive advantage.

In order to test Johnson's model, the number of seedlings a plot would be expected to produce was calculated. This was done individually for each oak and ash component, The number of individuals required to constitute a fully stocked plot of 12 points was multiplied by the probability that an individual from that class would be ftg at the end of year three. Similarly, the probability of a plot producing at least one ftg individual was determined. This was done in order to make sure that any plot which received 12 points had an equal probability of producing 1 ftg individual. Modifications to Johnson's point system were then suggested based on the findings of the study.

RESULTS

The species composition of the parent stands on the study sites was computed as a percentage of basal area. The most frequently occurring species was sweetgum which accounted for 22.4% of the basal area, more than twice the basal area of any other single species. The oaks as a group made up 38.5% of the overstory basal area. Red oak contributed 26.3% of the oak total and the other 12.2% was contributed by whiie oaks. Water oak, Quercus *nigra* L., willow oak, Quercus *phellos* L., and cherrybark oak, *Quercus pagoda* Raf., were the most important oaks comprising 9.2, 7.0 and 7.3% of the total basal area, respectively. The most common white oaks were white, Quercus *alba* L., overcup, Quercus *lyrata* Walter, and swamp chestnut, *Quercus michauxi* Nutti, making up 4.6, 3.7 and 3.3 percent of the total basal area, respectively. Hickories, *Carya* sp. accounted for slightly over 1 0% of total basal area.

The percentage of seedlings from each height class that survived one growing season after overstory removal indicates the ability of diierent sizes of advanced regeneration to withstand the disturbance and change in an environment created by logging. The percent of surviving individuals one year after overstory removal was calculated for each of Johnson's classes of potential advanced regeneration. During the first year, oak seedlings <1ft tall, prior to harvest, had a survival percentage of 23.6% compared to approximately 65% for the I-3ft and >3ft seedlings. The high mortality observed in the first year, 76, 33 and 35% for <1ft, 1-3ft and >3ft oak seedlings, respectively, was largely due to physical logging damage and microenvironment site alternations caused by logging and was not observed in the second or third year following harvest. The highest second year mortality, 11.3%, was observed in the <1ft preharvest oak seedlings. Mortality rates of 4.3 and 6.1 percent occurred the second year after harvest for the 1-3ft and >3ft oak seedlings, respectively. Mortality rates during the third year were less than 1.5% for all oak seedlings.

Ash seedlings exhibited the same trends as did the oak seedlings in overall first year survival. The <1ft seedlings had the lowest survival at 26.1 followed by the 1-3ft seedings which had 79.6% survival and the >3ft seedlings with 90.3% survival. The >3ft ash seedlings exhibited a greater survival rate than the 1-3ft seedlings which was not the case among oak seedlings. The mortality after the first year for all height classes of ash seedlings was low. During the second year following harvest, mortality rates of 16.7 (1 seedling), 2.6 (1 seedling) and 0 percent were observed for the <1ft, 1-3ft and >3ft seedlings respectively. No mortality occurred among ash seedlings during the third year.

The percentage of stumps producing a living sprout were calculated for Johnson's diierent oak and ash tree size categories. Sprouting percentages of 30, 28, 17 and 33 were observed for the 1.5-5.5, 5.6-10.5, 10.6-i 5.5 and >15.5 inch trees respectively. For ash only stumps from 1.5-5.5 inch trees were represented in the study. The ash stumps had a 78.6 percent sprouting rate.

The 30% sprouting rate for oak stumps from trees 1.5 - 5.5 inches dbh is considerably lower than found by Johnson (1975) and Sander (1988). This is probably due primarily to mortality caused by intensive operational logging. During plot measurement it was apparent that stumps from 1.5 - 5.5 dbh trees were more likely to be uprooted or destroyed during logging than larger stumps, however, if the smaller stumps remained intact they had a greater likelihood of sprouting. Thus, the resulting percentage of stumps producing sprouts was very similar for all dbh categories. If only undamaged stumps are considered, the stump sprouting percentage for the 1.5-5.5 and 5.6-l 0.5 inch catagories increases to 40 and 37% respectively. The percentage for ash stumps increases to 85% for stumps from 1.5-5.5 in ash trees.

Based on the species mix and growth habii of the species present on the study locations, it was the authors' determination that those seedlings which have achieved a ftg position in the third year following harvest will be in a position to compete for a codominant or dominant position as the stand develops and trees begin to compete for canopy space. Support for this determination is evidenced by the greater growth increment observed for the ftg seedlings than in the other competitive classes. Growth for ftg oak seedlings in the third growing season averaged 24

Table 1. Percent of oak and ash stems by competitive position three years after overstory removal for each of Johnson's potential regeneration classes

Regeneration Class	N	Mortality	OT	MC	FTG
Oak Seedlinos					
<1ft	239	70.7	12.5	a.4	a.4
I - 3 R	159	44.6	14.5	14.5	26.4
>3ft	122	49.2	4.9	7.4	38.5
Oak Stumps					
1.5 - 5.5	37	70.3	0	0	29.7
5.6 - 10.5	11	32.7	0	0	27.3
10.6 - 15.5	6	83.3	0	0	16.7
>15.5	6	66.7	0	0	33.3
Ash Seedlinos					
<1ft	11	72.7	18.2	0	9.1
I-3R	24	20.7	4.2	a.4	66.7
>3ft	44	18.2	0	15.9	65.9
Ash stumps					
1.5 - 5.5	14	14.3	0	14.3	71.4

inches compared to 16 inches for mc seedlings and 5.5 inches for ot seedlings. Growth of ash seedlings was very similar to that of the oak seedlings. Ftg seedlings averaged 25 inches of height growth during the third year compared to 16 inces for mc seedlings and 2 inches for ot seedlings.

The percentage of individuals in each competitive position was calculated for each of Johnson's classes of potential regeneration. The third year results for Johnson's oak and ash components are presented in Table 1. A total of 6.4 percent of the <1ft oak seedlings had reached a ftg position by the end of the third growing season compared to 26.4 percent for the 1-3ft oak seedlings and 36.5 percent of the >3ft seedlings. The greater success of larger seedlings was also found by Loftis (1966) and Sander et al. (1976). The oak sprouts produced from stumps were very competitive and 100 percent of all sprouts were ftg regardless of preharvest tree dbh.

Since mortality during the first year is largely due to direct logging damage and indirectly from site disturbances caused by logging it is somewhat independent of preharvest size. Thus to evaluate the competitive ability of the various regeneration classes it is instructive to examine the percent of individuals from each of Johnson's regeneration dasses that were alive at the end of year one that obtained a ftg position at the end of year three.

After three years, 25% of the surviving oak seedlings which were initially <1ft and 45% of the 1-3ft seedlings were ftg compared to 71 % of the surviving oak seedlings which were initially >3ft and 1 00% for all regeneration from oak stump sprouts. The competitive advantage of larger advanced regeneration is observed for ash as it was in oak. However, the 1-3ft ash seedlings showed no disadvantage when compared to the larger seedlings or stump sprout regeneration as was seen in the oak seedlings.

The third and fourth year results from this study give a preliminary evaluation of the technique prepared by Johnson (1960) for evaluating hardwood regeneration potential. It is assumed that a stocked plot, one which receives 12 points using Johnson's technique, is one which will produce a codominant or dominant tree, of desirable species at crown closure.

From the analysis of seedling growth and competitive position it was concluded that seedlings in a ftg position at year 3 are necessary to produce a codominant or dominant tree at crown closure. If each of Johnson's classes are considered independently and it is assumed that all points from a particular plot came from one component, then that class would be required to produce at least one ftg seedling at the end of the third year. For example, a I-3R oak seedling receives two points using Johnson's technique. In order to have a stocked plot of 12, 6 such seedlings would be required. The proportion of 1-3ft oak seedlings that were ftg at year three was 26.4, thus 6 x .264 = 1.56 ftg oaks at year three. If each class is considered separately, values indicating the number of ftg individuals expected at year three can be calculated. A final value of 1, calculated following the above example, would be the theoretical minimum any one component could

Table 2. Expected number of oak seedlings or stump sprouts at year-three

Points using Johnson's Method		# Seedlings to have a stocked plot 12 points	Probability of a seedling becoming ftg at year 3	Expected # of ftg seedlings at year 3
	1 pt			
<1ft	2 pt	12	.084	1.008
I - 3 f t		6	.264	1.584
>3ft	3 pt	4	.385	1.54
1.5 - 5.5	3 pt	4	.297	1.188
5.6 - 10.5	2 pt	6	.273	1.638
10.6 - 15.5	1 pt	12	.167	2.004
> 15.5	Opt	8		

produce and still be considered a "stocked' plot. A value below one would indicate that Johnson's technique gives too much potential credit to a specific class. A value considerably above one indicates that Johnson's technique may be too restrictive and that a higher point value might be assigned to that component. Table 3 shows the number of ftg individuals that can be expected for each of Johnson's oak components. Values are provided for all components. However, sample size for dbh categories above 5.5 inches was below 25 and are considered inadequate to draw conclusions. All components generated at least one ftg seedling at year three, with the <1ft oak seedlings producing one ftg seedling and the >3ft seedlings producing 1.5 ftg seedlings.

While it is true that a plot which is expected to produce one ftg seedling at year three may be considered stocked, it should be realized that each seedling's success is an independent event and is associated with its own probability of success. It is important then to determine not only the expected number of seedlings a plot will produce but the probability the plot will produce at least one ftg seedling.

To illustrate how the population of seedlings affects a plot's probability of producing at least 1 ftg seedling, it is helpful to calculate that probability given that a plot receives 12 points from a single height class of seedling. A plot with 12 points, all from seedlings <1ft tall would have a 65 percent chance of producing a ftg seedling at year 3 while a plot receiving a total of 12 points from I-3ft seedlings or >3ft seedlings would have approximately an 85 percent chance of producing at least 1 ftg seedling at year 3.

In order to put the diierent oak seedling height classes on an equal basis with respect to their probability of producing 1 ftg seedling at year 3, it would be necessary to adjust the number of points Johnson assigns to seedlings <1ft tall from 1 point to .5 point per seedling. If this point adjustment is made a stocked plot receiving 12 points would then have approximately an 85 percent chance of producing a ftg seedling at year 3 regardless of the seedling height class distribution within the plot.

It is clear from the results on the oak component of Johnson's system that very little adjustment is needed. The results indicate that Johnson's point assignment and total point requirement was appropriate. Other than the reduction in points assigned to seedlings <1ft in height, no other adjustments are indicated.

As was just presented for oak, calculations were performed on the ash component of Johnson's system providing the expected number of seedlings and the chance of producing at least one ftg seedling. Table 3 shows the expected number of ash seedlings ftg at year 3 for a fully stocked plot, one receiving 12 points. All values exceed the theoretical minimum of one. Values for I-3R ash seedlings, >3ft ash seedlings and 1.5-5.5 dbh ash trees were all at least 2.5 times that required to achieve a value of 1.

As was done for oak the probability of a plot producing at least one ftg seedling at year three was calculated. Twelve <1ft ash seedlings yield a 68% chance of producing a ftg seedling at year three compared to 99% for a fully stocked plot comprised of either I-3ft or >3ft seedlings.

The high expected number of seedlings for all ash components except the <1ft seedlings, combined with the very high probability of producing at least one ftg seedling indicates that perhaps these ash components should receive more points than Johnson's system allots. The actual number of individuals required within these components to produce a well stocked stand at year three is less than Johnson's system suggests. The calculations also indicate that, as with oak, ash seedlings, <1ft should receive less than one point.

Table 3. Expected number of ash seedlings or stump sprouts ftg at year-three

Points using Johnson's Method		# Seedlings to Have a stocked plot 12 points	Probability of seedling becoming Ftg at year 3	Expected # of ftg seedlings at year 3
<1ft	1 pt	12	.091	1.092
1 - 3 ft	2 pt	6	.667	4.002
>3ft	3 pt	4	.659	2.636
1.5 - 5.5	3 pt	4	.714	2.856

Table 4. Amended oak and ash reproduction inventory form

Circular 1/100th-acre plot (11.8' radius)
Points per tree and number of trees by species and size class

Species	Height (feet)						DBH (inches)						Total
	<1.0		1-2.9		>3.0		2-5		6-10		11-15		
Oaks	Pt.	#	Pt.	#	Pt.	#	Pt.	#	Pt.	#	Pt.	#	
	.5		2		3		3		2		1		
	.5		2		3		3		2		1		
	.5		2		3		3		2		1		
	.5		2		3		3		2		1		
	.5		2		3		3		2		1		
	.5		2		3		3		2		1		
Ash													
	.5		6		6		6		2		1		
	.5		6		6		6		2		1		
	.5		6		6		6		2		1		
	.5		6		6		6		2		1		
	.5		6		6		6		2		1		
	.5		6		6		6		2		1		

Stocked 12 points or more

Total points for plot

Adapted from:
Johnson, R. L. 1980. New ideas about regeneration of hardwoods. Proceedings of Hardwood Regeneration Symposium, Jan. 29, 1980, Atlanta, GA. pp. 17-19.

In order to put all ash components on an approximately equal basis with respect to their probability of producing at least one ftg seedling at year three, it is necessary to adjust Johnson's point assignment for ash. Ash seedlings <1ft would receive .5 points. While I-3R and >3ft ash seedlings along with ash saplings dbh 1.5-5.5 inches would all receive 6 points. This point assignment results in a probabilii of greater than 88% of producing at least one ftg seedling at year three for all ash components. This is slightly above but similar to the approximately 85% for all oak components. The new point assignments presented for ash are those suggested by the study's results. It should be noted that ash was not a large component of the parent stands. Sample sizes for the ash components were small and may suggest caution in utilizing the new point values.

CONCLUSIONS

The results of this study, which was designed to test Johnson's system of evaluating regeneration potential for oaks and ash, shows that Johnson's technique was well designed and very useful in its original form. The changes that were indicated by the results of this research may make the system more useful for the field forester in applying it to minor bottom site types. Table 5 shows a revised tally sheet for the oak and ash segment of Johnson's system with the revised point assignments. Twelve points per plot would still be recommended as the guideline in determining whether a plot is "stocked" or not. It should be realized that values falling below 12 but approaching it indicate considerable regeneration potential from the species which contribute the points. It should also be noted that caution is advised in situations where <1ft seedlings contribute heavily to the point totals for plots. While these seedlings can and do contribute to regeneration of the next stand, the possibilities for catastrophic loss among this height class of seedlings is much larger than for the larger seedlings. Extended inundation or severe droughts are both factors which can cause severe mortalii among these small seedlings. Also, when using this regeneration system, it is important not to average the scores across plots. An average score for the stand may indicate that regeneration will be adequate when in actuality a few plots with abnormally high populations of advanced regeneration may have skewed the average score upwards. A high variability in plot scores is commonly found when reproduction surveys are conducted. A more appropriate application of the system is to determine what percentage of plots meet the minimum threshold of 12 points. It may be helpful to map the plots with their corresponding scores in order to visualiie the distribution of the potential reproduction throughout the stand. A review of the literature, including Johnson and Deen (1993), indicates that 60-70% of plots meeting the 12 point minimum is usually considered acceptable. Plot layout and installment should follow a systematic sampling scheme and stratified sampling is suggested where different stand conditions are recognized and can be delineated. One 1/100th acre sample plot is recommended per acre for stands less than 50 acres. For stands exceeding 50 acres an additional plot is recommended for every additional two acres in stand size.

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ESTABLISHMENT OF WATER OAK IS NOT DEPENDENT ON ADVANCE REPRODUCTION'

Edward F. Loewenstein and Michael S. Golden'

Abstract-The stem origin of reproduction for water oak, *Quercus nigra* L., was investigated on a seven-year-old clearcut area in the floodplain of the Alabama River. Root systems of sample trees were excavated to determine the source of reproduction: old advance reproduction, new advance reproduction (sprouts) or new seedlings. The sample was stratified across crown classes to allow comparison of dominant/codominant stems ("potential crop trees") with intermediate and suppressed stems. Although advance reproduction was a significant component of water oak reproduction, over 40-percent of the potential crop trees, seven years after harvest, originated as new seedlings.

INTRODUCTION

Historically, there has been a lack of interest in southern bottomland hardwood silvics. This is due to the biology and economics of the system. These species tend to be slower growing and have brought extremely low pulp prices in relation to pine. Further, 80 percent of the hardwood resource in the eastern United States is provided by private landowners (Knight and Hilmon, 1978) many of whom see their hardwoods as self reproducing. As a result, there has typically been a single recommended prescription for bottomland hardwood stands: clearcut. This method of regeneration often results in a stand with acceptable composition and stocking, but if the landowner would like to emphasize a particular species or there is a problem species that needs to be controlled, a single prescription implemented without variation across all sites cannot suit their purposes. Foresters need to know the silvics of our target species and tailor our silvicultural prescriptions to them.

This study focused on gathering basic silvicultural information on the establishment and early development following a clearcut of water oak, a commercially important southern bottomland hardwood species. Specific objectives were to determine the time of rootstock establishment in relation to the harvest and to see if differences in the source of reproduction (stem origin) exist between potential crop trees (dominant/codominants) and subordinate stems.

METHODS

The study was conducted on a 40-acre tract of land, situated within Kings Bend on the Alabama River, a first bottom located approximately 3 miles south of Selma, AL. The land is managed by Buchanan Hardwood, Inc. of Selma, AL. It is a mixed bottomland hardwood stand subject to annual flooding during the winter and spring of most years.

In 1981, the study area was delineated and a pre-harvest inventory was conducted for both overstory (greater than 5.5 in. DBH) and understory (1 foot tall - 5.5 in. DBH) trees. Water oak comprised 5.7 percent of the overstory stems (7.3 stems/acre) and 13.7 percent of the basal area (19.1 sq. ft./acre). In the pre-harvest understory, water oak accounted for 8.5 percent of the large (0.5-5.5 in. DBH) understory stems (37.5 stems/acre) and 10.6 percent of the small (1 ft - 0.5 in. DBH) understory stems (72.9 stems/acre).

A commercial clearcut was conducted during the late summer and fall of 1982. Most stems greater than 4 in. DBH were removed, with the exception of cull trees greater than 10.5 in. DBH which were not felled. In 1989, during the seventh growing season after clearcutting, the study area was again inventoried. At that time, tree regeneration greater than 1 foot tall averaged 2219 stems/acre. Water oaks comprised 12.8 percent of the total. Pre- and post-harvest stand descriptions are detailed by Loewenstein (1992) and Golden and Loewenstein (1991).

Sampling Procedure

A random sample of 35 water oak stems, stratified across three crown class categories, were destructively sampled to determine stem origin and age. Groundline diameter, DBH and total height were recorded. Root systems of sample trees were excavated to a depth of at least 8 inches. The root system and stem to a height of 5 feet were removed from the site for processing and analysis in the laboratory. An additional disk was removed 5 feet below the terminal of all stems taller than 9 feet to aid in growth rate determination.

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Annual rings were counted from disks taken 2-inches below and above the ground line, at 1.5, 3 and 4.5 feet and from the additional disks collected from trees over 9 feet tall. Samples were categorized by stem origin based on the year of rootstock and stem establishment Stems with a root age less than or equal to the time since harvest were categorized as "new seedlings", regardless of the stem age. "New advance reproduction" had a root age greater than the time since harvest, but a stem age less than or equal to time since harvest. These stems had become established in the understory and resprouted following harvest "Old advance reproduction" had both root and stem ages greater than the time since harvest. These stems were established in the understory and were released by the harvest. Similar groupings have been utilized in other regeneration studies (Sander and Clark, 1971; Hillier, 1977).

Statistical Analyses

Duncan's multiple comparison tests were used to determine differences in height or diameter growth rates between stem origin types of potential crop trees (SAS Institute Inc., 1988). Fishers Exact Test was used to examine the effect of stem origin type on competitive ability as measured by crown class category. Intermediate and suppressed stems were pooled into one category for this test since the comparison of interest was between the potential crop trees and the subordinate stems. To obtain sufficient numbers of observations within cells, old and new advance reproduction were also combined into a single category: advance reproduction.

RESULTS

The potential crop trees were divided nearly equally among the three stem origin categories (Figure 1), while in the intermediate and suppressed classes the ratio of new seedlings to new advance reproduction was approximately 3: 1. Based on the Fisher's Exact Test (a = 0.05), no association was found between crown class and stem origin type; the number of stems observed in each class did not significantly differ from the number expected.

To determine whether differences in annual height growth existed among stem origin categories for the potential crop trees, height growth was divided into an establishment phase (growth up to 4.5 feet) and a growth phase (growth after 4.5 feet). The average annual height increment did not diier statistically (a = 0.05, Duncan's Multiple Comparison Test) among the stem origin categories for either phase of growth (Table 1). However, examination of diameter growth indicated that new seedlings were significantly smaller (1.57 in. DBH) than either old advance reproduction (2.82 in. DBH) or new advance reproduction (2.59 in. DBH).

Table l-Average annual height increment (feet), of dominanffcodominant water oak stems

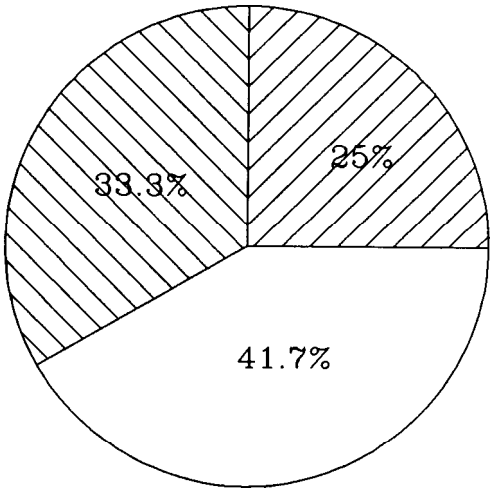
	Old Advance Reproduction	New Advance Reproduction	New Seedlings
Establishment Increment	1.125 (3)	2.813 (4)	2.475 (5)
Growth Increment	2.650 (3)	2.819 (3)	3.115 (4)
Average Increment	1.935 (3)	2.794 (3)	2.677 (4)

[a] Annual height increment during establishment phase, 0 to 4.5 ft tall.
[b] Annual height increment following establishment phase.
[c] Numbers in parentheses indicate sample size.

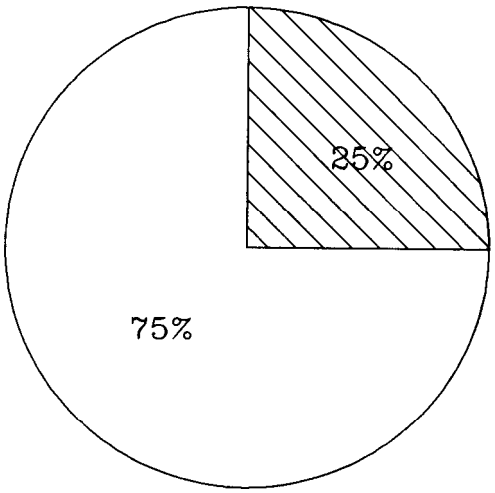
DISCUSSION

The stem origin of water oak was much different than might be expected after a review of oak literature. Most authors have found oaks to rely heavily or exclusively upon advance regeneration for competitive reproduction (e.g. Carvell and Tryon, 1961; Loftis, 1983; Sander and Clark, 1971). However, in this study, water oak did not depend upon advance regeneration for the production of all potential crop trees (Figure 1). New seedlings accounted for more dominanffcodominant water oak stems (42 percent), seven years after clearcutting, than did new (33 percent) or old (25 percent) advance reproduction. Bowling and Kellison (1983) suggested that advance reproduction may not be necessary to regenerate oak on bottomland sites. However, their study lacked pra harvest regeneration data and stem origin was apparently not determined. The present study offers objective evidence to support their assertion for at least one bottomland oak species. Although important for regenerating water oak, advance reproduction was not the exclusive producer of potential crop trees in this species on this site.

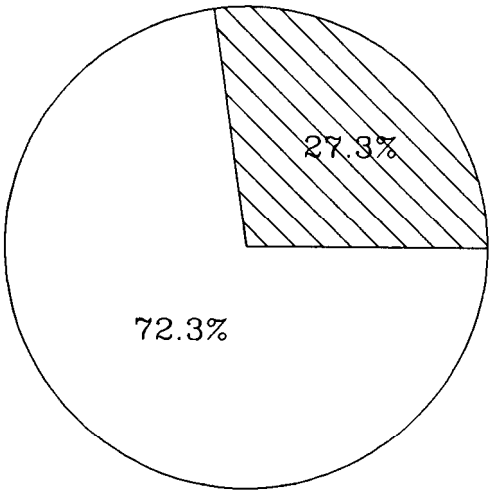
The initial growth rate of water oak also merits attention. Early height growth of water oak is reportedly slow (Vono, 1990), however, in this study water oak did not display this trait. New seedlings in the dominant/codominant crown classes exhibited an average annual height growth of 2.7 feet during the seven years following harvest (Table 1). This compared quite well with the 2.8 feet per year for new advance reproduction. Only the fact that new seedlings were over an inch smaller in diameter than either form of advance reproduction (1.6 verses 2.8 and 2.6 in.



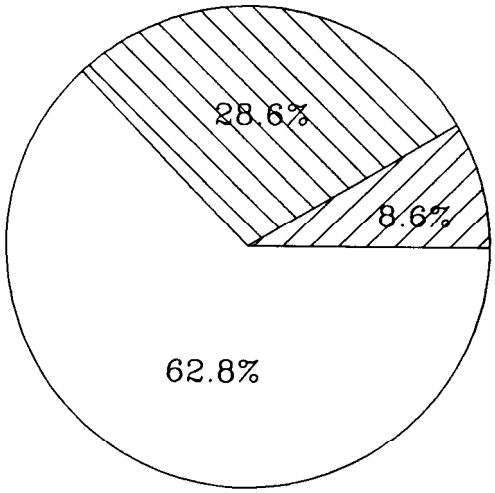
A. DOMINANT/CODOMINANT
n=12



B. INTERMEDIATE
n=12



C. SUPPRESSED
n=ll



D. ALL WATER OAK COMBINED
n=35

ØLD ADVANCE REPRODUCTION
NEW ADVANCE REPRODUCTION
NEW SEEDLINGS

Figure 4.Stem origin of water oak by crown class.

DBH, respectively) suggests that this stem origin type may be less desirable. Further research in long term differential size development of these two stem origin types, as well as their effect on stem quality, would certainly be useful.

Most oak research has been conducted on upland species which can successfully compete following disturbance only with a well developed root system or in harsh environments where interspecific competition is greatly reduced. Regeneration prescriptions for bottomland oaks have followed from these studies, but seemingly, water oak does not follow the same pattern of development as lts upland counterparts. New seedlings successfully compete following harvest. Thus, if water oak is not present in the understory and for some reason a harvest must be scheduled without prior consideration for regeneration, a manager can still obtain reproduction of this species following a harvest if an adequate acorn crop is present Stem origin studies on other bottomland oak species should be undertaken to see if this trend is common to all mesic oaks or peculiar to water oak. If such a trend were found, it could greatly influence recommended cultural practices for southern bottomland hardwood stands.

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EFFECTS OF FOREST FLOOR AMOUNT AND COMPOSITION AND ACORN PLACEMENT ON EMERGENCE AND EARLY ESTABLISHMENT OF WHITE OAK'

Brian R. Lockhart, Michael G. Shelton, and Yanfei Guo[2]

Abstract—Two forest floor compositions (pine and oak), five weights (10, 20, 30, 40, and 50 Mg/ha), and three acorn placements (forest floor, soil surface, and buried) were tested in a split-plot, randomized block design. Forest floor composition did not affect seedling emergence, but increasing weight significantly delayed emergence. A significantly lower seedling establishment occurred for the heaviest forest floor, but the overall effects of the forest floor on seedling emergence and properties were fairly minor. Burying acorns 1.5 cm below the soil surface significantly reduced emergence but increased number of leaves in the final flush.

INTRODUCTION

Mixed pine-hardwood stands are important resources in the southern United States, and recent interest has been expressed in developing silvicultural techniques for their creation and maintenance (Waldrop 1989). The oaks are the most desirable hardwood group, and techniques that would establish pine-oak stands are needed. Accomplishing this goal is complex because regeneration strategies for the pines and oaks differ. Natural pine regeneration principally develops from seeds disseminated after the reproduction cut. Favorable seedbed conditions for pine regeneration are exposed mineral soil and disturbed litter. By contrast, oak regeneration and/or sprouting potential must be adequate before the reproduction cut if oaks are to successfully compete with other vegetation (Loftis and McGee 1992). Oak advance regeneration relies on the existing forest floor and the underlying soil as a seedbed. Thus, information is needed concerning the effects of the forest floor in pine-hardwood stands on the establishment of oak regeneration. Most of the knowledge of the importance of oak seedbeds dates back to Korstian (1927) and is mostly observational rather than quantitative. The objective of this study was to evaluate the effects of forest floor weight, composition, and acorn placement on emergence and early establishment of white oak (Quercus *alba* L.).

PROCEDURES AND METHODS

The study was located in the School Forest of the University of Arkansas at Monticello in the West Gulf Coastal Plain (91° 46' W and 33" 37' 31" N). The soil is a Sacul loam (clayey, mixed, thermic, Aquic Hapludutts). The climate is subtropical humid with average rainfall of 1337 mm per year. The highest rainfall occurs in winter and early spring. Summers are usually dry. The study was installed in December 1992 and was terminated in September 1993.

A 5 X 3 X 2 factorial, split-plot, randomized block design with two replications was used for the study. The three factors were: forest floor weight, acorn placement, and forest floor composition. Five levels of forest floor weight were: 10, 20, 30, 40, and 50 Mg/ha. Three acorn placement treatments were: (1) acorns buried 1.5 cm below the soil surface and the designated forest floor added, (2) acorns placed on the soil surface and covered with designated forest floor, and (3) acorns placed on the fermentation layer of the forest floor and covered by the litter layer. Two forest floor compositions were tested, loblolly pine (*Pinus taeda* L.) and mixed oaks (Quercus spp.). Bulk forest floor material was collected during the fall of 1992 from a 22-year-old loblolly pine plantation and a 75-year-old mixed upland oak stand. Both stands were located in the University Forest. Forest floor material was collected by litter and fermentation layers to facilitate reconstruction and dried in a walk-in oven at 50" C. The fermentation layer was material that had undergone decomposition while the litter layer was freshly deposited material. A small correction in weight was made for the residual moisture content, which was determined by drawing a number of 100 g subsamples and drying at 105" C.

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The forest floor was reconstructed within wooden frames. Forest floor weight and composition were the whole plots and acorn placement was the subplot. There were 20 whole plots and 60 subplots. The size of each subplot was 0.145 m^2. Twelve acorns were planted in each subplot. Acorns were collected weekly from four nearby whiie oak trees and refrigerated until planted. A removable screen covered each frame to keep out seed-consuming animals.

Emerging seedlings were counted six times starting in April 1993 and ending in September 1993. The interval between counts varied based on the rates of emergence. Upon study termination, seedlings were harvested, and height, groundline diameter, and length and number of leaves for each flush were measured in a laboratory.

Analysis of variance (GLM, SAS Institute 1989) was used to test the treatment effects on length and number of leaves in each flush, groundline diameter, total height, and emergence of the seedlings. Individual means were compared at $P = 0.05$ following the method described by Steel and Torrie (1980). No further separation for forest floor composition was needed because there were only two levels. Interactions among the three factors were also tested.

RESULTS

Forest floor composition did not influence seedling emergence (fig. 1). The percentage emergence for the hardwood forest floor was slightly greater than that for the pine treatment, but the difference was not significant. Emergence of the seedlings reached a maximum of 78 percent on July 1 and did not change thereafter.

Increasing forest floor weight significantly delayed seedling emergence (fig. 2). On April 2, seedling emergence for a forest floor of 10 Mg/ha was more than 20 percent as compared to less than 8 percent for a forest floor of 30 Mg/ha. However, the effects of forest floor weight on seedling emergence decreased through time. No significant differences occurred among the forest floors after July 1, and the only significant difference on September 20 was between forest floors weighing 30 and 50 Mg/ha.

Acorn placement also affected seedling emergence (fig. 3). Buried acorns had the lowest emergence for all sampling dates. The final emergence of the seedlings was about 60 percent for the buried acorns, which was significantly lower than the 78 percent for the acorns placed on the soil surface and within the forest floor (fig. 3).

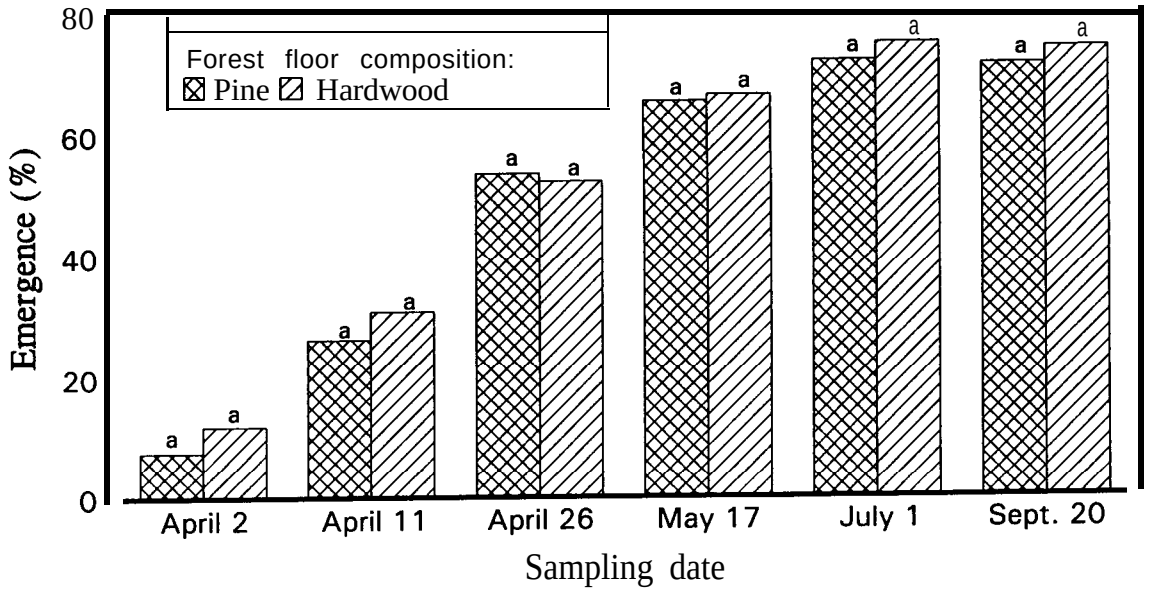


Figure l-Influence of forest floor composition on emergence of white oak. Bars with the same letter are not significantly different (P = 0.05)

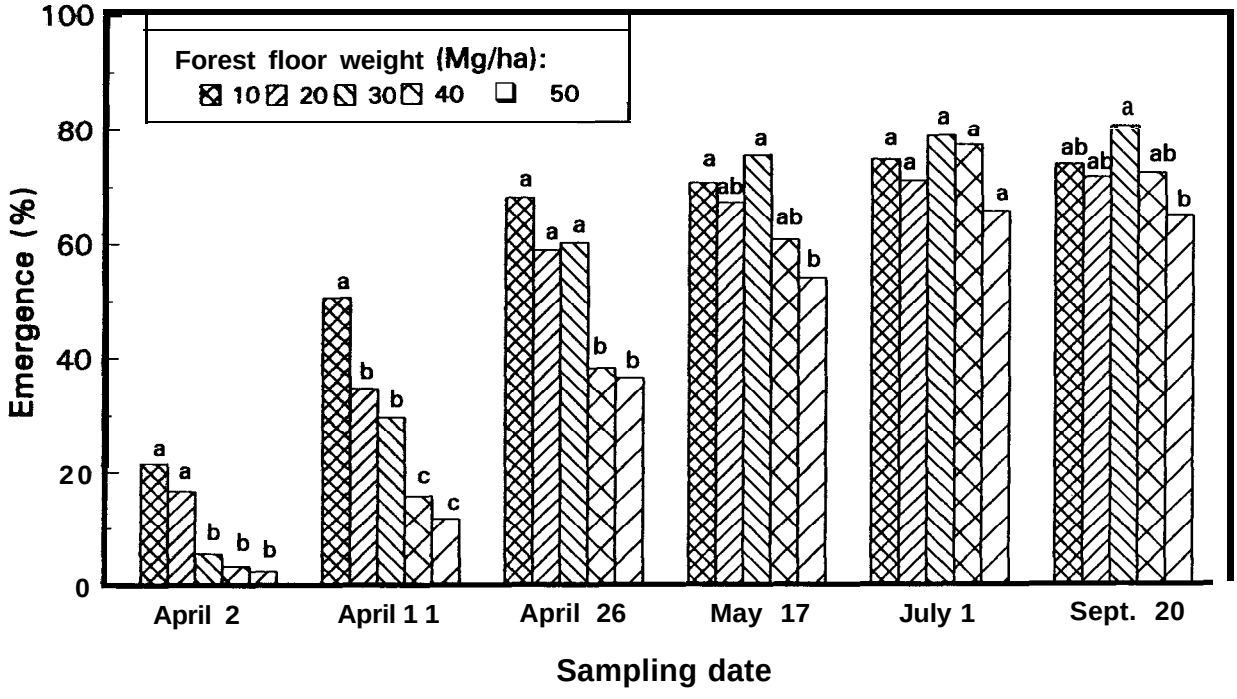


Figure 2–Influence of forest floor weight on emergence of white oak. Bars with the same letter are not significantly different ($P = 0.05$)

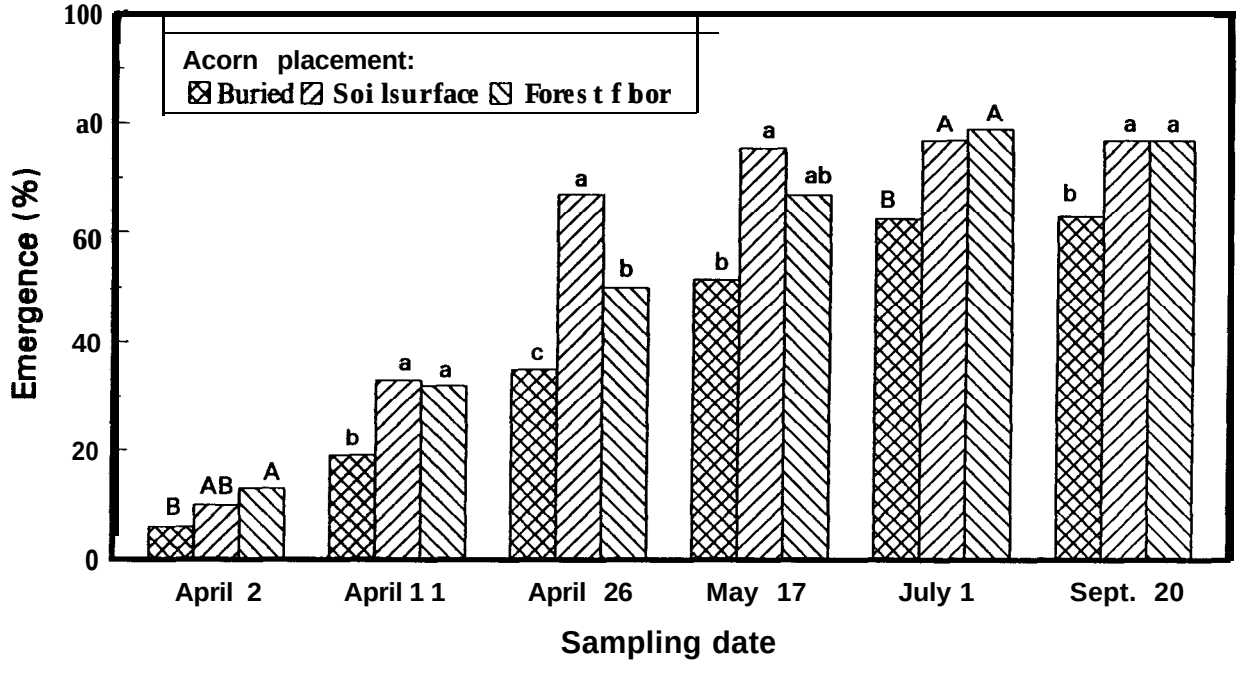


Figure 3–Influence of acorn placement on emergence of whii oak. Bars with the same letter are not significantly diierent (P = 0.05, lower case; $P = 0.10$, upper case).

The interaction of acorn placement and forest floor weight was significant. Buried acorns had the lowest final emergence at all forest floor weights (fig. 4). Emergence was greatest for the soil surface placement for all except the heaviest forest floor, where placement within the forest floor was the greatest.

Forest floor composition did not influence the average number of leaves for each flush (fig. 5). The number of leaves for each flush was relatively uniform, averaging about five leaves per seedling.

Acorn placement did not affect the number of leaves on the first three flushes but affected that on the fourth flush (fig. 6). For the fourth flush, seedlings from the buried acorns had a significantly greater number of leaves than that for seedlings from other acorn placements. Similarly, forest floor weight did not influence the number of leaves for the first three flushes, but affected the number of leaves on the fourth flush (fig. 7). The number of leaves for the lighter forest floors (10 and 20 Mg/ha) was significantly greater than that of the heavier ones (30, 40, and 50 Mg/ha).

Seedling height, groundling diameter, and flush length were not affected significantly by forest floor composition, weight, or acorn placement.

DISCUSSION AND CONCLUSIONS

The treatments tested in this study simulated conditions that may occur in the field. The amount and composition of the forest floor reflect the properties of the vegetation that produces it Switzer et al. (1979), who studied the successional development of the forest floor in upland sites of the Coastal Plain of Mississippi, found that weights maximized at a mean of 21 Mg/ha for 65-year-old pine stands and then decreased to 14 Mg/ha as hardwoods became dominant. We selected a greater range of forest floor weights to accommodate the large stand-to-stand and within-stand variation observed in the field. The acorn placement treatment was also designed to simulate field conditions. Although destruction of acorns by insects, rodents, and deer may reach 90 percent (Arend and Scholz 1969, Marquis et al. 1976, Galford et al. 1991), some acorns may remain on the soil surface and forest floor. In addition, acorns are commonly buried by small mammals and birds (Thorn and Tzilkowski 1991, Deen and Hodges 1991).

This study demonstrates that forest floor conditions affect emergence and establishment of white oak. Increasing forest floor weight delays seedling emergence, and excessive amounts, such as 50

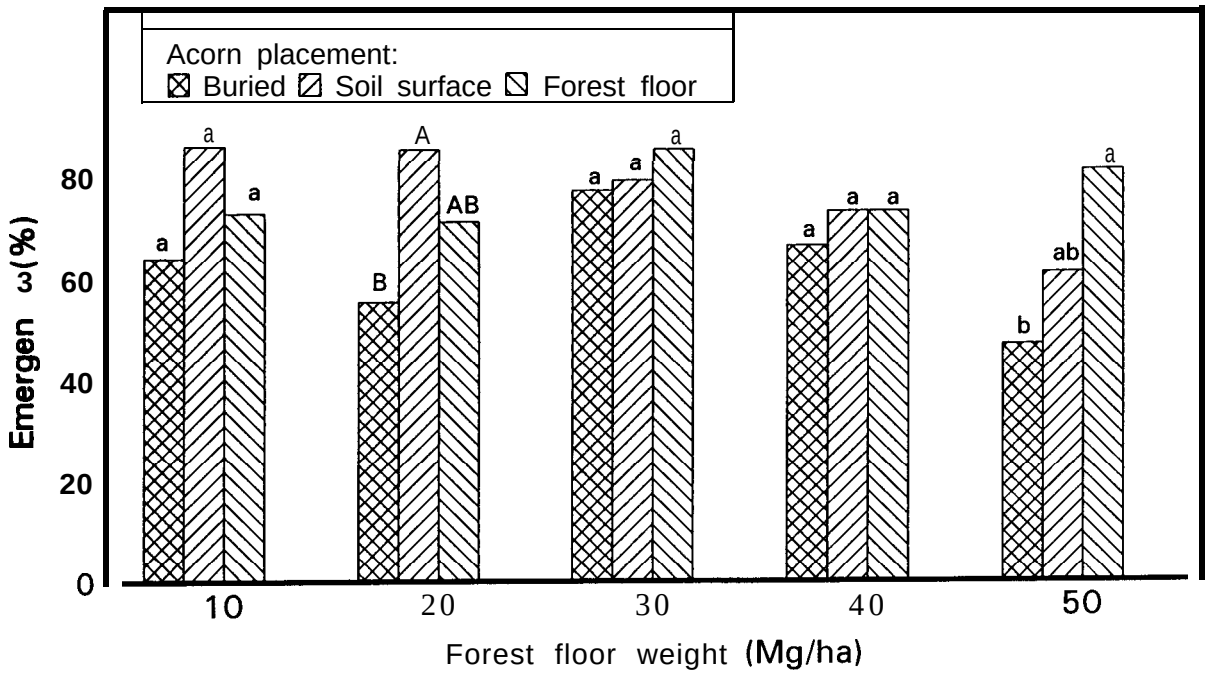


Figure 4-Influence of acorn placement and forest floor weight on emergence of white oak on September 20. Bars with the same letter are not significantly different (P = 0.05, lower case; *P* = 0.10, upper case).

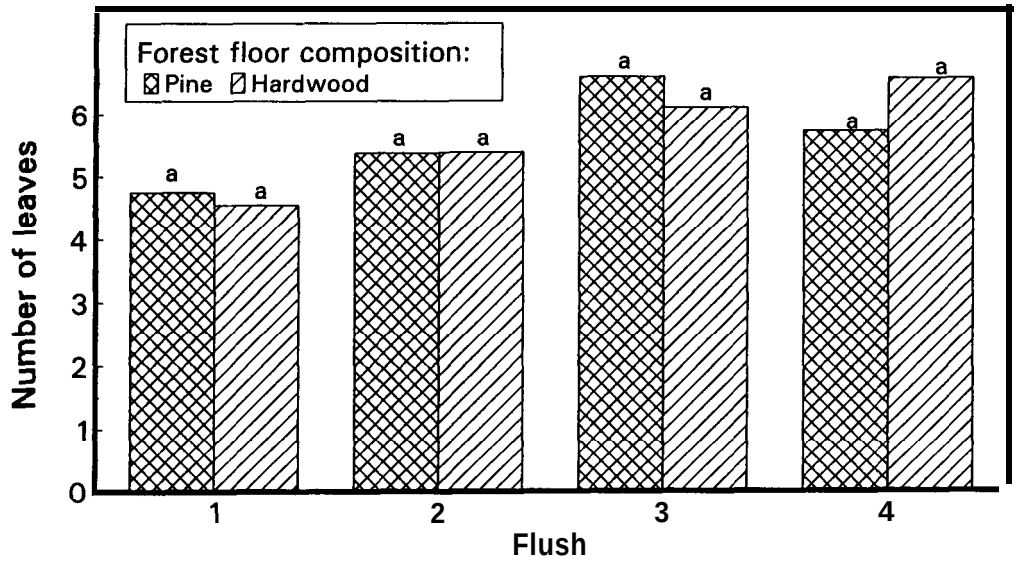


Figure 5--Influence of forest floor composition on number of leaves for each flush. Bars with the same letter are not significantly different (P = 0.05).

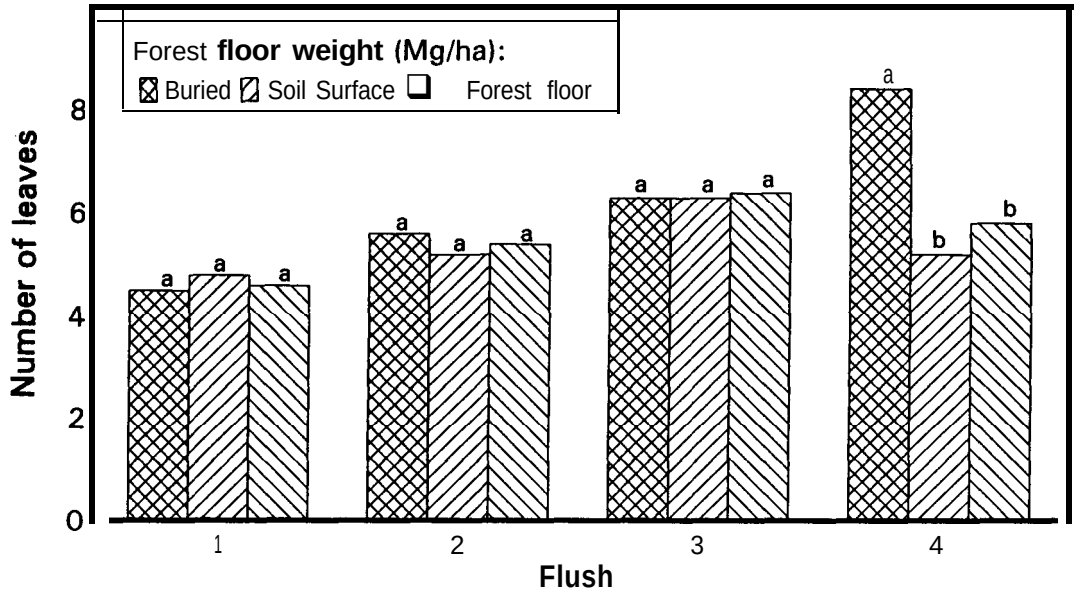
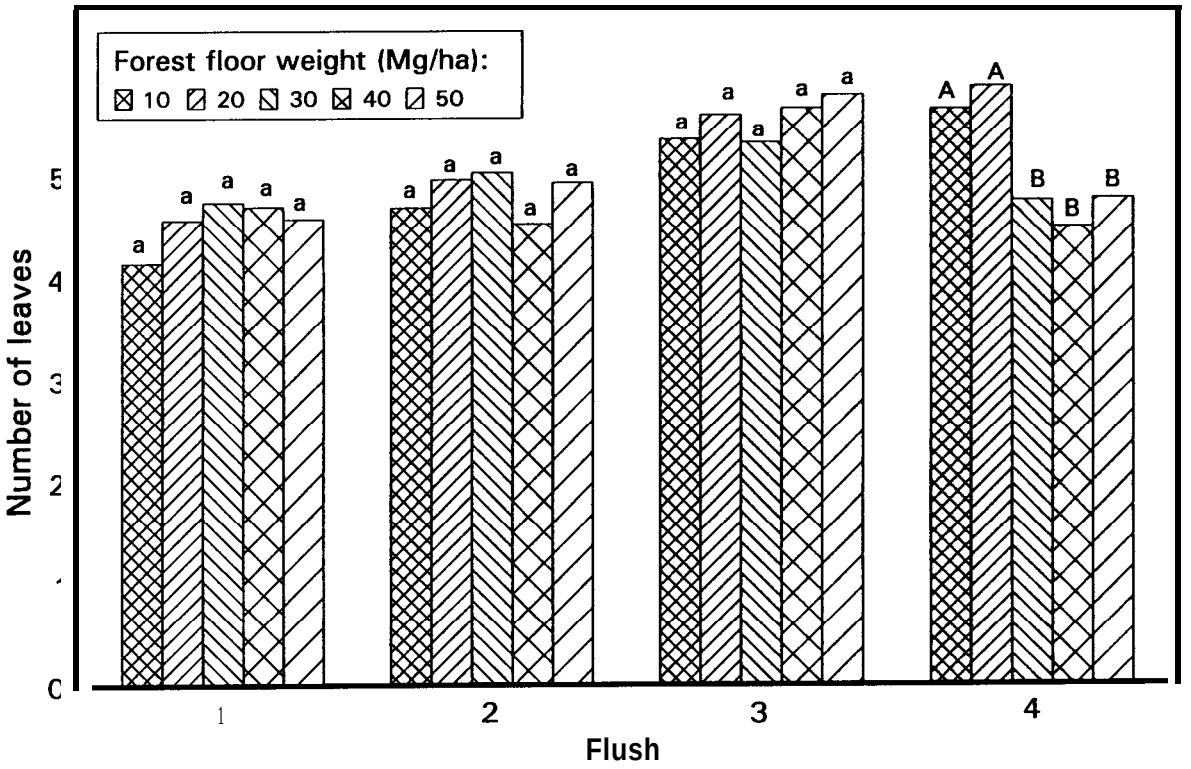


Figure 6--Influence of acorn placement on number of leaves for each flush. Bars with the same letter are not significantly different (P = 0.05).



Fiaure -/-Effect of forest floor weight on number of leaves for each flush. Bars with the same letter are not significantly diierent (P = 0.05, lower case; *P* = 0.10, upper case).

Mg/ha, may reduce seedling establiihment However, the overall effects of the forest floor seem to be minor, especially considering that the heavier forest floor weights tested here were much greater than those normally occurring in the field. Therefore, forest floor properties do not appear to be a major factor in the establishment of white oak seedlings when conditions are similar to those tested here.

Results of this study are supported by observations for other species. Barrett (1931), for example, reported that establishment of chestnut oak (*Quercus montana* Willd.) seedlings maximized at a liier depth of 2.5 cm. Peterson and Facelli (1991) found a significant delay in the emergence of yellow birch (*Betula alleghaniensis* Britton) seedlings by the forest floor, Shelton (in press) reported a similar relationship for loblolly pine. However, the effect of increasing forest floor weight on seedling establishment varies considerably among species. The forest floor appears to influence seedling establishment of the smaller-seeded species to a much greater extent than for the larger-seeded ones. Results of this study and that of Barrett (1931) showed that the large-seeded oaks were not strongly affected by forest floor weights. In contrast, seedling establiihment of loblolly pine, which has small, wind disseminated seeds, is substantially reduced by the forest floor (Grano 1949, Shelton [in press]). Apparently, the radide of small-seeded species must penetrate into the soil before stored food is depleted.

Burying whii oak acorns in this study resulted in lower seedling emergence and establishment, especially when a forest floor weighing 50 Mg/ha was present At the end of the growing season, however, seedlings from the buried acorns showed no significant differences in groundline diameter, height, and flush numbers and length when compared to those from other placements. However, seedlings from the buried acorns developed more leaves on the final flush, although the reason for thii is not dear. Lockhart (unpublished data) also observed that cherrybark oak (*Quercus pagoda* Raf.) seedlings developed more leaves as the sowing depth of acorns increased. Burying acorns may modify seedling morphology by changing hormone distribution or carbohydrate allocation. The superior seedling establishment from acorns placed within the forest floor or on the soil surface may reflect the relatively mild winter of 1992/93 and the fact that acorns were protected from predation. For example, Johnson and Krinard (1985) found the best seedling establishment occurred when acorns were buried 5 cm deep. They recommended that deeper depths might be used if losses to small rodents

are expected to be high and to reduce variability in soil temperature and moisture.

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Silvicultural Systems

Moderator:

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WHEN THE PAINT HITS THE TREE--ACCURACY OF IMPLEMENTING ALTERNATIVE REPRODUCTION CUTTING METHODS'

James M. Guldin, James B. Baker, Michael G. Shelton, and Timothy J. Mersmann[2]

Abstract—The accuracy of marking among different reproduction cutting methods was tested with data from the ecosystem **management research** project in the Ouachii ad Ozark**NFs.** Marking accuracy was **determined** using **dRBA,** the difference between observed and expected **residual** basal area, and was computed for conifers, hardwoods, and all species. Analyses we conducted by treatment (clearcutting **control,** two seed-tree methods, three **shelterwood** methods, two group **selection methods,** and four **single-tree** sektbn methods), by method (control, seed-tree, shelterwood, group selection, and **single-**tree **selection)** and by structure (control, **even-aged,** and uneven-sged). Conifer **dRBA** was significant **(P>F** 0.05) among **treatment,** method, and structure, and **varied** from -3.39 **ft²/ac** in the pine group sektbn method to 14.14 **ft²/ac** in the **low-impact** single-tree selection. Single-tree selection had slgnlfkantly larger conifer **dRBA** (7.13) than the other methods. Hardwood **dRBA** was significant by **treatment** and method, and structure, wlth **larger** differences in the uneven-aged treatments than **the even-aged treatments.** Hardwood **dRBA** was **also larger** than conifer **dRBA** by treatment, method, and structure. For all **species, dRBA** was **significant** by treatment, method, and structure. Single-tree **selection** and group **selection** both had total **dRBAs** greater than 10 **ft²/ac.** Overall, the uneven-aged methods were less accurately imposed than the even-aged methods, since they are more difficult to impose and to adjust when marking. Improving marking accuracy in uneven-aged stands may require progress in silvkultural theory, and greater emphasis in continuing education and forestry curricula.

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Stand Development/Intermediate Management

Moderator:

TIMOTHY B. HARRINGTON
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A COMPARISON OF DENSITY INDICES IN CONTROLLING GROWING STOCK IN A SLASH PINE SPACING-THINNING STUDY'

V. Clark Baldwin, Jr., Thomas J. Dean, and Robert B. Ferguson[2]

Abstract-Two common density indices are Reineke's stand density index (SDI) and stand basal area (BA). Three replications in a 17-year-old slash pins spacing study were thinned to prescribed values of SDI, and two were thinned to prescribed levels of BA. Effects on growing stock and stand growth will be compared. Plots had been planted at seven spacings ranging from 4 x 4 to 14 x 14 ft. At age 17, only the widest spacing did not need thinning. The prescribed residual stand basal areas ranged from 56 to 75 square feet per acre. The heaviest thinnings were applied to the closest spaced plots. In all, 14 thinning treatments were applied. Subsequent thinnings will be scheduled when upper limits of density, as indicated by SDI or BA in locally derived density management diagrams,are reached.

INTRODUCTION

In plantations density is managed through initial spacing of seedlings and through thinning. Elsewhere in these proceedings, we report 15-year results of a slash pine (*Pinus elliottii* Englm var. *elliottii*) spacing study (Ferguson and Baldwin 1995). Here we describe establishment of a thinning study in the same planting. At age 17 the plots in the spacing study were (1) thinned to values of Reineke's stand density index (SDI)(Reineke 1933), or (2) thinned to a residual basal area per acre level (BA), as determined from density management diagrams (DMDs) developed for West Gulf slash pine by Dean and Baldwin (1995). Our objective is to compare yields based on the effects of the timing and level of thinning prescribed by the BA DMD technique versus the timing and level of thinning prescribed by the SDI DMD technique. We think the study is the first established specifically to test the validity and practical usefulness of DMD theory.

Reineke's SDI is the equivalent number of trees per acre at a standard diameter of 10 inches:

$$SDI = TPA\,(QMD/10)^{1.6} \quad . \qquad (1)$$

where TPA = number of trees per acre,
QMD = quadratic mean diameter (inches) at breast height.

Stand basal area (square feet per acre) is defined as:

$$BA = .005454\,TPA\,(QMD)^2 . \qquad (2)$$

A DMD is a stocking chart based on natural stand development expressed as changes in average tree size (e.g., QMD) and TPA over time (Drew and Flewelling 1979). They are visual aids for the process of optimally selecting thinning timing and intensity using either residual SDI or BA targets The timing and intensity of thinning decisions have previously been made from DMDs based on current stand conditions relative to the determined upper and lower boundaries of SDI. As introduced by Dean and Baldwin (1995), this can also be accomplished in a similar manner using determined upper and lower boundaries of BA (figure I). The upper boundary usually represents a percentage of maximum stocking, and the lower value a percentage of stocking just above crown closure. A description of using DMDs to develop thinning schedules based on SDI is given in Dean and Baldwin (1993).

METHODS

The study area is about 1 mile east of Woodworth, LA, on the Alexander State Forest which is managed by the Louisiana Office of Forestry. Seedlings were produced from a single seed source of genetically improved parents. They were planted at seven spacings, 4x4 4x6, 6x6, 6x8, 8x8, 10x10, and 14x14 feet, in five randomized complete blocks. Each measurement plot within a treatment consisted of 8 rows of 8 trees Each measurement plot was surrounded by approximately a one-half chain (33 foot) isolation strip planted at the plot's assigned spacing. The study design eliminated genetic variability and varying numbers of trees per measurement plot as sources of error. In these Proceedings, Ferguson and Baldwin (1995) provide further information about the plots and the original study.

Three blocks were randomly assigned for SDI based treatments and two were assigned for BA based treatments. At age 17, trees on all plots were

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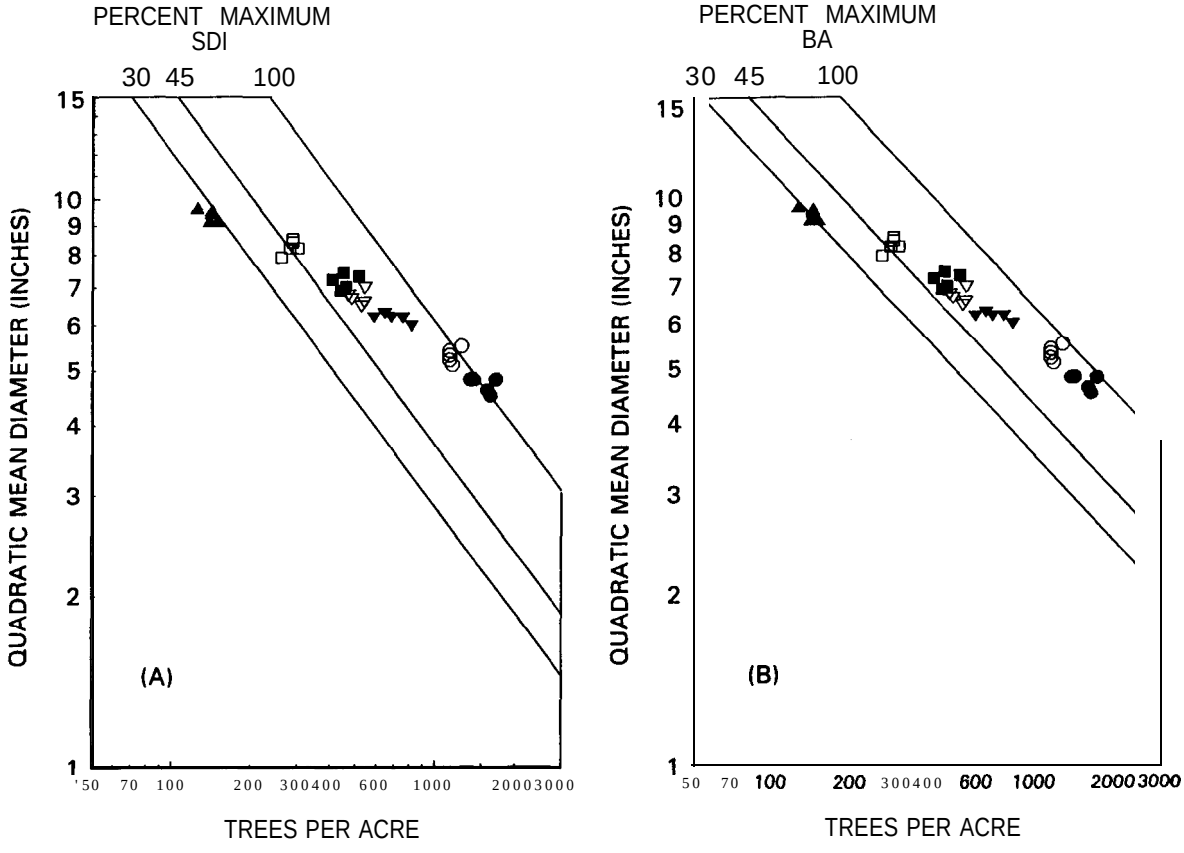

Figure I-Prethinning values of quadratic mean diameter and trees per acre for the slash pine plots in central Louisiana and their relation to percent maximum SDI (A) and to percent maximum basal area (BA) (b). Also shown are the prescribed upper and lower limits for this study, which are, respectively, 30 and 45 percent of either maximum SDI or maximum BA. Initial planting spacings are indicated by symbols: ( ) 4x4 ft; ( ) 4x6 ft, ( ) 6x6 ft, ( ) 6x8 ft, ( ) 8x8 ft, ( ) 10x10 ft, and ( ) 14x14 ft.

measured and average plot QMD and TPA were calculated. Then appropriate DMDs were examined for each plot to first determine if thinning was required at that age. The requirement for thinning was the existing SDI or BA be equal to or greater than 45 percent of the maximum SDI = 450, or BA = 220 square feet per acre, respectively, as determined by Dean and Baldwin (1995). These were the upper thinning boundaries. The rationale for their selection was that they be below the maximum, and that they provide for a time buffer between the time a stand definitely should be thinned to avoid self-thinning, and the time it might practically be scheduled for thinning.

Thinning was due, or past due, for all plots except those at the 14x14-foot spacing, and two of those at the 10x1 O-foot spacing (figure 1). Three 10x1 O-foot plots were ready for immediate thinning and two could have waited for another year; however, all plots of that spacing were thinned. The 14x14-foot plots will be thinned later. The optimal times for first thinning of the closer spaced plots were years earlier. Since we could not go back in time, this comparative study of the two DMD techniques can only emphasize the optimal timing of initial thinning for spacings of 10x10 and 14x14 feet. However, comparing the closer spaced plots and subsequent thinnings will provide valuable information about management strategies for carrying higher total volumes.

Target thinning levels were determined for each of the remaining plots. This was done for the SDI method by rearranging the SDI equation (1) to solve for TPA, modifying that equation slightly to account for the increase in QMD that occurs when thinning largely from below (QMD = 1.036 QMD), and inserting the 30 percent value for SDI (0.30 SDI_{Max} = 135) as shown below:

$$TPA_{30} = SDI_{30}(QMD_{30}/10)^{-1.6} = 135(1.036\ QMDMD_{45}/10)^{-1.6} . \quad (3)$$

Finally, the target residual basal area per acre was determined from:

$$BA = 0.005454\ TPA_{30}(QMD_{30})^2. \quad (4)$$

Figure 1 illustrates this procedure. The current QMD-TPA point must be located on the DMD. One then must move the point vertically 1.036 units and then horizontally to the left to the point of intersection with the lower SDI or BA boundary line. That line is 30 percent of the maximum SDI or BA values, or 135 trees per acre and 66 square feet per acre, respectively. For slash pine, this lower boundary is a point about 5 percentage points above the point of crown closure that was determined by Dean and Jokela (1992), and was chosen to insure maximum site occupancy. The point of crown closure was determined for the SDI method, the residual target TPA was then read directly below that point on the TPA axis, and the target BA calculated from equation (4). For the BA method the target residual BA is constant for all plots at the 30 percent of maximum BA value, or 66 square feet per acre. The constant multiplier 1.036 used in (3) above is the average amount of diameter increase that can be expected in a residual slash pine stand due to thinning largely from below and would not be required for a random or row thinning. The value was determined from the data used to develop the Zarnoch and others (1991) planted slash pine growth and yield prediction system.

The target residual basal areas were then averaged for each block - treatment combination and the plots were thinned to those targets. This process produced a total of 14 different thinning treatments (7 spacings x 2 density indices) but the range of residual densities was rather narrow (56 to 75 square feet per acre).

Logging damage on the plots was minimal. Residual trees skinned in logging were immediately treated with a pesticidefo minimize insect infestation. The plots will be measured periodically and thinned again to 30 percent of maximum density whenever observed density is greater than 45 percent of maximum for the appropriate DMD.

DISCUSSION

Technical Aspects

The position of each treatment before thinning with respect to percent maximum SDI and percent maximum BA is shown in figure 1. On log-transformed axes, constant values of either SDI or BA form negatively sloped lines within the plane defined by quadratic mean diameter and trees per acre. The main difference between the two density indices is that the slope for constant BA is shallower than the slope for constant SDI. In stands experiencing competition-related mortality, the log of quadratic mean diameter and the log of trees per acre forms a negative linear relationship. In contrast to conventional density-management theory, the slope observed in slash pine plots is not parallel to either the SDI lines or the BA lines. The reason that the slope in these slash pine plots is shallower than either SDI or BA is that age is constant across the plots. In this situation, the relationship follows the competition-density effect, not the typical tree size-tree number relationship (Hutchings and Budd 1981). In addition, two plots are actually above the 100 percent maximumn SDI line (figure 1). The maximum value of a density index is a stand attribute; the density of individual plots can exceed the stand-level maximum densities.

Stand Characteristics before and after thinning are displayed in table 1. Figure 2 illustrates statistically the comparative after-thinning tree size and stand density results. Note that the residual basal areas for the BA method treatments are within 4 square feet per acre of the target BA of 66 square feet per acre (30 percent of the maximum BA). As mentioned earlier, only the 10x1 O-foot spaced plots were ideally ready for thinning at age 17. The others were past due. Figure 2 also shows the nearly linear relationship between spacing distance and residual basal area. More basal area was removed in the closer spaced stands than in the wider spaced stands. Furthermore, had the first thinnings been done according to the timing dictated by the appropriate DMD, the initial BA density differentiation across spacings would probably have been greater in the SDI treatments.

Practical Considerations

A density management diagram helps a landowner determine the biologically optimum time for a thinning. Especially in the case of the first thinning, however, this may not be the best time economically. Often a landowner is willing to forego a portion of future stand quality by delaying the first thinning until pulpwood sales can cover all or part of the costs. That may not be possible if stands are thinned as early as the DMD may prescribe. Thinning slash pine at age 17, as we did in this study, was a compromise between biology and economics for the closer spacings. It was biologically on time for the 10x10 ft spacing, but too late for all the closer spacings.

We were aware, but did not compensate for, the possibility of ice and wind damage to these heavily thinned stands. Slash pine is particulary susceptible to this kind of damage in the northern portion of the southern coastal plain (Williston 1974) and is a moderately susceptible in our study area in central Louisiana. Rather than modifiy the thinning procedures further, we decided to accept the risk of ice damage. As the study progresses we will see if this decision was

Table l-Quadratic mean diameters, number of trees and stand basal areas before and after thinning by thinning method and planting spacing treatments

Thinning Method / Planting spacing	Quadratic Mean Diameter		Trees		Basal Area	
	Before thinning	After thinning	Before thinning	After thinning	Before thinning	After thinning
-Feet-	- - - Inch -		----Number/acre----		------Ft^2/acre------	
Stand Density Index Method						
4x4	4.7	4.9	1546	425	186	56
4x6	5.2	5.5	1180	287	155	58
6x6	6.2	6.5	787	287	151	63
6x8	6.7	7.0	515	250	126	66
8x8	7.2	7.4	429	215	121	65
10x 10	8.3	8.6	288	185	108	75
14x14	9.2	---	143	---	66	---
Basal Area Index Method						
4x4	4.7	4.9	1510	540	182	69
4x6	5.2	5.4	1147	419	169	67
6x6	6.2	6.4	634	295	133	66
6x8	6.7	6.9	504	256	123	67
8x8	7.2	7.5	484	218	137	66
10x 10	8.2	8.5	273	180	100	70
14x14	9.5	---	134	---	66	---

wise. If damage does occur, we will measure and evaluate its extent.

Rust-associated mortality was a big factor in the original spacing study (Ferguson and Baldwin 1995), and it will continue to be a factor in the thinning study, especially in the wider spacings. Selective thinnning at age 17 reduced occurence of fusiform rust bole infections from as high as 42 percent to less than 7 percent of the remaining stems in the four closest spacings. After thinning, 11 percent of the boles in the 8x8- and 10x10-foot plots and 22 percent of the boles in the 14x14-foot plots are still infected.

