Proceedings of Pine-Hardwood Mixtures: A Symposium on Management and Ecology of the Type

Atlanta, Georgia
April 18–19, 1989

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Proceedings of
PINE-HARDWOOD MIXTURES:
A SYMPOSIUM ON MANAGEMENT AND ECOLOGY OF THE TYPE

Edited by
Thomas A. Waldrop

Atlanta, Georgia
April 18-19, 1989

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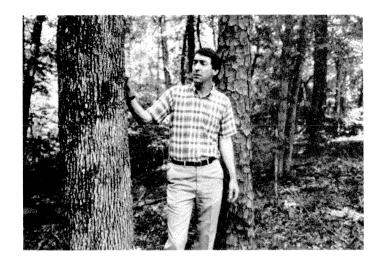
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PREFACE

Pine-Hardwood Mixtures: A Symposium on Management and Ecology of the Type was held on April 18 and 19, 1989, in Atlanta, GA. The meeting was attended by over 200 land managers, wildlife managers, and researchers. Thirty-seven papers and eight posters were presented over a period of one and one-half days. Subject areas included Silviculture and Ecology; Wildlife; Growth and Yield; and Management.

The purpose of the symposium was to stimulate interest in management and ecology of pine-hardwood mixtures. Papers were selected by the planning committee from abstracts submitted prior to the meeting. Preference was given to papers that would identify current research and present research results on silvicultural practices, environmental effects, wildlife interactions, and productivity. Other papers were selected to provide examples of management approaches, describe biologic and geographic limits of the pine-hardwood type, and identify research needs. Authors followed the review policies of their individual institutions, and the proceedings editor checked each paper for form and completeness.

The planning committee gratefully appreciates the efforts of authors and reviewers which contributed to a successful and informative program. Our appreciation is also given to Sara Baldwin, Timothy Evans, Donn Geisinger, John Haney, Darla Miller, Beth White, and David White for an excellent job of operating audio-visual equipment. A special note of thanks is given to the moderators who provided additional insight to each topic and kept the concurrent sessions on schedule. Moderators included: Gilbert P. Dempsey of the Northeastern Forest Experiment Station; M. Boyd Edwards, Jr., of the Southeastern Forest Experiment Station; David C. Guynn, Jr., of Clemson University; William L. Hafley of North Carolina State University; David Wm. Smith of Virginia Polytechnic Institute and State University; and Klaus Steinbeck of the University of Georgia.

DEDICATION TO DOUGLAS R. PHILLIPS

Douglas R. Phillips
1943-1988

Douglas R. Phillips was a native of Jefferson, NC. He received his Bachelor's degree from N. C. State University at Raleigh in 1965. His forestry career started at the Southeastern Forest Experiment Station as a group leader in Forest Survey. After a few years in the field, he returned to N. C. State University and received his Master's degree with the hope of getting into forestry research. Upon completion of his degree, he was assigned to the Wood Quality Research Work Unit at Athens, GA. I served as Doug's supervisor on his first research project in 1969, and watched him develop into a very productive research scientist with a great deal of curiosity, energy, and leadership qualities. Doug's leadership qualities were recognized early on and he was appointed as Project Leader of the Silvicultural Guidelines for Managing Piedmont Hardwoods Work Unit at Clemson, SC. While at Clemson, Doug was encouraged to pursue his Doctorate which he undertook while working full time. He became the first forestry Ph.D. graduate at Clemson University in 1985. During his tenure at Clemson, he established a new research work unit to study the silviculture and management of pine-hardwood mixtures in the Piedmont. In 1987, his leadership qualities were once again recognized and he was promoted to Research Coordinator for the Programs and Legislative Branch of the RPA staff in Washington, DC. Doug saw the advantages that could be realized from the pine-hardwood mixture concept and promoted its use through his research. It was his idea that this symposium on the ecology and management of pine-hardwood mixtures be held. It was unfortunate that he was unable to see the fruits of his labor since he died of cancer at the age of 44 in 1988.

It is fitting and proper that we dedicate these proceedings to Doug, a very lovable man, with a great sense of humor, vision, and dedication to his work and family. His memory will be perpetuated through contributions made by his friends to the Douglas R. Phillips Award for Graduate Students in Forestry at Clemson University.

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Moderator:

F. Thomas Lloyd
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ECOLOGY OF THE PINE-HARDWOOD TYPE

Arthur W. Cooper[1]

Abstract. — The mixed pine-hardwood type occurs over a wide array of soils and in a number of geographic regions in the Southeastern United States. During most recent full glacial time, genera and species now composing the type were confined to the Lower Coastal Plain of the gulf states. Rapid northward migrations followed glacial retreat and present species distributions in the Southeast were reached about 5,000 years ago. The vegetation of the Southeast before settlement by Europeans was heavily influenced by fire and other natural disturbances. On the Coastal Plain it consisted largely of longleaf pine savannas and woodlands, whereas a transition zone of longleaf and other pines mixed with hardwoods in savanna woodlands occurred along the edge of the largely hardwood dominated forests of the Piedmont plateau. Virtually all of this open pine and pine-hardwood forest is now gone. The present forests of the Southeast are classified into two regions. In the Oak-Pine region of the Piedmont stands of oak and hickory mixed with pine are dominant. The Southeastern Evergreen Region covers most of the Coastal Plain. Here, in the absence of fire, succession produces a mixture of pine and pine-hardwood types on the uplands. When distrubance is eliminated upland succession often leads to a mixed forest composed of many of the common Southeastern hardwoods.

Management of mixed pine-hardwoods can produce a number of benefits. Since the type develops naturally, its management does not usually involve large investments for establishment and hardwood control and the environmentally-controversial practices associated with plantation forestry. Mixed stand management also leads to stands that have greater diversity than plantations. Mixed stands have more niches and micro habitats, are genetically more diverse, and have greater variety in species composition and architecture than plantations. Management of mixed stands also allows the forester opportunities to create diversity and promote more varied wildlife populations. Mixed stands, under many circumstances, offer the landowner a management opportunity that is not only closer to his or her personal reasons for owning forest land but also may be financially more attractive. Consequently, emphasis on mixed stand management may bring more acres into production than would persistent efforts to promote plantations. Successful mixed stand management will require more silvicultural skill and knowledge and better growth and yield information than we now have. It will also require greater sensitivity on the part of foresters to the concerns of private landowners. Foresters must learn to incorporate land owner desires and those of the public into management practices rather than forcing their views on society.

INTRODUCTION

To discuss the ecology of pine-hardwood mixtures is a daunting task. The type occurs in most of the major forest regions of eastern North America and involves literally thousands of species, hundreds of soil types, and a number of climatic zones. When these are coupled with the wide array of impacts man may induce, the breadth required of a competent treatment is substantial. Furthermore, another paper on the program will discuss several significant aspects of the subject. Consequently, I will limit the scope of my comments by discussing in detail the pine-hardwood type in the Southeastern United States and some of the ecological and social benefits, both real and perceived, to be derived from a greater emphasis on management of the type. As should be clear, the standard against which management of the pine-hardwood type is measured is pine plantation management as it is now practiced throughout the Southeast. Although it would be productive to consider the pine-hardwood mixtures of New England and the Lake States, to do so would be more than can comfortably be handled in my alloted time.

EVOLUTION OF THE SOUTHEASTERN PINE-HARDWOOD TYPE

Although the genera, and even some of the species, that combine to make up the vegetation types of the present Southeastern pine-hardwood region have probably existed for millions of years, the forest types which we are now managing have existed for much shorter periods of time. Major climatic changes, ecological factors such as soil type, topography, and fire, and man's ability to alter the operation of these factors have combined in different ways at different points in time to produce an ever-changing landscape. In fact, given what we now know about the likelihood of climate change in the future, it is quite likely that our landscape will continue to change.

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In beginning our consideration of the history of the Southeastern pine-hardwood region, we must go back to the beginning of the most recent full glacial episode 50-100,000 years ago. At that time ice sheets began their slow movement south. Whatever vegetation existed at that time also migrated southward ahead of the advancing ice. This last cycle of glaciation, the Wisconsinan, reached its greatest extent about 20-18,000 years ago. At that time ice extended from the Rockies in Canada across the northern plains and then southward to southern Illinois, Indiana, and Ohio and thence eastward across southern New York and northern Pennsylvania to Long Island.

Although there has historically been much debate about what the forest types of the Southeast were during this full glacial time, it is now generally agreed that they were very different in composition and distribution than they are now (Delcourt and Delcourt 1979). The maximum displacement of eastern deciduous species occurred between 22,000 and 16,500 years ago (Delcourt and Delcourt 1979). Throughout most of the Piedmont and Upper Coastal Plain as far south as South Carolina boreal species of spruce and jack pine were the dominants. This type extended in a broad belt from Missouri to North Carolina and northward to a line running south from southern Minnesota, southern Illinois, Indiana, and Ohio to Pennsylvania.

The species that now comprise the eastern deciduous forest were confined to relatively small populations in the Lower Coastal Plain of the gulf states and Florida. During full glacial time, xeric oak-hickory woodland occurred in the Gulf Coastal Plain from central Texas to south Georgia and southern yellow pines persisted on the Alabama Coastal Plain (Delcourt and Delcourt 1979). Populations of oak-hickory type in Texas and Louisiana were isolated from those on the Gulf Coast (Delcourt and Delcourt 1979). Large portions of the Southeast were also much more arid than they are now (Davis 1981). The vegetation of the zone between the oak-hickory-southern yellow pine woodland and the spruce-fir-jack pine forests is not known, but Delcourt and Delcourt (1979) speculate that it was a tension zone somewhat similar to the northern hardwood zone of today's Lake States.

Retreat of the continental glaciers 16-10,000 years ago was rapid and accompanied by an equally rapid migration of species northward. In the extreme south, boreal species essentially disappeared by 15,000 years ago and were replaced by deciduous forest species. In the latitude of North Carolina and through most of the Piedmont and Upper Coastal Plain spruce and pine forests were replaced by components of what we now call northern hardwoods (beech, hemlock, sugar maple) by 10,000 years ago. Pollen data suggest that at that

time these forests may have contained southern genera such as *Liriodendron* and *Liquidambar*, and oaks and hickories and thus were not like the true northern hardwoods of today (Delcourt and Delcourt 1979). Over the next 5,000 years, northern hardwoods were replaced by the species that now compose the mixed oak-hickory and pine forests of the southeast. The Mixed Mesophytic forest migrated to its present location in the Cumberland and Alleghany Plateaus. A period of warming and drying about 5,000 years ago led to final elimination of most cool temperate genera from the Southeast. Presumably, changes occurring during the past 5,000 years led to development of the pre-settlement forest types of the Southeast.

There have been few extensive studies of the presettlement vegetation of the Southeast. The studies that have been done show that presettlement Southeastern forests were subject to much higher degrees of disturbance, particularly by fire, than might have been supposed. For example, Ware and others (in press) show that 97% of the Coastal Plain uplands and parts of the Piedmont was once covered by fire-influenced vegetation such as pine savannas and woodlands. Only 3% of the area was covered by Southern Mixed Evergreen Forest, which has been considered by many to be the "climax" type of the Coastal Plain. Longleaf pine, which was once the most abundant tree of the Coastal Plain, now occurs in only about 1% of its original range. Fire-influenced communities have declined throughout the 400 years that Europeans have been in the South. From this, one can infer that the view that succession in the Coastal Plain will lead to hardwood dominated forests essentially free of pine, although perhaps theoretically correct, will occur only if protection from fire is rigorously pursued. In the presence of fire, which was the normal state of affairs in the Coastal Plain prior to European settlement, forest types will tend more toward pure stands of pine or mixtures of pine and hardwood than pure stands of hardwood. Ware and others (in press) point out that in the Coastal Plain hardwoods were once mostly confined to the edges of swamps and their expansion into upland areas occupied by pine has occurred in the absence of fire and logging. These circumstances have led to the concept of a mixed hardwood forest as the "climax" type of the Coastal Plain.

Ware and others (in press) show that there were two major regions of presettlement forest within what is now the southern yellow pine region. The largest of these was a zone covering most of the Atlantic and Gulf Coastal Plain from southeastern Virginia to east Texas in which longleaf pine was the dominant species. Many ecologists refer to this region as the Southern Mixed Hardwood Forest. This zone was a "mosaic of pine savannas, sandhills and flatwoods", within which other, more

localized communities were mixed (Ware and others 1989). Between this vast region dominated by longleaf pine and the oak-hickory-shortleaf pine forests of the interior of the Piedmont Plateau lay a transitional forest in which longleaf pine in almost equal proportion was mixed with hardwoods (Ware and others 1989). This was not what we now call mixed pine and hardwoods, which occurs largely following logging, but a savanna woodland with varying mixtures of dominants including longleaf, shortleaf, and loblolly pine, post, white, and southern red oak, hickories, and scrub oaks (Ware and others 1989). The forests of this region were eliminated by logging many years ago. It is essentially gone from the landscape and no remnants of it are preserved anywhere.

PRESENT FOREST TYPES OF THE SOUTHEAST
From an ecological perspective, the area covered by the pine-hardwood type that is the focus of the majority of papers on this program, is essentially the Oak-Pine and Southeastern Evergreen Regions of Braun (1950) and is virtually conterminous with the distribution of the four major southern yellow pines (longleaf, loblolly, shortleaf, and slash). The Oak-Pine region covers the Coastal Plain of New Jersey, Delaware, and Maryland, part of the Coastal Plain and all of the Piedmont of Virginia, the Piedmont of the Carolinas and Georgia, the Piedmont and Coastal Plain of Alabama and Mississippi, and a section in southwest Arkansas, northwest Louisiana, and east Texas. It is frequently called the Eastern Oak-Hickory region because its dominant species are oaks and hickories many of which occur in the Oak-Hickory region of the midwest. The Oak-Pine region is now characterized by stands of mixed oak, with white oak frequently dominant, hickory, yellow poplar, beech, and other hardwoods. Although the region was probably less affected by fire than the Coastal Plain prior to European settlement, disturbance was still great enough so that pines were a common component of the canopy. Now pines, as a result of land clearing for farming, land abandonment and numerous cycles of high-grading, are major components of the forests of the region.

The Southeastern Evergreen Region covers the Coastal Plain of Southeastern Virginia, the Carolinas and Georgia, the Middle and Lower Coastal Plain of Alabama and Mississippi, and a small section of west Louisiana and east Texas. As indicated previously, much of the original vegetation of this region was longleaf pine maintained by continued fires. Now, the region is a mixture of pine forests, primarily loblolly and slash, in a variety of different physiographic situations, stands of mixed pine and hardwoods, and hardwoods. Bottomland and other wet forests are extensively developed. Whereas the original "climax" forests of this region

were undoubtedly pine forests over most of the area, now these forests are not naturally reproducing themselves and, where disturbances are eliminated, succession is leading toward a mixed hardwood forest (Quarterman and Keever 1962).

Thirteen upland SAF forest cover types (SAF 1980) are included in the region under consideration, including 9 southern yellow pine types and 4 oak-pine types (true mixed pine hardwood types). The oak-pine types include longleaf pine-scrub oak, shortleaf pine-oak, virginia pine-oak, and loblolly pine-hardwood. All of these types are, in one way or another, successional. The pine types are effectively early successional stages and the oak-pine types are transitional to some type of more stable hardwood type.

The U.S. Forest Service recognizes three broad types within the region – oak-pine, loblolly-shortleaf pine, and longleaf-slash pine (USDA-Forest Service 1969). These types occur in the Piedmont and Coastal Plain of the Southeast from Virginia to east Texas and northward into the Ridge and Valley Province of Tennessee.

From a vegetational perspective the Southeastern region is one in which the distinction between climax and successional types is heavily blurred by the activities of man. There are essentially no remaining stands of original natural vegetation. It is clear that man has altered the forest types of the region in a number of ways. By the early 1900's lumbering removed the vast stands of pine, chiefly longleaf, that occurred extensively throughout the region. They were replaced by pines and hardwoods with the exact species mix depending upon geography and site conditions. Land clearing for agriculture eliminated large areas of forest, particularly on the better soils. As soil deteriorated and the economic condition of agriculture waxed and waned, these lands were abandoned and quickly began to revert to pine forest, chiefly shortleaf, Virginia, and loblolly. Hardwoods quickly entered these pine stands. Natural succession, without further disturbance, produced stands in which there were mixtures of young hardwoods and older pines. Without disturbance, these stands eventually progressed to hardwood dominance with pines present only as scattered, mature trees. With logging, which occurred mostly as high-grading, these stands were quickly converted to pine-hardwood mixtures or hardwood stands with a varying, but smaller, component of pine. In almost all situations forests were protected against fire. Such protection tended to reduce the likelihood of pine reestablishment and to favor encroachment of hardwoods. Regardless of the nature of disturbance, natural successional trends led almost exclusively to the production of pine-hardwood mixtures and, eventually, to pure stands of hardwoods.

The loblolly pine-hardwood type, which is now so extensive in the Upper Coastal Plain and the Piedmont where it abuts the Coastal Plain, is a type of relatively recent origin. Loblolly pine was originally distributed largely as single trees or small groups of trees in or near swamps and other wetlands (Ashe 1915). Its prolific early seed production and rapid growth enabled it to expand its range following lumbering into abandoned agricultural fields and cutover woodlands (Ashe 1915). These natural stands of loblolly pine, frequently mixed with hardwood, became the original base of the post World War II pine lumber industry of the Southeastern Coastal Plain. The species further expanded its range following logging. Its silvical characteristics and desirable commercial properties caused it to become the favored species for intensive industrial management throughout much of the South.

BENEFITS OF MANAGING MIXED PINE-HARDWOOD STANDS

There appear to be a number of advantages to management of mixed pine-hardwood stands, at least when compared to plantation monocultures of pine. Although it is unlikely that the economics of management of mixtures will approach that of plantations, there are certain circumstances and situations when reduced dollar gain is more than balanced by non-monetary benefits.

As pointed out in my discussion of the evolution of the mixed pine-hardwoods, the type develops naturally, as a result of successional forces. Hardwoods invade pure stands of pine and become components of logged stands of pine or mixed pine and hardwoods. In fact, in order to maintain plantations in pine the forester has to devote resources to preventing this natural progression of pine to hardwood. Substantial sums of money are spent at establishment to control hardwood competition, either mechanically or with herbicides. In addition, fire and herbicides may be used later in the rotation to control hardwood encroachment. Such silvicultural practices are costly. Site preparation at establishment can add substantially to the front end cost of tree growing as can the cost of controlled burns, either at establishment or during the rotation. Herbicidal control of hardwoods is not only costly from a financial point of view, but it may also be costly from an environmental and public relations point of view. Many people do not accept herbicides, particularly when they are applied aerially as they often must be at establishment. Forest management that reduces dependency on chemicals for control of competition is, from a public relations point of view, highly desirable. Obviously, any management system that can reduce establishment costs and still produce a manageable stand, is also highly desirable.

Management of mixed pine hardwood stands is also preferable from a purely biological perspective in that it leads to forest stands which are more diverse biologically than are pure plantations of any species, particularly pine. This diversity is manifested in a greater number of species, not only trees and forest shrubs and herbs, but also in animal species. For example, in Oosting's classic study of succession in the North Carolina Piedmont, he found that in young pine stands there was only one canopy dominant (loblolly pine) and 10 young hardwood species (Oosting 1942). In mature loblolly pine stands the total number of canopy and transgressive species was about 20, and in mature oak-hickory stands the number was 28. The number of niches and microhabitats also increases as succession progresses.

It can be argued that mixed stand management promotes greater diversity in other ways, at least in comparison to plantation management. By relying to a greater extent on natural reproduction which encourages populations of both pines and hardwoods, the total genetic diversity of the stand is increased. Depending upon the origin of the pines in the stand, the gene pool may, or may not, be wider than that of the pines in a plantation. In light of the potential effects of climatic change of forests in the Southeast, this reservoir of genes in mixed pine-hardwood stands may provide the genetic flexibility that the type and its component species need to respond to future climatic warming or drying.

Emphasis on mixed stand management promotes diversity in another way in that it leads to greater landscape variety. Despite their orderly nature, plantation pine stands are viewed by many as creating a monotonous landscape. Pine-hardwood stands, however, because of the great variety and differing architecture of species found in them are more diverse in appearance and lead to a landscape with more variety in it. What may appear to the forester as a ragged, disorderly, unproductive landscape with patches of mixed-pine and hardwoods of varying composition and age, presents a greater variety in terms of aesthetic appeal and compositional and structural variation than a plantation-dominated landscape.

Management of the pine-hardwood type actually presents the forester with opportunities to create diversity through management practices. Through manipulation of species composition and age structure, the manager has a wide variety of options for creating stands of differing species composition and structure. Such different stands will contain populations of different lesser plant and associated animals species thus further contributing to the ob-

jective of promoting diversity. Because diversity is so much on the mind of forest managers and the public today, any practice which can reasonably be said to promote diversity is likely to find far wider acceptance with the public than will intensive, plantation forestry.

Mixed stands also favor more diverse wildlife populations. Pine plantations are noted for their limited ability to support large wildlife populations. Mixed pine-hardwood stands, on the other hand, can be expected to support substantial populations of many of our important game species. Deer, turkey, squirrel and rabbits are more likely to survive in large numbers in mixed stands. Quail are perhaps the only major game species favored by pure pine stands, and they do not survive without management assistance from a controlled burn program. Additional variety can be added by allowing dead pines and hardwoods to persist in mixed stands, a practice hardly compatible with plantation managment and clearcut regeneration. Although wildlife populations differ with differing mixes of pine and hardwoods, and will change as stands age and the mix of pine and hardwoods and of hardwoods changes, the manager is clearly promoting a social benefit by managing for stand mixtures.

Pine-hardwood mixtures also are probably aesthetically more appealing than are pure stands of pine. Although the forester is proud of a well-established, rapidly growing pine plantation regenerated with genetically improved stock, most non-foresters look on such stands as they do agricultural fields--as uninteresting, intensive uses of land for production purposes. They do not view plantations as forests. A pine-hardwood mixture, with its towering old pines and its ragged, multispecies hardwood understory, is much more a "forest" to the non-forester. In addition, older stands of mixed-pine and hardwoods, usually with no effort from the manager, develop significant populations of the rarer forest wildflowers and invertebrates that many forest lovers regard as the major benefit of forest management. With just a few exceptions, such as the pink ladyslipper, few wildflowers occur in pine plantations. On the other hand, the major locations where we seek spring and summer wildflowers is in deciduous woodlands. Many members of the general public are reacting negatively to monocultural forestry. To the extent that we can move to management of mixtures, it seems we may well recapture some of our lost support among the general public.

Management of mixed stands also presents an attractive financial alternative to private, non-industrial landowners who have neither the money or the desire to manage intensively for pine. Many private landowners hold their land only incidentally for production of timber. They are more interested

in the "other" benefits that can be derived from the woods they own. When approached with an intensive, monocultural management plan, such landowners recoil and turn to no management at all as their only perceived alternative. If we present such owners with true alternative land management schemes that involve managing mixed stands, using cutting regimes that leave a substantial amount of the stand after each entry, promoting plant and animal diversity, providing for structural diversity by leaving dead standing timber and promote fallen dead wood, and maintaining the values of the forest on which the owner puts emphasis, we run a much better chance of having our proposal accepted. In addition, under certain conditions management of mixed stands may actually be more attractive financially than plantations management.

Presentation of genuine management alternatives to private owners may have the effect of bringing more land into production than might otherwise occur. Many and, perhaps, the majority of small landowners, are simply not interested in intensive forest management. They can neither afford it nor can they accept its consequences in terms of perceived, or real, environmental damage. The net result is that the lands of such owners are effectively removed from those that might potentially be harvested. We may well be able to accomplish the objective of bringing more land into production to meet our timber goals by harvesting such lands more "lightly" and using practices which more closely approximate nature than by insisting on intensive forestry.

PROBLEMS IN MANAGEMENT OF THE PINE-HARDWOOD TYPE

It should be clear, however, that management of mixed stands is no panacea for the social and environmental problems that now beset forestry. There are a number of problems that will arise from mixed stand management and we should consider these well in making our plans for furthering such management.

First, it is likely that mixed stand management will require more silvicultural knowledge than we now have. More species are involved and we know very little about the silvics of some of these. For example, we are all well aware of the difficulty that we have encountered in regenerating oak on many lands that previously supported oak throughout the South. In a system stressing mixed composition in the managed stand, we well may not know enough about certain species to be able to manage them effectively. Further, we may not yet have the silvicultural skills – systems – to promote certain types of management. This is certainly true when our concern is lesser plant species or invertebrates. We

simply have too little experience with their management to be sure we can meet public demands for their production.

It is a certainty that we will need more and better information on growth and yield. Fortunately, a number of researchers are now beginning the development of growth and yield projections for mixed stands. A number of these are featured at this symposium. It is clear that we will need this information in order to make informed decisions about management alternatives and to develop a sound base on which to project the economics of mixed stand management.

Mixed stand management will require more sensitivity of the foresters making management recommendations than we have probably seen in the past. The usual posture of the forester when confronted with someone who criticizes professionally-accepted forest management practices is to regard the person as poorly informed. The forester assumes that if the person were "educated" to understand the forester's viewpoint, then the disagreement would go away. As Magill (1988) points out, professionals seem unable to accept the opinions of the public as sound, because they have not been scientifically reached, but rather regard them as "uninformed, emotional, and unimportant." As a consequence, professionals believe that in interacting with the public they must shape public opinion rather than incorporate it into their management policies (Magill 1988). This unwillingness to listen to the public and accept its views as valid lies at the base of many of today's resource disputes. How many times has each of us said, "If we could just educate the public about clearcutting, they would understand the practice and accept it." My guess is that we could spend the rest of our lives explaining clearcutting and our opponents will never accept it. In short, there is a clear distinction between forcing our views on the public and incorporating their views into our management programs.

CONCLUSIONS
Mixed stand management affords us an opportunity to incorporate many values about which the public feels strongly into forest management and, by so doing, making allies of persons who are now our bitter foes. In managing mixed stands, we will not have to emphasize controversial practices such as intensive site preparation and clearcutting. We can manage for timber production, albeit at a lower level of intensity, while at the same time managing for larger populations of the wildlife and lesser plant and animal species that members of the public value highly. We can also manage for aesthetics and emphasize practices that are likely to bring into production acres that otherwise might be unproductive from the perspective of timber production.

In a way, mixed stand management may well offer us an opportunity to regain some of our natural constituency in the public that we now seem to antagonize by virtually everything we do. Let us hope I am right and, if I am, that we as a profession are wise enough to take advantage of the opportunity.

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THE PINE-HARDWOOD RESOURCE IN THE EASTERN UNITED STATES

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Abstract. – In the Eastern United States, 31 million acres of timberland are classified as pine-hardwood. Many additional stands classified as pine or hardwood types are also diverse mixtures of softwood and hardwood species. The pine-hardwood resource is concentrated in the South. Natural forces and human activity cause these mixed stands to be transitory and dynamic.

INTRODUCTION

Mixtures of pine and hardwood are an inevitable component of the landscape wherever pines and other softwood species exist. Pine-hardwood stands form one of the major Eastern United States ecosystems (Garrison and others 1977). Once viewed as an end result to be avoided from a timber management perspective, mixed stands of pine and hardwood are now recognized as a viable, manageable forest resource (Phillips and Abercrombie 1987). Mixed stands supply significant quantities of timber, diverse habitats for wildlife, and large acreages for recreation. Perhaps the most important benefit is the diversity, both biological and esthetic, that these mixed stands provide.

This paper summarizes existing data documenting the extent of the pine-hardwood resource in the Eastern United States. These data were collected during periodic inventories conducted in each State by the USDA Forest Service. Forest Inventory and Analysis (FIA) Research Work Units at the North Central, Northeastern, Southeastern, and Southern Forest Experiment Stations, which are responsible for these broad-scale inventories in their respective sections of the Eastern United States (figure 1), provided the data for this descriptive analysis. For reference purposes the data have been dated 1989, but the statistics are from the most recent inventory

Figure 1.--Delineations of the Eastern United States, by regions of inventory responsibility.

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of each State and have not been updated to a common date. Inventory dates for individual States range from 1972 to 1988; inventories have been completed in most of the States involved since 1980. Most of the data presented are totals for the entire Eastern United States. Additional data are presented for the North and South. The North is comprised of the North Central and Northeast regions as depicted in figure 1; the South is made up of the South Central and Southeast regions.
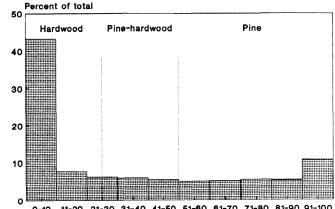
DEFINING THE TYPE

Any estimate of mixed pine-hardwood acreage must be related to a definition of what constitutes a mixed stand. Standards used by FIA in classifying forest types are based on the stocking of softwoods present in a stand relative to the total stocking of all species. A softwood forest type is assigned to all stands in which softwoods (excluding cypress) constitute 50 percent or more of the total stocking. Hardwood types are assigned when the softwood proportion is less than 25 percent (more than 75 percent hardwoods). All stands with between 25 and 50 percent softwood stocking are assigned an oak-pine type (referred to as pine-hardwood throughout the paper). The totals established for pine-hardwood stands in this paper are based on these forest type standards.

We acknowledge that these forest type standards exclude a portion of the forest resource that could be described as mixed stands of pine and hardwood. An extreme interpretation of forest type guidelines could include as pine-hardwood every stand except those that are 100 percent softwood or 100 percent hardwood. Perhaps the most realistic way to portray the relative magnitude of mixed stands is to array all stands on a continuum between 0 and 100 percent softwood stocking. Figure 2 displays a frequency distribution for timberland in

Figure 2.--Percentage distribution of timberland in the South, by softwood stocking proportion.

the South by 10-percent softwood stocking categories. More than half of the South's timberland is in the two lowest categories of softwood stocking. In other words, hardwoods make up 80 percent or more of the stocking on more than half of the South's timberland. Except for the 91-100 percent class, the remaining timberland is distributed almost equally among the remaining stocking categories. Stands classed as pine-hardwood are highlighted on the chart. The reader can approximate the impact of classifying a wider range of softwood proportions on the estimates of mixed stand area.

AREA

As defined, pine-hardwood stands currently occupy some 31.2 million acres throughout the East (table 1). Across this region, pine-hardwood stands account for 8.7 percent of all timberland. Mixed stands are concentrated in the South, where pines are more common. About 27.2 million acres, nearly 15 percent of the timberland area, are classified as

Table 1.--Area of pine-hardwood stands in the Eastern United States, by detailed type and region

Detailed forest type	Total	North	South
	Million acres		
White pine-hardwood	2.1	1.4	0.7
E. redcedar-hardwood	1.6	0.6	1.0
Longleaf pine-scrub oak	1.3	0	1.3
Shortleaf pine-oak	6.1	0.4	5.7
Virginia pine-hardwood	2.7	0.9	1.8
Loblolly pine-hardwood	14.0	0.2	13.8
Slash pine-hardwood	1.7	0	1.7
Other pine-hardwood	1.7	0.5	1.2
All pine-hardwood	31.2	4.0	27.2
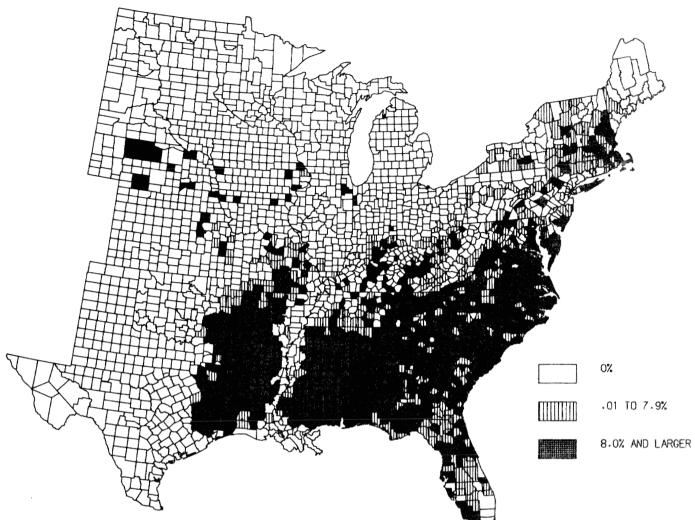
Figure 3.--Proportion of timberland in the Eastern United States classified as pine-hardwood forest type.

pine-hardwood in the South. The remaining 4.0 million acres are in the North.

Concentrations of pine-hardwood acreage are clearly indicated by mapping each county according to the proportion of timberland classed as pine-hardwood (figure 3). Most of the South's counties have more than 8 percent of their timberland classified as pine-hardwood. A notable exception includes counties along the Mississippi River that contain mostly bottomland hardwood forests. Further north, pine-hardwood stands occur less frequently but remain a common component of the landscape in much of Missouri, Kentucky, southern Illinois, Indiana, and Ohio, and northeastward to Maine.

The primary softwood species that mix with hardwoods change dramatically with geography. Even within local areas, many different softwood species may form various mixtures with hardwood species. FIA recognizes seven different pine-hardwood detailed types plus an "other" category. These detailed types are named according to the

primary softwood species present in combination with hardwoods, and their occurrence follows the range of each individual softwood species. These detailed types are listed and briefly described below. Scientific names of species are in table 2.

(1) Slash pine-hardwood. Slash pine and hardwood mixtures are confined to the southernmost States, where the slash pine ecosystem is located (Sheffield and others 1983). Slash pine-hardwood stands total 1.7 million acres. They occur most commonly in Florida, Georgia, Alabama, and Mississippi.

(2) Longleaf pine-scrub oak. This combination is more widely distributed than slash pine, but it is still generally confined to the southern area.[2] Longleaf-scrub oak mixtures occupy 1.3 million acres and are common in portions of Mississippi, Alabama, Florida, Georgia, and the Carolinas.

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[2]Kelly, John F.; Bechtold, William A. The longleaf pine resource. In: Longleaf pine management symposium proceedings; 1989 April 4-6; Long Beach, MS. (in process).

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Table 2.--Common and scientific names of referenced tree species

Common name	Scientific name
Softwoods:	
Eastern hemlock	*Tsuga canadensis* (L.) Carr.
Eastern redcedar	*Juniperus virginiana* L.
Eastern white pine	*Pinus strobus* L.
Fir	*Abies* spp. Mill.
Loblolly pine	*Pinus taeda* L.
Longleaf pine	*Pinus palustris* Mill.
Pitch pine	*Pinus rigida* Mill.
Pond pine	*Pinus serotina* Michx.
Shortleaf pine	*Pinus echinata* Mill.
Slash pine	*Pinus elliottii* Engelm.
Spruce	*Picea* spp. A. Dietr.
Table Mountain pine	*Pinus pungens* Lamb.
Virginia pine	*Pinus virginiana* Mill.
Hardwoods:	
Blackgum/tupelo	*Nyssa* spp. L.
Chestnut oak	*Quercus prinus* L.
Laurel oak	*Quercus laurifolia* Michx.
Northern red oak	*Quercus rubra* L.
Red maple	*Acer rubrum* L.
Scarlet oak	*Quercus coccinea* Muenchh.
Southern red oak	*Quercus falcata* Michx.
Sweetgum	*Liquidambar styraciflua* L.
Water oak	*Quercus nigra* L.
White oak	*Quercus alba* L.
Willow oak	*Quercus phellos* L.
Yellow-poplar	*Liriodendron tulipifera* L.

(3) Loblolly pine-hardwood. This mixture is by far the most common, covering 14 million acres. Loblolly pine occurs across an extensive geographic area in association with a wide range of hardwood species on both upland and bottomland sites. The occurrence of this mixture follows the natural and introduced range of the species (McWilliams and Birdsey 1984; Sheffield and Knight 1983). It is found throughout much of the South, extending as far north as Arkansas, Kentucky, Virginia, Maryland, and Delaware.

(4) Shortleaf pine-oak. Shortleaf pine mixes with numerous upland oak species to form the second most prevalent pine-hardwood type (6.1 million acres). These mixtures occur throughout much of the South and extend into the North. The most significant concentrations exist from Arkansas, eastern Texas, eastward through Mississippi and Alabama, and then northeastward through the Piedmont Plateau of the Southeast (McWilliams and others 1986). The type is also common in Missouri, Tennessee, Kentucky, West Virginia, and New Jersey.

(5) Virginia pine-hardwood. This type occupies some 2.7 million acres. It is not found in the extreme southern portion of the South, but occurs with high frequency in North Carolina, Virginia, Tennessee, West Virginia, and Kentucky.

(6) Eastern redcedar-hardwood. This mixture, totaling some 1.6 million acres, is the major non-pine association included in the pine-hardwood group. Redcedar-hardwood stands are especially prominent in Tennessee, Kentucky, and Missouri. They are less prominent but common over a much wider area.

(7) White pine-hardwood. White pine-hardwood mixtures are the most prevalent pine-hardwood type in the North. The type occurs with regularity in the Appalachian Mountains as far south as northern Georgia. Eastern hemlock is included in this association.

(8) Other pine-hardwood. This group includes all other pine species that occur in association with hardwoods. Pond, pitch, and Table Mountain pines are the major pine species comprising this group.

The majority of the pine-hardwood resource is controlled by nonindustrial private landowners, as are most forest ecosystems in the Eastern United States (U.S. Department of Agriculture 1988a). These landowners control 69 percent of the pine-hardwood resource (table 3)--66 percent in the South and 84 percent in the North. More than 11 percent of pine-hardwood stands are on public land, whereas 20 percent, or 6.3 million acres, are controlled by forest industry.

Across all ownerships and regions, significant portions of the pine-hardwood resource are found in each of three stand-size classes--sapling-seedling, poletimber, and sawtimber (figure 4). A fourth category, nonstocked, includes stands so poorly stocked that a stand-size classification is not meaningful. Excluding these nonstocked stands, 43 percent of the pine-hardwood stands are dominated by sawtimber-size trees, 28 percent have a predominance of poletimber-size trees, and 29 percent are primarily stocked with trees in the sapling-
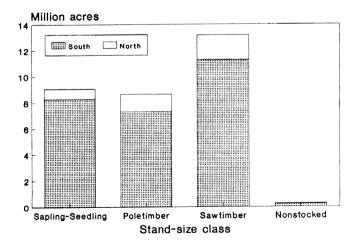
Figure 4.--Area of pine-hardwood forest type in the Eastern United States, by stand-size class and region.

Table 3.--Area of pine-hardwood stands in the Eastern United States, by stand size, stand origin, and ownership class

Stand size and origin	All ownerships	Public	Forest industry	Other private
	Million acres			
Sapling-seedling:				
Planted	2.5	0.2	1.6	0.7
Natural	6.5	0.5	1.1	4.9
Total	9.0	0.7	2.7	5.6
Poletimber:				
Planted	0.5	0.1	0.2	0.2
Natural	8.2	0.8	1.1	6.3
Total	8.7	0.9	1.3	6.5
Sawtimber:				
Planted	0.4	0.1	0.1	0.2
Natural	12.8	1.8	2.1	8.9
Total	13.2	1.9	2.2	9.1
Nonstocked (natural)	0.3	0	0.1	0.2
All sizes:				
Planted	3.4	0.4	1.9	1.1
Natural	27.8	3.1	4.4	20.3
Total	31.2	3.5	6.3	21.4

seedling size group (less than 5.0 inches d.b.h.). Concentration in the sawtimber group is evident in both major regions. Sapling-seedling stands are more common in the South than the North, reflecting the higher rates of timber harvest in the South. New stands of pine and hardwood often develop after timber harvests.

Almost 11 percent of all pine-hardwood stands, or 3.4 million acres, are planted (table 3). In these stands, the pine component has been planted but the hardwood stocking exceeds that of the pine. Planting efforts contribute 28 percent of the current sapling-seedling stands, but are relatively minor component of the more mature stands. Planted sapling-seedling stands are concentrated on forest industry land; nearly three-fifths of these young pine-hardwood stands on forest industry are planted. Sawtimber stands dominate the pine-hardwood resource on public and other private ownerships, whereas sapling-seedling stands dominate the type on forest industry land.

Pine-hardwood stands are found mainly on sites with average or better productive potential (figure 5). FIA measures of site quality are based on potential yields in cubic feet per acre of mean annual growth at the culmination of increment in fully stocked natural stands. Average sites (50-84 cubic feet

per acre per year) make up 39 percent of the pine-hardwood acreage. Poor sites (20-49 cubic feet per year) account for only 13 percent, and good sites (more than 85 cubic feet per acre per year) make up the remaining 48 percent.

These potential yields usually are not realized across large areas like entire States. This observation appears to be especially true for pine-hardwood stands. Throughout the five
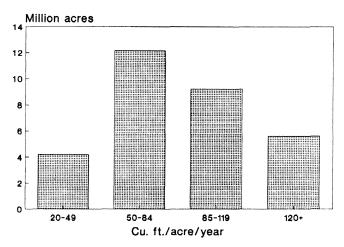
Figure 5.--Area of pine-hardwood forest type in the Eastern United States, by productivity class.

Southeastern States, net annual growth in pine-hardwood stands currently averages only 50 cubic feet per acre. Pine ecosystems tend to be more productive, averaging more than 70 cubic feet per acre annually. Part of the reason for low productivity of pine-hardwood stands is that conditions are less than desirable in these stands. Partial harvests (often high-grading) created many of the pine-hardwood stands that now exist. The cutting often left a poorly stocked residual stand that hampers the establishment and vigorous development of reproduction. Common treatment needs are displayed in figure 6. About 18 percent of all pine-hardwood stands in the East are so poorly stocked that a manageable stand does not exist. A new stand should be established through an appropriate stand regeneration method. Another 19 percent need intermediate treatments such as release cuttings to permit crop trees to develop unhampered by older residuals and culls.

INVENTORY VOLUME

The 31.2 million acres classed as pine-hardwood contain 33.7 billion cubic feet of growing stock (table 4). About 55 percent of this standing inventory is softwood and 45 percent is hardwood. This total inventory is equivalent to 1,080 cubic feet per acre. Consistent with the acreage distribution, about 85 percent of the volume is in the South.

The amount pine-hardwood stands contribute to total inventory volumes varies by region. Pine-hardwood stands contain 16 percent of the South's
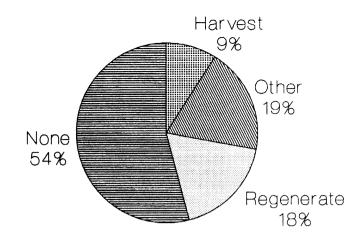
Figure 6.--Percentage distribution of pine-hardwood acreage in the Eastern United States, by treatment opportunity.

softwood inventory and 10 percent of the hardwood. In the North, these proportions stand at 4 percent for softwood and only 2 percent for hardwood. Under a more encompassing definition of pine-hardwood type, the contributions of these stands to regional inventory totals would increase.