Our study should provide useful new information about the timing and intensity of thinning. It should enable us to validate the Dean and Baldwin (1995) DMDs in particular, and DMD theory in general. Growth and yield will be monitored to schedule future thinnings and determine the amount of material to be removed. Results will be reported as they become available.

ACKNOWLEDGMENT

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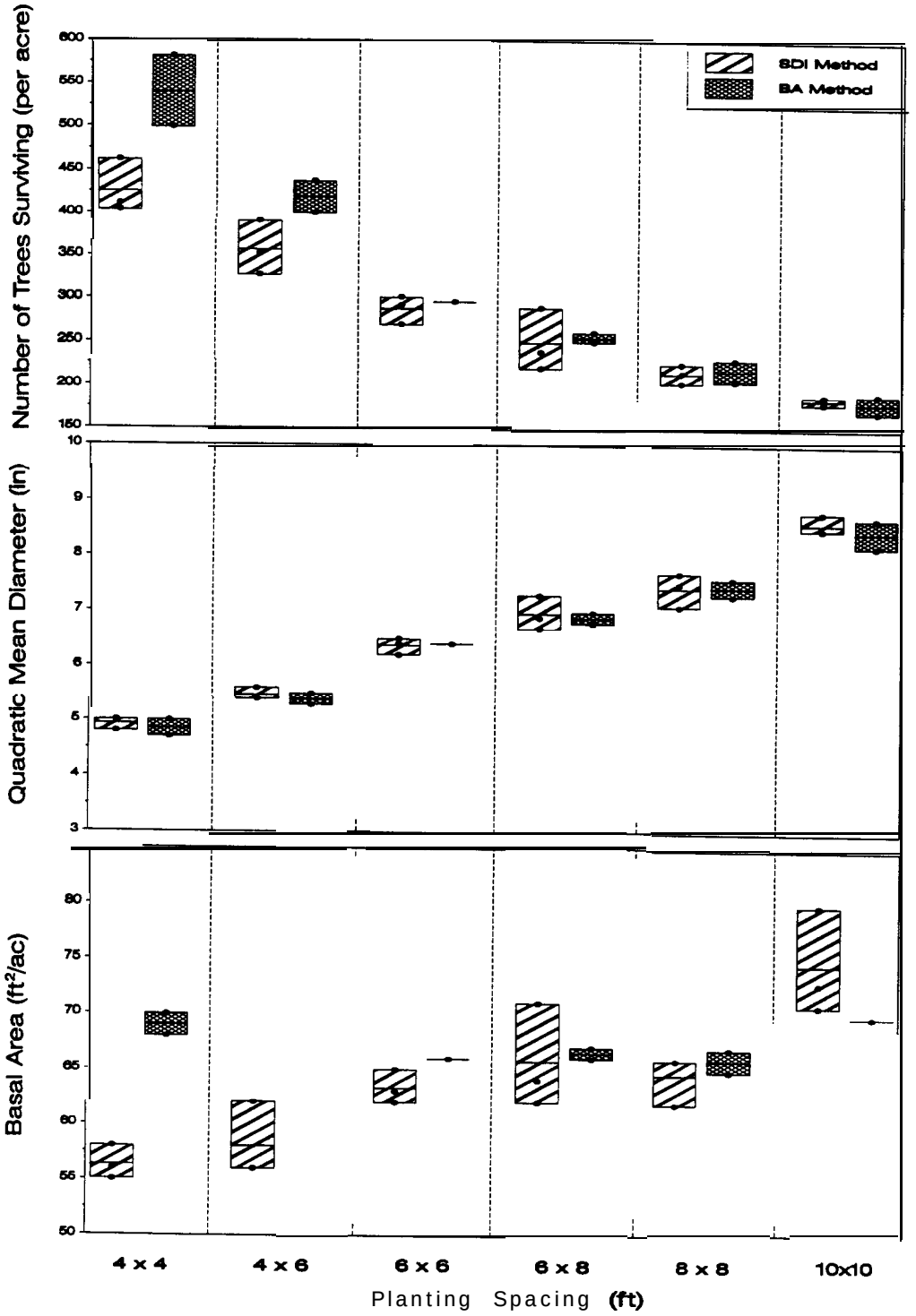

Figure 2-Statistical comparison of first thinning residual number of trees, quadratic mean diameter, and basal area per acre results using two thinning decision methods for six planting spacings of slash pine. Dots are the plot values, box ends are the range of plot values, and the horizontal bars are the treatment means.

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RELATIVE DENSITY MEASUREMENT AND SPECIES COMPOSITION IN THE MIXED UPLAND HARDWOOD FORESTS OF NORTH ALABAMA'

Lianjun Zhang, Brian P. Oswald, Thomas H. Green, and Susan L. Stout'

Abstract-Tree area ratio and stand density index were applied to data from 48 half-acre plots in the mixed upland hardwood forests of north Alabama. The tree area ratio model was used to place 24 species into four groups: (1) Red oak, (2) White oak and Chestnut oak, (3) Hickories, and (4) Sugar maple, Sweetgum and other minor species. These four groups are equally important in the modified stand density index model. The tree area ratio model and stand density index model produced similar results for measuring stand relative density.

INTRODUCTION

The mixed hardwood forests in the Tennessee Valley of north Alabama and adjacent regions contain a mixture of species with wide range of shade tolerance and growth rates. These forests are part of 13 million forested acres of the Interior Uplands found in Alabama, Tennessee and Kentucky (McGee 1982). Most of these stands have developed without any specific management or silvicultural activity, and have been subjected to repeated fires, insect and disease attack, as well repeated cuttings often in the form of high-grading.

Many of these stands are considered "low-quality", as they contain species not usually considered as "good" trees, even though individual trees may have "good' characteristics and high quality. The stands often have high number of stems per acre but low basal area. The lower canopy layers are often dominated by species with little or no commercial value. The stands are also commonly found on sites with low to moderate site quality (McGee 1982). These stands present a tremendous opportunity and challenge for silvicultural practice and forest management. However, little information on the relationship between species composition and the influence of crowding is available in north Alabama, which makes analysis, silvicultural prescription and management difficult.

Due to the natural characteristics of mixed hardwood forests, absolute measures of stand density such as basal area or the number of trees per acre may not be efficient in describing tree competition, stand structure and site potential. On the other hand, relative density is an index of crowding for forest stands and expressed as the ratio of absolute density to the density of a stand the same size and species composition at maximum density (Stout et al. 1987). Past expressions of relative density (Curtis 1982, Drew and Flewelling 1977, Reineke 1933, Stout and Nyland 1986) reflect the basic concept that undisturbed stands will reach a maximum degree of crowding that is characteristic for that forest type, and unless disturbed, will continue at that degree of crowding. Measures of relative stand density have proven to be useful in accounting for the effects of species composition on stand density in mixed-species forests and provide a practical tool for field use and planning silvicultural treatment (Stout and Nyland 1986).

The objective of this study was to apply two frequently used measures of relative stand density, tree ratio area and stand density index, to the mixed hardwood forests in the Tennessee Valley of north Alabama.

STUDY SITES AND METHODS

Three study sites were located in Monte Sano State Park and Redstone Arsenal, Madison County, Alabama and the Sipsey Wilderness, Bankhead National Forest, Lawrence County, Alabama. The sites were chosen to represent fully stocked stands of the mixed hardwood forests common to the region, and had no known management since stand establishment. The plots were placed between 800 and 1300 feet in elevation, and the soils were either Hartsell fine sandy loams, Smithdale sandy loams, Tidings-Banks Complex or Towiey-Apison Complex (Sherard et al. 1959, Swenson et al. 1979).

Within these sites, 70 half-acre plots were randomly established. On each plot, the diameters of all trees 0.5 inches and larger were measured at breast height (DBH) and tallied into 1 inch classes by species.

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Twenty-two plots contained Eastern Redcedar (*Juniperus virginiana*) and were not used in the analysis due to the increased variabilii introduced into hardwood stand density measures with the presence of coniferous species. For the remaining 48 plots, overall average tree DBH was 4.9 inches and stand density was 355 trees per acre. In total, 24 tree species were recorded. White oak (Quercus *alba*) represented 26 percent of the basal area of all the plots. Chestnut oak (Quercus *prinus*) / Chinkapin oak *(Quercus muehlenbergii*), Hickories (*Carya* spp.), and Red oak *(Quercus rubra* and *Quercus falcata*) each represented about 15 percent of the basal area. All others species, except Yellow poplar (*Liriodendron tulipifera*), each represented less than 4 percent of the basal area (Table 1). Only Hickories and White oak were found in every plot. Ash (*Fraxinus* spp.), Chestnut oak / Chinkapin oak, Dogwood (*Cornus florida*), Red oak, and Sugar maple (*Acer saccharum*) appeared in 80 percent of the plots (Table 2). For each species, the total number of trees, basal area percentage, averages and ranges of tree diameter in the 48 plots are listed in Table 1.

Two relative density measures were applied to the data: (1). Tree area ratio is based on the assumption that each plot was at average maximum density or had a relative density equal to 100 percent. Species composition was included by adding up the number of trees, tree diameters, and squared diameters for each species in the plot (Stout and Nyland 1986). The tree area ratio model has the following general form:

$$100 = \Sigma_i(\beta_{0i}*N_i + \beta_{1i}*\Sigma_j D_{ij} + \beta_{2i}*\Sigma_j D_{ij}^2) \quad [1]$$

where N, is the number of trees per acre of the Ah species; D_{ij} is the diameter (inch) of the *j*th tree of the *i*th species on the sample plot; and β_{0i}, β_{1i}, and β_{2i} are the regression coefficients estimated for the *i*th species.

Table 1 -- Total number of trees, basal area percentage and tree diameter of 24 species in all the 48 plots

Species name	Total number of trees	Basal area (pct)	Tree diameter (inch)		
			Mean	Min.	Max.
American elm	214	0.3	2.0	0.5	9.0
Ash spp.	709	2.5	2.7	0.5	21.0
Basswood	45	0.2	2.7	0.5	13.0
Beech	199	2.3	4.9	0.5	30.0
Black cherry	82	0.4	2.9	0.5	16.0
Black locust	36	0.9	8.4	0.5	21.0
Black maple	503	1.4	2.6	0.5	15.0
Buckthorn	534	0.6	1.7	0.5	11.0
Chestnut oak/Chinkapin oa	637	15.3	8.6	0.5	25.0
Cucumber tree	234	1.8	3.9	0.5	28.0
Dogwood	1062	1.8	2.2	0.5	15.0
Hickory spp.	1096	15.6	5.9	0.5	23.0
Ironwood	31	0.0	2.1	0.5	4.0
Mulberry	6	0.0	2.2	2.0	3.0
Post oak	5	0.1	10.0	8.0	12.0
Red oak	450	16.2	11.2	0.5	24.0
Sassafras	62	0.5	5.4	0.5	12.0
Sourwood	252	1.4	3.9	0.5	14.0
Shagbark hickory	240	3.7	6.0	0.5	21.0
Sugar maple	947	2.5	2.5	0.5	20.0
Sweetgum	103	0.8	4.9	0.5	16.0
Vaccinium spp.	71	0.0	0.9	0.5	2.0
White oak	840	25.9	9.9	0.5	29.0
Yellow poplar	171	5.9	9.7	0.5	30.0
Overall	8529	100	4.9	0.5	30.0

The tree area ratio for a species is related to lts number of trees per acre, basal area per acre, and the sum of diameters per acre which accounts for the differences in the diameter distribution of a species between stands (Gingrich 1967, Stout and Nyland 1986).

Table 2 -- Number of plots in which tree species appeared in all the 48 plots

Species name	Number of plots
American elm	25
Ash spp.	44
Basswood	9
Beech	IO
Black cherry	I2
Black locust	11
Black maple	24
Buckthorn	27
Chestnut/Chinkapin oak	40
Cucumber tree	17
Dogwood	46
Hickory spp.	48
Ironwood	4
Mulberry	I
Post oak	3
Red oak	45
Sassafras	12
Sourwood	25
Shagbark hickory	28
Sugar maple	38
Sweetgum	I5
Vaccinium spp.	I8
White oak	48
Yellow poplar	33

Commonly all tree species are divided into a few groups. These groups represent a family of reference lnes reflecting differences in the amount of basal area, growth rate and tolerance to shade in the species groups (Stout and Nyland 1986). The equation [I] was preliminarily applied to each species. Contrast (F-test) was used to detect significant differences between tree species. Combining the test results and tree ecological characteristics, the 24 tree species were categorized into a few basic groups. Different assignment of species to groups was tested by reapplying the equation derived for each tested species grouping to all the plots in the data and calculating their relative densities. A "best" grouping was determined by selecting one with the lowest standard deviation of the estimated relative density.

(2). Stand density index is based on the assumptions that the number of trees per acre decreases in constant proportion to the quadratic mean tree diameter raised to some power. Usually logarithmic transformation of the above relationship is used instead of power function. The effects of species composition can also be included in the stand density index model as follows (Stout and Nyland 1986):

$$\log(N) = \log(\alpha_0) + \alpha_1 * \log(QMD) + \Sigma_i(\alpha_{2i} * BA_i) \quad [2]$$

where log is natural logarithm; N is the number of trees per acre; QMD is the quadratic mean tree diameter (inch); BA_i is the percentage of the basal area represented by the ith species group identified in the tree area ratio analysis; and $a_{,}$, $a_{,,}$ and α_2 are the regressloh coefficients to be estimated. Then stand density index can be estimated by:

$$SDI = (N_{obs} / N_{predict}) * 100 \quad [3]$$

where SDI is stand density index (percent); N_{obs} is the observed number of trees per acre; and $N_{predict}$ is the predicted number of trees per acre from the equation [2]. Then, the equations [2] and [3] were applied to each plot in the data. The estimated SDI was compared with the estimated tree area ratio.

RESULTS AND DISCUSSION

According to the preliminary analysis of the tree area ratio model, all 24 tree species were placed into four basic groups: group one was based on Red oak, group two was based on White oak / Chestnut oak, group three was based on Hickories, and group four was based on Sugar maple, Sweetgum and all other minor species (Table 3). The total number of trees in all 48 plots, the sum of diameters per acre and the sum of squared diameters per acre for each species group are provided in Table 4. Figure I shows the relationship between the number of trees per acre and the sum of diameters per acre for each species group.

Trees in groups I and 2 tend to be larger than trees in groups 3 and 4 (Table 4). Most of the tree species in

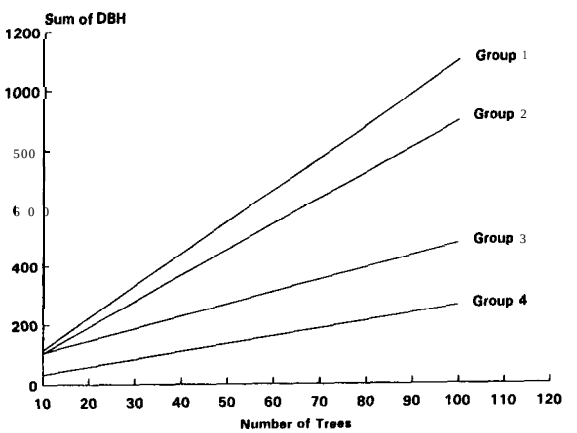

Figure I -- Relationships between number of trees/acre in each plot and the summation of tree diameters in each plot for the four species groups.

Table 3 -- Species grouping of "best" tree area ratio model

Species group	Species in group
1. Red oak	Red oak Post oak
2. White oak/Chestnut oak	White oak Chestnut oak Chinkapin oak Yellow poplar
3. Hickories	Hickory spp. Shagbark hickory
4. Sugar maple/Sweetgum/ other minor species	American elm Ash spp. Basswood Beech Black cherry Black locust Black maple Buckthorn Cucumber tree Dogwood Ironwood Mulberry Sassafras Sourwood Sugar maple Sweetgum Vaccinium spp.

group 4 (Sugar maple/Sweetgum/others) are minor species which never attain dominance in these type of stands, or are shade tolerant species which would not develop as major individuals on these sites for a long time after stand establishment. The other species in this group (e.g. ash, beech, and black cherry) can attain large diameters and heights on the sites, and occasionally were found to be some of the dominant trees. Since these same species had many smaller stems in the plots as well, they may have large number of trees per plot but did not provide the large numbers of "big" trees as found in groups 1 and 2. The growth rates of the hickories (*Carya ovata, C. cordifonnis, C. glabra*) in group 3 are less than the oaks found on the same sites (Burns and Honkala 1990), but greater than the species in group 4.

The oaks and Yellow poplar in groups 1 and 2 are early successional species on these sites, and became established on these sites at least 60 years ago, which was when the most recent management disturbance could have occurred on these sites. They are some of the fastest growing species on these sites, and can be expected to be the dominant trees on these sites for a number of years.

The tree area ratio model (equation [l]) was fitted to the four species groups. The estimated regression coefficients are shown in Table 5. The model had a standard deviation about the regression of 13.3 percent. When the above equation was reapplied to the 48 plots, the estimated tree area had mean 98.7 and standard deviation of 11.4. The above results were similar to other studies (e.g. Stout and Nyland 1986).

Table 5 -- Estimates of the regression coefficients for the "best" tree area ratio model

Species group	Pa	β_{1i}	β_{2i}
1. Red oak	-0.931046	0.161985	-0.004827
2. White oak/ Chestnut oak	0.241237	-0.031102	0.004822
3. Hickories	-0.286883	0.126857	-0.004183
4. Sugar maple/ Sweetgum/ other minor species	0.113826	0.044834	-0.000671

Table 4 -- The total number of trees, the sum of diameters per acre and the sum of squared diameters per acre for each species group in all the 48 plots

Species group	Total number of trees	ID/Acre			ΣD^2/Acre		
		Mean	Min.	Max.	Mean	Min.	Max.
1. Red oak	455	225	4	1682	3009	8	20086
2. White oak/Chestnut oak	1648	255	1	898	3232	1	11902
3. Hickories	1336	208	12	872	2107	40	10393
4. Sugar maple/Sweetgum/ other minor species	5090	117	1	760	612	1	7908

The traditional stand density index model was fitted to the data and the following equation was obtained:

$$\log(N) = 7.714684 - 0.959065*\log(QMD) \quad [4]$$

The model R^2 was 0.31, Root MSE was 0.1753, and Coefficient of Variation (C.V.) was 3 percent. Both the intercept and slope of the equation [4] were smaller than those (9.36 and 1.58, respectively) for northern mixed hardwood (Stout and Nyland 1986). Adding terms for basal area representation of the four species groups improved model fitting to the data. The model R^2 increased to 0.57, Root MSE reduced to 0.14, and C.V. decreased to 2.4 percent. The modified stand density index model was as follows:

$$\log(N) = 132.4291 - 0.764353*\log(QMD) - 1.246827*(BA_1\ pct) - 1.251403*(BA_2\ pct) - 1.250463*(BA_3\ pct) - 1.253185*(BA_4\ pct) \quad [5]$$

where BA_i pct is the basal area percentage of species group *i* (i = 1, 2, 3, and 4). All regression coefficients were significant at α=0.01. The regression coefficients for the four basal area percentage of species groups had the same sign and similar magnitude, indicating that the four species groups may be equally important in the SDI model. The equation [5] was applied to each sample plot to estimate $N_{predict}$ in the equation [3]. Then stand density index was calculated for each plot utilizing the equation [3]. The mean of the estimated SDI was 100.9 with standard deviation of 13.2.

The relationship between estimated tree area and SDI was linear (Figure 2) with Pearson correlation coefficient 0.75. The linear relationship can be expressed as:

$$\text{Tree Area} = 32.827433 + 0.653189*(SDI)$$

or

$$SDI = 15.055416 + 0.869266*(\text{Tree Area})$$

SUMMARY

It is apparent from these results that species composition is an important consideration in expressing stand density in the mixed hardwood forests of north Alabama. Both measures of relative stand density (tree area ratio and stand density index) are useful in describing the mixed hardwood forests of the Tennessee Valley. According to the tree area ratio model, the 24 tree species found in the 48 plots were placed into four basic groups: (1) Red oak, (2) White oak / Chestnut oak, (3) Hickories, and (4) Sugar maple and Sweetgum. The four species groups seemed to have equal contribution to the stand density index model. The tree area ratio model and stand density index model produced similar results for measuring stand relative density. However, the two models should be applied to stands on the Bankhead National Forest with similar stand structure where intermediate silvicultural cuttings are applied to evaluate the utility of those measurements for stand development with different management objectives.

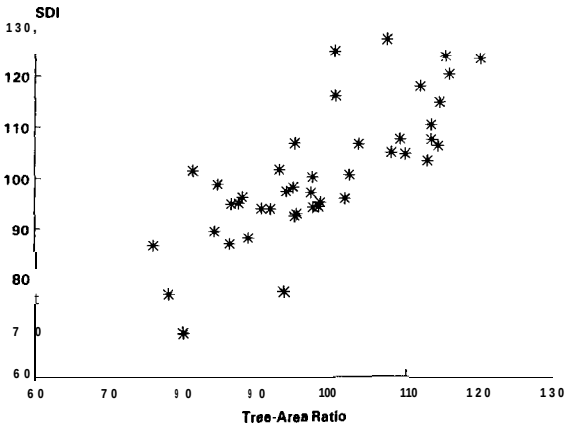

Figure 2 -- Relationship between estimated tree area ratio (from Equation [I] and Table 5) and estimated stand density index (from Equation [5]).

ACKNOWLEDGEMENTS

Funding for this project was provided by a USDA Cooperative Agreement Grant 23-91-03 between Alabama A & M University and the Northeastern Forest Experiment Station in Warren, PA. Special thanks are extended to Willie Adams, Paul Mignott and Ron DuPree who collected the field data.

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SPACING EFFECTS ON UNTHINNED SLASH PINE IN THE WEST GULF'

Robert B. Ferguson and V. Clark Baldwin, Jr.'

Abstract-Slash pines were planted at seven spacings ranging from 4x4 to 14x14 feet in central Louisiana. Development through **age** 10 showed no significant differences in average tree height among the spacings. At age 15 **average** heights differed significantly between the two widest spacings and the remaining five spacings. Mean heights ranged from 40.6 feet for the **4x4-foot** spacing to 47.0 feet for the 10x1 O-foot spacing, the second widest. Significant differences were also detected among spacing treatments for the mean heights of the 10 tallest trees per plot. Effects of spacings on diameter, basal ares, **and** volume of stands and individual trees were in the ranges repotted in previous studies. Previous **studies** In the West Gulf **have** not detected as strong an effect of spacing on mean and dominant stand height, however.

INTRODUCTION

Effects of southern pine planting density on diameter growth, rotation length, age of first thinning, log grade, and product grown in a specific time frame are widely recognized. Effects of initial spacing on height growth of dominant stems are not well understood or accepted. In the Southeastern United States, Bennett (1960) reported no correlation of height with stand density through age 7 in unthinned slash pine (*Pinus elliottii* var. *elliottii* Engelm.) plantings. However, at age 12 and beyond, significant differences in height were detected between closely and widely spaced plantings (Harms and Collins 1965, Bennett 1965) Similar results were reported by Bowling (1987) for 20-year-old slash pines in Georgia. Other tests of planted pines further west generally have not revealed significant effects of stand density on height growth (Haywood and others 1990, Clason 1994). Even a few feet of difference in height growth are important, however, because they can profoundly affect harvested volume and grade.

We report here the 15-year results of a slash pine study planted in the winter of 1976-77 in the West Gulf Region. Objectives of this study were to test the effects of planting density on (1) dominant height, (2) age of the onset of competition, and (3) volume, diameter, basal area growth.

MATERIALS AND METHODS

The study is about 1 mile east of Woodworth, Louisiana, on the Alexander State Forest which is managed by the Louisiana Office of Forestry. The soil on the site is Kolin silt loam (fine-silty, siliceous, thermic Glossaguic Paleudalf). A perched water table above a clayey subsoil occurs 1 to 2 feet below the surface during winter months. A very gentle slope allows adequate surface runoff.

Planting stock for this study was grown from open-pollinated seed from a single seed orchard of grafted, genetically improved parents. Seedlings were grown in a nursery adjacent to the seed orchard. All seedlings used to establish the study were graded for size.

Seven spacing treatments (4x4, 4x6, 6x6, 6x8, 8x8, 10x10, and 14x14 feet) were planted in a five randomized Mocks. Each measurement plot consisted of 8 rows of 8 trees each regardless of spacing. A 33-foot isolation strip with trees of the same spacing surrounded each plot.

To insure as nearly complete stocking as possible early mortality was observed in April, May, and June of the first growing season. Dead seedlings on the measurement plots and within one planting spacing of the measurement plot were replaced with healthy potted seedlings of the same age and seed lot as those originally planted.

Starting at age 2, each tree was examined for the presence of fusiform rust stem cankers (*Cronartium quercum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme*). Dead trees with stem cankers were classified as rust associated mortality (RAM). Dead trees with no apparent stem cankers were classified as non-rust associated mortality (NRAM).

Trees were measured annually through age 10 and then again at age 15. Total height to the nearest 0.1

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foot and ground line diameter to the nearest 0.1 inch were measured from age 1 through age 5. Beginning at age 6, total height was measured to the nearest 0.5 foot and diameter at breast height (d.b.h.) to the nearest 0.1 inch. The 10 tallest trees per plot (10-T) at each age were used to represent the dominant and codominant components of the stand.

Data were subjected to an analysis of variance for a randomized block design. Significant differences among means were identified with Tukey's test (Steel and Torrie 1960).

Beginning with age 6, total cubic-foot volume (outside bark) was computed with the equations of Lohrey (1985). Treatment volumes per acre were computed from all trees within a spacing. The per acre volumes for 10-T samples were computed from only the 10 tallest trees from each plot. Volumes for the tree of mean height and d.b.h. were computed for each spacing.

Although data were collected annually through age 10 and then at age 15, we present only data for ages 2, 6, 10, and 15 in this paper. Age 2 was selected because it was the first year fusiform rust stem cankers were recorded. Age 6 was chosen because it was the first year in which d.b.h was recorded. The last of the annual measurements were taken at age 10. Age 15 was the oldest data available. We do, however, refer to some general results for the full data set. Readers may contact the authors for further information.

RESULTS AND DISCUSSION

Most of the trends and inter-relationships among variables are as one would expect for a study of this kind. For example, trees of the largest average diameter at age 15 occur on plots planted at the widest spacing, and trees of the lowest average diameter occur on plots planted at the closest spacing. Because the site is fully occupied by trees at an earlier age, however, yields through age 15 are greatest for the closest spacings and lowest for widest spacings. Table 1 shows the effects of spacings on stand characteristics. Table 2 shows effects on individual trees.

For the sake of brevity, we will say little about the predictable results. Instead, we will focus on comparative tree heights at various ages, on trends in mortality, and on the influence of fusiform rust on mortality.

Height

Heights of all trees and heights of dominant and codominant trees (10-T) were not significantly or consistently influenced by initial planting spacing. Moreover, the range in treatment averages at age 10 was quite small-27.1 to 28.9 feet for all trees and 30.7 to 32.8 for 10-T samples.

By age 15, however, the range among treatment means was increasing-40.6 to 47.0 feet for all trees and 46.1 to 51.9 feet for 1 O-T samples. In addition, trees on the plots planted at the 4x4-foot spacing were significantly shorter than trees planted at most of the wider spacings (Table 1). Among 1 O-T samples, trees at the two closest spacings were significantly shorter than trees at the three widest spacings.

This is not the first report of an effect of planting spacing on slash pine heights. The trends we observed are similar to those found by Bennett (1960) and Harms and Collins (1965) for slash pines planted on old-field sites in Georgia. Our results differ from previous results in two ways: (1) the differences we observed did not occur until sometime between ages 10 and 15, and (2) we found significant differences among all trees in the stand as well as among dominant and codominant stems.

Mortality

Mortality at the end of the first growing season ranged from 7.2 percent at the 6x8-foot spacing to 2.2 percent at the 4x4-foot spacing. As we mentioned in describing our methods, these dead seedlings were replaced to maintain uniformity within treatments. We wanted to observe effects of spacing without these extraneous influences.

At all spacings, mortality rose fastest through about age 5, and RAM accounted for a majorii of total mortality (Figure 1). After age 5, mortality from all causes continued, but at a much reduced rate.

RAM occurred sooner and tapered off sooner at the closer spacings. It occurred somewhat later at the wider spacings. By age 15, however, mortality was similar at all spacings. At the 4x4-foot spacing, the loss to all causes was 40.3 percent, with 27.2 percent as RAM. At the 14x14-foot spacing, the total loss was 35.4 percent with 29.4 percent as RAM. Figure 1 clearly illustrates that in this study fusiform rust infection was the largest single cause of mortality by a wide margin. Examination of the individual plot records shows that distribution of rust infection over the study area was fairly uniform.

Diameter

Examination of average tree diameters suggests when serious intertree competition began at the various spacings. At age 6, when d.b.h. was first measured, trees at the 4x4-foot spacing already were significantly smaller in diameter than trees at the 10x1 O-foot spacing. Competition at the closest spacing had been going on long enough to create that difference in d.b.h. By age 10, intertree competition had significantly slowed diameter growth at all but the two widest spacings. And by age 15, there was a statistically significant difference in d.b.h. between trees at the 10x10- and 14x14-foot spacings.

Table l-Study means by spacing treatment for selected ages of unthinned planted slash pine in the West Gulf region.

Age and spacing	Volume(ob) (cu.ft./ (ft.)	Total heiaht All ac.)	Total heiaht 10-T (ft.)	Basal area (sq.ft./ ac.)	D.b.h. All (in.)	D.b.h. 10-T
Age 2						
4x4	-	2.4 a	3.2 ab			
4x6	-	2.0 a	2.7 b			
6x6	-	2.4 a	3.2 ab			
6x8	-	2.1 a	2.9 ab			
8x8	-	2.4 a	3.3 ab			
10x10	-	2.5 a	3.6 a			
14x14	-	2.3 a	3.1 ab			
Age 6						
4x4	430 a	13.9 a	16.7 a	50.0 a	2.1 b	2.7 c
4x6	246 b	12.8 a	15.5 a	31.0 b	2.3 ab	2.6 c
6x6	259 b	14.5 a	17.0 a	29.1 b	2.5 ab	2.9 abc
6x8	138 cd	12.6 a	15.4 a	17.4 c	2.2 ab	2.7 bc
8x8	166 bc	14.2 a	17.3 a	18.7 c	2.5 ab	3.0 ab
10x10	120 cd	14.1 a	17.4 a	13.2 cd	2.7 a	3.3 a
14x14	46 d	12.8 a	16.0 a	5.6 d	2.5 ab	3.1 ab
Age 10						
4x4	1892 a	27.2 a	31.4 a	122.8 a	3.4 d	4.2 e
4x6	1487 b	27.1 a	30.7 a	98.1 b	3.7 d	4.5 de
6x6	1388 b	28.7 a	32.3 a	86.2 b	4.3 c	4.9 cd
6x8	1004 c	27.0 a	31.0 a	65.1 c	4.4 bc	5.2 c
8x8	1073 c	28.9 a	32.8 a	65.5 c	4.8 b	5.7 b
10x10	808 c	28.5 a	32.8 a	49.3 d	5.2 a	6.0 ab
14x14	395 d	27.1 a	31.7 a	25.0 e	5.4 a	6.2 a
Age 15						
4x4	3686 a	40.6 c	46.1 c	168.0 a	4.4 f	5.3 f
4x6	3452 ab	41.5 bc	47.0 bc	153.4 a	4.9 e	5.9 e
6x6	3096 bc	44.9 a	50.1 ab	127.6 b	5.7 d	6.5 d
6x8	2551 de	44.5 ab	49.2 abc	106.9 c	5.8 d	6.9 d
8x8	2773 cd	46.7 a	51.8 a	110.3 bc	6.6 c	7.4 c
10x10	2221 e	47.0 a	51.9 a	88.0 d	7.5 b	8.4 b
14x14	1336 f	45.2 a	50.3 ab	53.8 e	8.3 a	9.1 a

Means followed by a common lower case letter do not differ significantly at the α=0.05 level.

Since 1 O-T trees represent successful competitors, one might have expected statistically significant differences in diameter to appear later among 1 O-T samples than among all trees on the plots. While such an effect could be inferred from the letters expressing mean d.b.h. separations in Table 2, that effect is not as strong as might have been expected.

Basal Area and Volume

The effects of planting spacing on basal area and volume are as one would expect from a study like ours. Basal area and volume per acre were greatest for the closest spacings and least for the widest spacings. In the period before intertree competition occurs, larger numbers of trees per acre translate into more rapid increases in basal area and volume.

The effects of planting spacing on basal areas and volumes of individual trees are the opposite of the effects on stands as a whole. Closer spacings translate into smaller basal areas and volumes.

In choosing an appropriate planting spacing, the silviculturist must make a difficult tradeoff between performance of individual trees and performance of stands. Stand yields normally are highest at relatively close planting spacings, whereas the performances of individual trees are normally best at relatively wide spacings.

Table 2--Mean values by spacing treatment for selected ages of unthinned planted stash pine in the West Gulf region.

Age and spacing (ft.)	Volume(o.b) All (cu.ft./tree)	Volume(o.b) 10-T (cu.ft./tree)	Basal Area All (sq.ft./tree)	Basal Area 10-T (sq.ft./tree)	Cumulative Mortaiii R A M (percent)	Cumulative Mortaiii NRAM (percent)	Cumulative Mortaiii Total (percent)
Age 2							
4x4					5.0 a	2.5 a	7.5 a
4x6	-				2.8 a	4.7 a	7.5 a
6x6	-				2.5 a	6.6 a	9.1 a
6x8	-				5.0 a	7.8 a	12.8 a
8x8	-				2.2 a	3.1 a	5.3 a
10x10	-	-			1.9 a	4.0 a	5.9 a
14x14	-				1.6 a	4.0 a	5.6 a
Age 6							
4x4	0.21 bc	0.37 bc	0.024 bc	0.039 bc	21.0 a	3.4 ab	24.4 a
4x6	.18 c	.32 c	.023 c	.036 c	21.2 a	4.7 ab	25.9 a
6x6	.30 abc	.45 abc	.033 abc	.046 abc	21.3 a	6.8 ab	28.1 a
6x8	.22 bc	.37 bc	.028 bc	.040 bc	21.9 a	8.7 a	30.6 a
8x8	.31 ab	.51 ab	.035 ab	.051 ab	18.1 a	3.2 b	21.3 a
10x10	.36 a	.60 a	.039 a	.059 a	17.5 a	4.7 ab	22.2 a
14x14	.27 abc	.47 abc	.033 abc	.052 ab	19.1 a	4.6 ab	23.7 a
Age 10							
4x4	0.96 c	1.51 e	0.062 c	0.094 d	23.8 a	3.4 a	27.5 a
4x6	1.14 bc	1.73 de	.075 bc	.106 d	23.5 a	4.6 a	28.1 a
6x6	1.66 b	2.27 cd	.103 b	.134 c	24.1 a	6.8 a	30.9 a
6x8	1.64 bc	2.36 bc	.106 b	.144 c	23.7 a	8.8 a	32.5 a
8x8	2.06 a	2.90 b	.126 a	.165 b	19.7 a	3.4 a	23.1 a
10x10	2.45 a	3.55 a	.150 a	.197 a	19.7 a	4.7 a	24.4 a
14x14	2.52 a	3.56 a	.159 a	.210 a	24.4 a	5.0 a	29.4 a
Age 15							
4x4	2.27 f	3.60 e	0.103 f	0.152 e	27.2 a	13.1 a	40.3 a
4x6	2.94 ef	4.53 e	.131 ef	.187 e	25.3 a	10.3 a	35.6 a
6x6	4.29 de	6.06 d	.177 de	.232 d	27.8 a	12.5 a	40.3 a
6x8	4.92 d	6.57 d	.206 d	.260 d	29.1 a	13.7 a	42.8 a
8x8	5.93 c	8.17 c	.236 c	.302 c	23.7 a	7.2 a	30.9 a
10x10	7.66 b	10.50 c	.304 b	.386 b	24.7 a	8.7 a	33.4 a
14x14	9.34 a	12.04 a	.376 a	.456 a	29.4 a	6.2 a	35.6 a

Means followed by a common lower case letter do not diier significantly at the α=0.05 level.

1/ RAM = Rust Associated Mortality; NRAM = Non-Rust Associated Mortality

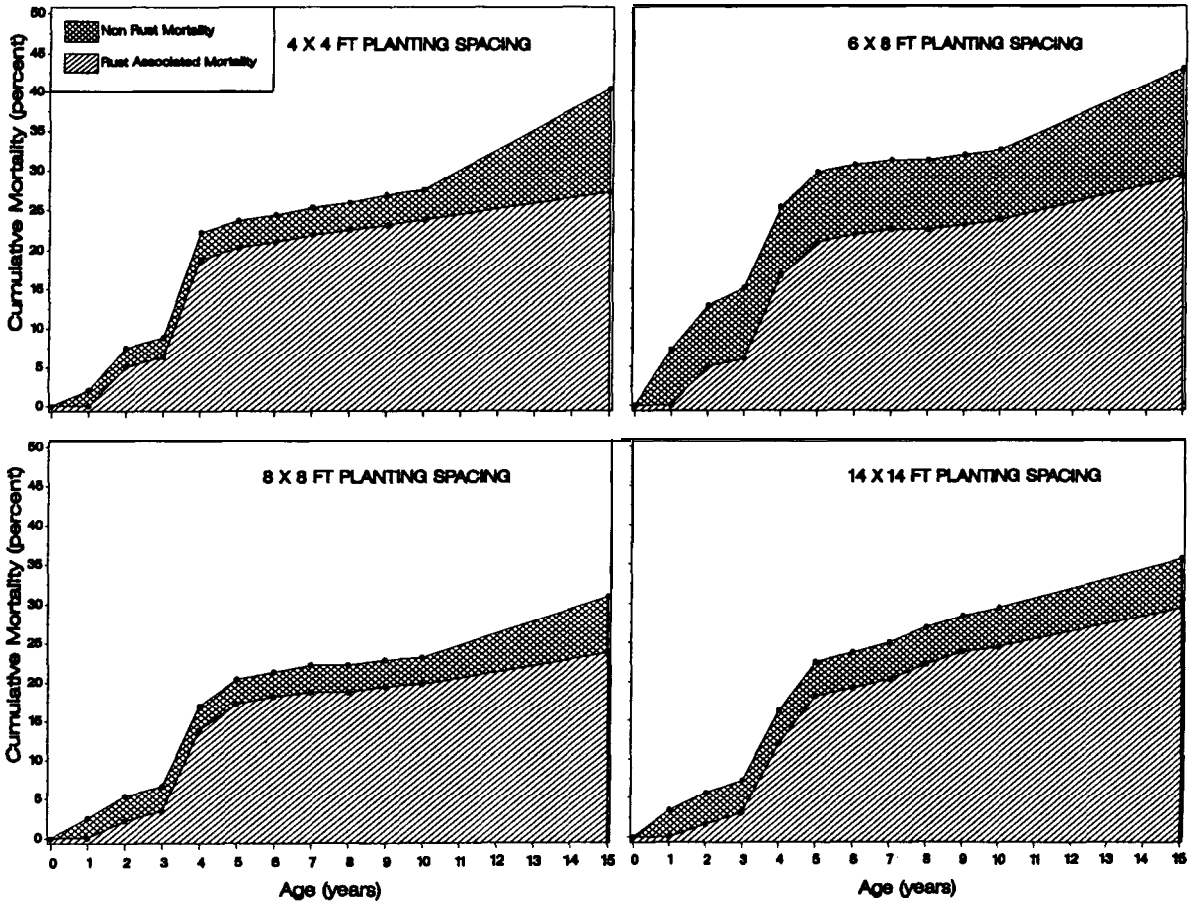

Figure l-Cumulative mortality expressed as a percent of the original planted stand for four selected spacing treatments of unthinned planted slash pine in the West Gulf region.

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SHELTERWOOD CUTTING AND UNDERSTORY CONTROL INCREASE GROWTH OF OAK, ASH, AND CHERRY REPRODUCTION IN NORTHERN ARKANSAS'

David L. Graney and Paul A. Murphy[2]

Abstract-Five- and nine-year growth of white oak, red oaks, white ash, and black cherry advance reproduction was evaluated in upland oak stands representing a range in site quality, residual overstory stocking, and three competition control treatments. Analysts of covariance was used to test and describe the growth relationships for individual species as affected by initial stem height, groundline diameter, site quality, overstory stocking, and intensity of competition control. Reproduction growth varied significantly by species. Growth was significantly affected by intensity of competition control, initial height, and time since treatment for all species. Height development for black cherry was also affected by site quality and residual overstory stocking.

INTRODUCTION

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

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

The oak component of future hardwood stands depends on sprouts from cut overstory stems and the number, size, and distribution of oak advance reproduction present at harvest (Sander 1971, 1972; Sander and Clark 1971; Sander and others 1984; Loftis 1990a). Newly established oak seedlings and small advance reproduction grow too slowly to compete successfully after harvest (Sander and Clark 1971, McQuilkin 1975). In contrast, large oak advance reproduction grows rapidly after harvest and has a high probability of becoming dominant in the new stand (Carvell 1979, Sander and others 1984, Loftis 1990a).

Upland hardwood stands in the Boston Mountains of northern Arkansas may have more than 1,000 stems per acre of advance oak reproduction and other desirable species, but most are less than 1 foot tall, and larger reproduction is often absent. Many of these stands are mature and fully stocked, and have well-developed understories of shade-tolerant noncommercial species. Given the size and status of existing reproduction, new stands that develop after harvest will almost certainly contain a low proportion of oak. In several areas, researchers are trying to stimulate the growth of small advance reproduction with light to medium shetterwood cutting plus partial to complete midstory and understory control (Sander 1979, 1987, 1988; Sander and Graney 1993; Loftis 1990b).

Variants of the shelterwood method for regenerating oaks has shown promise in the Missouri Ozarks (Schlesinger and others 1993) and the southern Appalachians (Loftis 1990b). In these studies, development of oak reproduction on productive sites hasbeenenhanced.

Most oak shelterwood studies have measured changes in numbers of stems in various size classes for (1) a single oak species, (2) for several combined oak species, or (3) all commercially desirable species combined. But individual oak and other desirable species may respond differently to various combinations of overstory and understory shelterwood treatments, and the responses may vary over time. Although models have been derived to predict the

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development of oak advance reproduction after overstory removal (Dey 1993, Sander and others 1984, Loftis 1990a), there is little information about development of oak and other desirabie reproduction under a shelterwood.

In this paper, we report height development of advance regeneration for 9 years after overstory and understory density control. Data are reported for white oak, *Quercus alba* L., black and northern red oaks, C?. *velutina* Lam. and Q. *rubra* L., black cherry, and white ash.

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.

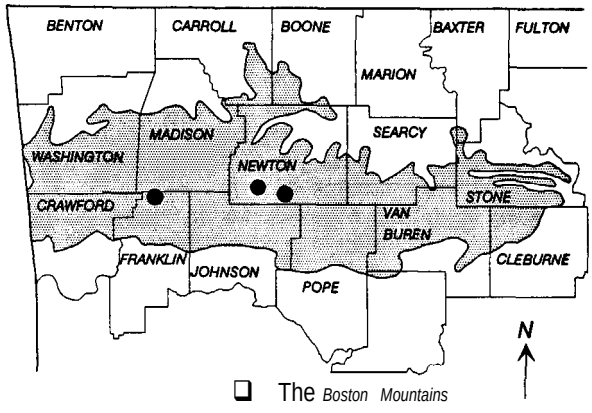

Figure 1 .-Location of study areas (two stands per area) in the Boston Mountains of northern Arkansas.

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 0.5 mile wide. Mountainsides consist of alternating steep simple slopes and gently sloping benches.

Soils on mountaintops and slopes usually have shallow to medium depth and are represented by medium-textured members of the Hartsells, Linker, and Enders series (Typic Hapludults). They are derived from sandstone or shale residuum, and their productivity is medium to low. In contrast, soils on mountain benches are deep, well-drained members of the Nella and Leesburg series (Typic Paleudults). They developed from sandstone and shale colluvium, and their productivity is medium to high.

Rocks in the area are alternating horizontal beds of Pennsylvanian shales and sandstones. Annual precipitation averages 46 to 48 inches, and March, April, and May are the wettest months. Extended summer dry periods are common, and autumn is usually dry. The frost-free period is normally 180 to 200 days long.

Study Description

Six mature upland hardwood stands were selected for study at three locations on the Ozark National Forest (fig. 1). Three stands are on upper north- or east-facing slopes, which have oak site indexes of 55 to 65 feet for northern red oak, base age 50. The other three stands are on north- or east-facing mountain benches with red oak site indexes of 66 to 80 feet. Six plots (approximately 1 acre in size) were established in each stand, and one of six overstory-understory treatments was randomly assigned to each plot.

Overstory (stems ≥1.6 inches d.b.h.) densities were reduced to either (1) 40 or (2) 60 percent relative stocking density (Gingrich 1967). Understory (stems <1.6 inches d.b.h.) treatments were: (A) no understory treatment (low), (B) kill all less-desirable stems taller than 4.5 feet (intermediate), or (C) kill all less-desirable stems (intensive).

Pretreatment overstory stocking for all plots averaged 106 percent and basal area averaged 118 ft^2 per acre (table 1). The overstory was cut from below. Ail subcanopy stems 1.6 inches d.b.h. and larger were

Table 1 .-Original and residual overstory stand values.

Stand condition	Site index		Basal area		Stocking[a]	
	Mean	Range	Mean	Range	Mean	Range
	---Ft---		---Ft^2---		---Percent---	
Before treatment	66	56-80	118	95-I 30	106	90-I 20
After treatment	66	56-80	63	43-81	50	37-62

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

removed first then the overstory canopy was cut to the prescribed stocking goat. Stumps of all less-desirable overstory stems were sprayed with 2,4-D plus picloram to reduce sprouting. Understory control treatments were imposed by cutting target stems near ground level and spraying stumps with the 24-D plus plicoram herbicide immediately after cutting. Understory treatments were completed in May 1980, and overstories were thinned during May to July 1980.

Overstories on all plots were predominantly oak. Northern red, black, and white oaks accounted for 80 percent of the overstory stocking before thinning and more than 90 percent after treatment. Ash and cherry represented less than 1 percent of the stocking on all plots.

Understories on medium sites were dense and mixtures of tolerant brushy or less-desirable species such as red maple, *Acer rubrum* L., serviceberry, *Amelanchier arborea* Michx. f. Fern., redbud, *Cercis* canadensis L., and blackgum, *Nyssa sylvatica* Marsh. Dogwood, *Cornus florida* L., hophornbeam, *Ostrya virginiana* (Mill.) K. Koch.), pawpaw, *Asimina triloba* L., and sugar maple, *Acer saccharum* Marsh., were common on good sites.

Reproduction was measured on a series of sixteen 1/735-acre subplots systematically distributed across the interior 0.25 acre of each plot. On each subplot, all reproduction up to 1.5 inches d.b.h. was tallied by species and l-foot height classes. In addition, all oak, ash, and cherry stems were identified and mapped for remeasurement, For these stems, height and basal diameter (1 inch above groundline) were measured to the nearest 0.1 foot and 0.1 inch, respectively. Reproduction was measured before treatment and 1, 3, 5, and 9 years after treatment.

Data Analyses

In this report, we analyzed only the reproduction that existed before treatment and that survived the study period (table 2). Mortality for oaks was relatively high, especially in the small height and basal diameter classes, and varied by understory treatment Because only survivors were analyzed, average numbers of stems for each species may be smaller and mean height and basal diameter values may be larger than would be expected for undisturbed stands.

Initially, the data were subjected to an analysis of covariance in which reproduction height 5 and 9 years after treatment was the response variable; species group, understory treatment, and measurement period (time since treatment) were class variables; and initial height, basal diameter, site index, and stocking were covariates. The model is as follows:

$$Y_{ijk1} = \mu + \alpha_i + \delta_j + \gamma_k + (\alpha\delta)_{ij} + (\alpha\gamma)_{ik} + (\alpha\delta\gamma)_{ijk} + \beta_{1ijk}H_{ijk1} + \beta_{2ijk}G_{ijk1} + \beta_{3ijk}S_{ijk1} + \beta_{4ijk}Q_{ijk1} + \epsilon_{ijk1},$$

where,

μ = overall mean,
α_i = species effect, i=1,2,3,4,
4 = time effect, j=1,2,
γ_k = understory treatment effect k=1,2,3,
$(\alpha\delta)_{ij}$ = interaction effect between species and time,
$(\alpha\gamma)_{ik}$ = interaction effect between species and understory treatment,
$(\delta\gamma)_{jk}$ = interaction effect between time and understory treatment,
$(\alpha\delta\gamma)_{ijk}$ = interaction effect among species, time, and understory treatment,
H_{ijkl} = initial height,
G_{ijkl} = initial basal diameter,
S_{ijkl} = initial stocking,
Q_{ijkl} = site index,
β's = coefficients,
ϵ_{ijkl} = error term, and
Y_{ijkl} = future height

This initial model identified group differences for species, time period, and understory treatment and heterogeneity of slopes if the covariates contributed significantly to the model. Scatterplots were also used to evaluate model adequacy. Variables were selected

Table 2.-Heights and basal diameters of white oak, red oaks, black cherry, and white ash advance reproduction before treatment.

Species	Number of stems	Height		Basal diameter	
		Mean	Range	Mean	Range
		—Ft—		—In—	
Whiie oak	375	1.6	0.2-9.3	0.25	0.10-1.50
Red oaks	1,158	1.1	0.2-7.4	0.18	0.10-1.40
Black cherry	483	1.8	0.2-8.8	0.23	0.10-1.20
White ash	509	1.8	-	0.28	-

for a reduced model on the basis of the results. The most parsimonious model that could adequately explain the data was sought. Anamalous observations were detected by residual analysis. These anomalies were further analyzed to see if they should be dropped from the analysis.

RESULTS

Tests with the initial model indicated that species, treatment, time since treatment, initial height, and the interactions among these variables were significant for all four species groups. In addiion, stocking and site index were important for black cherry. Further study also indicated that the square of initial height should also be added to account for some curvilinearity in the relation of initial to subsequent stem height. Therefore, separate regression analyses were done for each species group, treatments, and time since treatment combination with initial height and the square of initial height as independent variables. Site index and stocking were also used as independent variables for black cherry. The results are presented in tables 3 and 4.

Although the understory treatments affected subsequent height development, initial stem height was the single most important explanatory variable. Thus, stem size is a key indicator of likely response to treatment. The fit statistics for white and the red oaks are relatively good. Black cherry and ash both have less impressive R-squares and root mean square errors of 3.08 and 1.88, respectively (table 4).

Height Development of White Oak

White oak height growth was increased most by intensive competition control. The rate of increase was greatest for the small to medium stems (<1 .O to 3.0 feet tall at the outset) (fig. 2). Very small stems (<0.5 foot) grew about 0.3 to 0.5 foot during the first 5 years after treatment, but grew little over the next 4 years. However, stems initially larger than 0.5 foot increased in total height throughout the study period. The best response was to the most intensive competition control treatment.

White oak height development for the first 5 years was relatively slow after all understory treatments. Best 5-year growth was on large stems after intensive control. For stems of intermediate size, height growth responses to the intermediate and intensive treatments were about the same. Stems taller than 1.0 foot at the outset had no net increase in height over the initial 5 years on low intensity plots.

Between years 5 and 9, height growth of white oak reproduction in all but the smallest size classes increased significantly. Greatest increases were for stems >3.0 feet tall after intensive and intermediate competition control, but stems >4.0 feet tall on low intensity plots also grew about 2.0 feet over the 4-year period.

Height Development of Red Oaks

Black and northern red oak advance reproduction generally responded positively to understory density control (fig. 2). Height growth for the O-year period ranged from 0.5 to 0.6 foot for the smallest to 1.9 to 3.9 feet for the largest initial stem size. Response was greatest after intensive competition control. Stems on plots receiving intermediate- and low-intensity understory control averaged about 70 percent and 40 percent of the growth observed for the intensive treatment.

Rate of height growth for the O-year measurement period declined slightly with increasing initial stem size on the intensive and intermediate competition control plots. On the low-intensity control plots, growth remained constant for stems larger than 1 .O foot at the outset.

Although response of red oak reproduction to treatment was not rapid, it was somewhat faster than that of white oak. Five-year height growth of red oaks ranged from about 0.2 foot on the low-intensity plots to about 1.3 feet on the intensive plots. The initial lag in red oak height growth was most pronounced for 3.0-5.0 foot stems on the intermediate- and low-intensity plots. Red oak height growth increased significantly over the last 4 years of the measurement period. While all understory treatments increased height growth, larger stems on the intensive and intermediate control treatments produced the greatest response.

Height Development of White Ash

In previous reports from the Boston Mountains, growth response for ash and cherry reproduction were combined (Graney and Rogerson 1985, Graney 1989). Results of the present study indicate that ash and cherry reproduction respond differently to varying overstory and understory densities and possess significantly different height-growth potentials (fig. 2).

White ash advance reproduction responded positively to each of the overstory and understory treatments. The initial lag in response that was so apparent for the oak species was pronounced only for the largest ash stems. Over the 9-year measurement period, growth of ash reproduction ranged from about 1 .O foot for the smallest ash stems receiving the low-intensity treatment to about 4.5 feet for large stems on the high-intensity treatment plots. Height growth was slowest for the low-intensity treatment. It was about equal after the intermediate- and intensive treatments.

Height Development of Black Cherry

In terms of height growth of reproduction, black cherry may be the most aggressive species on upland sites in

Table 3.-Regression coefficients by species, treatment, and time period.

Species, treatment', and time period	Coefficients				
	Intercept	Height	Height^2	Stocking	Site index
White oak:					
Treatment A, 5 years	0.57146	0.60808	0.04242		
Treatment A, 9 years	0.33251	1.30156	-0.00340		
Treatment B, 5 years	0.03377	1.56488	-0.14578		
Treatment B, 9 years	-0.22336	2.80624	-0.28840		
Treatment C, 5 years	0.32288	1.07916	0.01206		
Treatment C, 9 years	-0.00071	2.59058	-0.17865		
Red oaks:					
Treatment A, 5 years	0.47705	0.81080	0.02834		
Treatment A, 9 years	0.47654	1.27371	0.00374		
Treatment B, 5 years	0.32118	1.26188	-0.06008		
Treatment B, 9 years	0.36760	2.06242	-0.11682		
Treatment C, 5 years	0.33940	1.35149	-0.03334		---
Treatment C, 9 years	0.31108	2.55141	-0.16762		---
Black cherry:					
Treatment A, 5 years	10.95365	2.14695	-0.12851	-0.26548	-0.12433
Treatment A, 9 years	10.96173	3.81155	-0.27886	-0.02668	-0.12604
Treatment B, 5 years	4.43350	2.61708	-0.18561	-0.04868	-0.01304
Treatment B, 9 years	4.90850	3.59990	-0.19518	-0.09351	0.03046
Treatment C, 5 years	11.67576	2.01111	-0.03946	-0.07772	-0.09176
Treatment C, 9 years	11.41406	4.28817	-0.26548	-0.07429	-0.07953
White ash:					
Treatment A, 5 years	0.92504	1.31324	-0.05738		
Treatment A, 9 years	1.62486	1.64940	-0.06350		
Treatment B, 5 years	0.94239	1.67879	-0.12301		
Treatment B, 9 years	1.78527	2.44456	-0.23207		
Treatment C, 5 years	1.10079	1.38060	-0.03277		
Treatment C, 9 years	2.68191	1.31608	0.00303	---	---

[a] A, B, and C are low, intermediate, and intensive understory control treatments.

the Boston Mountains. it may be the only species that will outgrow red maple stump sprouts. But height development of cherry reproduction on a given site is significantly influenced by a number of factors including initial stem height, understory density, overstory density, site quality, and time since treatment.

Cherry grew fastest of the species observed in our study. Nine-year height growth ranged from about 3 feet for the smallest stems in stands on the most productive sites thinned to 60 percent overstory stocking with no competition control to more than 12 feet for large stems on average sites thinned to 40 percent overstory stocking with intensive competition control. Greatest height growth for each measurement period was associated with the intensive treatment, and the difference between understory treatments increased with time and initial stem size. The intermediate treatment produced a somewhat lower response, while the low-intensity treatment produced the least response over all initial stem sizes. Black

Table 4.--Fit statistics for regression equations.

Species	R-square	Root mean square error
		---Ft---
White oak	0.86	0.78
Red oaks	0.82	0.62
Black cherry	0.56	3.08
Ash	0.54	1.88

cherry stems with initial heights of 1 .O foot and larger in stands receiving the intensive treatment produced height growth during the second measurement period (4 years) equal to or greater than that produced during the initial 5 years. On the other hand, cherry stems in stands receiving intermediate- and low-intensity treatments generally produced less height growth during the second than the first measurement period. Cherry height growth was also slightly greater in stands

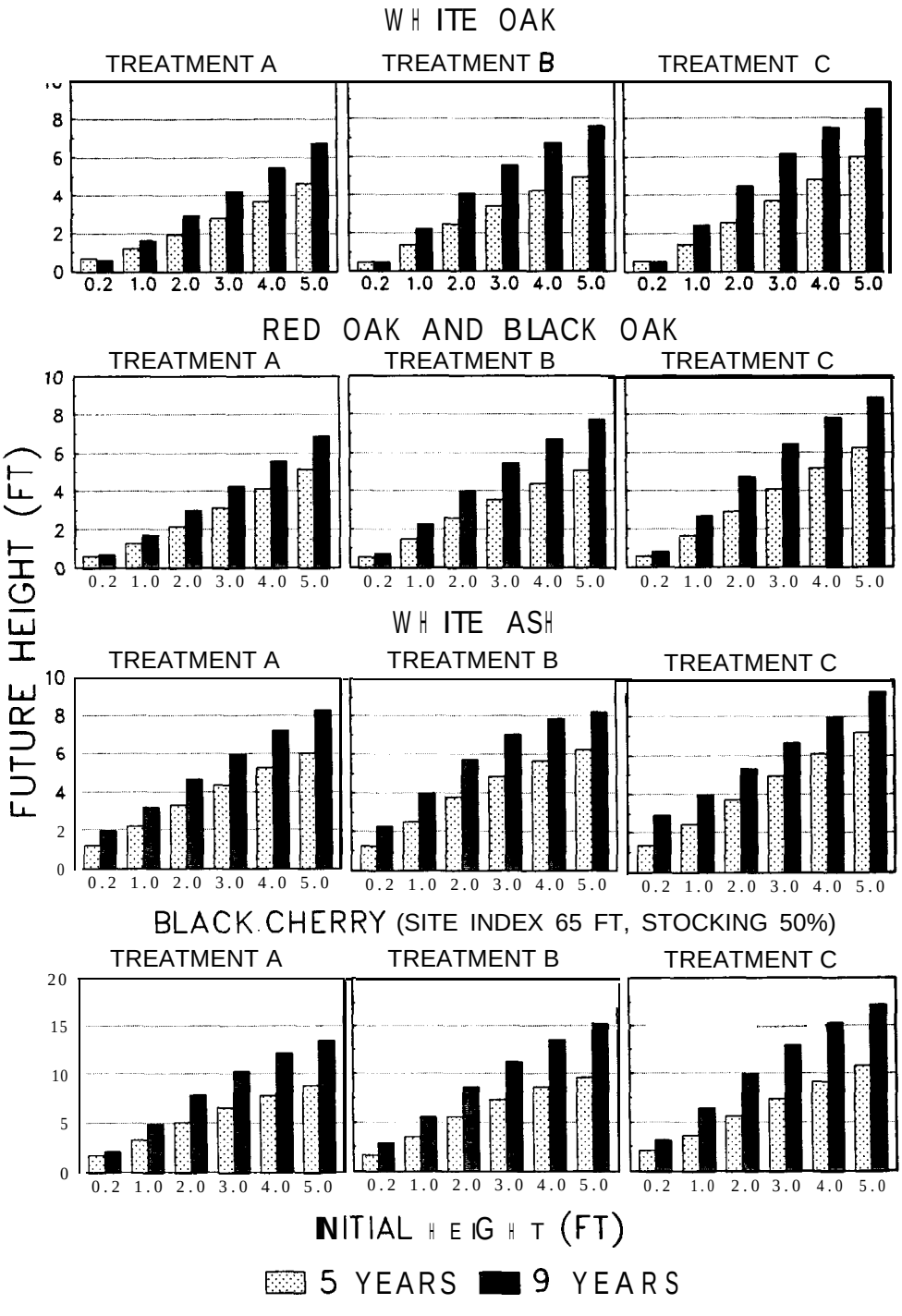

Figure 2.--Height development of advance reproduction as affected by initial stem size and intensity of understory control (A=low, B=medium,C=Intensive) by species 5 and 9 years following treatment in upland oak stands in the Boston Mountains.

thinned to 40 percent overstory stocking on medium sites.

DISCUSSION

The primary objective in applying the shelterwood method in mature upland oak stands is to increase the amount of large oak advance reproduction that can compete successfully after the shelterwood is removed. Theoretically, this goal can be accomplished by establishing new seedlings and stimulating their growth and by increasing the growth of small established stems. One problem is that reducing overstory density provides excellent conditions for the growth of species that compete with oaks. Often, therefore, oak regeneration is not improved by shelterwood cutting alone (Loftis 1983, Sander 1979). An appropriate combination of overstory density reduction and understory competition control, however can stimulate the growth of oak reproduction under shelterwoods (Loftis 1 990b, Schlesinger and others 1993, Wolf 1988) while retarding development of competing species (Loftis 1 990b).

In the Boston Mountains, established advance oak reproduction is present in adequate numbers in most upland stands (table 5). However, most of the oak reproduction is less than 1 .O foot tall, and few stems are taller than 4.0 feet Ash and cherry advance reproduction, though generally fewer in number in upland stands, often represent most of the desirable reproduction taller than 1.0 foot (table 5). Height growth of surviving oak, ash, and cherry reproduction in undisturbed stands is very slow and vanes by species (fig. 3). Few small oak stems grow into the larger height classes because of poor survival (table 5). Conversely, numbers of medium- to large-size ash and cherry reproduction increase over time, resulting in a pool of large advance reproduction that develops rapidly after harvest.

During the first 5 years after treatment development of the white and red oak, reproduction was very slow. Nearly all oak reproduction died back and resprouted during this period. Stems on plots receiving the most intensive understory control resprouted within 1 to 3 years after treatment, while resprouting after the less intensive treatment occurred throughout the initial 5-year period. Also, large oak stems generally resprouted later than small stems. Another factor that may have contributed to the poor overall response of the small oak reproduction is the typical rainfall pattern for northwestern Arkansas. While long-term monthly precipitation for June-September averages 3 to 4 inches, extended dry periods resulting in severe soil moisture deficits are common. Even where overstory density and understory competition are reduced, moisture stress is likely to reduce growth of all reproduction, and particularly that of small stems.

After intensive and intermediate competition control, red and white oak stems initially 2.0 feet and taller generally grew to heights of 4 to 8 feet over the Q-year period. However, upland stands on average to good sites in the Boston Mountains will typically have fewer than 100 oak stems per acre over 2 feet tall as advance reproduction. Therefore, continued development of the small oak stems will be required to achieve adequate numbers of large oak reproduction.

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

Table 5.–Mean height distribution per acre of oak, ash and cherry, and other species reproduction stems before treatment.

Species	Height class (ft)					
	Cl.1	1.1-2.0	2.1-3.0	3.1-4.0	4.1-5.0	>5.0
	Number of stems per acre					
Oaks	1,600	84	17	12	5	0
Ash and cherry	690	200	109	55	36	5
Other species	4,577	2,648	1,435	1,170	1,033	1,489

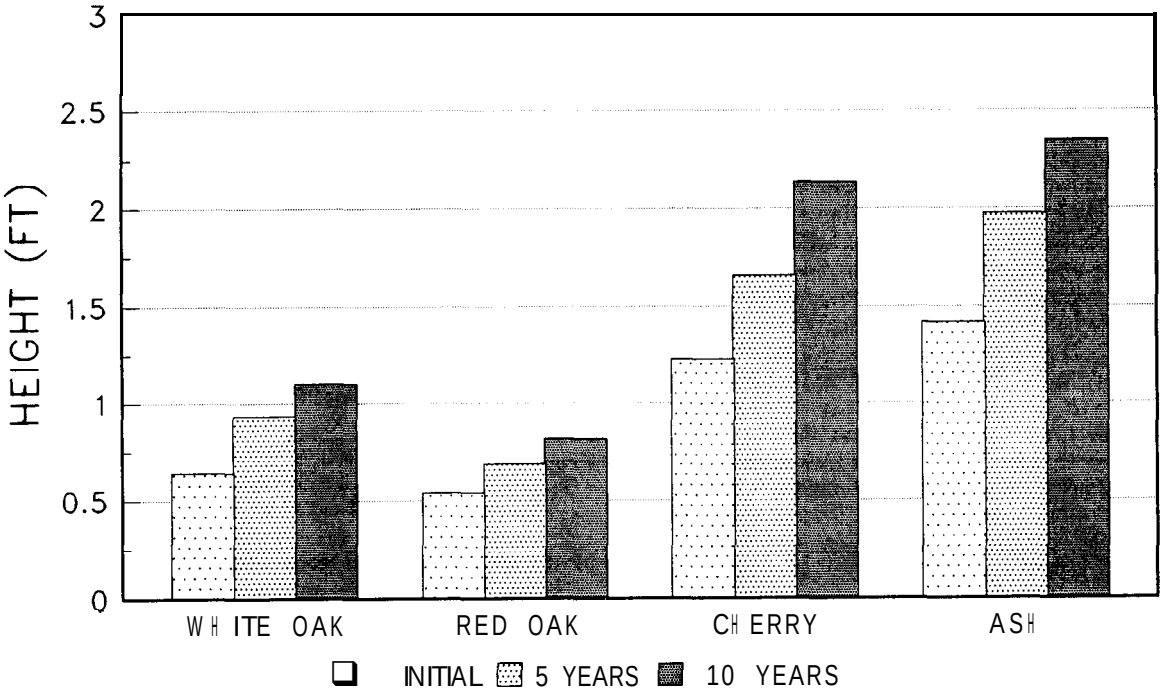

Figure 3.-Height development of advance reproduction in undisturbed upland oak stands in the Boston Mountains by species.

increased by a surge of herbaceous vegetation and vines, especially on the most productive sites.

The intermediate intensity of **understory** control increased growth of desirable reproduction, but its effect probably will not continue much beyond the ninth year. Understory development is most pronounced on plots thinned to 40 percent stocking where all small oak stems and most large stems are overtopped by competing stems. Wii that **overstory** stocking, only ash and cherry have maintained a favorable competitive position on plots receiving the intermediate intensity of understory control.

Although growth of desirable stems was significantly greater on plots receiving the intensive and intermediate understory control treatments, overstory thinning and midcanopy removal (stems **>** 1.6 inches) also increased growth of larger desirable reproduction. Ash and cherry produced the better response, but oak stems initially taller than 3 feet also responded.

MANAGEMENT IMPLICATIONS

On average to good upland sites in the Boston Mountains, numbers of oak advance reproduction is plentiful, but most oak stems are too small to successfully compete with less-desirable species after harvest. Consequently, the overall regeneration potential of the oaks is inadequate. Overstory thinning plus removal of midcanopy stems larger than 1.6 inches d.b.h. increases growth of oak advance reproduction initially taller than 3.0 feet, but few stems of this size are present in most mature upland stands. To enhance development of existing oak stems less than 3.0 feet, intensive understory treatment may be required. Removal of all or most of the competing understory may be necessary for oaks initially I- to **2-** feet tall to attain adequate size before final overstory removal. In fact, two understory treatments may be required. A relatively high **overstory** density would have to be retained to retard the redevelopment of the competing understory.

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

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SURVIVAL AND GROWTH OF PLANTED AND DIRECT-SEEDED CHERRYBARK OAK IN THE SANTEE RIVER FLOODPLAIN AFTER 11 YEARS'

John A. Stanturf[2]

Abstract—Five treatments were uaed to evaluate the survival and growth of planted and dire&seeded 2-0 cherrybark oak (*Quercus falcata* var. *pagodifolia* Ell.). Treatments included planting at two depths and top-pruning seedlings; and direct-seeding acorns. Survival averaged 64% after 11 years and treatment had no signifoant affect. Planting depth and pruning did not affect survival of planted seedlings. Stems from the direct-seeded acorns were 16 ft tall, on average, and signifioantly smaller after 11 years than planted stems (23 ft tall). There were no differences in the size of stems in the planting treatments.

INTRODUCTION

Oaks have been the backbone of the hardwood lumber industry in the South. Oaks are also preferred for wildlife. Public and private programs to reforest former agricultural land have stimulated interest in artificial regeneration of bottomland hardwoods. Intensively cultured plantations, however, are expensive to establish (Bullard et al. 1991). Two alternatives are direct-seed acorns (Johnson and Krinard 1987; Kennedy 1993) or plant fewer, large seedlings that may require less intensive weed control treatments.

This paper presents results after 11 years of a study designed to compare planting large 2-O cherrybark oak, Quercus *falcata* var. *pagodifolia* Ell., seedlings with direct-seeding cherrybark oak acorns. Seedlings were planted at two depths, with and without top-pruning, end survival and growth compared to seedlings that developed from direct-seeded acorns.

METHODS

Study Site

This study was established in the floodplain of the Sentee River, about 20 miles southeast of Manning, SC, on private lend. Harvesting began in late 1982, and the site prepared by sheering residual trees, removing debris, and root-raking. Planting end direct-seeding took place in March, 1983. Soils are of the Tawcaw series of fine, kaolinitic, thermic Fluvequenb Dystrochepts. These soils have dark brown silty clay A horizons over brownish clayey and loamy B horizons. Drainage is poor, and runoff end permeability are slow. Many areas are frequently flooded, and the water table ranges between 20 end 48 inches during winter end early spring. Site index is 90 to 100 ft at base age 50 for water oak, Q. *nigra* L., cherrybark oak, and willow oak, Q. *phellos* L.

Design and Treatments

The study was designed as a randomized complete Mock with five replications of five treatments. Blocks were approximately 60 ft by 100 ft in size. Each block contained six rows laid out 10 ft apart. One of five treatments was randomly assigned to each row in each block. Planting spots within rows were 5 ft apart, thus a spacing of 5 ft by 10 ft.

Treatments were es follows:

1. 2-O cherrybark oak, deep-planted, not top-pruned (D_{NP})
2. 2-O cherrybark oak, deep-planted, toppruned (D_P)
3. 2-O cherrybark oak, shallow-planted, not toppruned (SW)
4. 2-O cherrybark oak, shallow-planted, toppruned (S,)
5. Cherrybark oak acorns, direct-seeded (DS).

Seedlings for all treatments were collected near Stoneville, MS. Seedlings were grown in the nursery at the Southern Hardwoods Laboratory at Stoneville, MS.

Planting and Pruning

Seedlings were planted in g-inch-diameter holes dug with a gasoline-powered post-hole digger. Holes for deepplanted seedlings were approximately 2 ft deep, end those for shallow-planted seedlings were approximately 1 ft deep. The root systems of seedlings were pruned to about 9 inches in diameter end 1 ft in length before planting. Root collars for deepplanted seedlings were placed about 1 ft below the groundline. Toppruned seedlings were pruned 1 ft above the groundline et planting. Unpruned seedlings averaged 2

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to 2.5 ft tall at planting. Soil was replaced and tamped firmly around the roots. Four acorns per spot in direct-seeded rows were sown 1 to 2 inches deep. There were 20 seedlings or direct-seeded spots in each row. No weed control was done after planting.

Soil Sampling and Analyses

Soils were sampled at four points systematically located along each of two transects across the study area. Samples were taken from four depths at each point: 0 to 8 inches, and 1, 2, and 3 ft. Samples were composited by depth along each transect; thus, a total of eight samples, two from each depth, represented the study area. Soil was air-dried and ground to pass through a 2-mm sieve for analyses. Results are reported as the average of the two composite samples for each depth.

Soil N was determined by the Kjeldahl method. Phosphorus was determined colorimetrically (Donohue 1992). Concentrations of K, Ca, and Mg were measured by atomic absorption spectrophotometry after extraction in 1 N NH_4OAc. Soil pH was measured with a glass electrode in a 1:1 soil/water mixture. Oxidizable OM was determined by chromic acid oxidation and titration with $Fe(NH_4)_2(SO_4)_2$.

Measurements

Height, diameter at breast height (dbh), and survival were measured after the first, fifth, and eleventh growing seasons. Diameter was measured to the nearest 0.1 inch at 4.5 ft aboveground (dbh). Height was measured with a graduated aluminum pole to the nearest 0.1 ft. The four acorns planted at each direct-seeded spot were considered as one planting spot. If more than one acorn germinated, the height and diameter of the largest seedling was used in statistical analysis.

Statistical Analyses

The mean of each block by treatment combination was considered the experimental unit. Mean survival (arc-sine transformed), dbh, and total height of the seedlings in each treatment after the first, fifth and eleventh growing seasons were the variables tested. Variables were tested at the 0.05 level of confidence. Means were compared by orthogonal linear contrasts using the GLM program in SAS (SAS Institute 1989).

RESULTS

Nutrient levels in these soils are lower (Table 1) than are found on the best sites (Broadfoot 1978). Organic matter and phosphorous levels in the surface soil (0-6 inches) are higher than typically found on drier sites planted to pines (McKee and Wilhite 1988).

Survival of planted and direct-seeded cherrybark oak was not significantly different in any year. Small initial differences after the first and fifth growing seasons

Table l-Soil characteristics of the study area.

	Soil depth (inches)			
Component	Oto8	12	24	38
pH	5.0	5.0	4.8	4.8
Organic matter (pct)	3.29	1.01	0.49	0.47
Nitrogen (pct)	0.184	0.053	0.035	0.045
Phosphorus (ppm)	8	12	8	4
Potassium (ppm)	72	30	30	30
Calcium (ppm)	455	181	138	188
Magnesium (ppm)	89	42	38	38

(Figure 1) had disappeared by age 11. Survival of planted seedlings declined from near 80% after one growing season to 83% at age 11.

Cumulative height of direct-seeded stems was significantly less than planted seedlings on all dates. Initially taller, the planted seedlings not only maintained their height advantage, but appear to be growing faster (Figure 2). At age 11, planted stems averaged 23 ft tall, while the average height of stems in the direct-seeded treatment was 18 ft. The same patterns were evident in diameter growth (Figure 3). DBH of planted stems averaged 2.8 inches at age 11, as compared to 1.4 inches for direct seeded stems.

Deep planting and top pruning did not significantly affect survival of planted seedlings after the first 11 years (Table 2). Survival ranged from 50% to 73%. The lowest survival was in the most severe treatment, deep-planting and top-pruning, but was not significantly diierent from the other treatments. At the spacing of this study, stocking would be 438 to 838 stems per acre.

Both deep-planting and top-pruning reduced the initial height of planted seedlings. Planting stock in this study ranged from 1.9 ft to 3.8 ft tall, above the root collar. Prior to pruning, deep-planted seedlings averaged 1.8 ft tall above groundline; shallow-planted seedlings averaged 2.3 ft. Pruning removed as much as 2.5 ft of stem material. Nevertheless, neither treatment significantly reduced height or diameter of planted stems after 11 years (Table 3). The largest trees were in the shallow-planted and pruned treatment.

Cumulative height of planted trees is shown in Figure 4. Pruning to 1 ft above groundline at planting gave the unpruned seedlings an average 0.7 ft to 1.3 ft height advantage, depending upon planting depth. At the end of the first growing season, pruned seedlings were almost as tall as unpruned. By age 5, pruned stems were slightly taller, on average. By age 11, trees that had been pruned at planting averaged 0.5 ft taller than unpruned (23.8 ft vs. 23.3 ft, respectively).

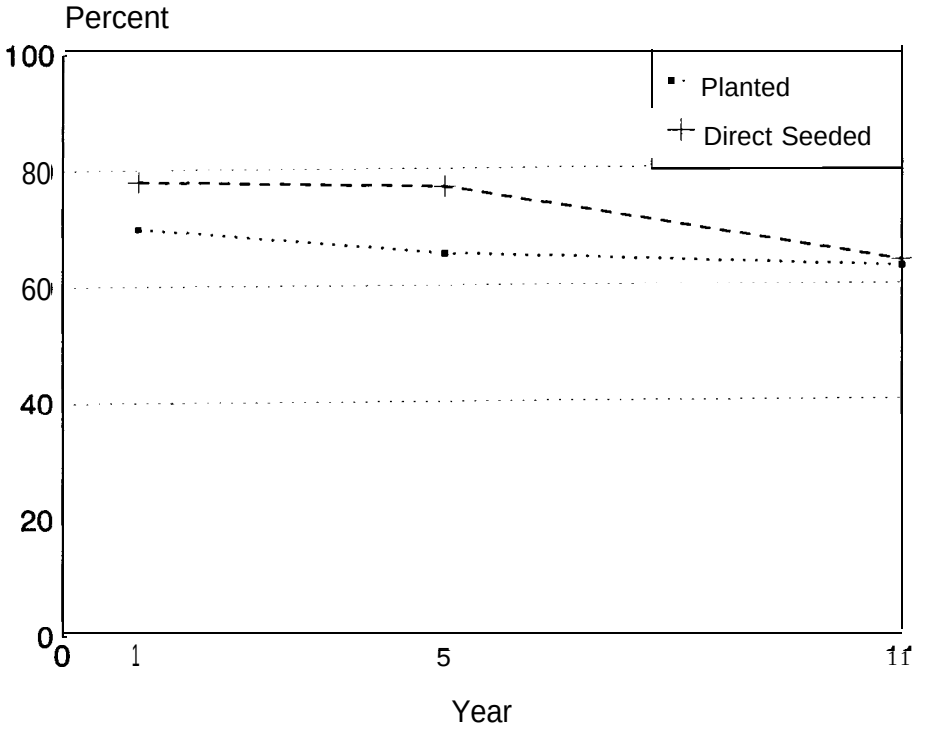

Figure 1. Survival at age 1, 5, and 11 years of direct-seeded and planted cherrybark oak.

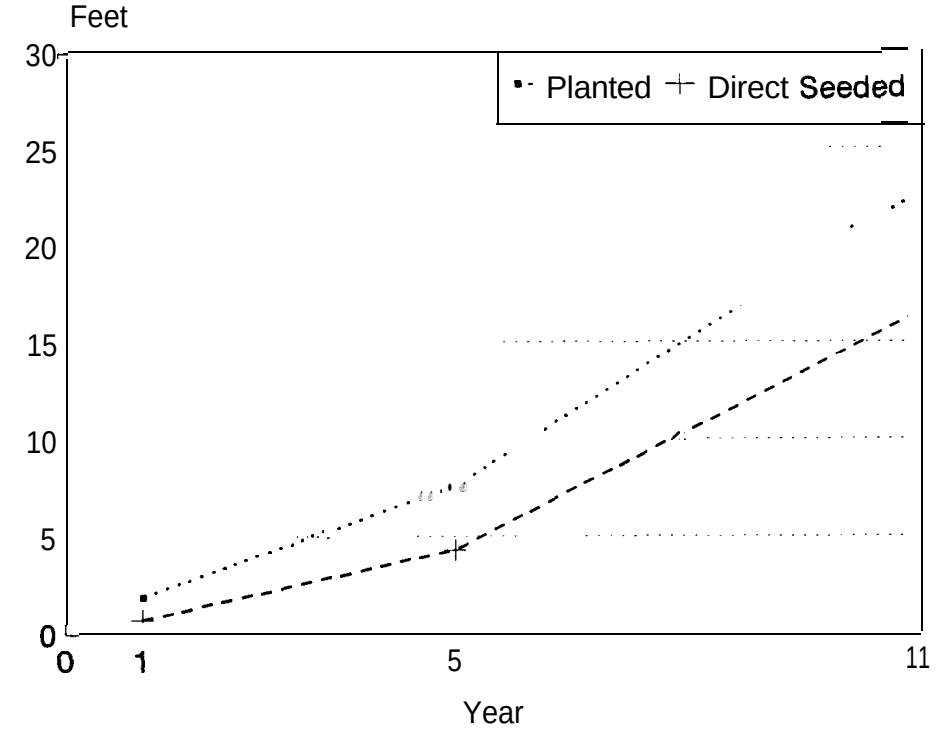

Figure 2. Cumulative height growth of direct-seeded and planted cherrybark oak at age 1, 5, and 11 years.

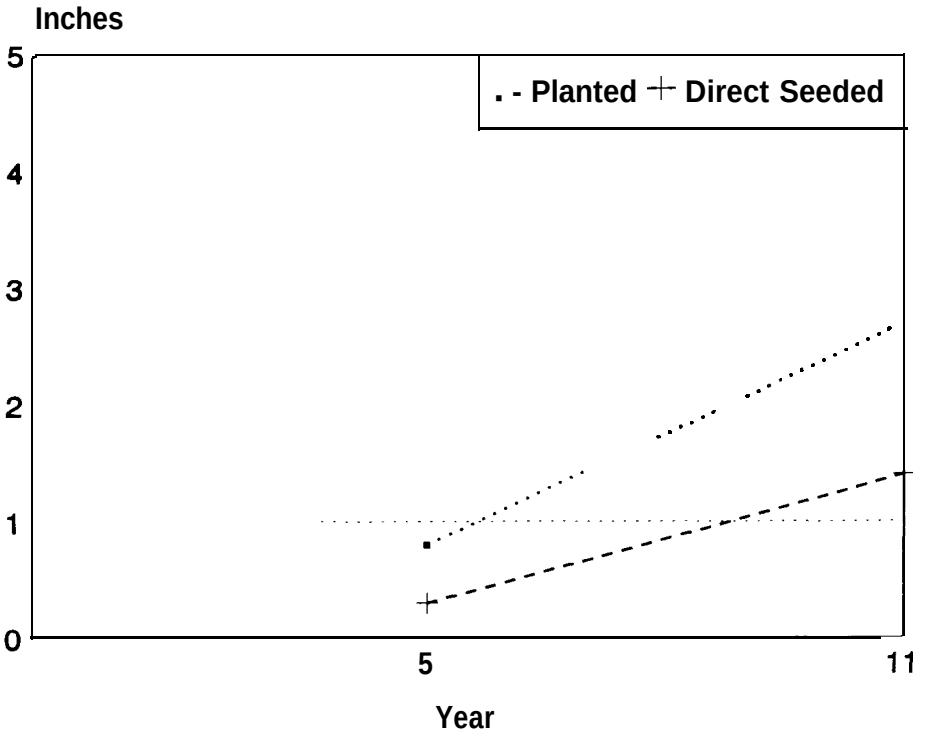

Figure 3. Cumulative diameter growth of direct-seeded and planted cherrybark oak at age 5, and 11 years.

Table 2. Percent survival at age 1, 5, and 11 years of cherrybark oak seedlings planted at two depths, with and without top pruning.

Treatment	-Year One-- Mean	Range	-Year Five-- Mean	Range	-Year Eleven-- Mean	Range
Deep Plant, Prune	60	1 O-80	55	15-75	50	15-65
Deep Plant, No Prune	83	75-90	76	70-85	73	60-85
Shallow Plant, Prune	69	15-100	69	20-I 00	68	20-I 00
Shallow Plant, No Prune	72	30-I 00	64	20-90	61	1 O-85

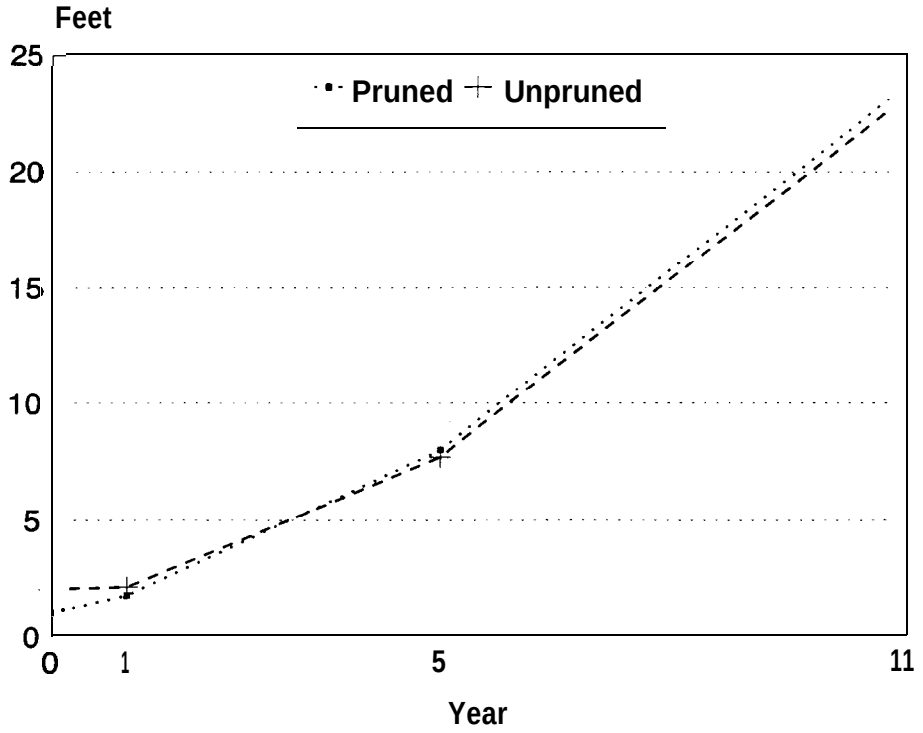

Figure 4. Cumulative height growth of pruned and unpruned cherrybark oak seedlings at age 1, 5, and 11 years.

Table 3. Mean height (cumulative) and d.b.h. of planted 2.0 cherrybark oak at age II.

Treatment	Height, ft	DBH, inches
Deep Plant, Prune	23.2	2.55
Deep Plant, No Prune	23.0	2.75
Shallow Plant, Prune	24.4	2.92
Shallow Plant, No Prune	23.6	2.61

DISCUSSION

The 63% survival rate of direct-seeded cherrybark oak in this study was similar to that found in other studies (Johnson and Krinard 1987) but greater than is achieved operationally (Kennedy 1993). The relatively intense site preparation removed or setback woody and herbaceous competitors and reduced habitat for small mammals that piifer acorns (Kennedy 1993). The slower height growth rates of direct-seeded trees (Figure I) may be due to competition from other oak stems that survived at the same planting spot.

Top pruning and deep planting had no significant effect on survival or growth of planted cherrybark oak. Large seedlings can be top-pruned without reducing survival, and will actually grow more vigorously than unpruned seedlings. Thus the advantage in top-pruning to reduce shipping and handling expense may be obtainable (Johnson et al. 1986). In this study, however, top pruning occurred after the seedling was planted. Pruning before outplanting may affect vigor in ways not tested in this study. Recommended planting depth is with the root collar at groundline for best survival (Kennedy 1993). Results from this study indicate that 2-O seedlings can be planted with the root collar as deep as 1 ft below groundline without a reduction in survival or growth, as long as the planting hole is adequate for the root system. This eases the operational requirements for planting large seedlings, as a standard hole size can be used rather than "custom digging" a hole for each seedling.

Application of the results of this study to reforestation of bottomland hardwood and wetland forests depends upon the objectives of the landowner. While direct-seeding has the lowest initial cost of any artificial regeneration method (Bullard et al. 1991), the landowner will have to accept smaller trees early in the rotation. Planting larger seedlings may have considerable merit on rougher sites without competition control. If expensive site preparation and vegetation management treatments can be avoided, those savings may offset the greater expenses associated with producing and planting larger seedlings. Further research, however, is needed to test this hypothesis.

ACKNOWLEDGEMENTS

Thii research was done in cooperation with the Mississippi Agricultural and Forestry Experiment Station and the Southern Hardwood Forest Research Group.

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RESPONSES OF LOBLOLLY PINE BIOMASS AND SPECIFIC LEAF AREA TO VARIOUS SITE PREPARATION TREATMENTS'

Mingguang Xu, Timothy B. Harrington and M. Boyd Edwards'

Abstract—In 1994, stem analyses of loblolly pine were conducted in an existing (1982) study of **plantation** responses to site preparation treatment located at the Hitchiti Experimental Forest near Macon, Georgia. The objective was quantify treatment effects on components of individual tree and stand productiiity. Treatments ranged in intensity from the absence of site preparation to the combination of root-raking, disldng, nitrogen fertiliition, and herbaceous weed control. On each of 30 trees (5 per treatment), height and DBH were measured and **specific** leaf ares and branch biomass were subsampled. Analysis of variance **indicated no significant** differences (**P=0.1** 1) in **specific** leaf area among treatments. **Regression** analyses indicated that branch diameter decreased **with** relative height and that the mid-crown had more foliige biomass than the upper or **lower** crown. Total **foliage biomass** per tree increased with DBH. **Specific** treatments affected the estimated parameters in each regression.

INTRODUCTION

Some studies demonstrate that silvicultural treatments, such as site preparation, can improve forest biomass production, but few of these studies have focused on quantifying individual branch and total tree biomass responses to treatment. Treatments can influence above-ground biomass production by affecting branch size and number within the crown (Gillespie et al 1994). Understanding how the treatments influence each component of stand biomass is needed to identify mechanisms of stand response, which can be used to refine specifications for silvicultural treatments. Therefore, the objectives of thii study were to quantify effects of several site-preparation treatments on specific leaf area and foliage biomass of planted loblolly pine and to infer how treatment has affected stand productivity.

TREATMENTS AND EXPERIMENTAL DESIGN

The research was conducted at an existing **site-**preparation study at the Hiichii **Experimental Forest** near Macon, GA. From fall 1981 to spring 1982, the following six treatments were applied to **0.8-ha** plots.

1. **Clearcut** only (CC): no site preparation.

2. **Clearcut** plus cut residual trees (CC+CUT): all residual trees greater than 2.5 cm DBH were cut with a chainsaw in August 1981.

3. Shear and chop (SC): shearing with a KG blade and chopping with a rotary drum were performed with a single pass of a D-7 tractor from September to November 1981.

4. Shear and chop plus herbicide (SC+H): SC plus Velpar **Gridball** pellets at 2.8 kg **a.i./ha** in March 1982.

5. Shear, root-rake, burn, and disk (SRBD): in September to October 1981, residual trees were sheared, rootstocks were raked into **windrows** and burned, remaining debris was scattered with a bulldozer blade, and plots were **disked** with an offset harrow to a depth of 15-20 cm.

6. Shear, root-rake, burn, disk, fertilize, and herbicide (SRBD+FH): SRBD plus ammonium-nitrate fertilizer (114 kg N/ha), Oust herbicide (0.42 kg **a.i./ha)were** applied from March to April, 1983.

The 6 treatments were arranged in a randomized complete block with 5 replications, for total of 30 plots.

TREE MEASUREMENTS

1. Stem analysis: One sample tree was selected randomly from each plot and measured for DBH (cm), total height(m), and diameter (mm) and height(m) of each branch. Relative height (RH) of each branch was calculated as follows: RH=branch height/total height.

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2. Specific leaf area (SLA, cm' leaf area/g foliage dry weight) and branch foliage (g) were measured on each of 5 branches per tree located at various relative heights.

STATISTICAL ANALYSIS

The following linear relationships were developed with backward elimination in stepwise regression (entry and departure of independent variables was controlled by α=0.05:

Dependant variable	Indebendent variable
Branch diameter	RH
Branch foliage biomass	RH, branch diameter
Tree foliage biomass	DBH

Indicator variables for each treatment were tested (α=0.05) for their effects on the parameters of each linear relationship.

RESULTS

Specific Leaf Area

Specific leaf area of loblolly pine averaged 28.9 cm^2/g, and it did not differ significantly (P=0. 11) among the treatments.

Branch Diameter

Branch diameter decreased with increasing relative height (Figure 1). Because they were older, branches at the bottom of the crown were larger than those at the top. The treatments SC and SRBD+FH, increased branch diameter relative to trees in clearcut-only plots for the lower (0.4-0.6 RH) and upper crown (0.8-0.9 RH), respectively.

Branch Foliage Biomass

Branch foliage biomass changed with branch relative height after adjusting for branch diameter (Figure 2). At middle parts (relative height =0.75) of the crown the

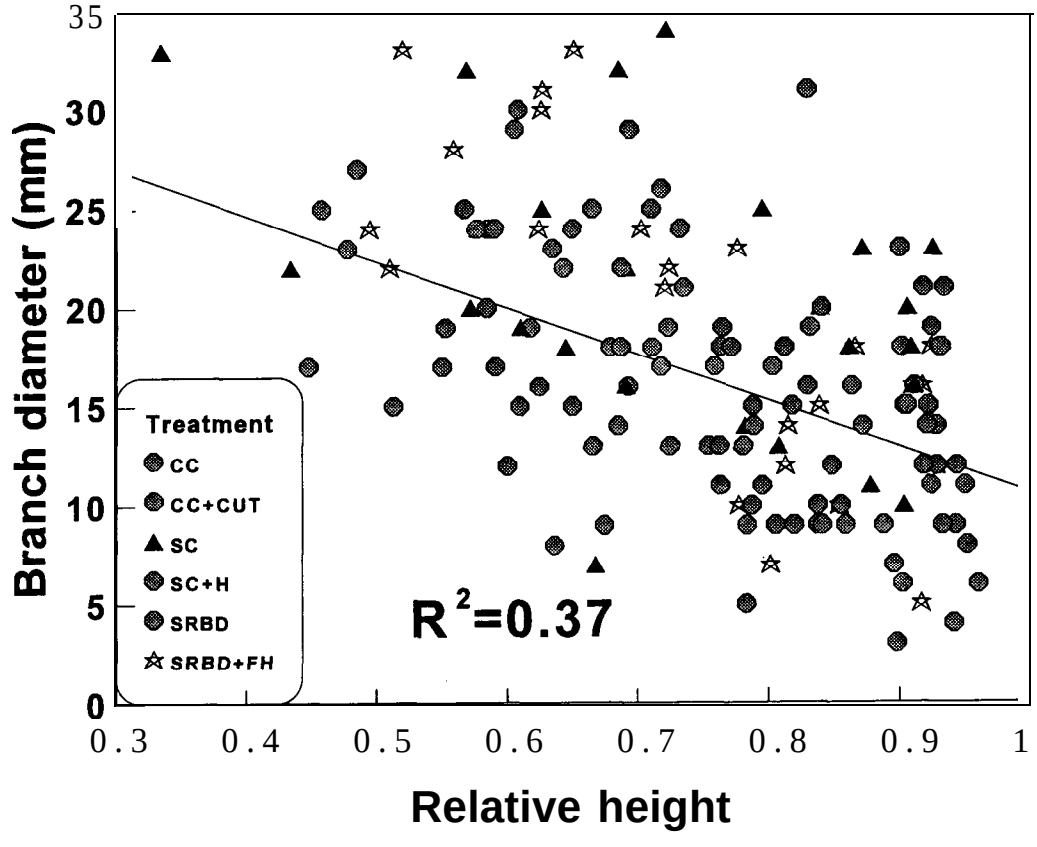

Figure l-Relationship between branch diameter and relative height. Treatments are: CC=clearcut only, residual trees remained; CC+CUT=CC plus manual cutting of residual trees; SC=shear and chop; SC+H=SC plus hexazinone; SRBD=shear, rootrake, burn piles, and disk; SRBD+FH=SRBD plus nitrogen fertilizer and sulfometuron.

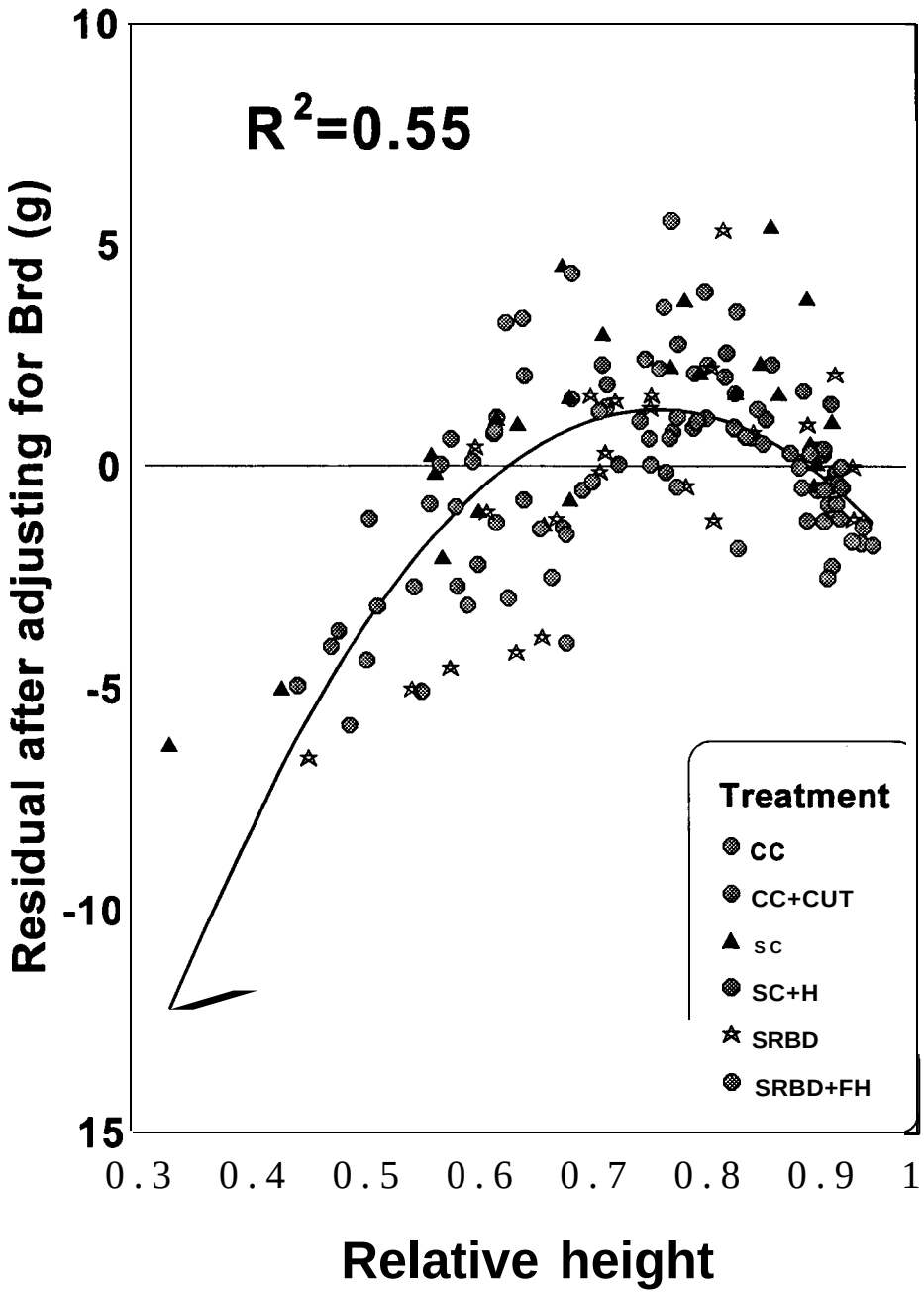

Figure 2-Relationship between the residuals of branch foliage biomass (after adjusting for branch diameter, Brd) and relative height. Treatments are: CC=clearcut only, residual trees remained; CC+CUT=CC plus manual cutting of residual trees; SC=shear and chop; SC+H=SC plus hexazinone; SRBD=shear, rootrake, burn piles, and disk; SRBD+FH=SRBD plus nitrogen fertilizer and sulfometuron.

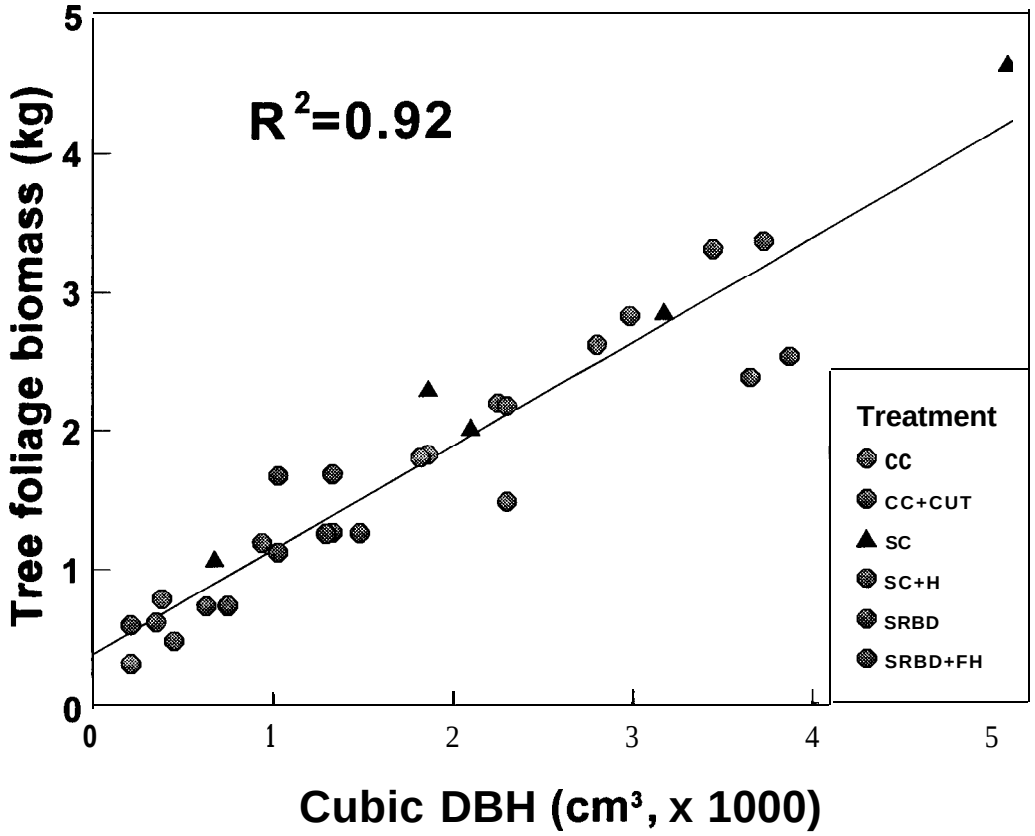

Figure 3-Relationship between tree foliage biomass and DBH. Treatments are: CC=clearcut only, residual trees remained; CC+CUT=CC plus manual cutting of residual trees; SC=shear and chop; SC+H=SC plus hexazinone; SRBD=shear, rootrake, burn piles, and disk; SRBD+FH=SRBD plus nitrogen fertilizer and sulfometuron.

branch foliage biomass is more than those at bottom or top of crown even though the branch size are larger at the bottom of crown (Figure 1). In the lower crown, treatment SC increased foliage biomass and the treatment SRBD decreased foliage biomass.

Tree Foliage Biomass

Tree foliage biomass increased with the cube of DBH (Figure 3). For a given DBH, trees in treatment SC had more foliage biomass than those in clearcut-only plots. Increases in tree foliage biomass from this treatment probably resulted from larger values for branch diameter and foliage biomass (Figure 1 and Figure 2).

CONCLUSIONS

1. Specific leaf area did not diier significantly among treatments.

2. Branch diameter decreased linearly with increasing relative height. Treatments increased branch diameter either in the upper (SC) or lower crown (SRBD+FH) relative to trees in clearcut-only plots.

3. Branch foliage biomass peaked at about 0.75 relative height. After adjusting for branch diameter, branch foliage biomass in the lower crown (0.4-0.6 RH) was either greater (SC) or less (SRBD) than that of trees in clearcut-only plots.

4. Tree foliage biomass increased with DBH. For a given DBH, trees in SC had more foliage biomass than those in clearcut only plots.

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TWENTY-YEAR SURVIVAL AND GROWTH OF SIX BOTTOMLAND HARDWOOD SPECIES'

M. Stine, J. L. Chambers, M. Wilson and K. Ribbeck[2]

Abstract-h 1970 and 1971, seven species, cherrybark oak (*Quercus falcata* var. *pagodifolia*), water oak (*Q.nigra* L.), willow oak (*Q. phellos* L.), Shumard oak (*Q. shumardii* Buckl.), Nuttall oak (Q. *nuttallii* Palmer), sweet pecan (*Caryaillinoensis* (Wangenh) K Koch) and blackgum (*Nyssa sylvatica* Marsh.), were planted on a Commerce silt loam site in the floodplain of the Mississippi and Red Rivers in east-central Louisiana. The original planting was conducted to compare the effects of two seedling types (bare-rooted and tublings) and two planting techniques (dibble-hole planting and auger-hole planting) on survival and growth (Roth II 1972). The lniiil study indllted that water oak was the best species for the site and that due to poor growth, blackgum was unsuitable for the site. After approximately 20 years of growth, water oak continued to maintain the best survival and height growth, while cherrybark oak had a greater mean diameter. Blackgum by age 20 had such poor survival that it was not remeasured. Of ths six surviving species, mean survival ranged from a bw of 17 percent for Shumard oak to a high of 68.2 percent for water oak. Mean diameter ranged from 6.2 Inches for sweet pecan to 10.3 inches for cherrybark oak. Height ranged from a mean of 37.4 feet for sweet pecan to 61 .O feet for water oak.

INTRODUCTION

In recent years there has been an increased interest in planting bottomland hardwood species in the coastal plain (Roth, Wheeler, and Covin 1992), with bottomland oaks being some of the most valued of all bottomland species in the Southeast. Most studies have reported on early survival and growth of many species established with venous planting methods (Kennedy et al. 1989, Allen 1990), while long-term growth data for bottomland oak plantations is critically lacking in the literature (Knnard and Johnson 1988; Roth II et al. 1992). We report here on the 20 year performance of seven bottomland species.

This plantation was established in 1970 and 1971 to compare species performance with diierent types of planting stock (bare root and containerized seedlings) and planting method (dibble-ski and auger-hole). The first and second growing season results are summarized in Roth II (1972). We were contacted by the Forestry Supervisor of the Red River Wildlife Management Area, where the plantation is located, about remeasuring the plantation. Remeasurement of plantations established years previously can provide some insight into growth expectations but can also provide incomplete or even misleading information.

In going through the records, and while at the site, we determined that errors in the original plantation map precluded determining the various treatment locations of planting stock type and planting methods in the current study. Thus, only species performance could be determined. This presents problems with determining if there are long-term effects of what the original study tested. We present here the current conditions of the plantation and the assumptions that must be made, and are often ignored, when measuring older plantations.

METHODS

This plantation is located on the Red River Wildlife Management Area, near Shaw, LA. It is located on an old-field site, between the Red River and Mississippi River levees. The site is mostly Commerce silty loam soil on 24 of the 28 plots, with two plots being Commerce silty clay loam, and two plots being Mhoon silty clay loam. The plantation layout did not control for the variation in soil types. The plantation was established over a two year period, beginning in 1970, with one-year-old nursery grown bare root seedlings planted the first year in either auger-holes or dibble-slits, in a split plot design. In 1971 one-year-old and eight- to ten-week-old tublings were planted in a second split-plot design. All seedlings were planted on a 10 x 10 foot spacing, with a total of 150 seedlings planted (50 for each planting method; dibble-slit, auger-hole, and tubiings) on each plot for each of the seven species, with four replications. Chemical and mechanical weed control was conducted through 1971.

Survival measured in 1970 and 1971, and heights measured in 1971, were reported by Roth II (1972). The plantation was remeasured for survival, height, and

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dbh in 1990. The exact planting method for the surviving trees could no longer be determined, thus planting method and year planted were not considered when the trees were remeasured. In 1990, ail trees were counted for survival data, and 20 trees were selected at random for height and dbh measurement. Plot means were arc sine transformed prior to analysis of variance and the Duncan's multiple range test with the Statistical Analysis System (SAS Institute inc. 1988). Untransformed plot means are presented in this report.

RESULTS

At the end of the bare-root seedling's first growing season, survival ranged from 76-97% with significant differences among species ($P < 0.01$) and planting methods ($P < 0.01$) and a significant species by planting method interaction ($p < 0.01$)(Roth II 1972). Similar results occurred in the second year, with black gum and sweet pecan respectively, having the highest and poorest survival in both years (Roth ii 1972). Growth at the end of the second growing season ranged from 0.34 ft for blackgum to 1.55 ft for water oak, with significant differences among species ($P < 0.01$) and planting method (dibble-slits best, $P < 0.05$), but the species by planting method interaction was not significant.

When the plantation was remeasured in 1990, the survival of Mackgum was near zero and this species was not included in the current measurements. For the remaining six species, significant differences for survival ($P = 0.0364$), height ($P = O.OOOl$), and dbh ($P = 0.0001$) were found and these results are summarized in Table 1. Current mean basal areas over the four replications ranged from a high of 123.3 ft^2/ac for water oak to a low of 19.8 ft^2/ac for Shumard oak. Cherrybark oak, willow oak, Nuttall oak, and sweet pecan were intermediate with mean basal areas of 84.1 ft^2/ac, 69.0 ft^2/ac, 49.9 ft^2/ac, 21.6 ft^2/ac respectively.

DISCUSSION

The performance of the species in this plantation are comparable to what has been reported in other studies. Site indices (at base of 50 years) on Commerce soils range from 85 to 105 for water oak, Nuttall oak and willow oak, from 90 to 110 ft for Shumard and cherrybark oaks, and from 95 to 115 for sweet pecan (Broadfoot 1976). Kennedy et al. (1987) reported mean lo-year heights of the tallest 100 trees of 20.0, 20.6 and 23.9 ft and mean diameters of 2.3, 2.6 and 2.7 inches for plantation-grown cherrybark, Nuttall, and water oaks respectively. These values should nearly double by age 20 based on other studies. At age 15, Krinard and Kennedy (1987) reported mean heights of 26.1 ft and 16.5 ft and mean dbh of 5.0 inches and 2.2 inches for Nuttall oak, and sweet pecan respectively, on Sharkey clay soils at Stoneville, MS. Krinard and Johnson (1988) reported mean height of 60.6 ft and mean diameter of 6.6 inches for 27-year old water oaks in plantations on Calloway silt loam or silty clay loams near Winnsboro, Louisiana.

For cherrybark oak, Francis (1983) reported 20-year mean heights of 39-41 ft and diameters of 4.2 to 4.4 inches and Clatterbuck and Hodges (1988) present similar 20-year heights (56 ft.) and diameters (6-9 inches) in natural stands. Roth ii et al. (1993) reported 21-year mean height of 55.5 ft and dbh of 5.7 inches (basal area 112.7 $ft.^2$) for cherrybark oaks planted on a 7ft x 8ft spacing. In our study the lower initial basal area was likely responsible for a considerably greater diameter growth. For treatments thinned at age 10 and having basal areas similar to ours at age 21, a mean height of 56.4 ft and dbh of 6.9 inches were reported (Roth II et al. 1993)

In this study we were forced to make several assumptions. The first was that since this was a long term study that utilized a plantation having significant levels of mortality over the past 20 years, we had to

Table 1. Twenty year measurements of survival, height, and dbh for the six surviving species. Values presented are plot means. Means followed by the same letter are not significant at a = 0.05

Survival		Heiaht		DBH	
Species	Percent	Species	Feet	Species	inches
water oak	68.2 A	water oak	61.0 A	cherrvbark	10.3 A
cherrybark	43.8 AB	willow oak	55.1 AB	water oak	9.5 AB
Nuttall oak	38.2 AB	cherrybark	51.0 B	willow oak	8.9 BC
willow oak	37.2 AB	Nuttall oak	43.6 C	Nuttall oak	8.0 CD
pecan	25.8 B	pecan	40.6 C	Shumard	7.4 DE
Shumard	17.1 B	Shumard	37.4 c	pecan	6.2 E

assume that the survivors were representative of the initial planting population. Thii assumption could be violated if survival were either positively or negatively correlated to height or diameter growth, or if there was a significant long-term species by planting method interaction. As with all long-term growth studies, if either of these biases were present, then the values presented for height or dbh may be unreliable. We also could not test for the effect of planting method or year on survival or growth due to incomplete record keeping at the time of planting. The effect of year was confounded because the trees planted in 1970 were bare-root seedlings, while those planted in 1971 were tube-grown seedlings. It can be argued that some of the above assumptions may not be valid because the planting method with the highest survival in 1970 was the dibble-slit method, while in 1971, seedlings planted auger-holes had higher survival and both years had significant species by planting method interactions ($P < 0.01$).

If we accept the above assumptions (i.e. no long-term effect of seedling type or planting method) we can make the following recommendations. Water oak, cherrybark oak, willow oak, and Nuttall oak are suitable for the site, with water oak performing the best overall. Cherrybark oak, while not common in the area, showed good growth and survival on thii site and should be considered for future planting in the area if the site is protected from flooding during the growing season. The good performance of cherrybark oak is probably because this species is commonly found on Commerce silty loam soils which are present on this site. While blackgum had the best early survival, black gum and Shumard oak are not suitable for the site due to a combination of poor long-term survival and growth. Sweet pecan may be suitable for the site, but early mortality due to herbivory (Roth 1972) impacted the long-term survival.

This study clearly demonstrates the need to match the species to be planted to the site conditions. It also shows how early survival does not necessarily predict long term survival. And finally, thii study reinforces the need for accurate record keeping so that maximum use can be made of all studies.

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Stand Development/Intermediate Management
Site Preparation

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EFFECTS OF FERTILIZER AND HERBICIDE APPLICATION ON THE GROWTH AND YIELD OF OLDER LOBLOLLY PINE PLANTATIONS--TWO-YEAR RESULTS'

Roger A. Williams and Kenneth W. Farrish[2]

Abstract-Three treatments of fertilizer, herbicide, and a combination of fertilizer and herbicide were apptii to loblolly pins (*Pinus* faeda L.) ptantations of age 25 and 30 years. Two year results show significant diameter and votume growth increases per tree and per acre with the application of fertilizer and the combination of fertilizer+herbicide as compared to the herbicide treatment alone and the control. Diameter increment of fertiiiied only trees was 29.6 percent greater than the control during the second year, averaging 24.5 percent over the two years since treatment. Trees receiving the fertilizer+herbicide treatment were 33.3 and 20.4 percent greater than the control during the second year and in the two year average, respectii. The votume increment for the fertilizer treatments over the same time period on a per tree and per acre basis displayed similar pementags gains over the control. A difference in growth response was noted between the two age classes, with the 25-year-old plantations displaying greater gains in diimeter growth (28.6%) than the 30-year-old plantations (17.6%) over the two-year period as compared to the controi. Similar growth gains in votume growth per tree and per acre were also realized.

INTRODUCTION

in the southeastern United States, forest fertilization has become an accepted silvicultural tool for increasing forest productivii. Over 1.2 million acres of loblolly pine *(Pinus* faeda L.) and 0.7 million acres of slash pine (*Pinus elliottii* Engelm.) were reported to have been operationally fertilized by 1987 (Allen 1987). These values have increased to 1.5 million and 1.07 million acres, respectively, by the end of 1988 (NCSFNC 1989). Operational forest fertilization recommendations have been developed from over 20 years of research involving extensive series of field trials that encompass a tide variety of stands and site conditions (Pritchett and Comerford 1983, Wells and Allen 1985).

With the rise in the use of fertilizers in forest management has also come increased interest in accurately predicting tree and stand growth responses to fertilizer treatment, and the subsequent volume and economic gains or losses. A survey of twenty-eight southern forest industries revealed that the use of soil grouping represented the most frequently used individual diagnostic technique (80%), followed by soil and foliar analysis (60%), to identify candidate stands and make fertilization prescriptions (Jokela et al. 1988). Foliar analysis is generally viewed as having greater diagnostic potential than soil analysis alone, since foliar analysis integrates soil nutrient availability and stand demand for a nutrient (Allen 1987). Foiiar analysis is the method that has been the most studied and reviewed (Leaf 1973, McNeil et al. 1988, van de Driessche 1974, Wells et al. 1973) and has been recommended, along with soils identification, for determining fertilization prescriptions for loblolly pine (Wells and Alien 1985).

The biological response of a forest stand to fertilization often depends on how well the native supply of nutrients in a site meet the demands of the stand. These nutrient demands are dynamic throughout the life of a stand and are dependent upon the stage of stand development. Older stands of southern pine are usually more responsive to additions of nitrogen (N) or N + phosphorous (P) than to P alone (Allen 1987). Volume responses of individual stands to fertilization vary depending upon site and stand attributes, but consistent gains of 40-50 cubic feet/acre/year have been reported across a range of species and regions (Allen 1987). Allen (1985) reports the potential return on real investments, depending on site quality and stand density, for 5-year response following N+P fertilization at age 20 to be from 3.5 to 20.3 percent for a product regime of pulpwood, chip'n'saw, and sawtimber at $15/cord, $40/cord, and $150/MBF (Scrlbner), respectively.

Wells and Allen (1985) suggest that stands that are to be fertilized should be burned within a year, but not just prior to fertilization. Burning is performed to enhance the effect of fertilization on the growth of the residual crop trees by eliminating the competing vegetation that would otherwise use fertilizer nutrients. However, a trend exists toward increased use of herbicides and away from burning for this purpose because of tighter regulations on smoke management and narrow

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windows to perform the burning due to weather conditions. The practice of combining herbicide or other cultural treatments and fertilizer simultaneously has been studied for loblolly pine and other *Pinus spp.* (Cellier and Stephens 1980, Haywood and Tiarks 1981, Squire 1977, Tiarks and Haywood 1981) but has been confined primarily to the time of planting or during the establishment period. Little research has been documented to date concerning the effectiveness of these combined practices in older plantations nearing rotation age. This paper reports the second-year results of a five-year study to examine the effects of fertilizer and herbicide applications on the growth and yield of older loblolly pine plantations at ages 25 and 30 years.

METHODS

A total of sixteen plantations were identified as potential candidate stands for this study based upon stand criteria (70 to 120 ft^2 of pine basal area; site index, base age 25, between 50 and 75 feet; approximately 25 or 30 years of age), accessibility, and soil texture (at least moderately well-drained upland loamy soils).

The plantations were sampled for pine foliage nutrient determinations. In each plantation, 15 randomly located co-dominant and dominant loblolly pines were selected. A 12-gauge shotgun was used to shoot a small branch from the upper crown of each tree. Foliage samples from the previous growing seasons were placed in labeled bags and returned to the laboratory. The foliage samples were oven-dried in a forced-draft oven at 70°C for at least 48 hours. The needles were then ground to pass a 40 mesh sieve in a Wiley mill and again dried at 70°C to constant weight.

Total Phosphorous

A 2 g sample of the ground foliage was placed in a numbered, acid-washed crucible and ashed at 550°C in a muffle furnace. The ash was then dissolved in dilute HCl and diluted with distilled water to 100 mls. A 2 ml aliquot of each sample was placed in a 50 ml volumetric flask and 5 drops of 0.25% pnitrophenol were added. the solution was neutralized with 5N NaOH until it reached a yellow end point. Each flask was filled hatf-way with distilled water, and then 8 mls of a solution containing $(NH_4)Mo_7O_{24}{*}4H_2O$, $KSbO{*}C_4H_4O_6$, and ascorbic acid was added. The samples were diluted to the 50 ml volume with distilled water. After 10 minutes, light absorbance was measured on these samples at 860 nm on a Baush and Lomb Spectronic 20 spectrophotometer. Results were expressed on a percent phosphorous by weight basis. Samples of pine foliage material from the National Bureau of Standards were analyzed along with the unknown samples to serve as a qualii control measure.

Total Nitrogen

The total nitrogen content (N) of the foliage samples were determined by the Kjeldahl method. A 0.1 g sample of the dried and ground foliage was placed in a digestion flask. Boiling chips were added with 4 mls of sulfuric-salicytic acid. The samples were left to soak in the acid overnight. Sodium thiosulfate pentahydrate (0.5 g) was added to the digestion tubes and they were then heated in a digestion block for 30 minutes at 350°C. The flasks were cooled and 1.1 g of K_2SO_4 catalyst was added to each. The solutions were again heated at 400% for one hour after initial clearing. The samples were quantitatively transferred to a 100 ml flask. A 5 ml aliquot was placed in a 150 ml beaker, and 40 mls of distilled water and 5 mls of 2.5 m NaOH were added. Readings were taken with an Orion ammonia electrode and Orion specific ion meter. Results were calculated as percent nitrogen by weight. Samples of pine foliage material from the National Bureau of Standards were analyzed along with the unknown samples to serve as a qualii control measure.

Final Stand Selection

As a resutt of the laboratory analysis, ten plantations- five in the 24-26 year-old class and five in the 30-32 year-old class were selected for study. The foliar analysis performed in the laboratory phase was the criteria used to select these ten plantations. Since it was determined that phosphorus (P) was more limiting than nitrogen (N) on sampled sites, values of P were used as the final selection criteria (Table 1). From these results, and from previously published data, it was determined that fertilizer would be applied to sample plots at a rate of 150lb. N, 50 lb. P. The attributes of the plantations used in this study are listed in Table 2.

Table 1. Nitrogen (N) and phosphorus (P) values determined for the study sites

study site	N (pct)	P (pct)	Age
	-- Age class = 25 --		
WI	1.34	0.097	25
w4	1.31	0.097	25
w2	1.32	0.099	26
W5	1.37	0.102	25
B13	1.48	0.107	26
	-- Age class = 30 --		
B12	1.26	0.093	32
W6	1.46	0.099	32
JI	1.39	0.105	32
B6.02	1.48	0.109	30
86.03	1.56	0.115	30

Plot Measurements

Each treatment plot is 0.25 acre in size, with a 0.1 acre circular measurement plot located at the center of each treatment plot. Diameter at breast height (dbh) was measured for each pine tree in the intermediate

Table 2. Summary of stand characteristics by treatment and ageclass

Treatment	Basal area (ft^2/acre)	Trees per acre	Average stand diameter (in.)	Average stand height (ft)	Volume per acre (ft^3,o.b.)
		-All Plots-			
Fertilizer	75.4	114	10.9	64.6	2326
Fertilizer + herbicide	77.9	125	10.6	64.2	2378
Herbicide	81.6	134	10.4	63.6	2471
Control	76.8	120	10.8	64.8	2354
		-Age Class = 25-			
Fertilizer	65.0	105	10.7	63.4	1956
Fertilizer + herbicide	74.4	132	10.2	62.6	2199
Herbicide	76.8	134	10.2	62.4	2270
Control	73.3	128	10.2	62.5	2172
		-Age Class = 30-			
Fertilizer	85.7	124	11.1	65.7	2695
Fertilizer + herbicide	81.2	119	11.1	65.8	2545
Herbicide	87.0	134	10.7	65.0	2703
Control	80.4	112	11.5	67.2	2549

through dominant crown classes on each plot. An aluminum identification tag was nailed to the tree with an aluminum nail just below the point at which dbh was to be measured. The dbh tape was situated on the tree for measurement by resting the tape on top of the nail, making sure the tape was aligned around the tree as best as possible before reading the measurement. A thin line was painted on the tree at the position where dbh was measured with orange paint. Thii was done so that (1) the point of measurement could be relocated if the nail was removed, and (2) measured trees could be easily seen.

Due to time constraints, total height measurements were recorded with a Suunto clineometer for two trees on each plot, for a total of 24 trees on each site, or a total of 240 trees from all ten sites. The total height of these same trees are measured each year. This data (dbh and total height) was used to generate a height equation for the purpose of developing a local height table. Non-linear regression analysis was perfomed to produce the equation:

$$H = 23.8675D^{0.4227}$$

where H = total height (feet) and D = dbh (inches). This analysis produced an R^2 value of 0.58.

The dbh and total height measurements have been recorded prior to treatment application, and for the first two growing years since treatment application. Measurments of these stand attributes will continue for three more years to give an evaluation of the effect of these treatments on growth and yield over a five-year period.

Treatment Applications

Fertilizer was applied late winter-early spring. Specially blended fertilizer at a ratio of 36-12-O was used. One hundred four pounds of this fertilizer was applied to each of the fertilizer and fertilizer/herbicide plots (6 plots per site) to achieve an application rate of 150 lbs N:50 lbs P per acre. Fertilizer was applied by walking across the plots with a spreader.

Herbicide was applied during early spring. Velpar L, in a 1:1 ratio mix, was applied at a rate of 1.25 gals/acre with a backpack applicator. This was accomplished by placing a 3-foot by 3-foot gridwork across treatment plots, and applying 2 ml of herbicide at the gridwork intersections.

RESULTS

Diameter Increment

In the second growing season after treatment, the fertilizer and fertilizer + herbicide treatments continued to surpass the growth response to the herbicide treatment alone and the control (Table 3). Diameter increment of fertilized trees was 29.6 percent greater than the control during the second year, averaging 24.5 percent greater over the two years since treatment (Figure 1). Trees receiving the fertilizer + herbicide treatment were not significantly different from the

Table 3. Diameter at breast height increment' (inches) by treatment and age class[b] for the first and second growing seasons following treatment

Treatment	AH Plots			Age Class = 25			Age Class = 30		
	Yr1[c]	Yr2	Yr1+2	Yrl	Yr2	Yr1+2	Yrl	Yr2	Yr1+2
Fertilizer	0.30[d]	0.35[d]	0.66[d]	0.32'	0.40[d]	0.72'	0.30[d]	0.31[d]	0.60[d]
Fertilizer + Herbicide	0.30[d]	0.36[d]	0.67[d]	0.32[d]	0.38[d]	0.70[d]	0.30[d]	0.34[d]	0.63[d]
Herbicide	0.24[e]	0.28'	0.52'	0.24'	0.31'	0.56'	0.24'	0.24'	0.48'
Control	0.26[e]	0.27'	0.53'	0.27'	0.29'	0.56'	0.26"	0.25'	0.51'

[a] increment values with same letters (d,e) indicate no significant difference at the p=0.05 level.
[b] age class at time of treatment application
[c] Yrl = the first growing season only; Yr2 = the second growing season only; Yr1+2 = the first and second growing seasons combined.

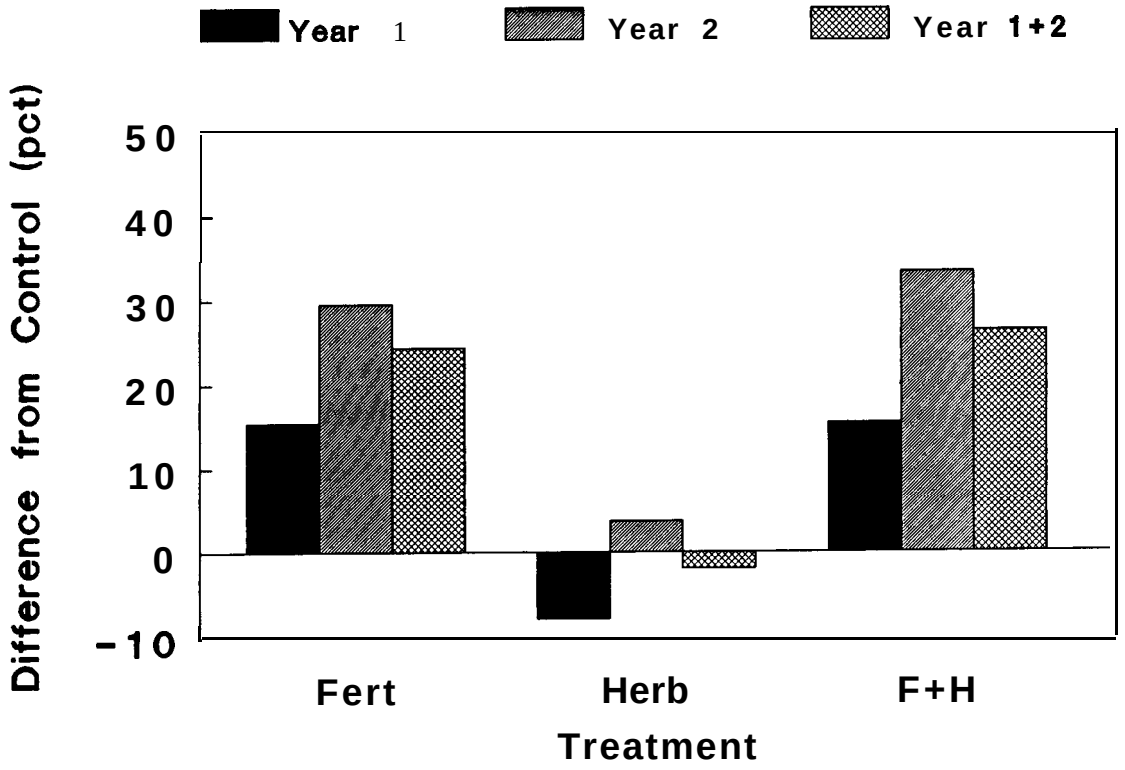

Figure I- Treatment effects of fertilizer, herbicide, and fertilizer plus herbicide on diameter increment of loblolly pine over two growing seasons as compared to the control (no treatment).

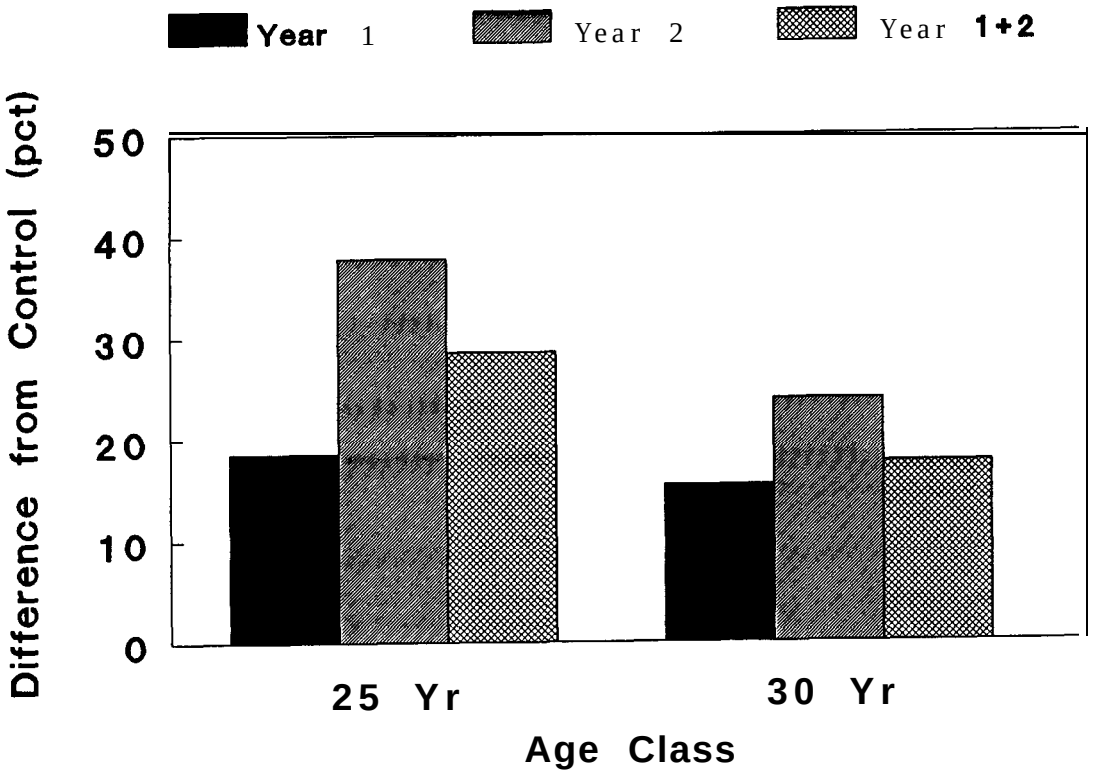

Figure 2-- Effect of fertilizer alone on diameter increment of loblolly pine by age class over the two growing seasons as compared to the control.

fertilizer alone treatment in diameter increment, but were 33.3 and 26.4 percent greater than the control in year two diameter increment and cumulative two-year diameter increment, respectively. The herbicide alone treatment produced diameter increments significantly different from the control.

The data from both growing seasons consistently show that the herbicide applications, either with or without fertilization, which were aimed at reducing mid- and understory competition for the crop trees, did not significantly influence the growth of those crop trees. In fact, the herbicide treatment alone displayed slightly reduced growth compared to the control after the first growing season, possibly as the result of herbicide stress placed on the crop trees. On the other hand, the fertilization clearly enhanced growth, actually producing greater growth gains in the second growing season than in the first following treatment (Figure 1). The fertilizer alone treatment which produced a diameter increment gain of 15.4 percent in the first growing season, produced a 29.6 percent gain in year two. This may suggest that the effects of fertiliier on growth gains of crops trees have not peaked during the second year following treatment. However, it is still premature to conclude.

A difference in the growth response of the two age classes (25 and 30 years at treatment) noted during the first growing season continued in the second (Figure 2). The 25-year age class was again more responsive to the fertilizer treatment, averaging a 37.9 percent increase in diameter increment over the control compared to 24.0 percent for the 30-year age class during the second growing season. Over two growing seasons, the 25-year age class showed a 28.6 percent increase in diameter increment over the control, while the 30-year age class was 17.6 percent greater.

Cubic Volume Increment_

Volume increment per tree was also calculated during the second growing season as was performed for the first. Volume equations by Amateis and Burkhart (1987) were used to estimate tree volumes. Volume increment per tree showed similar gains on the fertilizer treatments (Table 4). Average cubic volume (f?, o.b.) increment per tree increased 32.3 percent over the control in the fertilizer alone treatment during the second growing season. This brought the two-year average gain in that parameter to 26.9 percent over the control. Variabilii between trees in volume increment was greater than that measured for diameter increment alone since a second parameter, total height, was entered into the estimations.

Table 4. Average cubic volume (ft^3, o.b.) increment[a] per tree by treatment and age class[b] for the first and second growing seasons following treatment.

Treatment	All Plots			Age Class = 25			Age Class = 30		
	Yr1[c]	Yr2	Yr1+2	Yrl	Yr2	Yr1+2	Yrl	Yr2	Yr1+2
Fertilizer	1.61[d]	1.72'	3.30[d]	1.65[d]	1.79[d]	3.38[d]	1.58[d]	1.67"	3.24[d]
Fertilizer + Herbicide	1.52[de]	1.73[d]	3.23[d]	1.59[de]	1.79[d]	3.13[d]	1.45[d]	1.77[d]	3.32[d]
Herbicide	1.21'	1.28[e]	2.48[e]	1.16'	1.37[e]	2.53[e]	1.26[d]	1.18[e]	2.43'
Control	1.33[ef]	1.30'	2.60'	1.25"	1.25'	2.46[e]	1.40[d]	1.37.'	2.77'

[a] increment values with same letters (d,e,f) indicate no significant difference at the p=0.05 level.
[b] age class at time of treatment application
[c] Yrl = the first growing season only; Yr2 = the second growing season only; Yr1+2 = the first and second growing seasons combined.

Table 5. Average cubic volume (ft^3, o.b.) increment per acre by treatment and age class' for the first and second growing seasons following treatment

Treatment	All Plots			Age Class = 25			Age Class = 30		
	Yr1[b]	Yr2	Yr1+2	Yrl	Yr2	Yr1+2	Yrl	Yr2	Yr1+2
Fertilizer	183.7	196.7	377.7	170.8	186.9	353.6	196.5	206.5	401.7
Fertilizer + Herbicide	183.4	216.1	402.8	183.9	223.0	412.2	182.8	209.8	394.1
Herbicide	160.1	172.1	333.6	155.1	183.8	338.8	165.0	158.6	327.7
Control	157.4	156.5	313.3	155.9	159.5	315.4	158.8	153.3	311.0

[a] age class at time of treatment application
[b] Yrl = the first growing season only; Yr2 = the second growing season only; Yr1+2 = the first and second growing seasons combined.

Volume increment per acre also showed similar patterns of gain from fertilization (Table 5). Average cubic volume (ft^3, o.b.) increment per acre increased by 25.7 and 20.5 percent for the second growing season and the two growing seasons combined, respectively. Test of significance was not performed about the per acre volume gains because of the confounding factor of the number of trees per acre. Volumes per acre are obviously affected by the number of trees per acre as well as other factors. The number of trees per acre varied within and between treatments, although in most cases not substantially. Hence, a site may display greater volume growth per acre while realizing lower volume increment per tree because of the higher number of trees per acre.

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RESPONSESOFGROUNDCOVERUNDER LONGLEAF PINE TO BIENNIAL SEASONAL BURNING AND HARDWOOD CONTROL'

William D. Boyer[2]

Abstract-Responses of understory vegetation to season of bum were followed in young, naturally established, stands of longleaf pine (*Pinus palustris* Mill.). Treatments included biennial bums in winter, spring, and summer, plus a no-bum check. Groundcover biomass was measured before treatment and again 7 and 9 years later. Total green biomass on the forest floor was not significantly affected by treatment, but its components were. Green woody biomass constituted 91 percent of the total on unburned and 49 percent on burned plots. Woody understory vegetation and grasses were unaffected by season of bum. Forbs were most abundant with winter and summer bums, and legumes, with winter and spring burns.

INTRODUCTION

Control of understory hardwoods in young pine stands can increase growth of the overstory, reduce fuel loads, improve access, reduce cost of future site or seedbed preparation, and increase cover of grasses and other herbaceous vegetation.

A study was initiated in 1973 to determine the long-term effects of several hardwood control treatments on understory succession and overstory growth. Combinations of fire, mechanical, and chemical treatments were applied. A major objective was to record treatment effects on stand development over time and determine the composition and structure of midstory and understory vegetation that ultimately stabilized under the different treatment regimes.

I have already reported effects of treatments on growth of the longleaf pine (*Pinus palustris* Mill.) overstory (Boyer 1987, 1994). I also have reported the effects of a single chemical treatment, with and without fire, on development of woody vegetation (Boyer 1991), as well as development of hardwoods in relation to season of biennial burns (Boyer 1993).

METHODS

The study was established in 1973 on a sandy upland Coastal Plain site on the Escambia Experimental Forest in southwestern Alabama (maintained by the USDA Forest Service, Southern Research Station, in cooperation with the T.R. Miller Mill Company). Study sites supported natural stands of longleaf pine that were 14 years old from seed and 12 years from removal of a seed-tree overstory. Pine stocking averaged about 700 trees per acre. The last fire on all study areas was a prescribed burn in January 1982.

Three blocks were established, each with 12, square, 0.4-acre treatment plots. Plots were thinned to 500 well-distributed dominant and codominant pines per acre. All pines in O.l-acre measurement plots at the centers of treatment plots were marked and numbered, and their height and d.b.h. recorded. Trees averaged 22 feet in height and 3.2 inches in d.b.h. Basal area (BA) averaged 30 square feet/acre. Based on heights of dominant and codominant trees recorded in 1992, at age 33, estimated age-50 site indexes for longleaf pine (Farrar 1981) ranged from 77 to 81 feet on study blocks.

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 of all hardwood stems above l-inch in diameter with a herbicide in the spring of 1973, (2) cutting just above groundline of all woody stems, including volunteer pines, more than 4.5 feet tall in 1973 and as needed thereafter, and (3) untreated check. All plots with fire treatments were first burned in January 1974. Then season of burn treatments were begun. Spring burns were always in odd-numbered years. Since 1979, winter burns have been in even-numbered and summer burns in odd-numbered years.

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The pretreatment composition and biomass of groundcover vegetation were determined through destructive sampling of nine 3.1 foot by 3.1 foot sample plots within each O.l-acre measurement plot in the late summer of 1973. The above-ground potions of all living woody plants 0.5-inch or less in diameter 8 inches above groundline were harvested and species or genus was recorded. All remaining living vegetation in each sample plot was also harvested and sorted into three categories: (1) grasses and grass-like, (2) forbs, and (3) legumes. All harvested vegetation was ovendried to a constant weight at 70" C, and dry weight was recorded by measurement plot, sample plot, and category. Surface liier (all organic material above mineral soil) was collected from a 1 .0-square-foot plot nested within each 9.6-square-foot sample plot Litter was ovendried at 70° C and weighed.

Understory vegetation and organic litter were resampled, as described above, in the late summer and early fall of 1980 and 1982. Vegetation was harvested from nine new sample plots per measurement plot during each of these two examinations.

Information on understory biomass and composition from this study was compared with similar information from a study in mature longleaf pine. Well-stocked stands were thinned in 1957 to densities of 18, 27, 36, and 45 square feet of BA/acre. The same four burning treatments (biennial burns in winter, spring, summer plus unburned check) were established in 1970 under each of the four densities on two blocks. In all, there were 32 0.625-acre treatment plots. In 1970, residual pines averaged 80 to 70 years old. Understory vegetation and liier were sampled as in the present study before treatment and five times thereafter, with the last in 1981. At each of the periodic examinations, understory vegetation and liier on 10 sample plots per treatment plot were harvested, ovendried, and weighed.

RESULTS

Biomass Changes over Time

Understory biomass was sampled before burning treatments were initiated and nearly 12 years after the last burn. Plots had been burned four or five times before the first remeasurement, and once more before the second remeasurement. Total biomass averaged 8,251 lbs/acre before treatment, increased to 10,883 lbs/acre in 1980 and fell to 9,178 lbs/acre 2 years later (Table 1). Green biomass averaged 10 percent of total understory biomass at each examination. Overstory pine density increased from 30 square feet of BA/acre in the winter of 1973 to 75 square feet/acre in the winter of 1983. Despite the increase in overstory density, both green and total understory biomass were higher in 1982 than 1973. Despite biennial burning, the principal change was a steady increase in woody biomass from 55 to 82 percent of understory green biomass, and a parallel decline in the herbaceous component. This decline was entirely due to loss of grass biomass, which fell from 238 to 132 lbs/acre. Forb biomass actually increased from 131 to 204 lbs/acre and that of legumes rose from 8 to 10 lbs/acre from 1973 to 1982.