Pine-hardwood stands are diverse in species composition. A complete listing of species is too long for this discussion, but major species and species groups are listed, along with associated inventory volumes for the two major regions (table 5). In the North, white pine is the dominant softwood in pine-hardwood stands with 0.9 billion cubic feet of

Table 4.--Volume of growing stock on timberland in the Eastern United States, by region, species group, and stand type

Region and species group	All types	Pine-hardwood type	Other types
		Billion cubic feet	
North:			
Softwood	50.4	2.1	48.3
Hardwood	154.6	2.8	151.8
Total	205.0	4.9	200.1
South:			
Softwood	101.3	16.5	84.8
Hardwood	119.2	12.3	106.9
Total	220.5	28.8	191.7
Eastern United States:			
Softwood	151.7	18.6	133.1
Hardwood	273.8	15.1	258.7
Total	425.5	33.7	391.8

Table 5.--Volume of growing stock in pine-hardwood stands in the Eastern
United States, by species and region

Species	Total	North	South
	Billion cubic feet		
Softwood:			
Longleaf-slash pine	1.8	0	1.8
Loblolly-shortleaf pine	12.5	0.4	12.1
Other yellow pine	2.0	0.4	1.6
White-red pine	1.3	0.9	0.4
Other softwood	1.0	0.4	0.6
Total	18.6	2.1	16.5
Hardwood:			
Select oak	3.0	1.0	2.0
Other oak	5.0	0.5	4.5
Hickory	1.0	0.3	0.7
Soft maple	0.8	0.3	0.5
Sweetgum	2.1	0.1	2.0
Tupelo-blackgum	0.7	0	0.7
Yellow-poplar	1.1	0.1	1.0
Other hardwood	1.4	0.5	0.9
Total	15.1	2.8	12.3
All species	33.7	4.9	28.8

volume, or 44 percent of all softwood inventory in these stands. The remainder is equally divided between the loblolly-shortleaf group, other yellow pines (primarily Virginia and pitch pine), and a group of other softwoods (primarily eastern redcedar, hemlock, spruce, and fir). In the South, the loblolly-shortleaf group accounts for nearly three-fourths of the softwood total.

Oak species tend to dominate the hardwood component of the pine-hardwood resource throughout the Eastern United States. In the South, "other oak species" account for 4.5 billion cubic feet, or 37 percent of the hardwood total. This group includes laurel, willow, water, southern red, scarlet, chestnut oak, and numerous less common oak species. Select oaks, primarily white oak and northern red oak, account for 2.0 billion cubic feet, or 16 percent of the hardwood total in the South. Significant volumes of sweetgum, blackgum/tupelo, and yellow-poplar also exist in pine-hardwood stands in the South.

In the North, hardwood volume includes a noticeably higher proportion of select oaks. Select oaks account for 36 percent of the hardwood inventory in pine-hardwood stands in this region. The sweetgum/blackgum/yellow-poplar component is minor

in the North. Soft maples (primarily red maple) are the most common soft textured hardwood species.

In the South, the softwood component in pine-hardwood stands tends to be larger than the hardwoods (figure 7a). A higher proportion of the softwood volume exists in the 12-inch and larger d.b.h. classes than does the hardwood component. Hardwoods are more concentrated in the 6-, 8-, and 10-inch diameter classes. Softwood and hardwood distributions across all forest types in the South show just the opposite picture (figure 7b). Generally, the softwoods are smaller than the hardwoods. The concentration of hardwoods in the smaller diameter classes reflects the manner in which many of the current pine-hardwood stands were created. Partial harvesting in pine stands during previous decades has promoted the growth and development of understory and midstory hardwoods. Even though the hardwood component of these disturbed stands has thrived, the stems are smaller than those of most residual pines. From a timber supply standpoint, the larger pines in pine-hardwood stands will become a more and more attractive source of large diameter sawtimber as pine plantations account for more of regional pine inventories (U.S. Department of Agriculture 1988b).

(a) Pine-hardwood Stands

Percent of total

D.b.h. class (inches)

Softwood   Hardwood

(b) All Stands

Percent of total

D.b.h. class (inches)

Softwood   Hardwood
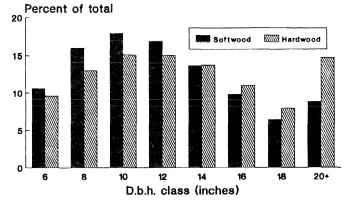
Figure 7.--Percentage distribution of growing-stock volume in the South, by species group and d.b.h. class.

FUTURE DIRECTIONS

What changes in the pine-hardwood resource can be expected in the future? Will there be more mixed conditions or fewer? Will mixed stands be older or younger? Will they contain high-quality timber needed to help meet future demands? We do not have a crystal ball to provide the answers. We can, however, develop likely scenarios from what we know about the present resource, how it came into existence, and how it has been changing.

Trends in Area

During the past two decades, acreage of pine-hardwood forest type in the Eastern United States has declined by 11 percent, dropping from 35 million acres in 1970 to the present 31 million acres (figure 8). In the North, acreage has remained at a constant 4 million acres. All of the decline has occurred in the South, especially in the latest decade.

Southern pine plantation acreage has increased during the past two decades, while the extent of both natural pine and pine-hardwood types has dropped (U.S. Department of Agriculture 1988b). Losses to nonforest land uses also have been a major contributing factor in these reductions.

A recent regional and national assessment of forest resources provided projections of timberland area for each of the major forest types[3] (U.S. Department of Agriculture 1988b). These projections suggest that the recent trends in pine-hardwood acreage in the Eastern United States will continue, at least for the near future. By the year 2000, pine-hardwood acreage is projected to drop another 4 million acres, with the bulk of the loss occurring in the South. Much of the reduction is projected for forest industry land. Thereafter, small declines are projected to 2040.

Driving Forces

The model used to estimate prospective change in area by forest type is based on a wealth of economic inputs, plus data on stand treatment and disturbance rates (Alig 1984). The rates of treatment by type are linked to probabilities that the treated stands will shift to another type or remain in the original type. Treatment and disturbance data, and resulting shift rates, were developed from FIA broad-scale inventory data. The repetitive nature of these forest inventories makes them a unique data source to quantify regional change in forest types. These inventories also help identify treatments and disturbances that play major roles in creating and diverting pine-hardwood stands. We should examine these forces since they will probably shape tomorrow's pine-hardwood resource unless we alter and control them in a positive manner.

Three major forces tend to create pine-hardwood stands: (1) partial harvests, (2) stand establishment or regeneration, and (3) successional change or stand development. Partial harvests include a number of kinds of timber cuttings, but all too often the cutting is best described as high-grading. Partial harvests in pine stands create an instant pine-hardwood type when the softwood stocking is reduced below that of the hardwood component. After more complete harvests, the regeneration that develops, or is planted, often results in a mixed condition. Natural regeneration on former pine sites results in a pine-hardwood condition more often than after planting. The third factor, natural succession, reflects the natural course of stand development. In established pine stands, natural

[3]Alig, Ralph J.; Murray, Brian; Hohenstein, William [and others]. Changes in timberland area in the United States by state and ownership, 1952-1987, with projections to 2040. Gen. Tech. Rep. WO- . Washington, DC: U.S. Department of Agriculture, Forest Service (in process).

MILLION ACRES
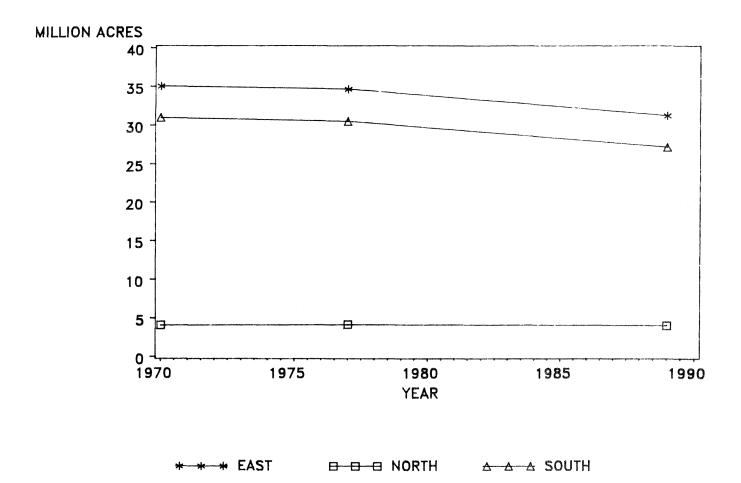
Figure 8.--Area of pine-hardwood forest type in the
Eastern United States, by region, 1970-89.
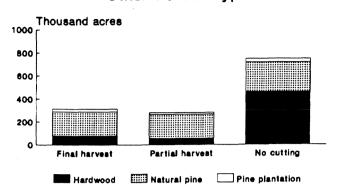
succession moves stands from pine to hardwood. As pine stands mature, the hardwood component assumes greater dominance and a pine-hardwood type eventually results. In very young stands with less than 25 percent pine, succession can favor the pines and move stands from a hardwood to a pine-hardwood type.

Three major factors divert acres from pine-hardwood: (1) stand harvests, (2) successional change or stand development, and (3) timberland clearing. When a pine-hardwood stand is completely or partially harvested, conversion to another type usually results. Sometimes the conversion is planned, such as when a pine plantation is established after a harvest. In many cases, however, the natural course of events is accepted. Successional change or stand development also plays an important role in losses of pine-hardwood in both young and older stands. In the more mature pine-hardwood stands, the successional forces continue until the hardwood stocking is high enough to move

the stand to a hardwood type. In young stands, changes can occur more rapidly. Newly established stands often begin as pine-hardwood mixtures. As these young stands develop, the pines often assume dominance and the stand takes on a pine type. Such changes during the early years of stand development are more common in planted mixed stands than in natural mixed stands[4]. The clearing of pine-hardwood stands is also an obvious and major factor in losses of mixed acreage.

Obviously, human activity and natural forces cause both gains and losses to the pine-hardwood resource over time. Figure 9 shows the net effect of final harvest, partial harvest, and "no cutting" on the annual change in pine-hardwood acreage in the South. The "no cutting" category includes all areas where no activity was recorded plus all forms of minor human activity and natural changes. The net effect of timber cutting (final and partial harvests) is to maintain the base acreage in pine-hardwood stands--annual additions to pine-hardwood offset

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[4]Data on file at the Southeastern Forest Experiment Station, Forest Inventory and Analysis.

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Pine-hardwood Gains From Other Forest Types

Thousand acres

Final harvest   Partial harvest   No cutting

■ Hardwood   ▒ Natural pine   ☐ Pine plantation

Pine-hardwood Losses To Other Forest Types

Thousand acres

Final harvest   Partial harvest   No cutting

■ Hardwood   ▒ Natural pine   ☐ Pine plantation
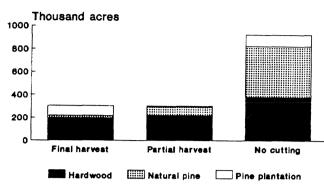
Figure 9.--Annual gains and losses of pine-hardwood acreage in the South, by type of treatment. Data developed from all States in the South except Tennessee. Most recent remeasurement period used--length ranges from 8 to 10 years.

annual diversions to other types. Additions that result from timber cutting come largely from natural pine stands. On the loss side, harvested pine-hardwood stands usually shift to hardwood types. Almost 28 percent of pine-hardwood stands moving to another type after a final harvest were converted to pine plantations. The "no cutting" category accounts for higher annual gains and losses; the net result is a 173,000 acre loss of pine-hardwood type annually. A surprisingly high proportion of the gains to pine-hardwood in this group were formerly hardwood types, suggesting that young hardwood stands often develop into mixed stands. For losses, most pine-hardwood stands that move to other types in the absence of cutting go to a pine designation, either natural or planted.

Regionally, pine-hardwood mixtures can be viewed as dynamic and transitory. With time, stands move into and out of the pine-hardwood classification very easily and often. In part, the high rate of change for this resource can be attributed to the range of softwood stocking used in defining it. The real driving force, however, is the human activity that has altered and speeded the natural tendency of these stands to change.

CONCLUSIONS

Three conclusions about the pine-hardwood resource can be drawn:

(1) Recent changes in the resource and the factors causing these changes suggest further short-term reductions in pine-hardwood acreage in the South. Two major factors influencing the prospective drop include continued favoring of pine plantations over natural stands and the clearing of pine-hardwood stands for nonforest uses. Mixed stands of pine and hardwood will continue to be a major component of forests in the Eastern United States because human activities and nature create mixed stands.

(2) The pine-hardwood resource will probably become younger. High harvest rates in the South will continue to create mixed sapling-seedling stands.

Younger stands could result in a pine-hardwood resource that is even more transitory than in the past.

(3) The quality of tomorrow's pine-hardwood resource will be determined by the collective actions of all of us. The resource we have today has been shaped profoundly by human intervention and activities. Some human influences have been positive, but all too often pine-hardwood stands are the product of poor pine management. The quality of tomorrow's resource is something we all have the opportunity to impact in a positive way. The growing awareness that pine-hardwood stands can be managed to maximize the benefits they offer is an encouraging step in that direction.

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ARE OUR TRADITIONAL ATTITUDES RESTRICTING FORESTRY MANAGEMENT OPTIONS?

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Abstract. — Environmental influences and market/processing trends are changing the future of forestry in the South. Forest management options must be broadened beyond the current mindset to achieve future environmental and economic goals. Pine/hardwood mixtures on appropriate sites is a positive response to future trends.

INTRODUCTION

Is it reasonable to grow, harvest, and regenerate pine and hardwoods in mixtures? For centuries, trees have grown this way without any management. The question is, "Can these mixtures be managed to meet the challenging environmental and economic needs of tomorrow's markets and society?"

Will foresters have time to study, debate, and test options or will the pine/hardwood mixtures or other systems be forced upon us without solid research? The answer isn't clear but let's explore some possibilities facing us today and tomorrow. Two major trends are shaping this management scheme: environmental influences and changing markets/processes.

ENVIRONMENTAL INFLUENCES

Southern forest managers' attention is being slightly diverted to address foreign or less popular concerns such as biological diversity, uneven-aged management and pine/hardwood mixtures. Public attitudes and special interests are raising this awareness. Some examples are public land pressures, environmental organization influx, hunting leases, nongame wildlife uses, landowner objectives and public opinion.

PUBLIC LAND PRESSURES

Environmental concerns dominated the national forest land management planning efforts in the South. In January 1988, 95 percent of the active issues under negotiation involved environmental issues. Interest was keen on the impact of timber management on wildlife (about 50 percent). Many of these interests prefer eliminating intensive plantation management. They would increase the hardwood component to avoid a perceived pine monoculture. Comments imply a reduced harvest on public lands, with the private lands to pick up the shift in supply.

HUNTING LEASES AND WILDLIFE INTEREST

Hunting leases are increasing on private lands in the South (1981). Smith reports that 26 percent of all nonindustrial private forest lands are leased to hunting clubs or require a fee to hunt. Similarly, 29 percent of industry lands are leased. Those percentages increased to 33 percent by 1985, as landowners gained higher fees and achieved other benefits such as road maintenance from such contracts (Marion and others, 1988).

Hunting rates can run $90 per day for deer hunting or $400 per day for quail. Best habitat, with high numbers of animals and demand near populated areas yield higher prices. Leases are expected to increase for hunting and nonconsumptive uses such as birdwatching, camping, and hiking. Hardwoods can enhance habitat diversity for both game and nongame species, and potentially yield higher lease fees.

NONGAME WILDLIFE USES

Birdwatching is another factor shaping public opinion. In 1987, Americans spent $1.1 billion on bird feed, according to Harmon (1988). In 1985, 82.5 million people--slightly more than one-third of our population fed birds. They spent $239 million on feeders, nest boxes and birdbaths. Nearly $375 million went for binoculars and spotting scopes. The trend for this activity is dramatically upward. Let these people (many urbanites) "perceive" that forest management has done anything to adversely affect their feathered friends and watch what happens!

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LANDOWNER OBJECTIVES

Landowner studies show that timber for profit is not the only motivator for landowners. Royer (1987) asked landowners to rate several factors on a scale of 1-10 (10 = high). Forty-nine percent rated 7+ for timber growing as a source of income. Similarly, 44 percent rated 7+ for recreational opportunity and hunting.

Fecso and others (1982) asked landowners who harvested timber, "Why do you own the land?" The results were: growing wood for sale (78 percent), recreation and hunting (30 percent), esthetics (19 percent), inherited the land (51 percent), and plan to pass land on to heirs (53 percent). Over one-half of the owners inherited the land and plan to pass it on to their heirs.

Haymond (1988) surveyed NIPF opinion leaders to determine the primary source of satisfaction in owning forest land in South Carolina. The primary reasons included pride of ownership and personal satisfaction, stewardship, best land use and conservation, privacy, recreation, pleasure and family. Lifestyle enhancement was primary to 52 percent of the respondents. Forty-eight percent chose economics and timber as the primary reason.

These studies show a preference for land stewardship, hunting, wildlife, and esthetics, as well as timber, in NIPF forest management options. These are the landowners who control 72 percent of our forest land base in the South. Pine/hardwoods in mixtures could enhance these values. Are we giving them that option on appropriate sites?

PUBLIC OPINION

An industry public opinion survey by the American Forest Institute (1986) and southern forestry associations surfaces conflicting messages. Sixty-seven percent agree that industry does a good job of conserving natural resources. Seventy one percent agree that industry grows and harvests trees in ways that are environmentally sound. Yet, only 29 percent agree that owners of forest land can be trusted to protect the beauty of forest lands and the quality of the environment without regulation.

ENVIRONMENTAL INFLUENCES SUMMARY

Environmental concerns are increasing in importance to land managers, private landowners, organized groups and the general public. Wildlife, esthetics and stewardship are key public and landowner concerns. These concerns can be turned into assets through increased diversity.

Environmental pressure is currently directed to public lands, but private land challenges are not far behind. We walk a fine line of public support.

Forest managers must improve the balance between environmental quality and economic development or the public will call our hand and make changes we don't need or want.

Much of our research, education and day-to-day operations emphasize maximum wood production (generally pine production). While we try to grow every cubic foot or ton of wood we can out of the landscape, landowners are saying stewardship and other resource values are equally or more important. Are our attitudes blinding us to other forest management options?

CHANGING MARKETS AND PROCESSES

Change in wood products and markets is the second major influence affecting pine/hardwood management options. Improved processing and wood for energy, and resultant hardwood stumpage prices will have the greatest impact on pine/hardwood use in the South.
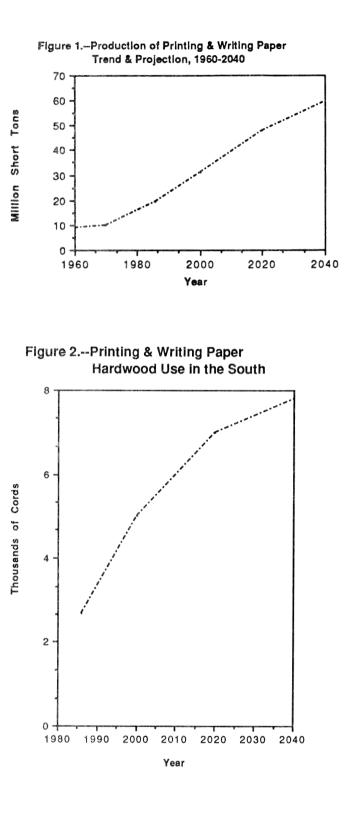
IMPROVED PROCESSING

In the pulp and paper industry, improved pressing technology, including wide nip and high impact presses, are being installed. Many mills in the South have installed this processing improvement since 1980. The result is that some kraft linerboard mills have been able to shift from less than 10 percent hardwood to 30 percent or more hardwood in fiber furnish.

Press drying or impulse drying in the future means even more hardwood in linerboard and newsprint. The press-dried papermaking process developed by USDA's Forest Products Laboratory can use up to 100 percent hardwoods to produce linerboard with improved strength. Here is a process using hardwoods, when compared to existing technology, can save on capital costs, energy, raw materials (by using hardwoods with lower current stumpage value) and at the same time increase yields from raw materials and reduce effluent (Ince 1983).

The rising demand for other paper and board products will involve the use of higher percentages of hardwoods. Substantial increases in demand are expected for printing and writing paper, tissue, and semichemical board (Ince and others, 1987). See figures 1, 2, 3, 4 and 5. Greater demand for these products means more use of hardwood since hardwoods are already heavily used in these materials.

Based upon a consensus of pulp and paper industry experts, the study projects major trends that will positively impact the use of hardwoods. For example:

Figure 1.--Production of Printing & Writing Paper Trend & Projection, 1960-2040

Figure 2.--Printing & Writing Paper Hardwood Use in the South

Figure 3.--Semichemical Board - Production South

Figure 4.--Production of Tissue Trend and Projection, 1960-2040

● 1. More hardwood fiber will be used in printing and writing paper, as demand is expected to rise substantially.

● 2. More use of short-fiber furnish in linerboard: New product market demands for stronger boxes with compression strength and printability is achievable with more hardwood fiber.

Better sheet additives, particularly strength-improving additives, and improved pressing technology, translates into general prospects for more use of hardwoods in kraft linerboard.

● 3. Further replacement of groundwood pulp by modern mechanical pulping methods such as thermomechanical and chemithermomechanical pulping is anticipated.

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**Figure 5.--Southern Pulpwood Prices
Proj., 1987-2035 Sfwd. & Hdwd.**

HARDWOOD STUMPAGE

Pulp and paper processing along the southern coasts has shifted from mostly pine to a higher percentage of hardwoods, some as much as 80 percent hardwood. Two reasons for this are cheaper stumpage price for hardwoods and an increasing market for high quality white paper (printing and writing paper). Industry is adjusting their machines to accommodate hardwoods rather than adjusting the landscape to pine. Some localized shortages of hardwoods have occurred and have brought hardwood pulpwood stumpage prices within $2 of, or even exceeded, pine prices.

The question behind most management options is, "How can the forest or landowner achieve the greatest benefit in the future?" This is usually judged by foresters to mean maximum timber values. The timber prices are measured by current and projected timber prices. These prices project a pine increase of 4 percent per year while hardwood stumpage remain static or a smaller increase than pine. Yet, with trends before us, hardwood prices are expected to increase at a faster rate than the price of pine. Accordingly, a leveling effect is forecast by 2010 (figure 5). Perhaps we need to rethink our economics and the advice given based upon past assumptions. This trend of increased hardwood use with resultant higher hardwood prices is expected to continue through 2035 when hardwood prices could exceed those for pine pulpwood.

MARKET INFLUENCE SUMMARY

These marketing and processing trends strongly suggest that industries and landowners will diversify their markets. Industry will diversify their raw materials and product mix as landowners diversify their management and production of raw materials. The increased use of hardwoods and a gradual leveling trend between pine and hardwood stumpage prices will stimulate this diversification, as well as economic development. Are our southern pine attitudes restricting forest management options?

3-D TEST

Based upon the trends we just discussed, it appears that every option for a pine/hardwood mixture site should be given the "3-D Test." This 3-dimensional test will review the management options for future environmental diversity, market product diversification and overall economic development.

Environmental diversity is a test for a variety of plants and animals living and growing together to satisfy wildlife, esthetics and stewardship concerns. Market product diversification tests the raw materials produced against current and future

Other research is underway to shape and mold paper and wood fiber. This opens the door for a whole new generation of wood products. An example is Temple Inland, Inc., moulded microwave dishes. The Forest Products Laboratory is experimenting with a new molded fiber product called spaceboard.

WOOD FOR ENERGY

Each day we hear of new mills being constructed to produce oriented strand board or flakeboard, which use a component of hardwoods. In addition, markets for quality hardwoods seems unlimited. Together, these processes and markets add up to increased use of hardwoods.

Wood for energy has potential. Technology for wood combustion and feeder systems is on the shelf and could easily be adopted if fossil fuel prices rise slightly. Any interruption of our oil imports, (which have gradually increased) will cause shortages, increased prices, and the use of more wood for fuel. Even with a lagging wood-energy market, more wood is consumed as fuel in the United States today than for all other uses combined.

markets, keeping an eye on new products and processes looming on the horizon.

Overall economic <u>development</u> tests for jobs, income and new business stimulated through forest management options. Major options are not just for timber, but also for hunting, bird-watching and other primary and secondary spinoffs from future forests.

Pine/hardwood mixtures on appropriate sites should certainly be a viable option against these tests. The test would also have to be within the framework of the landowners' objectives.

This 3-D Test will show that all our pine decisions in the past are not bad and that softwood management is not on the way out. Our past decisions have served us well. Basically, our southern pine attitudes are not bad, but perhaps they need some fine tuning. The questions we must ask is: "Will today's decisions serve us well in the future?" Are we ready to risk opening new frontiers in pine hardwood management that are less costly, work with nature to provide many environmental spinoffs yet potentially produce a little less wood.

UNLOCK OUR MINDS
How do we change thinking to broaden forest management options? First, reach landowners before the timber harvest decision is made. Then you should have options available.

Second, seek landowner objectives and don't listen selectively for a pine option or maximum timber production option. This means top level officials in your organization must have more than maximum timber profit on their agenda. The pine/hardwood option could mean a higher rate of return because of lower front-end costs and other resource economic benefits.

Third, remember the 3-D test--options for increased ecological diversity, product diversification, and overall economic development. Where it blends with landowner objectives and site conditions, try options other than pure pine.

Other thoughts are:

— Consider the hardwood component first because it will usually be regenerated naturally. Then consider supplemental planting or natural regeneration with pine.

— On regeneration cuts get total utilization to reduce regeneration costs and eliminate highgrading once and for all.

— Stimulate new or change existing incentives, programs, pilot projects and demonstrations to enhance pine/hardwood mixtures on proper sites.

— Accelerate research and technology transfer that improves our knowledge and management of pine/hardwood mixtures and creates new processes and markets for pine/hardwood use.

So now we stand on the threshold of continuing down the primarily pine management path or exploring a new opportunity on appropriate sites and managing for pine/hardwood mixtures. Will our traditional pine attitudes restrict forest management options? The answer is up to you.

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SILVICULTURE AND ECOLOGY

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EVOLUTION OF FOREST TYPES IN THE SOUTHEAST

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Abstract.—Two separate factors are involved in tracking the evolution of forest types in the Southeast - 1) the evolution of the species that comprise them and 2) the development of the forest associations that we identify as cover types. Of the two taxonomic groups that comprise Southeastern forests (gymnosperms and angiosperms) the gymnosperms are the more primitive dating from the Paleozoic era (over 300 millions years ago) while the angiosperms date to the Early Cretaceous Period (120 million years ago). In both groups most of the species found in Southeastern forests today evolved during the Cenozoic Era (in the last 65 million years). The present forest associations (forest types) found in the southeast developed since the last ice age, largely during the Holocene Epoch (last 10,000 years), and they are still changing. Anthropogenic influences were and still are important vectors in directing these changes.

INTRODUCTION

Among the more intriguing puzzles that scientific inquiry deals with is the question of how the "here and now" came to be. When the subject in question is the forest cover types of a region, ferreting out their origin and the evolutionary road to the present is of more than academic interest.

Understanding these pathways and the vectors that drove the processes should be the base on which sound forest management strategies are developed. The numerous environmental groups who are today insisting that forest managers return our forests to their "original" condition is further stimulus for gaining this understanding.

Once the evolution of the present forest cover of a region is tracked, the opportunities for keeping it in (returning it to) its "original" condition can be evaluated. Apparent in this process will be the recognition that forests are dynamic - they are and always have been changing through time, a fact that man's short life span often conceals.

The present forest types of Southeastern U.S. are composed of members of two taxonomic groups - gymnosperms (conifers) and angiosperms (hardwoods), mixtures of which are the primary focus of this symposium. The silvical characteristics of the species that are broadly distributed over the Southeast (pines and hardwoods) are such that pines usually become established in pure stands following major disturbances (pioneer species) while most hardwoods are later successional species that become established in various mixtures. The pine-hardwood mixture is characteristically a mid-seral stage that is ephemeral on a given site. It is maintained in a changing landscape mosaic where scattered disturbances re-initiate succession in a stochastic manner.

Two separate factors are involved in gaining an understanding of the origin of these associations. First is the evolution of the species that comprise the forests, and second is the development of the forest associations that are identified as cover types. These developments were largely independent of each other with most of the existing species having evolved earlier in the present geologic era (Cenozoic) while the present forest associations are more nearly "current events."

SPECIES EVOLUTION

Understanding the evolutionary pathways to the species comprising the present forest types of the Southeast poses a basic question - where do we begin? Assuming that the usual answer "in the beginning" is appropriate, scientists today are in general agreement that the setting for the evolutionary processes on Earth came into being some 4.6 billion years ago (table 1). As early as 3.8 billion years ago fossil evidence confirms that primitive marine plants had evolved: blue-green algae, bacteria, fungus-like organisms and green algae, or Chlorophyta, the probable precursors to the Tracheophytes, the vascular plants that "clothe" much of the land area of the Earth today (Cooper and others 1986).

More than 3.4 billion years was required for these original, primitive life-forms to evolve into the vascular plants that could survive on the drier, upland regions of the Earth. During the Silurian Period both plants and animals moved from marine to terrestrial environments. By late Devonian vascular, seed-bearing plants had developed, including the gymnosperms (Levin 1975).

During the following Mississippian and Pennsylvanian Periods (Carboniferous) broad areas of lowland forests (dominated by seed ferns) were buried under anaerobic conditions locking much of

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Table 1. Geologic events of signifigance to the evolution of forest types in Southeastern U.S.

Eras	Periods	Epochs	Significant Geologic Events	Time (MYBP)[1]
C E N O Z O I C	Quaternary	Holocene Pleistocene	Development of man. Most recent ice ages.	0.01
				——2.5——
	Tertiary	Pliocene Miocene Oligocene Eocene Paleocene	Speciation with the development of most of the plant species known today.	5 23 37 55
M E S O Z O I C	Cretaceous		Extinction of dinosaurs. Origin and rapid development of the ANGIOSPERMS along with insects.	——65——
				——144——
	Jurassic		Extinction of seed ferns.	
				——208——
	Triassic		Origin of dinosaurs.	
				——245——
P A L E O Z O I C	Permian		Appalachian Revolution = Uplift of SE & formation of Appalachian Mountains. Formation of Pangaea completed.	
				——286——
	Pennsylvanian (Upper Carboniferous)		Vast forests (largely sporophytes).	
				——320——
	Mississippian (Lower Carboniferous)		Major coal-forming swamps. Origin of conifers (including GYMNOSPERMS).	
				——360——
	Devonian		Seed ferns (first seed-bearing plants). Earliest forests.	
				——408——
	Silurian		Development of vascular plants. Earliest record of land plants.	
				——438——
	Ordovician			
				——505——
	Cambrian		Non-vascular, marine plant fossils (with reproductive spores).	
				——570——

PRECAMBRIAN TIME	Simple marine plants (blue-green algae, colonial bacteria, fungus-like plants & green algae (=Chlorophyta).----------3,800
	Origin of the Earth.--------------------4,600

[1]Million Years Before Present

the atmospheric carbon (present as CO_2) into the extensive coal beds that are a primary energy source today. (Our current use of this stored energy is creating environmental problems as this carbon is re-introduced into the atmosphere.)

At the end of the Paleozoic Era (Permian Period) another geologic event of great significance to plant evolution in the Southeastern U.S. occurred - the Appalachian Revolution. This was the time when the Appalachian uplands were formed. Over the millennia these now old, deeply weathered uplands have been eroding, their sediments now form the broad, flat regions known as the Gulf and South Atlantic Coastal plains. Although the coastal regions have been alternately inundated and exposed during the several ice ages that have occurred since their formation, the higher uplands have been available for plant occupancy throughout the Mesozoic and Cenozoic eras - some 260 million years.

During the middle of the Mesozoic Era (probably the Early Cretaceous Period - about 120 million years ago), angiosperms appeared in the landscape marking the next geologic event of signifigance in the evolution of Southeastern forest cover types. Not only did these, the flowering plants, appear suddenly in the fossil record, they flourished. By the end of the Mesozoic Era they were the most abundant land plants. This rapid proliferation is generally attributed to the concurrent evolutionary burst in insects, which were the primary pollinating vectors for the early flowering plants (such as magnolias). Today in Southeastern North America angiosperms comprise 95 percent of all living, terrestrial plants numbering over 250,000 species compared to only 675 gymnosperms, 525 of which are conifers (Harlow and others 1979).

During the millennia since their appearance, angiosperms have vied with gymnosperms for dominance on the uplands of the Earth. While gymnosperms first occupied good sites, the greater competitive ability of angiosperms has generally relegated gymnosperems to poorer, harsher sites. With only a few exceptions (e.g. Pacific coastal forests), they are now dominant only in boreal forests, on poor, xeric soils and following disturbances that remove the more aggressive angiosperms. Not only are the gymnosperms more restricted in distribution, their taxonomic diversity is greatly reduced from their "heyday" in the early Mesozoic Era. [The competitive positions of these two groups in today's landscapes are somewhat ironic as the gymnosperms are in much greater demand by industry than are the angiosperms.]

While the uplands of the Southeast were generally stable throughout the Mesozoic and Cenozoic Eras (in contrast to the general uplift and mountain building in western North America that marked these eras), changing climates and sea level fluctuations in the Southeast forced plant migrations that resulted in continued speciation (Cooper and others 1986). Most of the species found in the Southeast today were present when the last series of events that significantly influenced the forest cover types of Southeast occurred - the Pleistocene glacial events.

In the 2.5 million years since the Quaternary Period began there have been at least 20 major ice episodes with each glacial/interglacial cycle typically lasting 100,000 years. These advancing-retreating ice masses caused plant migrations that resulted in the extinction of over 50 percent of the pre-Pleistocene plant species found in Europe (Davis 1983). As a consequence of the essentially north-south orientation of the Appalachian Mountains migration corridors were open allowing plants to retreat before and advance after the various ice episodes (in contrast to the largely east-west orientation of mountains in Europe that forced plant extinctions rather than allowing migration). The Wisconsinan Continental Glaciation, the last and largest ice episode of the Quaternary Period, peaked approximately 18,000 years ago when the continental ice mass extended southward to approximately the present positions of the Missouri and Ohio rivers (Delcourt and Delcourt 1987).

At this time the zone just south of the glacial front was tundra as were the higher elevations of the Southern Appalachians (in contrast to the claims of Braun (1950) who saw them as a refuge for many of the plants that migrated northward as the glaciers retreated). The Southeast was a refuge for boreal, temperate deciduous and southeast evergreen forests during this time (Delcourt and Delcourt 1985). Northern pines, spruces, fir and larch comprised the dominant forest cover as far south as the southern borders of Tennessee and North Carolina. Temperate deciduous and southeast evergreen species found refuge in the deeper South, pines and oak-hickory on the upper, dry sites, possibly associated with fire regimes, while the mixed mesophytic species were on moister, more fertile bottomlands.

Northward migrations occurred rapidly as the ice mass retreated. Present woody plant distributions were largely "in place" by the beginning of the Holocene - some 10,000 years ago. Essentially concomitant with this was the first evidence of human occupations in the region - approximately 12,000

years ago (table 2). Thus "Man" (Homo sapiens) was a part of the Southeastern environment during the time significant climatic changes were driving major species migrations in the region.

HUMAN IMPACTS ON FOREST EVOLUTION
The extent of pre-Columbian human impacts on the landscapes of the Southeast has been largely overlooked by both historians and ecologists. Of the many ways in which pre-historic man modified the forest, only through his use of fire was his influence broad enough to significantly affect the evolution of forest types. Fire has been used by mankind as a cultural tool for nearly 2 million years in Africa. It was brought to America by the original settlers who crossed the land bridge (Beringia) that connected Alaska with Siberia during much of the Pleistocene. It was/is a cultural tool that can quickly and easily modify large segments of the landscape, generally to the advantage of primitive human populations as it encouraged both the heilophytes and herbivores that were primary food sources (Oakes 1939).

The original human inhabitants of the Southeast were the Paleo-Indians. Archeological evidence has established their presence in the region as early as 12,000 years ago (Chapman 1985). At this time boreal and northern tree species were being displaced by southern taxa from that portion of the Southeast north of 34° north latitude (approximately an east-west line through Atlanta, Georgia). The earliest of these inhabitants possibly contended with a periglacial climate (localized permafrost) as far south as an east-west line through Asheville, North Carolina (Keel 1976).

Paleo-Indians were largely hunter-gatherers whose use of fire to drive or trap large megafauna (large animals like buffalo and mastedon) is largely speculative. If, however, fire was used in this manner, subsistence needs would likely mean that fire was of frequent occurrence. Also, it is highly unlikely that their primitive tools enabled them to contain their fires. Fuel loading and weather probably determined their extent and intensity.

During this cultural period very rapid species adjustments were occurring throughout the Southeast in response to the rapid climate warming that followed the Wisconsinan glacial episode (Delcourt and Delcourt 1987). Jack pine (Pinus banksiana L.), currently a native of Eastern Canada, was then widespread throughout Tennessee, the Carolinas and northern Georgia. By the end of the Paleo-Indian period it was rapidly disappearing from the Southeast. Today jack pine has a highly serotinous cone indicating that fire was a primary factor "fixing" this feature in its genetic makeup.

The Archaic Period (8500 to 1000 B.C. or 10,500 to 3000 Before Present (B.P.)) was a time of human population growth and concentration in villages.

The stone hearths, pottery and middens found in archaeological excavations indicate the evolution of a much more sophisticated lifestyle (Keel 1976). The widespread occurrence of sites of Archaic age throughout the Southeast and particularly in the Southern Appalachians suggest that these people were using the entire landscape, not just the fertile river bottoms (Keel 1976). They continued to be nomadic, however, which may account for the large number of sites identified. By the end of this period there are indications of a primitive horticulture with squash and gourds as primary crops. Fire was the only feasible tool available to these people that could enable them to accomplish significant agricultural clearing.

Archaeological findings from the Woodland Period (1000 B.C. to 800 A.D. or 3000 to 1200 B.P.) reflect the development of stronger agrarian societies with increased trade with other regions. Village sites were occupied throughout the year and, toward the end of this Period, the cultivation of corn (Zea mays) was introduced from the Southwest. About this same time the development of the bow and arrow allowed for more efficient hunting.

By this time the center of the oak populations had moved out of the deep South and were concentrated in the central interior region, essentially their present positions. The southern yellow pines became the dominant species on uplands over much of the deep South, probably due to the effects of widespread burning.

The Mississippian Period (800 to 1540 A.D. or approx. 1200 to 500 B.P.) is considered by many archeologists to overlap with historic (Colonial) time in the Southeast. The Southeastern Indians were now highly dependent on agriculture with corn as their primary crop. Members of the various tribes were concentrated in villages located along the broad alluvial flood plains where shifting agriculture was their primary means of sustenance.

These continuous shifts in land cultivation plus their continued use of fire for clearing land and opening the forest probably kept a mosaic of various stand ages and types in the landscape. It also maintained open corridors that favored plant migration, especially for intolerant species[2]. Since the implements

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[2]Personal communication with Dr. Paul Delcourt and Dr. Hazel Delcourt.

Table 2. Late Pleistocene and Holocene events of significance in the development of forest types in Southeastern U.S.

CULTURAL EVENTS	calendar	years before present	CLIMATE/VEGETATIONAL STAGES
HISTORIC PERIOD: Modern times.	2000	0	Man-made forests widespread. Exploitation of forests & soil.
Settlement times. High Indian mortality.			
America discovered.	1500	500	Indian impacts (cultivation & fire) mold forest character.
MISSISSIPPIAN PERIOD: Indian cultures largely agrarian, large palisades.	1000	1000	
WOODLAND PERIOD:			
Pottery.	500	1500	
Corn cultivated; bow & arrow.	AD		
Burial mounds.	----0	2000	Northern pines had moved into Canada while southern pines had moved into Tennessee - their present distributions.
	BC		
ARCHAIC PERIOD:	1000	3000	
Marked increase in Indian population; exchange with other regions.	2000	4000	Sea level rises to modern position.
Beginnings of cultivation with fire as the only feasible tool for land clearing.	3000	5000	"Southern pine rise" = marked increase in dominance of southern pines in SE.
Archeological evidence that Archaic Indians used total landscape of So. Appalachians.	4000	6000	
	5000	7000	Increased summer warmth and drought.
	6000	8000	
	7000	9000	Central hardwood oak-hickory forests became established.
	8000	10000	Periglacial climate extended as far south as an east-west line thru Asheville, NC.
PALEOINDIAN PERIOD: Largely hunting/gathering tribes; fire was an available tool.	9000	11000	Temperate, deciduous forests replace Jack pine/spruce/fir.
First evidence of humans in the SE.	10000	12000	
		15000	Jack pine, fir and spruce are the primary forest types as far south as Tennessee.
		18000	Full glacial maxima.

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of this time were still Stone Age-type tools, the wide range in tree sizes likely enabled them to utilize forests to a much greater degree than would otherwise have been possible (e.g., very large numbers of pole-size, straight trees were needed to build the miles of pallisades constructed during this period; such trees are found only in young, evenaged stands).

The open character of the forest when first viewed by EuroAmerican settlers is well documented in early descriptions of the landscape as is the widespread use of fire by the native Americans (Guffey, 1977). How the popular notion of a closed, high forest (variously described as virgin, climax, pristine) covering Eastern North America from the Atlantic to the Great Plains (Day 1953) became so firmly entrenched in American thought and popular literature is difficult to explain. Fortunately, popular literature is now recognizing that ". . . the wooded valleys and lowlands where Indians lived had been cycled and recycled by swidden farming; they weren't the 'forest primeval' the 'discoverers' eulogized" (Billard 1989).

A factor that may partially account for historians failure to recognize the open character of the "original" landscape is the very high Indian mortality throughout Eastern North America during the 16th and 17th centuries. European diseases decimated Indian populations after their first white contact. DeSoto's large contingent of "explorers" roamed through much of the Southeast in 1539-40. Scattered accounts from various parts of Eastern North America claim that: 1) at least 80 percent of the Indian population of the Central Mississippi Valley died during the 16th and 17th centuries (Phillips and others 1951; Dobyns 1983 reported by Delcourt & Delcourt 1987) and 2) entire villages in the Northeast were wiped out (Cronan, 1975).

In the various villages these epidemics preceded by decades either the arrival of the first settlers or those literate enough to provide good historical records of the landscape. "Pestilence spreading ahead of a wave of settlers is only one example of how the influence of a frontier travels in advance of that frontier" (Billard 1989). Billard also states that "When the Spanish left Florida in 1763, they took with them the 83 Christianized survivors of a Timucua population that once had numbered 15,000."

By the time historical accounts were being written (18th century) former Indian old fields and fire-maintained uplands were supporting 50 to 150-year-old forests that could easily be perceived as pristine

and virgin. In the Deep South the forests described in these early accounts were commonly composed of yellow pines, which are pioneer species on disturbed sites. The magnitude of the effort required to keep pine on these sites rather than hardwoods, the species that comprise the later seral stages that replace pines, is well understood by industry today.