Biomass and Burning Treatments

Green Biomass.

Total green biomass in the understory was not significantly affected by burning treatments, but all components were (Table 2). Woody understory vegetation was most abundant on unburned and least on burned plots. This component amounted to 91 percent of total green understory biomass on unburned plots in 1982, but only 49 percent of the total on burned plots. All nonwoody components were least abundant on unburned plots.

Biomass of woody vegetation and grass were not significantly affected by season of burn, but those of forbs and legumes were. Forb biomass was significantly lower with spring than with winter or summer burns. Legume biomass was significantly lower with summer than with winter or spring burns. Legume biomass on summer-burned plots, however, was not significantly greater than that on unburned plots.

Table 1. Change in ground cover biomass with time (all plots).

Year	Stand basal area/acre	Green biomass			Organic liier	Total
		Woody	Herbaceous	Total		
	(Ft^2)	(Lbs/acre)				
1973	30	454	377	831	7420	8251
1980	60	824	432	1058	9807	10883
1982	75	588	348	914	8284	9178

Table 2. Effect of burning treatments on understory biomass in 1982.

Component	Season of burn			
	Winter	Spring	Summer	None
	(Lbs/acre)			
Woody	344b[1]	455 b	421b	1054a
Grasses	178a	154a	158a	39b
Forbs	292a	164b	298a	61c
Legumes	13a	16a	6b	4b
Total green	827	789	883	1158
Litter	4072c	7196b	6748b	15042a
Total biomass	49OOc	7985b	7631b	16200a

[1] Row means followed by the same letter do not differ significantly at 0.05 level, according to Duncan's test.

Overall, green understory biomass declined 13 percent between 1980 and 1982. The decline was higher on burned (18 percent) than on unburned (6 percent) plots. The composition of green biomass on all burned plots appeared to be nearing steady state in relation to season of burn. Shifts among the four components over the 2 years were quite small. The woody component increased from 48 to 49 percent of total green biomass, while grasses declined from 21 to 20 percent and other components were unchanged. Groundcover conditions on unburned plots had not yet stabilized, as woody vegetation increased from 86 to 91 percent of total green biomass between 1980 and 1982.

Litter.
Large quantities of litter accumulated on unburned plots. Twenty years after the last burn, dry weight of organic litter was 15,042 lbs/acre, more than double that with any burning treatment. Litter biomass was least plentiful with the winter burn, which was the last burn before sampling. The difference in litter biomass between spring and summer burns was too small to be significant. Most of the annual leaf and needle fall followed the spring and summer burns but preceded the winter burn.

Biomass and Supplemental Treatments

Supplemental treatments did not significantly affect total green biomass, organic litter, or any green biomass component in either 1980 or 1982 with the lone exception of forbs in 1982. At that time, forb biomass was significantly higher on hand-cleared than on untreated plots. There were no significant burn by supplemental treatment interactions for any biomass component in either year.

Biomass in Young versus Mature Pine Stands

Understory biomass in the young pine stands in 1982 was compared with understory biomass under the highest density mature stands sampled in 1981 (Table 3). At the time of sampling, young stands were 24 years old with an average of 482 trees and BA of 75 square feet/acre. Mature stands averaged 77 years old, with 48 trees and BA of 66 square feet/acre.

Table 3. Understory biomass in young and mature pine stands.

Component	Young stand	Mature stand	-Difference-	
	(Lbs/acre)			(Pct)
Woody	568	957	389	+68.5
Grasses	132	169	37	+28.0
Forbs	204	376	172	+84.3
Legumes	10	19	9	+90.0
Total green	914	1521	607	+66.4
Litter	8264	7838	426	-5.2
Total biomass	9178	9359	181	+2.0

Total organic biomass was almost the same in young stands as in mature stands. It averaged only 2 percent higher in mature stands. However, green biomass in mature stands made up 16 percent of the organic biomass on the forest floor, compared to 10 percent in young stands. As a result, green biomass was 66 percent higher in mature than in young stands. Each component of green biomass was also higher in mature stands, but the difference for grasses was less than that for any other component. Organic litter, however, was 5 percent lower in mature than in young stands.

The composition of green understory biomass in all mature stands in 1981 (32 treatment plots) was almost identical to that in all young stands (36 treatment plots) in 1982 (Figure 1). The woody component comprised 61.0 percent of green biomass in mature compared to 62.2 percent in young stands. Grasses made up 14.9 percent of green biomass in mature and 14.4 percent in young stands. Forbs made up 22.6 and legumes 1.5 percent of green biomass in mature stands compared to 22.3 and 1.1 percent, respectively, in young stands.

The difference between mature and young stands in composition of green understory biomass on burned and unburned plots was also quite similar. Woody ground cover in young stands comprised 49 percent of green understory biomass on burned and 91 percent on unburned plots. The woody component of green biomass in mature stands amounted to 47 percent of the total on burned and 89 percent on unburned plots. Organic litter on unburned plots was 15,442 lbs/acre in mature and 15,042 lbs/acre in young stands, nearly equal. Litter on burned plots averaged 5,303 lbs/acre in mature and 6,005 lbs/acre in young stands.

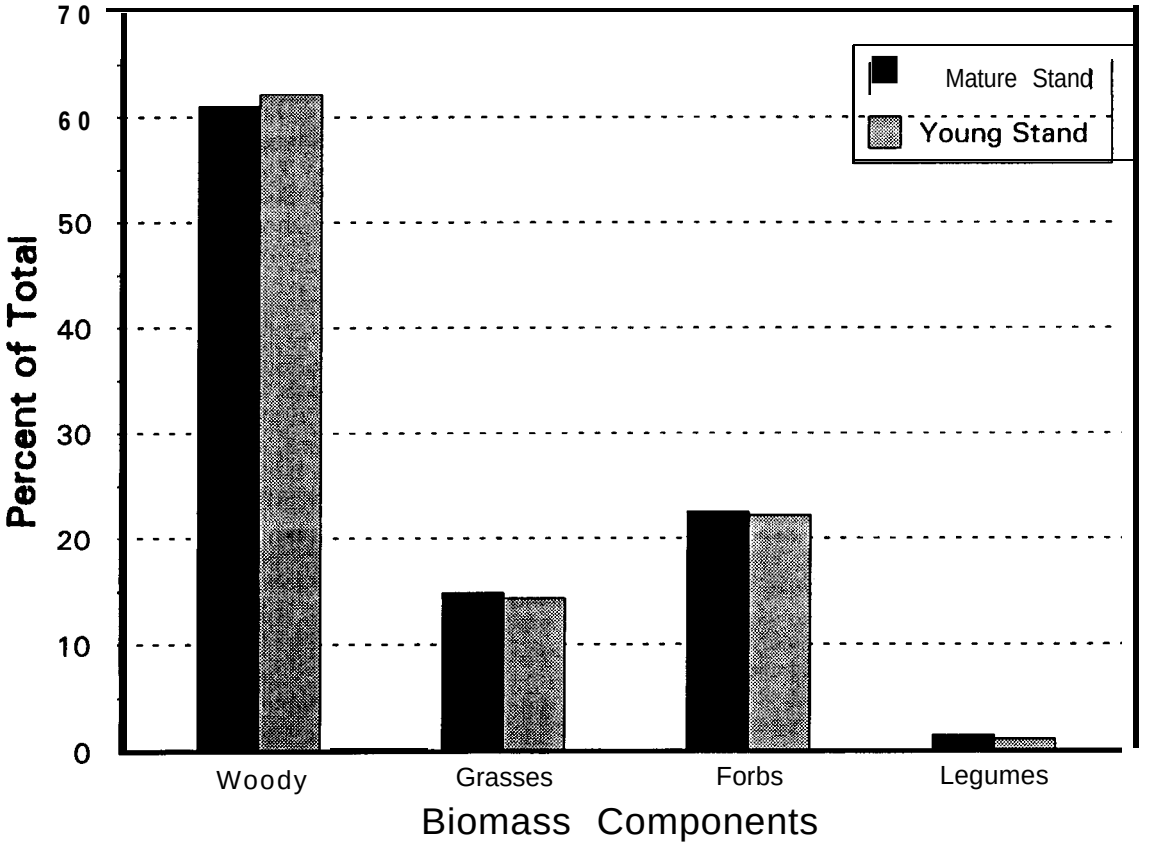

Figure 1 .-Composition of green biomass under young and mature longleaf pine stands.

DISCUSSION AND CONCLUSIONS

Green biomass constituted only 10 percent of total understory biomass in study areas for all three measurements. Total green biomass increased 10 percent from 1973 to 1982 even as pine density increased from 30 to 75 square feet of BA/acre. This rise was attributable to a 25-percent increase in woody understory biomass and a 56-percent increase in forb biomass. Grass biomass declined by 44 percent during this period. Grasses appear to be particularly vulnerable to increasing density of overstory pine. Halls (1955) reported a decline in grass production from about 1,000 lbs/acre in the open to about 300 lbs/acre under canopies ranging from 35 to 50 percent. In a study sampling 960 acres on the Escambia Experimental Forest, Gaines and others (1954) reported that herbaceous biomass as a whole declined from 1,000 lbs/acre in the open to a low of about 475 lbs/acre where stand BA reached 110 square feet. In that study, a decline in herbaceous biomass was more closely related to an increase in weight of tree litter (needles and leaves). Herbaceous biomass fell to about 260 lbs/acre when litter loads reached 8,000 lbs/acre. While Gaines and others (1954) did not separate herbaceous biomass into grass and forb components, they did observe declines in grass cover near pines. They reported a zone of influence extending about 6 to 8 feet from the bases of single trees, and 20 to 30 feet from groups of trees.

In the present study, burning treatments did not significantly affect total green understory biomass but it did affect all components of the total. Woody biomass increased while herbaceous biomass decreased on unburned plots. Woody biomass had reached 91 percent of total green biomass on unburned plots. It appeared to be stabilizing near 49 percent of the total on burned plots, down from 54 percent before treatment.

Season of burn did not affect biomass of woody understory vegetation or that of the grasses. Forb biomass, however, was lower with spring than with winter or summer burns. Legume biomass was lower with summer than with winter or spring burns. In a similar study in Louisiana, initiated in a longleaf pine seedling stand, Grelen (1975) also found no significant differences in herbage biomass or composition associated with burning treatments. However, grasses made up 90 to 94 percent of the herbaceous biomass

in his study. He measured effects of burning every 2 years for 12 years in March, May, and July.

Supplemental hardwood control treatments in the present study had no effect on any component of understory biomass with the exception of forb biomass in 1982. In that year, forb biomass was higher on periodically handcleared than on untreated plots. Particularly in combination with burning, supplemental treatments have had a major impact on the hardwood midstory (Boyer 1991), but not on hardwood regeneration on the forest floor (Boyer 1993). Sprout proliferation with periodic handclearing might have been expected to add to woody understory biomass, but it did not.

Total organic biomass beneath young stands in 1982 was only slightly less than that found in 1981 beneath mature stands approaching the same overstory density. Green biomass under the mature stands, however, was 66 percent higher than that under the young stands. The 9 square feet/acre higher BA in the young stands in 1982 does not appear to have been a factor. In 1980, both total and green understory biomass in young stands were higher and BA was lower than in 1982. Yet mature stands, with a slightly higher stand BA, still had 44 percent more green understory biomass than young stands.

Although green understory biomass was lower in young than mature stands, its composition was remarkably similar. This similarity between young and mature pine stands suggests that ground cover composition may be approaching steady-state conditions with respect to the burning treatments.

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INTENSIVE SITE PREPARATION FOLLOWING SITE DISTURBANCE DID NOT ALTER SUCCESSION OF WOODY SPECIES IN PINEYWOODS OF EAST TEXAS'

Vicky Estrada-Bustillo and Michael S. Fountain?

Abstract-Assessment of the impact that human disturbance has on forest community succession is critical if we want to continue to reflect the natural paths of succession. During 1982-l 983, over 1400 ha of mature pines in a pine-hardwood forest on the Sam Houston National Forest in Texas were killed by an epidemic infestation of the southern pine beetle (SPB). Between 1983 and 1988, this area was salvage logged, site prepared, and reforested, thus offering the opportunity to document woody species succession on these sites and to compare it to the continuing successional sere on adjacent undisturbed sites. Four salvage harvest/site preparation combinations (conventional logging methods followed by chopping and burning-CLSP, removal of logs by helicopter followed by chopping and burning-HLSP, no salvage logging followed by chopping and burning-NLSP, removal of logs by helicopter followed by herbicide application to release advance regeneration-HLH) were applied to various locations within the entire disturbed area. Permanent plots were located within each of these treatment areas as well asin adjacent undisturbed areas. Results indicate that dominant species and community similarity among treated areas became increasingly similar to the control areas over the initial five years following planting, according to their importance values (combined relative density and relative basal area). On these sites, it appears that intensive site preparation did not change species composition to the extent that it altered the successional sere of the sites.

INTRODUCTION

While there is much we do not yet understand about our environment and the fragile ecosystems that keep it intact, we have learned from experience that when we deviate from nature's method of land management, we often create situations that not only differ from our expected outcomes but result in new and unexpected obstacles. That is why as land managers we strive through our various activities, to imitate nature. Assessing the impact that human disturbance can have on forest community succession is critical if we want to continue to reflect through our activities, the natural path of succession.

The classical theory of secondary succession described by Clements (1916), as stated in Golley, 1977, is based on autogenic succession whereby a series of gradual species replacements following large-scale disturbance leads from a community dominated by early successional species to a community dominated by climax species. Authors continue to make inferences regarding successional change of a forest community based on autogenic succession citing physiological differences of species, including growth and mortality rates, as factors contributing to successional change.

However, allogenic disturbances, those dominating factors external to the plant, are today considered as or more influential in effecting successional change. In addition, we now realize that the nature of the disturbance itself must be taken into account so that the scale, intensity, number of occurrences as well as the origin are considered.

In this study a natural disturbance, infestation by southern pine beetle (*Dendroctonus frontalis*), was followed by human disturbance (intensive site preparation with chopping and subsequent burning). Through assessment of species importance and calculation of similarity between treatment areas, this study provides information necessary to assess the impact that a silvicultural, human disturbance can have on forest community succession.

DESCRIPTION OF STUDY AREA

Four Notch, the study area, is located on the Sam Houston National Forest (SHNF), approximately 17 kilometers east of Huntsville, Texas and south of State Highway 190. The Four Notch area, which is dominated by loblolly (*Pinus taeda*) and shortieaf (*Pinus echinata*) pines, is part of the greater Pineywood forest of east Texas.

Topography is typified by gently rolling hills (LaPoint 1990). Climate of the area is temperate, averaging 28

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degrees Celsius (82' F) in the summer and 11 degrees Celsius (51" F) during the winter. Annual precipitation is approximately 106 cm (41.3 inches) per year with 55% falling between the months of April and September (LaPoint 1990). Soils within the study area consist of Vet-tic Paleudalfs (Annona series), Arenic Plinthic Paleudalfs (Depcor series), Grossarenic Plinthic Paleudults (Gunter series), and Aquentic Chromuderts (Redco series) (USDA Soil Conservation Service 1979).

In 1982 the Four Notch area of the Sam Houston National Forest was designated to become a wilderness area under the second Roadless Area Review and Evaluation (RARE II) conducted by the USDA Forest Service. During the spring of 1982 major infestations of southern pine beetle (SPB) occurred within the proposed wilderness area. Control of these spots was initiated by the Forest Service.

However, a Federal Court restraining order was issued citing wilderness potential stated in the RARE II regulations combined with the presence of the Red Cockaded Woodpecker. Managements plans to cut and remove the infested trees were halted. By July 1983, when the Forest Service was allowed to initiate salvage logging operations, more than 1,400 pine-dominated hectares (3500 acres) had been killed (USDA-FS 1987).

Salvage logging began in August of 1983 using conventional rubber-tired skidders but was halted in late August due to the wet conditions following Hurricane Alicia. After four months salvage logging by conventional rubber-tired skidders was resumed in some areas, removal of logs by helicopter was initiated in others, and dead pine trees were felled but not salvaged in additional areas. All of these areas were site prepared using a tree crusher followed by broadcast burning with a helicopter drip torch during the summer and fall of 1987. Hand planting of loblolly pine seedlings at approximately 1700-I 900 per hectare was done during the early spring of 1988.

In the portions of the study area which were not exposed to beetle infestations or site preparation predominant understory woody species were American beautyberry *(Callicarpa americana)* and yaupon *(Ilex vomitoria)* accompanied by red maple *(Acer rubrum)*, loblolly pine and eastern hophornbeam *(Ostrya virginiana)* (Tables 1 and 3). Dominant species in the midstory and overstory included loblolly pine, yaupon, sweetgum *(Liquidambar styraciflua)*, winged elm *(Ulmus alata)*, eastern hophornbeam, post oak *(Quercus stellata)* and water oak *(Quercus nigra)* (Tables 2 and 3).

Table 1. Mean importance values for ten most dominant small stem species (<1.37 meters) occurring in the control areas (CTRL) from 1988-I 992

1988		1989		1990		1991		1992	
spp.'	IV	spp.	IV	spp.	IV	spp.	IV	spp.	IV
CAAM	*25.22*	CAAM	25.22	CAAM	25.22	CAAM	23.78	CAAM	23.78
ILVO	13.08	ILVO	13.08	ILVO	13.08	ILVO	19.94	ILVO	19.94ACRU
	6.40	ACRO	6.40	ACRU	6.40	MYCE	5.60	MYCE	5.60
PITA	5.60	PITA	5.60	PITA	5.50	QUAL	5.38	QUAL	5.38
OSVI	5.19	OSVI	5.19	OSVI	5.19	ACRU	5.13	ACRU	5.13
MYCE	4.63	MYCE	4.63	MYCE	4.63	OSVI	4.74	OSVI	4.74
COFL	4.15	COFL	4.15	COFL	4.15	COFL	4.01	COFL	4.01
FOLI	3.68	FOLI	3.68	FOLI	3.68	PITA	3.12	PITA	3.12
QUAL	3.67	QUAL	3.67	QUAL	3.67	LIST	3.02	LIST	3.02
SAAL	3.13	SAAL	3.13	SAAL	3.13	FOLI	2.89	FOLI	2.89

'Mnemonic acronyms are defined in Table 3.

Table 2. Mean importance values for ten most dominant large stem species (<1.37 meters) occurring in the control areas (CTRL) from 1988-I 992

1988		1989		1990		1991		1992	
spp.'	IV	spp.	IV	spp.	IV	spp.	IV	spp.	IV
PITA	32.88	PITA	32.68	PITA	32.68	ILVO	36.98	ILVO	36.98
ILVO	31.33	ILVO	31.33	ILVO	31.33	PITA	31.14	PITA	31.14
LIST	19.92	LIST	19.92	LIST	19.92	LIST	21.78	LIST	21.78
ULAL	17.05	ULAL	17.05	ULAL	17.05	ULAL	20.30	ULAL	20.30
OSVI	12.45	OSVI	12.45	OSVI	12.45	QUNI	10.21	QUNI	10.21
QUST	9.72	QUST	9.72	QUST	9.72	QUST	10.14	QUST	10.14
QUNI	8.98	QUNI	8.98	QUNI	8.98	QUAL	9.05	QUAL	9.05
PIEC	8.50	PIEC	8.50	PIEC	8.50	OSVI	8.63	OSVI	8.63
QUAL	7.38	QUAL	7.38	QUAL	7.38	COFL	6.88	COFL	6.88
COFL	5.65	COFL	5.65	COFL	5.65	PIEC	6.86	PIEC	6.86

'Mnemonic acronyms are defined in Table 3.

Table 3. List of ten most dominant large and small stem woody species found in the undisturbed areas (control) of the Sam Houston National Forest study site

Family	Genus/species	Common name	Mnemonic acronyn
ACERACEAE	*Acer rubrum*	red maple	ACRU
AQUIFOLIACEAE	*Ilex vomitoria*	yaupon	ILVO
BETULACEAE	*Ostrya virginiana*	eastern hophornbeam	OSVI
CORNACEAE	*Comus florida*	flowering dogwood	COFL
FAGACEAE	Quercus *alba*	white oak	QUAL
	Quercus nigra	water oak	QUNI
	Quercus *stellata*	post oak	QUST
HAMAMELIDACEAE	*Liquidambar styraciflua*	sweetgum	LIST
LAURACEAE	*Sassifras albidum*	sassafras	SAAL
MYRICACEAE	*Myrica cerifera*	southern bayberry	MYCE
OLEACEAE	*Forestiera ligustrina*	upland forestiera	FOLI
PINACEAE	*Pinus echinata*	shortleaf pine	PIEC
	Pinus taeda	loblolly pine	PITA
ULMACEAE	*Ulmus* elate	winged elm	ULAL
VERBENACEAE	*Callicarpa* americana	American Beautyberry	CAAM

METHODOLOGY

Vegetation data were collected from 330 square quadrats (5m by 5m) located in the following five treatment areas:

1. Conventional logging followed by site preparation with the tree crusher followed by broadcast burning (CLSP). A total of 100 quadrats were sampled.
2. Removal of logs by helicopter followed by site preparation with the tree crusher followed by broadcast burning (HLSP). Quadrats sampled totaled 100.
3. Removal of logs by helicopter followed by application of ground herbicide(hexazinone) in an effort to release advance pine regeneration from competing vegetation (HLH). Spot application of the herbicide was administered on an 8 x 8 ft. (2.4m x 2.4m) grid. A total of 30 quadrats were sampled.
4. *No* salvage logging was done prior to site preparation; dead trees were felled but left on site (NLSP). Sites were prepared using the same techniques described for treatments 1 and 2. Quadrats sampled totaled 50.
5. Areas unaffected by the SPB infestations and located in stands adjacent to the treated areas (CTRL). A total of 50 quadrats were sampled.

Woody vegetation within the control and harvest/site preparation treatment area quadrats were initially measured in August-September of 1988. The treatment area quadrats were remeasured annually through 1992 while the control quadrats were remeasured only in 1990. All measurements were

made during late August and early September of the year.

Woody species data collection was based on stem height. Woody stems equal to or greater than 1.37 m in height (large stem category) were tagged, identified by species; and measured at ground line with a caliper to determine the basal diameter (in millimeters). Woody stems less than 1.37 m high (small stem category) were identified by species and the number of stems per species recorded.

Comparisons of species composition were made between treatments using data collected in the 330 quadrats. One-way analysis of variance, in conjunction with Duncan's New Multiple Range test, was utilized to test for significant differences between treatments for all years. All tests of significance were conducted at a 95% level of confidence.

Species importance values, which use relative density and relative basal area to rank species in order of importance within a community (in this case treatment area), were used to determine similarity between treatments and to evaluate the effect of these treatments on vegetative succession. The Importance Value (IV) per quadrat for each woody species in each treatment was calculated to provide an importance rating scale for individual species. Two scaled importance value systems were used in this study. For the large stem class, a combined expression of relative density (RD) and relative basal area (RBA), was calculated. All importance values in the large stem class were based on two hundred (200) percent where:

$$IV = RD + RBA$$

The importance values for the small stem category were calculated without relative basal area since data for the small stem category were collected only as a count by species from which basal area could not be determined. Therefore small stem importance values were based on one hundred (100) percent using only relative density (RD).

Vegetative comparison between treatments was accomplished using importance values to calculate the coefficient of community similarity (CC). This resemblance function mewasures the number of species common (both present and absent) to different treatment areas. By using the CC indices, all species are given equal weight so that the effect of harvest and site preparation on rare species as well as common species can be measured. A simplified version of the formulas developed by Sorenson in 1948 and originally derived by Jaccard (1914) and Czekanowski (1913) was used to calculate both CC and Indices of percent similarii (Duncan 1988).

So that:

$$cc = \frac{2w}{A + B},$$

where
CC = coefficient of community similarity
W = number of species common to communities A and B
A = total number of species present in community A
B = total number of species present in community B

Species presence/absence alone can not determine species composition because the quantitative values, such as abundance and size of stems, are not taken into account. The percent similarity index (PS), a resemblance function that incorporates quantitative measures, was used to calculate similarity. The index is weighted according to some quantitative value, in this case importance value (relative basal area plus relative density), in order to measure the species contribution to the vegetation group. These values are used to detect subtle changes in composition and abundance due to chronic impact (Goodall 1978, Westman 1985).
So that:

$$PS = \frac{2\ (\min\ a,b)}{a + b}$$

where
PS = percent similarity
(min a,b) = lesser importance value of a species shared by communities A and B
a = total of importance values in community A
b = total of importance values in community B

RESULTS

An assessment of successional trends of woody stem species within treatment areas was made using four key species; shining sumac (*Rhus copallina*), loblolly pine, yaupon and flowering dogwood (*Cornus florida*). These species were selected because they exemplify the various degrees of tolerance that occur within the successional sere. Table 4 illustrates the mean importance values of these four species by large and small stem category within the five treatment areas over the five year period.

Although the importance values of species varied among treatments, the trends of these values were similar among all treatments during the five year period. In treatment areas where intolerant species (typical of the pioneer stage) were found, the importance value of the large stem component of shining sumac (RHCO) and loblolly pine (PITA) increased over the five year period, where as the small stem component of these species decreased in importance.

Table 4.-Mean importance value of large and small stem component for four species exposed to different treatments in years 1988-I 992.

Treatment	Species							
	Rhus copallina		*Pinus* faeda		*Ilex* vomitoria		*Cornus florida*	
	LS	ss	LS	ss	LS	ss	LS	ss
CSLP								
1988	2.00	11.47	2.00	19.20	0.00	3.93	0.00	0.23
1989	5.40	11.14	53.04	15.68	0.64	3.66	0.86	0.51
1990	8.32	12.48	134.56	16.69	0.42	4.45	1.48	0.52
1991	11.83	12.41	132.55	13.57	1.94	5.68	1.64	0.69
1992	15.05	7.52	129.56	10.75	3.83	7.04	1.40	0.26
HSLP								
1988	0.79	9.06	25.60	21.65	0.00	3.51	0.00	0.17
1989	3.68	8.00	89.20	16.71	0.22	5.42	0.00	0.26
1990	5.79	9.63	134.88	16.22	0.59	4.39	0.07	0.30
1991	8.50	9.61	127.67	11.35	1.50	5.24	0.09	0.21
1992	10.67	5.88	126.73	9.72	3.30	6.77	0.28	0.24
HLH								
1988	0.00	0.08	79.19	38.54	6.50	4.41	2.25	1.61
1989	0.00	0.17	95.35	29.24	7.41	5.49	2.18	1.42
1990	0.00	0.16	106.98	19.35	7.63	5.09	2.84	1.62
1991	0.00	0.09	109.09	13.76	7.32	7.04	2.83	0.86
1992	0.00	0.00	112.37	10.66	7.48	10.14	2.20	2.39
NLSP								
1988	4.00	22.79	0.00	11.42	0.00	3.18	0.00	0.06
1989	9.60	19.27	74.95	7.47	0.54	2.85	0.31	0.16
1990	13.55	24.82	121.63	2.15	1.82	3.50	0.41	0.12
1991	20.92	22.39	106.57	0.57	2.19	5.00	0.41	0.10
1992	30.48	13.48	98.00	0.48	3.72	6.36	0.38	0.10
CTRL								
1988	0.00	0.03	32.68	5.60	31.33	13.08	5.65	4.15
1989	0.00	0.03	32.68	5.60	31.33	13.08	5.65	4.15
1990	0.00	0.03	32.68	5.60	31.33	13.08	5.65	4.15
1991	0.00	0.00	31.14	3.12	36.98	19.94	6.88	4.01
1992	0.00	0.00	31.14	3.12	36.98	19.94	6.88	4.01

The importance value of yaupon (ILVO), a tolerant species typical of mid seral stage of succession, increased in both the large and small stem components within five treatments throughout the five year period. COFL, a very tolerant species, was not found in the large stem component of the Conventional Log Site Prep (CLSP), Helicopter Log Site Prep (HLSP) and No Log Site Prep (NLSP) treatments in 1988. However over the five year period there was an increase in both the large and small stem components of COFL in all treatment areas with a greater increase measured in the large stem component.

The coefficient of community similarity (CC) measures the degree of similarity in species composition with values ranging from 0 where no species are shared by the communities to 1 .0 where species composition is identical. Cox (1980) found that although it is theoretically possible to have a value of 1 .0, replicated samples for a single community usually show coefficients of only 0.85. Whittaker (1967) found values of highly similar habitats ranging from 0.60 to 0.94. Based on his research, the midpoint value of 0.77 was used as the standard so that communities with values of 0.77 or greater were considered highly similar.

Woody stem species common to the five treatments over the five year period were compared within large and small stem categories. In the large stem component (Table 5) similarity values were greatest throughout the five year period for HLSP/CLSP treatments with a value of 0.77 in 1988 which increased to 0.89 in 1992. Values were also high throughout this period for the CTRUHLH treatments with a value of 0.84 in 1988. Similarity between these two treatments decreased to 0.77 in 1992. With the exception of the CTRUHLH mentioned above, the number of species in the large stem component common among all treatment areas increased over

Table 5. Cooefficients of community similarity (cc) between treatments for small and large stem components in years 1988-1992

Treatment	HLSP		HLH		NLSP		CTRL	
	s s	LS	s s	LS	s s	LS	s s	LS
CSLP								
1988	0.84	0.77	0.77	0.20	0.81	0.46	0.82	0.17
1989	0.86	0.77	0.79	0.57	0.88	0.67	0.85	0.58
1990	0.83	0.76	0.87	0.66	0.88	0.78	0.80	0.67
1991	0.93	0.78	0.86	0.74	0.87	0.81	0.75	0.77
1992	0.88	0.89	0.85	0.76	0.93	0.90	0.80	0.73
HLSP								
1988		----	0.74	0.30	0.82	0.43	0.78	0.28
1989		----	0.84	0.64	0.90	0.57	0.84	0.59
1990		----	0.83	0.70	0.86	0.74	0.78	0.68
1991		----	0.88	0.71	0.90	0.78	0.77	0.71
1992		----	0.75	0.74	0.85	0.86	0.80	0.79
HLH								
1988		----		----	0.78	0.30	0.80	0.84
1989		----		----	0.84	0.56	0.88	0.79
1990		----		----	0.86	0.56	0.81	0.78
1991		----		----	0.86	0.67	0.81	0.76
1992		----		----	0.79	0.72	0.76	0.77
NLSP								
1988		----		----	----	----	0.78	0.33
1989		----		----	----	----	0.88	0.61
1990		----		----	----	----	0.85	0.60
1991		----		----	----	----	0.80	0.70
1992		----		----	----	----	0.75	0.75

time. By 1992 all CC values ranged from 0.72 to 0.90, indicating similarity between communities.

In the small stem component (Table 5), species common among communities was relatively high throughout the five year period (greater than 0.74). Although the number of species common to the CTRL/HLH and CTRUNLSP treatments decreased slightly over the five year period, the number of small stem species common among treatment areas remained basically the same or increased in number (HLH/CLSP and NLSP/CLSP) for the majority of treatments.

While presence/absence of species among communities gives some indication of their likeness, the abundance of the species occurring within these communities must also be considered. Percentage similarity using importance values for all species occurring within each treatment was calculated for the large and small stem categories (Table 6). The same range and standard values were used in measuring percentage similarity as those used for coefficiency of community.

Values for percentage similarity are expected to be lower since any differences in number of stems per species will lower the similarity. However, the general trends over the five year period were the same. The majority of treatments shared more species with increased similarity in relative density (small stem category) and relative density and relative dominance (large stem category) over time with the exception of the CTRL/HLH treatments. The small stem component of the HLSP/CLSP treatments had the highest number of species in common with greatest similarity in relative density among species. Initial values (1988) of the small stem component among all treatments were greater than the large stem category values but they did not increase much over the five year period.

By the end of the fifth year the CLSP, HLSP, and NLSP were still more similar to each other sharing a greater number of species in common with greater similarity in relative density and relative dominance. The HLH and CTRL treatments also remained more similar to each other than to the other treatments. However, all harvest/site preparation treatment areas became increasingly similar to the CTRL areas over the five year period.

Table 6. Percent similarity (ps)based on mean importance values by treatment type for small and large stem components in years 1988-l 992

Treatment	HLSP		HLH		NLSP		CTRL	
	SS	LS	SS	LS	SS	LS	SS	LS
CSLP								
1988	0.81	0.29	0.53	0.06	0.74	0.27	0.56	0.06
1989	0.84	0.75	0.59	0.54	0.78	0.68	0.54	0.45
1990	0.85	0.93	0.66	0.69	0.72	0.84	0.56	0.34
1991	0.84	0.92	0.71	0.70	0.75	0.79	0.54	0.35
1992	0.84	0.93	0.71	0.73	0.80	0.78	0.58	0.37
HLSP								
1988	----	----	0.55	0.36	0.77	0.33	0.44	0.36
1989	----	----	0.63	0.73	0.76	0.77	0.55	0.47
1990	----	----	0.68	0.71	0.75	0.87	0.58	0.40
1991	----	----	0.71	0.74	0.79	0.83	0.56	0.40
1992	----	----	0.74	0.76	0.77	0.80	0.58	0.41
HLH								
1988	----	----	----	----	0.49	0.24	0.53	0.65
1989	----	----	----	----	0.54	0.68	0.66	0.59
1990	----	----	----	----	0.54	0.75	0.72	0.57
1991	----	----	----	----	0.59	0.79	0.66	0.55
1992	----	----	----	----	0.65	0.73	0.68	0.52
NLSP								
1988	----	----	----	----	----	----	0.47	0.24
1989	----	----	----	----	----	----	0.56	0.51
1990	----	----	----	----	----	----	0.55	0.44
1991			----	----	----	----	0.55	0.48
1992	----	----	----	----	----	----	0.58	0.48

CONCLUSIONS

Looking at species data within five treatments it is apparent that the intolerant species in the small stem component decreased over the five year period. This reduction can be attributed to two factors; the growth of pines and hardwoods which eliminated them from the small stem category and placed them in the large stem category and the decline of stems due to mortality caused by competition.

Tolerant species (ILVO) became increasingly important in both the large and small stem components, and very tolerant species (COFL) also increased although at a slower rate than the less tolerant species. As stated by Gliienstein et al. (1986), species such as loblolly pine, which have limited longevity (100-300 years) and are limited in recruitment to periods immediately following large-scale disturbance, are likely to reach peak importance early in succession and decline thereafter.

Species occurring in the five treatment areas by the fifth year were very similar with coefficient of community similarity mean values measuring between 0.72 and 0.90. In addition, the size and number of stems of these species common among treatment areas became increasingly similar over the same period.

The initial application of hexazinone to reduce the hardwood presence did not appear to have any lasting affects on succession as the importance values for the small stem component of the HLH treatment were similar to the other treatments by the third year. This concurs with the findings of Zutter and Zedaker (1988), which showed that significant long term changes in woody species would not result from a single hexazinone application. In addition, as stated by Burkhart and Sprinz (1984), once hardwood competition becomes established, it remains a constant proportion of the stand growing stock over the rotation.

While much work continues to identify those factors that most contribute to forest community succession following a natural disturbance, the vegetation associated with each stage of succession has been identified. Natural disturbance (primarily wildfire) has historically maintained a mid-seral stage (mixed pine/hardwood) community in the Pineywoods of East Texas. Thus the findings in this study indicate that in these mid-seral stage stands, human disturbance (harvest and site preparation), does not radically alter species composition. Pine dominance was maintained by planting pines while other species were not eliminated.

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EFFECTS OF RIPPING (DEEP SUBSOILING) ON LOBLOLLY PINE PLANTATION ESTABLISHMENT AND GROWTH -- NINETEEN YEARS LATER'

Fred G. Fallis and Howard W. Duzan, Jr.?

Abstract-Paired plots were installed at twenty-one locations across southeast Oklahoma and central Arkansas during the winter of 1975 to evaluate the effects of ripping on loblolly pine *(Pinus taeda L.)* plantation establishment. Early findings indicated that ripping improved survival and growth on a range of well drained soils with high stone and fragment content which dominate this region. Pine growth has been monitored periodically at thirteen locations over the nineteen years since treatments were applied. Other stand management treatments such as thinning have been applied in the intervening years at all thirteen locations.

INTRODUCTION

The Ouachita Mountains in central Arkansas and southeast Oklahoma are characteiied by moderately steep to steep terrain with soils developed from sandstone, shale, and stony colluvium. These well drained soils vary in depth of surface horizon, often containing a greater proportion of rock and gravel than soil. The high rock content results in soils that tend to be droughty, a condition that worsens along a gradient of decreasing rainfall from Arkansas westward into southeast Oklahoma. Plantability is severely limited in these shallow soils dominated by rock.

It is difficult to physically make a planting spot deep enough to properly plant a tree. Getting the root system in direct contact with the soil is also a problem in these soils. The combination of droughty soils and poor planting conditions greatly increase the likelihood that the planted tree will die in the first growing season. Early growth can also be hampered on these soils by restricted rooting volume.

The amelioration of adverse soil conditions on upland sites can improve pine survival and growth by (1) breaking soil layers that hinder planting and restrict root development, (2) concentrating organic matter near the seedlings, and (3) increasing soil macropore volume, which improves aeration and may increase water holding capacity (Lowery and Gjerstad, 1990). The objective of this study was to quantify the long-term growth response of bareroot loblolly pine seedlings to soil ripping treatments in the Ouachita Mountain Province.

METHODS

Twenty-one study locations on Weyerhaeuser landholdings were selected from sites scheduled to be planted in 1975-76; six locations in Arkansas and fifteen in Oklahoma. The following site characteristics were described for each site by Weyerhaeuser soil surveyors: (1) detailed soil profile description, (2) slope percent, and (3) aspect.

Paired plots, each approximately 0.25 acres in size, were established at each location in the fall of 1975. One plot was randomly assigned the ripping treatment while the other served as the non-ripped control. All soil ripping treatments were completed during the period August 1975 to February 1976. The actual equipment used to rip the plots was different for each state. In Oklahoma, ripping was done with a straight shank rip tooth mounted to a drawbar on a D-8 or D-9 tractor. The drawbar had two ripping teeth mounted equidistant behind each tractor track. Rip depth for this type of equipment was 18-24 inches. The Arkansas locations were ripped with a single straight shank tooth mounted to the front blade of a D-4 tractor. Rip depth for these locations was 14-18 inches. The rips appeared to extend down into the B- hoiion at all locations. Total soil disturbance was more pronounced on the Oklahoma plots and some rip trenches are still evident nineteen years after treatment, but difficult to detect in the Arkansas plots. Because of these ripping differences, results are discussed separately by state.

Planting was completed between January and March 1976, 2 months or more after the ripping treatment with

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one exception. Location number eleven in Oklahoma (hereafter referred to as 011) was planted 1 month after the ripping treatment. The Oklahoma plots were planted at an average density of 862 trees per acre, while the Arkansas plots averaged 967 planted trees per acre. Locations that might have a cattle grazing problem were fenced for protection.

All locations were left untouched until the first thinning at ages 9 (Oklahoma) and 10 (Arkansas). The Oklahoma locations were pre-commercial thinned to approximately 200 trees per acre at age 9 and five of the ten received a commercial thinning at ages ranging from 16-18 years after outplanting. The Arkansas locations were pre-commercial thinned initially to approximately 450 trees per acre with a subsequent commercial thinning at age 16.

Pine growth has been monitored periodically at the thirteen active locations (3 in Arkansas and 10 in Oklahoma) over the nineteen years since the ripping treatment was applied. Growth parameters that were monitored included: (1) percent survival, (2) tree height, and (3) dbh -when achieved. The most recent measurement was completed October, 1994 when all locations had completed 19 growing seasons since outplanting.

RESULTS

Site Characteristics

Soil features for each location are summariied in Table 1. Four soil series are represented among the study locations. Solum depths vary from 27 to 60 inches. All of the soils are well drained, usually with loam A- horizons over clay or clay loam subsoils.

Rock content of the A- horiion is the major difference among the soil series. Average rock content varied by series and ranged from 15 to 85 percent. High rock content makes planting difficult and reduces available soil water storage. Arkansas rip plots 5 and 6 (AR-5, AR-6) had noticeable sheet erosion. This probably resulted from wind-rowing logging debris prior to the ripping treatments.

Survival

Seedling survival was high among the three Arkansas locations, averaging 92 percent after 2 years (Figure 1). There was no difference in survival between the paired treatment plots at these three locations.

On the Oklahoma locations, second year survival differences averaged 13 percentage points higher on ripped than on control plots (Figure 1). The Oklahoma survival difference between ripped and non-ripped plots can be attributed to the droughtier planting environment on these sites.

Table 1: 1975 Ripping Trials - Soils Information

Location	A Horizon Texture	A Horizon Thickness (in.)	A Horizon Pct Rock	B Horizon Texture	B Horizon Thickness (in.)
AR-4	Loam	9	50	Clay	18
AR-5	Loam	2	50	Clay	30
AR-6	Loam	8	30	Clay	41
OK-3	Sandy loam	10	35	Clay	50
OK-5	Loam	8	30	Clay	22
OK-6	Loam	23	70	Clay loam	12
OK-7	Loam	8	35	Clay	22
OK-8	Loam	14	85	Clay loam	21
OK-IO	Loam	12	70	Clay	38
OK-11	Loam	13	50	Clay	31
OK-12	Loam	13	50	Clay	22
OK-13	Loam	12	55	Clay	20
OK-15	Sandy bam	13	15	Sandy clay loam	21

Height Growth

Average height growth was improved by the ripping treatment at the Arkansas and Oklahoma locations. At the Arkansas locations, (Figure 2) average height gain over the control plots was 0.7 feet after 2 growing seasons and had increased to 1.2 feet after 4 growing seasons. After thinning these locations to 450 trees per acre at age 10, the average height gain for the rip treatment was 1 .I feet. Height gain remained steady at 1 .O feet at age 14 and increased to 1.6 feet 19 years after the ripping treatment. The age 19 measurement was taken after these locations had received a commercial thinning.

On the Oklahoma sites, (Figure 3) height gain over the control plots averaged 0.50 feet after 2 growing seasons and increased to 1 .1 feet after 4 growing seasons. After thinning these locations to 200 trees per acre at age 9 the average height gain jumped to 2.1 feet and then decreased to 1.4 feet at age 14. By age 19 the average height gain was 1.7 feet, this measurement was completed after five of the ten locations had received a commercial thinning.

Basal Area

Ripping increased total (includes standing, thinnings and mortality) pine basal area at twelve of the thirteen locations (Figure 4). Basal area gain over the control plot at age 19 ranged from 0.77 to 42.24 square feet.

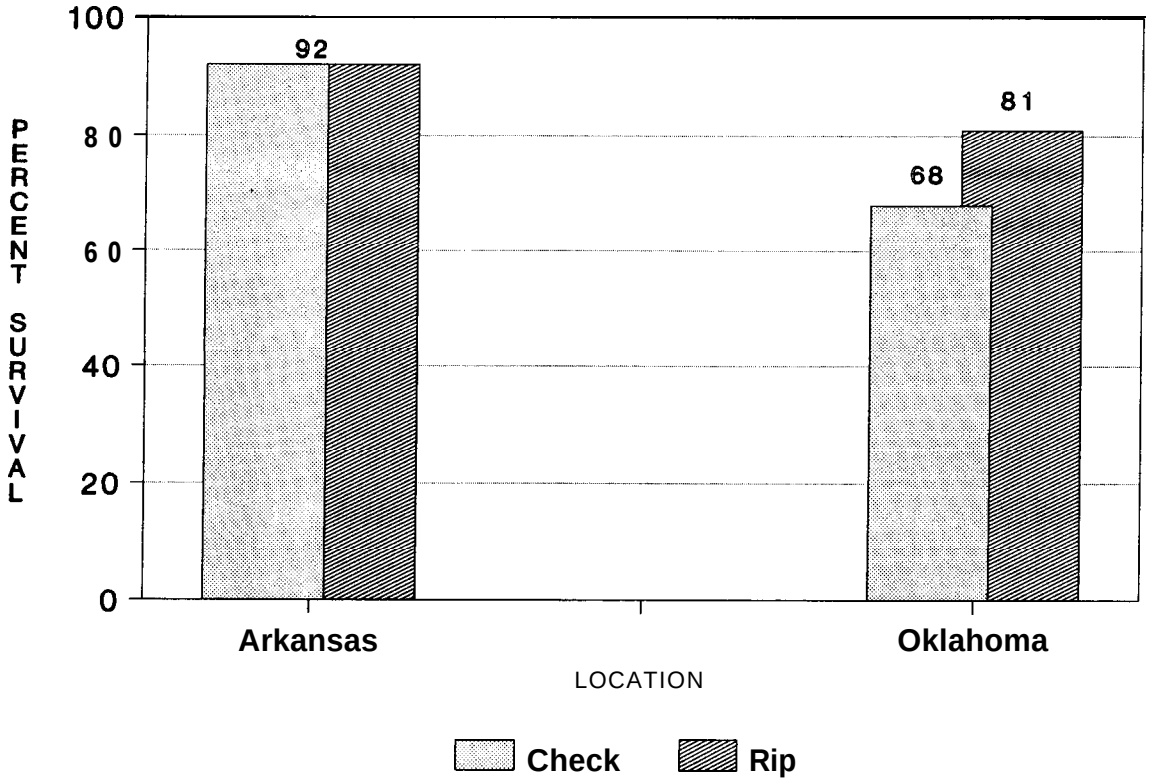

Figure 1. -- Percent survival after 2 growing seasons

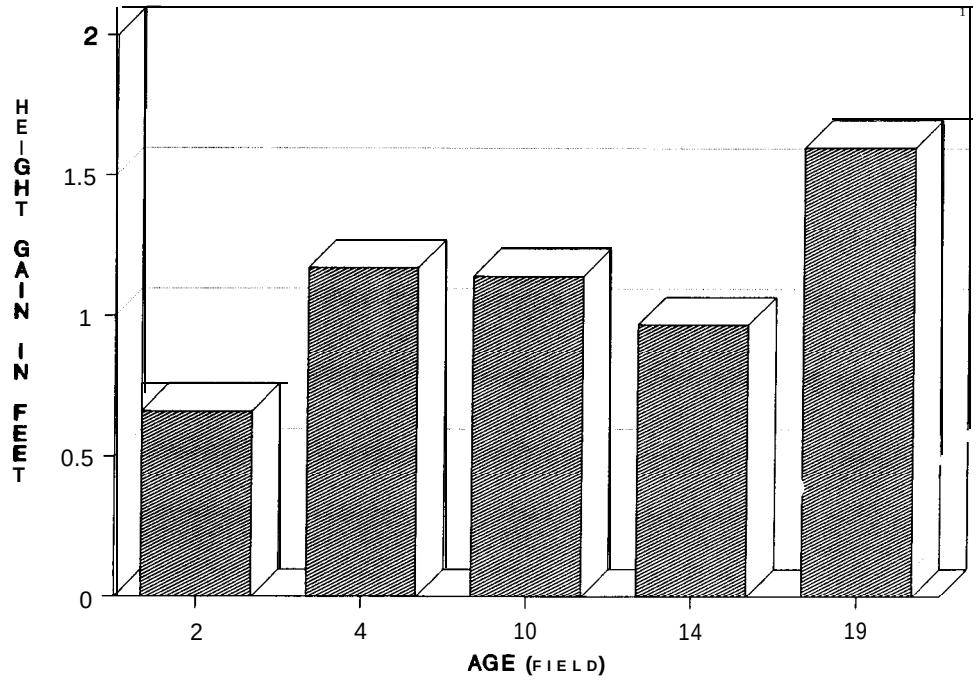

Figure 2. -- Average height gain from ripping treatment, Arkansas locations 4-6

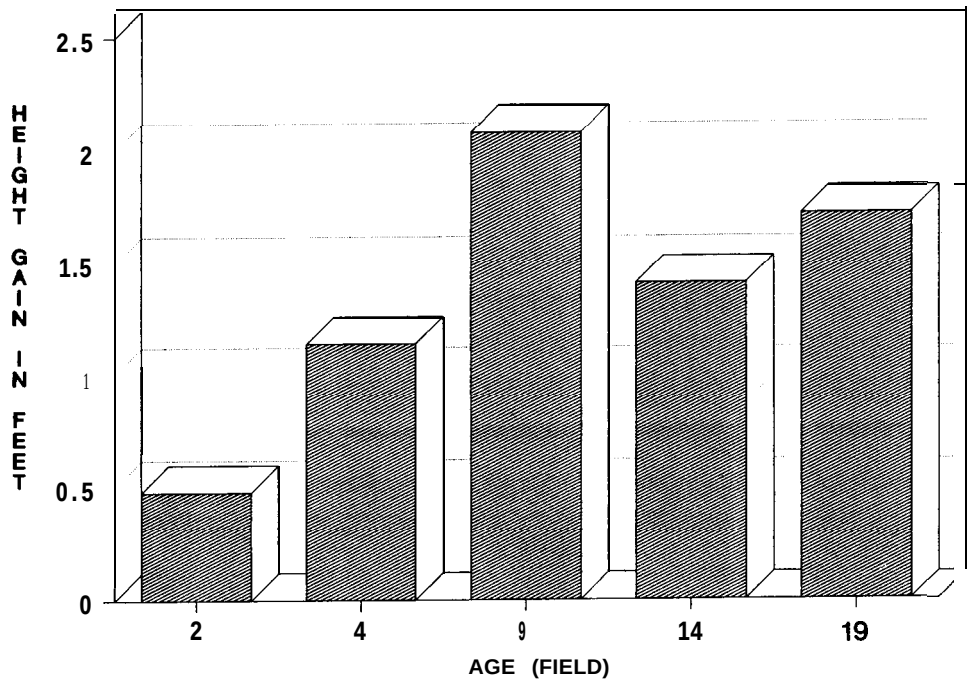

Figure 3. -- Average height gain from ripping treatment, Oklahoma locations

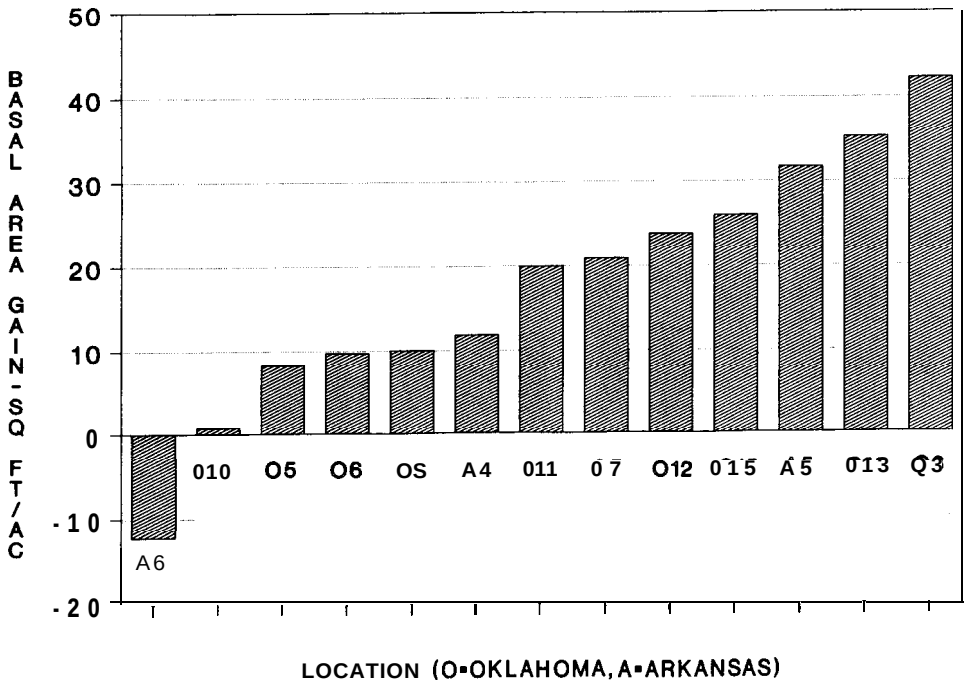

Figure 4. -- Gains in total basal area from ripping treatment at age 19, total basal area includes standing, thinnings and mortality.

Location A6, which exhibited a negative basal area response carried a high stocking rate (1,045 trees per acre) until pm-commercial thinning and was one of two Arkansas locations to experience sheet erosion during the first year after treatment.

CONCLUSIONS

Ripping improved early survival on the Oklahoma locations but not the Arkansas locations. The Oklahoma locations are typically harsher and drier sites that contain soils with a low water holding capacity. With average rainfall patterns the Arkansas locations are not as moisture-stressed as their Oklahoma counterparts. In years of extreme drought such as 1980, ripping could have a significant impact on seedling survival.

Average height gain appears to remain steady through age 19 at all locations. Although there is some fluctuations over the 19 year period it is tied closely with thinning interventions. Both Arkansas and Oklahoma locations exhibited similar height gains over the nineteen year period.

Ripping increased pine basal area on twelve of the thirteen locations. Only one location, A6, exhibited a negative basal area response, possibly attributed to higher stocking levels and early sheet erosion.

One observed, but not measured, effect of ripping at these locations was the decrease in hardwood density over the control plot. The rip tooth does a considerable amount of damage to stumps and root systems that it comes in contact with.

Ripping has the potential for encouraging more deep root development than any of the other tillage operations (Morris and Lowery, 1988) and when done parallel to topographic contours can trap overland water while reducing storm-flow water yield (Miller, 1984). As with any young age stand establishment treatment, it is necessary to use management techniques throughout the life of the stand that will keep the trees healthy and growing while allowing maximum access to sunlight, nutrients and water.

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VOLUNTEER PINES AND HARDWOODS MEDIATE RESPONSES OF PLANTED LOBLOLLY PINE TO SITE PREPARATION'

Timothy B. Harrington and M. Boyd Edwards'

Abstract-h the Georgia Piedmont, planted *Pinustaeda* L., volunteer pines, and hardwoods were measured 12 growing seasons after 6 site-preparation treatments. With increasing treatment intensity, basal area of planted pines increased (6.5 to 23.2 m^2/ha), while that of volunteer pines (22.0 to 5.3 m^2/ha) and hardwoods (6.6 to 0.9 m^2/ha) decreased. Volumes of planted pines following mechanical treatments (75.5 to 111.1 m^3/ha) were 3 to 4.5 times ($p \leq 0.005$) that in the absence of site preparation (24.0 m^3/ha). Site preparation from manual cutting of residual trees caused total volume of planted and volunteer pines (130.1 m^3/ha) to differ little ($p \geq 0.586$) from three of the mechanical treatments (121.9 to 133.8 m^3/ha).

INTRODUCTION

Stand development after clearcutting is strongly influenced by the timing and intensity of site preparation, because these treatment specifications affect the species, size, and abundance of residual and volunteer trees. In the Georgia Piedmont, intensive site preparation from chemical or mechanical treatments causes reductions in the size and abundance of competing vegetation sufficient to ensure the development of stands dominated by planted loblolly pine (*Pinus* faeda L.)(Shiver et al. 1990, Knowe et al. 1992).

Low-intensity site preparation, such as manual cutting of residual trees, can shift stand dominance from volunteer pines to hardwoods, depending on timing of cutting and minimum size of cut trees (McMinn 1992). Ten years after dormant-season cuttings, McMinn found that shortleaf pine (*Pinus echinata* Mill.) comprised 66 and 36 percent of all woody stems for 2.5 and I O-cm dbh cutting-limits, respectively; whereas, pine comprised only 6 and 2 percent, respectively, following growing-season cuttings. Only dormant-season cuttings provided the co-occurrence of a favorable seed bed (exposed mineral soil) with an abundance of pine seed from logging slash and adjacent seed trees.

Although volunteer trees often are a significant component in pine plantations, their long-term contributions to stand density and wood production have received little attention in previous silvicultural research. Such information could be used to select the intensity of site preparation that favors dominance by a specific stand component (e.g., planted pines, volunteer pines, or hardwoods), thereby resulting in the desired attributes at stand maturity. The objective of this research, therefore, was to determine how site-preparation intensity affects partitioning of stand basal area and volume among the categories of planted pines, volunteer pines, and hardwoods.

METHODS

Study Site and Treatments

The study was conducted at an existing site-preparation experiment (Edwards 1994) in the lower Piedmont of Georgia located on the Hitchiti Experimental Forest, 11 km southeast of Juliette. In spring 1980, the previous old-field stand of pine was clearcut harvested and non-merchantable pines and hardwoods were left standing. The following 6 site-preparation treatments were randomly assigned and applied to 0.8-ha plots arranged in a randomized complete-block design with five replications:

I. Absence of site preparation (CC or clearcut only).--Non-merchantable trees retained.

2. Manual cutting (CC+CUT).--CC plus cut all residual trees of dbh (diameter at I .37 m height) > 2.5 cm with a chainsaw (August 1981).

3. Shear and chop (SC).--Residual trees were sheared with a KG blade mounted on a D7 tractor, and debris was chopped with one pass of a single-drum chopper (September to November 1981).

4. Shear, chop, and herbicide (SC+H).--SC plus application of hexazinone herbicide (Velpar® Gridball pellets of 0.5 cm^3 volume) in a 0.58- x 0.58-m grid pattern at 2.8 kg a.i./ha (March 1982). Heavy rains soon after application accelerated herbicide spread and

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uptake, resulting in subsequent first-year mortality of approximately 35 percent of planted pines and an 80 percent reduction in first-year cover of associated woody and herbaceous species (Edwards 1994).

5. Shear, root-rake, burn, and disk (SRBD).--Residual trees were sheared, rootstocks were raked into windrows and burned, remaining debris was scattered with a bulldozer blade, and plots were disked with an offset harrow to a depth of 15-20 cm (September to October 1981).

6. Shear, root-rake, burn, disk, fertilize, and herbicide (SRBD+FH).--SRBD plus a broadcast application of ammonium-nitrate fertilizer at 114 kg N/ha and a 1.2-m band application of sulfometuron (Oust®) herbicide at 0.42 kg a.i./ha centered over planted pine seedlings (March to April 1983).

Seedlings of loblolly pine (I-0, bareroot, improved, Piedmont source) were hand-planted (January-February 1982) at a spacing of 1.8 x 3 m. All pine mortality following SC+H was replanted January to February 1983. A grid of 11 x 13 rows of seedlings within a centrally-located 0.08-ha measurement plot was marked for monitoring of pine survival and growth.

Vegetation Measurements and Statistical Analysis

Twelve growing seasons after treatment (September to November 1993), the following measurements were taken on each measurement plot: total height (nearest 0.3 m) and dbh (nearest 0.25 cm) of each planted pine, species and dbh of each volunteer pine or hardwood having a dbh ≥ 2.5 cm, and height of each of several randomly-selected, intact stems per species of volunteer pine (two to three stems per plot) and hardwood (one stem per species present in each row of planted pine).

Trees within each measurement plot were assigned to one of the following species groups: planted pines, volunteer pines, or hardwoods (Table 1). For each species group, a regression equation was developed to predict height from dbh of individual trees, and values of stand basal area (m^2/ha) and volume (m^3/ha, Clark and Saucier 1990, Clark et al. 1986) were calculated for each measurement plot. Means were compared among treatments with analysis of variance and Fisher's protected LSD (α=0.05) (Snedecor and Cochran 1980).

RESULTS

Twenty-two species of trees (2 pines and 20 hardwoods) were present on the measurement plots (Table 1). When averaged over all plots, loblolly pine and sweetgum accounted for 89 and 7 percent of the total basal area, respectively.

Table I-List of common and scientific names of trees by species group

Species group	Common name	Scientific name
Planted pines	loblolly pine	*Pinus taeda* L.
Volunteer pines	shortleaf pine	*Pinus echinata* Mill.
	loblolly pine	*Pinus* taeda L.
Hardwoods	Florida maple	*Acer barbatum* Michx.
	red maple	*Acer rubrum* L.
	American hornbeam	*Carpinus caroliniana* Walt
	pignut hickory	*Carya glabra* (Mill.) Sweet
	flowering dogwood	*Cornus florida* L.
	common persimmon	*Diospyros virginiana* L.
	white ash	*Fraxinus americana* L.
	American holly	*Ilex opaca* Ait.
	sweetgum	*Liquidambar sfyraciflua* L.
	yellow-poplar	*Liriodendron tulipifera* L.
	blackgum	Nyssa *sylvatica* Marsh.
	eastern hophornbeam	*Ostrya virginiana* (Mill.) K. Koch
	sourwood	*Oxydendrum arboreum* (L.) DC.
	black cherry	*Prunus serotina* Ehrh.
	white oak	*Quercus alba* L.
	southern red oak	*Quercus falcata* Michx.
	water oak	*Quercus nigra* L.
	post oak	*Quercus stellata* Wangenh.
	winged elm	*Ulmus alata* Michx.
	American elm	*Ulmus* americana L.

With increasing intensity of site preparation, basal area of planted pines increased from 6.5 to 23.2 m^2/ha, while that of volunteer pines (22.0 to 5.3 m^2/ha) and hardwoods (6.6 to 0.9 m^2/ha) decreased (Table 2). Site preparation via manual cutting of residual trees (CC+CUT) caused volunteer-pine basal area (22.0 m^2/ha) to exceed (p<0.001) values observed for each of the other treatments (5.3 to 11.7 m^2/ha). Presence of residual trees caused hardwood basal area in clearcut-only plots (6.6 m^2/ha) to be greater ($p \leq 0.035$) than that in CC+CUT, SC, SC+H, and SRBD.

Table 2-Average stand basal area and volume of planted pines, volunteer pines, all pines, and hardwoods 12 growing seasons after 6 site-preparation treatments in the Georgia Piedmont

		Site preparation treatment[a,b]					
Variable	Species group	c c	CC+CUT	SC	SC+H	SRBD	SRBD+FH
Basal area (m^2/ha)	Planted pines	6.5c	8.0c	16.8b	18.0ab	22.3ab	23.2a
	Volunteer pines	11.7b	22.0a	11.4bc	5.4d	5.3d	5.8cd
	All pines	18.2c	30.0a	28.2ab	23.4bc	27.6ab	29.0a
	Hardwoods	6.6a	2.8b	3.2b	0.9b	1.3b	3.9ab
Volume (m^3/ha)	Planted pines	24.0c	33.1c	75.5b	76.7b	100.3ab	111.1a
	Volunteer pines	48.9b	97.0a	51.8b	23.7c	21.6c	22.7c
	All pines	72.9c	130.1ab	127.3ab	100.4bc	121.9ab	133.8a
	Hardwoods	39.1a	12.3b	13.7b	4.1b	5.1b	18.2b

'Treatments are: CC=clearcut only, residual trees retained; CC+CUT=CC plus manual cutting of residual trees; SC=shear and chop; SC+H=SC plus hexazinone; SRBD=shear, root-rake, burn piles, and disk; SRBD+FH=SRBD plus nitrogen fertilizer and sulfometuron.

[b]Means for each variable followed by the same letter do not differ significantly ($p>0.05$).

Volume responses paralleled those for basal area (Table 2). Mechanical site preparation (SC, SC+H, SRBD, and SRBD+FH) caused volumes of planted pines (75.5 to 111 .1m^3/ha) to be 3 to 4.5 times greater ($p \leq 0.004$) than that observed in the absence of site preparation (24.0 m^3/ha). Volunteer-pine volume in manual-cutting plots (97.0 m^3/ha) was greater ($p<0.001$) than that (21.6 to 51.8 m^3/ha) in each of other treatments. Total volumes of planted and volunteer pines differed little ($p \geq 0.586$) among the treatments, CC+CUT, SC, SRBD, and SRBD+FH (121.9 to 133.8 m^3/ha). In addition, volunteer-pine volume in CC+CUT (97.0 m^3/ha) was similar to that of planted pines in the more intensive treatment, SRBD (100.4 m^3/ha). Hardwood volume in clearcut-only plots (39.1 m^3/ha) exceeded ($p \leq 0.041$) that in each of the other treatments (4.1 to 18.2 m^3/ha).

DISCUSSION AND CONCLUSIONS

When compared to clearcut-only plots, increases in volume of planted pines from site preparation ranged from 38 (CC+CUT) to 463 percent (SRBD+FH). In two treatments, competition from either residual hardwoods (CC) or volunteer pines (CC+CUT) strongly limited the volume of planted pines. In addition, planted-pine volume in SC+H was limited by delays in stand development because 35 percent of trees were replanted in 1983 to replace those which died from hexazinone.

With the exception of clearcut-only plots, where hardwood competition limited the volumes of both planted and volunteer pines, decreases in volume of planted pines were compensated by increases in volume of volunteer pines. As a result, the total volume of planted and volunteer pines differed little among the treatments, CC+CUT, SC, SRBD, and SRBD+FH. Therefore, for management of pulpwood it appears that a combination of manual cutting of residual trees and adequate natural pine regeneration can be substituted successfully for the more costly practices of mechanical or chemical site preparation plus artificial regeneration. This study emphasizes the importance of assessing all stand components, including volunteer pines and hardwoods, when attempting to quantify growth and yield responses of pine plantations to silvicultural treatments.

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SITE PREPARATION EFFECTS ON THE GROWTH OF A 15-YEAR-OLD LOBLOLLY PINE PLANTATION'

Timothy T. Ku, G. Laurin Wheeler, and Robert L. Colvin[2]

Abstract-Genetically improved loblolly pine, *Pinus taeda* L., seedlings were planted at 2.44 meters by 3.05 meters spacing in March 1979 in two site preparation treatments: (1) Maximally prepared-Rolling drum chop, burn, and disk, and (2) Minimally Prepared-Rolling drum chop only. At age 15, there were 2.3 times more wood produced from the maximally prepared site, 126.93 compared to 54.97 cubic meters per hectare from the minimally prepared site. In the meantime, 35.62 cubic meters per hectare of pulpwood were harvested from the maximally prepared site, whereas the minimally prepared site remained to be understocked at only 12.40 square meters per hectare of basal area.

INTRODUCTION

A long-term cooperative research project in the University of Arkansas system between the School of Forest Resources at Monticello and the Department of Horticulture at Fayetteville was initiated in 1975 to study the effects of intensive forest management practices on site productivity and nutrient cycling. This report will discuss the effects of site preparation intensities on the survival and growth differences of loblolly pine plantation.

SITE CHARACTERISTICS

The study site is located about eight kilometers northeast of Hope in southwestern Arkansas. The area has long, hot and humid summer, and mild winter with long growing season of seven months in a year. Annual precipitation averages 1300 millimeters.

The soil of the study area is Sacul loam, a Clayey mixed thermic, Aquic Hapludult. It is moderately well-drained with low natural fertility but the water capacity is high (Anon. 1979). Site index for this soil is fairly good, 26 meters for loblolly pine at 50 years of age (Zahner, 1957).

PLANTATION ESTABLISHMENT AND DEVELOPMENT

An old-growth, uneven-aged stand of mixed loblolly and shortleaf, *Pinus echinata* Mill., pines was harvested in January 1978 (Ku and others 1981; Ku, Wheeler and Colvin, 1991) by clearcutting, and site prepared prior to planting according to the following two treatments: (1) Maximum site preparation-Rolling drum chop, burn, and disk, and (2) Minimum site preparation-Rolling drum chop only. Sixteen 0.2 hectare randomized plots were established in replicates of eight plots for each treatment, with a 0.08 ha. measurement plot nested in the center of each. Genetically improved loblolly pine seedlings were planted in March 1979 at 2.44 meters by 3.05 meters spacing. Annual measurements were maintained in the dormant season to assess survival and rate of growth.

Early survival was very poor for the minimally prepared site due to an extremely drought-y year in 1980 following planting. The added competition from a greater amount of sprouts and ground vegetation in these minimally prepared plots during the first two years had reduced their survival to below 50 percent as compared with 72 percent for the intensively prepared plots (Table 1). However, the percentage of survival has levelled off after the sixth growing season for the minimally prepared sites whereas the maximally prepared sites remained constant after the second year.

In the maximum site prepared plots, from the very onset of plantation establishment, height growth accelerated at a consistently higher rate between 16 to 30 percent range as compared to the minimum site prepared plots (Table 1). The initial diameter measurement was taken in January 1985 when the plantation was 7 years old. Growth in diameter at breast height (DBH) for the maximally site prepared plots maintained about 2.5 centimeters advantage over the minimally site prepared plots from 6 until 12 years old. After that, the maximally site prepared plots reached complete crown closure and attained more than 20 square meters per hectare of basal area in 1991, the gap of diameter growth between the two sites was narrowed down to between 2.0 and 1.5 centimeters (Table 2).

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Table 1. Comparison of survival and height growth between maximum and minimum site preparation treatments

Year	Survival (pct)			Height (meters)		
	Max.	Min.	Gain	Max.	Min.	Gain (pct)
1980	81.6	67.8	20	0.36	0.36	--
1981	71.6	47.3	51	0.85	0.70	20
1982	71.4	47.3	51	1.52	1.31	16
1983	71.4	46.2	55	2.41	1.92	25
1984	71.4	43.3	65	3.51	2.74	28
1985	71.4	42.5	68	4.60	3.57	29
1986	71.4	40.5	76	5.61	4.45	26
1987	71.4	40.3	77	6.74	5.36	26
1988	71.2	39.7	79	7.74	6.16	26
1989	71.1	39.0	82	8.78	7.16	23
1990	71.1	38.8	83	9.85	8.05	22
1991	70.7	37.3	90	10.88	9.11	19
1992	70.6	37.3	89	11.73	9.91	18
1993	70.3	36.3	94	12.83	11.00	17

In term of basal area increment, the difference between site preparation effect is more dramatic, decreasing from more than 200 percent in the early years to the present 100 percent (Table 2). It was at this stage of stand development, when the plantation was 15 years old, a decision was made to reduce the density of maximally prepared plots by thinning from below. Trees with poor forms were removed to maintain a residual basal area of 18 square meters per hectare, following the accepted pine management practice in the southern United States (Reynolds, Baker and Ku, 1984). Six of the eight maximum prepared plots were thinned in the spring of 1993. The remaining two plots were left unthinned for future comparison purpose.

DISCUSSION

After the plantation was established in the spring of 1979, annual measurements were maintained in the dormant season to assess survival and height growth. The lower rate of first year survival at 81.6 percent for the maximum site prepared plot and 67.8 percent for the minimum site prepared plots can perhaps be contributed to a lower than normal rainfall and the difference is likely due to site preparation treatments. The severe drought experienced in 1980, the second year after planting, caused further increase of mortality, particularly for the minimum prepared site. The survival difference of 51 percent between site treatments in 1981 and the continuously increased difference to 90 percent in 1992 (Table 1) are certainty the resuits of increasing competition in the minimally treated sites from sprouts and lower vegetation growth.