PINE-HARDWOOD STANDS
The natural and anthropogenic forces that have been altering the Southeastern landscape for the past 1,000 to 2,000 years should have encouraged the widespread occurrence of pine-hardwood forest types. Indian old fields were probably "captured" by pure pine stands, as happened following widespread agricultural abandonment earlier in this century. If left undisturbed hardwood encroachment would result in a pine-hardwood mixture once the invading hardwoods filled the canopy openings that occur as pine stands mature and begin to break up. Left undisturbed long enough most sites in the Southeast will eventually become hardwood stands (Kuchler 1964).

A second mechanism was provided where fires caused hardwood mortality on frequently burned uplands created openings allowing the establishment and development of pines, resulting in a pine-hardwood mixture. The quality of hardwoods in these stands would be low as fire scars would encourage the decay fungi that cause butt rot. However, these "den trees" provide good wildlife habitat. Both of these mechanisms through which pine-hardwood mixtures were perpetuated depended on repeated disturbance.

In the pre-Columbian landscapes the pine-hardwood types were maintained as a mid-seral successional stage that occurred as a shifting mosaic. Efforts to "fix" pine-hardwood stands on specific sites in perpetuity will be difficult and somewhat "unnatural."

IN CONCLUSION
Over much of the Southeast disturbance-initiated species have been the dominant forest cover for as long as the extant species have been here. Furthermore, for at least the past 10,000 years man has been the originator of many of the landscape disturbances that have affected forest composition (according to some anthropologists, "man" is responsible for the serotinous-cone character of several pine populations).

The notion that some "natural" forest condition existed in 1492 in the sense of the broad landscape being composed of climax forest associations that formed independent of a human influence is a myth. Further, trying to devise management

strategies today to try to recapture this "figment of our romantic nature and imagination" is not a viable option. Any significant effort in that direction is counter productive.

A serious concern, not only to forest resource managers, but the public in general, must be the guidelines used to manage the Southeastern landscape. It is proper and desirable that there be public input into this process. Too often, however, the voices heard are from those who have little biological training and even less understanding of the "natural" condition that they want to "re-capture." Of great concern to the resource managers responsible for the wise management of the Southeastern forest is the demand that it be returned to some "natural" or "original" (pre-Columbian?) condition which they preceive to have evolved without disturbance. This demand becomes an anomaly when the evolutionary history of the Southeastern forest is understood.

The hard fact must be established that conditions that the average forest user of today perceives as "ugly" (i.e., just after a stand-replacement fire) are essential to the healthy and "natural" function of many forest ecosystems. Such impacts maintain the biodiversity that accomodates the wide range of species and forest types that characterize the Southeastern landscape. The extent to which forest managers are allowed to manage the Southeastern forests in what they perceive to be a wise manner may largely depend on their ability to tell this story to a public who increasingly is "calling the plays."

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THE DECLINE OF THE MISSOURI OZARK FOREST BETWEEN 1880 AND 1920

Robert J. Cunningham and Carl Hauser[1]

Abstract. — Missouri's presettlement pine and oak-pine forest once extended over six million acres. Today the pine and oak-pine cover types occur on less than 400,000 acres. Between 1880 and 1920, some of the Nation's largest producing sawmills were operating in Missouri's Eastern Ozarks region. A historic review of this period's industrial and social activities toward the Ozark forests illustrates how an area once dominated by pine was converted to hardwoods.

INTRODUCTION

Industrial and social activities occurring in the Missouri Ozarks between 1880 and 1920, dramatically changed the area's oak-pine forest cover. During this period, large-scale lumber companies and the workers they attracted, thoroughly exploited the virgin forest resources. The effects of this period relate directly to the formation of the present forest cover type.

PRE-INDUSTRIAL PERIOD

Before 1880, Missouri's pine and oak-pine cover types were estimated at 6.6 million acres (Law 1984; Liming 1946). The range primarily covered the southeast Ozark highland on a geographic unit known as the Courtois Hills (figure 1). Shortleaf pine (Pinus echinata Mill.) was the dominant species and was distributed unevenly across its natural range. Associated hardwoods included black oak (Quercus velutina Lam.), white oak (Q. alba L.), scarlet oak (Q. coccinea Muenchh), and post oak (Q. stellata Wangenh.). Often, it formed pure stands; otherwise, it mixed with the hardwoods. Early lumber company records indicated that old-growth pine volumes averaged 4,000 board feet per acre (Hill 1949). Occasional stands containing 25,000 board feet per acre were also recorded (Brinkman and Smith 1968; Record 1910). Individual trees with butt cuts nearly 4 feet in diameter at the small end of a 16 foot log were common (Hill 1949).

Immediately following the Civil War, most of the Ozarks was still isolated from settlement and commercial resource exploitation. Its rugged terrain discouraged the only practical means for lumber transportation: railroads. Because the demand for forest products was concentrated in the more populated eastern United States, Missouri's remote forests remained uncut.
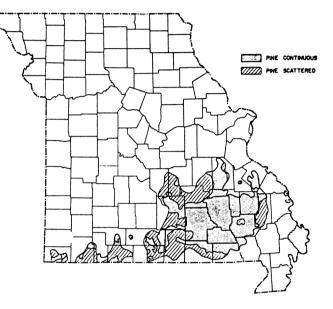
Figure 1.--Natural range of shortleaf pine in Missouri. (From Brinkman and Smith 1968)

By 1880, lumber output from the eastern forests had declined (Galloway 1961). The westward migration of people through Missouri and on to the treeless Great Plains greatly increased the demand for Ozark lumber. When railroad developers showed interest with line construction across southern Missouri, eastern timber speculators were attracted to the Ozark pineries. Uncut timberland was cheap and often sold for $1.00 per acre (Hill 1949). Investors pieced together major land holdings that formed the resource base for future lumber companies.

THE LUMBER BOOM

The Ozark's lumbering boom started in 1887 when the railroads began line construction (Hill 1949). By then, lumber companies were erecting enormous sawmills. Populations increased rapidly as loggers and their families were drawn to the new mill towns and logging camps. Large towns eventually

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developed at Grandin, Winona, Birch Tree, Leeper, Greenville, Doniphan, West Eminence, Midco and Bunker, MO (figure 2). Production peaked in 1899 when Missouri sawmills turned out 724 million board feet of lumber (Steer 1948). The boom lasted until the early 1920's.

Most of the large mills were engaged in the manufacture of pine lumber. The Missouri Lumber and Mining Company at Grandin, MO was the first mill to undertake large-scale lumbering in the Ozarks (Galloway 1961). Often referred to as the Grandin Mill, its practices and policies were developed under the leadership of General Manager John B. White and typified the activities of other regional sawmills.

The operations at Grandin were enormous considering current Missouri standards. The milling complex comprised two large band mills, one circular sawmill, four planing mills, fourteen drying kilns and thirty warehouses, with an annual production capacity of 75 million board feet. Seventy-five acres of old-growth pine were cut daily to feed the mills. In 1894, the Grandin Mill was the largest of its kind in Missouri and reputed to be the largest operating sawmill in the United States (Hill 1949).

Activities away from Grandin centered around the logging camps. An extensive network of company-owned railroads, or tram lines, connected the camps to the mill. Most of the logs were transported across these lines. Others were floated down the Current River during enormous log drives.

Logging practices were best described as "cut-and-get-out" operations. White had ordered all pine trees having a butt diameter larger than 12 inches, or hollow ones containing at least 5 inches of sound wood, to be cut and hauled to the mill (Hill 1949). Hardwoods were hewn into railroad ties and either used on the tram lines or sold to other railroads.

Mid-Continent Iron Company's (Midco) operation at Midco, MO, is another example of an industry that totally exploited the forest. Originally, Midco was an iron smelting facility. Local timber sources were converted into charcoal for use in the furnaces. Daily wood consumption equaled 180 cords. During World War I, the United States government installed a chemical distillation plant at Midco. Large quantities of wood alcohol, tar, calcium acetate and wood oils were recovered from the char-
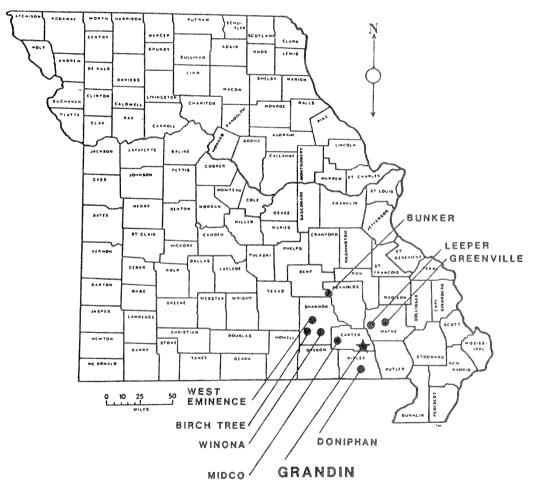
Figure 2.--Location of Missouri's large forest industry between 1880 and 1920.

coal process (Oakley 1970). During its operation period, thousands of acres were completely stripped of all forest resources.

SOCIAL AND ECONOMIC FACTORS CONTRIBUTING TO FOREST COVER CHANGE

The synergic relationship described below between the Ozark natives and the lumber companies eventually destroyed the intrinsic values each had placed upon the pineries. The activities of both groups had drastically curtailed pine regeneration, thus allowing a predominance of hardwood regrowth.

People living in the Ozarks prior to the lumber boom were subsistence farmers. Most received some income by raising livestock on the open range. Other forms of agriculture were very limited, owing mainly to the rough, stony character of the land. The pine forests were well suited to produce forage because they were naturally open with an understory of grass.

With the advent of the big mills came social and economic changes to the Ozarks. The industries provided employment and a means for woodland owners to liquidate timber assets. Reynolds County, MO, for example, was one of the last regions to be cut. Its population in 1920 was 10,106, of which half were engaged in lumbering (Krusekopf and others 1918).

Lumber companies had produced some short-term economic benefits for the people. However, when the timber supplies were exhausted, the companies abandoned their operations, leaving behind the unemployed timber workers. These vocationally unadjusted people returned to farming for an economic base. Krusekopf and others (1918) best described the effects that cutting the forest had on agriculture:

> "After the removal of the pine and the larger hardwood trees, a dense growth of young oak timber sprang up and the wild grasses diminished in abundance, greatly reducing the value of the range for pasture. This change did not prove particularly serious at the time, however, since more dependence was placed on the income from lumbering, but with the cutting of most of the marketable timber and return to agriculture the injury became more evident."

Those trying to pasture the cut-over lands had to contend with the hardwood regrowth. Intensive goat and sheep grazing was one technique used for pasture reclamation. Without the continuous grazing, the hardwood sprouts would always return. However, fire was the primary means used to sustain the dwindling grass cover. The repeat fires ex-

posed the thin Ozark soils to erosion, robbing the hillsides of the nutrients essential for both grass and tree growth.

Several factors contributed to the lack of pine regeneration. The lumber companies' severe cutting practices stemmed from the local property-tax situation. Much of the lands had been acquired at tax sales. Land with timber often sold for the same price as cut-over land (Hill 1949). Many of the tracts were purchased with uncertain titles. Because property taxes remained high after cutting, companies saved taxes and protected their investments against prior title claims by quickly removing any timber and disposing of the land. Without its timber, the land was useless to the lumber companies. The lands that could not be sold were abandoned and again auctioned at public tax sales. Any interest in reforestation or conservation was discouraged by the prospect of long-term tax investments.

Timber theft and fire also diminished the possibility of natural pine regeneration. Logging had already eliminated most of the potential seed trees. Remaining small-diameter pines were often poached from company lands. This practice of stealing timber was locally known as "Grandma-ing" (Galloway 1961). The term is derived from the statement a poacher would make as to the property from which a log was acquired: "... from Grandma's back 40". The annual woods burning by area farmers further destroyed pine regeneration. Fire killed pine seedlings and caused hardwoods to vigorously resprout. Germinating pine seedlings were unable to survive under the prolific hardwood canopy.

Artificial pine reforestation may have been considered by some industry leaders but never practiced. Galloway (1961), quoted John B. White's somewhat erroneous feelings on the matter:

> "I suppose that a vigorous pine forest exhausts from the soil that element most adapted for reproducing pine. All through the pine forests there are small oak bushes which are burned off from year to year by forest fires so that they do not get a good start. And they are also kept back by the shade of the pine forest trees, and when these are cut down they sprout and thrive in the sunlight and take possession of the ground once occupied by the pine. However, wherever a pine comes up it appears to grow and it would be easy in my opinion to reproduce the pine by transplanting and I do not believe that the soil is sufficiently exhausted to make it impracticable, but the oak, being more vigorous takes the place as opportunity offers."

After the sawmills were dismantled, some of the lumber companies still owned thousands of cut-over acres. By this time, many had switched from the manufacture of lumber to selling real estate. Marketing lands worth less than the taxes assessed against them was a difficult task. Listings were sent across the United States and often included advertisements overrating the land's potential to grow fruits and vegetables or sustain livestock. Ironically, such schemes were encouraging the same land use practices that had compounded the problem of pine regrowth. In turn, this discouraged the continued operation of the lumber companies. Large blocks of land were sometimes divided into lots of 2.5 acres or less, and then individually sold. One of the more famous subdivisions was created by the Munger Securities Company of Hunter, MO. Munger lots still retain their original pattern today, across many thousands of acres in Carter and Reynolds County. The size and abundance of these lots made timber management impractical.

POST LUMBER BOOM RESULTS

The second-growth forest contains less pine than the original stands. In many places, hardwoods have completely replaced pine. Today, the pine and oak-pine cover types occur on less than 400,000 acres of Missouri's remaining 12.4 million acres of forest land (Essex and Spencer 1976). The Pine Valley drainage of Reynolds and Carter Counties is a dramatic example of this change. Named for its once-bountiful pine forest, today Pine Valley is almost entirely covered with hardwoods. Scarlet and black oak are now the dominant species.

The result of the boom period was a reduction in the presettlement forest's unique composition and quality stemming from industrial and social interactions. This eastern Ozarks Region today is heavily affected by a disease complex known as oak decline. In Missouri, this gradual or sudden dieback or mortality of oaks is frequently found on sites formerly dominated by pines. Red oaks, particularly scarlet, are the most severely affected (Gass and Luley 1988). Since 1978, management of an estimated 180,000 acres of Mark Twain National Forest land has been altered as a result of oak decline (Law and Gott 1988). An estimated 30,000 acres of state forest land and many thousand acres of private land are also affected. The large scale conversion of the native pine and oak-pine types to forests dominated by black and scarlet oak undoubtedly contributed to the current problem.

To avoid similar conditions in the future, management recommendations must encourage species diversity, primarily oak-pine mixtures. This, combined with sustained yield management, should insure a healthy forest throughout the Missouri Ozarks.

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CHARACTERIZATION OF THE HARDWOOD COMPONENT IN SOUTHERN PINE COVER TYPES IN THE SOUTHEAST

Gregory A. Ruark and William A. Bechtold[1]

Abstract. — Forest Inventory and Analysis (FIA) data indicate that pine cover types comprise 41 percent of the total forest land in Florida, Georgia, South Carolina, North Carolina, and Virginia. Of these, 12.7 million acres are planted and 22.0 million acres are naturally regenerated. Many of these pine stands contain considerable amounts of hardwood. Understanding the dynamics of growth in these stands therefore requires knowledge of pine-hardwood interactions. Information is provided on the hardwood component within natural and planted stands of loblolly and slash pine, as well as natural stands of longleaf, pond, shortleaf, and Virginia pine on both Coastal Plain and Piedmont sites in the Southeast.

INTRODUCTION

While only 11 percent of the forested landbase in the Southeast (Florida, Georgia, South Carolina, North Carolina, and Virginia), is classed as oak-pine, an additional 26 percent is classed as naturally regenerated pine (figure 1). These proportions are similar for both the Coastal Plain and the Piedmont. However, total acreage differs, with 11.8 million acres of natural pine on the Coastal Plain and 7.8 million acres in the Piedmont. Large amounts of hardwood basal area are frequently encountered in these pine stands. In some cases the degree of hardwood competition is sufficient to suggest that these stands function more as mixed pine-hardwood than as pure pine stands.

This paper uses Forest Inventory and Analysis (FIA) data from the most recent (1983 thru 1987) State surveys to provide distributional information on stand-level variables of age, stocking, site quality, and hardwood competition within the major planted and naturally regenerated pine cover types in the Southeast (Bechtold and Ruark 1988). Our objective is to identify situations where pine forests are moving towards a pine-hardwood composition.

METHODS

The design of FIA is predicated on the collection of a well-distributed, systematic sample, with proportionate sampling of all major forest types, sites, and ownerships. Approximately 25,000 permanent plots are measured during the course of a survey cycle within the five state region administered by the Southeastern Forest Experiment Station. Each plot represents an average of about 3,400 acres.

Stand-level characteristics are measured on clusters of five sampling points per plot with a basal area factor (BAF) prism of 37.5. The basal area and
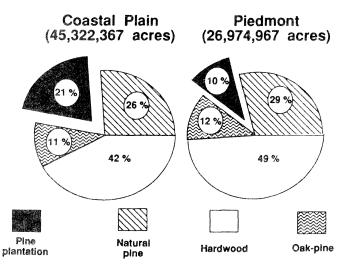
Figure 1. Percentage distribution of all timberlands in the Southeast, by broad forest type and physiographic region.

number of stems per acre are calculated for each major species on the plot (Beers and Miller 1964). Stand age and site index are determined from increment cores and height data from dominant and codominant trees in the stand (Schumacher and Coile 1960).

There are three to five survey units in each of the five States. Each survey unit is confined to one of three major physiographic associations (Coastal Plain, Piedmont, or Appalachian Mountains).

In this paper stand composition is evaluated by physiographic region averaged over all five States and by individual States averaged over physiographic regions. Means and standard deviations (weighted by acreage), as well as other statistics required to characterize the stand-level distribution of age, stocking, site index, and hardwood competition for a cover type are provided by Bechtold and Ruark (1988). Only mean values are discussed in this paper.

[1] Project Leader and Resource Analyst, respectively, USDA Forest Service, Southeastern Forest Experiment Station.

TABLE 1. Average characteristics of naturally regenerated pine stands by ownership[a]

	Age	Site index	Pine stems	Hardwood basal area	Acres	Plots
	Year	Feet	No./acre	pct	1000	No.
Coastal Plain						
National Forest	47	67	209	16	701	285
Other Public	41	64	225	20	1,253	561
Forest Industry	32	68	286	24	2,172	785
Farmer	36	73	259	24	2,918	1,030
Other Private	33	67	264	23	4,958	1,776
Piedmont						
National Forest	49	74	391	26	215	64
Other Public	40	67	357	21	336	194
Forest Industry	31	68	459	24	984	292
Farmer	33	68	383	28	1,917	535
Other Private	30	67	407	26	4,385	1,209

[a] From Tables 23-25, Bechtold and Ruark (1988)

RESULTS AND DISCUSSION
Ownership

Five ownership categories are recognized: National Forest, other public, forest industry, farmer, and other private. The average age of natural pine stands on National Forest lands exceeds that of other ownerships for both Coastal Plain and Piedmont sites (table 1). Site index does not vary greatly among ownerships, but site index is higher for farmers than others on the Coastal Plain and higher for National Forests on the Piedmont. The number of natural pine stems per acre is always much higher on Piedmont than on Coastal Plain sites. However, the average proportion of total stand basal area comprised by hardwoods ranges from 16 to 28 percent and does not differ greatly between the two physiographic regions. The lowest proportion of hardwood basal area is on Coastal Plain, National Forest sites, while the highest levels are manifested on Piedmont farmer ownerships.

The situation differs for planted pine stands (table 2). The average age of plantations ranges from 12 to 19 years across all ownerships. The greatest average age for plantations, 19 years, is for the other public catagory on the Coastal Plain. The lowest average site index on the Coastal Plain for National Forest land and the highest for farmer holdings. On the Piedmont, avearge site quality is similar for all owner groups. The average proportion of total stand basal area allocated to hardwoods ranges from 9 to 21 percent, with a notably high proportion of hardwoods in Piedmont National Forest plantations.

TABLE 2. Average characteristics of planted pine stands by ownership[a]

	Age	Site index	Pine stems	Hardwood basal area	Acres	Plots
	Year	Feet	No./acre	pct	1000	No.
Coastal Plain						
National Forest	13	61	562	9	247	104
Other Public	19	65	358	10	418	207
Forest Industry	14	69	373	9	6,170	2,243
Farmer	13	72	331	12	747	269
Other Private	15	68	345	10	1,877	698
Piedmont						
National Forest	13	70	457	21	74	23
Other Public	15	73	408	14	50	33
Forest Industry	12	70	377	11	1,606	485
Farmer	16	74	288	16	323	90
Other Private	17	73	299	10	767	210

[a] From Tables 23-25, Bechtold and Ruark (1988)

Overall, the ownership data in tables 1 and 2 suggest that there is a substantial hardwood component in naturally regenerated pine stands regardless of ownership. The situation exists on both the Coastal Plain and Piedmont across a range of age classes and sites.

South to North

On Coastal Plain sites the proportion of stand basal area relegated to hardwood species increases with latitude from south to north; ranging from 12 percent in Florida to 29 percent in Virginia (figure 2). These values reflect an average for all pine cover types. The difference in hardwood competition with latitude on the Coastal Plain is not related to the greater acreage of plantations on the south end of the gradient (figure 3). The same trend in hardwood competition is evident when planted and natural stands are viewed separately. There is no apparent latitude gradient on Piedmont sites, where the proportion of stand basal area occupied by hardwoods averages 24 percent in all five States.

TABLE 3. Average characteristics of naturally regenerated stands in the Coastal Plain (CP) and the Piedmont (P) of the Southeast[a]

	Age	Site Index	Total basal area	SDI[b]	--Hardwood-- Stems	Basal area	Acres
	Year	Feet	Ft^2/acre		--- pct ---		1000
				LOBLOLLY			
CP	34	75	103	256	66	29	4,326
P	31	72	98	243	51	23	4,449
				LONGLEAF			
CP	43	60	55	127	46	13	2,309
P	43	-	56	123	54	14	99
				POND			
CP	37	58	69	181	64	22	1,239
				SHORTLEAF			
CP	38	69	100	232	60	28	114
P	36	64	101	253	46	28	1,535
				SLASH			
CP	31	67	71	181	44	18	3,818
P	19	-	43	147	43	9	50
				VIRGINIA			
CP	35	68	121	301	49	27	109
P	32	66	105	265	51	24	1,571

[a] Calculated from Tables 2-5, Bechtold and Ruark (1988)
[b] Stand Density Index (Reineke 1933)

Naturally Regenerated Cover Types

Table 3 gives average age, stocking, site index, and hardwood composition for naturally regenerated pine stands in the Coastal Plain and Piedmont of the Southeast. The number of hardwood stems in each covertype ranges from 43 to 66 percent. Since many of the hardwoods are small diameter coppice sprouts, their basal area better reflects their influence on the pine than does the number of stems.
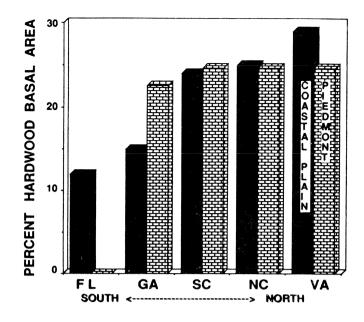
Figure 2. Percent of stand basal area in hardwood species by state and physiographic region, averaged for all pine cover types. (tables 6 and 11-20 from Bechtold and Ruark, 1988).
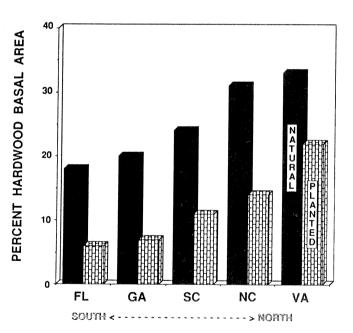
Figure 3. Percent of stand basal area in hardwood species in natural and planted stands on the Coastal Plain. Averaged and weighted by acreage for loblolly and slash pine. (tables 6, 11, 14, 17, and 19 from Bechtold and Ruark, 1988).

Loblolly, pond, shortleaf, and Virginia pine stands all average in excess of 22 percent hardwood basal area on both the Coastal Plain and Piedmont. Longleaf stands are the oldest and are often poorly stocked with low total basal area, but have only 13 and 14 percent hardwood basal area on the Coastal

TABLE 4. Average characteristics of natural (N) and planted (P) pine stands[a]

| | ---- Coastal Plain ---- | | | | ------ Piedmont ------ | | | |
| | Loblolly | | Slash | | Loblolly | | Slash | |
	N	P	N	P	N	P	N	P
Age (Years)	34	12	31	16	31	13	19	19
Site Index (Feet)	75	71	67	67	72	72	-	75
Basal area (Ft^2/acre)	103	60	71	53	98	59	43	67
Hardwood								
Stems (pct)	66	46	44	26	51	45	43	35
Basal (pct) area	29	15	18	8	23	12	9	7

[a]Calculated from Tables 2-5, Bechtold and Ruark (1988).

Plain and Piedmont, respectively. These low values may reflect the strong tendency of longleaf stands to form associations with scrub oaks. Natural slash pine stands have 18 percent hardwood basal area on Coastal Plain sites, but only 9 percent on the Piedmont. Piedmont slash pine stands are notably younger and may reflect recent changes in management. However, sample size was small for this resource.

Planted vs. Natural Stands

Loblolly and slash pine are planted across large areas in the Southeast. In excess of 1.2 and 2.4 million acres are planted to loblolly pine on the Coastal Plain and Piedmont, respectively. Slash pine plantations are concentrated onto 5.6 million acres of coastal sites, with only 337,000 acres planted on the Piedmont (Bechtold and Ruark 1988). Coastal Plain plantations of both species have roughly half the hardwood basal area proportion of corresponding natural stands, reflecting the success of site preparation practices and prescribed burning (table 4). This holds true for Piedmont loblolly pine plantations, but naturally regenerated slash pine stands on the Piedmont exhibit a characteristically low level of hardwood competition, but the sample size is small for this situation. For both loblolly and slash pines, the proportion of hardwood basal area was always greater on Coastal Plain than on Piedmont sites, regardless of stand origin. On Coastal Plain sites planted stands averaged as much as 15 percent hardwood basal area and natural stands ranged up to 29 percent.
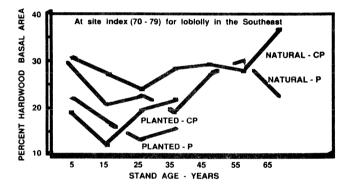
Figure 4. Basal area proportion of hardwoods by stand age on site index 70-79 loblolly pine sites in the Southeast. For planted and naturally regenerated Coastal Plain (CP) and Piedmont (P) sites. (figures. 18C, 19C, 26C and 27C from Bechtold and Ruark, 1988).

Hardwood competition varies with stand age (figure 4). Medium quality (site index 70-79 feet) loblolly pine sites in the Southeast were grouped by stand origin and physiography. The proportion of hardwoods was lowest between ages 15 and 25 for both natural and planted loblolly pine on the Coastal Plain. However, the hardwood component increased as stand age increased, with hardwoods comprising 37 percent of the basal area of natural loblolly pine stands by age 65. Piedmont sites showed a general decrease in percent hardwood basal area from age 5 to 25 regardless of stand origin, but no clear trend was present in more mature stands. In general, at any given age the proportion of hardwoods was greater in natural stands; the only exception was age 35, at which Coastal Plain plantations had more hardwood competition than natural Piedmont sites.

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State vs. State

Statewide totals for naturally regenerated loblolly pine on Coastal Plain and Piedmont sites were estimated for medium quality sites (site index 70-79 feet) in North Carolina and South Carolina (figure 5). At all ages, the proportion of hardwoods in North Carolina substantially exceeds that on comparable sites in South Carolina. Whether this difference is due to management, site, and/or environment is not apparent, but it clearly occurs throughout the length of the rotation.
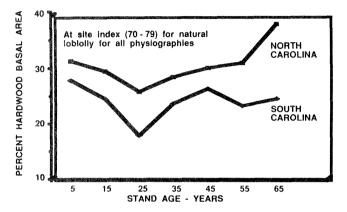
Figure 5. Comparison of hardwood basal area proportion in natural loblolly pine stands of North Carolina and South Carolina for site index 70-79 lands. (figures. 48C and 55C from Bechtold and Ruark, 1988).

Site Index

The proportion of hardwood basal area in planted loblolly pine stands declines as site quality improves (figure 6). On low quality loblolly pine sites, hardwood encroachment is large in both planted and natural stands. The tendency to intensively manage better sites may explain this difference. However, alternative explanations, such as the slower rate of canopy closure on poor sites, may result in more hardwood competition. On the best Piedmont sites, the hardwood competition in natural stands is notably low. For slash pine, the hardwood component is generally small across site classes, regardless of stand origin. Except for natural slash on the best coastal sites, slash does not seem to be severely challenged by hardwoods. However, our analysis does not examine competition from herbaceous plants that could substantially compromise the water and nutrient resources available to pines.

CONCLUSIONS

The mounting pressure to restrict the use of prescribed fire and herbicides, as well as economic constraints on management inputs, will likely present more obstacles towards limiting the degree of hardwood encroachment in pine cover types. In
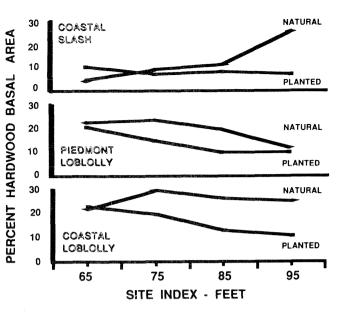
Figure 6. Hardwood competition within natural and planted pine stands by site quality in the Southeast at age 20-29 years. (figures. 18C, 19C, 20C, 21C, 26C, and 27C from Bechtold and Ruark, 1988)

the Coastal Plain and at increasingly northern latitudes, where hardwoods already comprise a large percentage of the stand basal area, lack of aggressive hardwood control measures at harvest will likely result in many of these stands being reclassed as pine-hardwood or pure hardwood cover types during the next rotation. Additionally, many naturally regenerated pine stands are already functioning as mixed pine-hardwood stands. This is particularly true of loblolly, shortleaf, and Virginia pine.

The structure of pine stands in the Southeast supports the need for accelerated research into pine-hardwood management.

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THE GYPSY MOTH IN PITCH PINE-OAK MIXTURES: PREDICTIONS FOR THE SOUTH BASED ON EXPERIENCES IN THE NORTH

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Abstract. – Historically, pitch pine-oak stands growing on xeric, poor quality sites in the Northeast have experienced frequent and severe episodes of defoliation by the gypsy moth. The dynamics of a gypsy moth outbreak in pitch pine-oak stands and in more mesic mixed hardwood stands in the Northeast were analyzed. Gypsy moth egg mass densities were sufficient in all stands to cause severe defoliation, but such defoliation occurred only in the pitch pine-oak stands. In these stands, oaks were severely defoliated, most for 2 successive years, but few pines were severely defoliated. Mortality of oak species ranged from 7 to 36 percent while mortality of pitch pine was only 13 percent. Oaks generally did not die unless completely defoliated for 2 years. Pitch pine always died when completely defoliated and some that were only 60 percent defoliated. Pines are not preferred hosts of the gypsy moth and early instar larvae cannot successfully establish on them; however late instar larvae can feed and complete development on pine. If the hard pines of the South are similar to pitch pine in their resistance to defoliation, mortality of pine from gypsy moth outbreaks will likely be minor.

INTRODUCTION

The gypsy moth (Lymantria dispar) causes substantial defoliation of northern temperate forests in Asia, Europe and North America (Montgomery and Wallner 1988). It was introduced from Europe into North America near Boston, Massachusetts, in 1869, and was restricted to the New England States until 1950 through the actions of regulatory quarantines and barrier zones (McManus and McIntyre 1981). In the last 20 years it has more than doubled its area of infestation and populations now extend south to Virginia and west to Ohio and Michigan.

Preferred hosts include oaks, poplar, some birches and larch (Lechowicz and Mauffette 1986; Mosher 1915). Pines cannot be utilized by small larvae, but late instar larvae are able to survive and develop on pines, including loblolly pine (Pinus taeda) and other species common to the southern United States (Barbosa and others 1983). When outbreaks of the gypsy moth occur, conifers such as white pine (Pinus strobus) and hemlock (Tsuga canadensis) may be severely defoliated. Hemlock is particularly vulnerable and catastrophic mortality is the usual consequence if it is completely defoliated (Turner 1963). White pine may be less vulnerable than hemlock, in part because it is less likely to be totally defoliated since the larvae will eat the new, current year needles of white pine only as a last resort (Stephens 1984).

There are no reports on susceptibility and vulnerability to defoliation by the gypsy moth of stands containing hard pines. Stands in the Northeast containing pitch pine (Pinus rigida) usually are classified as susceptible to gypsy moth defoliation. Stands susceptible to defoliation generally occur on xeric sites such as rocky ridgetops or well-drained sand plains (Houston 1981). In contrast, resistant stands occur on mesic sites with deeper soil. The resistant stands have a greater diversity of species, with oak often a minor component, whereas the susceptible sites are often 80 to 90 percent oaks.

Mixed pine-hardwood stands in the South occur on a wide variety of sites, but they are more common on the drier sites. Loblolly pine and shortleaf pine (P. echinata) are most frequently associated with hardwood species on these sites, particularly oaks (Quercus spp.) and sweetgum (Liquidambar styraciflua) (Knight and McClure 1974). Even those stands considered to be pure pine frequently have a significant hardwood component (Tansey 1983).

In this report, we will examine the progression and consequence of an outbreak of gypsy moth in two stands of mixed oak-pitch pine, one located on Cape Cod, Massachusetts, and the other in southern New Jersey. These areas were part of a system of research plots established at the onset of a region-wide outbreak of the gypsy moth in 1972. Results from laboratory studies to evaluate the performance of gypsy moth larvae on some common southern hardwoods and loblolly pine also will be given.

THE INTENSIVE PLOT SYSTEM

An extensive body of data including gypsy moth egg mass densities, sources of gypsy moth mortality, defoliation and subsequent tree mortality was

collected from 1972 to 1978 in six forest areas in the northeastern United States (figure 1). Each area of this "Intensive Plot System" (IPS) consisted of five to eight sites with each site fairly homogeneous in soil type and species composition. Within each site, there were five 0.04-ha plots and data were collected on all trees greater than 5 cm dbh. Altogether, data were collected on almost 10,000 trees for 7 years.

Figure 1.--Location of the Intensive Plot System study areas.

Areas 1 and 7 are oak-pitch pine stands located on coastal sand-plains, the other areas consist of mesic mixed hardwood stands that contain some white pine.

Resistant/Susceptible Stand Differences

Five of the six study areas contained 10 to 13 percent pine (table 1). The pine specie in Areas 2, 3 and 4 was white pine whereas Areas 1 and 7 contained pitch pine. Areas 1 and 7 contained few species other than pine and oak, the latter comprising 82 and 87 percent of the stand stems, respectively. Although Areas 2, 3, 4, and 6 contained proportionately less oak, the other species present included aspen and white birches and all these areas had at least 50 percent of the stems in the preferred food class. Thus, each area had the potential to support large populations of gypsy moth.

The current threshold for activation of gypsy moth suppression programs is 600 egg masses/ha (U.S. Department of Agriculture 1989). Densities of egg masses in each area, except Area 4, exceeded this threshold in at least one of the years (table 1). Severe defoliation, however, occurred only in the areas containing pitch pine. Egg mass densities of < 400/ha resulted in > 55 percent defoliation in these two areas whereas, peak densities of 453 to 2,394 egg masses/ha resulted in defoliation ranging from 12 to 40 percent in the other areas. The distinction between the pitch pine-oak stands and the other stands lies less in differences of resistance to population build-up than in resistance to defoliation by high populations of gypsy moth.

It is not certain why the mesic-site stands in the Intensive Plot System were less defoliated than the oak-pitch pine stands but disease could have caused population reduction before the larvae grew to a size that could consume large amounts of

Table 1.--Summary description of Intensive Plot System study areas

	Area					
	1	2	3	4	6	7
Basal area, m^2/ha	17.9	21.4	24.7	21.1	29.0	13.5
Total stems/ha (pct of total)	2006	1238	1242	1159	883	1644
Pines	10.5	11.9	11.7	11.0	0	13.0
Red oaks	53.3	25.0	23.8	12.3	15.7	27.7
White oaks	29.1	10.8	40.0	4.1	8.7	59.2
Other	7.1	52.2	24.6	72.5	75.4	0.0
Egg masses/ha						
Year 1972	316	1300	927	453	516	356
1973	1497	1345	446	319	2394	6018
1974	243	562	72	19	145	9
Defoliation (pct)						
Year 1972	90.4	35.2	16.5	12.1	13.2	55.8
1973	63.5	15.8	9.1	2.5	39.6	91.5
1974	9.1	9.2	3.0	0.9	8.4	2.3

foliage. Epizootics of virus disease triggered by starvation and other overpopulation phenomena are usually responsible for collapse of defoliating outbreaks. Disease incidence of older, 4th-6th instar larvae, may be higher on mesic sites than on drier sites (Campbell 1963). Oaks growing on xeric sites have higher levels of tannins in their foliage (Kleiner and others in press). These tannins apparently can decrease the susceptibility of larvae to viral disease (Keating and others 1988). Both pitch and loblolly pine foliage contain fairly high concentrations of condensed tannins (Montgomery, unpublished observation).

Utilization of Species in Oak-Pitch Pine Stands

The high susceptibility of the coastal-plain pitch pine-oak stands (Areas 1 and 7) is most likely a consequence of the high percentage of oak in these stands. The presence of a small amount of pitch pine, although not a favorable food plant, may be a contributing factor because it has structural characteristics that may allow the gypsy moth to better escape natural enemies.

Pitch, loblolly and other hard pines have very furrowed and rough bark that can provide refuge from predators on the forest floor. Bess and others (1947) introduced the importance of structural features, particularly rough, furrowed bark and loose bark defects, as a characteristic of forest stands susceptible to the gypsy moth. They found that in dense, mesophytic forests gypsy moth larvae that went to the forest floor had higher rates of mortality than larvae that remained above the floor on the tree bole. They observed that forests susceptible to gypsy moth defoliation had a higher proportion of trees with bark flaps and crevices that encourage larvae to remain on the tree bole.

Egg masses laid on pine may also be exposed to less parasitism and virus disease. Rossiter (1987) found that parasitism of gypsy moth eggs by _Ooencyrtus kuvanae_ was 25 percent lower on pitch pine than on oak. Larvae hatching from egg masses found on pine had only a 4 to 18 percent incidence of nucleopolyhedrosis virus (NPV) compared to 14 to 57 percent for those found on oak. As pupation approached, larvae began to use pine not only as a resting site, but also to consume it. At the onset of the fourth instar, Rossiter found 3 times the number of larvae per tree on oak as on pine, but the numbers of pupae were nearly equal on oak and pine, and the number of egg masses was 0.7:1 oak:pine. The work of Rossiter (1987) in low density populations provides further rationale for gypsy moth to utilize pitch pine as a resting and oviposition site.

The hypothesis that pitch pine is a preferred species for oviposition by the gypsy moth was tested by examining the distribution of egg masses among trees in Areas 1 and 7. To clarify the impor-

tance of rough bark, the oaks were separated into whites and reds, the former having rougher bark. Since tree size can also influence egg mass distribution and the mean dbh of pitch pine was 30 percent (Area 1) and 200 percent (Area 7) greater than oak, egg mass densities were calculated per stem dbh. In 1972, when populations were increasing, more eggs per dbh of stem were found on pine than on oak in both areas (figure 2). In Area 1 in 1972, all species of oak were defoliated and larvae moved to pine to complete development; hence, many more egg masses were present on pine than on oak in the Spring of 1973. White oaks were heavily defoliated in Area 7 in 1972 and larvae moved to the red oaks to complete development and oviposit the eggs that made up the starting population for 1973.
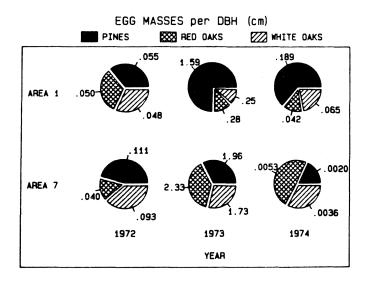
Figure 2.--Proportionate distribution and density of egg masses per cm of stem diameter in two pitch pine-oak stands.

Few egg masses were found in Area 7 in 1974 indicating that the population crashed before larvae reached maturity. Overall, populations were more stable in Area 1 than in Area 7 where use of pine was proportionately less.

Pitch pine did not experience heavy defoliation in either area even though many of the oaks were completely defoliated 2 years in a row (figure 3). In Area 1 in 1972, only 25 percent of the pitch pine received more than 60 percent defoliation and only 4 percent was completely defoliated. It was surprising that the pine was not defoliated more, since nearly all of the oak was completely stripped of foliage. The only species heavily defoliated for 2 successive years in Area 1 was white oak (_Quercus alba_). In Area 7, pitch pine was defoliated even less despite the extensive defoliation of oak in 1973. Both white oak and chestnut oak (_Q. prinus_) were

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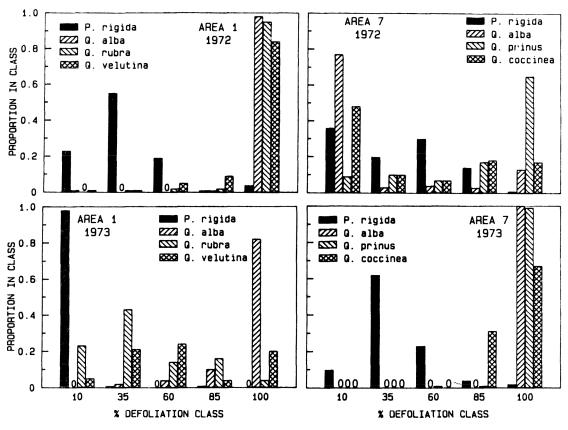
Figure 3.--Defoliation of the most common tree
species in two pitch pine-oak stands. Class values
are midpoints except for 100 percent.

severely defoliated in Area 7 with most of the
chestnut oak receiving 2 years of 100 percent
defoliation. Black oak (Q. velutina) was a minor
component (10 percent of total stems) in the stand,
and is not depicted in the figure, but it also received
severe defoliation by the gypsy moth in both years.

A shortage of food was likely the cause of the
population collapse in Area 7, but this seems inade-
quate to explain the collapse in Area 1. Likely, virus
disease and host specific parasites contributed to
the population collapse in Area 1, which has had a
resident gypsy moth population for over 60 years.
Parasites and disease may have been less
prevalent in Area 7 since this was the first time it
was severely defoliated. Natural enemies were
probably less established and hence only a
shortage of food could stop the population out-
break.

Tree Mortality in Oak-Pitch Pine Stands

Mortality of the major species in each area is given
in figure 4. In Area 1, white oak was the only
species severely defoliated for 2 successive years
and it had the highest mortality rate. All pines that
received 85 percent or greater defoliation in 1 year
died. In Area 7, chestnut oak and white oak were
the most severely defoliated species; however, mor-
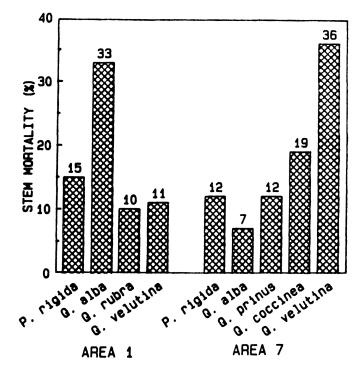
Figure 4.--Tree mortality during a 5-year period
(1973-1978) in two pitch pine-oak stands defoliated
by the gypsy moth in 1972 and 1973.

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tality was higher for the red oaks, black oak, and scarlet oak (Q. coccinea). This was puzzling since less than 10 percent of either species were overtopped and the trees were in good condition. Review of the original records revealed that these oaks received a third successive year of defoliation in 1974 by the fall cankerworm (Alsophila pometaria). As in Area 1, few pines died in Area 7 and some of this mortality may have been due to other causes, since a few lightly defoliated pines also died.

The percentage of stems dying was generally highest in the overtopped crown class, but for most species there were few stems in this category (table 2). Although 100 percent of the overtopped pine died in Area 1, this represented only 4 trees, or 17 percent of the total mortality of pine in Area 1. Pitch pine experienced about the same mortality in all three strata in Area 7. Overtopped oaks were also more likely to die than overstory oaks, but this represented a significant percentage of the total stems that died. Percent mortality was highest among overtopped northern red oak (Q. rubra) and black oak in Area 1. This represented one-third of the total mortality. In Area 7, mortality was highest among overtopped oak of all species and overtopped mortality was 26 percent of total mortality.

Considering the severity of defolialtion, the overall mortality of trees in the pitch pine-oak stands was low, about 16 percent. These forests occurred on poor sites for growth. Such sites where tree growth is slow may experience less mortality than better

sites where tree growth is faster (Houston and Valentine 1977). The small, slow-growing trees on the coastal sand-plains probably have low energy demands compared to faster-growing trees on better sites. Mortality associated with gypsy moth in central Pennsylvania, where growing conditions were better, averaged 23 percent for oaks (Gansner 1987).

LABORATORY FEEDING TRIALS

Gypsy moth larvae were reared in a quarantine facility at the University of Georgia at Athens to determine the survival and growth of larvae on several tree species that are common in southern forests. Newly-hatched larvae were placed on the foliage shortly after budbreak. The foliage was changed every other day to maintain freshness. Larvae were reared in two ways: in one case they had access to only one species; in the other, they had access to a hardwood species plus loblolly pine.

Survival of larvae varied with tree species. Survival was highest on water oak (Q. nigra) (29 percent), followed by sweetgum (26 percent), white oak, (22 percent), southern red oak (Q. falcata) (20 percent), and post oak (Q. stellata) (17 percent). Only 1 percent of the larvae survived on red maple (Acer rubrum) and no larvae survived beyond the second instar on loblolly pine. The best growth, as measured by pupal weight, was obtained on water oak (1.15 gm female, 0.45 gm male) followed by sweetgum, southern red oak, post oak and white

Table 2.--Percent mortality by crown class during a 5-year period after gypsy moth defoliation; in parentheses is the total number of stems, both living and dead, in each crown class.

		CROWN CLASS		
Area	Species	Upperstory	Intermediate	Overtopped
1	Pinus rigida	15.2 (112)	16.0 (50)	100 (4)
	Quercus alba	34.3 (271)	30.0 (120)	35.3 (68)
	Q. rubra	3.0 (263)	21.3 (89)	41.9 (31)
	Q. velutina	5.1 (275)	9.5 (148)	29.8 (47)
7	P. rigida	10.6 (113)	13.6 (88)	10.8 (37)
	Q. alba	0.5 (208)	9.8 (215)	27.8 (36)
	Q. prinus	5.9 (254)	10.3 (312)	28.8 (118)
	Q. coccinea*	13.7 (234)	20.8 (120)	27.8 (21)
	Q. velutina*	34.2 (76)	35.1 (37)	57.1 (7)

*Was also defoliated by the fall cankerworm following the gypsy moth outbreak.

oak with 0.85 gm female, 0.32 gm male pupal weights obtained on the latter. Since white oak is a superior host species in the northern states, these data indicate that the southern oak species are as suitable as the northern oak species, if not more so.

When the gypsy moth larvae were reared with a choice of either loblolly pine or one of the hardwood species, they always chose to feed on the hardwood, even if it was red maple. The larvae, at all stages of development, chose hardwoods over pine. However, loblolly pine was frequently selected as a pupation site.

Large, late instar larvae will consume and survive on hard pine foliage when given no other choice. Barbosa and others (1986) reared gypsy moth first on black oak until about half grown and then switched them to loblolly pine or Virginia pine (P. virginiana). Larvae switched to pine attained female pupal weights that were greater than if they had remained on black oak. They also observed that first instar larvae could not survive on pine. Thus, it appears that southern pines are not preferred hosts but may be suitable food for half-grown gypsy moth larvae.

When gypsy moth larvae do feed on pine, the amount of defoliation may be considerably higher than expected for a given population size. We placed fifth and sixth instar larvae on a three-needled pine with 20-cm long needles similar in appearance to loblolly pine but growing in Connecticut. Typically, a larva would extend out on a needle with its hind prolegs attached to the stem, sever the needle and backfeed to the needle sheath. These larvae, which averaged 0.35 gm dry weight, removed about 0.48 gm needles per day, but consumed only 0.17 gm. This low ratio of only 35 percent of the severed foliage being consumed indicates that relatively low numbers of larvae can cause considerable defoliation of pine. By comparison, the gypsy moth is estimated to consume 86 percent of the oak foliage it removes (Braham and Witter 1978).

CONCLUSIONS

Analysis of a historical defoliation episode in oak-pitch pine stands in the Northeast showed that pitch pine was lightly defoliated (< 40 percent) in years when oaks were severely defoliated (85-100 percent). The hard-needled pitch pine seems less susceptible to defoliation than the soft-needled white pine. In Area 2 of the IPS, where defoliation of oaks was only 50 percent, white pine was 21 percent defoliated. Herrick and Gansner (1981) observed a similar pattern of relative defoliation from a gypsy moth outbreak in Pennsylvania in 1981: overall average defoliation was 60 percent for chestnut oak, 9 percent for white pine and 1 percent for pitch pine.

Tree mortality varied by species and crown class. Nearly all pitch pine that was more than 85 percent defoliated died, but overall mortality was only 13 percent since few pines were defoliated this severely. Because it is a shade-intolerant species, few pitch pine stems occurred in the understory. Overtopped pine all died in Area 1, but in the very lightly stocked Area 7, mortality was the same in the understory as in the overstory. Mortality of oaks in the oak-pitch pine stands varied from 7 to 35 percent but differences between species were not consistent between the two areas. Generally, overtopped trees of all oak species were more likely to die. All oaks that died received two or more successive years of severe, usually complete, defoliation.

First instar gypsy moth larvae cannot successfully establish on pine foliage, possibly because they are limited to feeding on the tough, previous years' needles. However, laboratory tests have confirmed field observations that half-grown larvae will consume the foliage of hard pines when an alternative preferred food is not available. Pine foliage is nutritious to late instar larvae and we observed the highest number of eggs/egg mass and highest densities of egg masses in the stands containing pitch pine.

Based on our experience in the Northeast, we suggest that southern hard pines will be fairly resistant to defoliation by the gypsy moth. The dynamics of gypsy moth populations in southern oak-pine stands and their ultimate impact on the resource will vary substantially depending on the ratio of oak to pine basal area. A small component of pine in these stands may increase the susceptibility of oak to severe defoliation. Currently, plots are being established to acquire these data in loblolly pine-oak sites in Virginia that are being invaded by the gypsy moth.

For the moment, concern should be focused on what impact the gypsy moth will have on predominately oak stands in the South. A simulation model of the impact of gypsy moth on North Carolina forests (Byrne and others 1987) suggests that oak-hickory stands will decrease, while oak-pine stands with a high basal area in pine will increase.

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GYPSY MOTH IMPACTS IN PINE-HARDWOOD MIXTURES

Kurt W. Gottschalk and Mark J. Twery[1]

Abstract. — Gypsy moth has affected pine-hardwood mixtures, especially oak-pine stands, since the late 1800's. Several old and new studies on impacts in mixed stands are reviewed. When pines are heavily defoliated, considerable growth loss and mortality can occur. Mortality is heaviest in understory white pine trees. Impact information is used to suggest silvicultural management actions to minimize damage in northern mixed stands. Suggestions for pre-infestation treatments in southern mixed stands are made.

INTRODUCTION

Since its introduction into the United States in 1869, the gypsy moth has affected millions of acres of forest in the northeastern and middle Atlantic states. Many of these forested areas were mixtures of hardwoods and conifers, especially mixtures of oak and pine. These mixtures have been located primarily in southern New England. Information on the impacts of gypsy moth on these mixed stands has been collected by a number of people over a number of years. Our intent is to summarize these reports and suggest silvicultural treatments to minimize gypsy moth related impacts in these stands.

SUSCEPTIBILITY TO DEFOLIATION

The susceptibility to defoliation is the primary determinant of whether or not gypsy moth will affect a stand. Without heavy defoliation levels, there will be no significant impacts. Susceptibility will be considered on both the species and stand level.

Species Level

Gypsy moth feeding preferences are quite pronounced. Some species are favored as food by gypsy moth larvae (notably oaks, aspen, birch, and sweetgum), while other species are unfavored and are rarely fed upon (table 1.; Mosher 1915). All pines that have been tested have been intermediate; young larvae will not eat their needles, but older larvae will readily eat pine foliage. Larvae prefer the older needles of both pitch and white pine; only rarely do they eat the new needles of pitch pine, but new needles of white pine are eaten more readily (Hall 1935; Mosher 1915). Because of this feeding pattern, many of the current year needles are not damaged or only lightly fed on unless populations are very heavy. White pine growing in the understory of mixed or pure stands is much more susceptible to defoliation than trees growing in the overstory (figure 1). In contrast to pine, gypsy moth larvae prefer the new foliage of hemlock, so older needles are usually the ones left on the tree (Mosher 1915).

Most species tested for gypsy moth suitability have been northern species or southern species that reach their northern limit in southern New England. Loblolly, pitch, Virginia, and shortleaf pine are the only southern pines that have been tested and all are intermediate (Barbosa and others 1983, 1986; Mosher 1915). In general, soft (white) pines are generally preferred over hard (yellow) pines. Sweetgum is the only southern hardwood other than oak which has been found to be highly preferred (Martinat and Barbosa 1987; Barbosa and others 1983). Many other hardwoods are intermediate, while most southern hardwoods, especially understory species, have not been tested.

Stand Level

Susceptibility on a stand level is determined by species composition and site factors (Bess and others 1947; Houston and Valentine 1977; Herrick and Gansner 1986). By far the most important factor is species composition. As the percentage of basal area in highly preferred species increases, the susceptibility of the stand increases (table 2, figure 2). Pines growing in mixed stands are more susceptible than pines growing in pure stands because the availability of preferred foliage allows the young larvae to survive to the stage where they can then feed on pine foliage. In figure 1, overstory and understory white pines were more heavily defoliated when growing in oak-pine stands (50 percent oak), than in pine-oak stands (2 percent oak), which were in turn higher than pure pine stands (90 percent pine) (Brown and others 1988). The timing of defoliation in mixed stands proceeds as follows: first the preferred hosts are defoliated; as they approach moderate to heavy defoliation, understory pines are beginning to be fed on; as the preferred hosts are heavily defoliated, the understory pines are approaching moderate to heavy defoliation and the overstory pines have some feeding on them; and finally the preferred species and understory pines are completely defoliated, while the larvae moderately to heavily defoliate the overstory pines. In severe outbreaks, the overstory pines may suffer 1 year of moderate to heavy defoliation, while preferred hosts like oaks may suffer 1 or 2 years of moderate and 1 or 2 years of heavy defoliation.

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Table 1.--Break down of woody plant species by gypsy moth food preference (susceptibility) classes (adapted from Mosher 1915)

Class I: Species that are favored food for gypsy moth larvae during all larval stages.

Overstory: apple, basswood (American linden), bigtooth and quaking aspen, gray, paper (white), and river birch, boxelder, larch (tamarack), American mountain-ash, all oak species, lombardy poplar, sweetgum, willow.

Understory: alder, hawthorn, hazelnut, eastern hophornbeam, serviceberry, all sumac species, witch-hazel

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Class II: Species that are favored food for gypsy moth larvae after the earlier larval stages.

Overstory: chestnut, eastern hemlock, all pine species, all spruce species

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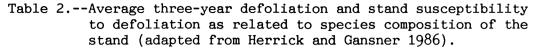
Class III: Nonpreferred species fed upon by later larval stages only when preferred foliage is not available.
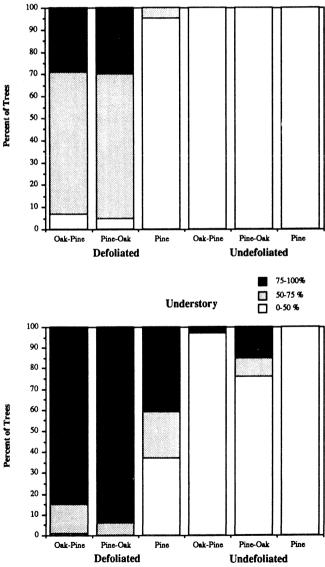
Overstory: American beech, black (sweet) and yellow birch, blackgum (tupelo), Ohio and yellow buckeye, butternut, sweet and black cherry, eastern cottonwood, cucumbertree, American and slippery elm, hackberry, all hickory species, Norway, red, silver, and sugar maple, pear, silver poplar, sassafras, black walnut.

Understory: blueberries, pin and choke cherry, American hornbeam, paw paw, persimmon, redbud, sourwood, sweetfern.

Class IV: Unfavored species that are rarely fed upon.

Overstory: all ash species, baldcypress, northern catalpa, eastern redcedar, balsam and fraser fir, American holly, horsechestnut, Kentucky coffee-tree, black and honey locust, mulberry, sycamore, tuliptree (yellow-poplar).

Understory: all azalea species, dogwood, elderberry, grape, greenbrier, juniper, mountain and striped maple, rhododendron, all rubus species, sheep and mountain laurel, spicebush, sarsparilla, all viburnum species

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Table 2.--Average three-year defoliation and stand susceptibility to defoliation as related to species composition of the stand (adapted from Herrick and Gansner 1986).

Preferred species	Three-year average defoliation	Stand susceptibility
pct	pct	
0 to 20	9	low
20 to 50	18	moderate
50 to 80	24	high
80 to 100	32	very high

Figure 2.--Defoliation and mortality between 1912 and 1921 on Melrose Highlands plots in New England, classed by percentage of oak (basal area) in the stands (Campbell and Sloan 1977).

Figure 1.--Distribution of defoliation of white pine trees in the overstory and understory on plots in Rhode Island classed as defoliated and un-defoliated in 1981 (Brown and others 1988).

IMPACTS ON PINE-HARDWOOD STANDS
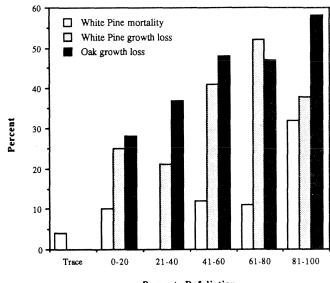
While the gypsy moth has many socio-political impacts in addition to its biological impacts on forest stands, we are only considering the impacts on timber production in mixed pine-hardwood stands in this paper. Vulnerability is the probability of a tree (or stand) suffering impacts, such as mortality of trees, growth loss, and changes in species composition, once it has been defoliated.

Mortality

Numerous papers have been written on the vulnerability to mortality of oaks to gypsy moth (Campbell and Sloan 1977; Quimby 1987; Herrick and Gansner 1987a). However, we would like to bring together the literature on vulnerability of white pine and hemlock in New England. Pitch pine, and to a smaller extent Virginia pine, have also been studied. Pitch pine is covered in another paper in these proceedings (Montgomery and others 1989).

As shown in figure 2, mortality of oaks is directly related to defoliation, although many other factors influence the process. As with oaks, defoliation intensity is a major factor determining vulnerability of white pine. Baker (1941) studied mortality of white pines defoliated between 1912 and 1921 (figure 3). When only a trace of defoliation occurred on old needles, mortality was less than 5 percent. When all old needles were completely eaten and new foliage was defoliated between 0 and 80 percent, mortality was around 10 percent. Only when defoliation of new foliage was greater than 80 percent, did mortality increase threefold. In 1953, similar results were obtained for both white pine and hemlock; mortality increased when defoliation surpassed 80 percent and hemlock mortality was 74 percent when completely defoliated (figure 4, House 1960). Similar and even more dramatic results were obtained for white pine and hemlock defoliated in 1981, where 94 percent of the completely defoliated hemlock trees died (figure 5, Stephens 1988). The difference in mortality rates between white pine and hemlock are related to the defoliation patterns. Since new foliage is consumed first for hemlock and it has no capacity for refoliation, complete defoliation causes severe mortality. White pine still has many new needles left and they have not yet completed elongation when gypsy larvae pupate, so they continue to develop some additional foliage and survive better.

Crown class and position also affect the defoliation and subsequent mortality of white pine and hemlock. Stephens (1988) found that understory white pine and overstory hemlock tended to be defoliated

Figure 3.--Mortality and growth loss of oak and white pine between 1912 and 1921 in New England, classed by percent defoliation of study plots. Trace defoliation represents old foliage present. All other categories have all old foliage eaten and various degrees of defoliation on new foliage (Baker 1941).
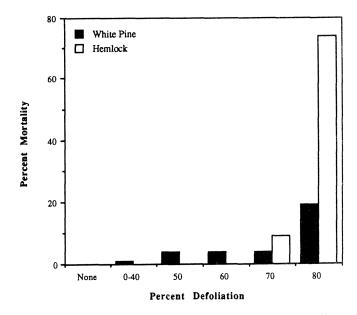
Figure 4.--White pine and hemlock mortality after different levels of defoliation in 1953 in New England (House 1960).
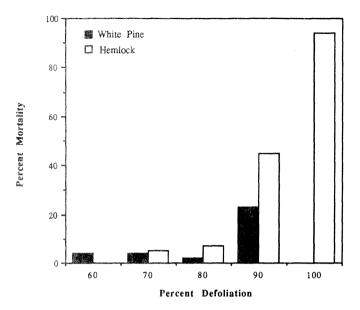
Figure 5.--Mortality in white pine and hemlock between 1981 and 1984 after defoliation in 1981 in Connecticut (Stephens 1988).

more heavily than overstory white pine and understory hemlock, although hemlock was much more uniform that white pine (figure 6). Mortality rates showed that while dominant hemlocks were defoliated slightly more, they died at half the rate of codominant, intermediate, and suppressed trees (figure 6). The only mortality in white pine occurred in understory trees, dominant and codominant trees were defoliated less and did not die because they suffered less than 80 percent defoliation (figure 6). Brown and others (1988) showed similar patterns of heavy mortality in understory white pine in mixed and pure pine stands that were defoliated, while undefoliated stands had much lower mortality rates (figure 7). Quimby (1987) reported mortality rates in Pennslyvania of 39 to 44 percent in pulpwood-sized conifers. Sawtimber-sized trees had mortalities of 3, 12, 9 to 17, and 0 percent for white pine, hemlock, pitch pine, and red pine, respectively. In New Jersey, mortality was 31 percent for hemlock and 20 percent for white pine (Kegg 1974). Heavy defoliation causes mortality in both white pine and hemlock. Overstory hemlock dies at a lower rate than understory hemlock. Hemlock dies at a higher rate than white pine. Overstory white pine rarely dies, but understory white pine is very vulnerable.

Growth Loss

Since many pines do not die following defoliation, the question of impacts on growth rate arises. What does the defoliation of needles do to the growth of pines? Baker (1941) examined increment cores from many oaks and white pines that were defoliated to various degrees. He found 20 to 60
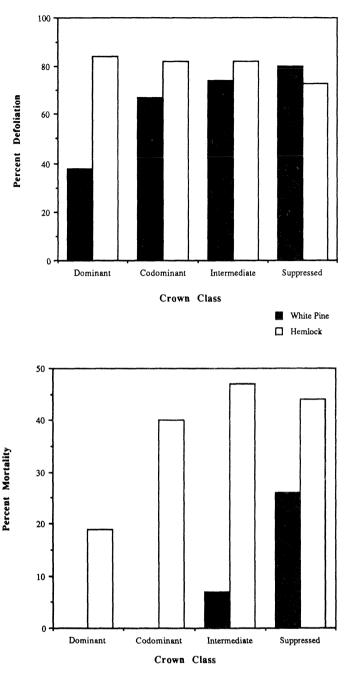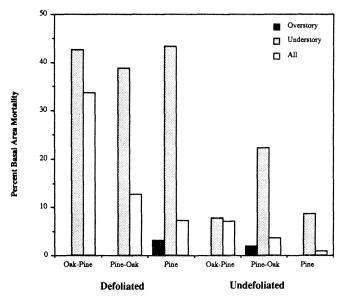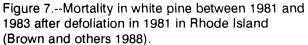
Figure 6.--Mortality and defoliation in white pine and hemlock by crown class after 1981 defoliation in Connecticut (Stephens 1988).

percent losses in radial growth of both white pine and oaks (figure 3). The losses in general increased with increasing defoliation intensity and were similar between the two groups of trees. House (1960) also looked at diameter growth losses of white pine and of hemlock (figure 8). Five-year diameter growth losses (compared to previous 5-year diameter growth) were not different from undefoliated trees for defoliation intensities up to 80 percent. For trees defoliated 80 to 100 percent, diameter growth losses were double the normal

Figure 7.--Mortality in white pine between 1981 and 1983 after defoliation in 1981 in Rhode Island (Brown and others 1988).
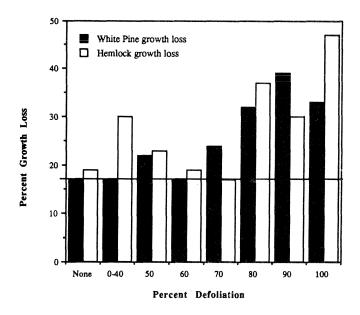
Figure 8.--Five-year diameter growth loss in white pine and hemlock after different levels of defoliation in 1953 in New England. The horizontal bar is a reference line representing baseline growth loss compared to the previous five years (House 1960).

loss. These studies suggest that growth losses can be as serious as mortality for trees that receive heavy defoliation levels. In an interesting study of oak-pitch pine mixtures, Campbell and Garlo (1982) showed mortality and decline in growth of defoliated black oaks in the stand and a corresponding increase in growth of pitch pines which were only lightly defoliated. Because pitch pine was more valuable than black oak, this infestation

actually increased stand value. Management of mixed stands may be affected by differential stand growth and developmental patterns resulting from differential defoliation patterns.

Change in Species Composition

When mortality or differential growth occurs in mixed stands, it is possible for the species composition to shift. In oak-white pine stands, greater mortality in the oaks may shift the stand to more dominance by white pine initially but with less pine in the long run due to loss of understory pines. In oak-hemlock stands, a purer oak stand may result from the heavy mortality in hemlock. When an oak shelterwood stand with white pine regeneration is defoliated, the pine can be almost eliminated preventing the conversion to pine or mixed oak-pine. It is also possible for a stand to remain at the same relative composition due to mortality in both groups (Brown and others 1988).

SILVICULTURAL AND MANAGERIAL RECOMMENDATIONS

Silvicultural treatments to cope with the gypsy moth were suggested very early in New England (Fiske 1913; Clement and Munro 1917). Many of the early New England prescriptions dealt with mixed oak-pine stands and recommended conversion to non-preferred species. The high value of oak stands limits the desirability of conversion. We have refined these prescriptions for northern stands and also suggested some similar treatments for southern stands, although with much less reliable information on which to base them.

Silvicultural Management of Northern Forest Types

There are limited options available to minimize impact of gypsy moth by silvicultural means. These have been practiced with some success in areas where gypsy moth has existed for many years, but they may still not be acceptable for some management objectives. The primary means of affecting the seriousness of gypsy moth outbreaks are to manipulate the species composition away from preferred host species and to maintain the vigor of the stand.

Mixed species conditions. In stands with mixed pine-oak overstories, the pines are at minimal risk. Where stands are white pine and red oak, the pines are often dominant individuals which are rarely fully defoliated and suffer little or no mortality (Stephens 1988). In New Jersey forests of black oak and pitch pine, Campbell and Garlo (1982) found increased growth and vigor of pines when the oaks suffered

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defoliation and mortality. If pine is the major product desired from stands such as these, little heed need be paid to the gypsy moth. However, if oaks are the primary species of interest, the trees should not be allowed to stagnate, because trees with small crowns and poor vigor are the most vulnerable to gypsy moth outbreaks and the secondary agents which follow.

Many stands in New England have an overstory of oaks with an understory of white pine. These stands are often managed as a shelterwood, with the overstory oak protecting the pines from the white pine weevil until they are over one log tall. The stand is then converted to pine by harvesting the oak overstory. If a gypsy moth outbreak occurs before the oak is removed, the understory pine is at great risk. Many of the understory pines will die when the larvae defoliate them after exhausting their food supply in the overstory. The best alternative for management of such a scenario is to harvest the overstory before an outbreak. If the overstory is not yet ready for harvest, spraying to prevent an outbreak is recommended.

Where the understory is hemlock instead of pine, the trees are at even greater risk. Hemlock does not recover after a full defoliation. However, it is also a less desirable species as timber. The primary situation where it is a desired part of the stand is where it is needed as cover for game species, in which case protection of the stand by spraying is the only recommended method for retaining hemlock in a mixture with oaks.

Stands where pines comprise the overstory and hardwoods the understory are not as common as they are farther south, but this situation does exist in some plantations and old-field stands. The understory hardwoods, however, are generally not those favored by gypsy moth, such as beech, red maple, and viburnum. These stands are generally not at risk from gypsy moth outbreaks. If the understory develops a large proportion of more favored species such as witch hazel, blueberry, or oak, then the situation may change.

Silvicultural options. Reduction of susceptible species in a stand is the most reliable way of reducing the threat from gypsy moth (Gottschalk 1982). Treatments which might be classified as sanitation or presalvage cuttings (Smith 1986) are typical methods of achieving this reduction. In these treatments the proportion of the stand in susceptible or vulnerable trees is reduced sufficiently to decrease the likelihood of an extensive outbreak. The extreme form of this method is stand conversion,

which leaves only trees which will not support a gypsy moth population.

If the situation is such that a susceptible species is still the most desired tree, such as in a stand dominated by red oak, the best available method to reduce hazard is to maintain a vigorous stand. The most vulnerable trees, even among favored host species, are those with small crowns or many dead branches within the crown (Herrick and Gansner 1987b). If a stand is maintained in an uncrowded, vigorously growing condition, there is less likelihood that a defoliation will cause mortality (Gottschalk 1982).

Potential Silvicultural Management in Southern Forest Types

Little information and few options are available to minimize impact of gypsy moth by silvicultural means in southern stands. Some success from areas where gypsy moth has existed for many years can be transferred south, but they still may not be acceptable for some management objectives and some conditions. The principal techniques for reducing the impacts of gypsy moth outbreaks farther south are to manipulate the species composition away from preferred host species and to maintain the vigor of the stand.

Mixed Species Conditions. Southern mixed stands have a much broader and more varied composition than northern stands. All across the South, the major mixed stands are oak-pine stands that contain 50 percent or more oak, and 25 to 50 percent southern pines with hickories and blackgum as common associates. In these stands, pine will probably not suffer extensively compared to the oaks. If pine is desired, then gypsy moth will not need to be managed. However, if oaks are important for timber or wildlife habitat, then they should be kept in vigorous condition with large, healthy crowns by thinning. Healthy trees are the least likely to die from gypsy moth defoliation and subsequent secondary organism attack.

In the Piedmont and Coastal Plain, southern pine stands can have up to 40 to 50 percent hardwoods growing with the pines. The variety of species differs widely with site and stand conditions. When enough of the hardwoods are preferred species such as oaks or sweetgum, it is likely that gypsy moth populations will rise high enough to affect the pine. However, since the pine is usually the desired product, loss of the hardwoods may be of little consequence and even benefit the growth and value of

the stand. One fear expressed by some southern entomologists, is that enough damage will be done to the southern pines, especially loblolly, to stress the trees sufficiently to cause a southern pine beetle outbreak to start in the stand.[2]

Stands where pines dominate the overstory and hardwoods the understory occur across millions of acres in the South. Many of these southern understory species have not been tested for their gypsy moth feeding suitability. If sufficient numbers of preferred species are present in the understory, it may be possible that enough gypsy moth larvae will survive to a stage where they can move to the pine foliage. Some tests have shown that this situation may enhance the survival of the gypsy moth (Rossiter 1987; Barbosa and others 1986). Again, just enough stress could be placed on these pine trees to trigger other pest problems.

Silvicultural Options

The best silvicultural treatment in mixed oak-pine stands is to reduce the proportion of susceptible species in the stand to a level that places less risk on the stand as a whole; less than 50 percent of the basal area is good, less than 30 percent is better, and less than 15 to 20 percent is best, but hard to achieve in less than two thinnings. The extreme form of this treatment results in stand conversion to non-preferred species, or a gypsy moth-proof stand.

Where is it neither practical nor desirable to convert or reduce preferred hosts sufficiently, then thinnings should be used to increase the vigor of the remaining trees. Development of large, healthy crowns will increase the probability of a tree surviving defoliation. It will also have the often desirable effect of increasing mast production of the oaks.

Many stands may need to be protected with a chemical or biological insecticide. Especially vulnerable are seed tree or shelterwood stands that are in the process of regenerating the stand. Loss of these trees can destroy the entire treatment.

Depending upon the situation with host suitability of understory trees, it may be desirable to remove preferred species from the understories of pine stands to protect them from stress caused by the gypsy moth. This treatment will have the benefit of preventing subsequent pest problems that may arise from stress on the pines at a much lower total cost than treating the secondary pests.

RESEARCH NEEDS
Many unanswered questions exist for mixed pine-hardwood stands, especially for southern forest types. A few of the more important questions are:

1. What are the host feeding preferences of many southern species?

2. What are the species compositions and stand factors that affect stand susceptibility in pine-hardwood mixtures in the South?

3. What are the impacts (mortality and growth loss) in pine-hardwood types in the South?

4. Can appropriate silvicultural treatments minimize gypsy moth impacts in pine-hardwood mixtures in both the North and South?

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SITE QUALITY: THE ECOLOGICAL BASIS FOR PINE-HARDWOOD MANAGEMENT DECISIONS

Robert Zahner and Glendon W. Smalley[1]

Abstract. — Site productivity and tree species composition are the essential ingredients in forest management planning for multiple uses. Pine-hardwood mixtures offer forest managers many choices and benefits for all resource outputs: timber quality and quantity, wildlife habitat, water quality and quantity, and recreation opportunities. Site quality either enhances or limits management choices of these outputs. Although desirable multiple forest benefits can be achieved with pine-hardwood mixtures on nearly all sites, specific resource outputs depend almost entirely on the edaphic characteristics of a given site. In light of an anticipated warming climate for the southeastern United States over the next several decades, a diversity of tree species on every site will provide maximum protection from erratic weather and attendant pests.

INTRODUCTION

It is a fundamental principle of forest ecology that site quality and climate together determine species composition and the productivity of those species (Spurr and Barnes 1980). In the South, much emphasis has been placed on the concept of species-site suitability, that is, adapting or matching a single pine species or a pure hardwood type to a given site, based almost solely on the economic productivity of certain species-site combinations (Barrett 1982). In managing mixtures of pines and hardwoods, this concept of species-site suitability goes one step further — to the desired resource outputs. As the magnitude of genetic input increases, so does the opportunity for more diverse resource output, but only as enhanced or limited by site quality and climate (figure 1). Resource outputs begin with the quality of sites existing under a given climate. Since the range of resource outputs increases in direct proportion to the degree of forest diversity, pine-hardwood mixtures seem to offer forest managers more options than either pure pine or pure hardwood forest types.

Another consideration that is certain to affect forest management decisions is the prospect of global warming. In the South, we can expect drier summers in the Piedmont and possibly wetter growing seasons along the coast and in the mountains (Manabe and Wetherald 1986; Bolin and Doos 1986). Consequently forest site quality will gradually change and, no doubt, site will exercise more control over forest resource outputs in the near future.

PINE-HARDWOOD SITES IN THE SOUTH

There are several recent overviews of forest habitats and their classification by physiographic provinces, landtypes, and climates throughout the South (Hodgkins and others 1976; Evans and others 1983; Zahner 1984; Pehl and Brim 1985; Smalley 1986a, 1986b; Myers and others 1986). We will not reiterate the details of these publications, nor discuss the edaphic and climatic factors contributing to variations in forest site quality. Many pine and hardwood species occur naturally in all regions of the South, and, evidently, in pre-settlement times al-
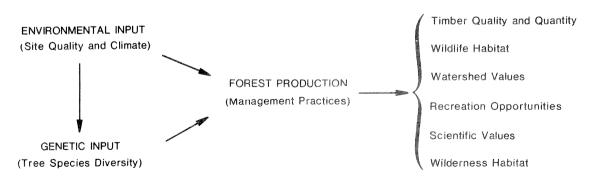
Figure 1. Diagram illustrating how site quality and climate constitute the ecological basis for forest resource outputs.

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most always in mixed stands (Braun 1950). With few exceptions, e.g. first bottom river floodplains and high elevation mountain habitats, there are probably no sites in the South that have not supported pine and hardwood mixtures at some time in the past. Therefore, the potential exists for the management of pine-hardwood mixtures in almost all forest habitats of the South.

For the remainder of this paper, we assume that the forest landowner or manager prefers to maintain stands of mixed pines and hardwoods. The management objectives may vary from timber and wildlife considerations to aesthetics. Today there is much emphasis on maintaining species diversity, both plants and animals, as an ecologically sound and ethically "right" approach to land stewardship (Wilson 1988). Thus the "value" to society of pine-hardwood mixtures lies in both economic and non-commodity resources. Also emerging in the biological sciences is an urgency to preserve (and to restore damaged) ecosystems of all types (Millar and Ford 1988; Cairns 1988). The diversity of habitats in the South, created by the diversity of landforms, soils, climate, and plant and animal species, assures that forest management can achieve all of the above societal values. In our opinion, managing for pine-hardwood mixtures can augment these values on nearly all sites.

Forest habitats in the South, of course, have been subjected to over 200 years of major disturbances by European man, and even the least disturbed sites or those with the longest periods of recovery are not truly pre-Columbian ecosystems. Abandoned agricultural lands are the most extensive altered ecosystems, but the nature of forest succession assures that both pines and hardwoods are present in the site recovery process. Extremely damaged sites, such as those resulting from strip mining or gully erosion, require restoration methods that utilize diverse mixtures of tree species, including both pines and hardwoods on the same site, in order to achieve desired rehabilitation objectives. Less-altered habitats, in particular those converted from hardwoods to planted southern pines, almost always continue to support a mixture of residual hardwoods that play an important role in soil structure and fertility. Mixed hardwood forest vegetation increases the incorporation of organic matter, improves soil nutrient status through more diverse cycling of minerals, improves nitrogen fixation, increases infiltration of water, improves soil aeration and water retention, and in general results in gradual, long-term improvement of site quality for both pines and hardwoods (Zahner 1982).

The array of historical land uses in the South amplifies opportunities for mixed pine-hardwood management through both the environmental and genetic inputs illustrated in figure 1. Site quality and species composition have been diversified by the many patterns of past land use and habitat disturbance and recovery, thus contributing to a wide array of possible management outputs.

In the following section we discuss some of these management outputs for various pine-hardwood habitats throughout the South.

EXAMPLES OF SITE-REGULATED MANAGEMENT DECISIONS
Piedmont Uplands

So-called "pine sites" in the Piedmont region were originally classed as oak-pine by early ecologists (Braun 1950). Both oaks and pines are naturally well-adapted to Piedmont uplands, and both types are drought tolerant. In spite of determined and aggressive attempts to control them, the typical mixture of hardwoods that occur on "pine sites" are here to stay and offer the landowner both economic and non-commodity resources. Quality hardwood sawlogs, of course, cannot practically be grown on many upland sites, but hardwood pulpwood is now as valuable a resource as pine.

Biomass produced during the early years by the hardwood component in a stand of equal mixture should exceed that of the pine because of the rapid growth of young hardwood sprouts and their high wood specific gravity (Zahner and Harris 1984). Typical Piedmont uplands with a basal area mixture of 60 percent pine, 20 percent oak, and 20 percent other hardwoods might reasonably be expected to support a volume of 24 cords of pine and 16 cords of hardwood per acre at age 30 (Zahner 1982). A thinning might remove 20 percent of the pine basal area and 40 percent of the hardwood, yielding perhaps 5 cords of pine and 6 cords of hardwood per acre. This type of management would leave a good mixture of pine crop trees for future sawlogs and mast-producing oaks and other hardwoods to enhance wildlife habitat.

Blue Ridge Mountains

The southern Blue Ridge Mountains were assigned to the oak-chestnut forest region (Braun 1950). Here the native mixture of eastern white pine and upland oaks and other hardwoods has undergone severe alteration by European man. The potential remains, however, to manage mixed pine-hardwood stands on many mountain sites for diverse multiple use outputs. Planting of eastern white pine at wide spacings on clearcut hardwood south slopes results in a future potential for pine sawtimber mixed with mast-producing oaks and

other hardwoods for enhancement of wildlife habitat. South-facing mountain slopes tend to have shallower soils than north-facing slopes, and, invariably support plentiful oak regeneration, but have little potential for producing hardwood sawtimber under a warming climate.

Several native species of pines whose seed source has been eliminated by past harvesting and other land-use practices, including eastern white pine, shortleaf pine, Table Mountain pine, and pitch pine, when reintroduced have excellent potential for small sawtimber in mixture with naturally occurring hardwoods. On north-facing lower slopes, and in coves, where yellow-poplar makes its best development in the mountains, eastern white pine also has its greatest potential for quality growth, with both species reaching a site index of 100 (base age 50). Eastern white pine and yellow-poplar were once natural mixtures on such sites, probably reproducing and surviving together in even-aged stands following natural disturbances through thousands of years (Braun 1950).

Southern Ridge and Valley

The Southern Ridge and Valley is split between the oak-chestnut and the oak-pine forest regions (Braun 1950). Because of drastic land-use changes wrought by European settlers during the 19th and 20th centuries, forests are largely confined to ridges and steep sideslopes, where soils are generally shallow over shale and sandstone and low in fertility. These uplands are a mosaic of oak-dominated communities, in mixture with Virginia and shortleaf pines (Martin 1971), with site indices for both oaks and pines varying locally from 60 to 80. Such forest sites obviously do not offer potential for large sawtimber, but wildlife habitat, recreation, and watershed values are high.

Most woodland ownerships are small and highly fragmented, enhancing these non-timber management options along with a high firewood demand. A few better sites offer potential for pine-hardwood timber production, where either natural or planted loblolly pine occurs in mixture with yellow-poplar on stream terraces, small bottoms, and talus slopes where soils are deeper and site index can reach 100 for these two species.

Cumberland Plateau and Mountains

Although this province has been classed in the mixed mesophytic forest region (Braun 1950), two-thirds of the Plateau surface supports natural mixtures of pines and hardwoods; the mesophytic forest types are restricted to coves, gorges, and cool slopes (Smalley 1986a). Virginia pine, shortleaf pine, and pitch pine are common associates with oaks on dry ridges with shallow to moderately deep

soils, where site index is generally below 75 for these pines and below 65 for oaks. Pure stands of native pine are generally limited to abandoned cropland and other disturbed sites, and support moderate to dense hardwood understories, providing potential for the development of true mixed pine-hardwood stands.

High quality sites are on cool slopes and in coves in the Mountains, and on cool escarpment slopes and in gorges and stream bottoms on the Plateau. Here, where site index approaches 100 for yellow-poplar and eastern white pine, and 70 to 80 for oaks and yellow pines, there is opportunity for quality sawtimber outputs of both pines and hardwoods.

Re-establishing native pines or introducing loblolly pine in mixture with hardwood residuals, offers a low-cost option for rehabilitating many low-quality stands (Sims and others 1981). Although loblolly pine has been extensively planted in aggressive management programs, this species may be limited to short rotation crops because of damage from periodic glaze storms. Another option may be planting eastern white pine in cut-over mixed stands on the undulating Plateau surface (Personal communication, W. C. Davis, University of the South).

Several recreation-oriented management outputs, including game animal habitat improvement and scenic values, are important in this region, and are enhanced by establishment of mixed pine-hardwood stands on a wide variety of sites.

Highland Rim-Pennyroyal

Although Braun (1950) described the forests of this province as a mosaic of oak-dominated communities reflecting the widespread influence of man, shortleaf and Virginia pines occur throughout the Rim, lending the forests naturally to mixed pine-hardwood management (Smalley 1986a). As with most of the other provinces in the Appalachian region, woodlands on the Eastern Rim consist for the most part of small fragmented tracts, but become more extensive on the Western Rim.

Loblolly pine occurs naturally on the Alabama portion of the Rim, and is also an option for planting farther north into middle Tennessee. As on the Cumberland Plateau, however, loblolly pine is susceptible to damage from winter glaze storms and may not be suitable for sawlog rotations along with oaks and other hardwoods. All landforms on the Rim support mixtures of pines and hardwoods, with site indices varying from 60 to 70 for upland oaks and native pines on ridges and north cherty slopes, and from 80 to 90 for yellow-poplar and planted loblolly pine on better sites. Planting yellow pines in cutover upland hardwoods is also a low-cost option for rehabilitating many poor sites and low quality

stands on the Rim-Pennyroyal (Sims and others 1981). Pine-hardwood management outputs on the Rim include a full array of options, with timber production, wildlife habitat, and recreation equally feasible.

Hilly Coastal Plain

This province is the most extensive in the Southeast, occupying all of the upper Coastal Plain south of the Piedmont Fall Line from Virginia into Alabama, thence northwest across northern Mississippi into West Tennessee, thence west beyond the Mississippi alluvial floodplain across Arkansas and Louisiana into East Texas (Zahner 1984; Smalley in press). Except for that portion occurring in Tennessee, the Hilly Coastal Plain encompasses the heart of native loblolly pine, and thus this species is the favored pine component in pine-hardwood management. Land use here is still highly agricultural, although the southern pulpwood industry has established extensive tracts of loblolly pine plantations throughout.

Today the focus of mixed pine-hardwood management is with non-industrial woodlands where wildlife and recreation outputs are more desirable than pine timber outputs. With the present hardwood pulpwood market expanding rapidly, all types of ownership may move strongly toward mixed pine-hardwood management in the near future. Site quality throughout the uplands of the Hilly Coastal Plain is generally good to excellent, where deep soils are well developed in the unconsolidated sands and clays. Managed stands are productive on every major land type, with site index over 85 for loblolly pine and comparable for such hardwoods as southern red oak, white oak, sweetgum, and yellow-poplar. Because mixed pine-hardwood stands should be more productive over a larger land area, as well as on a larger array of sites throughout this province than elsewhere, timber outputs will probably take precedence over other woodland management objectives.