Fourteen years after planting, there were 941 stems per hectare at an average DBH of 18.03 centimeters for the maximum prepared sites and 489 stems per hectare at an average DBH of 16.51 centimeters for the minimally prepared sites (Table 3). These amounted to 24.80 and 12.40 square meters of basal area per hectare for the maximum and minimum prepared sites, respectively. The average height was 12.83 meters for the maximum prepared site and 11 .OO meters for the minimum. Based on the volume tables developed by Minor (1950), there were 2.3 times or 131 percent more wood produced from the maximally prepared sites, 126.93 cubic meters per hectare or 8.46 cubic meters per hectare per year as compared to 54.97 cubic meters per hectare or 3.66 cubic meters per hectare per year from the minimally prepared sites (Table 3). From the maximum site prepared plots, 35.82 cubic meters per hectare of pulpwood, or 28 percent of the standing crop were harvested from thinning operation. It appears that there would be 3 to 5 more years before the stand on the minimum prepared site to reach fully stocked stage from present basal area of 12.40 square meters per hectare; and thinning operation on these minimally prepared sites will

Table 2. Comparison of diameter and basal area growth between maximum and minimum site preparation treatments

Year	DBH (cm)			Basal Area(m^2/ha)		
	Max.	Min.	Gain (pct)	Max.	Min.	Gain (pct)
1985	6.88	4.32	59	3.90	1.15	139
1986	8.64	6.35	36	5.97	1.84	224
1987	10.67	8.13	31	8.72	2.98	224
1988	12.19	9.40	30	11.48	4.36	163
1989	13.72	11.18	23	14.46	6.20	133
1990	15.49	12.95	20	18.14	8.27	119
1991	16.51	14.48	14	20.89	9.87	112
1992	17.02	15.24	12	22.27	10.79	106
1993	18.03	16.51	9	24.80	12.40	100

Table 3. Comparison of Stand Characteristics Between Site Preparation Treatments Before And After Thinning in 1993

	Maximum prepared site		Minimum prepared site (8 plots)
	Before Cut (8 plots)	After cut (6 plots)	
Stems/hectare	941	637	489
Average Height (m)	12.83	13.04	11.00
Average DBH (cm)	18.03	19.05	16.51
Basal Area (Sq. m/ha)	24.80	18.37	12.40
Volume (Cubic m/ha)	126.93	95.17	54.97
Vol. Cut (Cubic m/ha)	- -	35.82	---

not likely to occur for several more additional years beyond that. Difference in monetary gain between the two site preparation treatments will also likely be considerable. Evidently, intensive site preparation will certainly be beneficial in volume production which will likely also be profitable in economic returns.

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PINE GROWTH AND PLANT COMMUNITY RESPONSE TO CHEMICAL vs. MECHANICAL SITE PREPARATION FOR ESTABLISHING LOBLOLLY AND SLASH PINE'

James H. Miller and Zhijuan Qiu[2]

Abstract-Chemical and mechanical site preparation methods were studied for establishing loblolly (*Pinus taeda* L.) and slash (*P. elliottii* var. *elliottii* Engelm.) pine following both integrated fuelwood-pulpwood harvesting and conventional whole-tree harvesting of pines and hardwoods in southern Alabama's Middle Coastal Plain. Revegetation was assessed in year 1, planted pines were measured after years 2 and 5, and soil bulk density was examined. Site preparation treatments generally shifted the herbaceous component from grasses to forbs and blackberry (*Rubus* spp.). After integrated harvesting, mechanical and herbicide treatments performed equally well for loblolly pine, while disking treatments yielded greater fifth-year volumes than herbicide methods with slash pine. On conventional harvested sites, mechanical and chemical treatments performed equally well. Pine volumes were 10-fold greater within windrows than that between windrows. A single disking treatment returned topsoil to pre-harvest bulk densities.

INTRODUCTION

Over the past 30 years, a wide array of mechanical and chemical site preparation techniques have been developed for establishing loblolly (*Pinus* taeda L.) and slash pine (*Pinus elliottii* var. *elliottii* Engelm.) after harvesting short-wood and more recently, whole-trees. With the increased utilization of hardwoods for pulpwood and fuelwood, less woody biomass is left to be dealt with during site preparation. But with intensified harvesting comes increased logging traffic that can result in soil compaction (Gorden and others 1981, Miller and Sirois 1986, Slay and others 1987) and can hinder subsequent tree growth (Foil and Ralston 1967, Hatchell 1970, Lockaby and Vidrine 1984, Simmons and Ezell 1983, Tuttle and others 1988). Thus, there is an apparent need to redesign site preparation treatments to de-emphasize debris removal and enhance soil improvement treatments, while controlling competition (Morris and Lowery 1988).

This research is the site preparation phase of a multi-disciplinary investigation of harvesting and site preparation combinations and their efficiency and effects on subsequent stand development. Prior reports have been made on the harvesting aspects (Franchi and others 1984, Miller and others 1985a, Miller and others 1987, Stokes and others 1984, Stokes and Watson 1986,Watson and others 1986,Watson and others 1987). The objective of this part of the investigation was to study the growth of loblolly and slash pine established following both integrated and conventional whole-tree harvesting in combination with several options of mechanical and chemical site preparation. We compared site preparation treatments that range from no soil amelioration with competition control (herbicides) to intensive soil tillage resulting in woody competition control (rootraking and/or disking) on both integrated and conventionally-harvested plots. Soils were sampled to examine bulk density changes with treatment. Early plant community development was documented in the first growing season to assess competitive interferences, vegetative cover establishment, and floristic abundance.

METHODS

For this multidisciplinary investigation, two study areas (blocks) were established within 10 miles of each other on the Middle Coastal Plain in the southernmost part of Alabama (N 30" 15' W 87° 15') (Franchi and others 1984). Soils consisted of an Orangeburg fine sandy loam, 2-5% slope (siliceous, thermic Typic Kandiudult) and a Freemanville tine sandy loam, 2-5% slope (clayey, kaolinitic thermic Plinthic Kandiudult). Both series are well-drained upland soils with low fertilii and organic matter; they both have fine sandy loam to loam surface horiions to a depth of 14-17 in. and clay or sandy clay loam B-horiions. The two soil series have site indices (SI,) of 85-90 for loblolly and slash pine. Topography was similar at both sites with gently sloping ground. Pre-harvest timber stands were 20- and 23-year-old slash pine plantations. Hardwoods greater

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than 4-in. d.b.h. comprised 8.5% of the total green tons per acre (Stokes and Watson, 1986).

Harvesting Treatments

At both locations, three 20 ac harvesting plots (main plots) were established to test three harvesting methods for efficiency, recovery, and site preparation requirements (Watson and others 1986). At one location all three plots were contiguous and were within 1/8 mile of each other at the second location. One plot per block was harvested in a "conventional" manner. The conventional harvesting method removed all pine greater than 6 in. d.b.h. and hardwood sawlogs greater than 12 in. d.b.h. as whole-tree logs for pulpwood. Delimbing and toppings were done by chainsaws in the stand or at the deck after the trees had been processed through an iron gate. The tree length material was then skidded to the deck. This left 34-49% of the biomass of trees greater than 4 in. d.b.h. (measurement limit) on the site (Watson and others 1986).

The remaining two plots per location were harvested with intensive integrated methods leaving only 9-22% of the biomass on site (Watson and others 1986). With these integrated methods, pines and hardwoods below the merchantable standards for pulpwood (as used with the conventional harvest), were harvested for fuelwood using a one- or two-pass method. With the experimental one-pass method, both pulpwood and fuelwood were harvested simultaneously and separated by the machine operator. With the two-pass method, fuelwood was first removed so that it would not be crushed to the ground as occurs in a conventional system. With this procedure, it was necessary for the feller-buncher to carefully maneuver around the residual merchantable pulpwood trees during the first pass. All fuelwood trees were completely chipped on site as well as the tops and limbs of the pulpwood trees. Even though 8.5% more wood was recovered with the one-pass approach compared to the two-pass approach, no standing trees taller than about 8 ft remained on any integrated harvest blocks due to the heavy skidder traffic. The same rubber-tired feller-bunchers and grapple-skidders were used with all three harvesting methods. All harvesting took place in May-June, 1983.

Site Preparation Treatments

All study treatments are presented in Table 1. On each integrated-harvest main plot, site preparation sub-plots were 2.5 ac (165 x 660 ft) in size and 5 ac (330 x 660 ft) in size for check treatments (no site preparation). Disking treatments compared single- versus double-pass disking and whether disked for 1 or 2 years-four combinations. In each main plot, two sub-plots were single disked and two were double-disked in late-summer 1983. All disking treatments were performed with a D-4 double-gang, off-set, site preparation harrow. Double disking amounted to using the same disk-harrow and pulling it at right angles to the first single-disk pass. In 1984, one of the single disked and one of the double disked sub-plots per main plot were again disked using only a single pass. Tillage was about 6-10 in. deep, where stumps did not hinder disking depth. The two herbicide treatments were applied to sub-plots in 1984 after a year's regrowth (Table 1). Half of each sub-plot was planted to loblolly pine and half to slash pine by random assignment.

Table 1 .-Site preparation treatments tested on integrated and conventionally harvested sites.

Treatment	Treatment Explanation
Integrated Harvest of Fuelwood and Pulpwood	
Check	No site preparation
Single disk once	Single-disking, September 1983 + 1 year fallow before planting
Double disk once	Single-disking (perpendicular directions), September 1983 + 1 year fallow before planting
Single disk twice	Single-disking, September 1983 and again single-disking, August 1984
Double disk twice	Double-disking, September 1983 and again single-disking, August 1984
Herbicide early summer	1/2 GPA Tordon 101 + 1/2 GPA Garlon 4' applied in June 1984 + burning
Herbicide late summer	1 GPA Roundup + 1/4 GPA Garlon 4[1] applied in August 1984 + burning
Conventional Whole-tree Harvest of Pines and Hardwoods	
Windrowing:between[2] within	Shearing and rootraking into windrows, summer 1984 + burning
Windrow & double disk[2]	Shearing and rootraking into windrows and double-disking, summer 1984 + burning
Herbicide early summer	1/2 GPA Tordon 101 + 1/2 GPA Garlon 4' applied in June 1984 + burning

'Tordon 101, manufactured by DowElanco, is a mixture of *0.5* lb acid equivalent (aej picloram and 2 lb ae 2,4-D per gallon in an amine formulation; Garlon 4, manufactured by DowElanco, is 4 lb ae triclopyr in an ester formulation; and Roundup, manufactured by Monsanto, is 3 lb ae glyphosate in an amine formulation.

'Pines planted between and within windrows were measured, but vegetation response was assessed only between windrows.

On the two conventionally harvested main plots (20 ac each), half of each (10 ac) was randomly assigned either a mechanical treatment of rootraking into windrows or a herbicide treatment (Table 1). The mechanical-treated parts were halved again (5 ac) to compare disking versus no disking after windrowing and rootraking. Sub-plots were amply large to encompass the inter- and intra-windrow areas. Also, these sub-plots were further halved (2.5 ac) by random assignment and planted to the two pine species.

Operational herbicide treatments were tested-one that was normally applied in early summer and another for late summer-both with ground sprayers mounted on skidders (Table 1). The sprayer used in early summer had a manifold nozzle system and the one used in late summer had a cluster nozzle (Miller and others 1985b). Total spray volume was 35 gallons per acre. Taller hardwoods on conventionally harvested areas treated with herbicides were controlled only by the soil activity of the herbicide and the burn.

All herbicide treatments and windrows were prescribed burned in October, 1984. Pines were machine planted in March 1985, using a 9 x 6 ft spacing or 807 trees/ac. Because of the late planting date, slash pine seedlings had started height growth, which combined with severe drought, resulted in poor survival. Also, because of this study approach the one-year disking treatments had a full year of regrowth before planting, which could simulate an operational delay.

Measurements

Non-pine vegetation was assessed in November (before frost) of the first growing season using systematically-located sample plots. Three 3 clusters of nested sample plots were positioned 100-ft apart across sub-plot centers per pine species. Percent cover was ocularly estimated for herbaceous growth-form components (grasses, forbs, semiwoody, and vines), blackberry (*Rubus* spp.), and gallberry (*Ilex glabra* L.) on 6 square 0.025-ac plots per sub-plot-2 per cluster. Hardwood and shrub stems (besides gallberry) were counted by species and measured for total height (ii greater than 2 ft) on 3 strip plots per subplot that were 0.01-ac (6.6 x 66 ft)--1 per cluster.

Planted pines were measured after the second and fifth growing seasons using 0.05-ac circular measurement plots that were systematically located within subplots by pine species. Sample plot centers were randomly selected and positioned relative to the 6 permanent stakes marking vegetation sample plots. With loblolly pine, two pine measurement plots were established per subplot. Because of low slash pine survival, 2-6 plots were required to obtain a sufficient number of measurement pines per sub-plot (an average of 44 trees per sub-plot). Ground line diameter (g.l.d.), d.b.h., and total height were recorded for pines. A pine volume index was calculated as $g.l.d.^2$ x total height.

Soils were sampled before and alter harvest and after the first mechanical site preparation treatments. Samples were not collected after the second single disking or after herbicide treatments. Undisturbed cylindrical core samples (8.4 in.') were collected on a 200 x 200 ft grid at O-2 and 2-4 in. depths and resampled at approximately the same locations each time. Samples were oven-dried (105" C) for determining bulk density.

Experimental Design and Data Analysis

To test for differences in harvesting systems, an analysis of variance (ANOVA) of a split block design was used where blocks were locations, the three harvest methods were main plots, and site preparation treatments were sub-plots. Only fifth-year per-acre pine volume data from site preparation treatments common among all three harvest types were used, which were check and "herbicide early." Site preparation treatment differences were not specifically tested here since harvesting difference was the focus. The ANOVA source table was:

Source	df	
Block (B)	1	
Harvest method (H)	2	
B x H	2	Error A
Site Prep Effect (SP)	1	
SP x H	2	
B x SP	1)	
B x H x SP	2 }	Error B
Total	11	

Since the harvest effect was not significant, harvest main plots were used as additional replications for a more powerful test of site preparation effects. The integrated and conventional harvest methods were analyzed separately. The ANOVA source table for the integrated methods was:

Source	df	
Block (B)	1	
Site Prep Effect (SP)	6	
B x SP	6)	
Error	14)	Error
Total	27	

The source table for the conventional harvested method has only 2 degrees of freedom for treatment. Prearranged orthogonal contrasts were used to

examine differences in response to site preparation treatments for both harvest methods. Pine response for loblolly or slash pine were analyzed separately. Percent cover estimates were transformed using the arcsine square-root (Steel and Torrie 1960) and averages were calculated and transformed back for reporting.

Differences are considered significant at the 0.05 probability level, but probabilities of a Type I error are presented for contrasts to permit the reader to judge significance. Certain other near-significant contrasts are discussed with their probabilities presented. Soil bulk densities were analyzed using paired-t tests between harvested and site prepared soils to pre-harvest conditions. Differences here are considered significant at the 0.1 0-probability level.

RESULTS AND DISCUSSION

Site Preparation Influence on Herbaceous Plants and Gallberry

The common plant species that were identified during the first-year following site preparation are listed by component growth-form in Table 2. Table 3 contains the means of cover and woody stem numbers and sizes for both the integrated and conventional harvested sites. Revegetation was rapid; herbaceous cover exceeded 85% on all treated areas except those treated by windrowing with disking after conventional harvest, which averaged 62%. This latter treatment also resulted in considerable woody plant suppression compared to the other treatments on the conventional harvest. Complete or near-complete (> 0.2% cover) first-year control of gallberry was achieved by all treatments except single disking once. Gallberry was the principal shrub component in these forests prior to harvesting.

After integrated harvesting, total herbaceous cover was slightly less on treated plots compared to none site prepared checks (93% vs. 99%), less on mechanical treatments compared to herbicides (91% vs. 99%), and less on single disking twice compared to single disking once (86% vs. 97%) (Table 4). Forbs were significantly decreased by the repeated single disking.

Site preparation treatments reduced grass and gallberry cover and enhanced forb and rubus cover. Mechanical treatments had 39% less grass cover than herbicide applications but 26% more blackberry cover. Grasses have been shown to be severe competitors to planted pines (Miller 1987, Morris and others 1989). Grasses were less (probability of 6%) with Roundup + Garlon treatments compared to Tordon + Garlon. Tordon + Garlon treatments resulted in the greatest grass cover on both the integrated and conventional harvested plots. The semiwoody st. john's wort was completely controlled with the early-summer treatment with Garlon + Tordon.

Table 2.-Common species identified on study areas in the first year.

Common Names	Scientific Names
Hardwoods	
black cherry	*Prunus serotina* Ehrh.
blackgum	Nyssa *sylvatica* Marsh.
dogwood	*Cornus florida* L.
oak, southern red	*Quercus falcata* Michx.
oak, water	Q. *nigra* L.
persimmon	*Diospyros virginiana* L.
red maple	*Acer rubrum* L.
sassafras	**Sassafras** *albidum Nutt.*
sweetbay magnolia	*Magnolia virginiana* L.
sweetgum	*Liquidambar styraciflua* L.
Shrubs	
am. beautyberry	*Callicarpa americana* L.
blueberry	*Vaccinium elliottii* Chapman
gallberry	*Ilex glabra* L.
plum	*Prunus* spp.
privet	*Ligustrum sinense* Lour.
southern bayberry	Mytica *cerifera* L.
sumac, smooth	*Rhus glabra* L.
sumac, winged	*R. copallina* L.
yaupon holly	*Ilex vomitoria* Ait.
Semiwoody	
blackberry	*Rubus* spp.
jersey tea	*Ceanothus americanus* L.
st. john's wort	*Hypericum* spp.
Grasses	
broomsedge	*Andropogon virginicus* L.
panicum grass	*Panicum* spp.
pineland threeawn	*Aristida stricta* Michx.
Forbs	
asters	*Aster* spp.
common ragweed	*Ambrosia attemisiifolia* L.
dogfennel	*Eupatorium capillifolium* Lam.
goldenrod	*Solidago* spp.
goldenweed	*Polypremum procumbens* L.
pokeweed	*Phytolacca americana* (Tourn.) L.
poorjoe	*Diodia teres* Walt.
three-seeded mercury	*Acalypha* spp.
Fern	
bracken fern	*Pferidium aquilinum* (L.) Kuhn.
Vines	
grape	*Vitis rotundifolia* Michx.
greenbrier	*Smilax* spp.
japanese honeysuckle	*Lonicera japonica* Thumb.
morningglory	*Ipomoea* spp.
trumpet creeper	*Campsis radicans* L.
yellow jasmine	*Gelsemium sempetvirens* (L.) Ait.

Table J.-Mean herbaceous cover and woody competition by component in late summer of the first growing season after planting by harvest and site preparation regime.

Herbaceous Component Cover				Shrubs		Hardwoods					
Treatments	Total herbaceous cover	grass	forbs	semiwoody	vines	rubus	Gallberry cover	stems per acre	sum of heights	stems per acre	sum of heights
	percent							no.	ft	no.	ft
				Integrated Harvest							
Check	99.3	83.8	3.7	0.2	0.3	1.3	6.7	1071	3188	958	3537
Single disk once	97.1	51.8	14.3	0.7	0.5	20.9	0.8	496	1254	329	1242
Double disk once	93.6	36.1	7.9	0.9	0.2	42.4	0.1	742	2108	196	763
Single disk twice	86.4	34.6	4.7	0.4	0.1	24.0	0.0	125	313	108	338
Double disk twice	85.7	26.1	8.5	0.4	0.5	24.8	0.0	254	725	125	375
Herbicide early	99.3	88.7	9.4	0.0	0.0	0.2	0.0	229	571	242	692
Herbicide late	98.4	63.2	16.2	0.8	0.1	3.2	0.1	204	558	429	1408
				Conventional Harvest							
Windrow: between'	*92.7*	*26.1*	*13.2*	*1.2*	*0.4*	*36.4*	*0.0*	*500*	*1150*	*580*	*1940*
Windrow + double disk'	*61.7*	*8.2*	*3.7*	*0.3*	*0.1*	*37.5*	*0.0*	*313*	*900*	*300*	*747*
Herbicide early	*92.7*	*57.3*	*14.8*	*1.8*	*0.0*	*7.8*	*0.2*	*683*	*1185*	*566*	*1625*

[1] Vegetation assessments were only made between windrows.

Table 4.--Orthogonal contrasts showing the probability of a greater F-value (upper value) and contrasted group means (lower value) for herbaceous cover, cover growth-form components, and gallberry cover.

Treatment	Total herbaceous cover	Herbaceous component cover					Gallberry cover
		grass	forbs	semiwoody	vines	rubus	
				Integrated Harvest			
Check/ Treated	0.0218 99.3/93.4	0.0054 83.8/50.1	*0.0431* 3.7/10.2	*0.3590* 0.2/0.5	0.6901 0.3/0.4	0.0218 1.3/19.3	0.0009 6.8/0.2
Mechanical/ Chemical	0.0007 90.7/98.8	0.0002 37.2176.0	0.1703 8.9/12.8	0.2048 0.6/0.4	0.0869 0.3/0.1	0.0001 28.0/1.7	0.8626 0.2/0.1
Single disk/ Double disk	0.4014 91.7/89.7	0.2583 43.2/31.1	0.8211 9.5/8.2	0.8994 0.6/0.6	0.6913 0.3/0.4	0.2764 22.5/33.6	0.5950 0.4/0.1
Single disk once/ Twice	0.0154 97.1186.4	0.2680 51.7/34.6	0.0373 14.3/4.7	0.5724 0.7/0.4	0.3178 0.5/0.1	0.8134 20.9/24.0	0.2744 0.8/0.0
Double disk once/ Twice	0.1113 93.6/85.7	0.4844 36.1t26.1	0.8886 7.9/8.5	0.2443 0.9/0.4	0.4589 0.2/0.5	0.2379 42.4124.8	0.7228 0.1/0.0
Herbicide early/ Late	0.6086 99.3/98.4	0.0565 88.7/63.2	0.1917 9.4/6.2	0.0119 0.0/0.8	0.6653 0.0/0.1	0.3948 0.2/3.2	0.8365 0.010.1
				Conventional Harvest			
Mechanical/ Chemical	0.3127 77.2/92.7	0.0830 17.1/57.3	*0.4544* 8.5/14.8	*0.3478* 0.7/1.8	0.0933 0.3/0.0	0.1824 36.9/7.8	0.2585 0.0/0.2
Windrow/ Windrow+ Double disk	0.1422 92.7/61.7	0.2613 26.1/8.2	0.3329 13.2/3.7	0.3808 1.2/0.3	0.1351 0.4/0.1	0.9638 36.4/37.5	0.9054 0.0/0.0

After conventional harvest, the same general trends were evident of more grass cover with chemical treatments (8% probability level) and more rubus cover with mechanical treatments (18% probability level) as found with integrated harvesting. Gallberry was effectively eliminated during the first-year with windrowing in this test.

Site Preparation Influences on Woody Stems

On integrated harvest plots, number and size of shrub (other than gallberry) and hardwood stems were fewer and shorter on the treated plots than check plots (Table 5). In general, mechanical treatments were more effective in controlling hardwood regrowth than herbicide treatments, although sizable reductions in shrubs by herbicides were non-significant. Probabilities at the 6% level indicate a consistent reduction in hardwoods with single disking for 2 years compared to single disking once.

On conventionally harvest plots, no significant differences were evident in shrubs and hardwoods due to treatments. As expected, there were more and larger hardwoods following conventional harvest than evident on integrated harvested areas (see means for mechanical/chemical contrasts).

Site Preparation Influences on Pine Growth

For both harvesting methods, seedling stocking (trees/ac) for loblolly pine in the second year ranged from 563 to 875, while survival of the late-planted slash pine ranged from 167 to 607, excluding within-windrow areas (Table 6 and 7). Stocking decreased by a maximum of only 10% for all loblolly treatments from years 2-5, while there was up to a 36% decrease for slash pine. This relatively high mortality is at least partially due to the occurrence of record dry years in the second and third growing seasons (1986 and 1987).

Table 5.--Orthogonal contrasts showing the probability of a greater F-value (upper value) and contrasted group means (lower values) for woody components.

Treatment	Shrubs: stems per acre	Shrubs: sum of heights	Hardwoods: stems per acre	Hardwoods: sum of heights
		integrated Harvest		
Check/	0.0010	0.0010	0.0001	0.0001
Treated	107 1 /342	31881922	9581240	35381809
Mechanical/	0.2353	0.2768	0.0414	0.1863
Chemical	405/2 18	10981568	1 90/339	681 /1065
Single disk/	0.3153	0.2814	0.484 1	0.5106
Double disk	3151496	796/1 402	219/163	7901573
Single disk once/	0.1432	0.2264	0.06 17	0.0620
Twice	504/125	12791313	329/108	12421338
Double disk once/	0.0663	0.0957	0.5092	0.3970
Twice	7381254	20791725	200/125	7701375
Herbicide early/	0.9341	0.9958	0.0946	0.1186
Late	2291208	570/567	2421437	692/1 438
		Conventional Harvest		
Mechanical /	0.3010	0.3026	0.6821	0.7776
Chemical	4071683	1025/1 183	440/566	1344/1 625
Windrow /	0.5030	0.7295	0.4598	0.3581
Windrow + Double disk	500/3 13	1150/900	580/300	19401747

Table 6.--Loblolly pine: mean stocking, size, and volume per tree and per acre in the second- and fifth-year by harvest and site preparation regime.

	Second Year					Fifth Year					
Treatment	stocking	g.l.d.	height	volume index' per tree	volume index' per acre	stocking	g.l.d.	d.b.h.	height	volume index' per tree	volume index' per acre
	no./ac	in.	ft	ft^3	ft^3/ac	no.	in.	in.	ft	ft^3	ft^3/ac
Integrated Harvest											
Check	563	0.48	2.1	0.004	2.3	517	2.4	1.2	9.3	0.5	241
Single disk once	677	0.56	2.3	0.007	5.0	627	2.5	1.4	10.0	0.5	325
Double disk once	657	0.54	2.2	0.006	3.7	657	2.8	1.6	10.5	0.7	425
Single disk twice	760	0.72	2.3	0.011	8.5	687	3.3	1.9	12.1	1.0	707
Double disk twice	875	0.81	2.6	0.016	13.5	795	3.3	1.9	12.0	1.0	813
Herbicide early	707	0.71	2.6	0.012	8.6	650	3.1	1.7	11.4	0.9	601
Herbicide late	673	0.67	2.3	0.009	6.5	615	3.1	1.7	11.4	0.9	570
Conventional Harvest											
Windrow: between	663	0.50	1.9	*0.004*	*2.8*	*607*	2.5	1.3	9.3	0.5	303
within	800	1.77	5.6	*0.143*	114.8	790	5.5	3.9	18.8	4.3	3374
Windrow + double disk	717	0.73	2.2	0.011	7.5	683	3.2	1.9	11.8	0.9	646
Herbicide early	725	0.77	3.0	0.017	12.2	673	3.2	2.0	12.6	1.0	678

[1] Volume index = g.l.d.^{2} x ht

Table 7.--Slash pine: mean stocking, size, and volume per tree and per acre in the second- and fifth-year by harvest and site preparation regime.

	Second Year					Fifth Year					
Treatment	stocking	g.l.d.	height	volume index' per tree	volume index' per acre	stocking	g.l.d.	d.b.h.	height	volume index' per tree	volume index' per acre
	no./ac	in.	ft	ft^3	ft^3/ac	no.	in.	in.	ft	ft^3	ft^3/ac
Integrated Harvest											
Check	167	0.61	2.1	0.007	1.3	161	2.5	7.4	9.1	0.5	75
Single disk once	401	0.71	2.1	0.009	3.7	317	3.0	1.7	10.2	0.8	230
Double disk once	393	0.70	2.3	0.010	3.6	330	2.9	1.7	10.2	0.7	235
Single disk twice	431	0.93	2.4	0.019	8.0	424	3.4	2.0	11.4	1.1	445
Double disk twice	607	0.95	2.6	0.021	11.9	389	3.6	2.1	11.9	1.2	483
Herbicide early	276	0.88	2.6	0.023	8.7	251	3.0	1.8	9.7	0.8	223
Herbicide late	415	0.82	2.2	0.014	3.9	284	3.1	1.9	10.4	0.8	197
Conventional Harvest											
Windrow: between	5 10	0.73	2.2	0.011	5.1	447	2.8	1.6	9.5	0.6	258
within	800	2.00	5.4	0.166	133.1	800	5.4	3.7	17.9	3.9	3141
Windrow + double disk	480	0.96	2.5	0.021	9.5	447	3.4	2.3	12.1	1.1	473
Herbicide early	304	0.89	2.8	0.021	6.7	286	3.1	1.8	10.6	0.8	235

[1] Volume index = g.l.d.^{2} x ht

On the conventionally harvested plots, fifth-year per-acre volumes for loblolly after windrow-disking and after herbiciding were twice as much as that found between windrows without disking (Table 6). For slash pine following conventional harvest, fifth-year per-acre volume in the windrow-disked treatment was 83% greater than in windrowed-only plots (Table 7). Because of low survival, per-acre volumes of the herbicide treatment were comparable to windrowed-alone. It is unclear whether the high mortality with slash pine on herbicide treated plots was attributable to residual Tordon toxicity, which warrants further testing. For both pine species, volumes per-acre within windrows were over 10 times greater than those between windrows where disking was not used, indicating the usual concentration of site resources in windrows (Morris and others 1983).

After integrated harvesting, stocking and volume were greater on site prepared treatments compared to none-treated checks for both loblolly and slash pine (Table 8). Mechanical treatments produced more slash pine volume and greater stocking in year 5, while there were no differences between mechanical and chemical treatments with loblolly pine. No differences between mechanical and chemical treatments were significant because tree growth for chemical treatments fell between those for 1 and 2 years of disking, resulting in similar means. Single disking for 2 years produced significantly larger volumes for both pines by the fifth year than 1 year of single disking. The same was true for double-disking twice compared to once, except loblolly pine stocking was also improved. Both herbicide treatments produced similar growth of loblolly pine. For the herbicide treatments with slash pine, the

Table 8.--Orthogonal contrast showing the probability of a greater F-value (upper value) and the contrast group means (lower values) for stocking and volume index per acre for both loblolly and slash pines.

	Loblolly				Slash			
	Second Year		Fifth Year		Second Year		Fifth Year	
Treatment	Stocking	Vol Index	Stocking	Vol Index	Stocking	Vol Index	Stocking	Vol Index
				Integrated Harvest				
Check/	0.0017	0.0396	*0.0032*	*0.0052*	0.0211	0.0123	0.0019	0.0041
Treated	563/725	*2.317.6*	*5171672*	*2411574*	1671421	1.3/6.6	1611333	751302
Mechanical/	0.1586	*0.9503*	*0.1220*	*0.8388*	0.1833	*0.7448*	0.0194	*0.0225*
Chemical	7421690	*7.717.5*	*6921633*	*5681586*	4581346	6.8/6.3	365/267	348/210
Single disk/	*0.2648*	*0.4300*	*0.1184*	*0.3047*	*0.3815*	*0.3072*	0.8093	*0.7382*
Double Disk	719/766	6.8/8.6	657/727	*5161619*	*4161500*	5.9/7.8	*3711359*	*3371359*
Single disk once/	0.1741	*0.2869*	*0.3345*	*0.0121*	0.8214	0.1078	0.1053	0.0289
Twice	6771760	5.0/8.5	*6271687*	*3251707*	4011431	3.7/8.0	3171424	*2301445*
Double disk once/	0.0014	*0.0060*	*0.0377*	*0.0111*	0.1237	*0.0043*	*0.3528*	0.0135
Twice	6571875	3.7/13.5	660/795	*4251814*	*3931607*	3.6/11.9	*3301389*	2351483
Herbicide early/	*0.5567*	*0.5100*	*0.5705*	*0.8286*	0.3079	0.0737	0.6050	0.7773
Late	*7071673*	8.6/6.5	*6501615*	*6011570*	415/276	8.7/3.9	284/251	2231197
				Conventional Harvest				
Mechanical/		*0.3551*		*0.4034*		*0.0273*	-	0.0801
Chemical	-	16.3/12.5		*7641678*	-	19.3/5.5	-	566/236
Windrowl	-	*0.3407*		*0.0823*		0.4490		0.0942
Windrow +Double disk		14.0/18.5		*6091919*		18.0/20.5		392/740

Table Q.-Soil bulk density (g/cm^3) at two depths before and after harvest and after initial site preparation by harvest regime.

Depth	Before harvest	After harvest	After single disk	After double disk	After shearing, rootraking & double disk
			Integrated Harvest[1]		
O-2 in.	1.19a	1.55b	1.24a	1.23a	
2-4 in.	1.39a	1.60b	1.42a	1.38a	
			Conventional Harvest[2]		
0-2 in.	1.17	1.49			1.27
2-4 in.	1.41	1.50			1.36

[1] Different letters within a row indicate significant differences at the 0.10 level of probability as determined by a paired-t test between before harvest soil bulk density and subsequent samplings.
[2] No statistical tests were calculated.

decrease in survival with Tordon + Garlon applications by age 5 resulted in no differences in fifth-year per-acre volumes.

To calculate per-acre volume indices for windrowed plots on the conventional harvested blocks, it was assumed that windrows occupied 10% of the area (from field estimations) and the proportional growth within the windrows was added to the between windrow growth. When the within-windrow growth was included, the windrow-disk plots after conventional harvest had the greatest fifth-year volumes of all harvest-treatment combinations for loblolly (919 ft^3/ac) and for slash pine (740 ft^3/ac) (Table 8). Mechanical site preparation treatments generally performed better for slash pine when compared to chemical treatments, with a probability of 2% for second-year volumes and 8% for fifth-year volumes.

As far as projecting these relative volume increases, short- and long-term research suggests: (a) the maximum growth gains from site preparation occur within the first 8 years, and (b) these gains are maintained until rotational ages of 20 to 25 years on some sites. In support of these hypotheses, Cathey and others (1989) found that yearly incremental gains from mechanical site preparation for loblolly pine establishment on the Piedmont were greatest in years l-3 and declined to almost similar growth rates by age 6. Haywood and Tiarks (1990) observed the same pattern with both woody and herbaceous control treatments. On the sites reported by Haywood and Tiarks the response has been sustained through age 11. Glover and Zutter (1992) found that after 27 years, the heights and basal area of loblolly pines have not converged following various site preparation treatments on a Hilly Coastal Plain site in Alabama. Clason (1989) reported actual and projected treatment gains from vegetation control that were maintained to ages 20-30. Schmidtling (1987) also reported sustained height increments from cultivation for slash, loblolly, and longleaf pines up to age 25. There is evidence that these growth gains are probably maintained if nutritional demands are met (Allen and others 1990), which means that gains on some sites will not be maintained. It could be argued also that on some sites nutritional removals associated with integrated harvesting may result in mid-rotation growth declines (Tew and others 1986, Wells and Jorgensen 1977, Wells and Morris 1983). Long-term measurements of intensively harvested and site prepared plots, necessary to answer this latter question, are not generally available.

Harvesting and Site Preparation Influences on Soil Bulk Density

Soils were significantly compacted to a 4-in. depth with integrated harvesting as indicated by the bulk densities in Table 9. This level of compaction of sandy loam soils have been shown detrimental to loblolly pine seedling growth (Simmons and Ezell 1983, Tuttle and others 1988). Similar trends were evident with conventional harvesting. All three mechanical treatments yielded bulk densities comparable to pre-harvest conditions. No appreciable decrease in bulk density was evident by the additional right-angle pass of the disk (i.e., double disking). It is assumed, though not determined, that bulk densities remained elevated on herbicide treated plots.

Disk harrowing has been shown effective in reducing bulk densities after harvest-caused soil compaction (Campbell 1973, Gent and Ballard 1985). Such reduction in bulk density is an indication of improvements in both nutritional and physical properties that have been shown to increase early loblolly pine growth (Foil and Ralston 1967, Hatchell 1970, Lockaby and Vidrine 1984, Simmons and Ezell 1983, Tuttle and others 1988). Such treatments appear necessary with the extra traffic of intensive integrated harvested areas that results in compaction (Gorden and others 1981, Slay and others 1987).

Windrowing has been shown to increase bulk density of surface soils (Slay and others 1987, Stransky 1981), with the influence of disking to loosen soils still in question. The 80-100% increase in both loblolly and slash volume found in the current study following disking of inter-windrow areas would suggest an improvement in soil conditions and/or reduced competition. However, windrowing treatments can also displace and concentrate a significant amount of the site's nutrient resource into windrows (Morris and others 1983, Swindel and others 1988, Tew and others 1986). This displacement of topsoil into windrows has contributed to the greater than IO-fold difference in growth between the intra-windrow and inter-windrow grown trees in the current study. The future growth on the inter-windrow area may be slowed due to this displacement.

CONCLUSIONS

Mechanical and herbicide treatments for site preparation after intensive integrated harvesting can result in an increase fifth-year volume of two to three times greater than none-site prepared growth for loblolly and slash pine. Thus, intensive harvesting practices do not lessen the need for effective site preparation treatments. In general, disking treatments for two consecutive years resulted in the greatest early growth for both loblolly and slash pine. With loblolly pine, the herbicide site preparation treatments that were tested produced comparable fifth-year volumes to the range of mechanical treatments tested. But for slash pine, mechanical treatments yielded more fifth-year volumes than the herbicide treatments.

With conventional whole-tree harvesting, mechanical and chemical site preparation treatments produced comparable volumes for both slash pine and loblolly pine. But again, disking treatments yielded improved growth of slash pine.

As mechanized harvesting intensity increases, site preparation treatments that both ameliorate soil compaction and reduce competition will provide the greatest improvement in volume growth of loblolly and slash pine plantations.

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Poster Presentations

THIRD-YEAR RESPONSE OF DIRECT-SEEDED SHORTLEAF PINE AND HARDWOOD SPROUTS TO THREE METHODS OF HARDWOOD CONTROL IN THE ARKANSAS OZARKS'

Michael D. Cain[2]

Abstract-Compared to untreated checks, manual hardwood control and herbicide injection of hardwoods facilitated the development of direct seeded shortleaf pine (*Pinus echinata* Mill.) reproduction following a single-tree selection harvest in a mature, natural stand of shortleaf pine in northwest Arkansas. Three years after hardwood control, shortleaf pine seedlings on treated plots were 61 percent taller (P=0.05) in height and 64 percent larger (P=0.02) in groundline diameter than pine seedlings on check plots. Sprouts from treated hardwoods on manual control plots were taller (P=0.02) and their crowns were larger (P=0.01) than hardwood sprouts on herbicide injection plots.

INTRODUCTION

For regulated uneven-aged silviculture of shortleaf pine (*Pinus echinata* Mill.), the majority of stems in a stand should be in the seedling, sapling, and pulpwood 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, shade-intolerant pine seedlings that develop in the understory will most likely die (Cain 1987, 1988b).

Alternative methods 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 risks to humans, wildlife, and nontarget plants.

This study was initiated to demonstrate uneven-aged silviculture of shortleaf pine by converting a mature even-aged stand 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 control and herbicide control of the hardwood component.

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. At this location, soils are Nella (Typic Paleudult) and Mountainburg (Lithic Hapludult), gravelly or stony, fine sandy loam (USDA 1977); and annual precipitation averages 46 inches with extremes being wet springs and dry autumns and winters.

The south-facing slope contained a mature stand of shortleaf pines 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 in the stand during the last 20 years. Site indices at 50 years for 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 by 147.6 ft) each, with interior subplots of 0.25 acre (104.4 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

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topographic position-upper (22-percent slope), middle (26-percent slope), and lower (1 O-percent slope). Within each interior subplot, 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 l-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; and (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 l-inch d.b.h. classes).

Pine harvesting on study plots was completed in late June 1990. Cut pines were removed tree-length using an articulated rubber-tired skidder. Merchantable pines on an additional 40 acres surrounding the research plots were also marked for harvest using single-tree selection guidelines, but harvesting was delayed until the summer of 1991.

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.

Herbicide 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 0.0017 oz 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 .O inch or larger in g.l.d. were manually cut using chain saws. Stump heights averaged less than 1 .O ft.

Manual hardwood control, as needed-This treatment was accomplished using the same method as the previous treatment, but was to be repeated, as needed, to minimize the regrowth of hardwood sprouts. After the initial treatment, there was no additional hardwood control during the first three growing seasons.

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, and the volume of injected herbicide was measured. Six 0.5acre plots were assessed for herbicide injection cost, and six plots were assessed for chain saw felling cost. To assess the cost for labor, 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 gal). The cost of chain saw operation was based on dollar amounts taken from Miller (1984) with an addition of 5 percent annually for 6 years to account for inflation and was determined to be $2.76 per hour of chain saw use.

On the 40-acre nonresearch area that surrounded study plots, residual hardwoods greater than 1 inch in d.b.h. were controlled after pine harvesting was completed by using an edge-to-edge cut-surface treatment at waist height and applying Accord@ herbicide at recommended rates (25 to 50 percent concentration).

Pine Seed Crops

Natural pine seedfall was monitored during 3 consecutive seed years (1990-91, 1991-92, and 1992-93), from October through January, using 4 seed traps on each of the 12 plots. The four interior subplot corners were used as monumentation points for the seed traps. Individual seed traps had an opening of 0.9 ft^2 (Cain and Shelton 1993). All 3 seed years were judged to be complete failures because the number of potentially viable seeds ranged from 1,000 to 3,000 per acre per year. According to Liming (1945), 40,000 viable shortleaf pine seeds per acre (about 1 lb/acre) are purported to be necessary during any one seed year for adequate regeneration under natural conditions.

To ensure regeneration of the area, Bayou Ranger District personnel obtained shortleaf pine seeds from an Ozark Mountain source that had been stored at 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 lb 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 average 28,100 seeds per pound and had a germination rate of 86 percent. A heavy sowing rate was used because the seeds were not treated with repellents to control predators or stratified before direct seeding. The recommended rate for broadcast sowing of repellent-treated, stratified, shortleaf pine seeds is 0.48 lb/acre (Ezell 1988).

One year after direct seeding, the 40-acre area surrounding the research plots was hand-planted with I-O, genetically improved, bare-root, shortleaf pine

seedlings from an eastern Oklahoma seed source. These seedlings were outplanted with hoedads on a 12- by 12-ft spacing (302 trees per acre). To monitor the development of planted seedlings, an additional 0.5acre plot was established contiguous to each of the herbicide injection plots in the main study. Merchantable pine basal area was obtained by measuring all pines >4.5 inches in d.b.h. that grew within the boundary of the three planted plots. During autumn of 1992, 25 planted shortleaf pine seedlings were randomly selected for measurement within each planted plot and tagged for identification.

Measurements and Data Analysis

Following harvest and hardwood control, seedbed conditions were ocularly estimated to the nearest 10 percent on each of the twenty-five I-milacre sample quadrats per plot. Eight disturbance codes were used in that assessment (Cain 1993), but only the percentage of forest floor covered by manually cut hardwood slash is presented here.

In the fall of 1993, 3 years after hardwood control, pine seedlings were counted within each of twenty-five 1-milacre sample quadrats per interior subplot. The two tallest (dominant) pine seedlings (stems ≤0.5 inches in d.b.h.) within each milacre quadrat were measured for total height to 0.1 ft and g.l.d. to 0.04 inch. These dominant seedlings were assessed as being overtopped by nonpine vegetation 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 two saplings were present across all 12 plots, 3 years after harvest. Within the twenty-five I-milacre quadrats per plot, ground coverage was ocularly estimated to the nearest 10 percent for herbaceous vegetation (forbs, grasses, semiwoody plants, and vines) and for merchantable and submerchantable pines and hardwoods (including shrubs) by vertical projection of foliar cover to the ground.

During the fall measurement, hardwood rootstocks of seedling size were counted within each of the twenty-five I-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 the 2-milacre quadrats at even-numbered sample points, hardwood saplings were counted by I-inch d.b.h. classes, and the dominant hardwood sapling was identified by species. Where rootstocks were disturbed within the 2-milacre quadrats by harvesting or hardwood control, 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.

For residual hardwoods that were larger than 4.5 inches in d.b.h., a loo-percent inventory was conducted within each 0.5-acre plot. Number of stems were recorded by I-inch d.b.h. classes. These hardwoods were categorized into four groups: red oaks (principally *Quercus falcata* Michx., *Q. rubra* L., and C?. *velutina* Lam.), white oaks (C?. *alba* L. and *Q. stellata* Wangenh.), hickories (*Carya* spp.), and other hardwoods.

On the three plots established for monitoring planted pine development, surviving crop seedlings were measured in the autumn of 1993 to obtain total height to 0.1 ft and g.l.d. to 0.04 inch.

Because plots in which hardwoods were manually controlled as needed were not re-treated during the first 3 years, data from these plots were pooled before analysis with plots in which hardwoods were manually controlled only once. Analysis of variance was used to evaluate treatment effects on measured variables. Percentage values for quadrat stocking, free-to-grow condition, and ground coverage were compared following arc sine transformation. Statistically significant differences were tested by orthogonal contrasts. Analysis of variance was also used to compare the mean size of planted pines to that of dominant seeded pines on herbicide injection plots in the main study.

RESULTS AND DISCUSSION

Cost of Postharvest 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 (Cain 1993). Chain saw felling was accomplished at a cost of $0.07 per treated stem as compared to $0.14 per stem for herbicide injection. For the injection treatment, Garlon accounted for 78 percent of the cost, with labor at 22 percent. For manual hardwood control, labor was the highest cost factor at 79 percent, and chain saw use accounted for 21 percent of the cost. All hardwoods larger than 1 .O 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.

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 I-milacre quadrats contained hardwood slash, and ground coverage from felled hardwoods averaged 62 percent of the area

Table I-Status of 3-year-old pine seedlings by method of hardwood control.

Hardwood control treatment	Density (stems/acre)	Milacre stocking[a] (percent)	Total height[b] (ft)	G.l.d.[b] (inches)	Free-to-grow (percent)
Check	693	29	0.72a[c]	0.14a	10
Herbicide injection	1,800	48	1.24b	0.26b	62
Manual hardwood control	1,027	40	1.08b	0.20b	28
Mean square error	359,067	0.020	0.053	0.001	0.062
PR>F[d]	0.18	0.31	0.05	0.02	0.10

[a] Based on the presence of at least one pine seedling per I-milacre quadrat.
[b] Means for height and groundline diameter (g.l.d.) were derived from the two dominant pine seedlings within twenty-five 1 -milacre quadrats per plot.
[c] Columnar means followed by the same letter are not significantly different at the 0.05 level, according to orthogonal contrasts: check vs. HI + MHC and HI vs. MHC, where: HI = herbicide injection and MHC = manual hardwood control.
[d] The probability of obtaining a larger F-ratio under the null hypothesis.

within those quadrats. Because 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.

Seeded Pine Regeneration

In uneven-aged silviculture, 200 submerchantable-sized pines per 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 three growing seasons after direct seeding, pine seedling density averaged 1,173 stems per acre across all treatments. Statistically, there was no significant difference (P=0.18) in pine seedling density among treatments (table 1). Milacre stocking for pine seedlings ranged from 29 percent on check plots to 48 percent on herbicide injection plots. Even though milacre stocking did not differ statistically among treatments (P=0.31), all hardwood control treatments were within 2 percent to 10 percent of the optimum level for uneven-aged management, whereas milacre stocking on untreated check plots was 21 percent below that level (table 1).

With direct seeding, the study area was successfully regenerated. However, stand structure was a long way from a well-regulated condition. Results from uneven-aged management of shortleaf pines in the Ouachita Mountains of Arkansas suggest that old, even-aged sawtimber stands are the most difficult to convert to uneven-aged structure and will require the longest conversion period of any existing stand type (Murphy and others 1991).

Three growing seasons after establishment, dominant pine seedlings averaged 1 .01 ft in height and 0.2 inch in g.l.d. (table 1). Dominant seedlings on hardwood control plots were 61 percent taller in height (P=0.05) and 64 percent larger in g.l.d. (P=0.02) than those on check plots (table 1).

At the end of the three growing seasons, dominant pine seedlings were more likely (P=0.10) to be free-to-grow on hardwood control plots than on check plots (table 1). About 90 percent of dominant pine seedlings were judged as overtopped on check plots, as compared to an average of 55 percent that were overtopped on hardwood control plots.

Planted Pines

During autumn of 1993, merchantable pine basal area on planted plots averaged 66 ft^2 per acre and did not differ (P=0.91) from that on herbicide injection plots in the main study (table 2). Therefore, the negative effect of overstory pines on the development of pine regeneration should have been the same regardless of establishment technique.

Planted shortleaf seedlings were 64 percent taller (P=0.02) in height and 58 percent larger (P=0.04) in g.l.d. than the dominant seeded shortleaf seedlings on herbicide injection plots in the main study. Of the planted seedlings that were tagged for measurement, only 4 percent died during the 1993 growing season. Two years after outplanting, 22 percent of survivors were overtopped by nonpine competition as compared to 38 percent of dominant, seeded, shortleaf regeneration that was overtopped on injected plots in the main study.

Because of a natural seedcrop failure during the winter after harvest, direct seeding was chosen in the main study to simulate natural seedfall. Although no cost comparison was made between planting and direct seeding, 3-year results suggest that planting of shortleaf seedlings was superior to direct seeding in terms of growth response after controlling hardwoods by herbicide injection.

Table 2-Comparison of measured variables on seeded and planted plots where hardwoods were controlled by herbicide injection.

Measurement variable	Establishment technique[a] Seeded	Planted	Mean square error	PR>F[b]
Merchantable pine basal area (ft^2/acre)	67.4	66.2	147.7	0.91
Pine seedling total height (ft)	1.24	2.03	0.023	0.02
Pine seedling groundline diameter (inches)	0.26	0.41	0.932	0.04

[a] Both seeded and planted pines were 3 years old from seed at the time of measurement.
[b] The probability of obtaining a larger F-ratio under the null hypothesis.

Competing Vegetation

Three years after hardwood control, density of seedling-sized hardwoods averaged nearly 5,700 rootstocks per acre (table 3). Although manual control plots had 32 percent more hardwood rootstocks of seedling size than plots that were treated by herbicide injection, treatment differences were not significant (P=0.50). Dominant hardwood sprouts of seedling size were 93 percent taller (P=0.02) on manual control plots than on herbicide injection plots. In addition to being taller, these dominant sprouts had crowns that averaged 273 percent larger (P=0.01) than those on injected plots (table 3). Obviously, herbicide injection was more effective than chain saw felling by providing better control of hardwoods, 3 years after treatment.

Five woody species, or groups of species, predominated in the seedling size-class, and they accounted for 77-percent milacre stocking of all nonpine woody vegetation. These were *Cornus florida* L. (23 percent), *Quercus* spp. (20 percent), *Carya* spp. (15 percent), Nyssa *sylvatica* Marsh. (13 percent), and *Acer rubrum* L. (6 percent). Milacre stocking was less than 5 percent for other individual species of woody plants.

Density of hardwood saplings averaged 190 stems per acre (table 3), with no differences among treatments (P=0.14). Quadrat stocking of these sapling hardwoods averaged 22 percent across all plots (table 3). Manual control plots had 18 percent more (P=0.04) quadrats stocked with hardwood saplings than did herbicide injection plots. This result again reflects the efficacy of herbicide injection versus chain saw felling when used to control hardwoods in pine management. On check plots and herbicide injection plots, *Carya* spp. were the predominant hardwoods of sapling size, whereas *A. rubrum* and *Cornus florida* saplings predominated on manual control plots.

Three years after hardwood control, ground coverage by pine regeneration averaged only 2 percent (table 4), with no differences (P=0.47) among hardwood control treatments. Ocular estimates of percentage ground cover fromhardwoods of submerchantable size

Table 3-Status of nonpine competition 3 years after hardwood control.

Hardwood control treatment	-Seedling-sized hardwoods-- Rootstock Density	Total height[a]	Crown area[a]	-Sapling-sized hardwoods------ Density	Quadrat stocking[b]	Weighted d.b.h.[c]
	(no./acre)	(ft)	(ft^2/rtstk)	(stems/acre)	(percent)	(inches)
Check	5,440	3.34ab[d]	5.96ab	167	25ab	1.6a
Herbicide injection	4,960	2.60a	3.65a	56	11a	1.0b
Manual hardwood control	6,567	5.02b	13.62b	348	29b	1.0b
Mean square error	2,441,511	0.37	5.45	19,425	0.0036	0.0053
PR>F[e]	0.50	0.02	0.01	0.14	0.04	0.001

[a] Data from the dominant seedling-sized hardwood rootstock (rtstk) on twenty-five l-milacre quadrats per plot.
[b] Based on the presence of at least one hardwood sapling per 2-milacre quadrat.
[c] Means weighted by number of hardwood saplings in the l-, 2-, 3-, and 4-inch d.b.h. classes.
[d] Columnar means followed by the same letter are not significantly different at the 0.05 level, according to orthogonal contrasts: check vs. HI + MHC and HI vs. MHC, where: HI = herbicide injection and MHC = manual hardwood control.
[e] The probability of obtaining a larger F-ratio under the null hypothesis.

substantiates the differences in efficacy of the hardwood control treatments that were tested in this investigation. Ground coverage from these hardwoods averaged about 27 percent higher (P=0.01) on manual control plots than on herbicide injection plots (table 4). Ground coverage from merchantable-sized hardwoods averaged 59 percent higher (P<0.01) on check plots compared to plots where these trees were controlled 3 years earlier (table 4). 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 33 ft^2 per acre, Of that total basal area, 46 percent was in the white oak group, 28 percent in hickories, 17 percent in the red oak group, and 9 percent in other hardwoods.

Three years after treatment, ground coverage from herbaceous vegetation averaged 39 percent, with no differences (P=0.31) among treatments (table 4). In the first few years after establishment of pine regeneration, competition from herbaceous vegetation can be more detrimental to survival and growth of pine seedlings than woody competition, especially on good sites (site index >85 ft at 50 years) where herbaceous ground coverage can approach 100 percent, with multistoried layers (Cain 1988a). Given the combined ground coverage from sprouting hardwoods and herbaceous vegetation in the present study, and in the absence of site disturbance, it is unlikely that additional pine regeneration will become established from natural seedfall on this site, even in better-than-average seed years.

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 (Bernstein 1978, Lowery 1986, Walstad and others 1987). Where manual or mechanical hardwood control have 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). Because 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.

Three years after herbicide injection, only 36 percent of treated stems had produced root collar sprouts. On manual control plots, 92 percent of cut hardwoods had resprouted. *Carya* spp. were the most consistent resprouting species on herbicide injection plots and on manual control plots. Those species accounted for 48 percent of all sprouts on herbicide injection plots and 26 percent of all sprouts on manual control plots. Injected plots averaged only three sprouts per rootstock as compared to six sprouts per rootstock on manual control plots.

Three years after herbicide injection, Q. *alba* had the tallest root collar sprouts, averaging 7.3 ft in height. All other sprouting species on injected plots averaged less than 5 ft in height. In contrast, on manual control plots, three species had root collar sprouts that averaged

Table 4-Ground coverage by vegetative component 3 years after hardwood control.

Hardwood control treatment	Pine seedlings	Ground coverage Hardwoods 14.5 in. d.b.h.	Hardwoods >4.5 in. d.b.h.	Herbaceous vegetation
		(percent)		
Check	1.5	34.7ab[a]	60.9a	21.2
Herbicide injection	3.2	11.8a	3.4b	47.4
Manual hardwood control	1.3	38.4b	0.0b	47.6
Mean square error	0.00035	0.0028	0.00085	0.0517
PR>F[b]	0.47	0.01	<0.01	0.31

[a] Columnar means followed by the same letter are not significantly different at the 0.05 level, according to orthogonal contrasts: check vs. HI + MHC and HI vs. MHC, where: HI = herbicide injection and MHC = manual hardwood control.
[b] The probability of obtaining a larger F-ratio under the null hypothesis.

over 10 ft in height A. rubrum (14.3 ft), *Liquidambar styraciflua* L. (15.3 ft), and Q. *rubra* (10.6 ft). Also, 3 years after chain saw felling, an additional 10 species of woody plants on manual control plots had root collar sprouts that averaged taller than 5 ft. The mean height of sprouts across all species was 4 ft on herbicide injection plots and 6 ft on manual control plots.

Fewer species were likely to sprout from the root collar if injected with herbicide than if cut with a chain saw. Of those species that did resprout on injected plots, their sprouts were not as tall and there were not as many sprouts per rootstock as on manual control plots. 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 was the competition from original stems (Liming and Seizert 1943, Meade 1955).

SUMMARY AND CONCLUSIONS

Three years after broadcast sowing of shortleaf pine seeds, density and milacre stocking of pine seedlings were adequate on all plots, regardless of whether overtopping hardwoods were controlled or not. Nevertheless, dominant pine seedlings on treated plots averaged 61 percent taller and 64 percent larger in g.l.d. than those on check plots. The data suggest that, in uneven-aged pine silviculture, some form of hardwood control is required to ensure that a sufficient number of submerchantable pines will develop to sustain the production of high-quality sawtimber with pulpwood, poles, and pilings as important secondary products.

Resprouting hardwoods on manual control plots were 93 percent taller and had crowns that were 273 percent larger than those on herbicide injection plots. Because nearly twice as many established seedlings were overtopped by competing vegetation on manual control as on herbicide injection plots, followup control is recommended where hardwoods were chain saw felled. Retreatment would most likely negate the initial cost advantage of chain saw felling. If herbicide use is not an option on National Forest System lands because of public concerns, then manual girdling of the hardwood component is likely to result in fewer sprouts of smaller size than chain saw felling (Liming 1945, 1946).

Although the evaluation of planted shortleaf pine seedlings was conducted only as a side test to the main study, the genetically improved, nursery-grown pines provided better stocking and outperformed dominant shortleaf seedlings that were established by seeding. Consequently, when converting mature even-aged shortleaf pine stands to uneven-aged structure, planting appears to be a viable regeneration alternative to direct seeding or natural seeding, especially at locations where natural seed crops are consistently below average.

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EXPERIMENTAL DESIGNS FOR MIXED-SPECIES PLANTATIONS'

J.C.G. Goelz[2]

Abstract-Although an appropriate design is available for mixtures of two species-replacement series of multiple den&&a-studies cunceming competition among three or more tree species have not been as elegant. A fundamental problem in mixtures of more than two species is that there are many treatment combinations. As plots must be large if individual tree competition indices are used, studies of more than two species require more land and seedlings than is practical for a single study. A solution to this problem is to use a systematic or clinal design where species composition varies gradually across a large plot. For three species, the plot is triangular with each species dominating a vertex of the plot. With large numbers of species, no satisfactory design is available.

INTRODUCTION

Mixed-species plantations can potentially produce more biomass than monocultures (Harper 1977, Kelty 1992, DeBell and Harrington 1993) as well as provide more diverse plant and animal communities. However, Matthews (1989) believes it is unlikely that the yield of a mixture will be greater than the yield of a pure stand of a fast-growing species. Kelty (1992) believes that although it might be a rare occurrence, proper selection of species can make it more likely for mixtures to have greater yield than monocultures. Smith (1988) indicates that yield may be greater when a mixed stand is vertically stratified. There is evidence that a mixed-species plantation may be more productive than monocultures when one of the species increases soil organic matter or nutrient concentration (Matthews 1989; Smith 1988; DeBell and Harrington 1993). Mixed-species stands may provide boles of greater log qualii (Clatterbuck and Hodges 1988), and may be more resistant to pests than monocultures (DeBell and Harrington 1993). Forest visitors may view mixed-species plantations as more beautiful than monocultures (DeBell and Harrington 1993). In addition to these important values, the creation of mixed-species stands provides an opportunity to investigate the fundamental processes of inter- and intra-specific competition.

Although mixed species plantations may provide numerous benefits, the primary objectives of the designs discussed in this paper are to: (1) describe the trends of biomass or volume yield over a range of species composition and overall stand density; and (2) describe competition among trees of different species as it affects individual tree growth

ECOLOGICAL DESIGNS

Design of competition experiments are reviewed by Harper (1977), Radosevich (1987), and Cousens (1991). Some of the main points are synthesized below. The classical design for 2-species mixtures is the deWit replacement series (deWit 1980, Harper 1977). The treatments represent proportion of each species, with overall number of plants per unit area constant for all treatments. Typically 4 to 6 treatment levels are used, including monospecific stands. Harper (1977) calls this type of competition experiment a substitutive design. The constrast is the additive design, where number of plants of one species is held constant while varying the amount of plants of the other species; overall density is not held constant. Although substitutive designs are generally easier to interpret than additive designs (Harper 1977), additive designs can provide additional information. However, by establishing multiple deWit replacement series with diierent overall planting densities(as suggested by Spitters and others 1989), the strengths of both substitutive and addiive designs are obtained.

For studies involving more than two species, a design similar to a diallel analysis in genetics is used. A diallel is used in breeding programs to test controlled crosses of genotypes. In this design, all possible two-species and single species stands are planted (Norrington-Davies 1967, 1968, Norrington-Davies and Hutto 1972). Typically, monospecific stands and 50:50 mixtures of the two species are used, although Nance (1984) used 25:75 and 75:25 mixtures in a study involving diierent genotypes of the same species. These studies could be viewed as a group of replacement series with limited choices for proportions. Typically only two-species mixtures are used regardless of the number of species considered, although Nance (1984) supplemented his design with two mixtures of all genotypes.

The dialld-like studies could be used as screening studies to select promising species combinations. Species pairs reflecting patterns similar to figure 1

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could receive further study from a full replacement series. Although the studies cited above included all possible combinations of species, that is not necessary. One group of species could include desirable timber species and another group could include species chosen for benefit to wildlife or aesthetic quality of the stand. Mixes would be done between groups, but not within groups. There are numerous diallel designs in genetics and most of them do not provide for crosses among all individuals. They are still capable of defining general combining ability and specific combining ability. High general combining abilii implies a generally high productivity in mixures; specific combining ability reflects productivity for individual combinations of species. The diallel could be used to identify a few species of high general combining ability. Those species could be utilized in subsequent studies to define ideal mixtures of species.

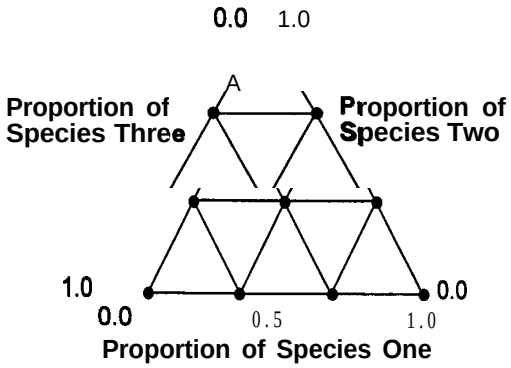

Figure 1-Scheffe's (1958) simplex lattice design of degree three for three components. Points indicate species proportions on the three-species simplex.

STATISTICAL DESIGNS FOR MIXTURES

Mixture experiments are used in the development of products as diverse as fruit punch, textiles, and petroleum. Cornell (1990) has summarized the design and analysis of mixture experiments. Most designs are derivative of Scheffe's simplex lattice and simplex centroid designs (Scheffe 1958, 1963). A simplex is merely a projection of an n-dimensional coordinate system onto an (n-l)-dimensional coordinate system. This projection is possible because all proportions of the mixture must add up to one. When there are two components of the mixture, the simplex is a straight line, and thus analogous to the classical replacement series within the ecological literature. For a three component system, the simplex is an equilateral triangle. Within a three-dimensional space, the possible mixtures are restricted to a two-dimensional triangle-most of the three-dimensional space represents an impossible combination because the sum of the proportions of the three species does not equal one. For a four component system, the simplex is an equilateral tetrahedron with each corner of the tetrahedron representing a pure stand and each face of the tetrahedron equivalent to a three component simplex. A commonly encountered simplex is the soil textural triangle, where proportions of three components are depicted on a two-dimensional graph.

One of Scheffe's (1958) designs, a simplex lattice for three components and degree three, is presented in figure 1. The designs are called lattices because the data points are evenly spaced. The degree of the simplex lattice corresponds to the degree of the polynomial model for which the data provide support. The diallel-like designs described above correspond to simplex lattice designs of degree two.

One of the major problems in applying mixture designs to mixtures of trees is the large number of experimental units that are required. Even when using a simplex lattice of degree three and three components, one of the most simple designs for three components, we have 10 different treatments. If, in addition to species proportion, we wish to consider different spacings and soil types we need many plots. Thus, a simplex lattice design of degree three and three components, at only two different spacings and only two different soil types with only two replications per treatment combination would require 80 plots and up to 32,720 seedlings and 69.3 acres. That represents a level of investment that may be greater than what is available. As far as degree of the simplex lattice, number of different spacings and soil types, number of replications, and number of border rows, this would represent a minimal study to investigate the chosen factors.

SYSTEMATIC DESIGNS

The Stoneville Design

A solution to this problem is to use a systematic, or clinal design. A Nelder's (1962) design is a well-known systematic design for spacing studies. In figure 2, a novel systematic design for three-species mixtures is displayed. Each vertex of the triangle is dominated by a single species, with the proportion of that species decreasing towards the opposite face. Each side of the triangle is dominated by a gradation of two species, and the center of the triangle is a relatively even mixture of all three species.

At a specific planting spot, species is assigned based on the probability defined by the triangular coordinate system. Each side of the triangle represents a range of proportion for a given species in even steps from 0 to 1. Thus for each corner of the triangle, one species has a probability of 1, while, the same species has a 0 probability to occur on the opposite face of the triangle. Each planting spot has a unique probability for each species. Species are assigned randomly, in proportion to the probability An algorithm was devised to ensure

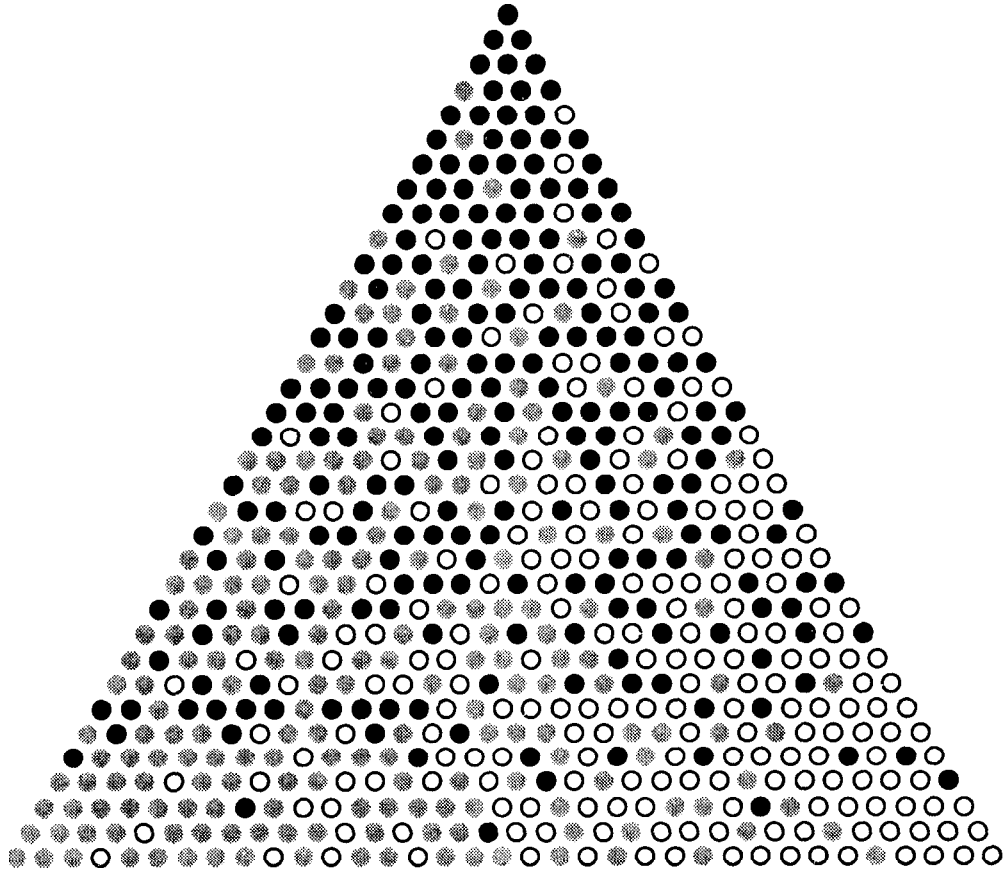

Figure 2--The Stoneville design for three species. Shading distinguishes species. Species is assigned to each planting spot using a constrained random procedure.

that species composition varied gradually rather than strictly randomly. If assignment was strictly random, clusters of one species could occur.

This design is easily expanded to four species. The simplex for a 4-component system is a three dimensional coordinate system, in this case, a tetrahedron, with each face identical to the triangular design for the three species mixture. The faces of the tetrahedron could be established as was the single triangular plot of the three component system. The four species mixture design should be augmented by plots with an even-mixture of all four species.

A Different P-Species Design,

Although multiple deWit replacement series are an effective way to investigate 2-species mixtures, an alternative design is presented in figure 3. The design is doubly-clinal, in that a species composition gradient is imposed perpendicular to a gradient of stand density imposed by a Nelder's (1962) design. The species composition gradient along each arc represents species proportions from 0 to 1, in even increments for each radius. As for the Stoneville design, some procedure should ensure that species composition varies gradually across radii so that pockets of one species do not occur. Potentially, the arcs of figure 3 could be extended into a complete circle and several species could be included. Radosevich (1987) suggested an alternative mixture study based on Nelder's (1962) design.

ANALYSIS OF THE STONEVILLE DESIGN

Although this section focuses on the Stoneville design, the principles apply to mixture experiments in general. The objectives of mixture studies involve describing the effect of species proportion on tree and stand-level growth. However, if any non-density-dependent mortality occurs, the desired treatment level is not obtained. Some early mortality would be expected in any plantation. We might not be able to conduct standard (i.e. ANOVA) tests to determine whether specific species proportions differ with regard to growth. However, ANOVA is not the most proper way to proceed to analyze a systematic design (Mead 1988). Cornell (1990) has also viewed mixture studies as response surface designs. Thus the emphasis is on describing the response of tree or stand-level growth to species proportion rather than testing whether two particular levels of species proportion differ with regard

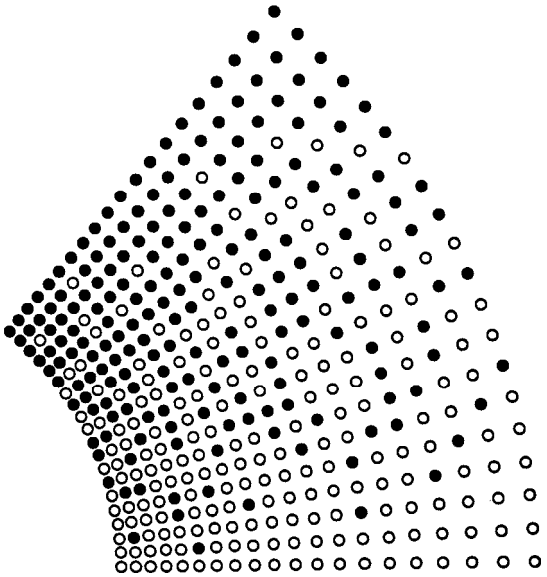

Figure 3-An alternative systematic design to investigate stand density and species proportion simultaneously for two-species mixtures. The radii reflect gradients of stand density and the arcs reflect gradients of species composition.

to observed growth. Emphasis should be placed on describing the response surface, whether with regard to individual tree or stand-level growth. As non-density-dependent mortality will affect actual species proportions, fitted values should be plotted that reflect estimates in the absence of mortality. In figure 4, a hypothetical contour plot is presented over the triangular simplex.

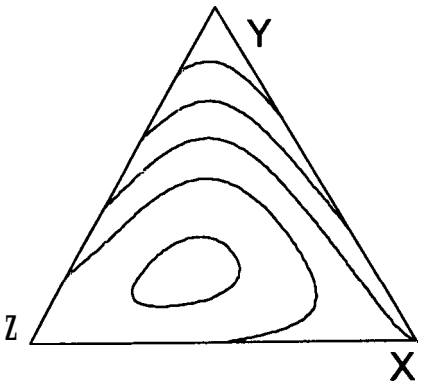

Figure 4--A hypothetical contour plot where predicted yield provides contours over the three-species simplex.

Modeling Stand-Level Response.
Non-overlapping subplots within the large systematic plot provide data for a given number of trees of each species per unit area. The general form of the equation would be:

$$Y = f(n_a, n_b, n_c, \text{Site, Age})$$

where Y is yield, and n_a, n_b, and n_c represent the number of trees of each species. The specific form of the equation should allow for yields of mixtures to be either greater or less than monocultures, as determined by magnitude or sign of the parameters.

Modeling Individual Tree Response.
Growth or survival of individual trees would be modeled with the following general equation:

$$Y = f(Y_0, D, M, S, \text{Time, Site}),$$

where Y_0 is the initial size of the subject tree, D is a vector of distances to all potential competitors, M is a vector of the magnitude, or size, of all potential competitors, and S is a vector of the species of all potential competitors. The specific form of this equation could include one of the standard competition indices or not. Model building could provide a test of alternative competition indices, or generate an objectively-defined competition function.

DESIGNS FOR MORE THAN FOUR SPECIES

Designs for more than four species are still a problem. There are two situations: (1) numerous species are to be considered, but identification of superior mixtures of two to four species is the objective of study; and (2) mixtures of many species are actually desired. In either situation, a diallel design could be used to identify species with high general combining ability as well as identifying specific combinations of species that grow well. After the initial screening, the next step for situation two is uncertain. For situation one, the initial screening may leave only two to five species for consideration. Then, the designs described in this paper could be used to identify ideal proportions of the species. The triangular arrangement could be planted for all possible three species combinations, and augmented with even mixtures of all possible combinations of more than three species. If competition among individual trees is the only objective of the study, a study of reasonable size is possible for even 10 or more species by randomly assigning species to planting spots. A model could be specified that predicted growth for each species as a function of competition which would be determined by the size of, species of, and distance to competitors. Thus,

competitive species-species that reduce growth of neighbors more than other other species do-and species that are less sensitive to competition-species whose growth is reduced less than another species given the same competitors-could be identified. The resulting individual tree growth models could be used to simulate numerous species compositions, and superior mixtures could be identified.

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EFFECTS OF A SUMMER WILDFIRE ON SITE CONDITIONS AND VEGETATION IN A MIXED OAK FOREST IN VIRGINIA'

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Abstract-In July 1 988, a low-severity surface wildfire burned through several mixed oak stands on Dovel Mountain, in the Shenandoah National Park, Virginia. These stands were even-aged, about 70 years old, and dominated by chestnut oak with lesser amounts of red maple, northern red oak, and blackgum. Two years following the tire, a detailed survey of forest floor and surface soil physical and chemical properties was conducted. Also, the vegetation in the overstory, understory, and regeneration strata was also characterized. There is evidence that repeated summer fires may have a xerifying effect on the site and improve its ability to support a spectrum of regeneration dominated by oak species. This fire impacted the forest floor by significantly reducing the weight of the Oi and Oe horizons, and also associated nutrient contents. The surface mineral soil, however, was enriched in carbon and mineral nutrients. The overstory mortality due to the fire averaged 336 stems per ha, mostly red maple. The dominant species, chestnut oak, was largely unaffected by fire. The greatest impact of the fire was on the understory stratum. Understory shrubs Iii azalea and mountain-laurel were burned to the ground; while oaks and larger understory tree stems fared better. The regeneration stratum was dominated by sprouting shrubs and seedling sprouts of chestnut wk. Oak regeneration in the burned areas averaged 9,102 per ha, and 16,897 per ha in the unburned areas.

INTRODUCTION

Fire has played an important role in shaping the composition, structure, and succession of plant communities around the world. Of particular interest is the role of fire in the regeneration, establishment, and maintenance of oaks (*Quercus* spp.). Maintenance of oaks on better quality sites is particularly diicult due to competition from more mesic species. On sites with a 65+ site index, oaks are believed to be seral and were thought to be established by severe conditions such as uncontrolled burning, abusive logging practices, and grazing (Merritt 1979, Rouse 1 986). Regeneration and establishment problems have been associated with the advent of fire suppression.

Loftis 1978, Wendel and Smith 1986, McGee 1979, and Van Lear and Waldrop 1988 have studied prescribed fire and its effect on oak forests, however, less is known about the role and impact of naturally occurring wildfire on flora and soils in mixed oak forests. Wildfires offer unique study opportunities because of variable fire intensities and the timing of the fire in relation to the physiological state of the vegetation. To date, our understanding of the role of fire in promoting oak regeneration, establishment, maintenance and its associated effect on site conditions is incomplete.

On July 11, 1988, the National Park Service (NPS) located a lightning-caused wildfire on Dovd Mountain in the Shenandoah National Park and adjacent private lands. The mid-July wildfire burned approximately 350 ha before being brought under control and declared extinguished on August 8, 1988.

This study was established to determine forest floor and mineral soil physical and chemical properties and vegetation characteristics following this variable intensity wildfire in a mixed oak forest type.

METHODS

Study Sites

The study area is located in the Blue Ridge Physiographic Province. Soils are derived from granodiorite, arkosic sandstone, and greenstone and have not been classified into series but are typically shallow and skeletal with numerous rock outcroppings. Elevations in the area range from 350 to 800 m and slope inclinations range from 40 to 65 percent. Upland mixed oak forests consist predominantely of chestnut oak (*Quercus prinus* Lamb.) and commonly occur on aspects ranging from 0 - 180 and 300 - 360 degrees azimuth.

Field Methods

Sites were selected within the burned and adjacent unburned forest so that conditions of uniform species composition, age, and density; slope position; aspect;

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elevation; and soil characteristics were represented. Fire intensity was not measured. Cumulative individual tree mortality was used to locate stands with similar fire severity based on minimal crown destruction and less than 33 percent mortality of the total overstory basal area (stems >5 m in height). Areas with greater mortality were rare within the boundaries of this fire and no areas of high severity were found (>75 percent mortality).

Six overstory plots, measuring 576 m^2, were established within the burned areas and six were established within the adjacent, unburned forest. Overstory stem measurements such as species, diameter, and crown class were confined to these plots. Within each overstory plot, three 36 m^2 subplots were established for measurement of the shrub stratrum, which was defined as all woody stems greater than 1 m tall but less than 5 m tall. Stems in these plots were tallied by species, height, and origin. Also within each overstory plot, six 1 m^2 subplots were established for measuring regeneration (<1 m tall) which was recorded by species, number of stems, and percent ground cover. Vegetation sampling was conducted at the end of the 1990 growing season which represents the second year after the fire.

Forest floor and mineral soil sampling occurred in conjunction with vegetation measurements during the second growing season after the fire. Eighteen sampling points were randomly located in burned and unburned areas. The forest floor was sampled with a 100 cm^2 template. At each sampling point, a knife was used to cut along the template border and the Oi-Oe layer was removed and bagged. The Oa layer was removed separately and bagged. Mean depth of the Oi-Oe and the Oa layer was determined. At each sampling point, three mineral soil samples were taken to a depth of 10 cm and combined to form one composite sample. Bulk density samples were also taken to the 10 cm depth at each sampling-point using the excavation method (Blake and Hartge 1986).

Lab Methods

Forest floor samples were oven-dried at 65°C for 48 hours and weighed to determine weight per unit area of the Oi-Oe and Oa layers. Forest floor samples were then sieved to remove mineral matter, ground in a 2 mm Wiley® mill, and remixed with the fine mineral fraction using a sample splitter to ensure a homogenized sample. Oven-dried samples were weighed and dry ashed at 300°C for 2 hours and then increased to 500°C for 12 hours. Following dry ashing, the samples were dissolved in 1 N HCl and filtered. Extracts were analyzed for total P, K, Ca, and Mg using a Jarrell-Ash@ model 9000 inductively coupled plasma emission spectrophotometer. Total nitrogen was determined using the micro-Kjeldahl method of Bremner and Mulvaney (1982). The resultant Kjeldahl extracts were analyzed for total nitrogen using a Technicon® autoanalyzer. Total carbon was determined using a Leco® high-temperature induction furnace (Nelson and Sommers 1982).

Composite mineral soil samples were air-dried and passed through a 2 mm sieve to separate out coarse fragments. Concentrations of exchangeable P, K, Ca, and Mg were determined using a Jarrel Ash@ model 9000 inductively coupled plasma emission spectrophotometer after extraction with a double-acid (0.05 N HCl + 0.025 N H_2SO_4) solution (Thomas 1982). Active acidity, measured as pH, was determined using a 1:2 soil to distilled water ratio and measured with a pH meter. Total nitrogen and carbon were determined using the same procedures as for forest floor samples. Inorganic N (NH_4-N and NO_3-N) was extracted with a 2M KCl solution and analyzed using a Technicon® autoanalyzer (Keeney and Nelson 1982).

Data Analysis

Density and dominance data for each species in the overstory stratum were used to calculate importance values. Density and frequency data were used to calculate importance values for each species in the shrub and regeneration strata using the procedure of Muller-Dombois and Ellenberg (1974).

Community diversity was determined by using the Shannon-Weiner alpha diversity index (Pielou 1977):

$$H' = -\sum_{i=1}^{k} (IV_i \times \log IV_i)$$

where IV_i = importance value of species i.
K = the number of species present in a stand.

Soil and vegetation data was subjected to two sample t-tests in order to detect significant differences at the 0.05 level between burned and unburned areas.

RESULTS AND DISCUSSION

Forest Floor and Mineral Soil

In forest ecosystems, the major portion of soil nutrients are tied up in the surface organic matter. These nutrients are slowly released through decomposition and mineralization. Under normal conditions, organic matter provides a slow release, revolving fund of nutrients for plant uptake. Conversely, fire rapidly releases these nutrients either by volatilizing lower molecular weight gases (H, 0, and N) into the atmosphere or concentrating basic cations in the residual ash.

The effect of wildfire on the total forest floor and surface mineral soil is displayed in Table 1. The forest floor in the burned areas had only 68 percent of the dry weight of the forest floor in the unburned areas. The bulk of

Table 1--Forest floor and mineral soil nutrient contents in burned an unburned areas on Dovel Mountain

Area	Forest Floor Nutrients (kg/ha)						
	Dry Wt.	C	N	P	K	Ca	Mg
Burned	**25,200a**	**13,800a**	499a	36a	40a	**322a**	**25a**
Unburned	**36,900b**	**20,400b**	601 b	38a	53b	299a	26a
	Mineral Soil Nutrients (kg/ha)						
Area	**pH**	C	N	P	K	Ca	Mg
Burned	4.6	8,278	238	**2.4a**	**11.8a**	**28.9a**	**4.2a**
Unburned	4.1	10,282	258	**1.4b**	**11.4a**	**13.1b**	**3.0b**

Means, within a column, followed by the same letter are not significantly diierent at the 0.05 level.

this reduction was associated with the Oi-Oe layer. In the unburned areas thii forest floor surface averaged 23,600 kg/ha, whereas in the burned areas it averaged only 14,000 kg/ha. Likewise, nutrient levels were generally lower in the burned areas. This was true for C, N, P, K, and Mg (Table 1).

The surface 10 cm of mineral soil was also affected by the wildfire. Soil pH in the burned areas was 4.6, compared to 4.1 in the unburned areas (Table 1). Also, levels of P, K, and Mg were significantly greater in the burned areas. These soils had no extractable NO,-N in either the burned or unburned areas. Levels of NH,-N were significantly greater in the burned areas, which had 12.2 ppm compared to 8.0 ppm in the unburned areas.

The result of these forest floor and soil effects is that more nutrients are available for uptake by the surviving vegetation and the regeneration. In adjacent pine stands this same fire had high severity levels, resulting in 100 percent overstory mortality and complete removal of the forest floor (Groeschl et al. 1993). In the oak stands, however, much of the forest floor remained intact, overstory mortalii was mostly less than 33 percent, and the nutrient cycle was not greatly disrupted. This "fertilization effect" of fire has been observed in other studies (Vlamis and Gowans 1961, Wells 1971, White et al. 1973), as has the elevation in soil pH (Grier 1975, Metz et al. 1961, McKee 1982). The increase in NH,-N is particularly noteworthy, as this form of N is readily available for plant uptake, and not as easily leached as NO,-N, which was absent. The increase is normally attributed to greater mineralization (Burns 1952, Wells 1971, Alban 1977, White 1986, Covington and Sackett 1986).

Forest Vegetation

The mixed oak forests on Dovel Mountain are dominated by chestnut oak with minor components of other hardwood species, such as red maple (*Acer rubrum*), scarlet oak (*Quercus* coccinea), and northern red oak (*Quercus rubra*). These forests are even-aged, at about 70 years, with overstory oak trees exhibiting multiple trunks which is indicative of past disturbances.

The wildfire had little impact on the overstory in these mixed oak forests. The total number of stems dropped from an estimated 906 stems ha^{-1} to 570 stems ha^{-1} in burned areas, which was significantly less than the 1024 stems ha^{-1} in unburned areas (Table 2). Although low intensity fires resulted in a 37 percent reduction in the total number of stems, basal area was reduced by only 5 percent. Losses were concentrated in smaller diameter classes, particularly with the thin-barked red maple. Chestnut oak, with its thick bark, is quite resistant to fire (Paulsell 1957). The second growing season after a wildfire in mixed oak stands, Regelbrugge (1988) similarly found that low intensity fires resulted in minimal changes in the overstory stratum. He reported that overstory density was reduced by 15 percent while basal area was reduced by only 8 percent, since mortality from wildfire is greater in smaller diameter trees (McCarthy and Sims 1935).

Table 2--Overstory density prior to fire, two years after fire, and in unburned stands on Dovel Mountain

	Burned Areas		Unburned Areas
	Pre-Fire	Post-Fire	
No. stems/ha	906	570a	**1,024b**
Basal area (m^2/ha)	31.9	**30.2a**	**28.8a**

The wildfire had a noticeable impact on the total number of stems in the shrub stratum. Two years after the fire, shrub density was significantly lower in burned areas, with 2,840 stems ha-' compared with 5,555 stems ha" in unburned areas.

The shrub stratum in the unburned areas forms an intermittent canopy comprised mainly of four species, including red maple, azalea *(Azalea* spp.), mountain laurel (*Kalmia latifolia*), and blackgum (*Nyssa sylvatica*). These same species were also prevalent in the burned areas prior to the fire. Two years after the fire, however, the four most important shrub species were serviceberry (*Amelanchier arborea*), red maple, witch-hazel (*Hamamelis virginiana*), and chestnut oak.

Oaks were present in fairly low numbers in the shrub stratum. The burned areas had 350 oaks ha-' and the unburned areas had 389 ha-'. Shrub stratum diversity averaged 0.72 in the burned areas, significantly lower than the 0.96 in unburned areas.

The regeneration stratum consisted of a mixture of woody shrubs and tree seedlings in both the burned and unburned areas. Blueberries (*Vaccinium* spp.) and azaleas dominated in both areas, however, there were significant numbers of tree seedlings as well. The most important were as follows:

Species	Unburned Areas (No. ha^{-1})	Burned Areas (No. ha-')
Red maple	2,853	1,058
Chestnut oak	13,825	8,255
Northern red oak	1,536	847
Black oak	1,536	
Blackgum	1,756	741
Sassafras	4,384	8,467
Flowerina doawood	2.633	—
Total	28,528	19,368

Overall floral diversity indices for the regeneration strata were 0.84 and 0.83 for the burned and unburned areas, respectively.

Although fire is thought to promote the regeneration and recruitment of oaks, the oak seedling numbers were noticeably lower in the burned areas. Two years after fire, however, it too soon to draw any conclusions about the eventual success of this advance regeneration. Although the oak numbers are lower, so are the numbers of competing shrub stems. Chances are that recruitment of the 9,000+ oak seedlings in the burned areas will be more successful, simply due to the reduced competition.

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COMPOSITION OF A VIRGIN, OLD-GROWTH LONGLEAF PINE STAND'

R. S. Meldahl, J. S. Kush, W. D. Boyer and C. Oberholster[2]

Abstract-Fire has been absent from a virgin, old-growth longleaf pine stand for the past 40-50 years. Efforts are underway to re-introduce fire and to collect as much pre-burn data as is possible. Absence of fire has permitted a substantial hardwood understory and midstory to develop. Longleaf pine regeneration and herbaceous vegetation has been virtually eliminated due to the accumulation of a thick litter layer. Longleaf pine average 128 stems/acre and 82 square feet/acre. Other pines average 28 stems/acre and 10 square feet/acre and hardwood species average 990 stems/acre and 34 square feet/acre, respectively.

INTRODUCTION

Natural communities dominated by longleaf pine and maintained by periodic fire once covered an estimated 80-90 million acres in a broad arc along the coastal plain and Piedmont from southern Virginia to east Texas, extending further inland in the Cumberland Plateau and Ridge and Valley physiographic provinces in Alabama. Exploitation of longleaf pine-dominated forests has led to a steady decline of its acreage (Frost 1994). By 1935, only 20 million acres were left, declining to 12 million acres by 1955. Today, estimates indicate that less than 3.2 million acres exist. Of this, it is estimated that less than 1000 acres of virgin, old-growth longleaf pine remain. Within the city limits of Flomaton, AL is a 60-acre stand of virgin, old-growth longleaf pine owned by Champion International Corporation.

The Alger-Sullivan Lumber Company, one-time owner, dedicated the stand to preservation in the first half of the century. The stand was regularly control burned until some time in the mid-1950's when the lumber company was sold. Absence of fire since has permitted a substantial hardwood understory and midstory to develop and allowed for an accumulation of a thick litter layer at the expense of longleaf pine regeneration and herbaceous vegetation. As part of a cooperative agreement among several organizations, efforts are underway to restore, monitor and manage the stand as an old-growth longleaf pine habitat and to conduct biological research which will provide information on old-growth stand dynamics and future ecological restoration work on what is now being called the Flomaton Natural Area (Meldahl et al. 1994).

METHODS

Efforts are underway to re-introduce fire to the stand in the winter of 1995. The stand has been broken up into 8 blocks and plans are to eliminate hardwoods from 4 of the blocks. The elimination of the hardwood component will provide an opportunity to restore the herbaceous component of the community more rapidly. The portion of the stand receiving only fire treatment will be used to monitor the amount of time it will take for fire to remove the hardwood vegetation. After the initial fire has reduced the fuel load, late spring/early summer fires will be used on a periodic basis to control/remove the competing hardwood vegetation and to restore the herbaceous component of the community more rapidly. In addition, a section of the stand separated from the main stand by a road has been designated to receive no treatment.

Plot centers have been established on a 3-chain by 4-chain grid with plot centers located at least 1.5 chains from the edge of the old-growth tract. Data recorded for every tree on the 1/5-acre circular plots includes: number, azimuth, distance, DBH, crown height, total height and litter depth at the base of the tree. Woody stems less than 0.5 inches DBH but larger than l-foot tall have been tallied by l-foot height classes. Longleaf pine greater than 3.0 inches DBH are being cored to determine age. Four milacre quadrats per plot have been flagged off and ground cover vegetation is being surveyed by species quarterly.

RESULTS

A total of 24 tree species have been recorded on the 1/5-acre measurement plots. Longleaf pine remains the dominant tree species accounting for 45 percent of the trees (> 4.5" DBH). However it comprises less than 7 percent of the saplings (0.6" to 4.5" DBH) and not even 1 percent of the seedlings (l-foot tall to 0.6" DBH). Absence of fire has allowed other pines (loblolly, slash, and shortleaf) and hardwoods to become a major component of the stand. The oaks, specifically water, laurel, and southern red, constitute a majority of

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the hardwoods. They account for 34 percent of the trees and are the predominant sapling and seedling species, comprising 57 and 64 percent, respectively. Other hardwoods of importance include southern magnolia, American holly, black cherry, sweet bay, black gum, and dogwood. Figure 1 presents the density of **longleaf** and species groups for the Flomaton Natural Area.

Longleaf pine accounts for 66 percent of the total basal area in the stand (Figure 2). Although 72 percent of the total tree basal area (> 4.5" DBH) is in **longleaf** pine, **longleaf** represents less than 14 percent of the sapling basal area. Oaks account for 45 percent of the stems in the **5-10"** DBH class (Figure 3). The trees in this DBH class occupy the **midstory** and will replace **longleaf** pine as mortality occurs. In the absence of human intervention or catastrophic events, the future stand will be dominated by oaks and a few other hardwood species.

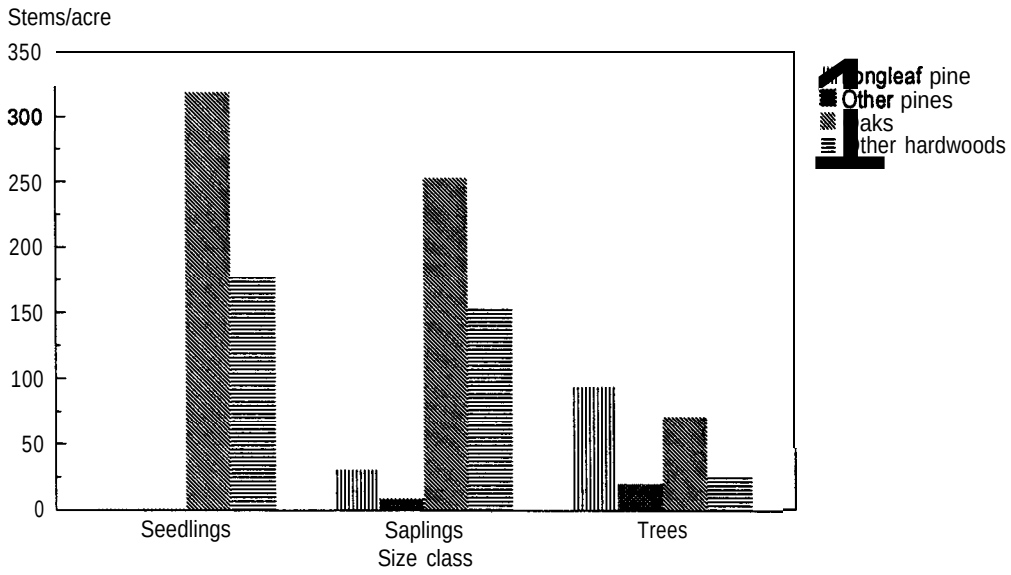

Figure l-Density distribution for the Flomaton Natural Area by species group and size class.

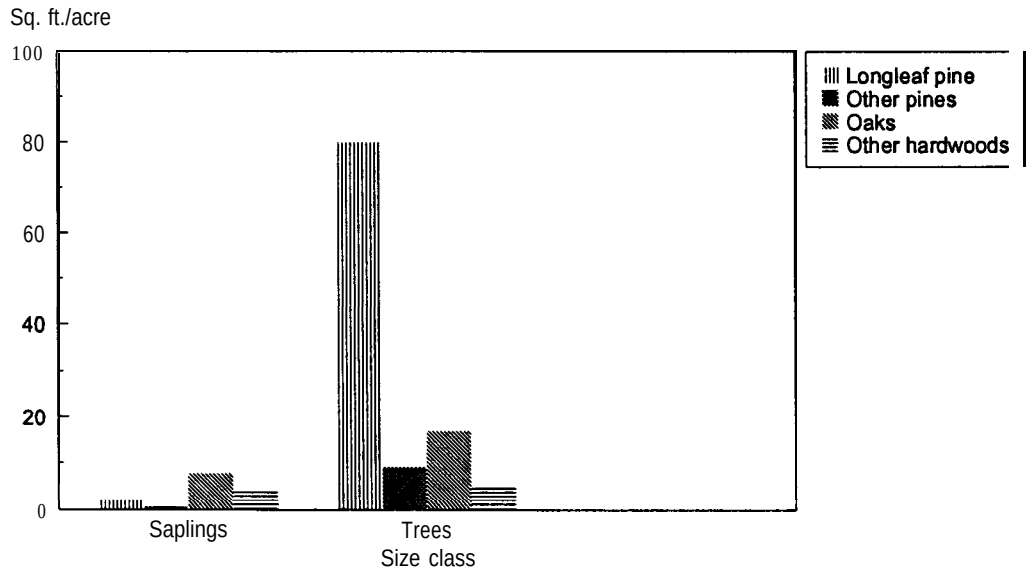

Figure 2-Basal area distribution for the Flomaton Natural Area by species group and size class.

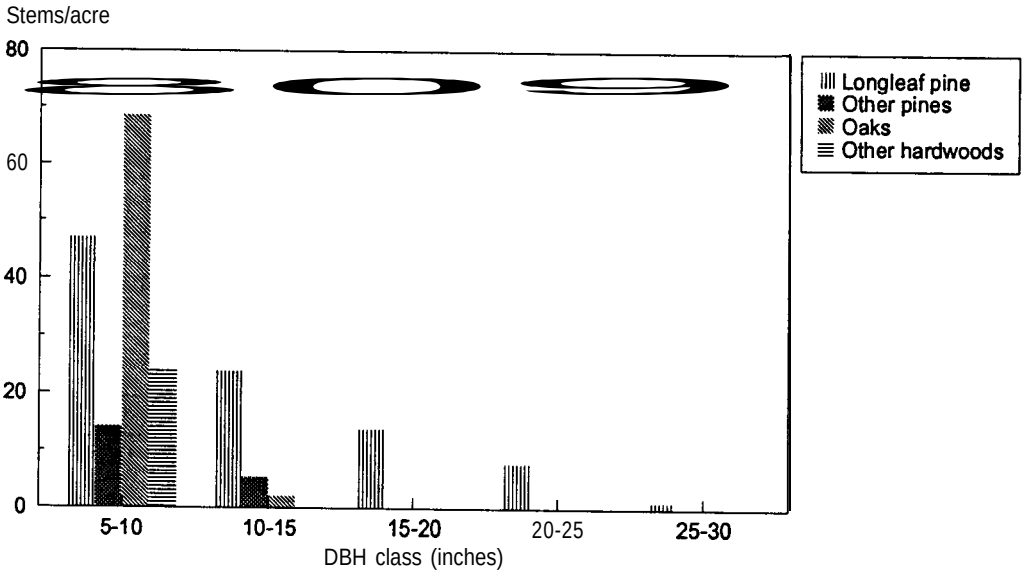

Figure 3-Tree density distribution for the Flomaton Natural Area by species group and DBH class.

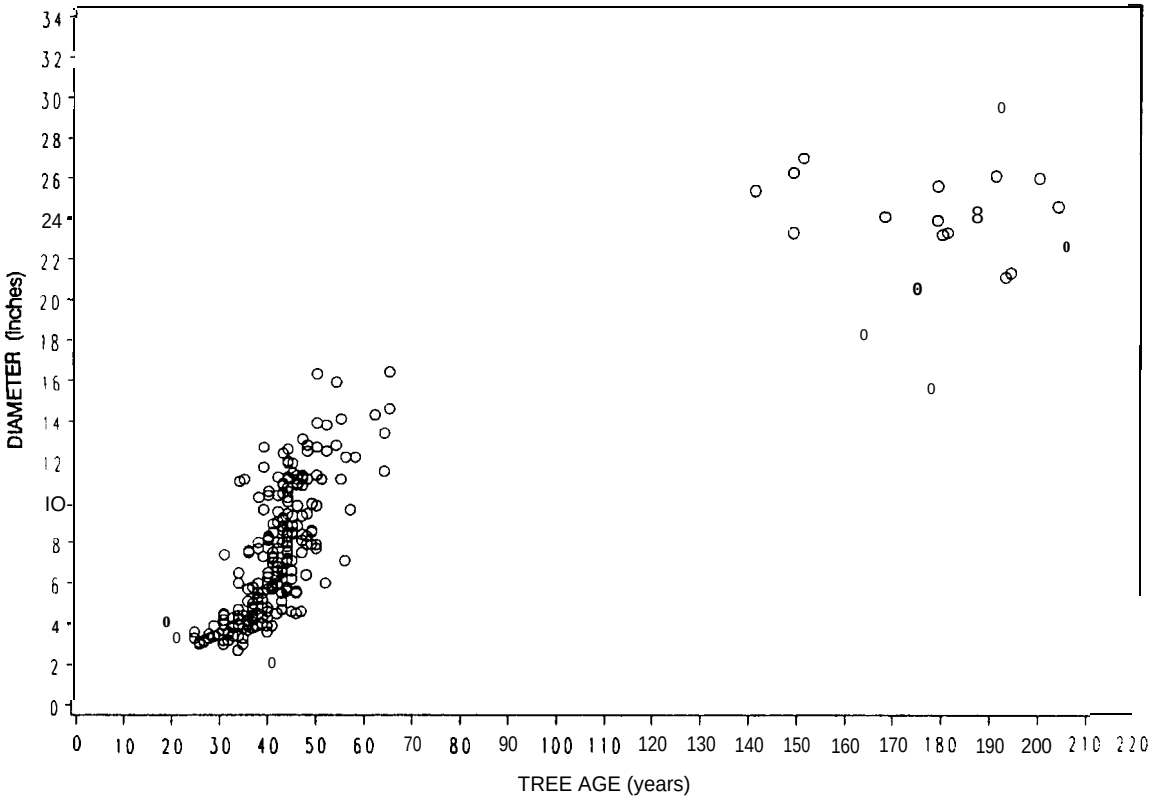

Figure 4--Diameter-age distribution for longleaf pine at the Flomaton Natural Area (tree age is ring count at 4 feet).

Efforts to core the longleaf pine are about a third of the way complete. The diameter-age relationships for the trees cored-to-date are shown in figure 4. There are a few scattered old trees with a majorii of the trees in the 40-50 year age class, with many possibly originating from the exceptionally heavy 1947 seed crop. These younger trees coincide with the cessation of burning. In gaps created by the death of a larger tree, younger longleaf pine have been found. With the radial increment measurement data and mapping of dead and downed trees, a better understanding should be gained of longleaf pine stand dynamics.

SUMMARY

A small remnant of the original longleaf pine forest that once covered approximately 2/3 of the southeastern U.S. exists on a 60-acre stand in Flomaton, AL. Restoration efforts involving the re-introduction of fire after a 40+ year absence and a study of longleaf pine stand dynamics are underway in the Flomaton Natural Area.

Longleaf pine remains the dominant species in the stand based on the density and the basal area of the overstory trees. This situation is temporary due to the small number of longleaf pine saplings and near absence of seedlings. Unless restoration efforts are undertaken, the stand will eventually covert into a mixed hardwood stand dominated by oaks. This succession may be a gradual process or it may happen rapidly through some type of catastrophic event, such as an uncontrolled fire or windstorm.

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SINGLY APPLIED HERBICIDES FOR SITE PREPARATION AND RELEASE OF LOBLOLLY PINE IN CENTRAL GEORGIA'

James H. Miller and M. Boyd Edwards'

Abstract-Separate studies were installed to evaluate site-preparation and release herbicide treatments for loblolly pine (*Pinus taeda* L.). Tests were at four locations each on the Piedmont and Coastal Plain of central Georgia. Six herbicide treatments were tested for pre-planting site preparation and seven treatments were applied in the third growing season for over-the-top release, both with untreated checks. Most herbicides were applied at maximum labeled rates. Six years after site preparation, per-acre pine volumes differed significantly ($p \leq 0.05$) among treatments as follows: Velpar® = Pronone® > Tordon® = Roundup@ > Garlon® = Banvel® > check. Four full growing seasons after release, Arsenal@ and Pronone treatments produced greater volumes than Roundup and check treatments and greater than all other treatments after 5 years. Because some release treatments grew less pine volume than the checks, proper release prescriptions appear more critical than site-preparation prescriptions.

INTRODUCTION

The use of herbicides for pine site preparation and release is increasing in southern forestry, especially as tank-mix applications. At the same time, little is understood about the control capabilities of the separate herbicides and their influence on pine and vegetative regrowth. A clearer understanding of each herbicide applied separately could result in more effective tank mixes.

This study was exploratory with tests on a wide range of sites to evaluate herbicides, in most cases applied singly, for both site preparation and pine release of loblolly pine (*Pinus taeda* L.). **Pine** growth was the primary focus. The practical objective of this cooperative research with the Georgia Forestry Commission was to identify herbicides suitable for reforestation by non-industrial private forest landowners after intensive harvesting of pines and hardwoods and small-diameter fuelwood. The Commission has long promoted the use of **fuelwood** as an alternative energy source. Prior reports from this research evaluated the projected **growth and economics of the site preparation and release treatments (Busby and others** 1993, **Busby and Haines** 1994) **and floristic** changes after the release treatments (Boyd and others 1994).

METHODS

Separate studies were installed to evaluate herbicide treatments for site preparation and for release of loblolly pine. Four locations were used with each: two in the Piedmont and two in the Coastal Plain of central Georgia (table 1). All test locations had been harvested for **fuelwood** to a 4-inch **d.b.h.** limit after commercial clearcuting, leaving few residual trees and maximum hardwood resprouts. For both treatment types, a randomized complete block design used locations as blocks. There were five blocks for the site-preparation study with two blocks established at the Piedmont location (McElroy) to include an eroded and **non-**eroded phase of a Piedmont soil. There were four blocks for the release study, but one block was destroyed due to an over-spray with a herbicide in the fourth growing season after treatment, which will be reflected in the analysis.

The prevalent hardwood species on these research areas were **sweetgum** (*Liquidambar styraciflua* L.), southern red oak (Quercus *falcata* Michx.), water oak (Q. *nigra* L.), black tupelo *(Nyssa sylvatica* Marsh.), red maple (*Acer rubrum* L.), flowering dogwood (*Cornus florida* L.), black cherry (*Prunus serotina* Ehrh.), persimmon *(Diospyros virginiana* L.), and **pignut** hickory (*Carya glabra* (Mill.) Sweet). Prevalent shrubs were hawthorn *(Crataegus* spp.), blueberry *(Vaccinium* spp.), and southern bayberry *(Myrica cerifera* L.).

Six herbicide treatments were tested for pre-planting site preparation and seven treatments were applied in the third growing season for over-the-top release. Check plots were established at each location. High labeled rates or affordable rates (i.e., for Tordon **10K** and Oust + Velpar L) were used, applied at what is generally considered optimum or near-optimum timings.

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The site-preparation treatments were:

Herbicides	Pounds of active inaredient (product) Der acre	Applied in
Velpar L	2.5 to 3.5 hexazinone (1.25 to 1.75 gal)	May
Pronone 1 OG	2.5 to 3.5 hexazinone (25 to 35 lb)	May
Tordon 10K	3 picloram (30 lb)	June
Garlon 4	4 triclopyr (1 gal)	June
Banve l+ Banvel 720	4 dicamba + 4 2,4-D (0.5 + 2 gal)	June
Roundup	4 glyphosate (1 gal)	August

Tordon 1 OK pellets are no longer manufactured, but the liquid formulation of picloram (Tordon K) is. Tordon K at 1.5 gal/acre would equal Tordon 1 OK at 30 lb/acre.

Also, the glyphosate formulation presently labeled for southern forestry is Accord, which is comparable to Roundup in concentration and therefore rate. The release treatments were:

Herbicides	Pounds of active inaredient (product) Der acre	Applied in
Pronone 1 OG	0.9 to 1.5 hexazinone (9 to 15 lb)	Aoril
MCI 54 Pellets@	(a) 2/3 the Pronone a.i. rate (20 to 33 lb)	April
	(b) 3/4 the Pronone a.i. rate (22 to 37 lb)	April
Velpar L	1.0 to 2.25 hexazinone (2 to 4.5 qt)	May
Oust® + Velpar L	0.09 sulfometuron (2 oz) +0.5 hexazinone (1 qt)	May
Arsenal AC	1.0 imazapyr (1 qt)	June
Roundup	2.0 glyphosate (2 qt)	September

The combination of Oust and Velpar was an experimental release treatment to test pine response to only herbaceous plant control at these rates.

Hexazinone rates (Pronone 1 OG and Velpar L) were prescribed according to soil texture and percent organic matter as specified on the labels. Thus, higher hexazinone rates were applied to Piedmont locations and lower rates to the Coastal Plain locations. An experimental product that is no longer manufactured, MCI 54 Pellets, was a concentrated nitrogen fertilizer (66 percent by weight) and contained 3 percent hexazinone. MCI rates were based on Pronone rates but were lower, assuming that hexazinone would be more effective when used with nitrogen fertilizer (and would have a higher price per pound of active ingredient (a.i.), requiring a lower rate to be competitively priced).

It was assumed that 1 inch of rainfall is required to activate the soil-active pelleted hexazinone and picloram herbicides (Pronone 1 OG, MCI 54, and Tordon 1 OK Pellets) and 0.5 inch to activate the liquid hexazinone treatments (Velpar L and Oust + Velpar L). Following these assumptions, Pronone 10G and Tordon 1 OK were activated 22 to 24 days after site preparation applications, while Pronone and MCI 54 Pellets were activated 16 to 19 days after release applications. Liquid hexazinone treatments (Velpar L and Oust + Velpar L) were also activated at 22 to 24 days after site preparation applications and on the day following release applications.

Treatments were applied on 0.5- to 2-acre plots using either a crawler-tractor-mounted sprayer equipped with a Boomjet cluster nozzle (45-ft effective swath) or an Omni spreader (85-ft effective swath). Both systems had application control systems that maintained test rates as ground speed varied (Miller 1988, 1991). The nozzle height was adjusted for each location to apply the herbicide mixture into the sides and over-the-top of most vegetation, although side shielding is always a problem with ground spray applications (Miller 1988). It is now recognized that the Boomjet cluster nozzle produces an uneven, within-swath distribution (Miller 1990), which may make foliar herbicides less effective (e.g., Roundup and Garlon), but be less critical for herbicides with soil-activity (e.g., Velpar, Arsenal, and Banvel). Sprays were applied at 40 gal/acre total herbicide-water mixtures, except for Roundup which was applied at 25 gal/acre (per label instructions). A 5-ft swath overlap was used for site preparation applications, while edge-to-edge swaths were for with release applications--assured by surveyed flagging stations and ground guidance.

At the site-preparation locations, harvesting was done at various times before treatment, from just 2 months (Hill tract) to 7 years (McElroy tract), allowing observations on treatment timing relative to harvest. Site-preparation treatments were applied from May to August 1984, and all plots including the checks were prescribe-burned in late October or early November 1984. Genetically improved loblolly seedlings were machine planted on a 6-by-9-ft spacing in February or

Table 1 .-Location and site and soil characteristics of Georgia study areas.

Tract	County	Province	Site index[a]	Soil and slope
		Site preparation		
Ellington	Laurens	Coastal Plain Sandhills	70	Ailey loamy sand, 8-17 percent slope, and Orangeburg loamy sand, 12-l 7 percent slope.
Grimsley	Twiggs	Coastal Plain	85	Tifton tine sandy loam, 2-5 percent slope and Norfolk loamy sand, 2-5 percent slope.
Hill	Twiggs	Coastal Plain	80	Norfolk loamy sand, thin solum, 2-5 percent slope, and Tifton fine sandy loam, 2-5 percent slope.
McElroy 1	Monroe	Piedmont	80	Gwinnett sandy clay loam, 2-15 percent slope.
McElroy 2	Monroe	Piedmont	75	Gwinnett sandy clay loam, 6-15 percent slope, eroded.
		Release		
Patton	Twiggs	Coastal Plain Sandhills	70	Ailey loamy sand, 8-17 percent slope.
Duggins	Laurens	Coastal Plain	85	Cowarts loamy sand, 2-5 percent slope, Fuquay loamy sand, O-5 percent slope, Lucy loamy sand, O-5 percent slope, and Orangeburg sandy loam, 5-8 percent slope, eroded.
Robinson	Monroe	Piedmont	75	Gwinnett sandy clay loam, 6-l 5 percent slope, eroded.
Davis	Monroe	Piedmont	80	Cecil sandy loam, 6-10 percent slope.

"Base age 50, with values derived from on-site soil series identification and from the Soil Conservation Service data base.

early March 1985. Fifty planted seedlings per plot were measured for total height and groundline diameter (g.l.d.) after 1, 2, 3, and 5 growing seasons. After the sixth growing season, total height and d.b.h. were measured. Measurements for both studies were made to the nearest 0.1 ft for heights, 0.01 in. for g.l.d., and 0.1 in. for d.b.h.

Release treatments were applied during the 1985 growing season. The planted, improved loblolly seedlings were in their third growing season in the field at the time of treatment. The seedlings had been planted on a 6-by-9-ft spacing after prescribed burning. Before treatment, 80 pine seedlings per plot were randomly selected for measurement: 20 in each of four woody competition classes:

Class 1. The seedling had no woody competitor near it that, when bent over, could touch the upper half of the seedling's main stem.

Class 2. The seedling had one woody competitor near it that could touch the upper half.

Class 3. The seedling had woody competitors on two sides that could touch the upper half.

Class 4. The seedling had woody competitors on three sides that could touch the upper half of the seedling's main stem.

This stratified sampling provided a population of measurement seedlings with competition conditions in fixed proportions. This approach minimized a major source of experimental error associated with release studies: unequal competition conditions at the start of the study. Height and g.l.d. were measured on the 80 seedlings before and after the treatment growing season and then 1, 3, and 4 full growing seasons after treatment (FGSAT). At 5 FGSAT, height and d.b.h. were measured. MCI treated trees were not measured past 4 FGSAT.

For the release study, competition cover was estimated in October 1986, at the end of 1 FGSAT. Woody, non-pine cover was ocularly estimated on two 33-by-33-ft sample sub-plots that were systematically positioned within each main plot. These sub-plots were quartered and estimates were made in each quarter for herbaceous cover by growth forms and the amount of bareground.

A per-acre volume index was calculated for the loblolly pine seedlings, as:

$g.l.d.^2$ (or $d.b.h.^2$) X height X survival X planting density.

Data were analyzed by analysis of variance, except that an analysis of covariance was used for release pine data using before-treatment measurements as the covariate. Duncan's multiple range test was used to compare means. Differences were considered significant at the 0.05 level for a Type I error.

RESULTS AND DISCUSSION

Site Preparation

Pine survival averaged across sites was 89 to 95 percent after the first year and 80 to 89 percent after six years, including the burned-only checks, and did not vary by treatment. This high survival resulted from the good quality of seedlings and planting operation, since below-average rainfall occured during the first four growing seasons. The lowest survival, 42 percent, occurred on the Sandhill site after applications of Tordon, where seedlings had toxicity symptoms for up to 2 years. Residual picloram toxicity has long been recognized as a problem on sandy soils.

Significant differences (ac0.05) among treatments were evident in per-acre pine volumes after 5 and 6 years, according to the following interpretation of the Duncan's analysis: Velpar = Pronone > Roundup = Tordon > Garlon = Banve I> Check (table 2 and fig. 1). After 6 years the per-acre volume for the Velpar treatment was about 6 times greater than the check and the Banvel treatment was 2.8 times greater. Velpar and Pronone (hexazinone treatments) yielded the greatest or second-greatest volumes after 6 years on most sites, while Tordon was second on the Grimsley tract and Roundup was second on the McElroy2 tract (eroded Piedmont). Pine growth response (and observed control) on the recently logged Hill tract was similar to that at other locations that had 1 to 7 years to regrow before treatment.

Greatest overall pine growth occurred at the Grimsley tract on the Coastal Plain and the lowest growth was on the Ellington tract on the Coastal Plain Sandhills. The extraordinary pine volume growth on the Grimsley site after Velpar application (1,031 ft^3/acre after 6 years) was due to 3 years of complete herbaceous and woody control on this poorly drained site, exceptional for residual control. Another soil-active herbicide, Tordon, yielded the second most growth on this site, indicating that surface moisture may influence the length of residual activity.

Release

In October of the year after treatment, woody cover was 10 to 20 percent less on the Arsenal, Velpar, and Roundup treatments than on the others (table 3). Grasses were least on Arsenal, Roundup, and MCI 2/3 treatments, with a concomitant increase in forbs where Arsenal and Roundup were used. Grasses are severe competitors of pine seedlings for soil moisture, while forbs are thought to be less competitive (Morris and others 1993). MCI 2/3 treatment also had the most bare ground, but was different only from the check at the 0.05 level. No consistent differences in vines were detected.

Table 2.--Site-preparation treatments: volume index (ft^3/ac, using d.b.h.) by location in the sixth growing season after treatment.

	Coastal Plain			Piedmont		
Treatment	Ellington	Grimsley	Hill	McElroy1	McElroy2	Mean'
		1,031				
Velpar	560[b]	574	483	518	280	575 a
Pronone	423		510	716	473	539 a
Roundup	254	572	295	219	419	351 ab
Tordon	42	700	340	369	285	347 ab
Garlon	94	471	293	385	196	288 bc
Banvel	223	332	219	399	153	265 bc
Check	81	72	124	105	91	95 c
MEAN	240	536	323	387	271	
ROOT MEAN SQUARE ERROR	351.5					

'Means in a column followed by the same letter are not significantly different at the 0.05-level of probability as determined by Duncan's Multiple Range test.

[b]A double underline highlights the greatest pine growth on a location and a single underline highlights the second-greatest growth.

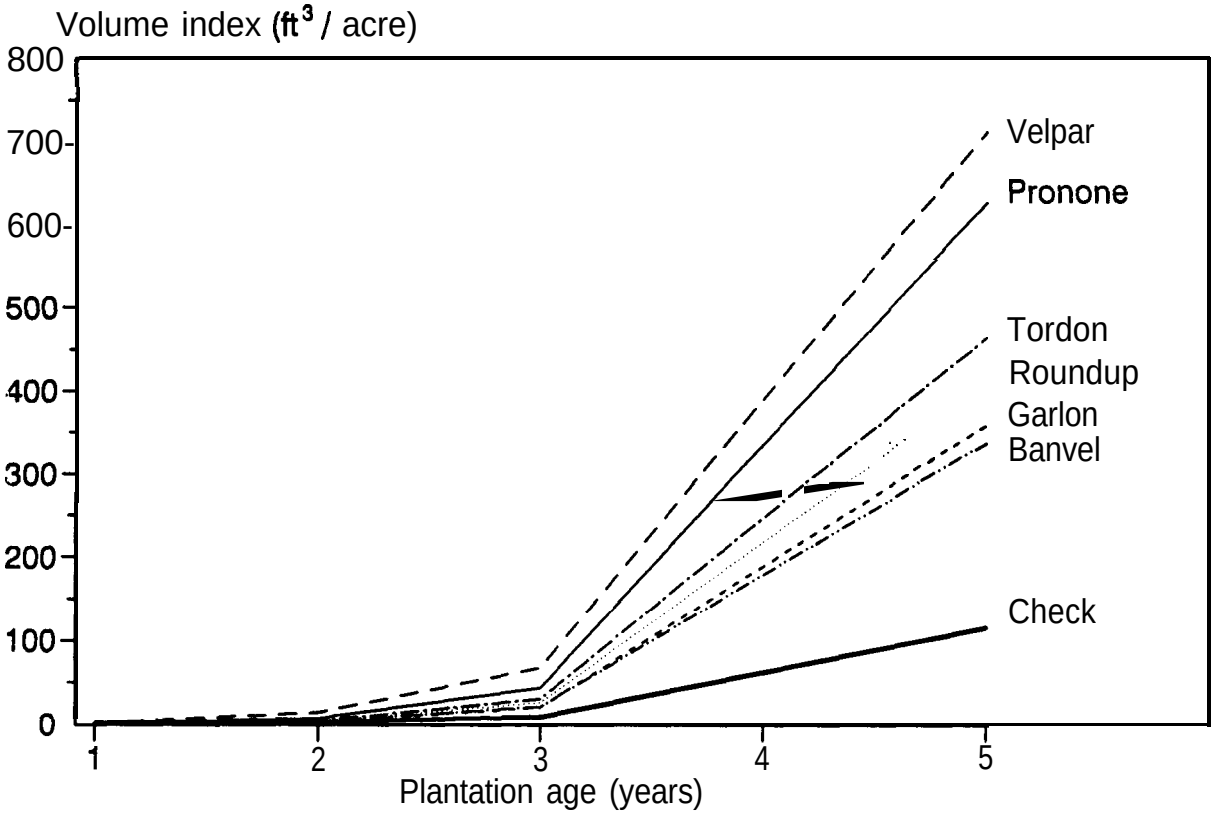

Figure 1 .--Loblolly pine volume index (using g.l.d.) after herbicide site preparation treatments.

Table 3-Pine release: mean cover estimates and the amount of bare ground (percent) in October of the growing season following treatment

Treatment	woody cover	Grass cover	Forb cover	Vine cover	Bare-ground
Arsenal	12 c[a]	26 bc	41 a	4 a	14 ab
Pronone	30 ab	46 ab	10 b	12a	13ab
Velpar	25 bc	46 ab	15 b	10 a	15ab
MCI 2/3	38 ab	27 bc	14 b	17a	19 a
MCI 3/4	38 ab	41 ab	19 b	14a	9 ab
Oust+Velpar	37 ab	39 ab	7 b	24 a	11 ab
Roundup	23 bc	18 c	44 a	4a	17ab
Check	42 a	50 a	15 b	6a	5 b
ROOT MEAN SQUARE ERROR	10.2	12.7	12.5	14.2	7.5

'Means in a column followed by the same letter are not significantly diierent at the 0.05-level of probability as determined by Duncan's Multiple Range test.

Pine survival was often reduced by release treatments, with Velpar causing the most mortality--an average 37-percent decrease compared to the check (table 4). Velpar toxicity was most pronounced at the higher-rate sites, 2.5 to 4.5 qt/acre, at Davis, Robinson, and Duggins. Seedlings at the Davis site were most exposed to direct application of herbicide because of the scattered amounts of hardwood competition, resulting in only 27 percent survival. Most herbicides caused some degree of pine toxicity, as evidenced by survival values at particular sites (table 4).

Table 4.-Release treatments: percent survival by location at the end of the growing season of treatment

Treatment	Coastal Plain		Piedmont		Mean'
	Patton	Duggins	Davis	Robinson	
Arsenal	97	93	74	97	87 a
Pronone	84	86	73	56	74 a
Velpar	83	59	27	58	55 b
MCI 2/3	89	86	89	93	88 a
MCI 3/4	88	64	78	83	74 a
Oust+Velpar	91	78	91	94	84 a
Roundup	90	85	76	87	83 a
Check	100	89	97	94	91 a
ROOT MEAN SQUARE ERROR	12.1				

Weans in a column followed by the same letter are not significantly different at the 0.05-level of probability as determined by Duncan's Multiple Range test

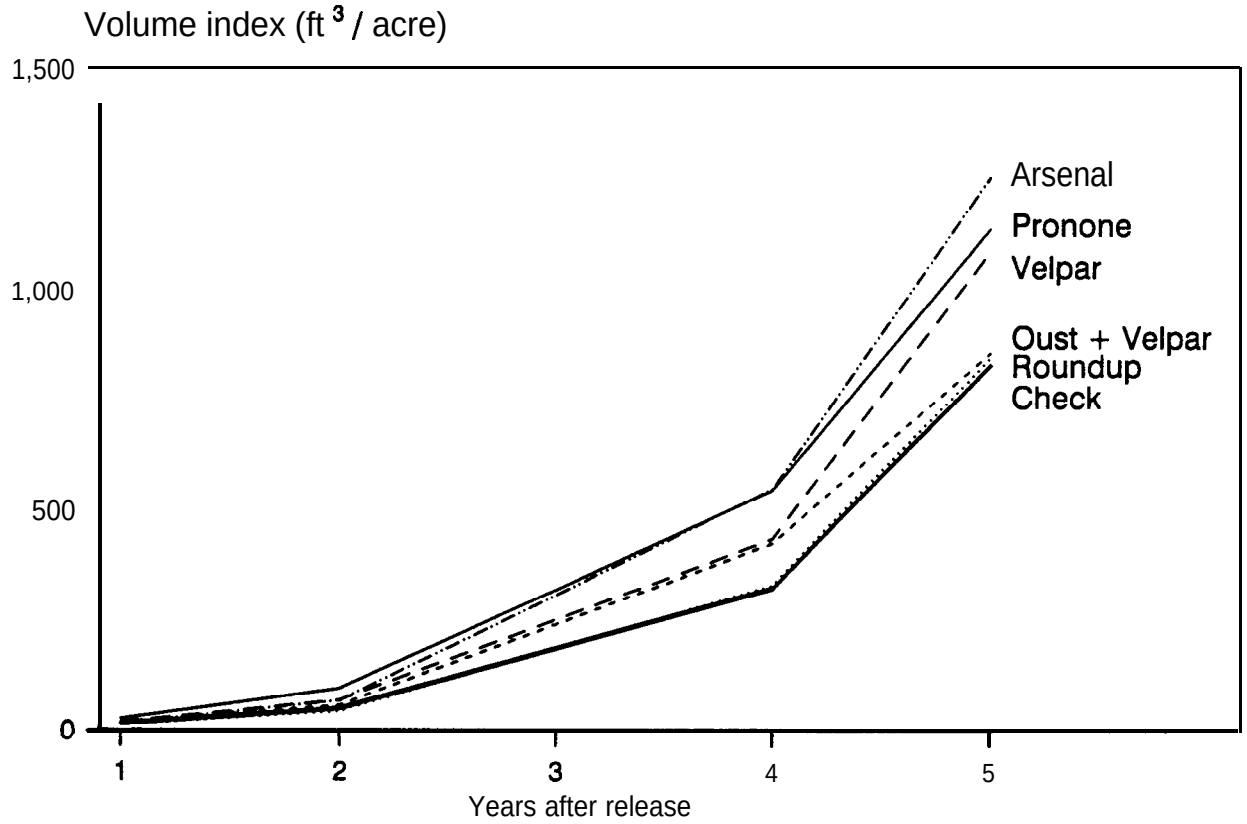

Figure 2.--Loblolly pine volume index (using g.l.d.) after herbicide release treatments.

The response to over-the-top release treatments is the combined result of phytotoxic injury, recovery time, and growth increase prompted by competition control. Pine growth response also varies according to the timing and degree of herbaceous and woody competition control (Miller and others 1991). Because of these different influences, pine response is more variable after release treatments than after pre-planting site-preparation treatments (compare Figures 1 and 2).

Arsenal and Pronone release treatments produced greater volumes at 4 FGSAT than the Roundup and check treatments (table 5) and greater volumes at 5 FGSAT than all other treatments (table 6). The highest yielding treatments varied widely by location. In

Table 5.--Release treatments: volume index ($ft^3/ac.$, using gld) by location, four full growing seasons after treatment (seven growing seasons after planting)

Treatment	Coastal Plain		Piedmont		Mean'
	Patton	Duggins	Davis	Robinson	
Arsenal	180	943	318	740	546 a
Pronone	141	1,308	372	346	542 a
Velpar	232[b]	941	236	322	433 ab
MCI 2/3	135	644	669	354	450 ab
MCI 3/4	228	612	656	222	429 ab
Oust+Velpar	118	692	448	434	423 ab
Roundup	111	637	172	398	330 b
Check	88	705	171	323	322 b
MEAN	154	810	380	392	
ROOT MEAN SQUARE ERROR	179.1				

'Means in a column followed by the same letter are not significantly different at the 0.05-level of probability as determined by Duncan's Multiple Range test.
[b]A double underline highlights the greatest pine growth on a location and a single underline highlights the second-greatest growth

Table 6.--Release treatments: volume index ($ft^3/ac.$, using dbh) by location, five complete growing seasons after treatment (eight growing seasons after planting)

Treatment	Coastal Plain		Piedmont	Mean'
	Patton	Duggins	Robinson	
Arsenal	128[b]	1,409	1,084	874 a
Pronone	95	1,808	588	831 a
Velpar	182	1.186	459	609 b
Oust+Velpar	49	'963	534	515 b
Roundup	a3	794	687	522 b
Check	38	1111	556	569 b
MEAN	95	1212	651	
ROOT MEAN SQUARE ERROR	179.1			

"Means in a column followed by the same letter are not significantly different at the 0.05level of probability as determined by Duncan's Multiple Range test.
[b]A double underline highlights the greatest pine growth on a location and a single underline highlights the second-greatest growth.

general, the control of only herbaceous vegetation using the Oust + Velpar mixture produced no significant growth increases by 4 and 5 FGSAT. Similar to the site-preparation test, overall growth was best on a Coastal Plain site (Duggins) and the least on the Sandhill site (Patton tract).

At all locations except the Patton Sandhill tract, one or more treatments produced pine growth that was no better than the checks. This indicates that the selection of the best herbicide is more critical for release than for site preparation, where all but one treatment produced better than the checks. Also, timing of application relative to pine growth flushes is critical. The poor performance of the Roundup treatment must be partially due to the fact that August rains after a dry, early summer resulted in abundant growth flushes just before the September 1 applications, Most new terminal and lateral leaders were killed.

CONCLUSIONS

Both site-preparation and release treatments increase pine volume growth on intensively harvested lands when the correct herbicide is prescribed and applied at the optimum time. Both treatments, when properly done, should be profitable investments as well (Busby and others 1993). It is clear that pine can grow faster after site preparation treatments than after release and thus site preparation is projected to yield greater economic returns (Busby and others 1993).

Futhermore, the lower rates of herbicide treatment used for release did not significantly alter the plant community and floristic diversity or adversely affect wildlife habitat 7 years after treatment (Boyd and others 1994). It is assumed that the higher rate site-preparation treatments respond similarly, but further study of the floristic changes are needed.

ACKNOWLEDGMENT

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A REGIONAL PERSPECTIVE OF THE PHYSIOGRAPHIC PROVINCES OF THE SOUTHEASTERN UNITED STATES'

J.H. Miller and K.S. Robinson'

Abstract-A landscape classification system using defined units for physiography, landform, and soils is needed to organize ecological information and to serve as an aid for landscape management. To assist this effort, a composite physiographic map is presented for 12 southeastern states. The physiographic classification system and maps for five states were devised by a committee formed in the early 1970's through the Society of American Foresters, directed by Earl Hodgkins, Auburn University. Maps were prepared by state teams delineating physiographic provinces, regions, and subregions-forest habitat regions. The five state maps were combined and the province delineations extended to the surrounding states using information from topographic, geologic, and soil maps for states and counties. The system is a refinement of the traditional physiographic provinces that have been recognized in the Southeast for some time.

INTRODUCTION

Southeastern forests grow on a repeating spatial mosaic of soils across landform patterns unique to physiographic provinces. The patterns are created through the perpetual dynamics of climate moving across varying geology to create landforms and soils that support an evolving vegetation. Within human life spans, vegetation and weather change while geology, landform, and soil are more permanent as classifiers. By using a classification system that recognizes different landscape units, ecological information can be placed and viewed in scales of interest to aid in landscape management.

This paper introduces a complete-coverage, concise physiographic map for 12 southeastern states. The map is based upon a system of landscape classification that can be used to organize ecological and silvicultural research findings. The map and system may be useful for introducing visitors and students to the Southeastern Forest Region.

The physiographic (or geomorphic) regions of the United States have been long recognized, but an accurate depiction in a regional map has been only possible with the advent of aerial photography and satellite imagery (Miller and Golden 1991). Physiographic provinces of the Southeastern United States were recognized as early as 1705 (White 1953), with preliminary maps as early as 1895 by Major Joseph W. Powell (shown in Thornbury 1965). A comprehensive map with approximate boundaries was produced by a committee of the Association of American Geographers, chaired by N.M. Fenneman, and reported at the 1916 annual meeting. Fenneman (1938) went on to write the widely recognized book, *Physiography of Eastern United States,* describing the provinces. The subject was revisited and the information updated in comprehensive detail by Thornbury (1965), although without a map. These works mainly focused on the wealth of geological data amassed early in this century. However, little information was available that linked surficial geology to soils and vegetation. One notable exception was the publication in 1911 of forest *Physiography* by Isaiah Bowman, who devoted considerable space to discussing the interaction of climate and soils with vegetation.

SOURCES OF MAP INFORMATION

The natural ties between forest communities and physiography-geomorphology stimulated foresters to undertake defining the physiography of the Southeastern region. An organized effort was conceived in the 1960's by Earl Hodgkins, Auburn University Department of Forestry, and coordinated with the assistance of W.F. Miller, Mississippi State University Department of Forestry. A committee of researchers from the southern states was formed under the Southern Forest Environment Research Council through the Society of American Foresters.

The classification system was developed by Hodgkins (1965) and initially summarized in *Southeastern forest* habitat regions based on *physiography.* The classification system is based on physiography that delineates uniformities that result from the interaction of geomorphology (i.e., geology and landform) and climate (e.g., increased rainfall and cooling with increases in elevation, lengthened growing seasons

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with decreased latitudes, etc.). The major classification units are province (e.g., Piedmont Province), habitat region (e.g., Piedmont Foothills Region), and habitat subregion (e.g., Upper Foothills). Regions and subregions represent finer subdivisions primarily of geomorphology.

Maps showing "forest habitat regions" were prepared for five cooperating states and overlaid on Landsat multi-spectral scanner imagery at a scale of 1:1,000,000. States with published maps and unit descriptions are Alabama and Mississippi (Hodgkins and other 1976, 1979), Louisiana (Evans and others 1983), Georgia (Pehl and others 1985), and South Carolina (Myers and others 1986). Further, physiographic provinces were identified for North Carolina and discussed relative to this system (Cheshire 1982). In addition, the provinces of Florida and the Sandhills of Georgia were presented by Hodgkins (1965) and have been incorporated with verification and details from USDA Soil Conservation Service (SCS) county soil maps.

To complete the province delineations for the 12 southeastern states, other sources of information were used. The Blue Ridge Mountain Province of Virginia was delineated from the Virginia base map (U.S. Geological Survey 1973) with the Piedmont and Coastal Plain boundaries taken from Virginia geological maps (Mixon and others 1989). The provinces of Arkansas were derived from the Geologic Map *of* Arkansas (Haley and others 1976) and county soil surveys. Provinces within the eastern forested areas of Oklahoma were defined from the Geologic *Map of Oklahoma* (Miser 1954) and *A Forest Atlas of the South* (Nelson and Zillgitt 1969). The province delineations of Tennessee came from Smalley (1986). State soil maps formed the base for eastern Texas (Godfrey and others 1973). Final details came from available SCS county soil surveys.

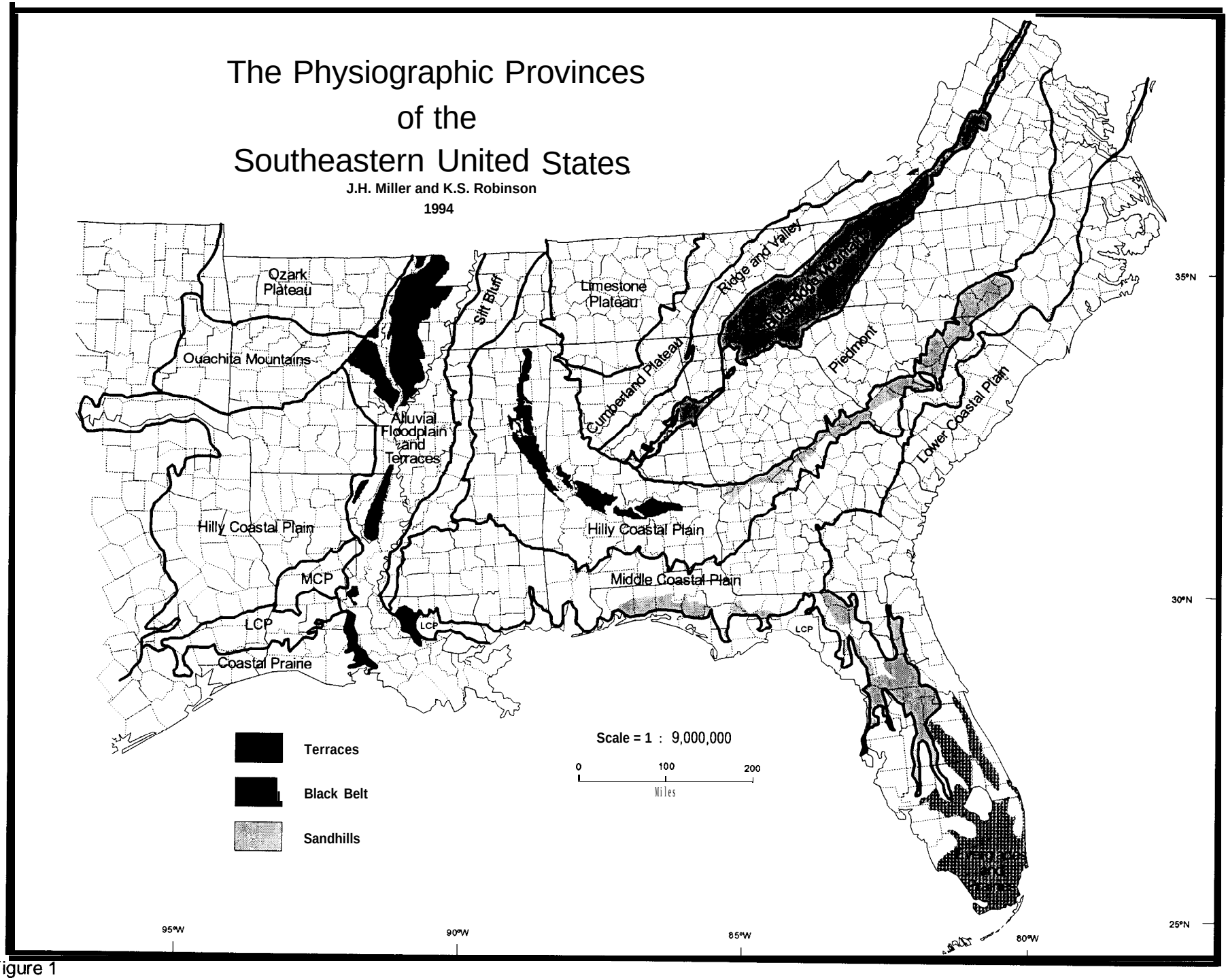
Province names mostly correspond to conventional physiographic provinces (Nelson and Zillgitt 1969) with more divisions of the coastal plain and some changes in nomenclature.
The provinces and selected habitat regions shown on the comprehensive physiographic map of the Southeastern United States, figure 1, are as follows:
Lower Coastal Plain Province (LCP)
    Everglades and Prairie Marsh Region
Middle Coastal Plain Province (MCP)
    Florida Sandhills Region
Hilly Coastal Plain Province (HCP)
    Sandhills Region
    Black Belt Region
Piedmont Province
Blue Ridge-Talladega Mountain Province
Ridge and Valley Province
Cumberland Plateau-Mountain Province
Limestone Plateau Province
Silt Bluff Province
Mississippi Alluvial Floodplain and Terrace Province
    Mississippi Terrace Region (shaded)
    Mississippi Alluvial Floodplain Region (non-shaded)
Coastal Prairie (Marsh) Province (Texas and Louisiana)
Ouachita Mountain Province
Ozark Plateau Province
The county delineations have been incorporated to aid in locating areas of interest.

Province names recommended by Hodgkins (1965) have been slightly modified according to what is perceived as traditional usage. Hodgkins' Flatlands Coastal Plain Province has been changed to Lower Coastal Plain Province, which is also commonly referred to as the Flatwoods Coastal Plain. (The "flatwoods" name is reserved to denote habitat regions and subregions in both the Lower and Middle Coastal Plain Provinces.) His Great Appalachian Valley Province has been changed to the Ridge and Valley Province. Deep Loess Province has been changed to Silt Bluff Province. Usage of these terms may evolve, but consistency should be sought. Provinces that are not directly shown on the map, but should be recognized are the extensive Alluvial Flood Plain and Terrace Province(s) (shown only for the Mississippi River) and the Coastal Marsh and Island Province(s) (shown only for Texas and Florida).

Soil series represent a finer logical unit for site characterization and research reporting, derived from available SCS county soil surveys. It is recognized that finer descriptors for taxonomic soil series are required to delineate differences in forest site quality, engineering considerations, and habitat (Van Lear 1991). Other mid-units, above soil series, have been developed or are proposed within this classification system, i.e., land type, land subtype, and habitat type (Hodgkins and others 1979, Miller and Golden 1991). Maps have not yet been prepared for these. Other finer delineations using landform (drainage) have been defined for the Limestone Plateau and Cumberland Plateau Provinces (Smalley 1982, 1984, 1986, 1991), the Blue Ridge Province (McNab 1992), the Lower Coastal Plain Province of Florida (Fisher 1981), and the state of South Carolina (Jones 1991).

LANDFORM

As a third-dimensional supplement to figure 1, the relative progression of elevational changes and general landform shapes within provinces are shown in figure 3 for transects indicated in figure 2. These cross sections were drawn using topographic maps of individual states having 200-ft contour intervals, with the exception of Louisiana, which had 50-ft intervals. The greater detail afforded by the 50-ft contours is evident for the extensive coastal plains of Louisiana. These cross-sections show that the Lower Coastal Plain in Louisiana has more elevational relief than in Florida and


The Physiographic Provinces
of the
Southeastern United States
J.H. Miller and K.S. Robinson
1994
Ozark Plateau
Ouachita Mountains
Alluvial Floodplain and Terraces
Hilly Coastal Plain
MCP
LCP
Coastal Prairie
Sfft Bluff
Limestone Plateau
Ridge and Valley
Blue Ridge Province
Cumberland Plateau
Piedmont
Lower Coastal Plain
Hilly Coastal Plain
Middle Coastal Plain
LCP
LCP
LCP
Terraces
Black Belt
Sandhills
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80°W

Figure 1

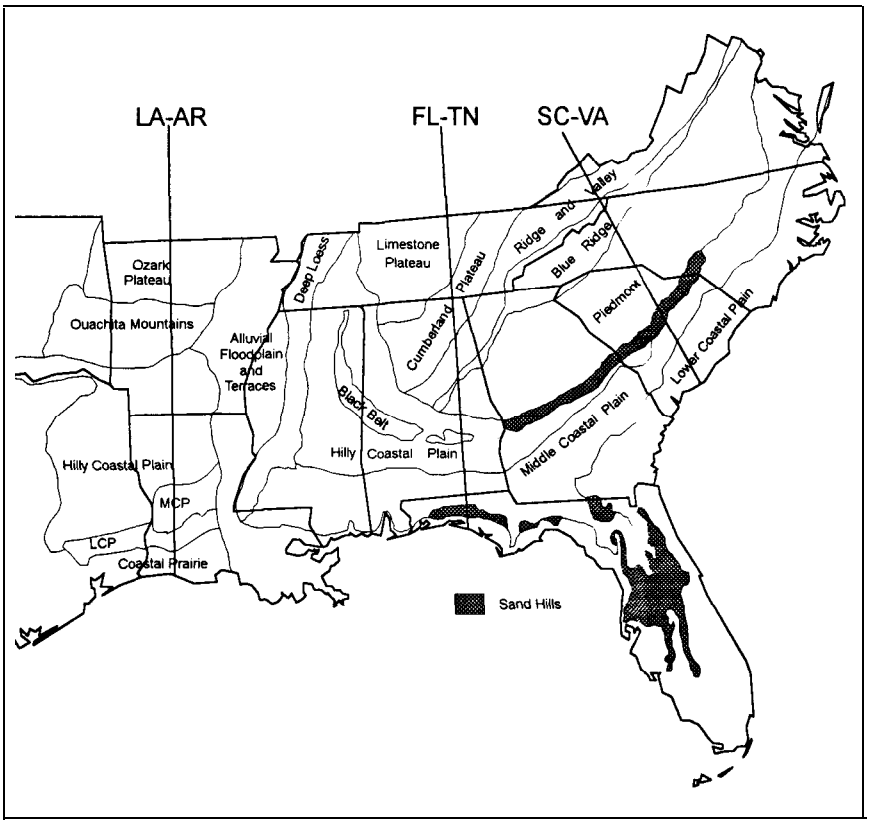

Figure 2.--Cross-sectional relief transects shown in figure 3.