In West Tennessee, the soils of this province are fragile, formed in loess overlying the unconsolidated sands and clays that are the typical soil parent materials of the rest of the province. Here, just north of the natural range of loblolly pine, native shortleaf and Virginia pines predominate in natural mixed pine-hardwood forests. Because loblolly pine has been extensively planted on former croplands, particularly to aid control of severe erosion of these fragile soils, stands of mixed pine-hardwoods are serving the important primary objective of watershed protection along with various wildlife and recreation outputs.

Deep Loess

This province lies east of the Mississippi River floodplains, where high-quality sawtimber stands of both pines and hardwoods occur in a mosiac of species types conforming to the broken topography and land forms (Zahner 1984). Soils are fertile with a moist water regime, developed in loess parent materials in the high rainfall climate of the central Gulf Coastal Plain. Loblolly pine, cherrybark oak, yellow-poplar, and sweetgum occur in both pure stands and natural mixtures, with site index for all species generally over 100. Here forest management opportunities include a wide variety of timber and wildlife outputs blended with stand-by-stand species composition (Mann and others 1979). The combination of soils and mixed pine-hardwoods assures continued high levels of quality forest outputs for expected climate changes in this region.

Coastal Plain Bottomlands

Pine site index is usually greater than 100 feet on most second bottoms and river terraces throughout the South, with the exception of the Mississippi Delta and other broad floodplains. In mixture with the native hardwoods, these "hardwood sites" of today once supported many large individual pines that were cut during Colonial settlement (Braun 1950). With the uncertainties today of regenerating quality bottomland hardwoods such as cherrybark oak, a feasable management option is to plant pines on such sites, permitting natural hardwood regeneration to develop in mixture with the pine. The landowner then has the opportunity to produce quality pine sawtimber at half the rotation age of hardwoods, without diminishing either wildlife habitat or the value of the stand to develop quality hardwood crop trees for the future. The introduction of loblolly pine in particular on such bottomland sites should be a sound precaution against a warming climate with possibly more frequent droughts. In any case, the diversity of a pine-hardwood mixture adds more options on bottomlands than do hardwoods alone in an uncertain future climate.

CONCLUSION

Multiple-use forest management is enhanced, and choices are amplified for both economic utilization and habitat preservation, by the occurrence and maintenance of mixed pine-hardwood stands on the widest diversity of sites. The more diverse are sites, the more potential for mixtures of forest species, and therefore the greater the possible management outputs. With the added uncertainties of forest responses to expected climate changes over the next 50 years, site quality will doubtless play an even greater role in determining forest habitat uses in the future.

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APPLICATION OF LANDSCAPE ECOSYSTEM CLASSIFICATION IN IDENTIFYING PRODUCTIVE POTENTIAL OF PINE-HARDWOOD STANDS

Steven M. Jones[1]

Abstract.—The concept of site as the basis for determining silvicultural and forest management practices is unquestioned. The need for site classification of forest land has been recognized for decades. Yet, the ability to recognize sites with similar capability is possibly the greatest deficiency in management and silviculture. The landscape ecosystem approach expresses the interrelationships between (1) vegetation and landform, (2) vegetation and soils, and (3) landform and soils. In developing the classification, the complex gradients of an area are broken into ecosystem units that recur in the landscape. The ecosystem units (sites) can be distinguished by landform, soils, and vegetation. This approach has been successfully applied within the Coastal Plain and Piedmont of South Carolina and is useful in identifying the productive potential of sites where management for pine-hardwood mixtures is desirable.

INTRODUCTION

Within a given physiographic region, the three basic ecosystem components are landform, soils, and vegetation. Traditionally, approaches to site classification have stressed either landform, soil, or vegetation. Users often overlay single factor classifications to produce a component classification. It should be understood that this does not produce an ecological classification because the interrelationships are unknown. Classifications systems that include climate, soils, landform, and vegetation have been developed and are in use but are not necessarily ecological (Rowe 1978).

An ecological classification expresses the interrelationships (1) between vegetation (overstory, understory, and groundcover) and landform, (2) between vegetation and soils, and (3) between landform and soils (Barnes and others 1982). The influence of landform and soils on the composition, size, and productivity of vegetation can only be understood when their relationships to vegetation is known. Likewise, silvicultural interpretations from landform and soil factors are dependent on knowledge of the interrelationships with vegetation.
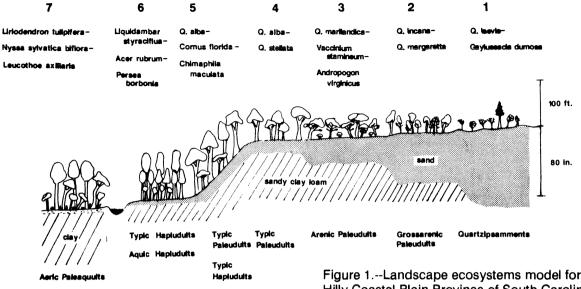
The term landscape is used as a modifier to emphasize that ecosystems are geographic units extending horizontally over the land (Barnes 1989). It is the units of land with similar productive potential that we are striving to identify. We must provide the land manager with the information to identify each homogeneous landscape unit. This can only be achieved by considering landform as the key component used simultaneously with easily recognized attributes of soils and vegetation as a check-and-balance system.

Barnes (1982) and Albert (1986) demonstrated the practical use of landscape ecosystem classification in Michigan. The purpose of this paper is to demonstrate this approach to classification of forestland in the southeastern United States and to show its use in identifying sites desirable for pine-hardwood management.

METHODS

The classification approach has been applied in two separate studies within South Carolina. One was conducted within the Upper Loam Hills Region and Sandhills Region of the Hilly Coastal Plain Province and a second within the Midlands Plateau Region of the Piedmont Province (Myers and others 1986). Forest stands representing the full range of upland and bottomland site conditions were sampled within the Hilly Coastal Plain Province. Within the Piedmont Province only the range of upland conditions were sampled. In both studies, relatively undisturbed steady state or near steady state stands were selected to identify the interrelationships with soil and landform variables. The classification was then applied to disturbed or successional stands. Over 200 stands have been sampled to date.

Sampling on 0.1 acre plots included quantitative vegetation measurements, correlation of soils, description of soil morphology, particle size distribution (in the Piedmont), slope position, aspect, and landform type. Data were analyzed and vegetative classifications developed through multivariate analysis techniques (ordination and cluster analysis). Soil and landform data were related to the vegetative classifications through informal, visual or imperical recognition of pattern in variables and through discriminant analysis procedures. Species associations that are characteristic

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7	6	5	4	3	2	1
Liriodendron tulipifera–	Liquidambar styraciflua–	Q. alba–	Q. alba–	Q. marilandica–	Q. incana–	Q. laevis–
Nyssa sylvatica biflora–	Acer rubrum–	Cornus florida –	Q. stellata	Vaccinium stamineum–	Q. margaretta	Gaylussacia dumosa
Leucothoe axillaris	Persea borbonia	Chimaphila maculata		Andropogon virginicus		

Typic Hapludults · Typic Paleudults · Typic Paleudults · Arenic Paleudults · Grossarenic Paleudults · Quartzipsamments
Aquic Hapludults
Typic Hapludults
Aeric Paleaquults
Typic Albaquults

Figure 1.--Landscape ecosystems model for the Hilly Coastal Plain Province of South Carolina.

of a certain set of environmental conditions were identified through synthesis table construction. Plot design, measurements, and analytic procedures have been described in detail elsewhere (Jones and others 1984; Jones 1988).

RESULTS
Hilly Coastal Plain Model
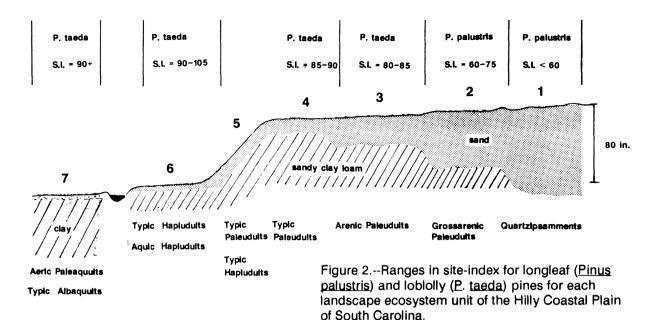
Within the Hilly Coastal Plain Province, seven landscape ecosystem units were identified across an environmental gradient which was interpreted as a moisture gradient (figure 1). Each landscape

ecosystem unit is associated with a unique set of landform and soil conditions. The major variables controlling productive potential are thickness of the sandy epipedon, internal drainage, and landform type (table 1). Conditions ranged from xeric thick sands to poorly drained alluvial bottoms. Since vegetation is an expression of environmental conditions, the composition and productivity of vegetation is unique for each landscape ecosystem unit. Detailed descriptions of the soil, landform, and vegetation for each landscape ecosystem unit are published elsewhere (Jones and others 1981; Jones and others 1984; Van Lear and Jones 1987).

Table 1.--Classification of landscape ecosystem units for the Hilly Coastal Plain Province

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UPLAND LANDFORMS
    I. Sandhills
        A. Sandy surface >80 inches (Quartzipsamments)
            1. Turkey oak - dwarf huckleberry
   II. Flats and gentle slopes
        A. Sandy surface 40-80 inches thick (Grossarenic
           Paleudults)
            2. Bluejack oak - dwarf post oak
        B. Sandy surface 20-40 inches thick (Arenic Paleudults)
            3. Blackjack oak - deerberry - broomsedge
        C. Sandy surface <20 inches thick (Typic Paleudults)
            4. White oak - post oak
  III. Moderate to steep slopes
        A. Sandy surface <20 inches thick (Typic Paleudults and
           Typic Hapludults)
            5. White oak - dogwood - pipsissewa