Table I-Physiographic provinces, their range in elevation, age of soil-forming parent materials, and predominate type of rocks

Province	Elevation range	Age of parent material	Type of rocks
	(ft)	(million yrs)	
Lower Coastal Plain	< 100	< 2	Unconsolidated water-, ocean-, and wind-deposited sediments.
Middle Coastal Plain	75-600	2-5.5	Same as above.
Hilly Coastal Plain	100-800	5.5-22	Same as above.
Piedmont	200-I ,200	200-600+	Varying zones of deeply weathered metamorphic rocks with lesser areas of sedimentary and igneous rocks.
Blue Ridge and Talladega Mountains	1,200-6,684	500+	Uplifted metamorphic and igneous rocks (and sedimentary along western edge) with wide aprons of colluvium.
Ridge and Valley	ridges 1,000-4,500 valleys 400-I ,400	500+	Folded and tilted sedimentary rocks with sandstone ridges and limestone valleys with wide aprons of colluvium.
Cumblerland Plateau	800-3,200	270-320	Horizontal layers of sandstone, shale, and limestone sedimentary.
Limestone Plateau	500-1,100 (2,100 exception)	320-340	Consolidated sedimentary.
Silt Bluff	100-400	0.01-0.125	Wind blown silt from glacial outwash plains.
Mississippi Alluvial Floodplain and Terraces	floodplain <400 terraces 100-400	recent 0.01-0.125	Sand, silt, and clay alluvium; and wind-blown silt terraces.
Ouachita Mountains	200-2,700	500+	Folded and tilted sedimentary rocks with sandstone ridges and limestone valleys with wide aprons of colluvium.
Ozark Plateau	800-2,200	500+	Horizontal layers of sandstone, shale, and limestone sedimentary.

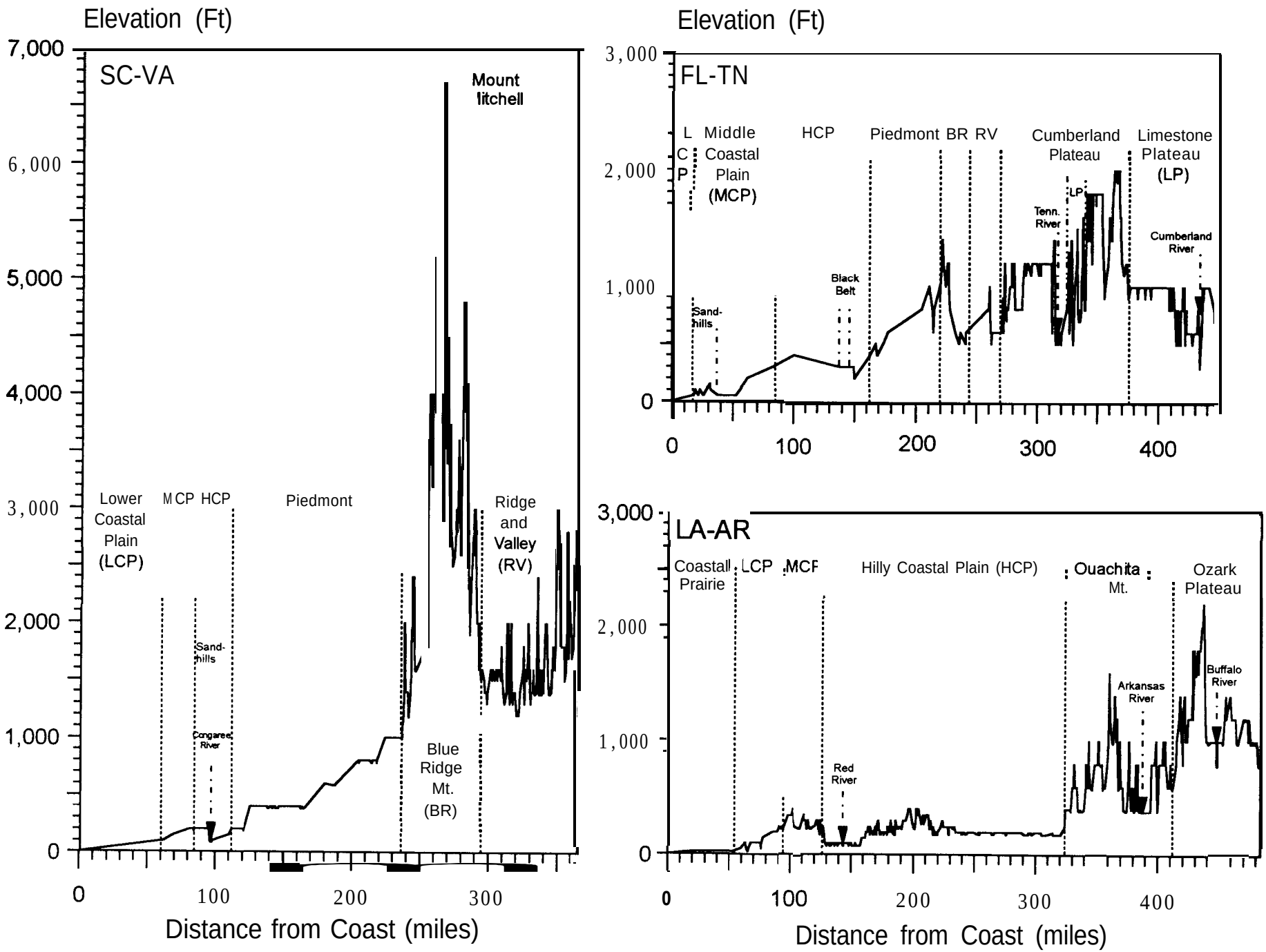

Figure 3.--Cross-sectional relief of the following transects: SC-VA, from the coast of South Carolina, through North Carolina, Tennessee, and Virginia; FL-VA, from Florida coast through Alabama and Tennessee; and LA-AR, from the Louisiana coast through Arkansas.

South Carolina. Elevational ranges within provinces and the geologic parent material for soil formation and its age are summarized in table 1.

The greatest range in elevation within the Southeast is shown in figure 3 SC-VA with the cross-section through South Carolina, North Carolina, and Virginia. Elevations range from zero at the coast up to 6,684 ft at Mount Mitchell, the highest point in the United States east of the Mississippi River. Some of the highest yearly precipitation with the coolest temperatures and shortest growing seasons are associated with the Blue Ridge Mountain Province, due to the orographic effect.

It is evident that the landforms found in the Ridge and Valley Province have comparable traits to the Ouachita Mountain Province, and may have similar geologic origins (Thornbury 1965). One interesting feature shown in figure 3 (FL-TN) is an inclusion of Limestone Plateau (LP) as a narrow band within a portion of the Cumberland Plateau (i.e., the Sequatchie Valley). This is an example of an area that was too small to delineate in figure 1.

SOILS

Previous reports have presented maps and discussions of the soils in the Southeastern United States (Nelson and Zillgitt 1969, Buol 1973) and generalities will be discussed here relative to physiography. Each physiographic province has a suite of soils. Some are unique to a province, while some are shared with other provinces as is the case with the coastal plain provinces. Many of the soil forming forces--climate, geologic material, biotic organisms, relief, and time--- are similar between adjacent provinces.

The influence of time has varied by province and habitat regions within provinces (table 1). Erosional processes have been working on the mountains and uplands including parts of the Piedmont for over 500 million years. About 250 million years ago the Blue Ridge Mountains were comparable in elevation to the Rocky Mountains. While only 54 million years ago, the warm sea that eventually formed the coastal plains was at the “Fall Line” at the base of the Piedmont and at the lower slopes of the Ouachita Mountains and Ozark Plateau. With the fluctuating subsidence of the sea and rise of the unburdened land, the coastal plains were successively formed through upland erosion and coastal deposition starting about 22 million years ago.

Over the last 2 million years, during earth’s latest ice age, sea level has fluctuated during the 40+ advances and retreats of glaciers, alternately exposing and inundating expanses of the Lower Coastal Plain and continental shelf. During this period, windblown glacial outwash was deposited to form the Silt Bluff and River Terraces of the Mississippi River, which are some of the youngest inland geology. Presently, the Coastal Marsh and Island Province(s) is gradually being flooded during the current interglacial age (the last 20,000 years), while coastal deposition continues or has been accelerated due to human disturbance (Pielou 1991). For the most part, the climate of the Southeast has fluctuated between temperate to tropical over the last 200 million years; remarkably remaining within similar latitudes as today, even as the mega-continent, Pangaea, broke-up and drifted apart (Conkle 1992). Presently, the Southeast is in the subtropical climatic domain except for the southern tip of Florida, which is tropical (Bailey 1983).

Because of the warm humid climate, lengthy weathering period, and minerals in the parent rock, the dominant soils of the region are *Ultisols* (Nelson and Zillgitt 1969, Buol 1973)---well-developed, highly weathered soils with distinct horizons. Exceptions are:

a. Alluvial Floodplain Province, mostly *Inceptisols* and *Entisols*, i.e., relatively young soils with no or weakly differentiated horizons.
b. Silt Bluff Province and Mississippi Terrace Region, mostly *Alfisols*, i.e., soils that are medium or high in bases with gray to brown surface horiions and subsurface horizons of clay accumulation.
c. Lower Coastal Plain of Florida, mainly *Entisols, Histosols*, i.e., wet organic peat and muck soils, and *Spodosols,* i.e., soils low in bases that have a subsurface horizon of accumulated organic matter and compounds of aluminum and iron.

The extensively-formed *Ultisols* have red-to-brown clayey subsoils below sandy or loamy surface soils. These soils are acid and relatively infertile, because the clays are the type that retain few nutrients. Eastern coastal plain soils from Virginia to Alabama have clays that are dominantly kaolinite and vermiculite, while those from Mississippi, Arkansas, and Texas consist of montmorillonite, chlorite, and illite in addition to the kaolinite and vermiculite (Fiskell and Perkins 1970). Kaolinite and vermiculite retain less nutrients than montmorillonite, chlorite, and illite. In general, soil nutrient retention is by the accumulated organic matter fraction in the surface and subsurface horizons (Wallace 1994). Coastal plain soils increase in nutrient holding capacity as pH increases. This pH-dependent, nutrient- holding capacity arises from soil organic matter and presumably from the highly weathered clays.

Soils in the mountainous Blue Ridge, Ouachita Mountain, and Ozark Plateau Provinces have formed over 500 million years (Thornbury 1965). Few, if any, have formed in place on level surfaces, because of erosive forces. The pattern of soils depend upon landform and whether they are derived from residual or transported parent material. Residual soils occur more towards ridge summits, while colluvial soils increase down slopes, grading into alluvial soils near water courses. But even on broad mountain tops in the Blue

Ridge Province, streams with flood plains and terraces can be found with alluvial soils as also occur in the well-formed valleys between mountain ridges. The cooler, wetter climate of mountains result in typically more fine-loamy textured soils compared to the clayey textured soils that dominant provinces at lower elevations.

Soils of upland Piedmont sites are primarily *Ultisols*, with *Alfisols* in localized areas. Most are residual soils, having weathered in place for greater than 600 million years from underlying materials. In general, in this province, forest site productivity increases with increasing depth to a clay-textured horizon (Hodgkins 1965).

The marine sediments of gravel, sand, silt, clay, and chalk that underlie the Hilly Coastal Plain Province were deposited at a time when the shoreline was located along the Fall Line (table 1). Along the eastern-part of the Fall Line, soils of the Sandhills Region were formed in thick beds of marine sands and have minimal profile development. In the Black Belt Region (also called the Black Prairie), that extends across northeastern Mississippi and central Alabama, dark-colored soils with about neutral pH are formed in chalk deposits.

The Middle Coastal Plain Province is a transition zone between the Hilly Coastal Plain and the Lower Coastal Plain Provinces. Soils developed from marine deposits of gravel, sand, and clay, that are geologically younger that those in the Hilly Coastal Plain Province and older than those of the Lower Coastal Plain Province (table 1). The Middle Coastal Plain Province is characterized by flat to rolling topography and generally coarse-textured soils. Regions within this Province reflect the composition of the original sediments and are delineated by parallel bands of low-lying ridges. A predominant ridge system is the Southern Loam Hills Region, which extends as a belt from Virginia to Louisiana. Because the marine terrace sediments of the Middle Coastal Plain Province have been exposed for a relatively long time, the land surface is moderately well dissected by a dendritic drainage pattern. The moderately dense drainage pattern is better developed than in the Lower Coastal Plain Province, but less dense than in the Hilly Coastal Plain Province.

The Lower Coastal Plain Province (often referred to as the flatwoods coastal plain) is characterized by flat to undulating topography, high water tables, and generally coarse sandy soils, except where broken by areas of extensive swamp lands containing mostly organic soils. Soils were developed from marine deposits over the last 2 million years. All of the province was intermittently covered by shallow coastal waters during the receding periods of northern glaciation that ended only 20,000 years ago. Regional delineations are a result of the differences in the ages and elevations of old shoreline-related landforms. One of the most unique regions is the Everglades and Prairie Marsh Region in southern Florida that contains the Everglades, Big Cypress Swamp, and Lake Okeechobee (Thornbury 1965). This is a region of recently formed organic soils. Trees only grow on hammocks or "tree-islands", which are separated from each other by water areas and are oriented according to the direction of drainage.

The extensive flood plains, river and stream terraces, bogs, marshes, and the margins of lakes and ponds have generally younger and different soils than in the surrounding uplands, and also present unique habitat features vital to specialized life-forms such as neotropical birds (Hunter and others 1992).

PLANTS

Some plant species tend to be associated with specific provinces, while many are not confined owing to the uniform climate that characterizes much of the Southeastern Forest Region (Nelson and Zillgitt 1969). The high elevations of the Blue Ridge Mountain Province harbor the most unique assemblage of plants and animals as does the deep valleys of the Cumberland Plateau. Commonly shared species characterize much of the flora in the Piedmont, Hilly and Middle Coastal Plain Provinces, while more constrained species are found in the Lower Coastal Plain.

Examples of tree species not constrained and constrained by physiographic province boundaries are as follows (Harlow and Harrar 1958, Brown and Kirkman 1990):

Not Constrained

Occur across all provinces except along the lower Mississippi River and South Florida:

Acer rubrum L.	red maple
Fagus grandifolia Ehrh.	American beech
Carya cordiformis (Wang.) K. Koch	bitternut hickory
C. *glabra* (Miller) Sweet	pignut hickory
Cornus florida L.	flowering dogwood
Ilex opaca Aiton	American holly
Morus rubra L.	red mulberry
Nyssa sylvatica Marshall	blackgum
Pinus taeda L.	loblolly pine
Quercus alba L.	white oak
Q. *falcata* Michaux	southern red oak
Q. *marilandica* Muenchh.	blackjack oak
Q. *stellata* Wangenh.	post oak

Constrained

Occur within limits of physiographic provinces:

Abies fraseri Miller	Fraser fir	Only in Blue Ridge Mountains.
Picea rubens (Du Roi) Link	red spruce	Only in Blue Ridge Mountains.
Tsuga caroliniana Engelm.	Carolina hemlock	Only in Blue Ridge Mountains.
Pinus pungens Lamb.	table mountain pine	Only in Blue Ridge and scattered monadnocks.
P. rigida Miller	pitch pine	Only as far south as Blue Ridge of GA and SC.
P. strobus L.	eastern white pine	Only as far south as Blue Ridge of GA and SC.
P. virginiana Miller	Virginia pine	Occurs as far SW and W as Talladega Range, Ridge-Valley, Cumberland Plateau, and Limestone Plateau.
Quercus prinus L.	chestnut oak	Not in coastal plains (CP).
C?. *nigra* L.	water oak	Everywhere except in Blue Ridge.
Q. *shumardii* Buckley	shumard oak	Everywhere except in Blue Ridge.
Celtis laevigata Willd.	sugarberry	Everywhere except in Blue Ridge.
Pinus palustris Miller	longleaf pine	South of upper boundary of Hilly CP in NC.
P. serotina Michaux	pond pine	South of upper boundary of Hilly CP in GA, SC, NC, and VA.
Taxodium ascendens Brongn.	pondcypress	South of upper boundary of Hilly CP in GA, SC, and NC.
Pinus elliottii Engelm.	slash pine	South of upper boundary of Middle CP.
Quercus laurifolia Michx.	laurel oak	Only in CP.
Q. *incana* Bartram	bluejack oak	Only in CP.
Q. *laevis* Walter	turkey oak	Only in eastern CP.
Nyssa *sylvatica* Marsh.	black tupelo	Only in CP.
Pinus echinata Miller	shortleaf pine	Everywhere except in Lower CP in MS, AL, and GA.
Juniperus virginiana L.	eastern redcedar	Everywhere except in Lower CP.
Carya ovata (Miller) K. Koch	shagbark hickory	Not in Lower CP except in LA and TX.
Taxodium distichum (L.) Rich	baldcypress	Only in CP, Silt Bluff, and Alluvial Floodplains of major rivers that flow from the Ouachita Mountains and Limestone Plateau.

Less information has been published regarding the physiographic range of the 500+ species of shrubs and 3,000+ species of herbaceous plants growing within the Southeastern United States.

MAP AND SYSTEM USES

Hodgkins (1965) envisioned using the physiographic classification system as: (a) a guide for selecting sampling strata whenever site or habitat are experimental variables, (b) a framework for local site classification, and (c) a logical context for reporting research results. The last use appears to be extremely pertinent now as ecological (and management) information gathering increases. Research sites could be categorized by province, region, subregion, landform position, and soil series to define a scope of inference for research results. This is now possible for the five states-South Carolina, Georgia, Alabama, Mississippi, and Louisiana--with maps delineated to the subregion level. Copies of these maps and unit descriptions are available from the Agriculture Cooperative Extension Service of each state. Figure 1 will permit province delineation for the remaining seven southeastern states and can be used in conjunction with available county soil surveys and/or other land classification systems (e.g., Smalley 1986) to classify sites. The map was constructed in Lotus Freelance Graphics version 2.0 for Windows and a diskette copy of the map is available from the authors.

An example of site specification would be as follows:

State: Alabama
Province: Hilly Coastal Plain Province
Region: The Upper Loam Hills Region
Subregion: The Loam Hills Border Terraces
Landform: upper slopes and ridge tops
Soil series: Cowarts loamy sand, 6 to 10 percent slope fine-loamy, siliceous, Thermic Typic Hapludults

The further division of coastal plain provinces into Atlantic, East Gulf, or West Gulf can be used, because it is evident that climate and soils do vary by these subdivisions (Nelson and Zillgitt 1969). The reporting of the past land-use practices also characterizes site quality and determines ecological response (Van Lear 1991).

Further refinements are needed to delineate and define units to the subregional level in the seven states not yet completed and further refinements to this system will continually be warranted. As ecological land classification develops (Bailey 1983), physiographic units should naturally comprise a middle tier of

categorization and still will remain useful. As researchers and managers continue to obtain and utilize more information pertaining to southeastern ecosystems, it becomes more critical that common terminology be used in order to improve understanding and decrease confusion. Adoption and use of common physiographic landscape nomenclature would benefit us all as we begin to manage ecosystems and restore landscapes.

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EFFECT OF HARVEST METHOD ON NUTRIENT RESOURCES IN SAND PINE SCRUB'

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Abstract—Ocala sand pine, *Pinus clause* var. *clausa* D.B. Ward, scrub grows on relatively poor sandy soils with low nutrient reserves. A windrow tree-length harvest system with limbing spread across the site and a full-tree harvest system using limbing gates at strategic locations were compared. With the limbing gate system 66 percent of the crown material is concentrated in a few large piles with nutrients unavailable to most of the area. Nitrogen reserves and inputs are sufficient to sustain both harvest systems for some time. Phosphorus losses however, could decrease site productivity with the full-tree limbing gate system because of the losses from removal of crown material.

INTRODUCTION

Sand pine, *Pinus clausa* (Chapm. ex Engelm.) Vasey ex Sarg., is a major component of the scrub native to sandhills sites of Florida and Baldwin County, Alabama. The largest concentration of the Ocala variety grows in the center of Florida on an area of rolling sandhills known as the Central Highlands. The Choctawhatchee variety, *P. clausa* var. *immuginata* D.B. Ward, is found along the Gulf Coast of northwest Florida from the Apalachicola River westward into Alabama (Little, 1979). Although a minor southern pine, sand pine is important in Florida where it is the dominant tree species on approximately 1.2 million hectares (Eyre, 1980).

Scrub grows on sandy marine deposits formed as dunes, bars and spits, mostly during the Pleistocene epoch of fluctuating sea level. These sandhills have infertile soils consisting largely of deposits of quartz sands, ranging from a meter to more than 7 meters deep. Organic matter content is low because the climate promotes rapid oxidation. Because of the low levels of organic matter and of clay colloids, cation exchange capacities, and thus nutrient retention, of these soils are low (Burns and Hebb, 1972). Poor sites, like these deep, infertile sands and shallow soils over bedrock, have the greatest immediate potential for site productivity declines due to whole-tree harvesting (Boyle et al. 1973, Green and Grigal 1980, Jorgensen et al. 1975, Waide and Swank 1976, Weetman and Weber 1972). The objective of this study was to determine the nitrogen and phosphorus losses from sand pine scrub harvested by two different methods.

METHODS

Nutrient removals were evaluated based on two harvest systems routinely used for sand pine (Outcalt 1988). With the full-tree limbing gate system, although only the bole is used, the entire tree is removed and limbs are removed at a few convenient locations leaving the crown in a few large piles. Samples were collected across a typical 40 hectare site harvested by this method on the Ocala National Forest, Florida. The 50 year old stand that was harvested had 530 sand pine per hectare with an average diameter of 16.75 cm and an average height of 12.9 m. Based on the distribution of biomass in sand pine trees (McNab et al. 1985) the stand should have contained 11,000 kg/ha of crown material.

The windrow system is a tree-length method removing only the bole. Limbing, however is done after the trees are gathered in windrows spread across the entire harvest area. Samples were collected from two sand pine stands age 37 and 42 years with 435 trees/ha, average diameter 17.5 cm, and average height 13.1 m. Based on stand data there was 10,200 kg/ha of crown material in these stands prior to harvest.

All fresh crown material was collected immediately after harvest from thirty randomly located 1 m square samples plots on each of the three sites. This fresh crown material was bagged, returned to the laboratory and dried at 65 °C and weighed. Nitrogen and phosphorus content of sand pine are based on samples collected from 60 Ocala sand pine trees harvested for an earlier study (Rockwood et al. 1987). Trees were selected in a stratified random system based on diameter distribution. Selected trees were felled and divided into stem and crown portions. The crown was further divided into three equal length sections of lower, middle and upper. Each section of the crown and the bole were weighed and subsamples were collected for dry weight and nutrient determinations. After drying, material was ground in a

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wiley mill. A subsample of each ground sample was taken with a riffle sampler for nutrient analyses. Nitrogen (N) was determined on 1 g samples by the micro kjedahl method and phosphorus (P) was measured with a spectrophotometer after dry ashing and dissolving in acid.

Potential nutrient losses or removals with these different harvest systems were estimated as follows. The average diameter and height of sand pine were inserted into the equations from McNab et al. (1985) to calculate the biomass of the various tree components. Crown and stem weights were then multiplied by the percent N and P for Ocala sand pine based on analyses of samples collected from the 60 trees. Lastly, these numbers were multiplied by the number of trees to estimate the amounts of N and P per unit area in the various portions of sand pine stands. Finally the potential removals under different harvest systems were calculated by adding the contents of N and P for the appropriate tree components together.

RESULTS AND DISCUSSION

Based on information from Brendemuehl(1968) estimated soil reserves of N and P for a typical sandhills soil are 3600 kg/ha of total N and 3.5 kg/ha of available P to a depth of 2 meters. Because there is little iron and aluminum in these sandy soils (Pritchett, 1979) most of the P is contained in the soil organic matter. The N to P ratio for sandy soils is 10:0.2 -- 0.4 (Russell, 1973) giving an estimate of 72 to 108 kg/ha for total P. Total P can alternatively be estimated by assuming that about 3 percent of the soil organic matter cycles each year to maintain the 3.5 kg/ha of available P, which gives an estimate of total P of 117 kg/ha.

Nutrient inputs are mainly from precipitation and dust. Total N inputs range from 1 to 2 kg/ha/yr in western locations (Sollins et al., 1980) to 13 kg/ha/yr at sites near major industrial centers (Henderson et al., 1978) and average about 5.6 kg/ha/yr in Florida (Burger, 1979). Phosphorus inputs are smaller but just as variable ranging from 0.1 in Ontario (Foster and Morrison, 1976) to 1 kg/ha/yr in Florida (Riekerk, 1981). Nutrients are removed from forest sites by water in either dissolved form or as sediments contained in runoff. Leaching typically removes only small amounts of elements from undisturbed forest systems (Fredriksen 1970, Riekerk et al. 1979). This is due to the internal conservative features of the forest. Although fair quantities of nutrients maybe leached from the forest floor, most are removed before the ground water has penetrated beyond rooting depth. Losses of nutrients by erosion and sediment removal are low in undisturbed forests. McColl and Grigal (1979) used data from various studies to derive estimated annual losses of N, K, Ca, and Mg of less than 0.1 kg/ha/yr. Since P is strongly adsorbed by soil particles, losses as sediment can be higher than in the dissolved form. However losses are still typically small at less than 0.2 kg/ha/yr (Duffy et al. 1978)

Dry weight of slash left on the full-tree limbing gate harvested site was 3,700 kg/ha. The rest of the crown material was concentrated at and adjacent to the three limbing and loading areas. Any nutrients in this concentrated crown material are now essentially unavailable. The two windrow tree-length harvested sites averaged 10,200 kg of crown material left on site. Although not distributed in an entirely even pattern, virtually all the crown was left on site where the nutrients will be available for use.

Based on the estimates derived by the above process (Table 1), harvest of sand pine from scrub sites should not cause a depletion of N reserves. Even with the full-tree limbing gate system, the atmospheric inputs are large enough to offset removals and result in an accumulation of nitrogen. The soil although poor does have a sizable nitrogen reserve. Assuming a turnover rate of only 1 percent per year, 36 kg/ha is available for use which should be adequate for estimated demands (Burger 1979, Gholz et al. 1985). Thus, either of the harvest systems with rotations of 35 plus years would not have nitrogen losses sufficient to reduce site productivity.

Table I--Effect of different harvesting systems on nitrogen balance in Ocala sand pine under 40 year rotation

	Windrow Tree-Length Chip	Full-Tree Limbing Gate Chip
	-kg/ha----	
Soil Reserves		
O-8cm	300	300
8-200cm	3300	3300
TOTAL	3600	3600
Harvest Removal	24	68
Atmospheric Input	224	224
Change after Harvest	+200	+156

A very different situation exists for phosphorus. There are few P containing minerals in the soil to weather and P inputs are small and balanced by outputs so soil reserves must essentially supply the needed P. The reserves of P in the soil are significantly smaller than N reserves (Table 2). It appears that with the full-tree limbing gate harvest system P reserves will eventually be sufficiently depleted to cause a productivity decline. Pritchett and Morris (1982) concluded that phosphorus may become limiting after only a few rotations in intensively managed slash pine plantations on phosphorus poor soils of the southeastern coastal plain.

Table 2-Effect of different harvesting systems on phosphorus balance in Ocala sand pine under 40 year rotation

	Windrow Tree-Length Chip	Full-Tree Limbing-Gate Chip
	-----kg/ha-----	
Soil Reserves		
O-8cm	9	9
8-200cm	91	91
TOTAL	100	100
Harvest Removal	1	5
Change after Harvest	-1	-5

Considering the above estimates of reserves and potential removals of P under different harvesting systems, precautions need to be taken to avoid a long term reduction in site productivity. This means replacing the full-tree limbing gate harvest system which concentrates crown materials and therefore nutrients in piles with systems like the windrow technique where the crown is left distributed across the site. The crown material, especially the needles, are a valuable source of organic matter and nutrients. Thus, as for lodgepole pine forests in the northern Rocky Mountains (Entry et al. 1987), management should foster conservation of organic matter on sand pine scrub sites.

In addition placing the branches and needles in large piles removes nutrients from most of the site and creates a few areas with abnormally high concentrations. This artificial distribution of nutrients on the site will impact the scrub vegetation. Weedy, opportunistic species will likely be favored on the highly disturbed and relatively nutrient rich areas where crown materials are concentrated. The long-term effect on the scrub vegetation of this abnormal distribution of nutrients is unknown but ecologically inadvisable.

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HEIGHT-DIAMETER RELATIONSHIPS OF DOMINANT TREES IN THE MIXED UPLAND HARDWOOD FORESTS OF NORTH ALABAMA'

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Abstract-The 15 dominant trees on each of 70 half-acre plots were utilized to evaluate the height-diameter relationships of 16 species found on three upland hardwood sites in the north Alabama. Regression analysis was performed using the linear model such that Height = $\beta_0 + \beta_1 \cdot$ (DBH). The species were placed into 5 groups: (1) Ash / Hickory, (2) Chestnut oak / Chinkapin oak, (3) Red oak / White oak, (4) Yellow poplar I Black cherry, and (5) minor species, based on the similarity of the intercepts and slopes of the regression lines. The coefficients of the model were estimated and residual analysis was conducted for each species group.

INTRODUCTION

There are about 13 million forested acres in Alabama, Tennessee and Kentucky known as the Interior Uplands (McGee 1982). Many of these stands are considered as "low-quality' hardwood sites due to repeated fires, insect and disease attack, and repeated cuttings. These hardwood stands have generally developed without any specific management or silvicultural activity, and often have high number of stems per acre but low basal area. The lower canopy layers are often dominated by species with little or no commercial value. The stands are also commonly found on sites with low to moderate site quality (McGee 1982). The Tennessee Valley of north Alabama is a typical region of "low-quality" mixed hardwood forests, containing a mixture of species with wide range of shade tolerance and growth rates.

However, these stands offer great opportunities and challenges for improving yields, regenerating desirable species, and providing great diversity and substantial wildlife habitat. Therefore, more studies are needed on site quality, species composition, tree competition, and effects of silvicultural treatments for the "low-quality hardwood stands in the Interior Uplands.

The objective of this study was to evaluate the dominant tree height-diameter relationships of major species in the mixed upland hardwood forests of the Tennessee Valley.

STUDY SITES AND METHODS

Three study sites were located in Monte Sano State Park and Redstone Arsenal, Madison County, Alabama and the Sipsey Wilderness, Bankhead National Forest, Lawrence County, Alabama. The upland sites were chosen to represent fully stocked stands of the mixed hardwood forests common to the region, and had no known management since stand establishment. The plots were placed between 800 and 1300 feet in elevation, and the soils were either Hartsell fine sandy loams, Smithdale sandy loams, Tidings-Banks Complex or Towley-Apison Complex (Sherard et al. 1959, Swenson et al. 1979).

Within these sites, 70 half-acre plots were randomly established. On each plot, 15 dominant trees were sampled for diameter at breast height (DBH) and total height (HT), and recorded by species. Dominance was defined as those trees with crowns extending above the general level of the canopy, larger than the average trees in the plot, and with crowns well developed but possibly somewhat crowded on the sides (Smith 1986). In total, 16 tree species were found in 1044 dominant trees from all the 70 plots. The total number of trees, averages and ranges of tree diameter and total height of each species are provided in Table 1. Overall, the average DBH of the 1044 dominant trees was 14.7 inches and the average total height was 84 feet.

Preliminary analysis indicated that the relationship between tree height and DBH of the dominant trees was linear. Other equations such as quadratic equation were also tested, and the results showed that higher order terms in the equations were statisticaly non-significant. Therefore, the following equation was used for each species:

$$HT = \beta_0 + \beta_1 \cdot (DBH) \qquad [1]$$

Based on the similarity of the intercepts and slopes of the regression lines for each species, the 16 species were placed into species groups. The equation [I] was then fitted to each species group. Residual analysis was also conducted for each model.

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Table 1 -- Total number of trees, averages and ranges of tree diameter and height of the 1044 dominant trees

Species name	Total No of trees	DBH (in)		Height (ft)	
		Mean	Range	Mean	Range
Ash	30	13.8	8-24	76.8	50-I 10
Beech	4	14.5	12-18	96.0	88-I 04
Black cherry	3	15.3	11-19	102.0	86-112
Black locust	8	15.4	7-21	92.4	70-115
Black maple	4	14.3	11-17	89.3	82-I 05
Chestnut oak/Chinkapin oak	171	14.3	6-49	74.1	50-I 02
Cucumber tree	11	16.9	8-28	91.5	65-I 05
Hickory	190	13.4	8-29	79.3	50-I 25
Post oak	3	17.7	13-21	91.3	86- 97
Red oak	196	14.9	8-28	85.8	50-I 28
Sassafras	1	12.0	-	82.0	
Shagbark hickory	65	14.2	Q-22	77.7	56-I 13
Sourwood	2	11.5	9-14	76.5	65- 88
Sugar maple	4	13.5	8-22	76.0	68- 85
White oak	289	15.2	7-29	88.5	53-I 35
Yellow poplar.	63	17.7	8-33	104.2	69-125
Overall	1044	14.7	6-49	84.0	50-I 35

RESULTS AND DISCUSSION

Among 1044 dominant trees sampled, 63 percent were oaks (Quercus spp.) and 24 percent were hickories (Carya spp.), followed by yellow poplar *(Liriodendron tulipifera) (6* percent) and ash (*Fraxinus* spp.) *(3* percent). All others were minor species and each had less than ten trees. In average, yellow poplar and black cherry (*Prunus serotina*) were the tallest trees followed by beech (*Fagus grandifolia*), black locust (*Robinia pseudoacacia),* cucumber tree *(Magnolia acuminata*), and post oak *(Quercus stellata*). But cucumber tree, post oak and yellow poplar had larger diameters (Table 1).

The equation [1] was fitted to each species with more than 30 trees, and other trees were combined into one minor species group. Based on the similarity of the intercepts and slopes of the regression lines for each species and the minor species group, the 16 species were placed into 5 groups: (1) Ash *(Fraxinus* spp.) / Hickory (Carya spp.), (2) Chestnut oak *(Quercus prinus) /* Chinkapin oak *(Quercus muehlenbergii), (3)* Red oak *(Quercus rubra* and *Quercus falcata*) */White* oak *(Quercus alba), (4)* Yellow poplar (*Liriodendron tulipifera*) / Black cherry (*Prunus serotina),* and (5) minor species (Table 2). Then the equation [1] was refitted to the 5 groups and the resulting models are as follows:

(1). Ash/Hickory:
HT = 43.64 + 2.57 • (DBH)
with n = 285, R^2 = 0.34, and C.V. = 15 percent.

(2). Chestnut oak / Chinkapin oak:
HT = 65.28 + 0.62 • (DBH)
with n = 171, R^2 = 0.10, and C.V. = 15 percent.

(3). Red oak / White oak:
HT = 53.31 + 2.26 • (DBH)
with n = 488, R^2 = 0.37, and C.V. = 15 percent.

(4). Yellow poplar / Black cherry:
HT = 92.59 + 0.66 • (DBH)
with n = 66, R^2 = 0.07, and C.V. = 12 percent.

(5). Minor species:
HT = 61.90 + 1.80 • (DBH)
with n = 34, R^2 = 0.41, and C.V. = 12 percent.

The equation [1] was also fitted to the 1044 trees to provide an overall equation for the relationship between height and diameter of the dominant trees:

HT = 54.94 + 1.97 • (DBH)

with model R^2 was 0.28, and C.V. was 17 percent.

Table 2 -- Species groups and tree species in each group

Species group	Species in group
1. Ash / Hickory	Ash Hickory Shagbark hickory
2. Chestnut oak / Chinkapin oak	Chestnut oak Chinkapin oak
3. Red oak/White oak	Red oak Post oak White oak
4. Yellow poplar / Black cherry	Yellow poplar Black cherry
5. Minor species	Beech Black locust Black maple Cucumber tree Sassafras Sourwood Sugar maple

Residual analysis showed that no special trend was detected for any of the above models. Although the R^2s of the models seemed low, the primary purpose of the study was to evaluate the relationship between height and diameter of the dominate trees, not for prediction.

The simulations using the above models for the 5 groups were illustrated in Figure 1. The heights and diameters found on these plots for the various species fit the results of past studies (Burns and Honaka 1990). As expected, Yellow poplar and Black cherry were the tallest trees for most DBH classes. The minor species group (Group 5) were species with few individuals found or those species commonly found in these dominant canopies showed outstanding growth.

The majority of the dominant trees were those species found in the remaining 3 groups. The Red oak/White oak group (Group 3) showed outstanding growth in both height and diameter. The Ash / Hickories group (Group 1) reflected the traditional height / diameter growth pattern of those species that are more shade tolerant and less aggressive in early growth than oaks,

The group we found most interesting was the Chestnut oak / Chinkapin oak group (Group 2). While a wide range of diameters were observed, there was little variation in height (Table 1). Little is known on the growth characteristics of Chinkapin oak (Sander 1990), but both species appear to develop large diameter trees with little additional height growth on these

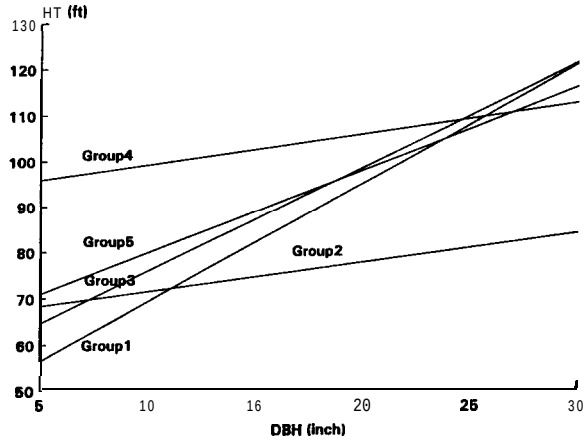

Figure 1 -- Simulation of the relationships between dominant tree height and diameter for the 5 species groups.

undisturbed sites. On medium quality sites, Red oak / White oak usually produce greater heights than these two species at age 60; this appears to be the case on these sites, since the last known management activity on any of these sites occurred 60 years ago.

SUMMARY

Based on the above results, it appears to us that the upland sites evaluated in this study can produce high quality trees of a variety of hardwood species. Since ages were not determined, we are not sure whether these stands were even or uneven aged; we are assuming that they were predominantly even-aged. In either case, management of these stands would require a great deal of effort. The management options as described by McGee (1982) would be useful guidelines to these stands. Although these stands will always produce a variety of low and high quality timber, the relationships in height and diameter found in this study show promise in the ability of these stands to produce high-quality timber in many cases if silvicultural activities are instigated to rectify past mis-management and high-grading. In most cases, removal of most if not all of the materials on the sites, followed by natural regeneration, should result in improved stand quality and fewer low-quality species. Although the results of this study are preliminary, they do fill a gap in our current knowledge of the hight-diameter relationships of the species of the mixed hardwood forests in this region.

ACKNOWLEDGEMENTS

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GRAVEL PIT RECLAMATION: BEDDING, MULCHING, AND FERTILIZATION EFFECTS ON LOBLOLLY PINE SEEDLING ESTABLISHMENT'

Charles E. Rowell, Ph.D.2

Abstract-The effects of bedding, mulching amendments (hay, bark, topsoil and woodash) and fertilization were evaluated on first year establishment and growth of loblolly pine seedlings on a reclaimed north Louisiana gravel pit. No survival differences were noted between fertilized and unfertilized loblolly pine seedlings; however, trees planted on bedded sites had significantly higher survival rates than those planted without bedding. Ash, bark, and hay amendments had the lowest survival rates. First year seedling growth was effected by fertilization, with fertilized plants having S-8 percent greater mean heights and diameters than the unfertilized plants. The hay mulch amendment produced the largest plants on both the bedded and unbedded areas, while the top soil amendment produced the smallest plants on both areas.

INTRODUCTION

Many federal and state reclamation laws have been enacted to deal with the environmental impacts of surface mining. In the State of Louisiana, wetland sites are protected from environmental degradation. However, there are many abandoned gravel pits on upland sites that are not governed by state or federal regulations. Many of these areas are now becoming a public concern as they are often left unproductive after mining activities have ceased. Some landowners, such as those in the timber industry, realize that it is to their advantage to reclaim such areas for timber production. Reclamation of gravel pits includes problems with compacted surfaces, severe erosion, and soils deficient in essential mineral nutrients and organic matter (Capp 1978).

Compaction of soils during the grading process of reclamation using heavy equipment has a detrimental effect on subsequent plant growth by causing lower rates of water infiltration and percolation, greater soil density, and reduced pore space (Adams and Froehlich 1981; Philo and others 1982). Use of a bedding plow prior to planting has been shown to help ameliorate these physical impediments to plant growth (Glover and others 1978; Pritchett and Wells 1978; Seifert and others 1984).

There is also considerable evidence that soil amendments can be helpful in revegetating severely disturbed sites (Berry and Marx 1977, Graves and Carpenter 1978). Two locally available amendments, tree bark and hay, are especially effective in maintaining temperature and moisture levels advantageous for plant growth. Carpenter and Graves (1978) found that bark waste significantly increased the amount of moisture available for plant growth on surface mine spoil. Albers (1978) found that grass mulches, such as hay, also significantly improved moisture levels in the spoil surface. In both cases, the extreme conditions found on surface mined spoils were buffered by these mulches.

On drastically disturbed sites many mineral nutrient deficiencies commonly exist, and fertilization has been effective in improving plant reestablishment and growth (Ringe and Wittwer 1975). Albers and others (1978) found that returning top soil to the surface of new mining spoils also improved initial plant survival by making mineral nutrients more available for plant growth. Capp (1978) found that flyash placed on the surface of disturbed sites also improved nutrient availability.

This study was implemented to evaluate the effectiveness of previously successful mining spoil reclamation techniques on reestablishing timber production on abandoned gravel pits in north Louisiana.

MATERIALS AND METHODS

The gravel pit reclamation project was located approximately 5 miles north of Heflin, Louisiana in Webster Parish on property owned by Martin Timber Inc. The soils, prior to mining, were a Ruston Fine Sandy Loam (fine-loamy, siliceous, thermic, Typic Paleudult) varying in slope from 1 to 8 percent (Soil Survey Staff, 1975). The vegetative cover was predominantly loblolly pine (*Pinus* taeda L.) with a site index of about 85 feet at 50 years. After mining was completed, the 55 acre area was graded to

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approximate natural contour. The post mining surface and sub-surface material consisted of an undifferentiated reddish brown sandy loam material.

In the Spring of 1984, a replicated, randomized, split-plot design was established to evaluate the survival and growth of fertilized and unfertilized loblolly pine on bedded and unbedded areas of the study site. No effort was made to establish herbaceous ground vegetation prior to study initiation. Three replications of four topical amendments (bark, top soil, wood-ash and hay) and a control (no amendment) were established on the surface of the bedded and unbedded treatments. Bark was obtained from a debarker operation of a local saw mill and distributed to about a three inch depth over the treatment plots. Top soil material was obtained from nearby forests and was also applied to a three inch depth. Wood-ash was obtained from a wood burning boiler at a nearby plywood plant and applied to a one inch depth. Coastal Bermuda grass hay was purchased on the local market and applied to a three inch depth. Each treatment plot contained 36 tree seedlings.

Each pine seedling was hand planted as bare root stock (1-O) with a planting bar. One of every two seedlings in a six plant row was randomly selected for fertilization with a 10 gram Agriiorm control-release (18-8-3,+Mg) tablet placed in the secondary hole during planting. A Rone disk was used for bedding and resulted in mine soil material being drawn into beds eight feet apart and approximately two to three feet in height on slope contour.

The field layout, amendment application, seedling planting and tree fertilization were carried out in the spring of 1984. Composite spoil samples were taken prior to planting in each treatment of each replication and determinations were made for total nitrogen (N), extractable phosphorus (P), exchangeable potassium (K), exchangeable calcium (Ca), exchangeable magnesium (Mg), pH, and organic matter (OM). Measurements (cm) of total above ground height and root collar diameter were accomplished before growth initiation and again in September after the first growing season. Qualitative observations were also made about erosion, tree appearance, and changes in site conditions during the study.

RESULTS AND DISCUSSION

Pre-planting Soil Condition

At planting, the gravel pit soils were extremely low in organic matter and no statistical differences were found either among treatments or between the bedded and the unbedded areas for P, K, or Mg concentrations. However, Ca and pH both had somewhat higher mean values on the unbedded area (Table 1).

Table 1: Pm-planting spoil nutrient concentrations, pH and organic matter content by treatment.

VARIABLE (Per Acre)	TREATMENT BEDDED Mean (Range)	TREATMENT UNBEDDED Mean (Range)	F-TEST VALUE BETWEEN / AMONG SITES /TREATMENTS
Phosphorus mg kg^{-1}	5.2 (5.0 - 7.0)	5.1 (5.0 - 6.0)	0.19ns / 0.70ns
Potassium mg kg	30.9 (23 - 40)	35.0 (19 - 50)	2.16ns / 2.22ns
Magnesium mg kg	88.6 (63 - 119)	107.7 (59 - 158)	2.65ns / 0.25ns
Calcium mg kg	165.3 (135 - 179)	240.8 (190-410)	12.42** / 0.45ns
Acidity (pH)	4.38 (4.2 - 4.5)	4.46 (4.4 - 4.6)	6.78* / 0.35ns
Organic Matter (Pct)	0.01 (0.006 - 0.02)	0.01 (0.003 - 0.02)	0.03ns / 0.17ns

ns=non-significant at the 0.05 probability level.
● =significant at the 0.05 probability level.
**=significant at the 0.01 probability level.

Plant Survival

No first growing season survival differences were found between the fertilized and unfertilized seedlings using Chi-Square analysis. However, differences were found in the numbers of plants surviving on bedded and unbedded areas and among treatments (Table 2). Seedling survival was best on the soil amendment, with the ash, hay, and bark amendments exhibiing the poorest survival (Table 2). Survival was similar among amendments within the bedded and the unbedded treatments, with the soil amendment on both treatments having the lowest mortality. Bark, ash, and hay amendments had the highest mortality, with bark having the poorest survival on the bedded areas and hay the poorest on unbedded area. Plant survival was best overall on the bedded area (Table 2).

Plant Growth

The hay treatment produced the greatest first year height growth, while the control and hay treatment produced the most increase in diameter growth (Tables 3 and 4). The least first year height and diameter growth was found with the bark amendment.

Table 2: Loblolly pine seedling survival by site, treatment and fertilization as found on a north Louisiana gravel pit.

	TREATMENT						
	BEDDED			UNBEDDED			AMENDMENT
	FERT'	UNFERT	TOTAL'	FERT[1]	UNFERT	TOTAL[2]	TOTAL'
AMENDMENT	(Pct)						
CONTROL	85	93	89	52	46	49	69
SOIL	87	93	90	63	63	63	76
BARK	46	44	45	37	31	34	40
ASH	72	72	72	30	31	31	51
HAY	72	72	72	31	22	27	50
COLUMN MEAN	74	76	75	40	38	39	57

[1] No differences in percent survival between fertilized and unfertilized seedlings using Chi-Square analysis at the 0.05 probability level.
[2] Differences were found in percent survival between bedded and unbedded sites using Chi-Square analysis at the 0.05 probability level.
[3] Differences were found in percent survival among treatments using Chi-Square analysis at the 0.05 probability level.

Table 3: First year height growth of loblolly pine on bedded, fertilized and amended gravel pits in north Louisiana.

	TREATMENT						
	BEDDED SITE HEIGHT			UNBEDDED SITE HEIGHT			AMENDMENT
	FERT	UNFERT	MEAN'	FERT	UNFERT	MEAN'	MEAN'
AMENDMENT	(cm)						
CONTROL	35.4	32.9	34.1 b	22.8	18.9	21 .Oa	29.5b
SOIL	26.9	24.8	25.8d	17.5	17.7	17.6bc	22.5d
BARK	31.0	27.8	29.4c	22.1	18.6	20.4ab	25.6c
ASH	36.1	29.5	32.8b	24.1	21.5	22.8a	29.8b
HAY	43.0	39.7	41.3a	25.2	21.9	23.2a	36.5a
MEAN	34.8	31.2	33.0	20.8	18.6	19.8	28.5

'Values in a row followed by the same letter do not differ significantly at the 0.05 probability level.

Table 4: First year diameter growth of loblolly pine on bedded, fertilized and amended gravel pits in north Louisiana.

	TREATMENT						
	BEDDED SITE DIAMETER			UNBEDDED SITE DIAMETER			AMENDMENT MEAN'
	FERT	UNFERT	MEAN'	FERT	UNFERT	MEAN'	
AMENDMENT	(cm)						
CONTROL	1.15	1.01	**1.08a**	0.68	0.55	**0.62a**	**0.92ab**
SOIL	0.66	0.64	**0.65c**	0.53	0.57	**0.55ab**	**0.61d**
BARK	0.92	0.80	**0.86b**	0.64	0.61	**0.62a**	**0.76c**
ASH	1.02	0.86	**0.94b**	0.73	0.55	**0.64a**	**0.85b**
HAY	1.07	1.13	**1.09a**	0.55	0.64	**0.58ab**	**0.96a**
MEAN	0.99	0.91	0.95	0.61	0.55	0.59	0.83

Significant differences were also found in heights and diameters between the bedded and unbedded areas. Heights (Table 3) and diameters (Table 4) increasesd 16 and 15 percent, respectively, on the bedded area. A ranking of bedded and unbedded area mean differences placed the hay treatment first in height growth on the bedded area, while the hay, control, and ash amendments were ranked equal in height growth on the unbedded area (Table 3). The top soil amendment had the least tree height growth on both areas. Diameter growth on the bedded area was greatest on the hay amendment and the control, with the soil amendment producing the least diameter growth (Table 4).

Only the ash amendment on the bedded area had significantly better height growth than other amendments, again a possible result of the fertilizer additions (Table 3). No differences in height growth were found with nutrient additions on the unbedded area. Significant diameter growth differences were found for fertilized seedlings on the check and ash amendments for both the bedded and unbedded areas (Table 4).

CONCLUSIONS

Loblolly pine exhibits the ability to grow and survive over a wide range of soil conditions. The pre-planting site conditions, although limiting, were considered within the range acceptable for the species as found by Fowells (1965). However, survival and growth differences of loblolly pine seedlings between the bedded and unbedded treatments and among amendments were immediately apparent after planting.

Needle browning and lack of initial terminal growth was apparent at the first measurement period (three weeks after planting) on many of the seedlings of the unbedded area. The need for herbaceous vegetation to stabilize the surface of the mine soil material was also apparent early in the study when surface water flow from rain resulted in severe sheet and rill erosion. By the second measurement period, at the end of the growing season, erosion had cut many gullies into the unbedded areas, and much of the surface area that was not gullied was covered with a layer of gravel and sand indicating considerable overland flow of water. In addition, a continuous clay strata, two to three inches below the surface, developed. Fowells (1964) states that the development of restrictive clay layers within the rooting depth drastically reduces site productivity for loblolly pine.

In contrast, during this first measurement period on the bedded area liffle down slope movement of surface material was apparent. However, finer soil particles were being deposited between rows as water stood and infiltrated. However, no layering of fine particles was apparent in the 2 to 3 feet of raised spoil material in the rows. The loblolly pine planted in the bedded area were larger and better developed than in the unbedded area, an effect that can be expected to continue for up to five years (Seifert and others 1984).

Ringe (1979) found that fertilization increased survival of trees on surface mine spoil. However, few survival differences were found between the fertilized and unfertilized seedlings in this study. Although fertilizer was added in a concentrated form, and in close proximity to each fertilized seedling, the amount may not have been sufficient to noticeably influence seedling survival and growth.

The higher levels of mortality in the hay and bark mulch amendments may have been the result of the addition of these, non-decomposed, amendments. High carbon-nitrogen ratios, insects, high cambium temperatures in the dark bark mulch amendment and the demands of plants introduced to the site as seed in these organic mulches could have contributed to the mortality of some pine seedlings. The ash amendment and the check were void of factors brought on by the addition of orgainc mulches, while the soil amendment,

though on a small scale, brought the advantages of an established natural forest soil surface.

Diameters and heights were highly variable within the soil, bark, and hay amendments, with fertilized plants having statistically greater mean diameters only for the control and ash amendments (unbedded sites), and mean plant heights only for the ash amendment (bedded sites). The nutrients made available from the ash amendment, in combination with nitrogen additions from the fertilizer were readily assimilated and expressed as increased growth. There was little competition for the pine seedlings on the check and ash amendments, and the reduced growth rates for non-fertilized plants on these amendments implies a possible need for fertilization. Through not statistically significant, the fertilized plants were larger on all amendments.

Seedling growth in response to added amendments differed significantly. The largest heights and diameters were found on the hay mulch amendment, and the smallest trees were found on the soil amendment. Carpenter and Graves (1978), and Albers (1978) stated that organic amendments (hay and bark) improved moisture holding properties of mine soil. These materials have an added effect of bringing organisms which reestablish the development of nutrient cycles advantageous to plant development. Hay and soil materials, and to some extent bark, also introduced seed that quickly reestablished small herbaceous and woody plants whose roots penetrate the mine soil, stabilizing the growth medium, reducing bulk density, reintroducing organic material into the profile and as root mortality occurs, providing pore space for moisture infiltration.

ACKNOWLEDGMENTS

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FORECASTING LOBLOLLY AND SHORTLEAF PINE SEED CROPS'

Michael G. Shelton and Robert F. Wittwer[2]

Abstract—Preliminary guidelines are presented for forecasting acceptable seed crops for natural regeneration. Sample trees are visually placed in one of three cone-density classes based on cone spacing, occurrence of cones in **clusters,** and distribution of cones within the crown. The procedure was field tested during 1993 in 17 stands being monitored for seed production. Stands represented a wide range of stand conditions and sites. Classification took **<1** minute per tree, allowing a large number of trees **to** be evaluated rather than making precise counts on **a** few trees. The stand's mean cone rating and basal area explained 58 percent of the variation in seed production. Only **two** seed crop failures **occurred,** and they were correctly forecasted.

INTRODUCTION

An adequate seed supply is critical to the natural regeneration of **loblolly,** ***Pinus*** *taeda* L., and shortleaf, *P.* ***echinata*** Mill., pines (Cain 1991, Wittwer and Shelton 1992). Some silvicultural strategies, such as retaining fruitful trees as seed trees and promoting their general vigor, can be used to enhance seed production within a stand, but these techniques are by far secondary to the uncontrollable influences of seed and cone consumers and weather. Considering these restrictions, foresters relying on natural regeneration need to know the periodicity of seed crops of the species that they tend. Because seed production is fairly reliable for some species and regions, less attention needs to be paid to annual variation in seed crops. For example, seed crop failures occur about once in 5 years in loblolly pine stands on the West Gulf Coastal Plain (Cain 1991, Campbell 1967, Grano 1973). Because seedbeds generally remain receptive for 2 years on good sites and perhaps longer on poorer sites, the probabiii of successful regeneration in this region is good. However, successive seed crop failures may rarely occur in this region (Grano 1957). In contrast, poor seed crops are more common for loblolly pine in the Piedmont (Brender 1958, Wakeley 1954) and for shortleaf pine throughout its range (Witlwer and Shelton 1992).

Where low seed production limits the prospects for natural regeneration, foresters should schedule site preparation and reproduction cutting to ensure that an adequate seed supply coincides with a receptive **seedbed.** Objectives of our study were to develop and field test a procedure for forecasting loblolly and shortleaf pine seed crops.

METHODS

Cone rating of sample trees

The **2-year** pine reproductive cycle affords a fairly long time period for observing the development of a seed crop (fig. 1). We modified a cone-rating procedure that was developed for western conifers (McDonald 1992, **Rietveld** 1978, Schubert and Pitcher 1973) by employing several quantitative and qualitative features that permit rapid evaluation of the cone density in a tree's crown. Cone density was visually rated based on cone spacing, the occurrence of cones in clusters, and the distribution of cones within the crown (table 1). In our procedure, cone density is rated only for the side of the crown facing the evaluator (that is, the crown face).

Ranges for cone density are from a rating system for ponderosa pine, *P. ponderosa* Laws. (Schubert and Pitcher 1973). These ranges seem reasonable for loblolly and shortleaf pines. For example, Thorbjornsen (1960) reported a 2-year mean for loblolly pine of 52 cones per tree with a range of 0 to 372. Data from Yocom (1971) indicated a **5-year** mean of 130 cones per tree in shortleaf pine stands. Furthermore, a shelterwood stand with 30 trees per acre and an average cone density rating (90 cones per tree) would yield about 108,000 seeds per acre, which is considered an acceptable seed crop to regenerate most seedbeds.

Cone spacing is fairly easy to observe. A few sample cones can be selected and the distance to their nearest neighboring cone can be estimated. Class limits for cone spacing in table 1 were based on the area of the crown face. This area was calculated from predicted

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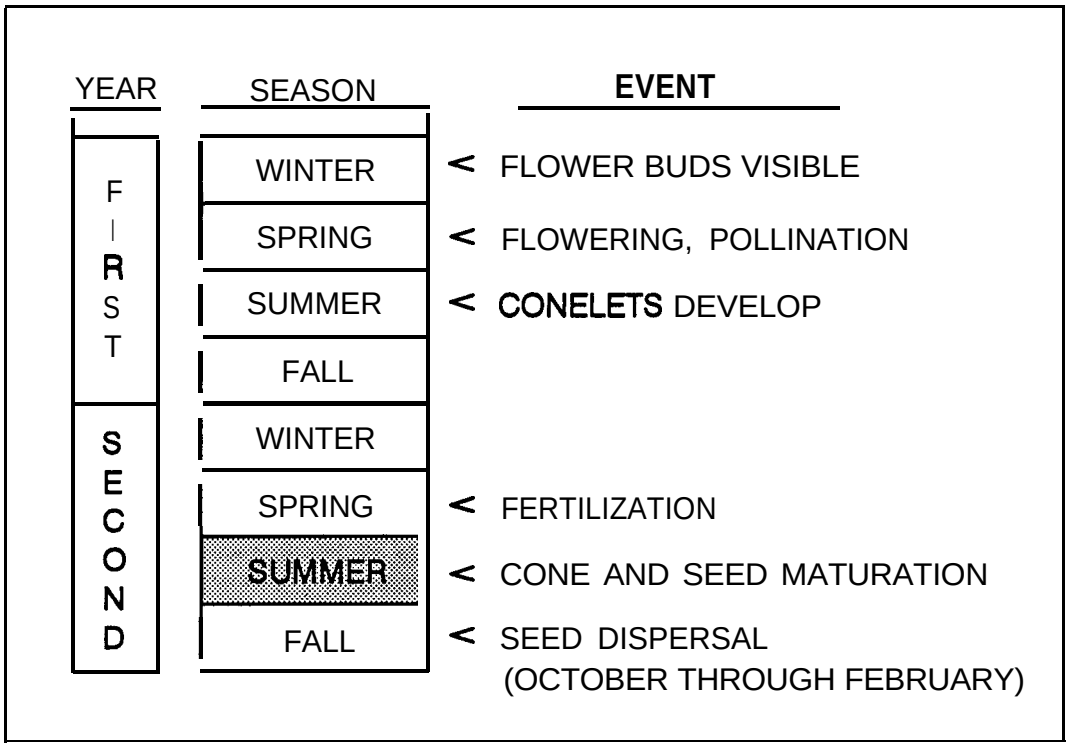


Figure I-The reproductive cycle of loblolly and shortleaf pines (modified from Wittwer and Shelton 1992). Cone density is rated during the summer of the second year.

Table l-Cone-density classes used to rate loblolly and shortleaf pine sample trees

Property	Cone-density class		
	Few	Average	Good
Spacing between cones (feet)	>7	2.5 - 7	c2.5
Multiple cones on branchlets	Rare	Occasional	Common
Distribution within crown	Erratic	Upper half	Uniform
Cones per crown face	<10	10 - 80	>80

crown dimensions using equations developed for loblolly and shortleaf pine trees from a number of our existing studies. The area of the crown face was calculated as a parabola and for a tree with d.b.h. of 15 inches. Mean cone spacing was simply the square root of the mean crown area per cone (that is, area divided by one-half of the tree's cone density). Class ranges for cone spacing were selected to yield similar values as those for cone density.

Cone density of a tree also depends on the proportion of branchlets that bear multiple cones and the number of cones present in these clusters (that is, two or more). Field observations indicated that fruitful loblolly and shortleaf pine trees usually have a fairly uniform distribution of cones over the entire crown face, while the cones of less fruitful trees are concentrated in the upper portion of the crown.

In application, the cone rating of trees was a rather subjective integration of all features to choose the proper cone-density class. A pictorial of class limits for the average cone class is shown in figure 2. Similar visual-rating systems have also been developed for evaluating crown density as an expression of tree vigor (Belanger and Anderson 1989).

For good visibility, evaluators stood one to two tree heights away from the sample tree with the sun to their back and used high-quality, 7-power binoculars. Most trees were classified in the early morning or late afternoon and on days with low cloud cover and light winds. Eleven of the stands were classified in July and six in September. Although three evaluators rated stands, each stand was rated by a single evaluator. Maturing cones were distinguished from older cones based on: (1) maturing cones were yellowish green to

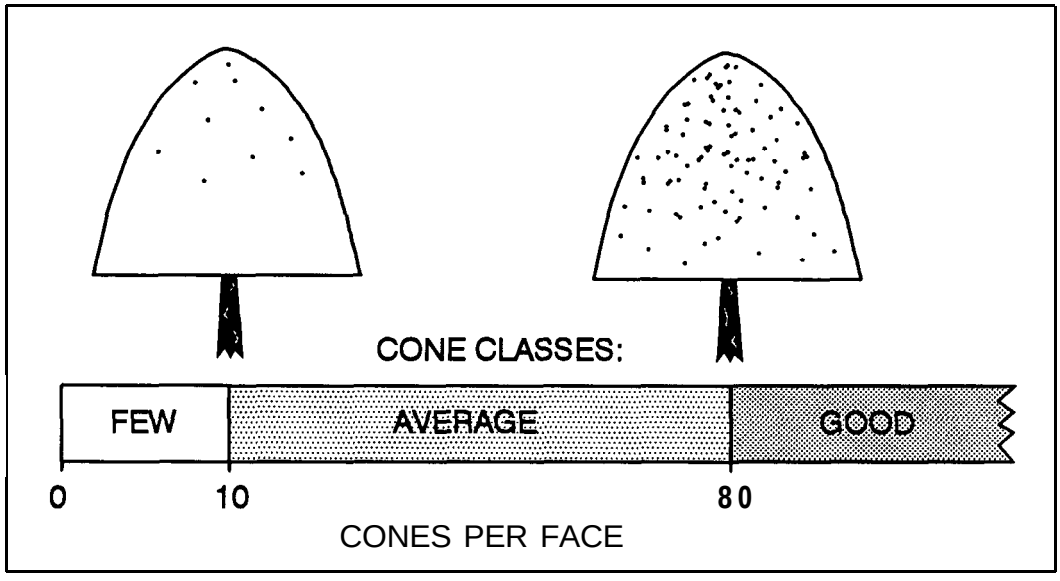


Figure 2-Typical crowns representing the lower and upper limits of the average cone-density class.

green compared to dark brown for older cones, (2) maturing cones were closed while older cones were open when dry, and (3) maturing cones were among the needles while older cones were farther back from the tip where needles had been cast. Evaluation was avoided on cloudy days following a rain because the older cones were closed and the low light intensity made the color differences subtle.

Cone rating of stands

Numerical values were arbitrarily assigned to the three cone-density classes as follows: 0 for few, 1 for average, and 2 for good. However, the rating of sample trees was modified to accommodate borderline occurrences of classes by assigning pluses and minuses in the field tally. A plus indicated the tree was near the upper limits of the class, while a minus indicated the lower limits. Such variation would probably have averaged out, but it may have been critical in situations where a high percentage of the trees were near a class limit. Most important, assignment of pluses and minuses prevented evaluators from dwelling on the class of borderline sample trees. For calculating stand averages, a value of 0.3 was added to the class value for a plus or subtracted for a minus (for example, a "1+" had a value of 1.3, and a "1—" had a value of 0.7).

Data for testing the procedure

A common observation of studies making precise cone counts is that they tend to underestimate the actual number of cones on the tree because all the cones on the crown face are not visible from a single observation point. Such bias undoubtedly also occurred in our procedure, but it was corrected by using cone rating as a predicator of observed seed production in a series of test stands that were evaluated for both cone rating and seed production in 1993.

The study area extended from eastern Oklahoma through southwestern Mississippi, and included 17 stands that were being monitored for seed production in conjunction with various studies of natural pine regeneration (table 2). Stands were in three physiographic regions: the Ouachita Mountains of Arkansas and Oklahoma (nine stands), the West Gulf Coastal Plain of Arkansas and Louisiana (six stands), and the Silty Uplands of Mississippi (two stands). Reproduction cutting methods were two seed tree, two shelterwood, three group selection, and nine single-tree selection stands. In addition, there was one even-aged, sawtimber stand. Compositions included one pure loblolly pine, seven loblolly-shortleaf mixtures, and nine pure shortleaf pine stands.

Procedures for monitoring seed production varied from study to study based on stand area, number of plots, and objectives. Five to 24 seed traps with an area of 0.9 or 4.0 ft^2 per trap (Cain and Shelton 1993, Scholtens 1979) were placed in each stand. As a minimum, seeds were collected at the middle and end of the October-to-February monitoring period. Seed traps in the group-selection stands were located near the center of 0.25acre openings. For all stands except those located in Oklahoma, 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 and were tallied as sound seeds. Shortleaf pine seeds were distinguished from those of

Table 2-Stands evaluated for cone rating and seed production

Stand type	Number of stands	Basal area[a]	Physiographic regions
Seed tree	2	12	Ouachita Mountains
Shelterwood	2	38	Ouachii Mountains
Even-aged sawtim ber	1	60	West Gulf Coastal Plain
Group selection	3	50	West Gulf Coastal Plain
Single-tree selection	9	52	Ouachita Mountains, West Gulf Coastal Plain, Silty Uplands

[a] Mean pine basal area (ft^2 per acre) in trees ≥ 10 inches in d.b.h.

loblolly pine by size (shortleaf pine seeds are smaller) and the amount of force required to splii them (shortleaf pine seeds require less force). For the Oklahoma stands, seeds were considered sound if they sank in ethanol (Krugman and Jenkinson 1974). A subsample of these seeds was splii, and the floatation test yielded the same results as the splii test

Cone density was rated for about three sample trees of seed-producing sizes (that is, ≥10 inches in d.b.h.) randomly selected within one to two tree heights from each seed trap. In stands where mensurational data were not available, basal area was determined with a BAF 10 prism at a point centered over each seed trap. Basal area in the groupselection stands was the basal area of the residual trees divided by the total stand area (including openings).

Data Analysis

Basal area and cone rating were averaged by species for each stand. Regression was then used to evaluate the effects of species, basal area, and cone rating as

$$S = B^{(b_1 + b_2 L)} R^{(b_3 + b_4 L)} \quad (1)$$

predictors of the stand's seed production as follows:

where:
S = thousands of sound seeds per acre by species;
B = basal area per acre by species in trees ≥10 inches in d.b.h.;
L = 0 for shortleaf pine and 1 for loblolly pine;
R = mean cone rating by species;
bs = coefficients to be determined.

This approach allowed the regression coefficients to compensate for the effects of: (1) the number of sound seeds per cone, (2) underestimation of the actual number of cones on trees by evaluators, (3) the arbitrary numerical values assigned to cone-rating classes, and (4) conversion of cone density for the crown face to values for the tree. The coefficients for species (that is, b_2 and b_4) were not significant (P = 0.05). Thus, stand-level values for seed production, basal area, and cone rating were combined for the two species and used for fitting the final equation. Examination of the residuals indicated an unequal error variance, which was remedied by square root transformation of seed production values. The final equation was retransformed for presentation and for calculation of fit statistics as described by Schlaegel (1982).

RESULTS

The 1993 Seed Crop

The 1993 seed crop was generally good throughout the study area. Mean and median seed production in the 17 stands were 1,223,000 and 734,000 sound seeds per acre, respectively. However, production in individual stands ranged from failures to bumper seed crops. Two stands, both in Oklahoma, produced less than 10,000 sound seeds per acre. Three stands produced moderate seed crops with values in the vicinity of 100,000 per acre, and the remaining 12 stands had good-to-bumper seed crops with values over 250,000 per acre. Production was most variable in Oklahoma, ranging from failures to bumper crops.

The seven mixed loblolly and shortleaf pine stands offer some interesting comparisons between the species (table 3). Shortleaf pine is reputed to be a less prolific seed producer than loblolly pine, but most observations of shortleaf pine have come from the poorer sites where it tends to dominate (Wittwer and Shelton 1992). In the stands of this study, which are located on good sites, seed production did not diier significantly between the two species in 1993. The only observed significant difference was for the percentage of total seeds that were sound, which was about one-third greater for loblolly than shortleaf pine.

Cone ratings for the 15 stands where the seed crop was not a failure averaged 1.06, and the standard deviation averaged 0.49. These values can be used to estimate the number of sample trees needed to provide a desired confidence interval for the stand's mean cone rating at a specified probability level using a formula presented in most statistical texts (for example, Steel

Table 3-Properties of loblolly and shortleaf pines in seven, uneven-aged, mixed-species stands on good sites (site indices of about 90 feet at 50 years for loblolly pine)

Property	Loblolly	Shortleaf	*t*	*P* > *t*
Basal area' (ft^2 per acre)	27	22	0.62	0.56
Cone rating'	1.26	1.19	1.16	0.29
Sound seeds (thousands per acre)	903	867	0.09	0.93
Total seeds (thousands per acre)	1,101	1,386	0.54	0.61
Sound seeds (percent of total)	82	63	9.80	0.0001

'Trees ≥ 10 inches in d.b.h.

and Torrie 1980). Assuming that the mean cone rating is 1 .O and the standard deviation is 0.5, about 70 trees should be evaluated to provide a confidence interval half-width of 0.1 at the 0.1 probability level. Thus, a reasonable sampling intensity in a 40-acre stand for this level of confidence would be about two trees per acre.