BOTTOMLAND LANDFORMS
   IV. Well-drained and moderately well-drained alluvial terraces
        A. Gray mottles (low chroma) present only in lower part of
           the soil profile; no gray layers present (Typic
           Hapludults and Aquic Hapludults)
            6. Sweetgum - red maple - redbay
    V. Poorly-drained alluvial terraces
        A. Gray (low chroma) layers present (Aeric Paleaquults and
           Typic Albaquults)
            7. Yellow-poplar - swamp tupelo - dog-hobble
```

P. taeda	P. taeda	P. taeda	P. taeda	P. palustris	P. palustris
S.I. = 90+	S.I. = 90-105	S.I. + 85-90	S.I. = 80-85	S.I. = 60-75	S.I. < 60

80 in.

Aeric Paleaquults
Typic Albaquults

Typic Hapludults
Aquic Hapludults

Typic Paleudults
Typic Hapludults

Typic Paleudults

Arenic Paleudults

Grossarenic Paleudults

Quartzipsamments

Figure 2.--Ranges in site-index for longleaf (Pinus palustris) and loblolly (P. taeda) pines for each landscape ecosystem unit of the Hilly Coastal Plain of South Carolina.

Associated with the environmental gradient defined by the 7 landscape ecosystem units was a productivity continuum. This continuum is most easily expressed in terms of site index for loblolly (Pinus taeda) and longleaf pines (P. palustris) (figure 2). Site index at base age 50 years for longleaf pine ranged from approximately 55 to 75 feet. Landscape ecosystem units 1 and 2 were considered most appropriate for longleaf pine management. Loblolly pine site index ranged from 80 to 105 feet across landscape ecosystem units 3 through 7. Site index for landscape ecosystem unit 7 actually decreases due to poorly drained conditions.

Piedmont Model

Within the Piedmont Province, 5 landscape ecosystem units were identified within upland landforms on gneiss-schist derived parent material. This model did not include those landscapes associated with gabbro-diabase or Carolina slate because relationships are altered on these sites. Figure 3 represents some of the possible combinations of landform and soil conditions resulting in these 5 units.

The five landscape ecosystem units occurred across a range of site conditions extending from

MESIC→ FAGUS GRANDIFOLIA - Q. RUBRA - POLYSTICHUM ACROSTICHOIDES

SUBMESIC→ Q. RUBRA - Q. ALBA - GERANIUM MACULATUM

INTERMEDIATE→ Q. ALBA - Q. RUBRA - SMILACINA RACEMOSA

SUBXERIC→ Q. ALBA - Q. COCCINEA - VACCINIUM STAMINEUM

XERIC→ Q. STELLTA - Q. VELUTINA - VACCINIUM VACILLANS

Figure 3.--Landscape ecosystems model for the Piedmont Province of South Carolina.

Table 2.--Classification of landscape ecosystem units for the
Piedmont Province: relatively unaltered soils

  I. Flats to slight slopes; or slopes: upper-slope positions
     A. Clayey subsurface soils; clay horizon within 12 inches
        of soil surface
        1. Post oak - black oak - lowbush blueberry
     B. Clay to sandy clay subsurface soils; fine-textured
        horizon 12 to 24 inches within surface
        2. White oak - scarlet oak - deerberry

 II. Slopes: mid-upper to mid-slope positions;
     southerly/westerly aspects
     A. Clayey subsurface soils; clay horizon within 12 inches
        of soil surface
        1. Post oak - black oak - lowbush blueberry
     B. Clayey to sandy clay subsurface soils; fine textured
        horizon 12 to 24 inches within surface
        2. White oak - scarlet oak - deerberry
     C. Clay loam to sandy clay loam subsurface soil; fine
        textured horizon 12 to 24 inches within surface
        3. White oak - northern red oak - false solomons seal

III. Slopes: mid-lower; southerly/westerly aspects
     A. Clayey to sandy clay subsurface soils; fine textured
        horizon 12 to 24 inches within surface
        2. White oak - scarlet oak - deerberry
     B. Clay loam to sandy clay loam subsurface soil; fine
        textured horizon 12 to 24 inches within surface
        3. White oak - northern red oak - false solomons seal

 IV. Slopes: mid-upper to mid-slope positions;
     northerly/easterly aspects
     A. Clayey subsurface soils; fine textured horizon within 12
        inches of surface
        2. White oak - scarlet oak - deerberry
     B. Clay loam to sandy clay loam subsurface soil; fine
        textured horizon 12 to 24 inches within surface
        3. White oak - northern red oak - false solomons seal

  V. Slopes: mid-lower; northerly/easterly aspects
     A. Clay loam to sandy clay loam subsurface soil; fine
        textured horizon 12 to 24 inches within surface
        4. Northern red oak - white oak - wild geranium

 VI. Slopes: lower; any aspect
     A. Clay loam to sandy clay loam subsurface horizons; fine
        textured horizon 12 to 24 inches within surface
        4. Northern red oak - white oak - wild geranium
     B. Sandy loam subsurface horizons at any depth
        5. American beech - northern red oak - christmas fern

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xeric upland flats and upper slopes to mesic lower slopes. Thus, the endpoints of an environmental gradient were defined by extremes in landscape position. This environmental gradient was interpreted as a soil moisture gradient and could be characterized by the combination of slope position, aspect, depth to clay or rock, and texture of subsurface horizon (table 2). Xeric conditions (landscape ecosystem unit 1) were associated with high landscape positions, southerly and westerly aspects, and heavy clay textures or rock close to the soil surface, while mesic conditions (unit 5) were associated with low landscape positions, northerly and easterly aspects, and soils with loamy subsurface horizons. A vegetational continuum was associated with the environmental gradient with distinct species groups for each landscape ecosystem unit. Detailed descriptions of the soil, landform, and vegetation for each landscape ecosystem unit are available elsewhere (Jones 1988a; Jones 1988b).

DISCUSSION

It is obvious that not all sites are suitable candidates for growing mixtures of pines and hardwoods. A general "rule of thumb" historically held by foresters has been to manage for pines on the least productive and intermediate sites and

manage for hardwoods on the most productive bottomland sites or mesic coves. In general, the southern pines compete aggressively against most hardwood regeneration on xeric sites (Nix and others 1989). As site quality improves, hardwood regrowth will be more vigorous until pine survival is reduced on the most productive sites (Sims and others 1981).

In consideration of natural competition strategies, the logical choice for the regeneration of pine-hardwood mixtures is those sites which are intermediate in productive potential. In the Hilly Coastal Plain model, the classification units 1,2, and 3 are naturally occupied by undesirable hardwood species, such as turkey oak (Q. laevis), blue-jack oak (Q. incana), dwarf post oak (Q. margaretta), and blackjack oak (Q. marilandica). Classification units 6 and 7 are alluvial bottoms where hardwoods are the preferred species due to equipment limitations and potentially low pine survival due to competition from hardwoods and other woody understory species. Classification units 4 and 5 are occupied by desirable hardwood species and potential for growth is adequate to compete with the pines. Southern red oak (Q. falcata) is a component of heavily disturbed or successional stands, while white oak (Q. alba) is a component of those stands that are late successional or near steady state.

Within the Piedmont, the landscape ecosystem model identifies the classification units 1 and 2 as relatively low in productive potential. Site index for white oak was estimated to range from 60 to 70 on classification unit 1 and from 65 to less than 80 on classification unit 2. These xeric and subxeric sites are not considered optimal for regeneration in pine-hardwood mixtures because the pines are likely to dominate at an early age (Nix and others 1989). Classification units 4 and 5 are considered quality hardwood sites. Site index for white oak on classification unit 3 was estimated to range from 80 to 90 feet. These sites were considered intermediate in soil water status relative to the mesic and xeric sites and have the greatest potential to regenerate in favorable mixtures of pines and quality hardwoods.

Landscape ecosystem classification has an advantage over other classification approaches in the ability to predict productive potential from the permanent features of landform and soil even though the vegetation component is absent. For example, Hilly Coastal Plain classification unit 4 is most often in agricultural crops; however, these upland flats can be identified and mapped by the presence of less than 20 inches of sand over sandy clay loam.

Traditionally, foresters have used existing stand conditions (species composition, form, and growth) as criteria to judge site quality. This approach can lead to misclassifications when stands have a long history of being high-graded. For instance, Phillips and Abercrombie (1987) reported lower volumes of harvested timber on sites capable of relatively high productivity when compared to lower quality sites. Stand conditions prior to harvest gave the impression that the better quality sites were of low quality (Abercrombie 1987, personal communication). Soil conditions were used as a more accurate measure of productive potential.

IMPLICATIONS

Landscape ecosystem classification has valuable application both in research and management. As we strive to develop regeneration techniques directed at achieving pine-hardwood mixtures, it is imperative that site quality be a prime consideration in experimental design. The ability of researchers to make technology transfers with predictable results is dependent upon identification of sites with equivalent productive potential. Although this is a simple and widely recognized concept, it is all too often ignored. Reliable technology transfer requires testing regeneration techniques and developing growth and yield models for each classification unit, an approach currently adopted through cooperative efforts between Clemson University and the Southeastern Forest Experiment Station.

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BIOMASS ACCRUAL IN FOUR-YEAR-OLD PINE-HARDWOOD REPRODUCTION ACROSS A SOIL MOISTURE GRADIENT

John C. Adams and Kenneth W. Farrish[1]

Abstract. — Pine, red oak, sweetgum, and total biomass for four-year-old seedlings was sampled across a soil moisture gradient from the top of a hill down into a small stream bottom. There was no difference in biomass production for total or within individual species from the bottom to the top of the hill. There was also no difference in size (diameter and height) within individual species. On these sites hardwoods had grown at faster rates than the pine at age four. Regression analysis revealed some positive correlation between soil fertility and hardwood biomass and subsoil moisture and pine biomass. However, these variations did not appear to be related to elevation of the sample plots.

INTRODUCTION

Most southern pine management has been directed toward production in even aged-pure stands. These stands are thought to be more productive (economically), with the less desirable hardwoods removed through the use of fire, mechanical means or herbicides. Release operations (Smith 1986) provide foresters with techniques to manage forests and control undesirable vegetation.

During the last 10-15 years, concerns have been raised about the use of fire and herbicides in forest management. Smoke management and liability concerns have kept many managers from using fire to control hardwood encroachment in pine stands. In addition, restrictions on the use of herbicides and the lack of suitable chemicals have also prevented the control of hardwoods in pine stands. As a result, there has been an increase in the number of acres in the mixed pine-hardwood type. In 1985, there were approximately 26,908,000 acres of forest in the South classified as mixed pine-hardwoods (USDA Forest Service 1988). If this trend continues, many more acres of young stands will be in this type.

Policy objectives on public lands have been modified to include the management of mixed pine-hardwood stands. Public opinion has dictated the use of silvicultural practices that increase the occurrence of the mixture. However, change to the pine-hardwood mixtures has been done with little knowledge of the regeneration, growth, and silvicultural management of these complex ecological communities.

The forests of north-central Louisiana are generally classified as pine timber types. However, within this region are also found numerous creeks and small river floodplains that support primarily hardwoods, but also scattered pine. These hardwood sites are usually narrow and are surrounded by the uplands which contain a greater percentage of pine. The accepted belief for these sites is that the bottoms are more productive (higher site index) than are the upland sites, and that pine will have superior growth compared to the hardwoods.

The purpose of this study is to provide information on the growth, development, and biomass accumulation of a four-year-old pine-hardwood mixture that extends from a bottomland to an upland site.

METHODS AND PROCEDURES

The study site was located in north central Louisiana and is an area typical of the upper Gulf Coastal Plain. The site had been clearcut, chopped and burned, and planted with loblolly pine. However, the planting was a failure and most of the seedlings occupying the study site originated as natural reproduction.

Species composition was a mixture of loblolly pine (Pinus taeda L.), shortleaf pine (P. echinata Mill), sweetgum (Liquidambar styraciflua L.), water oak (Quercus nigra L.), red oak (Q. falcata Michx.), cherrybark oak (Q. falcata var. pagodifolia) Ell.) and a group of less important species listed as miscellaneous. In this study, loblolly and shortleaf pine were grouped together as pine, and red and cherrybark oak were grouped as red oak.

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The stand was more than well stocked with 66,040 seedlings and sprouts per hectare. There were 5,080 water oak, 3,810 red oak, 3,302 sweetgum, 18,034 miscellaneous hardwood, and 35,814 pine per hectare. Included in the count was a large number of one- and two-year-old loblolly pine seedlings.

Site index was measured on the upland and the bottom for mature loblolly pine growing in an adjacent stand. Soil conditions and topography were essentially the same as the study site. Site index (age 50) for the bottom was 33.5 meters and at the top of the slope was 27.5 meters.

Biomass

Biomass sampling was done the first week in June 1988 on a transect from the top of the hill down into the bottom (a 15 meter change in elevation over a surface distance of 360 meters). Nineteen plots (one meter radius) were placed at 20 meter intervals. All above ground woody vegetation was removed, separated by species groups, and prepared for drying. Samples were oven dried at 70o C until equilibrium was reached and weighed to determine biomass dryweight.

From each sampling plot on 0 azimuth, the first two individuals of pine, water oak, sweetgum and red oak were collected for measurement of height, groundline diameter, and dryweight. These trees were measured to provide information on individuals within species from the top of the hill into the bottom.

Soils

At the center of each plot, the soil was sampled with a bucket auger. The depth to the first gray mottles was observed and recorded during the auger boring. Soil samples were collected from 0-10, 10-20 and 90-100 centimeter depths. Soil moisture content of the samples was determined gravimetrically. Total Kjeldahl nitrogen (Bremmer and Mulvaney 1982), extractable phosphorus (Olsen and Sommers 1982), and exchangeable potassium

(Knudsen and others 1982) were measured. Soil pH was determined on a 1:4 soil/water suspension.

Analysis of Data

The closeness of the linear relationship between variables was estimated with correlation coefficients using the PROC CORR procedure of SAS (SAS 1985). The Stepwise procedure was then used to search for appropriate multiple regression models to relate site variables to tree productivity.

RESULTS
Soils
Soil drainage and moisture. Soil drainage class, as determined by depth to gray mottles, ranged on the study plots from well-drained to somewhat poorly drained. Unexpectedly, some of the shallowest depths to gray mottling occurred at midslope (plots 12-15), suggesting side slope seepage of a perched water table (figure 1). The higher potassium levels and moisture content at the time of sampling in the subsoil (90-100 cm) of these plots are also evidence of water seepage at midslope with potassium being transported in the groundwater (table 1). As expected, the depth to gray mottles was relatively shal-

RELATIVE ELEVATION AND GRAY MOTTLES
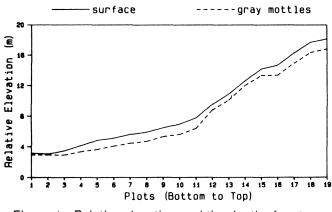
Figure 1.--Relative elevation and the depth of mottles for the study area.

Table 1. Mean values for selected soil properties of the study area.

Depth	N	P	K	pH	Soil Moisture
(cm)	(pct)	-----(mg kg)$^{-1}$------			(pct dry)
0-10	0.15(0.109)[a]	5.8(2.61)	94(48.2)	4.9(0.20)	13.6(2.87)
10-20	0.08(0.047)	2.4(1.35)	58(26.8)	4.9(0.32)	9.1(2.96)
90-100	0.04(0.015)	0.4(0.75)	95(47.4)	4.5(0.26)	18.0(4.85)

[a]Value in parenthesis is standard deviation.

low in plots at the bottom of the slope in the alluvial deposit. The driest soil moisture regime (based on depth to gray mottles) was on plots at the top of the slope and those below the seepage area on the side slope. However, the only trend in subsoil moisture content among plots was higher moisture content in plots 12 through 15, indicative of side slope seepage as stated earlier. Soil moisture at the time of sampling was least in the 10-20 centimeter depth, ranging from 4-13 percent of dry weight. Due to recent precipitation events, the surface soil (0-10 cm) moisture was somewhat higher, ranging from 9 to 19 percent moisture content. Subsoil (90-100 cm) moisture was highest, ranging from 12 to 32 percent.

Chemical properties. Total Kjeldahl nitrogen, while extremely variable, tended to decrease with increasing depth in the soil profiles, consistent with decreasing organic matter with increasing depth. There was no apparent relationship between total nitrogen and plot location.

Extractable phosphorus content generally decreased with increasing depth in the soil profiles. Phosphorus content of the subsoil (90-100 cm) was extremely low, below detectable levels in some samples. This is consistent with Ultisols of the region, which are often deficient in phosphorus for optimum tree growth. There was no apparent trend with extractable phosphorus and location. Exchangeable potassium did not seem related to the depth. Potassium was considerably higher in the subsoil of plots 12 through 15 as stated earlier. There was also no apparent trend in soil pH in relation to plot location or depth. Soil pH ranged from 4.1 to 5.3.

Regression equations relating individual species plot biomass to measured soil properties are summarized in table 2. The models revealed some positive correlations between hardwood biomass and soil fertility levels, especially nitrogen and phosphorus. The equation for pine suggested that subsoil (90-100 cm) moisture had a positive correlation with biomass.

Biomass

The mean total woody biomass on the study area was approximately 16.8 metric tons ha^{-1}. Biomass by species totals (table 3) were not different among the plots, regardless of the plot location (figure 2). There were also no among plot differences detected for biomass of individual tree species. No individual groups, including the miscellaneous group, showed any substantial trend in relation to plot location.

PLOT BIOMASS TOTALS
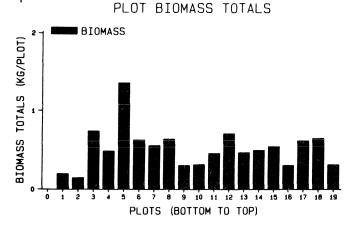
Figure 2.--Total plot biomass from the bottom to the top of the hill.

Table 2. Summary of regression models for woody biomass and soil properties[a].

Dependent Variable	Independent Variable(s)	Probability	r^2
Pine Biomass	Moisture(90-100)[b], K(10-20)	0.009	0.47
Red Oak Biomass	P(0-10)	0.674	0.18
Water Oak Biomass	N(10-20), P(0-10)	0.001	0.72
Sweetgum Biomass	N(90-100), N(0-10)	0.004	0.52
Misc Biomass	pH(10-20), K(0-10)	0.018	0.41
Total Biomass	pH(10-20)	0.026	0.27

[a]Based on individual plot biomass values.

[b]Value in parenthesis is depth of sampling in centimeters.

Table 3. Biomass, diameter and height by species for four-year-old mixed pine-hardwood reproduction.

Species	Mean Biomass (Tons ha-^{1})	Mean Diameter (cm)	Mean Height (m)
Pine	5.26	2.90(0.803)[a]	2.48(0.408)
Red Oak	1.31	3.16(0.926)	3.22(0.669)
Water Oak	2.68	2.63(0.446)	3.45(0.523)
Sweetgum	1.96	3.60(0.860)	3.48(0.720)
Misc	4.82		
Total	16.03		

[a]Value in parenthesis is standard deviation.

The hardwood species averaged almost one meter taller than the pine on the study area. This is the opposite of findings of Phillips and Abercrombie (1987) for Piedmont mixed pine-hardwood stands. Diameters (groundline) were more variable, with water oak having the smallest mean diameter followed in ascending order by pine, red oak and sweetgum (table 3). There was no difference by species in height or diameter regardless of the location of the measured individuals on the slope. These data indicate that the four species were growing at the same rate whether at the bottom on somewhat poorly drained soils or at the top on well-drained soils.

DISCUSSION

In this study of four-year-old mixed pine-hardwood reproduction, no difference could be detected for total biomass, height, or groundline diameter in relation to location on the slope. There was a soil moisture gradient from the bottom to the top of the slope as expected (figure 1). Unexpected was the lack of effect of this moisture gradient on tree growth. In contrast the adjacent 40 to 60 year-old stand of loblolly showed a six meter difference in site index (bottom vs. hilltop). Since this site quality difference was not expressed in the four-year-old reproduction, site factors that would limit growth later in the stands rotation had apparently not yet affected the stand. Total seedling numbers were high, but no seedling mortality caused by competition was observed. This information, combined with the lack of growth difference between slope position, would suggest that at this stage of stand development the site is not fully occupied and competition for soil moisture had not yet become limiting.

Although the data indicate that no relationship exists between species biomass and slope position, the regression equations revealed some correlation between soil fertility and hardwood biomass, and subsoil moisture content and pine biomass. This might imply that on this study area, soil fertility was beginning to limit hardwood development and soil moisture was beginning to limit pine development as the stand begins to fully occupy the site.

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FELL AND BURN TO REGENERATE MIXED PINE-HARDWOOD STANDS: AN OVERVIEW OF RESEARCH ON STAND DEVELOPMENT

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Abstract. — The fell-and-burn site preparation technique has been used successfully on the Sumter National Forest in the mountains of South Carolina to regenerate poor-quality stands to productive pine-hardwood mixtures. Young stands typically have numerous hardwood sprouts, but growth and survival of planted pines are excellent. Despite this success, many questions remain. The Southeastern Forest Experiment Station is studying this and other techniques to establish pine-hardwood mixtures in the Piedmont. In this region, variations in the fell-and-burn technique may be required due to differences in species composition and site. Burning prescriptions must be developed to protect the thin root mats. Growth and yield are being projected for mountain and Piedmont sites.

INTRODUCTION

Because demands for softwood and hardwood timber are increasing in the Southeast, forest managers and researchers are searching for profitable methods to increase forest productivity. One alternative is to place poorly stocked, unmanaged forest lands under some form of management. The Piedmont and mountain regions of the Southeastern United States have 39.5 million acres of commercial forest land. Over 65 percent of this timberland (26.8 million acres) is occupied by hardwood or mixed pine-hardwood stands (Bechtold and Ruark 1988). Private nonindustrial landowners, who control 72 percent of these stands, usually do not manage their woodlands.

Since hardwood competition is vigorous in these regions, conversion to stands of pure pine requires extensive site preparation. Most landowners have chosen to leave their forests unmanaged rather than spend the $150 to $250 per acre required for reforestation. The result has been a large acreage of poorly stocked stands with large numbers of undesirable stems. To encourage private landowners to manage their forests, low-cost alternatives for site preparation must be developed along with projections of future yields and returns on investments.

A less expensive alternative to pine plantation management is the culturing of pine-hardwood mixtures. A low-cost site preparation technique, called fell and burn (Abercrombie and Sims 1986), has been successful in the Southern Appalachian Mountains for converting low-quality hardwood stands to productive pine-hardwood mixtures. On the Sumter National Forest in South Carolina, over 3,500 acres on mountain sites have been converted by the fell-and-burn technique over the past 9 years. For less than $100 per acre, including site preparation and planting costs, hardwood sprout growth is controlled enough to allow shortleaf pine (Pinus echinata Mill.) seedlings to become established and grow (Phillips and Abercrombie 1987). In three randomly selected 4-year-old stands, survival of free-to-grow shortleaf pine seedlings was generally over 75 percent. Hardwood sprouts were numerous, but they were generally less than 6 feet tall, while planted shortleaf pines averaged over 8.5 feet tall.

The success of the fell-and-burn technique is apparent in young stands on the mountains of the Sumter National Forest. However, many questions remain, including application to new regions, the need for intermediate treatments, and stand growth and yield. This paper presents an overview of research being conducted by the Southeastern Forest Experiment Station's Research Work Unit for the Silviculture and Management of Pine-Hardwood Mixtures in the Piedmont (SE-4105). Silvicultural techniques proven in the Appalachain Mountains will be tested in the Piedmont, and growth and yield of the new mixed stands will be projected.

THE FELL-AND-BURN TECHNIQUE

The fell-and-burn technique was described in detail by Abercrombie and Sims (1986), Phillips and Abercrombie (1987), and Van Lear and Waldrop (1988). Briefly, the technique involves clearcutting of hardwood or pine-hardwood stands and chainsaw felling of standing residual stems over 5 feet tall in mid-April to early June. At this time in the Southern Appalachian foothills of South Carolina, most trees are three-quarters to fully leafed out. Timing is critical because the dried leaves and twigs

are needed as fuel to carry a summer broadcast burn. Also, sprout vigor is reduced by cutting when carbohydrate reserves in root stocks are in low supply. When trees are cut after they have leafed out, twigs and small branches dry more quickly through transpirational drying (McMinn 1986) and the depletion of hardwood carbohydrate reserves helps pines that will be planted later to compete for growing space.

Broadcast burns are conducted 4 to 6 weeks after residual stems are felled, generally in mid-July to early August. The desired burn is a high-intensity fire over a moist fuel bed. Burning is generally conducted 1 to 3 days after a soaking rain when the moisture content of 10-hour timelag fuels (1/4 to 1 inch in diameter) is 10 percent. At that time, the felled stems have sufficiently dried to carry an intense fire but the forest floor and surrounding stands are too moist to burn. This timing ensures that only a portion of the forest floor will be consumed, leaving a protective cover over the mineral soil. Guidelines for broadcast burning safely and effectively in the Southern Appalachians are discussed by Danielovich and others (1987). During the winter following burning, improved shortleaf pine or loblolly pine (P. taeda L.) seedlings are planted on a 10- by 10-foot spacing.

During 1988, the total cost of regenerating by the fell-and-burn technique was $88 per acre. Contracts for chainsaw felling averaged $35 per acre. Broadcast burning was conducted by the South Carolina Forestry Commission for $9 per acre. Planting contracts averaged $27 per acre, while the cost of seedlings was $17 per acre.

Summer broadcast burning is probably the more beneficial of the two steps in this site-preparation technique. Sprouts that develop after chainsaw felling are top-killed by the fire and new sprouts are less vigorous. Burning removes over 65 percent of the woody fuels less than 3 inches in diameter (Sanders and Van Lear 1988), making the site more accessible for planting. After planting, the black surface makes green seedlings more visible, ensuring a better job of planting. The fire also kills aboveground buds on hardwood stumps, forcing new sprouts to originate from below ground (Augspurger and others 1987). Therefore, these new sprouts will be well anchored and of better form.

In trials of practical scale, broadcast burns removed 80 percent of the surface forest floor, but 67 percent of the root mat remained intact (Danielovich 1986). This root mat is important for its water holding capacity. It acts as a mulch, allowing young pines

to survive and grow. The root mat also helps prevent erosion. Van Lear and Danielovich (1988) found that erosion, measured as trapped sediment, did not increase in clearcut and burned areas when compared to clearcut areas that were not burned. Lack of erosion following clearcutting and burning was attributed to large stems and stumps acting as debris dams; vigorous shrub and herbaceous regrowth; and burning under moist conditions so that the root mat remained intact. A summary of the effects of the fell-and-burn technique on Appalachian soils is given by Van Lear (1989).

To monitor growth and development of stands regenerated by the fell-and-burn technique, sample plots were installed in the oldest stands on the Sumter National Forest that were site-prepared by the fell-and-burn technique and planted with shortleaf pine and loblolly pine. To prevent ice damage, loblolly pine was planted on sites lower than 1000 feet above mean sea level while shortleaf pine was planted on sites above 1000 feet. Plots were inventoried during the winter of 1987. At that time, the oldest shortleaf pine stands were 6 years old and the oldest loblolly pine stands were 7 years old. From 7 to 10 sample plots, 1/20 acre in size, were established at random locations within each of two stands for each species.

Sites planted with shortleaf pine had over 7500 stems per acre, the majority of which (85 percent) were blackgum (Nyssa sylvatica Marsh.), red maple (Acer rubrum L.), and other hardwoods (table 1). Even though hardwoods were numerous, survival and growth of planted pines was excellent. Of the 436 seedlings planted per acre, 83 percent survived for 6 years and were free to grow. Planted pines averaged 9.4 feet in height while hardwoods were generally less than 6 feet tall.

Lower-elevation sites planted with loblolly pine were also dominated by hardwood sprouts (table 2). Of the 4,883 stems per acre tallied on study plots, 87 percent were hardwoods. However, pine survival and growth were excellent. Over 95 percent of the planted pines survived and were free to grow. In addition, 186 volunteer pines per acre were present. Planted and volunteer pines were taller than most hardwoods and on some plots a closed pine canopy was beginning to develop. Red maple sprouts were prolific and dominated the overstory on some plots.

CURRENT RESEARCH
In 1986, the Southeastern Forest Experiment Station established a Research Work Unit at Clemson, SC, entitled "Silviculture and Management of Pine-Hardwood Mixtures in the Piedmont". Two problem areas were identified. The first includes the development and testing of silvicultural techniques to establish pine-hardwood mixtures in the Piedmont.

Table 1.--Species composition and mean height by species for 6-year-old shortleaf pine stands regenerated by the fell-and-burn technique

Species	Stems/acre (pct)	Mean height (feet)
Planted shortleaf pine	362 (5)	9.4
Natural pines	194 (3)	7.0
Select oak[a]	539 (7)	5.6
Blackgum	3,108 (41)	5.1
Red maple	1,192 (16)	8.2
Other hardwoods	2,147 (28)	5.2
Total	7,540 (100)	

[a] Scarlet oak (Quercus coccinea Muenchh.), southern red oak (Q. falcata Michx.), white oak (Q. alba L.), post oak (Q. stellata Wangenh.), black oak (Q. velutina Lam.), chestnut oak (Q. prinus L.).

Table 2.--Species composition and mean height by species for 7-year-old loblolly pine stands regenerated by the fell-and-burn technique

Species	Stems/acre (pct)	Mean height (feet)
Planted loblolly pine	417 (9)	11.6
Natural pines	186 (4)	11.5
Select oak[a]	329 (7)	8.4
Blackgum	1,193 (24)	5.2
Red maple	1,414 (29)	9.5
Other hardwoods	1,324 (27)	6.9
Total	4,883 (100)	

[a] Scarlet oak, southern red oak, white oak, post oak, black oak, chestnut oak.

Included in this problem area are studies of early stand development, intermediate treatments such as release and thinning, and effects of these treatments on vegetation, soils, and wildlife. The second problem area is designed to provide information on the productivity of pine-hardwood mixtures. Several approaches are being attempted to develop prediction models for stand growth and yield.

Due to the diverse nature of pine-hardwood mixtures and the fact that management of this type is relatively new, numerous topics have not been studied. The following discussion is an overview of some of the work being done by the Pine-Hardwood Research Work Unit on the fell-and-burn technique. It is not intended as an exhaustive review of research needs for pine-hardwood management.

Application in the Piedmont Region

Until recently the fell-and-burn technique had not been attempted outside of the Southern Appalachian Mountains. Due to differences in soils, topography, climate, and species composition, the technique may not work well in the Piedmont region. Variations of the technique or other site preparation methods may be necessary to establish pine-hardwood mixtures in this region.

A study, funded by the Georgia Forestry Commission, was begun in 1987 to test the fell-and-burn technique in the Piedmont. Study plots were established on the Dawson Forest in Dawson County, GA; the Clemson Experimental Forest in Pickens County, SC; and on private land in McCormick County, SC (figure 1). Selected sites were on
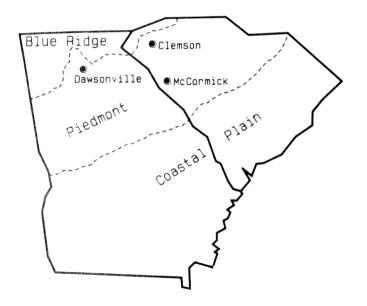
Figure 1.--Fell and burn to convert low-quality stands to productive pine-hardwood mixtures: Piedmont study sites.

predominantly south-facing slopes with stands dominated by scarlet oak (Quercus coccinea Muenchh.), southern red oak (Q. falcata Michx.), and hickories (Carya sp.). Clearcutting was completed during the winter of 1988. Chainsaw felling and broadcast burning were completed in May 1988 and July 1988, respectively. Loblolly pine seedlings were planted during February 1989. Rather than the usual 10 by 10 foot spacing, pines were planted on a 15 by 15 foot spacing (193 per acre) to allow hardwoods to compete and become a major component of the stand.

Three treatments were imposed in each of seven replications: fell and burn, fell only, and burn only. The fell only and burn only treatments were selected for two reasons. First, they are less expensive than felling and burning and may be attractive to private landowners. Second, they allow hardwoods a better chance to become a component of the stand. Loblolly pine is a vigorous competitor on many Piedmont sites, so the combination of felling and burning may not be necessary for pine survival. Since many landowners do not have the experience and resources to burn safely, the elimination of this step would be particularly attractive.

Early results of this study indicate several differences in applying the fell-and-burn technique in the Piedmont. Species composition of competing hardwoods is more variable than on the mountain sites of the Sumter National Forest. Study sites on the Clemson Experimental Forest are located in the Upper Piedmont and have many species similar to the Sumter National Forest (table 3). However, sourwood (Oxydendron arboreum L.) and dogwood (Cornus florida L.) are more numerous. Even though these species will not be major competitors in older stands, they may overtop planted pines in early years. McCormick County study sites are representative of the Middle Piedmont. The dominant species on these plots are sweetgum (Liquidambar styraciflua L.) and naturally-regenerated loblolly pine. Sweetgum sprouts prolifically and grows rapidly. Both felling and burning may be required to control sweetgum growth enough to allow pines to compete.

Broadcast burning may damage Piedmont sites. Because of the history of farming on Piedmont sites, root mats there are not as well developed as in the mountains. On the Sumter National Forest, root mats are often over 3 inches thick, while they were less than 1 inch thick on all Piedmont study plots. Strict burning guidelines must be developed to prevent soil exposure and erosion on Piedmont sites.

Two additional studies have been established in these study areas. One will document the effects of spring felling and summer broadcast burning on

Table 3.--Species composition of seedlings and sprouts on two Piedmont sites prior to planting.

Species	Clemson Forest	McCormick County
	--------- Stems per acre (pct) ----------	
Pines:		
Loblolly	---	2,133 (18)
Shortleaf	16 (<1)	---
Oaks:		
Scarlet	1,160 (10)	---
White	841 (7)	747 (6)
Black	827 (7)	---
Post	509 (4)	167 (1)
Other oaks	678 (6)	94 (1)
Other Hardwoods:		
Blackgum	1,678 (14)	233 (2)
Sourwood	1,665 (14)	---
Hickory	1,419 (12)	27 (<1)
Dogwood	1,984 (17)	---
Sweetgum	---	6,473 (55)
Miscellaneous	927 (8)	1,927 (16)
Total	11,704 (100)	11,774 (100)

sprout vigor. While these treatments are known to slow hardwood growth, the degree of reduction has not been documented. This study will provide insight into alternatives of the fell-and-burn technique that may be needed to allow pines and hardwoods to grow together. The other study will document the effects of the various treatments on the quality of habitat for several wildlife species. Detailed descriptions of the vegetation available for browse are being compiled. In addition, small mammals are being trapped to obtain an estimate of utilization.

Site Selection

Success in establishing pine-hardwood mixtures with the fell-and-burn technique depends on site selection. On sites of low productivity, hardwoods are generally absent or grow slowly and have poor form. Culturing quality hardwoods on these sites would be expensive or, in many cases, impossible. Highly productive sites, on the other hand, are best suited for hardwoods. Planted pines are quickly overtopped by vigorous hardwood sprouts. On the Sumter National Forest, the technique has been successful on medium sites -- slopes with south to southwest aspects and a site index of 65 to 70 feet for upland oaks at 50 years. No effort has been made to determine the upper and lower bounds of site quality for which pine-hardwood mixtures can be successful.

On many sites in the Southern Appalachian Mountains and Piedmont, existing stands are poor indicators of site quality. High-grading, fires, and mismanagement have produced low-quality stands on sites with high productive potential. To evaluate the potential of such sites for pine-hardwood management, a classification system based on factors other than standing trees is needed. A cooperative study has been established with Clemson University to develop an ecologically based classification system for the Piedmont using a technique proposed by Jones and others (1984) and Jones (1989). Under this system, site types are described as specific combinations of understory and overstory vegetation, land forms, and soil types. Site types suitable for pine-hardwood mixtures will be identified.

In the study of the fell-and-burn technique in the Piedmont, mentioned above, study plots were established on slopes with south and southwestern aspects. In five of the seven replications, however, sites ranged from dry upland ridges to moist north-facing slopes and coves. In each case, the entire

harvested area was prepared by the fell-and-burn technique. Additional study plots are being established in these stands on as many site types as possible. These plots will be used to validate the Piedmont site classification system and to gain insight into the relationship between site quality and the success of pine-hardwood regeneration.

Growth and Yield

Information on stand growth and yield is limited for pine-hardwood mixtures. The small amount of reported research has either viewed the hardwood component as a competing understory (Smith and Hafley 1987, Burkhart and Sprinz 1984) or has focused on relatively short term projections (20 years or less) using inventory data form pine-hardwood stands in the Southeast (Meldahl and others 1988). As a result, permanent growth and yield plots are being established in the Piedmont to develop forecasting systems for pine-hardwood mixtures.

One study examined the ability of six mixed-species models developed for other regions to describe the development of young pine-hardwood stands on the Sumter National Forest. The models tested were SILVAH (Marquis and others 1984), OAKSIM (Hilt 1985), G-HAT (Harrison and others 1986), Central States TWIGS (Belcher 1982), GATWIGS (Meldahl and others 1988), and FORCAT (Waldrop and others 1986). All candidate models under-estimated stem numbers over a 5-year simulation period (ages 2 to 7 in loblolly pine mixtures and 1 to 6 in shortleaf pine mixtures), primarily because stem numbers in young clearcuts typically increase for several years as sprouting increases and seedlings develop. Another problem dealt with the relative growth rates of hardwoods and planted pines. Hardwood vigor is reduced by the fell-and-burn technique (Geisinger and others 1989), making it easier for pine seedlings to compete with hardwood coppice regeneration. Each model predicted fast growth of hardwoods at the expense of pine growth and survival. None of these models was developed for young clearcuts in the Southern Appalachians or Piedmont, so poor model performance was not unexpected.

Formulation of forecasting predictors for early stand development (prior to crown closure) is important because change is rapid, and subtle differences in establishment conditions can dramatically affect the percentage of pines capturing a position in the overstory. Once crowns have closed, subsequent changes in species composition are slow and are the result of competition and self-thinning instead of the relative ability of species for rapid early height growth. As a result, a modeling approach is being developed on the principles that 1) there will be separate model components for pre-closure and

post-closure development stages which are driven by different inputs and linked by some measure of the size of the pine component at crown closure, and 2) both phases will be driven in part by height growth and built around a site classification system based on aspect, slope position, and depth to the maximum clay content (Jones 1989). Details of this modeling approach are presented by Lloyd (1989) elsewhere in these proceedings.

Fire Effects on Piedmont Sites

Site protection after the fell-and-burn technique depends largely on maintaining a thick root mat. This root mat protects the soil from erosion and acts as a mulch, retaining moisture for planted pines. Particularly on Piedmont sites, protection of the root mat is mandatory. Observations indicate that this mat is not as well developed on Piedmont sites, so the margin for error is slim. Little is known about the origin and distribution of root mats. Research is needed to determine the extent to which root mats occur in the Piedmont and the factors that influence their development.

Prescription guidelines have not been developed for broadcast burning on Piedmont sites. On the Sumter National Forest, fuel moisture sticks are used to determine when to burn. Generally, when these sticks contain 10 percent moisture, downed woody fuels are dry enough to burn but the forest floor and root mat are moist. When stick moisture content is below 10 percent, burning becomes risky. Fuel moisture sticks may prove useful on Piedmont sites, but they are untested. In addition, the relationship of fuel moisture, fuel type, weather, slope, and firing technique to fire intensity and fire severity must be established.

Scientists of the USDA Forest Service, the University of Georgia, and Clemson University have begun a cooperative research effort with the Agricultural Research Service in their Water Erosion Prediction Project (WEPP). WEPP is a nationwide program to develop a physical process-based model of surface erosion after disturbance to replace the Universal Soil Loss Equation. The initial research efforts in the Southeastern Piedmont are to study the effects of the fell-and-burn technique. A variety of sites will be burned by several firing techniques and at varying levels of fuel moisture to produce a range of fire severity. This work will determine how soil erosion and sediment production are influenced by rainfall, fire severity, soil properties, and slope. It will also provide preliminary data for developing guidelines for broadcast burning in the Piedmont.

SUMMARY AND CONCLUSIONS

Low-quality hardwood and pine-hardwood stands in the Southern Appalachian Mountains have been converted to productive pine-hardwood mixtures by the fell-and-burn technique. Since, the technique is inexpensive, it may attract private landowners to put their unmanaged stands into timber production. Introduction of pines to previously unmanaged hardwood stands improves stand value and increases management options while maintaining quality habitat for several wildlife species.

On sites at 1000 feet above mean sea level or higher, shortleaf pine is planted at a 10- by 10-foot spacing. These stands have numerous hardwood sprouts, but planted pines exhibit high survival and most are free to grow. At lower elevations, loblolly pine is planted. Even though these stands also have numerous hardwood sprouts, these sprouts are overtopped by the fast-growing pines within a few years. On these sites, a wider planting spacing or other refinements to the fell-and-burn technique may be necessary to allow hardwoods to compete with the pines.

The Southeastern Forest Experiment Station is studying several aspects of the fell-and-burn technique and pine-hardwood management. Research topics include application of the technique to Piedmont sites, site selection, growth and yield, and predicting fire effects. Many important questions remain. Once a pine-hardwood stand is established, for example, are intermediate treatments such as thinning or release needed? If so, how will growth and yield be affected? What products can be expected at various stocking levels and rotations? Can uneven-aged management techniques be used to establish pine-hardwood mixtures? How does the culturing of pines and hardwoods together affect wildlife habitat, water quality, and forest protection? As the fell-and-burn technique is refined and applied in new regions, it should prove useful in establishing pine-hardwood mixtures.

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FELL AND BURN TO REGENERATE MIXED PINE-HARDWOOD STANDS: AN OVERVIEW OF EFFECTS ON SOIL

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Abstract. — Effects of the fell-and-burn technique on the soil depend on many variables. When a substantial quantity of forest floor and root mat remain after burning, soil erosion will be minimal. Burns which expose large areas of mineral soil in steep terrain are likely to cause excessive erosion. Excessive nitrogen volatilization and forest floor losses can be prevented by burning under proper fuel and soil moisture conditions. Research conducted over a range of physiographic regions and sites is needed to evaluate the appropriateness of this regeneration method.

INTRODUCTION

Foresters have long been concerned with fire effects on soil (Arend 1941, Keetch 1944, Wells and others 1979). Much concern developed from observations of erosion following fires in steep terrain. In addition, questions regarding effects of burning on site nutrient status and long-term productivity have increased as forest management practices have intensified. Increasing use of broadcast burning to prepare sites for conversion of low-quality stands to mixed pine-hardwood stands in the Southern Appalachians (Abercrombie and Sims 1986) has heightened interest in effects of fire on the soil.

Reaction to fire and its immediate after-effects is often emotional, especially in today's society. The charred appearance of burned landscapes presents the image of devastation and destruction to the general public. Foresters realize, however, that most Southern forest ecosystems evolved under regimes of frequent or periodic fire (Komarek 1974, Van Lear and Waldrop 1989), and that fire has been the predominant agent of forest regeneration in the South over the millennia. Southern forest ecosystems are generally resilient to fire perturbations, and effects on soil are usually, but not always, minor.

The objective of this paper is to present an overview of the effects of fell-and-burn regeneration on soil erosion and nutrient loss. Because the method is relatively new, this discussion is based on limited information. Hopefully, this discussion will stimulate further research regarding effects of the fell-and-burn method on soil.

TYPES OF PRESCRIBED FIRE AND THEIR RELATION TO FIRE INTENSITY AND SEVERITY

Prescribed fires are generally classified as being one of three types: head, backing, and flanking fires (Brown and Davis 1973). Head fires are of relatively high intensity and move with the wind or upslope at relatively rapid rates of speed. The intensity of a fire is defined as the rate of heat release per unit of ground surface area.

Backing fires move at slower rates of speed and burn into the wind or downslope. They are of lower intensity than head fires and more easily controlled. However, slower burning rates require more time, making backing fires more expensive.

Flanking fires are set parallel to wind direction with ignition moving into the wind. They are seldom used to burn entire areas, but often supplement other burning techniques.

Fire intensity per se may or may not be closely related to soil response to burning. This apparent anomaly is because other factors, such as fuel characteristics, soil moisture, and residence time can greatly modify effects of fire intensity on the soil. For example, a high intensity fire moving rapidly (short residence time) through well-aerated logging debris when soil and lower forest floor layers are moist will generally have little impact on soil properties. Only the upper part of the forest floor will be consumed. Conversely, a backing fire burning slowly in light fuels during droughty conditions, may consume all surface organic matter exposing mineral soil and resulting in serious erosion in steep terrain.

The most important factor affecting soil response to burning is fire severity, i.e., the condition of the ground surface after burning (Wells and others 1979). Severe burns consume all organic matter on the soil surface and alter mineral soil structure and color. Moderate burns char the litter and duff, but do not visibly change the properties of the mineral soil. Light burns only scorch forest floor layers, leaving considerable residual organic material over mineral soil. In addition, the depth of the organic layers above mineral soil must be considered prior

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to burning. Burns of similar intensity and residence time will be more severe on sites where the organic layer was thin before burning.

EFFECTS OF THE FELL-AND-BURN TECHNIQUE ON SOIL

A detailed description of the fell-and-burn method is presented in other papers in these proceedings. Briefly, residual stems after clearcutting are felled in spring when trees have leafed out and allowed to cure 6-8 weeks. Felling is followed by a moderate- to high-intensity broadcast burn shortly after a soaking summer rain. The goal is to reduce logging debris and hardwood competition, yet leave a significant portion of the forest floor and most of the root mat to protect the soil from erosion. After the summer burn, the area is planted to pine the following winter. High survival rates of planted pine, plus development of better quality hardwood coppice, produces a mixed pine-hardwood stand.

This technique has been used to regenerate dozens of sites previously occupied by low quality hardwood and pine-hardwood stands to good quality pine-hardwood stands in the Southern Appalachians (Abercrombie and Sims 1986). The technique is now being tested in the Piedmont.

We consider the regeneration process to be independent of the harvest operation, which generally disturbs 20 to 40 percent of the area in conventional skidder logging (Hatchell and others 1971, Nutter and Douglas 1978). Elements of the technique that have immediate effects on soil consist of two basic components, i.e., manual felling of residual trees and broadcast burning of logging slash. The former has no detrimental effect on the soil as no heavy machinery is used and no organic matter is removed from the site. Burning with relatively high intensity fires is the component of concern.

Although the fell and burn components are separated in time, they are not independent of each other. Without the flashy fuels created by the felling, it would not be possible to conduct the burn as quickly following a soaking rain. Under most conditions, the longer a burn is delayed the greater will be the consumption of the forest floor, which results in greater erosion and nutrient loss from the site.

Soil and Nutrient Loss by Erosion Following a Broadcast Burn of Low Severity

The effects of broadcast burning on soil erosion and nutrient loss are related to the severity of the burn. Following a low-severity burn on an Evard soil in the Southern Appalachians, Van Lear and Danielovich (1988) found that soil movement was not increased significantly on slopes ranging from 21 to 43 percent (table 1). Erosion did not increase for several reasons, most important of which was the fact that mineral soil was exposed on only 15 percent of the burned area. Sufficient residual forest floor and a thick mat of fine and medium roots remained to protect the surface of the mineral soil. Thus, burn severity was light, even though fire intensity was moderate to high, i.e., flame heights over most of the area averaged between 5 and 13 ft. Most of this area was fired with strip head fires, so residence time was short. Much of the 0.71 t/ac of soil trapped behind these sediment dams, which were on upper slopes, would not have reached the drainage channel; most would have settled out on the more gentle grades of lower slopes.

Losses of available phosphorus and exchangeable cations (0.02 to 1.02 lbs/ac/yr) on eroded sediments from burned plots were too low to cause concern about possible adverse effects on site productivity (table 1). The pH of sediments was increased by about one-half unit because of increased exchangeable bases in ash from the consumed forest floor. The pH of the mineral soil was not measured in this study, but other studies have reported slash burning raised soil pH by as much as 1 to 2 units (Tarant 1956, Issaac and

Table 1.--Soil and nutrient loss by erosion in the year following a broadcast burn of low severity in the Southern Appalachian mountains (adapted from Van Lear and Danielovich 1988).

Treatment	Trapped sediment	pH	Available P	Exchangeable		
	t/ac/yr		------------lbs/ac----------		K	Mg	Ca
Control-no burn	0.59	4.7	0.01	0.04	0.03	0.31
Fell and burn	0.71	5.3	0.02	0.05	0.05	1.02

Hopkins 1937). Increased nutrient availability at higher pHs may account for frequently reported positive plant response following fire (Wells and others 1979). However, some investigators attribute these responses, at least in part, to a soil sterilization effect (Raison and others 1985).

Regrowth was rapid on the clearcut area. Shrub and herbaceous biomass on burned plots was almost twice that on unburned plots by the end of the first growing season after planting. Winter dieback of herbaceous vegetation, much of which was annuals, provided a protective mulch over the residual forest floor. Slash weights were reduced from 30 to 38 percent by burning, but 11 to 14 t/ac remained. In rare instances, large pieces of logging debris served as sediment dams. Infiltration rates remained high on burned plots, averaging 67 in/hr. Infiltration rates of this magnitude far exceed maximum rainfall rates, indicating that overland flow is minimal on burned sites where significant quantities of residual forest floor remain and the root mat has not been significantly reduced. If overland flow is minimal, erosion will be minimal.

All these factors collectively minimize erosion after broadcast burns of light severity. Results of this study indicate that broadcast burning can be conducted in relatively steep terrain of the Southern Appalachians with little increased erosion. However, if burning is conducted under inappropriate fuel and soil moisture conditions, or if improper firing techniques are used, erosion may be dramatically accelerated.

Soil and Nutrient Loss by Erosion Following a Broadcast Burn of High Severity

In contrast to the favorable results found in the preceeding study, large soil losses were measured on a small watershed (0.87 ac) within a fell and burned area in the Georgia Piedmont. The harvested area was burned in July of 1988, 4 days after a 1.5 in rain. Observations soon after burning indicated that there was little to no residual forest floor or root mat left on much of this watershed. Prior to burning, this Piedmont site did not have the thick duff layer (which includes the root mat) characteristic of sites on the Sumter National Forest in the Southern Appalachians. Mineral soil was exposed on more than 50 percent of the area and close inspection indicated it would just be a matter of time before mineral soil would be exposed on the entire watershed and erosion would accelerate. That time came during the last week in July when the area received a storm that delivered over 4.3 in of rain in one day.

Erosion was estimated from a systematic sampling of pedestaled rocks at 50 locations throughout the watershed and bulk density of trapped sediments collected at the outlet of the watershed. Bulk den-sity of eroded sediments from this Evard soil averaged 1.0. During the first 9 months after burning, about 156 t/ac of soil was lost, primarily by sheet erosion. Projected to a yearly basis, erosion would amount to 207 t/ac (table 2). Sheet erosion refers to soil movement resulting from raindrop splash and surface runoff (Beasley 1972). Pedestaled rocks, which are indicative of sheet erosion, averaged about 1.4 in above the eroded surface and were scattered rather uniformly throughout the watershed.

DeBano and others (1971) found that a water repellent layer developed in soils when brushy areas were burned in California. This sub-surface layer contributes to increased erosion because the wettable layer above it becomes saturated and results in overland flow. It is not known if Typic Hapludult soils in the Piedmont develop a hydrophobic layer below the soil surface during burning. Infiltration rates were not adversely affected in the mountains by broadcast burning (Van Lear and Danielovich 1988), suggesting that these water-repellent layers did not form. However, infiltration rates were not measured on the Piedmont site and erosion rates were high.

A major gully network developed on this watershed soon after burning. Although the area in gullies was less than 1 percent of the total area, some gullies had cut through the surface horizons to a depth of 10 in or greater, and were transporting large volumes of soil. Greatest soil loss in gullies occurred in the first 4 months after burning (figure 1). Depth of gullies did not increase markedly once the incised channel reached the underlying clay subsoil. However, their width continued to increase throughout the winter due to accelerated erosion associated with freezing and thawing of the exposed gully banks. In addition, gully banks continually slumped as their sides were undercut by water flowing down the channels.

Although the low-severity burn discussed earlier increased the rate of secondary succession, regrowth on this severely burned watershed was markedly delayed. Apparently, seed stored in the lower layers of the forest floor were destroyed by burning and freshly deposited seed were washed away by overland flow. Because of the slow rate of revegetation, these gullies will continue to cut headward and expand in width for years. Only after crown closure and litter provide surface protection and root development binds soil particles together will these gullies stabilize.

If one assumes that nutrient concentrations on sediments deposited on the Piedmont site were similar to those on sediments sampled after burning in the mountains, then losses of P, K, Mg, and Ca are 3.9,

Table 2.--Conditions at time of burning and subsequent erosion on sites in the Southern Appalachians and Piedmont.

Site	Conditions	Erosion
		t/ac/yr
Southern Appalachians	1. slope=21-43 pct 2. woody slash=18-22 t/ac 3. fuel moisture sticks=10 pct 4. date of burn=8/24/1984 5. weather: RH=47 pct Air temp=83 F Wind=N3mph	0.7
Piedmont	1. slope=23 pct 2. woody slash=13 t/ac 3. fuel moisture sticks=9 pct 4. date of burn=7/8/1988 5. weather: RH=42 pct Air temp=83 F Wind=S3mph	207
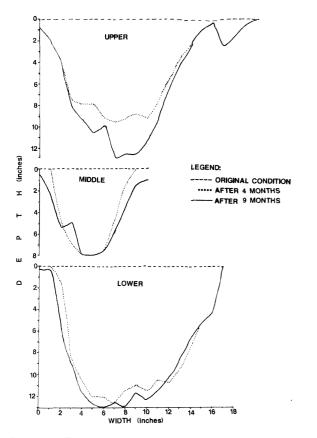
Figure I. Transect across a gully 4 and 9 months after a broadcast burn in the Georgia Piedmont.

11.2, 12.1, and 224 lbs/ac, respectively, during the 9 months after burning. However, since these estimates do not include ash from the consumed forest floor, they are considered conservative.

Why was there such a wide difference in soil erosion rates following broadcast burning in the two situations described above? Fuel loading, fuel moisture stick readings, season of burning, current weather conditions, and time since the last rain were similar for both sites (table 2). In fact, slopes were steeper and fuel loading was higher at the Southern Appalachian site, yet erosion rates were minuscule compared to erosion rates at the Piedmont site. The explanation of the difference must lie in two facts. First, even though soil series was the same at the two sites, the forest floor and root mat was much thicker and better developed on the mountain site than that at the Piedmont site. The cooler and moister conditions of the mountains would favor the development of a thicker forest floor than would be found in the Piedmont. Secondly, the 2 months prior to burning the Piedmont site were exceedingly dry (a total of only 1.6 in of rain was recorded for May and June). Because of these droughty conditions, the normal moisture gradient between the mineral soil and the lower layers of the forest floor ceased to exist. The relatively heavy rainfall (1.5 in) that fell shortly before the Piedmont burn apparently only wet the surface litter and did

not restore moisture contact between the mineral soil and forest floor. As a result, the dry forest floor was completely consumed, which exposed mineral soil and accelerated erosion. Numerous completely burned-out stump holes on this watershed attest to the dry site conditions at time of burning.

These two examples of broadcast burning illustrate the range of potential effects burning can have on sediment and nutrient loss by erosion. In the first case effects were minimal, while in the latter, losses were extreme. Ballard (1978) and Glass (1976) have shown that large reductions in pine growth can occur on sites where large quantities of soil have been displaced by careless windrowing. Growth of the new stand would be adversely affected whether the soil was displaced mechanically or via erosion. In addition, the deleterious effects of sedimentation on productivity of aquatic ecosystems (Miller 1987, Seehorn 1987) must not be overlooked. Sediment in streams reduces invertebrate abundance, decreases feeding success of sight-feeding species, and negatively affects spawning success of many fish species. Because of these adverse on- and off-site effects, high rates of erosion cannot be tolerated by forest managers. Further research is needed to determine the applicability of the fell-and-burn technique under Piedmont conditions, as well as its suitability in other physiographic regions.

This comparison dramatically illustrates the importance of predicting the proper time and conditions for conducting broadcast burning to minimize impacts on soil. Fuel moisture sticks are useful as an aid in determining when it is possible to burn following a soaking rain (Abercrombie and Sims 1986); however, they were not designed to predict potential site damage. What is needed is a model that will enable the manager to predict consumption of the forest floor and root mat on the surface of the mineral soil. Although such models have been developed in the Rocky Mountains (Little and others 1986), we are not aware of similar models for the Southeastern United States. Until such models are developed, experience and judgement in assessing fuel and soil moisture and empirical knowledge relating these conditions to fuel consumption provide the only means to predict proper conditions for burning.

NUTRIENT LOSSES DURING BROADCAST BURNING

Nitrogen losses from logging debris, because of its well-aerated arrangement, can be estimated from measured reductions of slash during burning and nitrogen concentrations of slash components. Sanders and Van Lear (1988) measured fuel loadings before and after broadcast burning in clearcuts

in the Southern Appalachian mountains. These burns were conducted on the Sumter National Forest by Jim Abercrombie, the originator of the fell-and-burn technique. Erosion losses appeared to be minimal on these burns as about 45 percent of the duff layer (which included the root mat) remained after burning (table 3). Woody slash averaged 30 t/ac after harvest and was reduced 52 percent during burning. Burning also reduced other fuel components, including litter and small live fuels by 98 and 100 percent, respectively. Within the woody slash category, which comprised more than 60 percent of the total fuel, reduction by burning was inversely related to diameter class (figure 2).
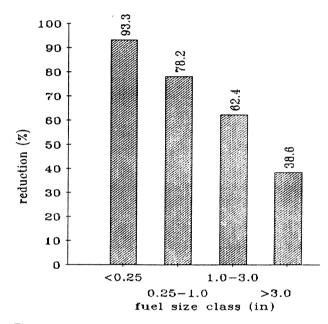
Figure 2. Reduction by burning of four size classes of woody fuel (from Sanders and Van Lear 1987).

If weight reductions of the various size components in figure 2 are multiplied by nitrogen concentrations of mixed hardwood logging slash (data available upon request from the authors), then 74 lbs/ac of nitrogen would be volatilized during consumption of logging debris. This calculation assumes that all nitrogen in consumed logging debris of various size classes is volatilized. Since nitrogen volatilizes at relatively low temperatures of about 390° F, this assumption is probably valid.

Nitrogen losses from the forest floor during burning are more difficult to estimate. The largest amount of nitrogen reported lost from the forest floor during burning was over 714 lbs/ac in a wildfire in extremely heavy fuels in Washington (Grier 1975). Knight (1966), in a laboratory study, estimated that 25 to 64 percent of the nitrogen content of an old growth

hemlock-fir forest floor would be volatilized during burning, depending on temperature. However, in another laboratory study, Morz and others (1980) found no significant difference in the preburn vs. postburn nitrogen content of forest floors of three forest types after simulated fires. The discrepancy in results of these two studies is probably caused by different methods of simulating fire. However, they indicate the difficulty in estimating nitrogen losses even under controlled conditions. Shock and Binkley (1986) plotted estimated nitrogen volatilization losses versus forest floor consumption from several southeastern fire studies. They found that about 10 lbs of nitrogen are lost for each ton of organic matter consumed. If this figure holds for the data in table 3, an estimated 132 lbs/ac of nitrogen would be volatilized from the forest floor during burns of this type.

Estimates of total nitrogen volatilization from consumption of all fuel components in table 3 indicate that in excess of 238 lbs/ac of nitrogen are lost to the atmosphere during a typical broadcast burn in the Southern Appalachians. However, this estimate may be too high. Morz and others (1980) measured increases in nitrogen content of the lower layer of the forest floor after simulated burning, which tended to balance losses from the surface layer. Condensation of vaporized organic com-

pounds as they are forced downward by heat (De-Bano and others 1970) may explain the immediate increase in nitrogen content of the lower forest floor. Whether this figure over- or under-estimates the actual quantity, it is clear that broadcast burning results in substantial losses of nitrogen. Burning under conditions of drought when all the forest floor is consumed, as well as a much larger proportion of the logging slash, could conceivably double nitrogen loss. Again, the importance of burning under conditions which minimize consumption of the forest floor is underscored.

Based on nitrogen inputs of about 4.5 to 5.5 lbs/ac/yr in bulk precipitation to Piedmont and Southern Appalachian ecosystems (Van Lear and others 1983, Swank and Waide 1988) and the conservative nature of nitrogen cycling in southern forest ecosystems (Waide and others 1988, Van Lear and others 1989), the nitrogen status of harvested sites should not be adversely affected by infrequent (once per rotation) and properly conducted broadcast burns. This input, in conjunction with gains from nitrogen fixation (Boring and Swank 1984, Waide and others 1988), probably would exceed losses to harvest, burning, and leaching over sawtimber rotations currently recommended for hardwood or pine stands.

Table 3.--Mean dry weight and reduction by broadcast burning for various fuel components in the Southern Appalachian mountains.

Fuel Component	Weight (Tons/ac)	Reduction (Pct)
Slash		
Preburn	30.3	
Postburn	14.5	52
Litter		
Preburn	6.1	
Postburn	0.1	98
Duff		
Preburn	13.5	
Postburn	6.1	55
Live		
Preburn	0.2	
Postburn	0.0	100
Total		
Preburn	50.1	
Postburn	20.7	59

Little is known concerning the fate of nutrients other than nitrogen during and after broadcast burning. Nutrients contained in ash may be transported off the site by wind or water, or retained on site by vegetation regrowth or microbial immobilization. Although the magnitude of these processes has not been determined following the fell-and-burn technique, it is safe to say that the former processes will dominate on sites where little forest floor remains and erosion is great.

SUMMARY AND CONCLUSIONS
The fell-and-burn technique of regenerating mixed pine-hardwood stands is relatively new. Much research is needed to evaluate the silvicultural effectiveness of the technique and to document its effects on the soil. Currently, there are only a few studies that quantitatively describe effects of the technique and the generality of results of these studies is not known.

When prudently conducted by experienced practitioners on the Sumter National Forest in the Southern Appalachians in South Carolina, evidence (both empirical and experimental) suggests that the fell-and-burn technique has little adverse effect on the soil. In fact, the combined mulching effect of the residual forest floor and die-back of annual herbaceous plants may improve soil water relations for the new stand. If a substantial quantity of the residual forest floor remains and covers most of the burned area, hydrologic functioning of the soil is not impaired and erosion is not increased. Nitrogen volatilization, even under favorable conditions, is considerable during broadcast burning but can be minimized by burning when the soil and lower forest floor are moist. The goal of burning with this technique should be to reduce logging debris to the degree necessary to facilitate planting, yet leave as much residual forest floor and root mat as possible. Rough calculations indicate that the nitrogen status of harvested and burned sites over the course of typical sawtimber rotations will not be negatively impacted by judicious application of the technique.

The effectiveness and suitability of the fell-and-burn technique in the Piedmont and other physiographic regions has not been demonstrated. Preliminary evidence suggests that Piedmont sites may be more sensitive to high intensity fires than mountain sites. Because the forest floor and associated root mat appears to be thinner in the Piedmont, fires of similiar intensity are likely to be more severe in the Piedmont than in the Southern Appalachian mountains.

Broadcast burning under droughty conditions can lead to severe erosion and nutrient loss. When normal soil moisture gradients from the forest floor into the mineral soil are lacking in dry weather, broadcast burning may consume the entire forest floor and associated root mat. Models that predict consumption of forest floor components during burning are urgently needed as the fell-and-burn technique is increasingly used in steep terrain.

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SPROUT GROWTH FOLLOWING WINTER AND SPRING FELLING WITH AND WITHOUT SUMMER BROADCAST BURNING

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Abstract. — Young naturally regenerated pine-hardwood stands are often characterized by vigorous hardwood sprouts overtopping pine seedlings. For several years, mixed stands have been regenerated successfully in the Southern Appalachians by planting pines in hardwood clearcuts. Hardwood competition has been controlled by spring felling of residual stems and summer broadcast burning. This study documents the effect of these treatments on first-year sprout growth in the Piedmont of South Carolina. Four treatments were imposed following a commercial clearcut: (1) winter felling of residuals, (2) spring felling of residuals, (3) winter felling followed by a summer broadcast burn, and (4) spring felling followed by a summer broadcast burn. Spring felling followed by a summer burn provided the greatest control of height growth and crown spread of hardwood sprouts. The effect of burning was more important than season of felling because of the reduced time for sprout development. Number of sprouts per clump was generally unaffected.

INTRODUCTION

Approximately 80 percent of the forested land of the Southeast Piedmont area is owned by individuals or family groups. The tracts are small (average about ten acres) and most are cutover lands or old abandoned farms. The existing timber on these scattered lands is, for the most part, of low quality and is usually comprised of mixed pine-hardwood or hardwood species that are not highly desirable or suitable for the production of commercial wood products (McMinn 1983). An inexpensive regeneration system to change these low-quality stands to a productive state is needed.

A site preparation technique called fell and burn has been used in the Southern Appalachians to effectively and economically establish mixed pine-hardwood stands on certain sites (Phillips and Abercrombie 1987). The fell-and-burn procedure is described in detail elsewhere in these proceedings (Waldrop and others 1989) and consists of spring felling of residual stems (after clearcutting) followed by a summer broadcast burn. The objective of this study was to determine the effects of season of felling and summer burning on sprout development.

METHODS

Study sites are located on the Clemson University Experimental Forest. These sites were selected for consistency and similarity of aspect, soil, and vegetation. Before harvesting in December 1987 and March 1988, major tree species included white oak (Quercus alba L.), southern red oak (Q. falcata Michaux.), black oak (Q. velutina Lam.), scarlet oak (Q. coccinea Muenchh.) chestnut oak (Q. prinus L.), hickory (Carya sp.), and shortleaf 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 1/40th acre plots were established in three replications of four treatments. Treatments included:

1. winter felling of residuals with no burning,

2. spring felling of residuals with no burning,

3. winter felling of residuals with summer broadcast burning, and

4. spring felling of residuals with summer broadcast burning.

Spring felling was compared to winter felling to determine if sprout growth is reduced by felling when carbohydrate reserves are typically low. Chainsaw crews felled all residual stems over 5 feet tall that were present after commercial clearcutting. Winter felling was completed in early March 1988; spring felling was conducted in June 1988.

Burning took place 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 five MPH. Moisture content of 10-hour timelag fuels (1/2-1 inch in diameter) was 12 percent at 10:00 A.M. and 9 to 10 percent after noon.

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Burning was accomplished with hand crews and drip torches. 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. Fuel loading varied from little or none to very heavy, depending upon disturbance by skidding and the presence of tree tops. Fuels consisted of large logs, old down materials, freshly felled residuals, tops, branches, leaf litter and new growth. Fuel loading before and after the broadcast burn was determined by the planar intersect method (Brown 1971). Sizes, quantities, and depths of fuels were measured.

Data collected at the end of the first growing season included: 1) stump height and diameter, 2) number of sprouts per stump, 3) height of the dominant sprout on each stump and 4) crown diameter of each sprout clump.

Treatments were compared by analysis of variance and means separation was by linear contrast. Number of sprouts per stump, height of the dominant sprout and diameter of the sprout clump were used as indicators of sprout growth. Treatment differences were compared with each variable for the common species or species groups including: oak, hickory, blackgum, other hardwoods and all species combined.

RESULTS AND DISCUSSION
Broadcast burns were of high-intensity with flames reaching heights of 10 to 15 feet where fuel loading was heavy. However, fire severity was low with exposure of mineral soil on no more than 22 percent of the burned areas (table 1).

Burning in spring-felled areas was more complete and uniform than in winter felled areas. Loading of fine fuels (.5 inch diameter) prior to burning averaged 0.4 ton per acre in both winter- and spring-felled areas (table 1). After the burn, fine fuel loading had been reduced by 75 percent in the spring-felled areas but by only 50 percent in the winter-felled areas. The depth of all fuels was reduced by 77 percent in spring-felled areas and by 54 percent in winter-felled areas. These differences were partially due to the presence of leaves on the stems felled during spring. After a tree is cut, the transpirational function of leaves continues to remove water from the bole and branches (McMinn 1986). Dry leaves also served as fuels to carry the fire.

Species composition of regeneration closely resembled that of the pre-harvest stand. Regeneration at the end of the first-year growing season (table 2) consisted of scarlet oak, southern red oak,

Table 2.--Species composition of regeneration.

Species	Stems per acre
Shortleaf Pine	57
Select oaks[a]	4,290
Hickory	1,350
Blackgum	1,647
Other Hardwoods	4,347
Total	11,691

[a] Scarlet oak (Quercus coccinea Muenchh.), southern red oak (Q. falcata Michx.), white oak (Q. alba L.), post oak (Q. stellata Wangenh.), black oak (Q. velutina Lam.), chestnut oak (Q. prinus L.).

Table 1.--Characteristics of fuels and exposed soils before and after burning by season of felling.

	Winter felled	Spring felled
Weight of fine fuels (<0.5 in dia)	(tons per ac)	
Before burning	0.4	0.4
After burning	0.2	0.1
Percent reduction	50	75
Depth of all fuels	(in)	
Before burning	8.5	7.7
After burning	3.9	1.8
Percent reduction	54	77
Soil exposure	(pct)	
Before burning	4.0	7.6
After burning	22.1	20.3

Table 3.--Average number of sprouts per stump by species group and treatment.

Treatment	Oak	Hickory	Blackgum	Other Hardwoods	All Species
Winter fell/no burn	5.7 a[1]	2.1 a	5.6 a	14.6 a	7.8 a
Spring fell/no burn	5.1 a	4.7 b	4.6 a	12.4 ab	6.8 a
Winter fell/burn	6.5 a	4.3 b	5.9 a	11.3 ab	7.4 a
Spring fell/burn	4.2 a	4.1 b	4.6 a	10.1 b	7.0 a

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

white oak, post oak (Q. stellata Wangenh.), black oak, chestnut oak, hickories, blackgum, sourwood and dogwood. Minor species included black cherry (Prunus serotina Ehrhart), red maple (Acer rubrum L.), yellow-poplar, holly (Ilex opaca Aiton), persimmon (Diospyros viginiana L.) sassafras (Sassafras albidum (Nuttall) Nees) and hawthorn (Crataegus spp.). Primary invader species were present in the burned areas, but few or none were found in the unburned treatments. These invader species included vetch (Vicia spp.), butterfly pea (Clitoria mariana L.), fireweed (Erechtites hieracifolia (L.) Raf), and pokeweed (Phytolacca americana L.).

Spring felling and summer burning had little effect on the number of sprouts per stump for oaks, blackgum, and all species combined (table 3). For hickory, the winter fell treatment with no burning produced significantly fewer sprouts per stump than other treatments. In the other hardwoods group, the number of sprouts per stump was reduced to some degree by spring felling alone and by winter felling with burning. The combination of spring felling and burning produced the fewest sprouts per cut stem. These findings appear to con-

tradict those of Augspurger and others (1987) and Waldrop and others (1985) who found that the number of sprouts per acre was increased by fire. However, this difference may be due to the shorter growing period of this study or from the methods used to determine sprout numbers (on a per acre basis vs. a per stump basis). Since burning created open conditions, additional seedlings and sprouts may develop during the second growing season.

Summer broadcast burning reduced the height of the dominant sprout of most species groups by approximately 50 percent (table 4). Spring felling with summer burning reduced height more than did winter felling and burning and produced a significant reduction in the growth of blackgum, hickory, and other hardwoods. Spring felling without burning had little affect on height growth. These results suggest two primary advantages of spring felling over winter felling: 1) spring felling provides fuels for more uniform and timely burning and 2) spring felling contributes to the overall control of hardwood sprout growth in the fell-and-burn method. Of the two components, burning had

Table 4. Average height (in) of dominant sprout by species group and treatment.

Treatment	Oak	Hickory	Blackgum	Other Hardwoods	All Species
Winter fell/no burn	39.7 a[1]	18.1 a	30.6 a	41.9 a	36.4 a
Spring fell/no burn	36.2 a	14.7 ab	29.5 a	40.7 a	32.4 b
Winter fell/burn	18.7 b	13.5 b	24.0 a	23.1 b	18.3 c
Spring fell/burn	18.6 b	9.5 c	12.5 b	18.8 c	15.8 c

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

more effect on growth than spring felling. The reduction in height of competing hardwoods on burned plots was due to a shorter growing period rather than an inhibitive response to burning (Danielovich and others 1987).

The average diameter of the crowns of sprout clumps was affected by summer burning and spring felling (table 5). Burning significantly reduced crown diameters of oak, other hardwoods, and all species combined. Without burning, spring felling had no effect. However, the combination of spring felling and burning produced the smallest crown diameters of all treatments. Similar to height growth, burning was more critical for controlling crown spread than season of felling. However, spring felling produced more uniform burning conditions.

SUMMARY AND CONCLUSIONS
Spring felling of leafed-out residuals followed by summer burning (fell-and- burn site preparation) produced the greatest reductions in heights of the dominant sprouts and crown diameters of sprout clumps. Of the variables measured, number of sprouts per stump was least affected by the treatments. Burning reduced average sprout height for most species from generally over 3 feet to less than 1.5 feet. Spring felling with summer burning was more effective than winter felling and burning in reducing growth of several species groups. Reduction of dominant sprout heights and crown

diameters should reduce shading of planted pines thus allowing the successful establishment of a pine-hardwood mixture. Reduced growth of sprouts was attributed primarily to a shortened time to develop after burning, although sprout vigor may also have been affected.

The oaks appeared to be somewhat less affected by spring felling than each of the other species groups. After burning, sprouts of hickory, blackgum, and other hardwoods were smaller (height and crown diameter) in spring felled areas than in areas where felling was conducted in the winter (tables 4 and 5). The oaks showed no significant reductions in height growth or crown spread due to spring felling. If this pattern remains apparent over several growing seasons, the combination of spring felling and summer burning may prove beneficial to establishment of the more desirable oak species.

The success of the fell-and-burn technique for establishing pine-hardwood mixtures has been attributed, in part, to controlling hardwood sprout growth (Phillips and Abercrombie 1987, Danielovich and others 1987). This control was assumed to be the effect of carefully timed broadcast burning and felling of residuals when carbohydrates are in low supply. After a single growing season, this study shows that the fell-and-burn technique effectively reduced hardwood growth in the Piedmont of South Carolina. The reduced size of hardwood sprouts (both height and crown diameter) was primarily due to burning. Felling residual stems during the spring was less effective in reducing sprout growth than anticipated. Without burning, spring felling had little affect on sprout growth.

Table 5.--Average diameter (in) of clump crown by species group and treatment.

Treatment	Oak	Hickory	Blackgum	Other Hardwoods	All Species
Winter fell/no burn	24.0 a[1]	10.1 ab	24.1 a	33.3 a	24.9 a
Spring fell/no burn	24.1 a	10.3 a	22.7 a	29.3 a	22.9 a
Winter fell/burn	18.1 b	11.8 a	21.8 a	20.0 b	16.1 b
Spring fell/burn	13.6 b	7.9 b	10.3 b	16.0 c	13.2 c

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

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INFLUENCE OF WHOLE-TREE HARVESTING ON STAND COMPOSITION AND STRUCTURE IN THE OAK-PINE TYPE

James W. McMinn[1]

Abstract.—Oak-pine stands in the Upper Piedmont of Georgia were harvested with small feller-bunchers in both the dormant season and early growing season to 1-inch and 4-inch lower diameter limits. After 9 years of natural stand development, both season and intensity of harvesting significantly influenced species composition and stand structure. Areas harvested during the growing season developed into essentially hardwood stands, while dormant-season harvests produced a substantial pine component. On the 4-inch-limit areas, competition to regeneration from the harvest residuals was still apparent.

INTRODUCTION

Intensive whole-tree harvesting can be a practical way to remove poor stands with little timber-producing potential (Butts and Preston 1979). Key questions remain, however, about the species composition and stand development of natural regeneration that follows intensive harvesting. To address these questions, a study was established in a mixed hardwood-pine association on the Upper Piedmont of Georgia. Study variables were intensity and season of harvest. Treatment effects on hardwood sprout coverage and pine regeneration through the first five growing seasons after harvesting were presented by McMinn and Nutter (1988). This paper presents results based on the entire stands nine growing seasons after harvest: it is the first time in the study that the same response variables--basal area and number of stems per acre--are applied to the hardwood coppice, pine regeneration, and harvest residuals.

METHODS

The study area is on the Dawson Forest, which is managed by the Georgia Forestry Commission. Prior to management by the Commission, the area had been abandoned for agriculture, undergone natural succession, and been subjected to high grading typical of stands in the region. Soils are eroded phases of Fannin fine sandy loam with inclusions of Tallapoosa fine sandy loam. Both soils are Ultisols in the Typic Hapludult and Ochreptic Hapludult subgroups, respectively. The initial hardwood component was comprised primarily of scarlet oak (Quercus coccinea Muenchh.), post oak (Q. stellata Wangenh.), black oak (Q. velutina Lam.), chestnut oak (Q. prinus L.), southern red oak (Q. falcata Michx.), hickory (Carya spp.), blackjack oak (Q. marilandica Muenchh.), sourwood (Oxydendrum arboreum (L.) DC.), white oak (Q. alba L.), dogwood (Cornus florida L.), and black-gum (Nyssa sylvatica Marsh.) in descending order of basal area (table 1). Predominant conifers were shortleaf (Pinus echinata Mill.), Virginia (P. virginiana Mill.), and loblolly pine (P. taeda L.).

Table 1.--Mean number of stems and basal area per acre prior to harvest by species group and size class

Species group[a]	Stem d.b.h. class (in)		
	0.5 - 5.4	5.5 - 9.4	>9.4
	Stems (no./acre)		
Shrub	67.7	-	-
Yellow pine	112.2	47.0	5.4
Soft hardwood	66.7	2.7	0.3
Hard hardwood	500.4	51.4	25.9
Miscellaneous	141.1	11.7	1.0
All species	888.1	112.8	32.6
	Basal area (ft^2/acre)		
Shrub	0.4	-	-
Yellow pine	6.6	14.6	3.4
Soft hardwood	0.7	0.8	0.4
Hard hardwood	14.2	15.7	21.8
Miscellaneous	6.5	3.1	0.7
All species	28.4	34.2	26.3

[a]Species are grouped according to standard Forest Survey categories.

One-acre treatment plots were harvested with a typical whole-tree system that included a small feller-buncher and grapple-skidders. Harvesting removed all material down to 4-inch or 1-inch diameter limits in both January and June of 1980. Each combination of season and intensity was replicated three times in a completely randomized design. Detailed observations and measurements were confined to the interior 0.5 acre of each 1-acre plot. In November and December of 1988 nine 0.01-acre circular subplots were located systematically on each 0.5-acre measurement plot. D.b.h. of all stems greater than 0.4 inch d.b.h. on each subplot was measured to the nearest 0.1 inch. Basal area and number of stems per acre were computed by species group and compared among treatments by analysis of variance.

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RESULTS AND DISCUSSION

The 9-year-old stands originated from a combination of hardwood coppice regeneration, pine seedling regeneration, and in some treatments small pine and hardwood harvest residuals (table 2). At this stage, the stands have not reached a stable number of stems per unit area, but substantial mortality has occurred in pine seedlings and hardwood sprouts. To understand the factors affecting the species composition and structure of the stands, it helps to first focus on pine and hardwood regeneration alone and then the combination of regeneration and harvest residuals.

Table 2.--Mean values by stand trait and harvesting treatment after nine growing seasons

		Harvesting treatment		
	Season:	Dormant	Dormant	Growing	Growing
Stand trait	Diameter limit:	1-inch	4-inch	1-inch	4-inch
		Regeneration only			
Stems per acre					
Pine		5188	1104	115	42
Hardwood		1984	1222	2070	1192
Basal area (sq.ft.per acre)					
Pine		61.4	13.5	1.2	0.4
Hardwood		16.5	9.8	15.8	8.3
		Residuals and regeneration			
Stems per acre					
Pine		5188	1141	119	100
Hardwood		1984	1637	2070	1619
Basal area (sq.ft.per acre)					
Pine		61.4	18.1	1.2	4.9
Hardwood		16.5	28.4	15.8	22.3

Regeneration Alone

Overall, different harvesting treatments gave rise to different stand characteristics, primarily through influences on pine regeneration (table 3). Very large effects of harvest season are probably related to the presence of viable pine seeds on the ground at the time of harvest. In this study, most of these seeds came from pines in the harvested stands, and harvesting provided the only site preparation for seeds that had already fallen. This regeneration technique has been formally characterized as the "seed-in-place" method (Langdon 1981). There were few pine seedlings in place prior to harvesting. In the absence of harvesting disturbance, few seedlings become established because the forest floor prevents seed contact with mineral soil (Pomeroy 1949; Yocum and Lawson 1977). Seed predators and fungi likely destroy a substantial proportion of the seed crop by early summer. Seedlings that do become established are vulnerable to destruction by the harvesting operation. Timing the harvest after an adequate seedfall and before hot weather, therefore, is crucial to regeneration success with this technique. Adjacent stands were the probable seed source for the few pine seedlings on plots harvested in the early growing season. The difference in pine seedling occurrence by harvest intensity is

probably due partly to mechanical disturbance and partly to competition by residual woody vegetation. Significantly more mineral soil was exposed by the more intense harvesting.

Table 3.--Summary of analysis of variance results for naturally regenerated oak-pine stands nine growing seasons after harvesting

	Source of variation		
Stand trait	Season	Limit	Season x limit
	Regeneration Only		
Pine stem count	**[a]	**	**
Hardwood stem count	NS	NS	NS
Pine basal area	**	**	**
Hardwood basal area	NS	NS	NS
	Residuals and regeneration		
Pine stem count	**	**	**
Hardwood stem count	NS	NS	NS
Pine basal area	**	*	*
Hardwood basal area	NS	*	NS

[a]** = significant at the 0.01 alpha level, * = significant at the 0.05 alpha level, NS = nonsignificant.

At age 9 there was no significant difference in number of hardwood coppice stems or basal area by treatment. However, hardwood coppice crown coverage had been significantly greater at age 2 after dormant season harvests and with a 1-inch limit. At age 4 and 5 coppice coverage was significantly greater on the 1-inch areas and exhibited evidence of competition from pine seedlings established after dormant season harvests (McMinn and Nutter 1988). Although statistically nonsignificant, some effect of diameter limit was apparent in hardwood regeneration at 9 years. The 1-inch limit produced an average of 68 percent more stems with 79 percent greater basal area than the 4-inch-limit harvests. This difference is attributed primarily to competition from the harvest residuals. A negligible proportion of hardwood sprouts originated from trees less than 4 inches d.b.h. A high proportion of the smaller stumps were destroyed to below the groundline by the tracked feller-buncher, and all sprouting was associated with identifiable stumps.

The net effect of treatments after 9 years was a drastic difference in the relative predominance of pine and hardwood. Dormant season harvest resulted in stands with a large pine component, but there was a substantial difference between harvest limits within the dormant season treatment. Pine basal area on the 1-inch-limit plots was over 3.5 times the hardwood basal area. On the 4-inch limit plots, pine basal area was less than 1.5 times the hardwood basal area. In sharp contrast to the dormant-season treatments, the growing season treatments exhibited less than 10 percent as much pine as hardwood basal area.

Regeneration and Residuals

After the 1-inch-limit harvests, regeneration comprised essentially the entire stands. After the growing-season 4-inch-limit treatment, a relatively modest number of residual stems translated into a substantially larger basal area at age 9: the majority of this basal area was hardwood. This effect was even more pronounced after the dormant-season 4-inch-limit treatment. Among regeneration, 58 percent of the basal area was pine. However, with residuals added, pine basal area comprised 39 percent of the stand.

The differences in total stand characteristics by treatment are most evident in diameter class distributions of stems and basal area by species group (tables 4 and 5). In the dormant-season 1-inch-limit treatment, 68 percent of the total stems and 59 percent of the total stand basal area was 1- and 2-inch pines. The greatest number of stems is in the pine 1-inch diameter class and the greatest basal area is in the pine 2-inch diameter class. By contrast, in the dormant-season 4-inch-limit treatment the largest number of stems is in the hardwood 1-inch diameter class and the greatest basal area in the hardwood 4-inch diameter class. The most skewed distribution of both stems and basal area occurred in the growing-season 1-inch-limit treatment: hardwoods in the 1- and 2-inch diameter classes accounted for 93.6 percent of the stems and 87.6 percent of the basal area. The growing-season 4-inch-limit treatment produced the most even distribution of basal area across diameter classes, but the majority of the basal area was from residual stems.

Table 4.--Diameter class distributions by species group and treatment after nine growing seasons

Species group	D.b.h. class (inches)					
	1	2	3	4	5	6
	- - - - - - - -Stems (pct)- - - - - - - -					
Dormant season, 1-inch limit						
Pine	46.8	20.9	3.9	0.7	0.1	0.0
Hardwood	22.0	4.4	1.2	0.1	0.0	0.0
Dormant season, 4-inch limit						
Pine	25.2	11.9	2.5	0.9	0.3	0.3
Hardwood	40.5	9.6	3.7	4.0	0.9	0.1
Growing season, 1-inch limit						
Pine	3.7	1.4	0.3	0.0	0.0	0.0
Hardwood	75.5	18.1	1.0	0.0	0.0	0.0
Growing season, 4-inch limit						
Pine	2.2	1.6	0.7	0.5	0.2	0.7
Hardwood	68.0	16.7	4.7	2.9	1.6	0.2

Table 5.--Total stand basal area distribution by species group and diameter class after nine growing seasons for four harvesting treatments

Species group	D.b.h. class (inches)					
	1	2	3	4	5	6
	- - - - - - - Basal area (pct) - - - - - - -					
Dormant season, 1-inch limit						
Pine	22.6	36.0	14.7	4.9	0.5	0.0
Hardwood	7.9	7.6	5.0	0.8	0.0	0.0
Dormant season, 4-inch limit						
Pine	7.7	13.7	6.4	4.9	2.4	3.6
Hardwood	10.1	11.6	10.5	20.0	7.7	1.3
Growing season, 1-inch limit						
Pine	1.8	3.5	1.8	0.0	0.0	0.0
Hardwood	42.9	44.7	5.3	0.0	0.0	0.0
Growing Season, 4-inch limit						
Pine	0.7	2.6	2.2	2.2	1.8	8.1
Hardwood	17.7	19.6	13.7	15.9	12.5	3.0

CONCLUSIONS

Both season and intensity of whole-tree harvesting significantly influenced species composition and stand structure after 9 years of natural stand development. Areas harvested during the growing season developed into essentially hardwood stands, while dormant-season harvests produced a substantial pine component. On the 4-inch-limit areas competition of residuals with pine seedlings and hardwood coppice was apparent.

The results have some clear silvicultural implications for forest types similar to the one studied here. The intensity and timing of harvests can be expected to strongly influence the species composition and structure of naturally regenerated stands. To maximize the pine component of such stands, harvesting should be done during the dormant season with adequate numbers of seeds in place. Harvests during the growing season will produce almost pure stands of mixed hardwoods. Standing harvest residuals will influence the character of the stand indefinitely, so possible long-term silvicultural benefits should be weighed against the expense of removing all standing material. The treatments with only minor modifications appear to be good options for low-cost management.

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THE DEVELOPMENT OF FIVE-YEAR-OLD MIXED UPLAND
HARDWOOD-PINE STANDS

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Abstract. — The effects of harvest season and four regeneration treatments on natural hardwood and planted loblolly pine density and height were evaluated five years after clear felling on the upper Piedmont of Virginia. Low-input cultural treatments resulted in a full range of stand conditions from almost pure pine to mixed hardwood-pine to pure hardwood stands. Hardwood species composition after clear felling differs dramatically from pre-harvest conditions in that shade intolerant to intermediate species are being replaced with more tolerant associates.

INTRODUCTION

Low-input forest stand regeneration alternatives are attractive to many forest landowners who do not have the resources, or do not desire to use capital-intensive forest management systems. Landowners need management information for low-cost regeneration of forest stands to meet product objectives that could be obtained from mixed hardwood, hardwood-pine mixtures, and pure pine stands.

Considering the costs of establishing and maintaining pine plantations, the abundance of hardwood stems in the Piedmont, and the uncertainty of future market conditions, some researchers have advocated the use of pine-hardwood mixtures in the Piedmont (Boyce and Knight 1980, Zahner 1982, Phillips and Abercrombie 1987). Less intensive regeneration practices associated with pine-hardwood mixtures are especially important in Virginia, where 81 percent of the total forest land is owned by farmers, professionals, and absentee landlords who often have limited funds and/or a limited commitment to carry out intensive forest management.

Research is needed to determine the feasibility of low-input woodlot management systems for pine-hardwood mixtures which optimize wood production and can be effectively implemented with limited funds. For farmers, cost-effective techniques which allow for the successful establishment and sustained regeneration of pine-hardwood mixtures would increase crop diversification and reduce sensitivity to market fluctuations in livestock and agricultural commodities. In addition, low-input cultural techniques that create mixed forests will enhance environmental quality by providing improved soil and water protection, as well as increasing species diversity and creating new wildlife habitat.

The objectives of this study were to determine the effects of site quality, season of harvest, and four even-aged regeneration treatments on the growth and development of natural hardwood and planted loblolly pine following clear felling.

STUDY AREA

The study area is located on the upper Piedmont at the Virginia Polytechnic Institute and State University's Reynolds Homestead Agricultural Experiment Station in Patrick County, Virginia. The soils are typical of the Piedmont and are leached, severely eroded Ultisols developed from granitic and metamorphic bedrock. Slopes range from 2 to 20 percent with 6 to 8 percent most common. Slope exposure is variable and important in determining site quality. The cooler northerly and easterly slopes are normally more productive than southerly and westerly aspects. Annual precipitation averages 49 inches and is well distributed throughout the year. As a result of the eroded and shallow surface horizon, the high clay content of the subsurface soil horizon, and summer precipitation in the form of infrequent, high-intensity thunderstorms, high tree moisture stress is common during the hotter months of July and August.

The forest stands of the study area are also typical of the Piedmont and are composed of mixed oak species on medium and poor sites, with yellow-poplar being a main canopy species on the better sites. Most of the stands have reverted to forest cover following abusive agriculture and abandonment within the past 125 years. High-grading and partial cutting have been used indiscriminately in the past, and, in most cases, the resulting stands have poor quality stems and the species composition has shifted to more tolerant, less desirable species.

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METHODS

Study plots were located in 50- to 80-year-old second-growth mixed oak forests on site qualities ranging from SI_{50} 48 to 75 feet for white oak (Carmean 1971, Doolittle 1958). Differences in stand composition based on the presence or absence of site-specific species enabled division of stands into two classes of site quality – poor sites with SI_{50} less than 65 feet and good sites with SI_{50} greater than 65 feet. Three plots were located in each of the two site classes. Pre-harvest stands contained an average of 106 square feet of basal area per acre on the poor sites and 118 square feet per acre on the good sites. Oak species comprised about 59 percent of the basal area on the poor sites and 34 percent on the better sites. The dominant species on the poor sites included chestnut oak, scarlet oak, red maple, and sourwood, with scattered Virginia pine and eastern white pine. White oak, yellow-poplar, red maple, sourwood, and northern red oak dominated the good sites.

The experimental design was a split-split-plot designed to evaluate site quality, season of harvest, and regeneration treatment. The study contains three blocks. Each block contains the two site qualities, good and poor, representing the whole plot. Whole plots were randomly split into growing and dormant season harvest. The dormant season split-plots were clear felled with chainsaws and whole-tree yarded with rubber-tired skidders between February 21 and March 23, 1983. The growing season harvest was conducted in a similar manner between June 21 and July 25, 1983. All stems greater than one inch in dbh were felled.

Four regeneration treatments were randomly assigned to each site class-harvest season unit, representing the second split. Each regeneration plot was 98.4 x 98.4 feet and contained one of the following treatments:

T1) Clear felling and whole-tree yarding only

T2) Clear felling, whole-tree yarding, and planted loblolly pine seedlings

T3) Clear felling, whole-tree yarding, herbicide treatment of all hardwood stumps, and planted loblolly pine seedlings

T4) Clear felling, whole-tree yarding, herbicide treatment of all hardwood stumps, planted loblolly pine seedlings, and a release treatment of pine seedlings.

Treatments 2, 3, and 4 included planting genetically improved 1-0 loblolly pine seedlings from a Virginia Piedmont source in March 1984. Seedlings were hand planted on a 6.6 x 6.6 feet grid resulting in a density of 1000 seedlings per acre.

The cut-stump herbicide application used in Treatments 3 and 4 consisted of a thin stream of undiluted herbicide applied to the cambial region of the stump immediately following cutting. All hardwood stumps were treated at an average rate of 0.85 oz. of chemical per square foot of basal area. Individual stems in the regeneration treatments 3 and 4 split-split-plots were treated with one of the following: triclopyr ([(3,5,6-trichloro-2-pyridinyl)oxy] acetic acid as Garlon-4® 61.6 percent EC); glyphosate (N-(phosphonomethyl) glycine as Roundup® 41.0 percent SL); dicamba (3,6-dichlor-2-methoxybenzoic acid as Banvel CST® 10.6 percent SL); picloram + 2,4-D (4-amino-3,5,6-trichloropicolinic acid + 2,4-dichlorophenoxy acetic acid as Tordon-101® 5.4 percent SL); or hexazinone (3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1H,3H)-dione) as Velpar L® 25 percent SL) (Zedaker and others 1987). Thus, the hardwood reduction and pine response reported for treatments 3 and 4 represent an average response for all these herbicides.

Treatment 4 plots received a pine release in March 1985. Plots were randomly split so that each half received a basal bark spray or a soil-applied herbicide release treatment. The basal-bark-spray release method consisted of 4 percent triclopyr (ester) (as Garlon-4® 61.6 percent EC) diluted with diesel fuel and applied with a backpack sprayer. The mixture was applied to the bottom 6-8 inches of treated stems until runoff. All stems within 3.3 feet of loblolly pine seedlings were treated. An average of 0.36 gallons of triclopyr and 8.8 gallons of diesel fuel were used to release 526 loblolly pines per acre. An average of 4.7 man-hours was required to treat one acre. The soil-active herbicide was applied as 50 percent hexazinone as Velpar L® 25 percent SL in water with a spotgun. The mixture was applied in six evenly spaced 0.084-ounce (2.5 ml.) spots arranged in a 3.3-feet-radius circle around each loblolly pine seedling. An average of one gallon of hexazinone was used to release 526 loblolly pines per acre. The time required to treat one acre averaged 2.7 man-hours. For this report, the data for the different herbicide release plots were combined and represent the mean response of low-input release treatments.

Sampling Procedures

To evaluate the effects of site quality, harvest date, and regeneration treatment, two 32.8 x 32.8-feet measurement plots were located within each split-split-plot. All stems 2 inch DBH were measured for

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diameter and height. In each measurement plot two 6.6 x 6.6 feet nested plots were randomly located to measure stems 2 inch DBH. The height and crown diameter of all rootstocks in these nested plots were measured. Species-specific regression equations developed by Zedaker and others (1987) were used to convert crown volumes of hardwood root stocks to basal area at breast height. Statistical analyses were performed using SAS procedures for general linear model analysis of variance.

RESULTS AND DISCUSSION

Five years after establishment, harvest timing and low input regeneration treatments have resulted in significantly different stand conditions. Stands harvested in the growing season, without subsequent herbicide treatment, carry about half of the hardwood basal area of those harvested in the dormant season (table 1). The addition of pines to the naturally regenerated hardwood stands has had little impact on hardwood basal area to date. Stump treatment with herbicides resulted in an average basal area reduction of 63 percent. Another 60 percent average reduction occurred as a result of backpack-applied herbicide release treatments. Pine

regeneration treatments had minor effects on hardwood species composition (table 2). Differences in susceptibility of the hardwood species to the herbicides used would account for most of these changes. For example, half of the plots released in 1985 were treated with hexazinone. Yellow-poplar, which increased in basal area composition 14 percent from stump-treated to stump-treated and released plots, is known to be resistant to hexazinone.

Pine basal area increased significantly with increasing herbicidal control of regenerating hardwoods (table 3). Pine basal area in stump-treated and released plots was an order of magnitude greater than that for non-herbicided plots in stands harvested during the dormant season. Harvesting low-quality hardwood stands during the growing season alone accounted for an average increase of over 200 percent in pine basal area. Rescheduling dormant season harvests to the growing season would be as beneficial in increasing pine basal area as stump treatment and subsequent release. The growing-season-harvested, planted-pine plots averaged 88 percent of the basal area of dormant-season-harvested, stump-treated, and released plots. Still, low-input herbicide treatments resulted

Table 1. Summary of hardwood basal area by season of harvest and regeneration treatment five years following clear felling of Virginia Piedmont hardwood stands[1]

REGENERATION TREATMENT	HARVEST SEASON		
	Dormant	Growing	Mean
	- - - - - - (sq. ft./ac.) - - - - -		
Clearcut	50.8	26.2	38.5
Clearcut, Pine	57.1	24.7	40.9
Clearcut, Stump Treat, Pine	15.0	15.1	15.1
Clearcut, Stump Treat, Pine, Release	6.5	5.3	5.9
Mean	32.4	17.8	--

[1]Significance of main effects: Harvest   p = .26
Treatment   p = .005

Table 2. Relative hardwood basal area composition by regeneration treatment five years after clear felling of Virginia Piedmont hardwood stands.

	REGENERATION TREATMENT			
SPECIES	Clearcut	Clearcut, Pine	Clearcut, Stump Treat, Pine	Clearcut, Stump Treat, Pine, Release
	- - - - - - - - - - - -(pct) - - - - - - - - - - - - -			
Red Maple	32	33	26	38
Yellow-Poplar	25	21	9	23
Sourwood	13	16	19	8
Chestnut Oak	13	13	3	12
White Oak	4	5	8	2
Scarlet Oak	1	2	5	2
Black Cherry	2	<1	12	7
Black Locust	<1	<1	6	3
Other	9	8	12	5

Table 3. Summary of pine basal area by season of harvest and regeneration treatment five years following clear felling of Virginia Piedmont hardwood stands[1].

	HARVEST SEASON		
REGENERATION TREATMENT	Dormant	Growing	Mean
	- - - - (sq. ft./ac.) - - - -		
Clearcut	--	--	--
Clearcut, Pine	0.4	3.9	2.1
Clearcut, Stump Treat, Pine	1.3	5.3	3.3
Clearcut, Stump Treat, Pine, Release	4.4	11.4	7.9
Mean	2.0	6.9	--

[1]Significance of main effects: Harvest   p = .02
Treatment p = .001

in large significant increases in pine dominance. Spending $10 to $15 per acre for stump treatment resulted in a 43 percent increase in pine basal area. An additional investment of $45 to $55 for backpack release resulted in an additional 140 percent basal area increase. Clearly, the 2,700 percent difference in the range of pine response between the poorest and the best treatment/harvest combination leaves ample room for customization or optimization in stand pine-hardwood ratios (table 3).

Predicting future stand conditions from five-year-old data is tenuous at best. Hardwood basal area in the natural regeneration plots and in the pine planted but non-herbicided plots is 30 to 50 percent of its probable maximum for stands of moderate site index. The rate of hardwood basal area growth should be decelerating rapidly. Conversely, pines should just be approaching the point of rapid acceleration in basal area growth. Past experience tells us that, even in stands that were not stump-treated or stump-treated and released, pine basal area will increase dramatically relative to hardwood basal area. Exactly how much of an increase will occur is currently unpredictable but is probably dependent on site conditions and the current relative dominance of hardwood and pine species. The extent to which site conditions are favorable to the silvical characteristics of each tree species will determine much of the final outcome in stand dominance.

Harvest timing and regeneration treatments have already created differences in mean height (table 4). Mean pine height exceeds mean hardwood height in all cases except in non-herbicided, dormant-season-harvested plots. Reductions of hardwood height and basal area as a result of the herbicide treatments have resulted in significant increases in pine height. However, the mean height of many of the most dominant hardwood species still exceeds that of the pines (table 5). The mean height of sourwood, the third most dominant species, exceeds that of loblolly pine in all but the stump-treated and released plots. Black cherry and black locust are also keeping pace in many of the stands. If pine domination is desired, release is necessary to insure that no hardwood species are taller than the pines.

Table 4. Summary of mean loblolly pine and hardwood heights by season of harvest and regeneration treatment five years following clear felling of Virginia Piedmont hardwood stands[1].

REGENERATION TREATMENT	HARVEST SEASON					
	Dormant		Growing		Mean	
	Pine	Hardwood	Pine	Hardwood	Pine	Hardwood
	- - - - - - - - - - - - (ft.) - - - - - - - - - - - - -					
Clearcut	--	5.6	--	4.8	--	5.2
Clearcut, Pine	5.3	6.3	8.5	5.9	6.9	6.1
Clearcut, Stump Treat, Pine	6.4	5.1	9.0	4.5	7.7	4.8
Clearcut, Stump Treat, Pine, Release	8.7	2.3	10.8	2.1	9.8	2.2
Mean	6.8	4.8	9.4	4.3	--	--

[1]Significance of effects: Harvest: pine p = .02, hardwood p = .17.
Treatment: pine p = .02, hardwood p = .001.

Table 5. Mean height of dominant hardwood species by regeneration treatment five years after clear felling of Virginia Piedmont hardwood stands.

| SPECIES | REGENERATION TREATMENT | | | |
	Clearcut	Clearcut, Pine	Clearcut, Stump Treat, Pine	Clearcut, Stump Treat, Pine, Release
	- - - - - - - - - - - - - (ft.) - - - - - - - - - - - - -			
Red Maple	5.8	6.6	4.7	1.7
Yellow-Poplar	5.4	5.1	4.7	2.3
Sourwood	9.2	10.5	8.8	2.4
Chestnut Oak	4.9	6.4	4.3	2.4
White Oak	4.7	5.2	4.7	2.1
Scarlet Oak	2.8	3.1	3.9	1.6
Black Cherry	8.1	5.9	8.4	4.4
Black Locust	7.8	8.6	8.6	4.2

In the first five years following harvest, hardwood regeneration development has been extremely vigorous, averaging nearly 8 square feet of basal area per acre per year, and the dormant season harvest having twice the hardwood basal area as growing-season-harvested sites. When compared to pre-harvest stand composition, there is a significant increase in the red maple composition at the expense of the more desirable oak species. In the pre-harvest stand the oaks represented about half the total basal area (Kays and others 1985). Five years following harvest the oaks represent less than 20 percent of the total basal area. Sourwood is a dominant species in terms of height; however, as the stand closes it is expected that it will quickly lose its present height advantage and assume an intermediate or perhaps co-dominant canopy position.

CONCLUSIONS
The study has demonstrated that by using appropriate combinations of harvest season, herbicide stump treatment at the time of tree felling, and post-planting herbicide release of pine, it is possible to develop forest stands composed of mixed hardwoods, hardwood-pines, pine-hardwoods, or plantations dominated by loblolly pine. These various species mixes are achieved with minimal costs and environmental perturbations. What remains is to quantify and optimize yield responses that can be obtained from these low-input methods to create mixed hardwood-pine stands.

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CONVERTING LOW-QUALITY HARDWOOD STANDS TO PINE-HARDWOOD MIXTURES

Charles E. McGee[1]

Abstract. — Low-quality hardwood stands on the Cumberland Plateau and Western Highland Rim of Tennessee were harvested by shearfelling and on-site chipping. Feasibility of introducing loblolly pine into these harvested stands with minimum or no site preparation is explored. The resulting pine-hardwood mixtures are now 11 and 7 years old. This paper describes these mixtures, evaluates the pine and hardwood components, and discusses some of the problems and opportunities associated with pine-hardwood mixtures. Current composition, freedom to grow, and general outlook for further development are considered. An intensive harvest as provided by the shearing is clearly an important factor in the low-cost conversion of poor hardwood stands to pine-hardwood mixtures.

INTRODUCTION

Low-quality hardwood stands on the Cumberland Plateau and the Western Highland Rim are good candidates for either conversion to pine or for natural regeneration to mixed hardwoods. These stands also offer good opportunities for planted pine-natural hardwood mixtures. The purpose of this paper is to describe the development of pine-hardwood mixtures following intensive harvesting, limited site preparation, and the planting of loblolly pine.

An approach to mixed stand development is prescribed by some of the philosophy that underlies our recent recognition of pine-hardwood mixtures as a management entity. The recognition by this symposium of the importance of the pine-hardwood type is a giant step forward in forest management. Ten years ago, when Dan Sims and a few others seriously began considering pine-hardwood mixtures, we were often met with open derision. The pine groups looked upon anyone that would tolerate, much less promote, a hardwood in a pine plantation as a heretic. The hardwood groups were not interested in pine as an opportunity. So it is with a great deal of personal satisfaction that I see this symposium called to order. Yet, we should not get so caught up in the euphoria of the moment that we overlook some silvicultural, ecological, and economic traps and pitfalls that may lurk in the pine-hardwood forest.

One trap is the temptation to classify as desirable those pine-hardwood mixtures that are only tolerable. In my paper today I will present some situations that are tolerable; these situations are probably not the most desirable development, and for some landowners, they may not even be acceptable. One key to tolerance of pine-hardwood mixtures is cost. For example, a landowner spending $250 per acre for site preparation is not likely to tolerate any invasion of hardwoods in the plantation. On the other hand, a landowner spending $30 per acre for competition control in pine conversion may tolerate many hardwoods and accept a pine-hardwood mixture. However, we should not confuse tolerance with desire. The landowner spending $30 per acre would usually desire a pure pine stand if he could get it for $30 but will accept or tolerate a mixture at that reduced cost.

Another trap involves extrapolating pine-hardwood results across site-quality zones. My data will show results that probably would not be achieved if the quality of the site were only slightly better. In our interpretations of pine-hardwood relationships we need to be as precise as possible with site-quality data, and when we cannot be precise we should be very careful with recommendations.

The successional status of pine-hardwood stands may also provide a high risk temptation. Some landowners may become so pleased with a pine-hardwood mixture that they will attempt to perpetuate the mixture. While flexibility of management is one of the great attributes of pine-hardwood mixtures, perpetuation of a precise mixture may be difficult and costly to accomplish. In many cases the maintenance of a stable mixture may be more difficult than moving the stand toward pure pine or pure hardwood.

A final pitfall is the temptation to use a pine-hardwood mixture as an excuse for having made poor site preparation. As we recognize the benefits of pine-hardwood mixtures, we should not let our increased tolerance for mixtures allow an increased

tolerance for poor workmanship in conversion areas where pure pine stands are a bonafide goal of the landowner.