Forecasting the 1993 Seed Crop

The equation relating sound seed production (S in thousands per acre) to basal area (B in ft^2 per acre) and cone rating (R as defined) is:

$$S = B^{1.769} R^{2.353} \quad (2)$$

The number of observations for equation (2) was 17; root mean square error was 795; fit index was 0.58; and the mean seed production was 1,223,000 sound seeds per acre.

Figure 3 compares predicted with observed seed production. The wide variation in levels of seed production that occurred in 1993 is apparent; observed values ranged from less than 10,000 to 3,500,000 per acre. The greatest deviations between predicted and observed values were for the larger seed crops; this pattern is common in biological relationships. The equation correctly predicted the two seed crop failures that occurred in Oklahoma. Assuming the lower limit for acceptability to be 50,000 sound seeds per acre, seed production in the other stands was forecasted to be at least acceptable, and acceptable seed crops were produced.

Several obvious sources of error are associated with our forecasting procedure. First, a sampling error is associated with each variable in equation (2). Second, variation in the number of sound seeds per cone will

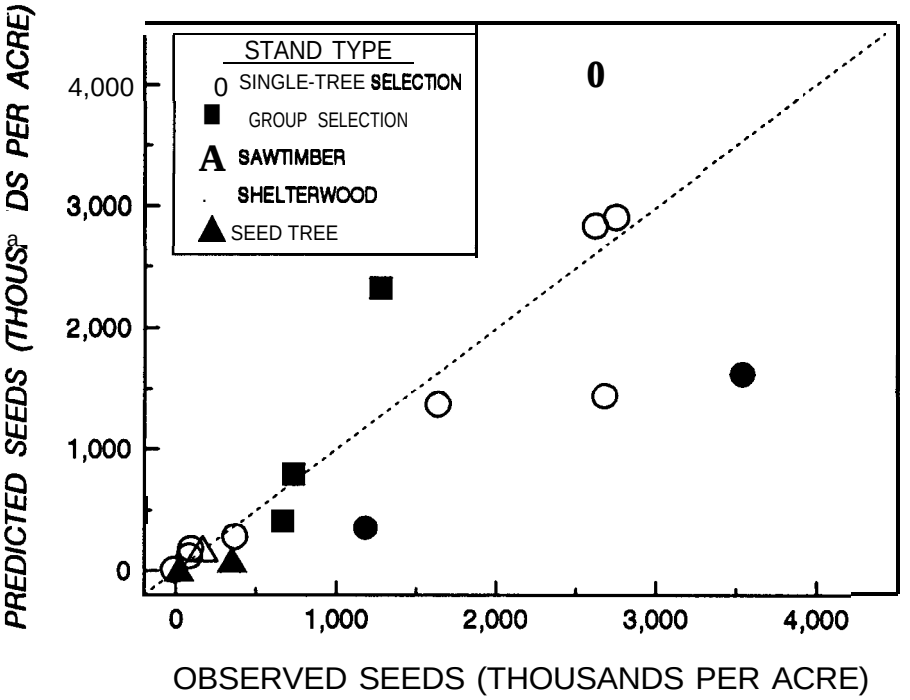
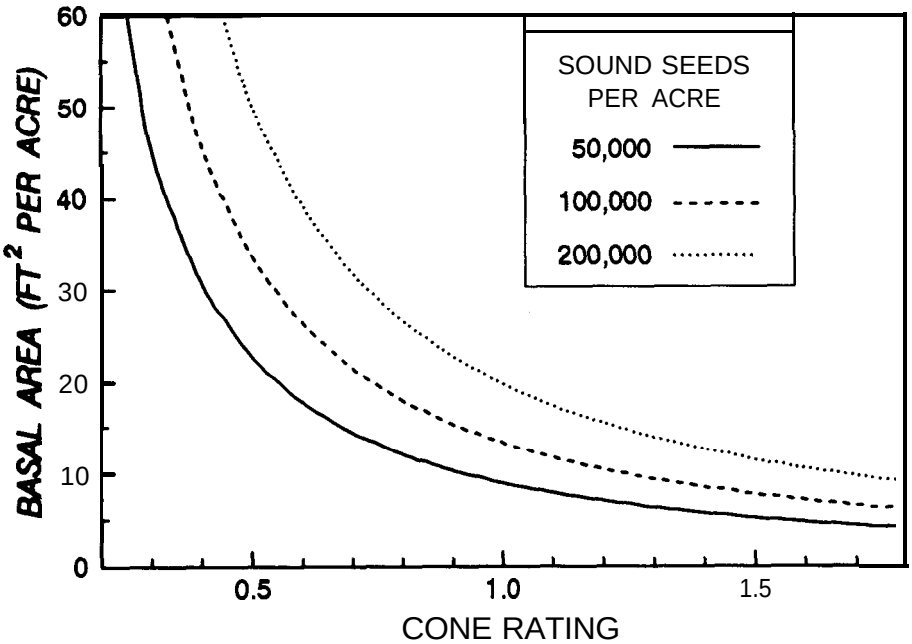


Figure 3--Predicted production of sound seeds plotted against observed values. The dashed line represents equal values.



Fiaure 4-Combinations of cone rating and basal area that yield the specified seed production in loblolly and shortleaf pine stands. Calculated from equation (2).

cause predicted values to deviate from observed seed production. The forecasting procedure does not currently include a sampling scheme to determine the number of sound seeds per cone. Thus, the seed density in cones was assumed to be intrinsically accounted for in the cone rating. Wakeley (1954) reported that loblolly pine produces 40 to 50 sound seeds per cone during good years, while shortleaf produces 25 to 35; values for poor years are reduced by about one-half. Procedures for estimating the seed yields from cones exist (for example, Bramlett and Hutchinson 1964, McLemore 1962), but additional sampling is required. Such evaluations are most likely to be needed when seed production is predicted to be marginal.

Values generated from equation (2) are plotted in figure 4, which shows that a given level of seed production can be achieved by an array of basal areas and cone ratings. High basal areas coupled with low cone ratings can yield the same seed production as low basal areas and high cone ratings. Figure 4 can also be used to judge the acceptability of the upcoming seed crop based on a stands cone rating and basal area. If stands are to be harvested prior to seed dispersal, the residual basal area should be used and the cone rating should reflect the retained trees.

Our forecasting procedure requires visual rating of the cone density on sample trees, determining stand basal area, and estimating seed production with equation (2) or figure 4. The number of seeds required for successful regeneration depends on a myriad of factors that include seed consumers, seedbed conditions, competing vegetation, weather, and overstory vegetation. These factors must also be viewed within the context of landowner goals. Thus, proposing guidelines for making silvicultural decisions about the adequacy of a seed crop should include sufficient latitude for the skill and judgment that are the hallmarks of foresters. If 50,000 to 100,000 sound seeds per acre are assumed to provide acceptable natural regeneration, figure 4 suggests that preliminary guidelines for the minimum value for mean cone ratings should be 1 .0 to 1.5 for seed-tree stands, 0.5 to 1 .0 for shelterwood stands, and 0.25 to 0.75 for uneven-aged stands, Generally, shortleaf pine stands should be at the middle to upper end of this range because seedling-to-seed yields for shortleaf tend to be below those of loblolly pine. Some confirmation of the presence of a reasonable number of sound seeds in cones is recommended, especially when the cone rating is at the lower end of these ranges. Future trials of this procedure will attempt to determine the annual extent of variation in the seed density of cones.

CONCLUSIONS

The visual cone-rating procedure evaluated in this study provides some insight into the adequacy of the upcoming seed crop. It is rapid and appears to be sufficiently accurate to aid in making silvicultural decisions about the intensity and timing of site preparation and possibly the scheduling of reproduction cutting. This forecasting procedure

provides a maximum lead time of about 5 months prior to the onset of seed dispersal. Longer lead times are possible with silvicultural treatments that do not require application before seed dispersal for optimum effectiveness. For example, hardwood control can extend from the time of cone rating through the early part of the growing season following seed dispersal. If a bumper seed crop was forecasted, prescribed burning for site preparation might be extended later into the dormant season than is normal for optimizing seedling establishment (Cain 1986). The same logic could probably be extended to harvesting. In areas of fairly reliable seed crops, the greatest utility of this forecasting procedure will probably be in matching the intensity of site preparation with the size of the seed crop-the better the seed crop, the lower the intensity of site preparation that is needed to obtain acceptable natural regeneration.

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IMPACTS OF BURNING SEVERITY ON A SOUTHERN APPALACHIAN SITE'

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Abstract-This study was designed to evaluate and compare the short- and long-term effects of high- and low- severity bums to site quality. The study area was commercially clearcut and treated using the fell-and-burn technique. Treatments of high- and low-severity burns were replicated four times in a completely random design. Rainfall runoff, sediment production, and nutrient concentration were measured after every rainfall event for one year after burning. Biomass production, planted pine survival, and hardwood sprouts were measured after one growing season. High-severity burns exposed mineral soil, increased sediment production, and decreased total biomass, but significantly increased the survival of planted pines. Low-severity burns had minimal erosion and greater total biomass, but decreased pine survival. This decrease probably results from a lack of competition control.

INTRODUCTION

Scientists have long been concerned about fire's effects on soil (Arend 1941, Wells and others 1979), and some have studied erosion, site productivity, and water quality following fires on steep terrain (Van Lear and Kapeluck 1989). However, little quantitative information is available on the effects of high-severity burning after timber harvest on variables such as runoff, sedimentation, and net primary productivity (Robichaud and Waldrop 1994). Fire severity refers to the condition of the forest floor after burning (Wells and others 1979), and burning effects range from minimal consumption of the litter layer (low-severity) to total consumption of duff and litter layers and exposure of mineral soil (high-severity) (Phillips and Abercrombie 1987, Wells and others 1979).

On the Andrew Pickens Ranger District of the Sumter National Forest, site preparation burns are often used to regenerate low-quality hardwood stands to pine-hardwood mixtures. The fell-and-burn technique (Abercrombie and Sims 1986) where residuals are felled in the spring followed by burning in the summer has been used successfully. This technique creates productive pine-hardwood mixtures with high pine survival rates and improved hardwood quality (Phillips and Abercrombie 1987). However, in two studies of the fell-and-burn technique, high-severity fires created excessive erosion that may have reduced long-term site productivity (Van Lear and Kapeluck 1989, Evans and others 1992). These studies identified a need for site-specific burning prescriptions that protect the forest floor, thereby protecting the mineral soil.

In this study, low- and high-severity burns were conducted to evaluate and compare short- and long-term effects of the two treatments. Runoff, sediment loss, site productivity, plant nutrient content, and stand development were measured for both treatments. This paper discusses short-term effects one year after treatment.

METHODS

The study was conducted on steep terrain on the Andrew Pickens Ranger District of the Sumter National Forest in northwestern South Carolina. Slopes within the study area, of 14 hectares, range from 24 to 39 percent with a southern aspect. The predominant soil type is the Cowee series, a fine, loamy, oxidic, mesic Typic Hapludult formed in residuum from weathered granite, gneiss, and schists.

The study area was commercially clearcut during the winter of 1990-l 991. The major overstory hardwoods included: scarlet *(Quercus coccinea* Muenchh), northern red (Q. *falcata* Michx.), black (C?. *velutina* Lam.), white (Q. *alba* L.), chestnut (Q. *prinus* L.), and post oaks (Q. *stellata* Wangenh.). The predominant overstory pine species was shortleaf pine (*Pinus echinata* Mill.). Understory and midstory hardwoods included red maple (*Acer rubrum* L.), blackgum (*Nyssa sylvatica* Marsh.), sourwood *(Oxydendrum arboreum* L.), persimmon (*Diospyros virginiana* L.), and black cherry (*Prunus serotina* Ehrh.). Residual stems greater than 1.5 meters tall were felled in May and June 1991 for both burn treatments.

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Table l-Fuel and weather conditions at time of ignition and selected fire behavior patterns for low- and high-severity burns

Measurement	Low severity	High severity
Date	June 5	July 15
Relative humidii	48%	55%
Wind	SE 5-l 1 kph	SE 8-l 1 kph
Fuel moisture sticks	11%	8%
Ambient temperature	18 deg C	30 deg C
Firing technique	Strip headfire	Strip headfire
Flame height	1-3 m	2-6 m
Fireline intensity	215-2,945 kw/m	655-l 3,295 kw/m
Time	1100 - 1300	1500 - 1730
Litter moisture	65.2%	5.9%
Duff moisture	98.2%	36.9%
Soil moisture	35.7%	24.5%
Rain	6 days before-37mm	12 davs before-44mm

On June 5, 1991, six days after a 37 mm rainfall event, low-severity burns were applied to four 0.4 ha treatment plots (replicates). High seventy burns were applied to another four plots on July 15, 1991, twelve days after a 44 mm rainfall event. Low-severity burns were of high-intensity and over a moist forest floor. High-severity burns were of high-intensity and over a dry forest floor. Relative humidity and wind speed were similar for the two burn treatments, however, the fine fuel moisture and ambient temperature were quite different (Table 1).

Conditions for both fires fell within the guidelines established by the USDA-Forest Service, Southern Region. Andrew Pickens District guidelines are more conservative than the Region's, requiring 9 and 8 percent moisture content, respectively, of woody fuels 6-26 mm in diameter. Fuel moisture content met the Region's guidelines for the high-severity burns while the fuel moisture content for the low-severity burns surpassed both guidelines at 11 percent (Table 1).

Fuel loading, litter and duff layer thicknesses, and mineral soil exposure were measured along fifteen 15-meter transects, prior to burning. Starting points for the transects were randomly located, however, azimuths were varied to ensure sampling along several slope gradients. Pins were installed flush with the top of the duff layer to estimate forest floor consumption. Consumption was measured in millimeters from the top of the pin to the forest floor. Woody fuels, forest floor, and mineral soil were sampled immediately prior to ignition to determine moisture content. Post-burn transect measurements determined fuel load consumption and mineral soil exposure. Shortleaf pine seedlings were planted in the fall of 1991.

One 3 m x 10 m plot had been randomly located in each treatment area for a previous study of artificial rainfall (Robichaud and Waldrop 1994). One of these plots was randomly selected from the four replicates of each burn treatment to monitor total runoff and sediment resulting from natural rainfall. Samples were collected in 55-gallon barrels fed by covered channel tubing, located at the base of the plot, that extended the width of the plot across the slope. Depth of runoff in barrels was measured after each rainfall event to determine volume.

Sediment in runoff was measured after adding 1000 ml of 0.2-N aluminum sulfate (Alum) to flocculate suspended solids. This solution was poured into beakers, oven-dried at 75 degrees C, and weighed to determine concentrated sediment. A 1,000 ml runoff sample was collected to determine phosphorous (P) and potassium (K) concentration that was measured by the Clemson University Agricultural Chemical Services Department.

Runoff and sediment production were measured after each rainfall event, from September 1991 through September 1992. A portable weather station recorded rainfall intensity and duration on a data logger, downloaded after each rainfall. This information was used to help correlate rainfall and erosion.

Vegetative response was measured at the end of the first full growing season after burning (September 1992). Within each treatment area, one 0.2 ha plot was randomly located to measure survival and height growth for planted pines. Two vegetation plots, measuring 0.01 ha each and randomly located within each treatment area, were used to measure height growth of hardwoods and naturally-regenerated pines. Hardwood stumps were mapped and inventoried for species identification, number of sprouts, height of dominant sprout, and crown diameter. A 0.004 ha plot was established in the center of each 0.01 ha

vegetation plot for an inventory of all regenerated woody stems-sprouts and seedlings.

Plant biomass was sampled in four 0.25 m x 4.0 m plots, located at all corners of each 0.01 ha vegetation plot (a total of 8 biomass plots per treatment area). All vegetation within these small plots was clipped at ground level and separated into categories: forbs, grasses, vines, shrubs, and trees. Samples were oven-dried at 80 degrees C for 48 hours, weighed, and ground with a Wylie mill using a 2-mm screen. Nutrient concentration was measured by the Clemson University Agricultural Chemical Services Department.

RESULTS AND DISCUSSION

Prior to ignition, ambient temperature and forest floor moisture content differed significantly between treatments. The low-severity burns occurred at midday when ambient temperature had not yet peaked, while high-severity burns occurred in the afternoon when the sun was most intense (Table I). Liier, duff, and soil moistures prior to low-seventy burns were significantly higher than those prior to the high-severity burns (Table I). The greatest difference occurred in moisture content of the litter layer which contained 65.2 and 5.2 percent for low- and high-severii burns, respectively.

The two burn treatments resulted in widely differing forest floor conditions. Low-severity burns consumed 73 percent of the liier layer and 30 percent of the duff layer. The low-severity areas had a blackened, charred appearance after burning, indicating partial to minimal forest floor consumption. The forest floor was 63 mm thick and mineral soil was exposed on less than 1 percent of the area. Less than half of the fine woody fuels (< 6 mm) was consumed.

In contrast, high-severity burns consumed 96 percent of the litter layer and 76 percent of the duff layer. After burning, high-severity areas had an ashy-white and brown appearance, indicating near total consumption of forest floor and visible exposure of mineral soil. These areas had a thin forest floor (11 mm) and mineral soil exposure on 47 percent of the area (Table 2). Virtually all fine fuels (< 6 mm) were consumed.

During the year after burning, 31 rainfall events occurred. Although total rainfall for the year was very similar for both treatments, sediment lost from the low-severity site was less than sediment lost from the high-severity site (Table 3). The sediment yield and percent rainfall lost as runoff are shown (Figures 1 and 2, respectively) for major rainfall events (> 25mm). Remarkably, infiltration rates remained high for both areas as shown by the small percentage of rainfall lost as runoff (Table 3 and Figure 2).

Three major storms accounted for 29 and 69 percent of annual sediment production from the low- and high-severity treatments, respectively (Figure 1). A storm on 22 July reached a 5-minute maximum intensity of 176.6 mm/hr (Figure 3). Sediment production from this storm was 2080.6 kg/ha on the high-severity site, 15 times the sediment loss on the low-severii site for the entire year.

Table 2--Pre- and post-burn forest floor characteristics for low- and high-severity burns

	Low severii	High severity
Liier depth		
Pm-burn	78 mm	29 mm
Post-burn	10 mm	<1 mm
Duff depth		
Pre-burn	76 mm	42 mm
Post-burn	53 mm	10 mm
Soil exposure	<1%	47%

Table 3--Total runoff and sediment loss for one year after burning (Sept 1991 - Sept 1992) for low- and high-severity burns.

	Low severity	High severity
Rainfall (mm)	1,358	1,352
Runoff (mm)	16.9	79.2
Percent of rainfall	1.2	5.9
Sediment loss (t/ha)	0.14	5.75

Plant biomass production was twice as high for the low-severii treatment after one growing season, the largest difference shown in forbs and grasses (Table 4). The forest floor on low-severii sites acted like mulch, limiting surface evaporation. Tree biomass was greater on high-severity sites, but not statistically significant. All sampled trees were hardwood sprouts emerging from stumps having well-developed root systems and less dependency on forest floor coverage than grasses and forbs.

Soil samples indicated no significant differences in nutrient content between the two treatments. Total nitrogen, phosphorous, and potassium (N,P,K respectively) content in all plants collected from low-severity sites was greater than those from high-severity sites due to larger biomass production (Table 5). However, concentrations of N, P, and K were significantly higher on high-severity sites, suggesting that moisture limited plant growth rather than nutrient availability. Conversely, lower concentrations of nutrients in plants on the low-severity site, where infiltration and water retention was higher, suggest that nutrients were limited.

The lower planted pine survival rate on low-severity sites probably resulted from greater competition from herbaceous growth. Height growth of planted pines was unaffected by fire severity (Table 6).

Hardwood regeneration was significantly different between the two treatments. Number of hardwood stems was 1.8 times greater on high-severity sites than on the low-severity sites (Table 7). This difference is probably a result of a greater number of stems prior to harvest, because the number of sprouts per stump was not affected by the burning treatment.

Table 4-Biomass production one growing season after low- and high-severity burns

	Low severii	High severii
	(t/ha)	(t/ha)
Grasses	0.41a	0.08 b
Forbs	0.66a	0.22 b
Vines	0.08a	0.08a
Shrubs	0.13a	0.01 b
Trees	0.39a	0.43a
Total	1.67a	0.79 b

Means followed by the same letter within a row are not significantly different at the 0.05 level.

Table 5--Plant concentration and content of nitrogen, phosphorous, and potassium (N,P, and K, respectively) for low- and high-severii burns

	Concentration(%)		Content(kg/ha)	
	Low Severity	High Severity	Low Severity	High Severity
Grasses				
N	1.06a	1.26 b	534.7a	251.4 b
P	0.08a	0.10 b	65.9a	32.8 b
K	1.07a	1.25a	1,284.9a	437.2 b
Forbs				
N	0.81a	1.15 b	439.3a	104.8 b
P	0.10a	0.15 b	33.2a	8.3 b
K	1.95a	2.00a	443.4a	104.0 b
Trees				
N	1.02a	1.19 b	397.6a	513.0a
P	0.09a	0.10 b	35.1a	43.1a
K	0.50a	0.78 b	230.0a	336.2a
All Plants				
N	1.01a	1.20 b	1,535.4a	954.4 b
P	0.09a	0.12 b	150.6a	93.4 b
K	1.17a	1.24a	2,080.9a	939.6 b

Means followed by the same letter within a row are not significantly different at the 0.05 level.

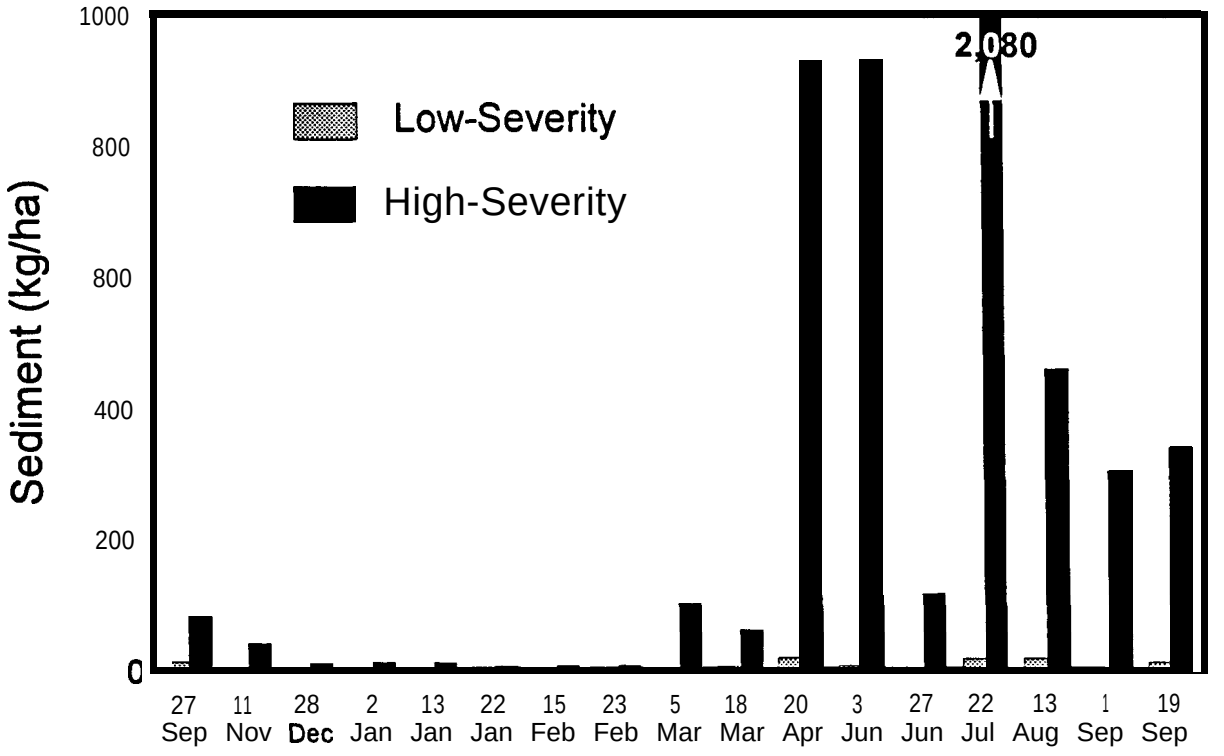

Figure I-Sediment produced (kg/ha) during 17 major rainfall events (September 1991 - September 1992) for low- and high-severity burns

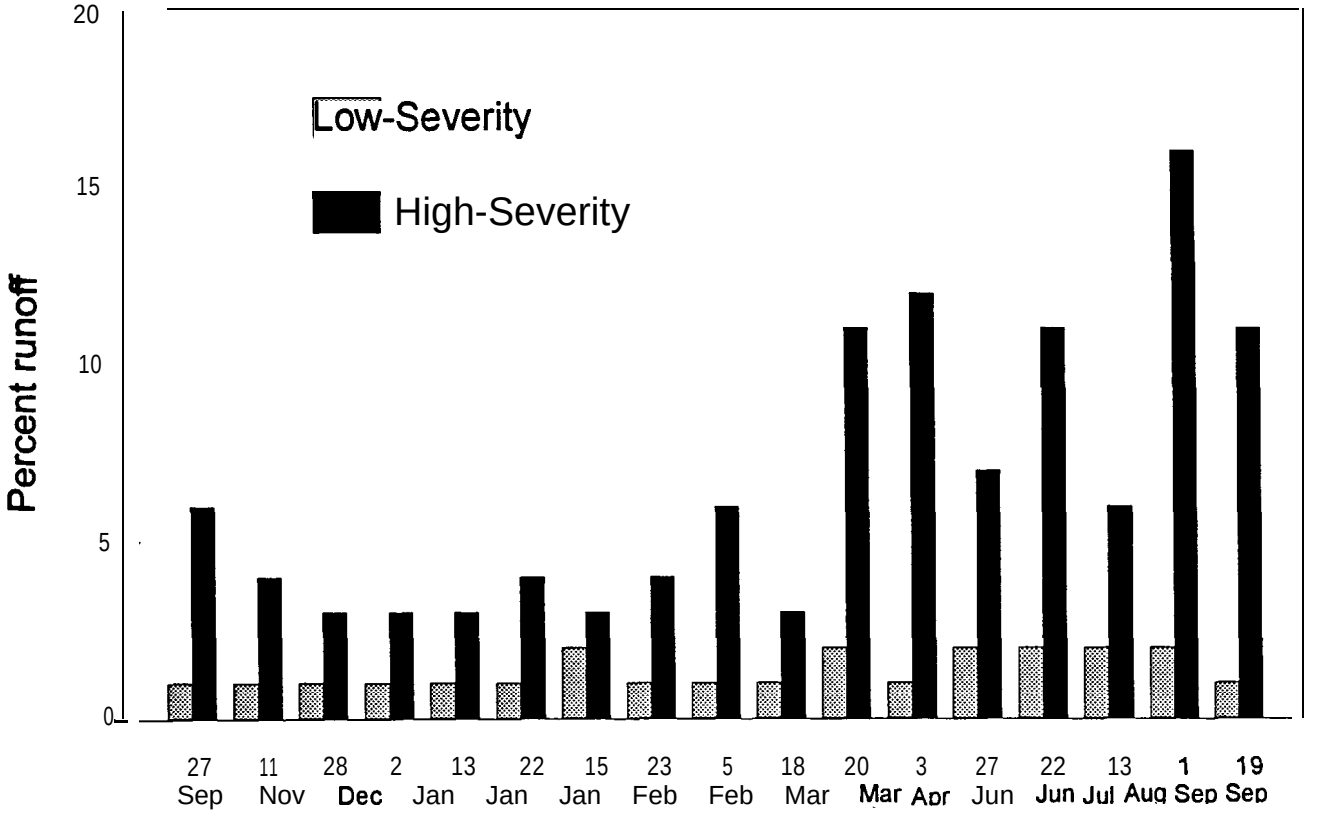

Figure 2-Percent rainfall lost as runoff on low- and high-severity burns for 17 major rainfall events (September 1991 - September 1992).

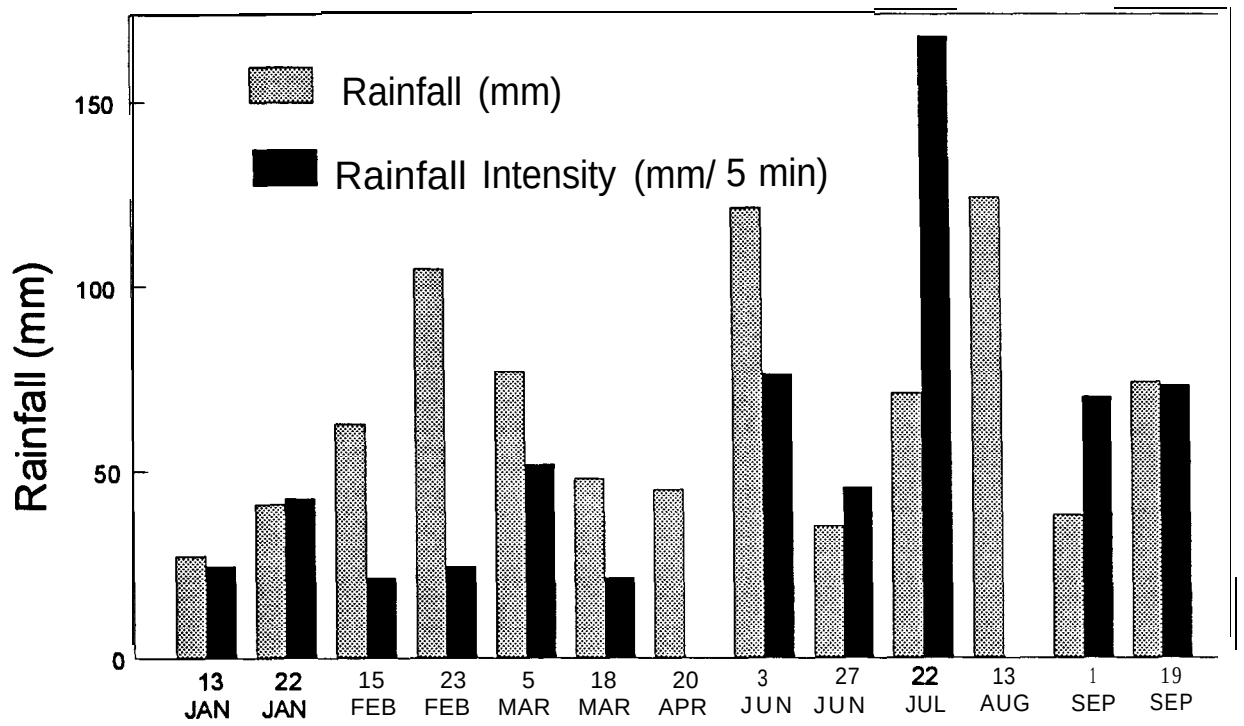

Figure 3-Rainfall and rainfall intensity for 13 major rainfall events (September 1991 - September 1992)

Table 6-Height growth and survival of planted pines

Fire severii	Height growth	Survival
	(cm)	(%)
High	27.9a	77a
Low	28.5a	58 b

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

Table 7-Hardwood regeneration after one growing season for low- and high-severity burns

Fire Severii	Blackgum	Oak	Other Hardwoods	All species
Stems per hectare				
High severity	1,704a	2,124a	4,026a	8,744a
Low severity	1,803a	1,309a	1,630 b	4,965 b
Sprouts per stump				
High severity	7.1a	6.5a	10.2a	8.5a
Low seventy	6.0a	7.3a	5.1 b	6.9a
Sprout height(m)				
High severity	1.0a	1.0a	0.9a	1.0a
Low severii	1.4 b	1.2 b	l.la	1.2 b

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

Height growth of hardwood sprouts was lower in high-severity burn areas compared to that on the low-severity burn areas (Table 7). Danielovich and others (1987) showed that the fell-and-burn technique significantly reduced the height growth of hardwood sprouts, because it shortened the growing season. Hardwood sprouts in burned treatment areas were significantly shorter than in unburned areas for all species and groups (Waldrop 1994). These findings suggest that spring felling of residuals and summer burning will significantly reduce hardwood sprout height-growth for at least the first growing season. Results also suggest that fire severity affects height-growth of hardwoods. However, these differences may result from the timing of the burns rather than their effect on growth rates.

CONCLUSIONS

This study suggests fire severity can have negative effects on runoff, sediment production, and site productivity. The high-severity treatment resulted in almost total consumption of litter and duff layers, excessive exposure of mineral soil, increased runoff, increased erosion, and lower biomass production. After high-severity burning, the thin residual forest floor decayed, exposing more mineral soil to erosion. Decay will probably continue until invading vegetation begins to rebuild the forest floor. Positive effects include increased pine survival rates and decreased hardwood sprout growth. By comparison, the low-severity treatment retained most of its forest floor, which

protected the site from erosion and runoff. This treatment also had greater biomass regeneration in addition to unburned slash, which formed debris dams reducing runoff and sediment movement. However, the survival of planted pines was reduced.

Long-term effects are still unknown. Planted pines on high-severity sites may lose vigor for several years, but may ultimately benefit from reduced competition. Since high-severity burns reduce overall short-term site productivity, they should probably be avoided. Burning prescriptions must be developed to protect the forest floor, and, therefore prevent erosion and other negative effects. Burning prescriptions in this study met regional standards for temperature and relative humidity, indicating the need for more site-specific standards. Liier and duff layer moisture content may be a more critical measure in protecting site quality than fuel moisture stick readings. Site-specific methods developed to prevent forest floor consumption based on weather and fuel conditions could reduce future losses in site and/or water quality.

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LEACHING FOREST SOILS WITH ACIDIC AND NON-ACIDIC SOLUTIONS'

G.L. Wheeler, T.T. Ku, and R.J. Colvin[2]

Abstract-M a different study, we found that forests in Southern Arkansas were being exposed to acidic deposition. To determine what effect acidic deposition might have on nutrient teaching rates, we collected cores from a Sacul loam at Hope and Monticello, Arkansas. The cores were leached with distilled water for four weeks and then for 26 weeks with an acidic solution with pH 4.0 and a "non-acidic" solution with pH 5.2. Potassium and sodium ware leached more with ths acid solutions. Ammonium behaved differently, there was greater ammonium loss from cores that received the non-acidic solution.

INTRODUCTION

The soils of the pine belt in Arkansas are generally believed to be at risk to acid deposition because of their low base saturation and potential exposure (Anonymous 1985, Beasley 1986). Acidic deposition causes accelerated leaching by removing cations from the soil exchange column and by adding paring anions.

In a long term study on nutrient cycles of pine forest in southern Arkansas, we found that rainfall pH had remained relatively constant at pH 5.4 over a ten year period. During the same period the pH of throughfall declined from about pH 5.4 to 4.5 and stemflow declined from 4.5 to 3.7. Given that forests in Southern Arkansas maybe experiencing acidic deposition, we were interested in knowing if it will cause accelerated leaching.

MATERIALS AND METHODS

We picked the Sacul loam, a Clayey mixed thermic, Aquic Hapludult for this study because of its accessibility and because of its importance in the southern pine belt. It is moderately well-drained with high water holding capacity. The Sacul has low natural fertilii and has a base saturation of 40%. A total of 28 cores were collected from five sites at Hope and two site at Monticello, Arkansas by driving a steel sleeve, containing a 15 cm section of 3.5 inch (8.2 cm id) PVC pipe, into the soil. The PVC pipe, soil core, and litter were removed from the soil and placed in plastic bags for transport to the laboratory. Before mounting the cores on plexiglass supports, small section of fiberglass wool was placed on the bottom of the cores, The cores were mounted on plexiglass with silicone glue over a small hole that was centered under the core and served for drainage.

The cores received 4.7 cm (248 gm) of solution weekly. The first four week the cores received distilled water to allow for a period of equilibration. Thereafter, cores received either an acidic solution (pH 4.0) or a "non-acidic" solution (pH 5.2). Both solutions had ionic strength and concentration similar to that for rainfall found by Wagner and Steele (1982) for Northwest Arkansas. The solutions differed in their pH and concentration of potassium and sodium, which were used in place of the hydrogen ion in the "non-acidic" solution. A 1 liter stock solution was prepared for each treatment and diluted each week to the appropriate concentration.

Each week, the leachate was collected, weighed, pH determined with a glass electrode, and the concentration of Al^{3+} Ca", Mg^{2+}, Na^{+}, K^{+}, Fe"', Mn", Cl, NO;, NH,+, SO_4^{2-} concentrations were determined. Ammonium was determined by steam distillation (Bremner 1965) and titration, the remaining cations by atomic absorption spectroscopy, and the anions by reversed-phase ion-pair chromatography (Perrone and Gant 1984, 1985).

The data presented have been adjusted for input amounts of a given cation or anion. The mean nutrient loss from week 5 through week 30 for each ion was computed for each core. These mean values were used in an analysis of variance. Statistical analyses were made with Procedure GLM (SAS Institute 1985). A significance level of 5% was used with all tests.

RESULTS AND DISCUSSION

Most of the elements did not respond to the acidity of the solution, and the pattern of leaching appeared to be random. Nitrate, Al", and Fe^{3+} had distinct patterns although there were no differences between solutions.

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[1]Paper presented at the Eighth Biennial Southern Silvicultural Research Conference, Auburn, AL, Nov. I-3, 1994.

[2]Associate Professor, University of Arkansas, Fayetteville; Professor, University of Arkansas at Monticello; and Research Assistant, Southwest Research and Extension Center (Respectively).

Nitrate was the dominant anion in the leachate. Nitrification began in most cores by week five, and the mean rate of nitrification increased until week 16 when the NO; concentration in the leachate reached ca. 50 mg/l. The NO; concentration in the leachate began to decline slowly after week 16. Al^{3+} (Fig. 1) and Fe" both increased initially in concentration and then declined to a minimal value by week 10 and remained there. This same pattern has been seen in other leaching studies (Wheeler and Lawson 1988) and it is probably caused by changes in redox potential when the core is removed from the soil.

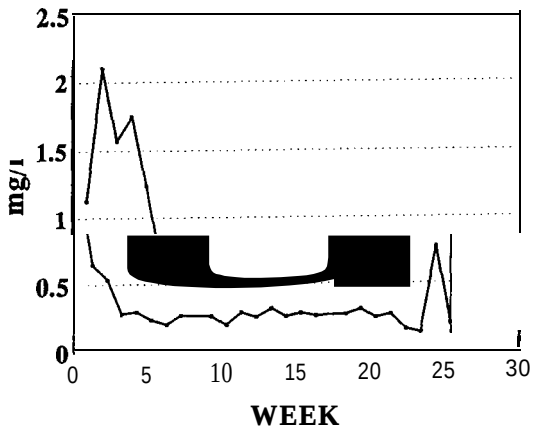

Figure I-Aluminum concentration in leachate.

Leachate pH, K^+, Na', and NH,'-N all differed between the acidic (Acid Rain) and non-acid solutions (Rain). As expected, the pH of the acid rain (pH 4.6) was lower that the rain (pH 4.9), but the difference was slight. The cores were absorbing H^+ ions in the acid treatment. The H^+ produced by nitrification may be obscuring any effect of solution pH.

There was net K^+ absorption in the cores receiving the rain solution between weeks six and 10 (Fig. 2). After week 10 there was a net loss from the rain treatment, and the weekly loss from both treatments was roughly parallel. The average weekly K^+ loss from the acid rain treatment was 309 mg, nearly 3.5 times greater than the rain treatment of 92 mg.

Na^+ in the leachate of both treatments increased initially, declined and separated by week nine (Fig. 3). After week nine the acidic treatment Na' in the leachate was generally greater than the non-acidic treatment. The average weekly loss from the acidic treatment was 67.5 mg compared to 47.0 mg in the non-acidic treatment.

NH,-N differed from the other variables in that it was greater in the rain treatment and it was more erratic (Fig. 4). During week 10, NH,'-N increased in the leachate, and the output from the rain was greater than

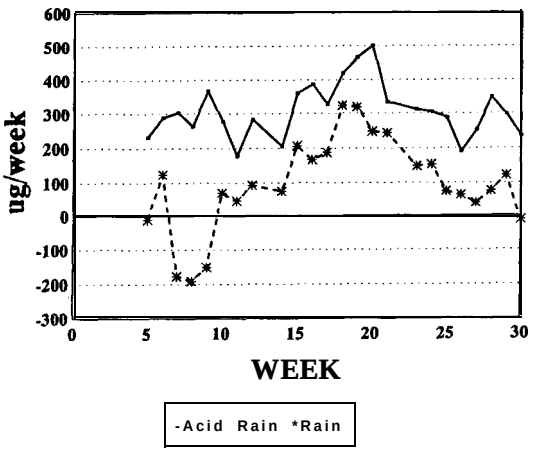

Figure 2-The weekly potassium loss from cores receiving acid rain or rain.

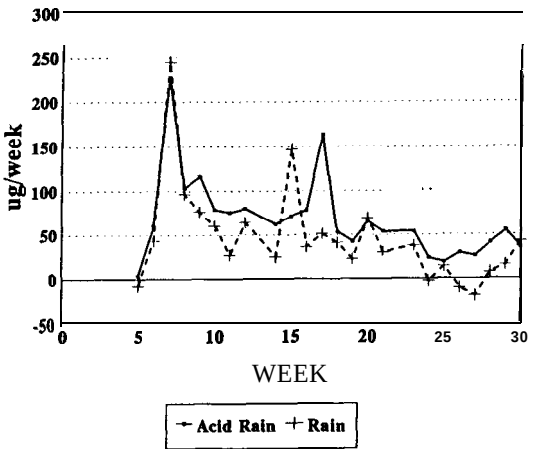

Figure 3--The weekly sodium loss from cores receiving acid rain or rain.

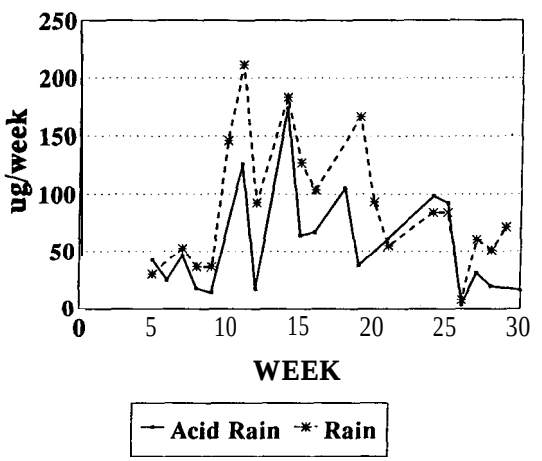

Figure 4--The weekly ammonium loss from cores receiving acid rain or rain.

that from the acidic rain until week 21. The treatments were similar until week 26, when the rain was greater again. The average weekly loss in the rain was 62 mg vs 17 mg in the acid rain treatment. The difference in NH,+-N between treatments suggests that there should also be a difference in NO; between treatments. However, this was not so.

SO_4^{2-} concentrations in the leachate differed little from the input solution concentrations when water loss was accounted for. As with pH, SO,* activity may have been masked by nitriication.

CONCLUSIONS

Nitrates from in situ nitrification was the dominant anion in the leachate. It is unclear what effect this has on the pattern of cation leaching that we observed.

Soil acts as a buffer raising the pH of an acidic leaching solution probably through cation exchange. Nitrification or cation exchange reduced the pH of the "rain" so that there was little difference between the pH of treatment leachates.

Both Na^+ and K^+ had elevated leaching by the acidic solution. The loss of Na' should be inconsequential. With sufficient exposure to acidic solution, the K^+ loss could be important.

NH,+-N in the leachate was less in the acidic solution. This indicates that either ammonification was inhibited or nitrification was enhanced by the acidic solution.

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FELLING AND BURNING TO PREPARE SOUTHERN APPALACHIAN SITES OCCUPIED BY MOUNTAIN LAUREL'

Donvilla L. Williams and Thomas A. Waldrop[2]

Abstract-This study tested felling of residual stems and summer site preparation burning as means of controlling mountain laurel (*Kalmialatifolia* L.) to facilitate the establishment of a pine-hardwood stand after clearcutting. Three replications of two treatments (fell-only and fell-and-burn) were established and measured after one, three, and seven growing seasons. Mountain laurel height was significantly less in the fell-and-burn plots than in fell-only plots. Both treatments appeared to reduce mountain laurel density and crown cover significantly. Pines and hardwoods grew well and overtopped the mountain laurel in both treatments. Burning significantly reduced the height of the hardwoods and increased the height of the pines, However, these differences were relatively small, indicating that burning may not be necessary if harvesting sufficiently damages the mountain laurel understory.

INTRODUCTION

As a result of fire exclusion, reduced grazing, and increased timber harvesting, mountain laurel (*Kalmia latifolia* L.) probably covers a larger area in the Southern Appalachian mountains today than ever before. This shrub commonly forms a dense understory that can interfere with the regeneration of commercially valuable trees. On the Andrew Pickens Ranger District, Sumter National Forest, in northwestern South Carolina, managers estimate that competition from mountain laurel reduces the amount of harvested land that can be regenerated by up to 15 percent. After clearcutting in the Southern Appalachians, a mountain laurel understory is often left standing because heavy machinery use on steep slopes is limited and chainsaw felling is expensive.

Several studies report attempts to control mountain laurel, but emphasis has been placed on expensive techniques. Wahlenberg (1950) found that mechanical means were successful in controlling laurel and rhododendron, but the cost was high. Sluder (1958) found that foliar and basal sprays were unsuccessful. Yawney (1962) was able to kill rhododendron with a basal spray of 2.4, 5-T, but according to Hooper (1969), the costs ran about $137 per acre.

Site preparation burning may provide an inexpensive means of controlling mountain laurel. Hooper (1969) noted that documented evidence of intentional burning in the mountains is limited. Keetch (1944) experimented with prescribed burning and found that a good stand of oak sprouts formed after one to three burns. However, fire intensity may be too low in dense sprout-clusters to top kill mountain laurel stems. Moreover, mountain laurel sprouts may out compete the desired pines and hardwoods after burning. This study tested felling of residual stems and felling plus summer burning as inexpensive ways to control mountain laurel and regenerate mixed pine-hardwood stands after clearcutting.

METHODS

Three stands supporting dense mountain laurel understories on the Andrew Pickens Ranger District in Oconee County, South Carolina were selected for this study. These stands were clearcut in 1986 and regenerated to pine-hardwood mixtures by the fell-and-burn technique (Abercrombie and Sims 1986, Phillips and Abercrombie 1987). Prior to harvest, the overstory was mixed oak and pine (Table 1) with a dense understory of mountain laurel (> 60 percent cover). The mountain laurel averaged 12.4 feet tall with 1,000 or more stems per acre (Table 2).

Each stand was a block in a randomized complete block design. To examine the effects of fire on mountain laurel regeneration, two treatments were installed in each block: 1) a fell-only treatment and 2) a fell-and-burn treatment. To measure stand development, three 14-x 14-meter measurement plots were established in each of the two treatments areas within each stand.

Contract crews felled residual stems in May 1987. All pine and hardwood stems over 5-feet tall were felled with chainsaws and left on study plots. Following Ranger District procedures, crews did not fell mountain laurel stems.

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'Forester and Research Forester, respectively, Southeastern Forest Experiment Station, Clemson, SC.

Table I- Species composition prior to harvest

Species	Stems	Basal Area
	(#/ac)	(ft^2/ac)
Oaks		
Scarlet	25	14.8
Southern Red	8	3.7
White	22	12.2
Pines		
Shortleaf	16	15.9
Virginia	9	3.4
White	14	5.5
Red Maple	46	6.4
Sourwood	54	11.3
Misc. Hardwoods	55	10.2
Total	249	83.4

Table 2--Number and height of mountain laurel sprout clumps by treatment and year

	Clumps (#/ac)			Heiaht (ft.)		
Sample Period	Fell & Burn	Fell	Only	Fell & Burn	Fell	Only
Preharvest	1,164a[1]	995a		12.0a	12.8a	
Year 1	409a	423a		0.6a	2.0	b
Year 3	551a	735a		1.7a	2.6	b
Year 7	355a	536a		4.3a	5.5	b

'Means followed by the same letter within a row are not significantly different at the 0.05 level.

Site preparation burning was conducted in July 1987 using the spot fire technique with aerial ignition by helitorch. Fire lines were plowed around fell-only treatment plots and pumper trucks were used to prevent spotting. Wind speeds ranged from 5 to 9 miles per hour and relative humidity was 55 percent. High intensity fires, with a maximum flame height 12 to 15 feet, removed most of the logging slash. However, because only the litter layer was consumed, the organic mat was left to protect against surface erosion.

White pine seedlings were planted at a 12 by 12-foot spacing (302 per acre) during the following winter.

Sample plots were measured at the end of one, three, and seven growing seasons after treatment (1988, 1990, and 1994). Measurements included height and number for pines, hardwoods (by species), and mountain laurel. Crown diameter was also measured for mountain laurel sprout-clusters. Regeneration has been documented from 1987 to 1994.

RESULTS

The harvesting and felling operations used in this study reduced mountain laurel presence more than anticipated. With the fell-only treatment, the number of mountain laurel sprout-clusters was reduced from 995 per acre prior to harvest to 423 per acre at the end of the first growing season (Table 2). Mean height of mountain laurel was reduced from 12.8 feet to 2.0 feet without burning. In study plots that were felled and burned, mountain laurel height was less than in fell-only plots and remained significantly shorter throughout the seven-year study period.

Crown cover of mountain laurel was reduced in both treatment areas from over 90 percent to less than 5 percent by felling and harvesting operations (Figure 1). In the fell-and-burn areas, crown cover was reduced to near-zero levels and remained significantly lower than in the fell-only areas throughout the study period (Figure 1). Mountain laurel crown cover remained below 30 percent in both treatment areas through seven growing seasons.

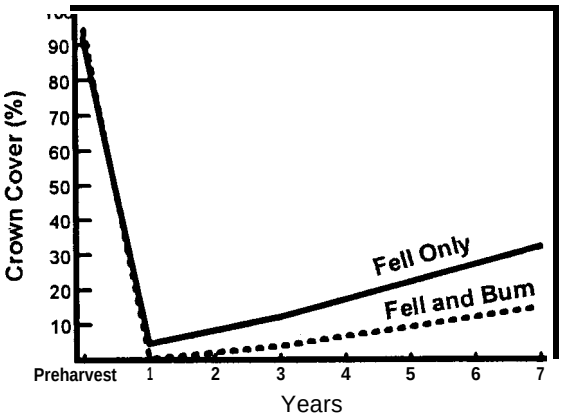

Figure I--Percent crown cover of mountain laurel by treatment.

Burning in this study reduced hardwood competition with planted pines more than it reduced mountain laurel abundance. Hardwood stem density during years one and three was significantly less in burned plots. However, this difference was not apparent at year seven (Table 3). Burning reduced the height of hardwoods by reducing the length of the first growing season. This difference was significant for all hardwood species for the first three years after treatment and for sourwood during the seventh year (Table 3).

While the difference in the survival of planted pines between the two treatments was not significant, height growth was greater in the fell-and-burn treatment plots

Table 3--Density and height of hardwood sprouts by species group, treatment, and year

	Density (#/ac)		'Heiaht (ft.)	
	Fell & Burn	Fell Only	Fell & Burn	Fell Only
YEAR 1				
Oaks	39a	**56a**	**1.7a**	2.5 b
Red Maple	**87a**	440 b	**1.8a**	4.3 b
Sourwood	**33a**	267 b	**1.6a**	3.9 b
Others	**32a**	315b	**2.2a**	3.0 b
Tot/Avg	**191a**	**1,078 b**	**1.8a**	**3.5 b**
YEAR 3				
Oaks	Oa	220a	---	4.7
Red Maple	**1,010a**	**1,450a**	**6.6a**	10.3 b
Sourwood	**550a**	310a	**4.4a**	**5.5a**
Others	330a	**1,530a**	**3.0a**	**4.6 b**
Tot/Avg	**1,870a**	3,510 b	**4.3a**	5.6 b
YEAR 7				
Oaks	292a	286a	**8.9a**	**6.3a**
Red Maple	596a	577a	**4.0a**	**5.9a**
Sourwood	247a	357a	**9.2a**	17.5 b
Others	**1,214a**	**1,660a**	**7.5a**	**6.5a**
Tot/Avg	**2,349a**	**2,880a**	**7.3a**	**8.2a**

Means for density or height followed by different letters within a row are significantly different at the 0.05 level.

(Table 4). During year seven, 245 pines per acre were counted in fell-and-burn treatment areas, but this was not significantly different from the fell-only treatment areas. A large number of volunteer pines was observed during the third growing season after treatment but these pines did not persist through year seven. Pine height growth was slow in both treatments during the first three growing seasons. By the end of the seventh year, however, pines in fell-and-burn treatment plots were significantly taller than in fell-only areas (13.6 feet vs. 11.2 feet). This difference probably results from controlling mountain laurel and hardwood sprouts provided by site preparation burning.

Table 4-Number and height of pines by treatment and year

	Density (#/ac)		Heiaht (ft.)	
Sample Period	Fell & Burn	Fell Only	Fell & Burn	Fell Only
Year 1	**302a**[1]	302a	**0.5a**	**0.5a**
Year 3	764a	332 b	**2.3a**	**2.1a**
Year 7	245a	292a	**13.6a**	11.2 b

[1] Means for density or height followed by the same letter within a row are not significantly different at the 0.05 level.

SUMMARY AND CONCLUSIONS

The results of the experiment indicate that burning can be used as a tool for temporary control of mountain laurel but it may not be necessary. The great reduction of mountain laurel by the harvesting and felling operations was unexpected. Hardwood density was less in burned plots through the third growing season but matched the fell-only areas after seven years. Hardwoods killed back by fire grew for only part of the first growing season. After seven years, pine density did not vary by treatment, but pine heights were significantly greater in burned plots. Although burning appears to reduce competition from mountain laurel, the minimal gains in pine height growth are probably not worth the extra expense and added risk of burning. Burning may prove beneficial in areas where harvesting does not damage mountain laurel understory as much as was observed in this study.

ACKNOWLEDGMENTS

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STRIP CLEARCUTTING IN BOTTOMLAND HARDWOOD FORESTS AS AN ECOSYSTEM MANAGEMENT TOOL -- A FIRST YEAR CASE STUDY'

Roger A. Williams[2]

Abstract-A strip clearcut was performed in an industrial bottomland hardwood stand. Based on basal area (ft^2/acre), the stand was comprised mostly of oak (55%) and gum (21%). One year after clearcutting the reproduction numbered 25,340 stems/acre in the cut strips, representing an 18 percent reduction in the total stems/acre. The oak reproduction per acre in the cut strips numbered 17,925 (71% of the total), displaying a 36 percent reduction in numbers. Significantly more reproduction occurred in the cut strips near the residual strip borders compared to that occurring in the center, with more stems occurring along the northern edge than thesouthern edge. However, more reproduction occurred in the taller height classes in the center of the cut strip than along either edge.

INTRODUCTION

Many of the southern bottomland hardwood forests are in poor condition as the result of past high-grading practices. The earliest loggers in the bottomlands took only the largest of the best species, gradually lowering their quality over time. These practices have generally continued to the present time. In the recent past only about 20 percent of the hardwood land supported trees of good form and vigor and of acceptable composition (Smith and Linnartz 1980).

The current best recommendations that have been afforded to achieve quality natural regeneration is a simple matter of complete removal of the overstory, including all weed trees, because reproduction of desirable species (i.e., green ash and the oaks) is usually present and other reproduction will develop rapidly from sprouts (Barrett 1980). Clearcutting as a natural regeneration method for southern bottomland hardwood forests, usually in the form of block clearcutting, has been widely recommended as being reasonably effective for reestablishing and even increasing the most valuable hardwood species (Kellison et. al. 1981, Toliver and Jackson 1989, Golden and Lowenstein 1990), although the results have not always been satisfactory (Gresham 1985).

Recently, this silvicultural practice, as well as others, has been going through a renaissance as the forestry profession becomes more intensively focussed on the long-term health and sustainabilty of forest ecosystems. The term forest ecosystem management has recently been added to the working dictionary of foresters as other components of the forest ecosystem besides trees, i.e., water quality, role of natural disturbances, woody debris, non-game wildlife, etc., become placed upon forest management agendas. Certainly no other silvicultural system can have greater impact upon a riparian forest, such as some bottomland hardwoods, as that of block clearcutting. This is due to the resulting harsh change that occurs in these environments as it pertains to habitat requirements, aesthetics, and soil and nutrient losses. However, clearcutting is an important and legitimate tool in the forester's box of techniques when it comes to managing either for timber or wildlife. Therefore, the purpose of this study is to examine a modification to block clearcutting in the form of strip clearcutting and determine its effectiveness in regenerating bottomland hardwood forests satisfactorily.

METHODS

An industrial bottomland hardwood forest in north Louisiana that was ready for a harvest was chosen for this study installation. The cut strips were oriented in an east-west direction so that the cut areas would be exposed to sunlight throughout the day. Five strips were cut at a width of 132 feet (2 chains) during the late summer of 1992, with the residual strips likewise 132 feet in width. Each cut strip was 1,320 feet in length, producing a total cut area over the five strips of 20 acres. The 132-foot widths were chosen in order to make strips wide enough to produce an economical harvest, but not too wide to prevent sufficient seeding-in from the residual strips and adjacent forests.

Due to harvest scheduling conflicts and weather, the strips were cut before permanent measurement plots could be installed. Therefore, overstory and regeneration plots were installed following harvest in the residual strips in an attempt to quantify the forest

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Table I. Stand summary of the overstory prior to strip clearcut harvest as characterized by the residual strips

Species	Trees per acre: Number	Trees per acre: Percent of total	Basal area: Ft^2 per acre	Basal area: Percent of total	Average stand diameter (inches)
Oak[a]	41	56.2	48.2	55.0	13.9
Gum[b]	I6	21.9	18.5	21.1	13.2
Hickory	2	2.7	3.1	3.5	16.4
Elm[c]	2	2.7	0.7	0.8	9.7
Ash[d]	1	I.4	0.4	0.4	9.8
Other[e]	I I	15.1	16.8	19.2	16.4
TOTAL	73	100.0	87.7	100.0	14.7

'Oak species include Quercus *lyrata*, *Q. nigre, Q. pagoda*, and Q. *phellos*.
[b] Gum species include *Liquidambar styraciflua* and Nyssa *sylvatica*.
[c] Elm species include *Ulmus americana* and *U. elate.*
[d] Ash species include *Fraxinus pennsylvanica* and *F. americana*.
[e] Other species include Se/ix *nigra* and *Taxodium distichum*.

condition before harvest. Permanent regeneration plots were established in the cut strips also at this time.

Five transects were located across and perpendicular to the direction of the cut strips. Each transect was equally spaced apart as reasonably as possible. The first transect was located from the front of the cut at a distance of 2 chains, wlth each successive transect located at a distance of 3 chains. Three permanent mil-acre regeneration plots were located along these transects in each of the cut strips, with one plot located in the center of the cut strip, and the remaining two plots at a distance of 0.5 chains from the edge of the residual strips on either side of the center plot. One permanent 0. I acre overstory plot was located along these same transects in the center of each residual strips, with a mil-acre regeneration plot located about the same center as the overstory plot.

On the overstory plots in the residual strips, diameter at breast height (dbh) was measured to the nearest 0.1 inch with a diameter tape, and species recorded. On all regeneration plots, a total count of stems were recorded by species, and each stem was placed in one-foot height classes.

Cherrybark oak (Quercus *pagoda* L.) seedlings (I-O stock) were planted after harvest to supplement the natural regeneration. Cherrybark oak was only present as a minor component prior to harvest as the result of past high-grading, and was a desired species to regenerate. Twenty-five of these seedlings were tagged throughout the cut strips and measured. Total height was measured to the nearest 0.1 foot and the diameter at groundline was measured with small calipers to the nearest 0.1 inch. Height and diameter measurements were not recorded et the time of planting, but were recorded only one year after planting. Since second-year data collection is not completed at thii time, survival and growth data are not reported in this paper, but will be reported in subsequent reports.

RESULTS

The stand summary of the overstory prior to harvest as characterized by the residual strips are displayed in Table I. The bottomland hardwood in this study had a basal area of 87.7 ft^2 per acre with 73 trees per acre and an average stand diameter of 14.7 inches. Oak species (overcup oak *(Quercus lyrata),* water oak (Q. *nigre),* cherrybark oak (Q. *pagoda*), and willow oak (*Q. phellos*)) made up over half of the total basal area and the number of trees per acre. Of these oak species, water oak was by far the predominant species, accounting for 85.7 percent and 87.6 percent of the number of oak trees per acre and the oak basal area per acre, respectively (Table 2). Of the 30,785 stems of regeneration per acre counted within the residual strips, 91.4 percent of these stems comprised of oak species (Table 3). In addition to the oak species represented in the overstory, other oak species (swamp chestnut oak (Q. *michauxii*), white oak (Q. *alba*), southern red oak (Q. *falcata*)) were present in the reproduction. Of this oak reproduction, water oak accounted for the largest representation (84.3%) of the oak species (Table 4).

Total number of reproduction stems per acre one year after harvest in the cut strips was 25,340 (Table 5). This compares to 30,785 stems per acre before harvest, or a reduction of about 18 percent. Oak reproduction was reduced to 17,925 stems per acre as compared to

Table 2. Stand summary of the overstory Oak component prior to strip clearcut harvest as characterized by the residual strips

Oak Species	Trees per acre: Number	Trees per acre: Percent of total	Basal area: Ft^2 per acre	Basal area: Percent of total	Average stand diameter (inches)
Water	36	85.7	42.2	87.6	14.1
Willow	4	9.5	4.8	10.0	14.5
Cherrybark	1	2.4	1.0	2.1	11.3
Overcup	1	2.4	0.2	0.4	6.7
TOTALS	42	100.0	87.7	100.0	13.9

Table 3. Stand summary of reproduction within the residual strips

Species	Stems per acre: Number	Stems per acre: Percent of of total	Average height class (feet)
Oak'	28,143	91.4	1.3
Elm[b]	929	3.0	3.3
Gum[c]	57	1.2	2.2
Maple[d]	143	0.5	3.0
Ash'	71	0.2	12.0
Hickory	71	0.2	1.0
Other'	1,071	3.5	1.9
TOTALS	30,785	100.0	1.5

"Oak species include *Quercus nigra, Q. phellos, Q. pagoda, Q. lyrata, Q. michauxii, Q. alba,* and Q. *falcata.*

[b]Elm species include *Ulmus americana* and *U. alata.*

[c]Gum species include Nyssa *sylvatica* and *Liquidambar styraciflua*

[d]Maple species is *Acer rubrum*

"Ash species include *Fraxinus pennsylvanica* and *F. americana.*

'Other species include *Cephalanthus occidentalis, Styrax grandifolius, Taxodium distichum, Carpinus caroliniana, Ostrya virginiana,* and *Fagus grandifolia.*

Table 4. Stand summary of the oak reproduction component within the residual strips

Species	Stems per acre: Number	Stems per acre: Percent of total	Average height class (feet)
Water Oak	23,714	84.3	1.2
Willow Oak	2,571	9.1	1.3
Overcup Oak	857	3.0	2.7
Cherrybark Oak	643	2.3	0.5
Swamp Chestnut Oak	214	0.8	1.7
White Oak	72	0.3	1.0
Southern Red Oak	72	0.3	0.5
TOTALS	28,143	100.0	1.3

Table 5. Reproduction summary in the cut strips one year after harvest by species

Species	Stems per acre: Number	Percent of total	Average height class (feet)
Oak[a]	17,925	70.7	1.6
Gum[b]	1,377	5.4	4.4
Ash[c]	774	3.1	4.5
Elm[d]	755	3.0	2.8
Maple[e]	717	2.8	2.0
Hickory	377	1.5	1.8
Other[f]	3,415	13.5	3.2
TOTALS	25,346	100.0	2.9

'Oak species include *Quercus pagoda, Q. nigra, Q. phellos, Q. michauxii, Q. falcata,* and Q. *Iyrata.*
[b]Gum species include *Nyssa sylvatica* and *Liquidambar styraciflua*
[c]Ash species include *Fraxinus pennsylvanica* and *F. americana.*
[d]*Elm* species include *Ulmus americana* and *U. alata.*
[e]Maple species is *Acer rubrum*
[f]Other species include *Cephalanthus occidentalis, Styrax grandifolius, Taxodium distichum, Carpinus caroliniana, Ostrya virginiana, Fagus grandifolia, Halesia diptera, Caikarpa americana, Dyospyros virginiana, Ilex opaca, Cornus florida,* and *Forestiera acuminata.*

28,143 stems per acre before harvest, or about a 36 percent reduction in numbers. Of the oak reproduction following harvest, water oak represented 73.5 percent of the oak reproduction, followed by willow oak (13.3%) overcup oak (10.8%), and cherrybark oak (1.7%) (Table 6). Swamp chestnut oak and southern red oak together accounted for less than one percent of the oak reproduction.

The total height of all reproduction were placed into even one-foot height classes. However, averages were calculated by species to obtain the closest average height class. These results indicated that the average height of all reproduction fell dose to the 3-foot height class (2.9) (Table 5). Species showing the largest average height were the ashes and gums, displaying an average height class of 4.5 and 4.4 feet, respectively. The oak species displayed the lowest height class of all species at 1.6 feet.

When comparisons were made between plot data on the north aide, south side, and center of the cut strips, reproduction *numbers were* higher along the strip borders than in the center (Table 7), with 35,320 stems per acre and 23,180 stems per acre on the north side and south side of the cut strips, respectively. This

Table 6. Oak reproduction summary in the cut strips one year after harvest.

Species	Stems per acre: Number	Percent of total	Average height class (feet)
Water oak	13,170	73.5	1.6
Willow oak	2,377	13.3	1.4
Overcup oak	1,943	10.8	1.5
Cherrybark oak	302	1.7	1.1
Swamp chestnut oak	76	0.4	4.8
Southern red oak	57	0.3	1.0
TOTALS	17,925	100.0	1.9

Table 7. Reproduction summary in the cut strips" one year after harvest by location within the cut strips (north or south side, or center)

Location	Stems per acre	Average height class (feet)
North Side	35,320	2.1
Center	16,350	2.6
South Side	23,180	1.7

[a] Cut strips were oriented east-west.

compares with 16,350 stems per acre of reproduction in the center of the strip. How much the shelter of trees in the residual strips affects the survival of reproduction is unclear at this time. However, trees in the residual strips, including the heavy-seeded species, are apparently providing seed for new regeneration one year after harvest. This may also explain why the average height classes of trees along the cut borders display shorter heights as the result of more newly germinated seed. The average height class of trees in the center of the strip displayed the greatest height on average, possibly as the result of more sprout-origin reproduction and advanced regeneration as compared to newly germinated seedlings.

DISCUSSION

First-year results would indicate that sufficient regeneration is becoming established in the cut strips of desirable species, even though the numbers are reduced as compared to what was possibly present before harvest. The seeding-in of species from the adjacent residual strips appears to be taking place along the cut borders.

Strip clearcutting has been an effective means of employing the clearcut method in northern hardwoods (Leak et. al 1969). The recommended cut widths for northern hardwoods has varied from 50 to over 130 feet (Leak et. al. 1969, Barrett 1980). This has included species to regenerate such as oaks, hickories, maples, birches, beeches, ashes, yellow-poplar, black cherry, and basswood. Residual strip widths should, in general, be at least as wide as the height of the timber (Smith 1962) to provide a sufficient seed source as well as make these strips more wind firm.

In addition, good future planning would be required to insure a sustainable flow of wood to the market. In this case study, a total of 20 acres was harvested. It might require the similar cutting of an another tract to achieve the cut volume from a 40 acre block. The management scenario here would follow that once the next forest has become established and in these cut strips and a particular growth and size has been attained, then the residual strips from the first harvest could be cut. Furthermore, the residual strips must contain enough timber to make the second or even third operation practical as a logging proposition.

Strip clearcutting may become a part of a management regime over a landscape that minimizes effects of habitat fragmentation, and may be demonstrated as an alternative to large block cuts in this regard. It also provides advantages other than its ease of application, effectiveness in providing regeneration, and the minimizing of habitat fragmentation. Esthetics are of greater concern than in the past. The remaining residual strips provide a view that appears to be not as devastating as a large block clearcut even though the appearance of residual strips do not provide a natural look. Still, the disturbance from logging is not so apparent.

Strip clearcutting may have a lesser impact on water quality in bottomland hardwoods than block clearcuts. Hornbeck et. al. (1975) found that erosion and stream sedimentation following strip clearcutting was significantly less than that produced from larger block clearcuts. Although, it is possible with the use of best management practices when performing block clearcuts to effectively protect the site and stream quality (Pelren et. al 1990).

It is generally recognized that group selection and clearcutting in small patches are most conducive to improvement of wildlife habitat, especially for deer and turkey. Clearcutting produces a substantial number of stems for spring browsing and supplies more winter forage than uncut areas. However, clearcutting greater than 50 acres can produce such an abundance of growth that the regeneration soon becomes too dense and is relatively inaccessible to deer (Barrett 1980), particularly toward the middle of the cut area. At the same time, desirable browse in small clearcuts (1 acre) quickly declines due to intense deer utilization and overstory competition. This would suggest that medium clearcuts would provide the optimum since they produce ample browse that remains available for a longer period of time. A series of cut strips should accommodate this latter scenario by providing successive narrow cuts in long strips. Krefting and Phillips (1970) found that strip clearcutting produced this best scenario for deer habitat when compared with selection, diameter- limit, shelterwood, and block clearcut systems.

The use of strip clearcutting shows a potential of means of maintaining corridors between adjacent ecosystems instead of interspersing large blocks across the landscape. The effectiveness of such corridors would be dependent upon the organisms being considered. Narrow strips may, however, still provide a deterrent for some larger organisms. But, when considering natural landscapes, ecosystems display much more connection to each other than those heavily shaped by humans (Noss 1987).

CONCLUSIONS

A consideration of how readily a forest will become established on a site after a disturbance such as a clearcut should be made. In forest ecosystems where large-scale disturbances are common place block clearcutting should not be a problem. However, in forest ecosystems where small-scale disturbances are the norm could present problems. The problem of a harsh change in the environment can be ameliorated to some extent by the shelterwood or seedtree methods (Hunter 1990). Strip clearcutting may likewise provide an ameliorating effect over the harsh environmental change created by block clearcutting, and still provide the necessary means of converting abused, unproductive hardwood forests into productive stands.

The first-year results of this study show that regeneration in manageable numbers and species composition can be accomplished through strip clearcutting. The challenged for forest managers will be to determine how to implement this regime in management strategies where block clearcutting has been the norm.

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