The following discussion applies to pine-hardwood mixtures on the Cumberland Plateau and the Western Highland Rim. Complete descriptions of study areas and methods are available in earlier publications (McGee 1986, McGee 1980, Sims and others 1984).

STUDY METHODS
The Cumberland Plateau Study Area

The 40-acre study site, located on top of the Cumberland Plateau, supported a fully-stocked low-quality stand of mixed hardwoods. Due to shallow soils, burning, and high grading, most of the larger trees were culls.

The study area was separated into 1-acre plots. Six of these plots were designated for planting to loblolly pine. Site index for oak for the general area was estimated prior to logging to be about 60-65 feet at age 50. Site index based upon the height of the 11-year-old loblolly pine trees on the 6 plots ranged from 53 to 57 feet at 25 years. Desirable hardwood species on this area included the oaks, yellow poplar, black cherry, and hickory. Undesirable species for timber included red maple, dogwood, sassafras, and blackgum.

The harvest. Harvesting of the low-quality stand was by shearing with a Drott Feller Buncher to 4 inches dbh; skidding the trees to a central location; chipping the entire tree; and piling the chips for later removal.

The site preparation. Three of the six plots were randomly selected to receive a herbicide injection. Residual trees over 4 1/2 feet tall were injected with Tordon 101 in the spring following harvest. Later in the summer, trees that had escaped the injection were retreated. Control of residuals on these three plots was almost 100 percent effective. The untreated plots contained about 300 residuals between 1 and 4 inches dbh. The residuals occurred mostly in clumps.

The planting. Loblolly pines from a regional source were planted at a spacing of 8 x 10 feet. The planting areas constituted a subplot and the relationships of planted pines to natural hardwoods were based upon survival, growth and development within and between these 8 x 10 foot subplots. There were 143 subplots on each central 1/4-acre measurement area.

The Western Highland Rim Study Area

The 40-acre study area in Humphries County supported a fully-stocked, mixed-hardwood overstory with many intermediate stems and a wide variety of understory plants. Soils were mostly cherty and relatively shallow. Oak site index estimates on the area ranged from 57 to 74 feet at 50 years. Desirable timber species included the oaks, the hickories, black cherry, white ash, and yellow-poplar. Blackgum, red maple, dogwood, and sourwood were the most predominant undesirable timber species.

The harvest. The harvest was conducted in September and October 1980. All trees over 1-inch dbh were sheared and skidded to central locations for chipping. The shearing and skidding removed almost all standing woody vegetation from the study area.

The Planting. Loblolly pines were planted at a 10 x 10 foot spacng in March 1981 on 8 1-acre plots.

Site preparation to release the planted pines from encroaching hardwoods was planned for 4 of the 8 plots. However, to date no site preparation or release has been done.

In the interior of each 1-acre plot, 121 of the 10 x 10 foot subplots were established with a planted pine in each subplot center. The relationships of the planted pines to the natural hardwoods were based upon survival, growth, and development in these subplots.

RESULTS
Pine Establishment

Because the objective of the investigation reported here was to successfully introduce a component of loblolly pine into a cutover hardwood forest at moderate cost, then the goal must be judged successful. Survival rate of planted pines was above 75 percent on 13 of the 14 1-acre study plots. Clearly, pine dominance was related to the intensity of the harvest and the extent of site preparation.

On the 6 plots on the Cumberland Plateau, average heights of the planted pines after 11 years ranged from 24 feet to 31 feet (table 1). Site index ranged from 52 to 57 feet on a 25-year base. The pines on the 3 plots where the residual hardwoods were injected averaged 3 feet taller than those pines on the uninjected plots. On the injected plots 79 percent of the 8 x 10 foot subplots (planting spaces) contained a dominant pine. On the uninjected plots 57 percent of the subplots were occupied by a dominant pine (figure 1).

Table 1.--Development of the pine component by location and years following treatment

Location and treatment	Survival	Average diameter	Average height	Height of tallest 200 per acre	Free to grow
	percent	inches	feet	feet	percent
Cumberland Plateau:	------------------------11 years-------------------------				
Hardwood residuals injected	84	5.1	29	32	68
Hardwood residuals not injected	74	3.8	26	30	32
Highland Rim:	-------------------------3 years-------------------------				
Shearing	89	-	5.3	6.4	36
	-------------------------7 years-------------------------				
Shearing	86	-	15.9	18.3	91

On the 8 plots on the Western Highland Rim, average height of the planted pines after 7 years ranged from 13 to 18 feet (table 1). Sixty-nine percent of the 10 x 10 foot subplots (planting spots) contained a dominant pine (figure 2).

The Pine-Hardwood Mixture

In addition to the pines, a component of hardwoods grew in each plot (table 2).

On the 3 injected plots on the Cumberland Plateau, about 11 percent of the subplots contained a desirable and dominant hardwood. An additional 11 percent of the subplots contained a dominant and undesirable hardwood. These plots contained, in addition to the dominant hardwoods and planted pines, an average of 225 desirable and 195 undesirable hardwoods per acre at sizes greater than 1.5 inches dbh.

On the 3 Plateau plots that were not injected, 16 percent of the subplots contained a dominant regenerating hardwood classed as desirable. An additional 11 percent of the subplots contained a dominant desirable residual hardwood. Thus 84 percent of the subplots were occupied by a dominant loblolly pine or a dominant desirable hardwood. These plots also contained 330 desirable and 336 undesirable hardwoods per acre larger than 1.5 inches dbh.

Through the first 7 years the mixture of dominant pine and dominant hardwood appeared to be relatively uniform on the 3 plots on the Plateau that had the residual hardwoods injected. The 3 plots without injection did have clumps of hardwood residuals. Now, after 11 years, there is clumpiness
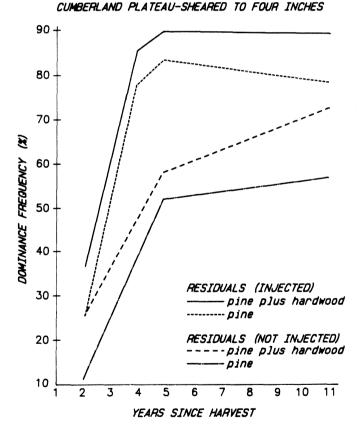
Figure 1.--Frequency of pine or pine plus a desirable hardwood being the dominant tree on 8 x 10 subplots (planting spots) on the Cumberland Plateau.

Table 2. Characterization of hardwoods, 1.6 inches dbh and larger, by location and years following treatment

Location and treatment	Desirable hardwoods			Undesirable hardwoods		
	Subplots where dominant	Average height	Hardwoods per acre	Subplots where dominant	Average height	Hardwoods per acre
	percent	feet	number	percent	feet	number
Cumberland Plateau	---------------------------11 years after treatment---------------------------					
Hardwood residuals injected	10.7	22.5	225	10.5	20.6	195
Hardwood residuals not injected	26.8	29.0	330	15.9	22.3	336
Highland Rim	---------------------------7 years after treatment---------------------------					
Shearing	21.8	14.4	169	9.2	11.7	22
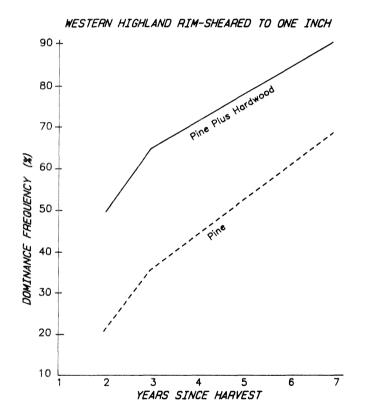
Figure 2.--Frequency of pine or pine plus a desirable hardwood being the dominant tree on 10 x 10 subplots (planting spots) on the Western Highland Rim.

on all of the plots. Therefore, instead of a genuine mixture of individual pines and hardwoods, the outlook is for a mixture of clumps.

On the Western Highland Rim plots, about 22 percent of the 10 x 10 foot subplots are occupied by a dominant and desirable hardwood. About nine percent of the subplots are dominated by an un-

desirable hardwood. In addition to the dominant hardwoods, 169 desirable and 22 undesirable hardwoods per acre larger than 1.5 inches dbh are supported by these plots.

DISCUSSION

The hardwood component amid pine plantations established in cut-over forests is influenced by a wide array of factors. Site preparation, site quality, harvest intensity, the original hardwood population and pine spacing are chief factors. In the cases just described, intensive harvest, minimal or no site preparation, and mediocre site quality have allowed the development of pine-hardwood mixtures.

From several standpoints the plots on the Plateau that received no site preparation are of considerable interest. These plots were harvested by shearing to a 4-inch diameter limit, which is a practical and achieveable harvesting goal in many locations. The only cost to the landowner was that for loblolly seedlings and planting. What is the outlook for these 11-year-old plots?

For the past 6 years, more than 50 percent of the planted pines in these plots have maintained dominance on the 8 x 10 subplots and are mostly free-to-grow (figure 1). Thus, 250-300 pines per acre can be projected to be codomiant at about age 20 and about 250-300 pines will have died or become hopelessly suppressed. The average diameter of the dominant pines after 11 years was about 4 inches dbh. By age 20, diameters of the dominant pines should range from about 5 to 10 inches dbh. Based upon these rough projections, the earliest the pine in these plots could be thinned would be about age 26-28 when the smaller dominant pine would be about 6 inches dbh.

On these plots, the hardwoods consist of two populations: the residuals, which were up to 4 inches dbh at the time of logging, and the natural hardwood regeneration, which resulted directly from the harvest cut.

Desirable residuals include the oaks, a few black cherry, occasional yellow-poplar and some hickories. Some of these residuals are 10 inches dbh and 45 feet tall. They occur mostly in clumps. There are very few residuals of undesirable species that are dominant at this time. Although the quality of the residual hardwoods is medium to low, these trees will soon be a source of both hard and soft mast. Some of these trees will make tie logs or small sawlogs when the pines are ready for thinning in about 15 years.

The desirable hardwood regeneration has much greater potential for quality growth than the residual hardwoods. This new hardwood growth is dominant on 16 percent of the subplots. Quality sprouts of white oak, black oak, scarlet oak, a few black cherry and an occasional yellow-poplar average about 29 feet in height when they dominate a subplot. These trees range from 3-5 inches in diameter and should be large enough for thinning in 15 years.

Thus, about 27 percent of the 8 x 10 subplots are dominated by a desirable hardwood, about 16 percent by an undesirable hardwood and 57 percent by a loblolly pine.

The 8 1-acre plots on the Western Highland Rim were harvested to a 1-inch diameter limit. When this level of utilization can be achieved, great opportunities for low-cost regeneration occur. Seven years after planting, with no additional site preparation, the loblolly pine are dominant in 69 percent of the 10 x 10 subplots. The average height of all planted loblolly is 15.9 feet and the height of the tallest 200 per acre is 18.3 feet. Based upon current data, about 250 to 300 pines per acre will be codominant for at least the next few years.

The hardwood component on the Highland Rim plots consists entirely of regrowth following the harvest. Desirable hardwoods dominate 22 percent of the 10 x 10 subplots. Desirable hardwoods include white oak, hickory, white ash, yellow-poplar, other oaks, and black cherry. The average height of the dominant desirable hardwoods is 14.4 feet. The long-range outlook for these desirable hardwoods is fair to good. Site quality is adequate to produce some good sawtimber in a 60-80 year rotation. Undesirable hardwoods occupy 9 percent of the subplots and the average height of the dominant undesirable hardwoods is 11.7 feet.

A landowner would have a choice with the 7-year-old plots on the Highland Rim. Left alone these plots will probably maintain a pine-hardwood mixture. Probably less than half of the planted pines will be available for thinning at age 22-25. The dominant pine component could be increased and the potential pine yield increased with immediate cleaning and release. The cost of the treatment should be carefully weighed against the expected increase in value of the pine.

CONCLUSIONS

Intensive utilization of low-quality hardwood stands on the Cumberland Plateau and Western Highland Rim followed by planting of loblolly pine will produce a mixture of pines and hardwoods. The extent of the pine component will increase as the intensity of utilization or site preparation increases. Pine-hardwood mixtures on the mediocre sites discussed in this paper present landowners with considerable flexibility, but also require complex silviculture and management. The mixed stands described in this paper will probably not be considered ideal or optimum by many landowners. However, many landowners will accept or tolerate the mixtures because the cost of attainment can be quite low. These mixed stands provide species diversity and will continue to provide good habitat for a variety of wildlife. The economic value of the stands in the near future will depend upon markets for mediocre to low-quality hardwoods and pine pulpwood. The long-term prospects for producing mature pines and hardwoods are good. The maintenance of the pine-hardwood mixture beyond the first rotation by natural regeneration will be difficult and may not be a practical alternative.

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EARLY CROP TREE PRESENCE IN UPLAND PINE-HARDWOOD STANDS RELATED TO SITE QUALITY AND PREHARVEST STAND COMPOSITION

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Abstract. — Mixed stands of planted loblolly pine and natural-origin, upland hardwoods, 5-10 years old, that had been injected, clearfelled and burned to varying degrees were examined in the South Carolina Piedmont to determine the presence of potential crop trees. The stands ranged from old-field shortleaf pine to varying mixtures of shortleaf pine-upland hardwoods prior to regeneration. The stands were subdivided into two distinct site types and crop trees were related to preharvest stand composition and herbicide treatment effort. Site quality exerted a strong influence only on the height of hardwood crop stems, but not on any attributes of pine crop stems. The number and relative dominance of hardwood stems were negatively influenced by a high preharvest pine composition and herbicide effort. In areas of poor site quality as affected primarily by aspect, hardwood crop tree number was satisfactory (2-300 stems per acre), but height growth was uniformly poor, resulting in many potential crop tree stems being subordinate to the taller, planted pines which numbered 3-400 stems per acre.

INTRODUCTION

It has been estimated that 70 to 80 percent of all timberland in the South is held by non-industrial private owners (Phillips and Abercrombie 1987). This type of landowner typically has multiple goals for ownership of forest land (Fontenot and Martin 1974). Furthermore, most small private owners lack the capital needed to convert their existing holdings to intensive pine monoculture (Zahner 1982).

If demand for forest products continues and more forest land is removed from production, the large proportion of forest lands held by the small private owners will need to be as productive as possible, commensurate with the diversity of landowning objectives. It is vital for professional foresters to develop alternative strategies of management of these forests that are acceptable and affordable by the small private non-industrial forest owners.

Since multiple benefits are desired by most private landowners, the culturing of pine-hardwood mixtures in lieu of pine monocultures may be a viable alternative. Regeneration costs are reduced in such culture by about 50 percent, promising good net returns, while wildlife benefits are enhanced by increased browse for deer and increased diversity and cover for small game such as quail, turkey and rabbit (Phillips and Abercrombie 1987). Squirrels, deer, and turkey benefit from increased mast production and den sites provided by hardwood mixtures (Uhlig 1956). Pine-hardwood mixtures also provide the best natural protection against outbreaks of the southern pine bark beetle by increasing the distance between pines (Zahner 1982). Stroempl and Beckwith (1978) list other benefits occurring from interplanting or underplanting a

desirable species in a stand that is naturally developing, i.e., greater stability against mechanical and biological injuries, improved nutrient status, and increased aesthetic values.

Some aspects of pine-hardwood mixtures are in dispute or, at least, open to question. Phillips and Abercrombie (1987) cite as a disadvantage the reduced value of intermediate and harvest cuttings due to the lower valued hardwood component. Stroempl and Beckwith (1978) suggest that the return from the more valuable oak should outweigh possible reduction in pine production in their Canadian study of enrichment planting. Another disadvantage is the delay in thinning income (Phillips and Abercrombie 1987); however, as markets develop, many hardwood stems of a mixed pine-hardwood stand will eventually be as valuable for intermediate products as the pine (Zahner 1982). Owners may then be encouraged to improve low-quality hardwood stands by regenerating pine-hardwood mixtures with reduced cost for site preparation or release (Sims and others 1981).

Data on the amount, type, and growth rates of regeneration for both weed and crop trees as they relate to site quality and preharvest stand composition are needed to develop strategies for improving the quantity and quality of pine and hardwood crop trees on harvested upland stands. Clearfelling in hardwood stands does little to alter species composition (Zahner 1982). In addition, Trimble (1973) failed to demonstrate conclusive relationships between site quality and abundance or distribution of hardwood reproduction. In contrast, Smith (1979) reports that regenerated species composition is dependent on site quality or type of advanced reproduction, overstory competition and cutting intensity in central Appalachian hardwoods. The present study was undertaken to relate hardwood

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crop tree presence in developing pine-hardwood stands to easily determined preharvest stand conditions and site quality differences on upland Piedmont sites in South Carolina.

MATERIALS AND METHODS
In order to assess the effects of site quality and preharvest stand composition and treatment on the number and quality of crop stems, young stands of planted loblolly pine (Pinus taeda) and natural-origin upland hardwoods in the Southeastern Piedmont were sampled at nine locations on the Clemson University Experimental Forest near Clemson, SC. The preharvest stand compositions ranged from a moderately high density stand (90 ft^2 of basal area per acre) with 80 percent old-field shortleaf pine (Pinus echinata) to varying mixtures and densities of shortleaf pine-upland hardwoods. The stands had been clearcut, selectively injected at differing levels of effort to reduce undesired species and large stump sprouting and were clearfelled and burned prior to regeneration. Herbicide treatment effort ranged from 5 to 50 man hours per acre. Loblolly pine was planted at 8 X 10 feet spacing and averaged 70 percent survival. The stands ranged from 5 to 10 years old.

Measurements of tree height, diameter at 4.5 feet height, number of dominant stems per acre and crop tree status were taken on 5 one-hundredth acre plots located one-half chain apart on the good and poor sites at each location. Crop stem dominance potential was determined for the nine locations by calculating a dominance index based on the mean crop stem diameter for both the good and poor sites for hardwoods and pines divided by the overall stem diameter mean for the given location/site combination. Crop tree status was determined by species and site combinations, each tree being a crop tree or not (Zahner and others 1985). Crop trees were required to have all of the following characteristics: dominant or codominant canopy position, good stem form, and commercial species, e.g., loblolly pine (planted) or hardwoods of seedling or basal sprout origin consisting of southern red oak (Quercus falcata), northern red oak (Q. rubra), white oak (Q. alba), black oak (Q. velutina), yellow-poplar (Liriodendron tulipifera), and in the absence of more desirable species, water oak (Q. niger), scarlet oak (Q. coccinea), and chestnut oak (Q. prinus).

"Good" and "poor" site selection was based on a landscape ecosystem model developed by Jones (1988). This ecological approach to classification identifies sites with equivalent productive potential on the basis of the interaction of landform, soils, and vegetation (Barnes 1982). This site classification method essentially identifies a soil moisture gradient ranging from xeric, upland flats with thin,

clayey soils to mesic, lower slopes with northerly and easterly aspects and loamy soils. This study was confined to the intermediate and sub-xeric portions of the soil moisture gradient where site productivity is relatively low. Site index (base age 50 years) ranged from 70 to 80 for mixed oaks and from 60 to 75 for shortleaf pine. Study sites were restricted to the upper one-third slope position and soils were clayey with the clayey argillic horizon occurring within 12 inches of the soil surface. Aspect varied from northerly to southerly slopes. The "good" sites were northerly aspects and the "poor" sites were generally southerly aspects in this study.

Data were analyzed using the General Linear Models procedure with analysis of variance, and linear and nonlinear regression analysis procedures of the SAS statistical computer package (SAS 1985). Independent variables used in the analysis were previous stand basal area per acre (PBA), site quality (good vs. poor), man-hours per acre (MH) expended in site preparation or release activity prior to the planting of pine, and age of the young stands.

RESULTS AND DISCUSSION
Hardwood crop tree height was the variable most affected by site quality, whereas pine crop tree height was not affected (table 1). Site quality, as delineated in this study, had little effect on any of the other crop tree variables of either pine or hardwoods (table 1). However, pine crop trees were significantly larger, more numerous, and higher in dominance potential (as measured by dominance index in this study) than were hardwood crop trees on both good and poor sites (table 2).

Table 1.--Effects of site quality on crop tree characteristics in young pine-hardwood stands of the South Carolina Piedmont

Species	Variable[a]	Site Quality		Difference	
		Good	Poor		
Hardwood	Diameter (in)	1.8	1.7	0.1	NS
	Height (ft)	16.9	15.3	1.6	**
	Crop trees/ac	238	262	24	NS
	Dom. index	0.79	0.78	0.01	NS
Pine	Diameter (in)	2.6	2.7	0.1	NS
	Height (ft)	18.6	18.4	0.2	NS
	Crop tree/ac	393	344	49	NS
	Dom. index	1.16	1.19	0.03	NS

** Highly significant difference, alpha = 0.01.

NS No significant difference.

[a] Dominance index is the ratio of crop tree stem diameter to plot mean stem diameter.

Table 2.--Comparison of young pine and hardwood crop tree characteristics on good and poor sites in the Piedmont of South Carolina

	Good Site			Poor Site		
Variable	Pine	Hardwd.	Diff.	Pine	Hardwd.	Diff.
Diameter (in)	2.6	1.8	0.8 **	2.7	1.7	1.0 **
Height (ft)	18.6	16.9	1.7 **	18.4	15.3	3.1 **
Crop trees/ac	393	238	155 **	344	262	82 *
Dom. index	1.16	0.79	0.37 **	1.19	0.78	0.41 **

** Highly significant difference, alpha = 0.01.

* Significant difference, alpha = 0.10.

There were more hardwood crop trees per acre on the poor sites, but more pine crop trees on the good sites, though the differences were not statistically significant (table 1). This apparent site effect contributed strongly to the widening gap between numbers of crop trees of pine versus that of hardwoods on the good sites (table 2). The difference in all other crop tree variables (diameter, height, and dominance index) between pines and hardwoods, actually was least on the good sites, implying a greater response of the hardwood crop trees to site quality than that of the pines. Although this difference in responsivity is often noted, the reasons are obscure as the indeterminate pine should prove more opportunistic than the mostly determinate hardwoods (Zahner 1982). Perhaps the presence of the site responsive yellow-poplar among the mostly oak hardwood crop trees in this study provides some explanation for this site response anomaly. As the stands age, site conditions favor the pine crop trees over the hardwood crop trees, especially on the poor site type where the differences in size and number are greatest (table 2). With a density of 3-400 trees per acre and such a wide gap in diameter, height, and dominance potential (dominance index) at these ages (5-10 years), the pine crop trees will likely dominate the stand in another 10 years (by age 15-20 years). The hardwood crop trees show little indication of "catching up" with the pines with passage of time, i.e., differences have changed little in the 5-year time span between the youngest (5 years old) and the oldest (10 years old) stands in the study. This conclusion is reinforced by observation of some older (15-25 year old) mixed stands near the study sites, where the loblolly pine component has completely dominated most of the stands after crown closure occurred.

Size, number and dominance potential of pine and hardwood crop trees were not significantly linearly related to preharvest stand composition as measured by previous pine basal area. Number of hardwood crop trees per acre, however, showed a strong linear relation to previous stand basal area (PBA) (table 3). Crop tree size and dominance

were generally positively but not significantly correlated with PBA, although dominance index of hardwood crop trees was negatively correlated with PBA (table 3). There is little explanation for the reversal in the correlations except that one would logically expect all the hardwood crop tree characteristics to be negatively correlated with PBA, especially the number of crop trees per acre, because of the reduced potential for hardwood reproduction with increasing density of stand overstory. However, with an increase in overstory density there may be a decrease in size with an increase in number of hardwood stems in the understory of the stands. This increase in smaller stems also may be involved in the response to the herbicide site preparation-release effort.

Table 3.--Crop tree characteristics as related to previous stand basal area (PBA) and man hours of herbicide effort (MH) in young pine-hardwood stands in the South Carolina Piedmont

		Relation to PBA		Relation to MH	
Species	Variable[a]	Linear R value	Nonlinear R^2 value	Linear R value	Nonlinear R^2 value
Hardwood					
	Diameter	0.51 NS	None	-0.38 NS	None
	Height	0.30 NS	None	None	None
	Crop trees/ac	0.74 *	0.59 *	None	0.90 *
	Dom. index	-0.32 NS	None	-0.54 NS	None
Pine					
	Diameter	0.47 NS	None	None	None
	Height	0.50 NS	None	None	None
	Crop trees/ac	None	None	0.66 *	None
	Dom. index	0.44 NS	None	None	None

* Significant at alpha = 0.01

NS Not Significant at alpha = 0.10

[a] Where R or R^2 values were less than 0.30 and not significant at alpha = 0.10, no relationship was assumed between variables.

An analysis of the effects of the intensity of preharvest site preparation-release efforts as indicated by stand records of man hours expended per acre (MH) on number and size of crop trees produced mixed results. Release efforts appeared to both increase and decrease crop tree numbers. Hardwood crop stems increased as MH increased to 20-25 hours per acre, but then decreased with further release-site preparation effort. The range of MH in the stands was 5 to 50 hours per acre and graphical analysis indicated that, response to MH was non-linear. The effects of level of MH on one of the nine stands evaluated was confounded by earlier stand treatments, including beetle-killed pine removals and axe-girdling of hardwoods. When this questionable stand was deleted from the analysis, the non-linear relationship was strengthened significantly by fitting a third-degree polynomial, the cubic regression. The coefficient of determination for this equation is strong (R^2 = 0.898, p = 0.019) and lends credence to the assumption of non-linearity in the relationship (table 3). This inference is only logical if one assumes that at low MH (20-25 hours) mostly large stems or stumps are treated,

whereas, at high MH treatment is extended to an increasing number of smaller stems, thus reducing potential hardwood crop trees in the future stand.

As expected, the number of pine crop trees per acre was significantly and positively correlated with MH (R = 0.67 at alpha = 0.05). Another relatively strong but unexpected relationship was found in the positive and statistically significant correlation of the number of hardwood crop stems per acre with stand age (R = 0.58 at p = 0.099). This strong correlation suggests that almost all of the hardwood reproduction being examined in this study is seedling or small sapling origin, rather than large stump (4-10 inch diameter) sprout origin. Observations in the field favor this conclusion as many of the crop hardwood stems in the study areas are associated with small stumps (3 inches groundline diameter) or have no evidence of stumps at all.

The pattern of development of seedlings or small saplings released by the harvest of these stands is commensurate with a characteristic seedling or small sapling lag in development for several years followed by an increase of height growth (after 5-6 years) to reach a crop tree dominant stem status in the stand. There is also a relatively high proportion of crop-quality trees within the total number of dominant hardwood stems in the stands, e.g., 79-85 percent. This high proportion of crop-quality stems suggests either that the various degrees of post harvest burning have made a substantial contribution to the quality of sprout origin crop stems as suggested by Phillips and Abercrombie (1987) or that, again, most of the crop stems were of seedling or small sapling origin (the best "quality" stems) because many larger stems were in fact injected with herbicide prior to stand harvest. The smaller stems would have escaped herbicide application due to their number and size at the time the site preparation-release work was done, and after overstory removal, clearfelling and/or burning would have been released to provide a major proportion of the hardwood reproduction.

Following harvest, most desirable natural hardwood regeneration develops from stump sprouts (Sims and others 1981). Rot is not as significant in sprout-origin stems as once was thought (Smith 1979) and the incidence of decay is less in basal sprouts originating close to the ground which can be encouraged by prescribed fire following harvest (Augspurger and others 1987; Phillips and Abercrombie 1987). Growth rates of stems of sprout origin, however, are usually impressive. Height and diameter of yellow-poplar and red oak sprouts can be as much as double that of seedlings at age 12 (Smith 1979). Small stumps are still the most desirable coppice regeneration since they tend to produce a minimum number of sprouts and

still give rapid height growth (Augspurger and others 1987). In the oak-pine region of the Southeast, Zahner (1982) reports that oak sprout regeneration grows more rapidly than pine for the first 10-20 years following establishment, but loblolly pine eventually outgrows even the best oak stems by 10 to 20 feet in height by age 50 years on good sites. In the present study, however, the planted loblolly pines are already well ahead of the hardwoods.

CONCLUSIONS
The fact that a high proportion of the dominant hardwood stems in this study are crop-quality, but are so far behind the planted pine crop stems at this stage suggests that they are in fact of seedling or very small sapling sprout origin. The use of herbicides to reduce large stump sprouting may have contributed to this condition. Also, despite the fact that "good" and "poor" sites were delineated in each stand, the overall site quality is poor, as suggested by the essentially sub-xeric classification of these sites by Jones (1988). Perhaps the stands chosen are not well-suited for hardwood crop tree development and are essentially "pine" sites as the future is likely to prove. Nonetheless, the presence, at these ages (5-10 years), of a reasonable number of hardwood crop tree stems per acre (2-300) in a "free to grow" status is encouraging in view of their substantial contribution to the desired diversity and achievement of the multiple use objectives of such stands. The importance of the hardwood crop trees in the future of these stands may well depend on the spacing of the dominant pines. Obviously, the wider the pine spacing the more likely the hardwood crop stems will remain in at least a codominant canopy position. At a pine stocking much higher than the 300 or so stems per acre observed in this study, the hardwood crop stems are likely to be relegated to a midstory role in the future.

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A COMPARISON OF LOBLOLLY PINE GROWTH AND YIELD ON PURE PINE AND MIXED PINE-HARDWOOD SITES

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Abstract. — The case histories of four loblolly pine (Pinus taeda L.) sites were examined to determine if differences in growth and yield could be associated with stand type. The stand types were pure loblolly pine and mixed loblolly pine-hardwood. All sites were located on silt loam soils, and mechanical site preparation was carried out on all sites before regeneration. The pure loblolly pine sites had greater rates of individual tree growth and yielded more inside-bark volume per acre than pine trees on the mixed loblolly pine-hardwood site. Pure loblolly pine yielded approximately 830 to 1,520 ft^3/ac 9 years after site preparation. In contrast, loblolly pine trees on the mixed pine-hardwood site yielded only 152 ft^3/ac after 9 years.

INTRODUCTION

A vegetation management study was established within a mixed loblolly pine (Pinus taeda L.)-hardwood stand in 1984. Almost all the pines in this stand appeared to have a very slow growth rate, even the larger sapling loblolly pine trees. It was concluded that interference from the hardwood trees and shrubs was the most likely reason for the slow diameter and height growth of these pine trees (Bacon and Zedaker 1987, Clason 1984, Glover and Dickens 1985, Haywood 1986), and the severity of hardwood competition partly resulted from a series of management errors that often occur when regenerating lands to loblolly pine (Haywood 1988). Because several data sets were available from pure loblolly pine stands, a decision was made to examine differences in growth and yield associated with stand type.

The purpose of our comparison was to determine if growth and yield differences existed among four independently established field studies. Differences would suggest that forest managers may have to accept a curtailment in pine growth and yield at the beginning of the rotation when managing mixed loblolly pine--hardwood in the West Gulf Coastal Plain, thus eliminating early commercial thinnings.

DATA SELECTION AND PRESENTATION

Inherent differences among sites, climate differences among growing seasons, and differences in genetic quality of the regeneration make it difficult to compare the case histories of independently established research studies. Our analysis was limited to plots established on silt loam soils in order to eliminate as many of these confounding factors as possible. Four data sets were used to represent a full range of stand types: two sites of pure loblolly pine planted on open-range maintained by fire and livestock grazing (Haywood 1983, 1980), one site of pure loblolly pine that had become sucessfully established despite interference from successional woody vegetation (Haywood and Burton 1989, Haywood and others 1981), and one site representing a mixed loblolly pine-hardwood stand (Haywood 1988). Mechanical site preparation had been carried out on all sites before regeneration. For all sites, stand age was referenced to the first growing season after site preparation because the exact age of individual trees in the mixed loblolly pine-hardwood stand was not known, and rotation length is an important economic consideration. Three of the four sites were located in Rapides Parish, Louisiana, and the fourth site was located in Drew County, Arkansas. All loblolly pines growing on a single site were similar in size and yield, so plot data were averaged for each of the four sites. Sampling age and tree size differed among sites, which precluded formal statistical analysis (Walstad and Kuch 1987). For each site, Schmitt and Bower's (1970) formula was used to calculate the inside bark volume for each pine tree at least 4.5 ft tall.

METHODS AND PROCEDURES

Sites I and II

Sites I and II (pure loblolly pine) were located on a cutover longleaf pine (P. palustris Mill.) site in Rapides Parish, Louisiana, that had been maintained as an open range. The growth of bluestem (Andropogon spp.) had been favored by periodic burning and grazing. The woody plant component consisted of small scattered southern bayberry (Myrica cerifera L.), post oak (Quercus stellata Wangenh.), and blackjack oak (Q. marilandica Muenchh.). At Site I, the soils were Beauregard

(Plinthaquic Paleudult, fine-silty, siliceous, thermic) and Caddo (Typic Glossaqualfs, fine-silty, siliceous, thermic) silt loams. At Site II, the soils were Acadia (Aeric Ochraqualf, fine, montmorillonitic, thermic), Beauregard, and Kolin (Glossaquic, Paleudalf, fine-silty, siliceous, thermic) silt loams. The silt loam soils at both Sites I and II were moderately to highly productive for loblolly pine, with site indices of 85 to 90 feet at 50 years (Kerr and others 1980).

Prior to plot establishment, Site I was prescribe burned, and the woody vegetation was cut and removed at both sites. Site preparation treatments of harrow or harrow-bed were applied 6 months before planting at Site I and 4 to 6 months before planting at Site II. Bare-root 1-0 loblolly pine seedlings were planted by hand at a 6- by 8-ft spacing in February 1962 at Site I and in February 1964 at Site II. Because hardwood trees and shrubs were not a significant component of the vegetation during these studies, hardwood interference with the planted pine trees was considered minimal at both sites.

Diameter at breast height (d.b.h.) and total height of loblolly pine trees were measured 5, 10, and 13 years after site preparation at Site I and 5, 10, and 15 years after site preparation at Site II. Both the harrow-only and harrow-bedding treatments had similar loblolly pine tree growth and yield for each of the two sites. Therefore, the loblolly pine tree data from both treatments were combined before constructing the case histories for Sites I and II.

Site III

Site III (pure loblolly pine) was an upland hardwood sawtimber site in Drew County, Arkansas. Before logging, the dominant and codominant hardwoods were sweetgum (Liquidambar styraciflua L.), white oak (Q. alba L.), willow oak (Q. phellos L.), water oak (Q. nigra L.), and hickory (Carya spp.). The timber was clearcut in 1970 and 1971. After logging, the site averaged at least 500 hardwood stems 1 inch or larger in d.b.h. per acre, with a basal area of more than 20 ft^2/ac before site preparation. The soils were Calloway (Glossaquic Fragiudalf, fine-silty, mixed thermic) and Henry (Typic Fragiaqualf, coarse-silty, mixed thermic) silt loams (Larance and others 1976). These soils were moderately productive for loblolly pine trees with a site index of 80 ft at 50 years.

Mechanical site preparation (chop-burn and shear-burn) was carried out on the research plots the summer before planting in 1970. Bare-root 1-0 loblolly pine seedlings were planted by hand at a 6- by 8-ft spacing that winter. Hardwood trees and shrubs numbered 3,860 stems/ac 3 years after site preparation, and brush interference with the pine trees was considered severe on all plots for 7 years. However, 12 years after site preparation, the pine

trees had overtopped most hardwood competitors, and the brush was no longer an important portion of the basal area. Thus, hardwood interference was considered unimportant 12 years after site preparation.

The d.b.h. and height of loblolly pine trees were measured 7 and 12 years after site preparation. During these measurements, the pine trees were each classed as either potential crop trees or suppressed trees. Potential crop trees were pines that should reach merchantable size, were free-to-grow or intermediate, and had at least a 10-percent chance of capturing a place in the crown canopy. Suppressed trees were pines that were overtopped by other woody plants, with less than a 10-percent chance of capturing a place in the crown canopy. Loblolly pine trees from both the chop-burn and shear-burn treatments had similar yields 12 years after site preparation, so the pine data from both treatments were combined to construct a case history for Site III.

Site IV

Site IV (mixed loblolly pine-hardwood) was in Rapides Parish, Louisiana. The soil type was a Beauregard silt loam with a site index of 90 ft at 50 years for loblolly pine. The previous forest stand had been clearcut, which was followed by a chop and burn site preparation in the summer of 1978. In February 1979, the tract was direct seeded from a helicopter at a rate of 1 lb/ac of loblolly pine seeds. Conditions for direct seeding were good, but sufficient regeneration was not obtained. In February 1980, bare-root 1-0 loblolly pine seedlings were planted by hand into a tall grass cover at a 6- by 10-ft spacing. In December 1980, survival of the planted pines was 29 percent, but the site was considered 91 percent stocked (550 pine trees/ac) when natural, direct-seeded, and planted seedlings were combined. Six years after site preparation, the planting rows were undistinguishable, and the number of loblolly pines averaged 1,210 trees/ac, which was well above 100 percent stocking.

Six years after site preparation, hardwood trees at least 4.5 ft tall numbered 2,025 stems/ac at Site IV. Sweetgum, the most common hardwood, was in a mixture that consisted mainly of blackgum (Nyssa sylvatica Marsh.), red maple (Acer rubrum L.), southern red oak (Q. falcata Michx. var falcata), water oak, live oak (Q. virginiana Mill.), and post oak. Shrubs numbered 7,300 stems/ac. Blackberry (Rubus spp.) was common (1,600 canes/ac), as were several vines.

The d.b.h. and height of pine and hardwood trees were measured each year from the 6th through the 9th year after site preparation. Each pine tree was

classed as either a potential crop tree or a suppressed tree as at Site III. Data from the pine and hardwood trees were used to construct a case history for Site IV.

RESULTS

Site I

Volume growth of individual loblolly pine trees was very good on this cutover open range, although the total number of loblolly pines decreased by only 36 trees/ac from the 5th to 13th year after site preparation (table 1). Therefore, Site I was the most productive of the four sites based on the combination of good stocking and rapid growth of individual trees (figure 1). Mean annual increment (m.a.i.) was 345 ft^3/ac from the 5th to 10th year and increased to 372 ft^3/ac between the 10th and 13th year after site preparation. Total pine yield was 2,980 ft^3/ac after 13 years.
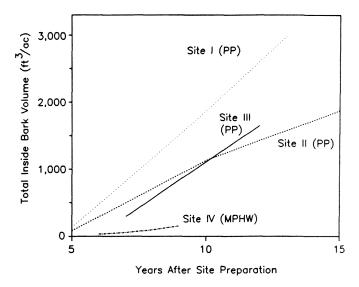
Figure 1.--The total inside bark volume per acre for loblolly pine trees at each site. Sites I, II, and III were pure loblolly pine (PP), and Site IV was mixed loblolly pine-hardwood (MPHW).

Table 1. Density and mean growth and yield of loblolly pine at least 4.5 ft tall on four sites in the West Gulf Coastal Plain.

Years after site preparation	Density	d.b.h.	Height	Average volume per pine
	trees/ac	inches	ft	ft^3
Site I[1]				
5	802	2.1	13.1	0.17
10	795	5.3	37.3	2.34
13	766	6.1	48.3	3.89
Site II				
5	756	1.6	10.7	0.11
10	703	4.8	30.0	1.61
15	662	5.7	37.9	2.83
Site III				
7	772	2.8	17.1	0.38
12	722	5.3	33.3	2.28
Site IV				
6	718	0.6	7.3	0.05
7	849	0.9	8.5	0.07
8	911	1.3	10.4	0.10
9	1,042	1.5	12.5	0.15

[1]Sites I, II, and III were pure loblolly pine, and Site IV was mixed loblolly pine-hardwood.

Site II

Individual loblolly pine tree growth was not as rapid at Site II, although the mortality rate was somewhat greater than at Site I (table 1). The m.a.i. was 210 ft^3/ac from the 5th to 10th year, but this decreased to 148 ft^3/ac between the 10th and 15th year after site preparation. Total pine yield was 1,873 ft^3/ac after 15 years (figure 1).

Site III

The stocking of loblolly pine trees was good despite interference from hardwood trees and shrubs during the first 7 years after site preparation (table 1). Once the pine trees were established, the growth rate increased, and the m.a.i. for all pine trees was 270 ft^3/ac from the 7th to 12th year. It is evident from figure 1 that the m.a.i. was less than the 270 ft^3/ac before the 7th year. Total pine yield was 1,641 ft^3/ac after 12 years (figure 1). Of the three pure loblolly pine sites, this was the least productive 7 years after site preparation, but by 12 years, Site III was producing more volume per acre than Site II.

Six percent of the loblolly pine trees were suppressed 7 years after site preparation; this comprised only 3 percent (8 ft^3/ac) of the total yield. After 12 years, 11 percent of the pines were suppressed because the canopy had closed, but suppressed trees still comprised 3 percent (49 ft^3/ac) of the total yield. The potential crop trees yielded 290 and 1,592 ft^3/ac 7 and 12 years after site preparation, respectively (figure 2).

Site IV

The number of loblolly pines on this site increased by 324 trees/ac from the 6th to 9th year after site preparation, and the mean size of the pine trees was much smaller than at the other three sites (table 1). The increasing number of pine trees had a negative influence on mean d.b.h., height, and volume per tree, so the mean growth of these trees was very slow for the 3-year period. Nevertheless, the m.a.i. for all pine trees was 39 ft^3/ac between the 6th and 9th year after site preparation, and total pine yield was only 152 ft^3/ac after 9 years. Clearly, the mixed loblolly pine-hardwood site was the least productive of the four sites for pines (figure 1).

The actual number of potential loblolly pine crop trees remained constant over the 3-year period, with an average stocking of 632 trees/ac. The number of suppressed pine trees increased from 101 to 425 from the 6th to 9th year after site preparation, showing that although many new pine seedlings and saplings were developing, the majority, if not all, remained as suppressed trees. After 6 years, 14 percent of the pine trees were suppressed, comprising 12 percent (4 ft^3/ac) of the total volume/ac, but after 9 years, 41 percent of the pine trees were suppressed, comprising 18 percent (27 ft^3/ac) of the total volume/ac. The potential crop trees yielded 31 and 124 ft^3/ac 6 and 9 years after site preparation, respectively (figure 2).

Both intraspecific and interspecific competition contributed to the low productivity of loblolly pine trees at Site IV. The loblolly pine regeneration often
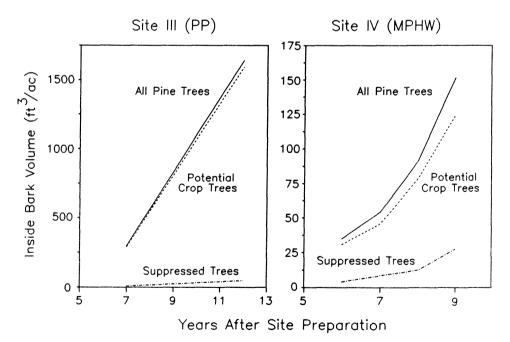
Figure 2.--The inside bark volume per acre for loblolly pine trees at Sites III and IV by three classifications: all pine trees, potential crop trees, and suppressed trees. Site III was pure loblolly pine (PP), and Site IV was mixed loblolly pine-hardwood (MPHW).

Table 2. Density and mean growth of hardwood trees at least 4.5 ft tall on Site IV, a mixed loblolly pine-hardwood stand.

Years after site preparation	Density	d.b.h.	Height
	stems/ac	inches	ft
6	2,025	0.5	7.5
7	1,998	0.6	7.8
8	2,829	0.7	9.0
9	3,206	0.7	9.9

formed clusters of pine trees. Consequently, the larger crop trees crowded or overtopped adjacent pines, and this slowed the diameter and height growth of the smaller trees. Conversely, because the intermediate or suppressed trees were growing so close to the larger pine trees, the diameter and height growth of the larger trees was also adversely affected. Interference from hardwood trees was also a factor. The number of hardwood trees at least 4.5 feet tall increased by 1,181 stems/ac from the 6th to 9th year after site preparation, due largely to ingrowth, and the average d.b.h. and height of these hardwood trees increased 0.2 inches and 2.4 ft, respectively, between the 6th and 9th years (table 2). There were also 1,559 hardwood trees/ac less than 4.5 ft tall and 7,102 shrubs/ac after 9 years.

DISCUSSION

The successful development of planted loblolly pine trees on Sites I and II was probably due to quick establishment of the regeneration where herbaceous plants were the most common competitors. Timely pine regeneration was also established at Site III, and quick establishment permitted planted seedlings to stay abreast of competing hardwoods and to eventually overtop the brush. Once the brush was overtopped at Site III, pine m.a.i. increased. Therefore, timely planting and successful establishment of seedlings after mechanical site preparation resulted in pure stands of loblolly pine trees without additional efforts to reduce competition from other species after planting.

On the other hand, Site IV became a loblolly pine-hardwood mixture primarily because the attempts at artificial regeneration by direct seeding and planting failed. This allowed the hardwood trees to gain a competitive advantage or equal status with the pine seedlings. The site was well-stocked with pine seedlings 2 years after site preparation because of natural loblolly pine regeneration. However, the pine trees at Site IV were clearly inferior in growth and yield to pine trees at the other three sites after a similar period of time.

After the direct seeding failed, planting of seedlings without additional site preparation resulted in further failure and was a poor investment. Although the site eventually became stocked by natural regeneration, the delay from failure of the artificial regeneration resulted in a mixed loblolly pine-hardwood stand.

These results suggest that artificial regeneration must be established quickly after site preparation, otherwise it is likely that the stand will become a mixed loblolly pine-hardwood stand. Such mixed stands result in curtailment of pine growth, and yield at the beginning of the rotation and early commercial thinnings may not be possible.

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EVEN-AGED MIXTURES OF CHERRYBARK OAK AND
LOBLOLLY PINE IN SOUTHWESTERN ARKANSAS

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Abstract. – Mixtures of cherrybark oak (Quercus falcata var. pagodifolia Ell.) and loblolly pine (Pinus taeda L.) were studied in southwestern Arkansas on minor stream bottoms to determine if these highly valued species could be managed together in even-aged stands. The management objective was to have pine pulpwood and sawtimber in short rotations and quality oak sawtimber in longer rotations. Two of the three studied stands were 34-year loblolly pine plantations established on old field sites. Volunteer cherrybark oaks had invaded these old fields a few years before pine planting. The third stand was a naturally regenerated oak-pine mixture over 100 years old. Site index for loblolly pine at all three sites averaged 95 feet at 50 years. Stem analyses showed that loblolly pine generally surpassed cherrybark oak in height and diameter. The few cherrybark oaks that were dominant were open-grown. The oaks, even though crowded and sometimes overtopped by pines, persisted in these stands, suggesting the possibility of an oak stand after a pine harvest. However, cherrybark oak form and bole quality were seriously compromised when grown adjacent to pine. Without intermediate silvicultural treatments to promote oaks and/or to alter spacings, mixtures of cherrybark oak and loblolly pine do not appear to be a feasible alternative on the studied sites for the production of high quality oak sawtimber.

INTRODUCTION

Mixed stands of oak-pine (Quercus spp.-Pinus spp.) exist on many Piedmont, Coastal Plain, and Interior Upland sites in the South. Most mixed stands are the accidental result of incomplete harvesting and site preparation, fire, or abandonment of farm land and pasture (Zahner 1982). However, such stands are often attractive alternatives to pure stands with regard to wildlife habitat (Sweeney 1980), aesthetics (McGee 1984), and timber production (Phillips and Abercrombie 1987). The benefits of mixed oak-pine stands have been reviewed (Zahner 1982; Sims and others 1981), however little growth and management information is available. The development and silvicultural potentials of even-aged mixtures of cherrybark oak (Quercus falcata var. pagodifolia Ell.), a species highly valued for sawtimber, and loblolly pine (Pinus taeda L.), a shorter rotation species grown primarily for sawtimber and fiber, are described in this paper.

STUDY AREA

Three even-aged stands containing mixtures of cherrybark oak and loblolly pine were examined in southwestern Arkansas (Clark County). These stands were located on the lower side slopes and terraces of minor streams in the Coastal Plain. Characteristics of the stands are described below.

Stands 1 and 2 were 34-year-old loblolly pine plantations established on old field sites with existing cherrybark oak volunteers. Whether the fields were pasture or row cropped and abandoned several years before planting is unknown. The spacing of pines both between and within rows was variable, ranging from 6 to 12 feet. No thinnings or cultural treatments have been done since planting. The stands are presently in the stand exclusion stage (Oliver 1981) with both loblolly pine and cherrybark oak in the dominant canopy. Oak species comprise 20 percent of the stand basal area.

Site index for loblolly pine (base age 50) in stands 1 and 2 was estimated to range from 82 to 87 feet (Hoelscher 1987). However, direct measurements indicate that these stands are much more productive, with dominant pines averaging 90 feet of height in 34 years. Although no candidate trees were available for measurement, the site index for cherrybark oak was estimated to be 94 feet at 50 years (Baker and Broadfoot 1979).

Soils of stand 1 are Gurdon silt loam (coarse-silty, siliceous, thermic Aquic Paleudults) or Urbo silty clay loam (fine, mixed, acid, thermic Aeric Haplaquepts) (Hoelscher 1987). Both soils are deep, somewhat poorly drained, and occasionally flooded; they developed in silty to clayey alluvium on 1- to 3-percent slopes.

The soils of stand 2 are Wilcox silt loam (fine, montmorillonite, thermic Vertic Hapluadalfs) (Hoelscher 1987). These soils are deep, somewhat poorly drained, and developed in clayey shale on 3- to 8-percent slopes.

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Stand 3 is a natural mixed oak-pine stand that is over 100 years old. Stand origin is unknown, but it was probably an abandoned old field that naturally regenerated to both pine and oak. A heavy thinning occurred in the early 1940's. Dominant oaks averaged 20 inches in dbh (diameter breast height) and 100 feet in height, while dominant loblolly pines were 24 inches in dbh and 110 feet in height. The stand is in the understory reinitiation stage (Oliver 1981), with loblolly pine and cherrybark oak comprising the dominant canopy. Understory vegetation includes hickories (Carya spp.), hollies (Ilex spp.), and hornbeam (Carpinus caroliniana Walt.). Oak species comprise 50 percent of the stand basal area. Soils are Gurdon silt loam (Hoelscher 1987), as previously described. Site index for stand 3 was similar to that of stands 1 and 2.

PROCEDURES

Ten plots were established in stands 1 and 2. Each plot contained a subject cherrybark oak as the plot center and included those trees interacting with it. An interacting tree was defined as any adjacent tree whose crown touched the crown of the subject tree or whose crown was above or below the edge of the subject tree crown (Smith and Lamson 1983). Plot size was, therefore, variable and irregular and ranged from 0.04 to 0.11 acre. The use of variable plot sizes with a subject tree as the plot center is common in studies of stand development (Oliver 1982; Clatterbuck and Hodges 1988). Data from the 10 plots in stands 1 and 2 were pooled because these stands were similar in site quality and age.

For a cherrybark oak to be selected as a subject tree, it had to be surrounded on three sides by loblolly pines. Subject trees were chosen from the dominant, intermediate, and suppressed crown classes. Codominant cherrybark oak trees were infrequent in these stands and were not sampled. The following data were recorded for all trees 4.0 inches in dbh on each plot: species, azimuth and distance of interacting trees from the cherrybark oak subject tree, crown class, diameter at 4.5 feet, total height, and log grade.

Stem analysis was conducted on the 10 cherrybark oak subject trees and on 8 interacting loblolly pines for reconstruction of height and diameter growth patterns. All trees were sectioned at 0.5 foot above ground and at 4-foot intervals thereafter along the bole to the tallest centrally located growing tip. The number of annual rings of each section was subtracted from the total age to determine the age of the tree when its terminal leader was at or near the height of each section. Heights were plotted over the corresponding ages to illustrate the height growth pattern of each tree. Diameter growth at 4.5 feet was determined by measuring the annual increment along four perpendicular radii. Height and

diameter data were analyzed using normal stand reconstruction procedures (Oliver 1982). Only mean height and diameter relationships are presented in this report, because the small sample size does not allow an adequate statistical test.

In stand 3, two dominant cherrybark oak plots were established similar to those described for stands 1 and 2. Stem analysis was not attempted on these older, large diameter trees. Increment cores were taken at 4.5 feet on each cherrybark oak subject tree and on an interacting dominant loblolly pine on each plot to determine age-diameter relationships.

RESULTS

The cherrybark oaks in stands 1 and 2 were volunteers that were 3 to 10 years older than the planted loblolly pines. Because they were older, the oaks had an initial height advantage over loblolly pines (figure 1). At the time of pine planting, the existing cherrybark oaks were already 18, 9, and 3 feet tall for dominant, intermediate and suppressed crown classes, respectively. However, the loblolly pines surpassed intermediate and suppressed oaks in height 10 years after planting and surpassed dominant oaks after 25 years. Diameter growth patterns (figure 2) are similar to the height growth patterns for dominant pines and intermediate and suppressed oaks. Dominant cherrybark oaks have maintained approximately a 4-inch diameter advantage over loblolly pines.
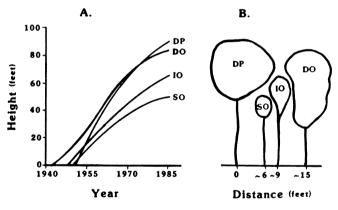
Figure 1.—A.--Mean height growth patterns of dominant (DO), intermediate (IO) and suppressed (SO) cherrybark oaks and associated dominant loblolly pines (DP).

B.-- Approximate distance of dominant, intermediate, and suppressed cherrybark oaks from competing dominant pines.
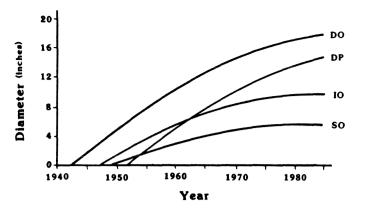
Figure 2.--Mean diameter (dbh) growth patterns of dominant (DO), intermediate (IO) and suppressed (SO) cherrybark oaks and associated dominant loblolly pines (DP).

The size and crown class of each of the cherrybark oak subject trees in stands 1 and 2 appear to be related to both the distance to the nearest interacting dominant or codominant loblolly pine and the age difference between the pine and the oak. For example, oaks became dominant only if they were 8 or more years older than the planted pines and at least 15 feet away from an interacting dominant pine. With increasing distance and age difference between the two species, there is a progressive increase in the size of cherrybark oak trees (figure 1). The irregular spacing and the small sample size in this study make it difficult to predict height and diameter growth of cherrybark oaks at varying distances from the pines.

Diameter growth patterns of oaks and pines in stand 3 (figure 3) indicate that the oaks were released in a partial cutting in the early 1940's. The two subject cherrybark oaks were 5 inches in dbh and 55 years old at the time of release and presently are 20 inches in dbh and 100 years old. The dominant loblolly pines have maintained a fairly steady rate of diameter growth at 2.7 inches per decade. In comparison, the cherrybark oaks averaged 3.5 inches per decade after release.

Even though height growth of cherrybark oak was not documented by stem analysis in stand 3, the height where the terminal leader resumed height growth after release from suppression may be deduced from the presence of crooks and forks on the dominant oak stems. For the subject trees, this height was 42 feet. The height growth pattern for these cherrybark oaks most likely resembles the suppression and release pattern shown in figure 3.
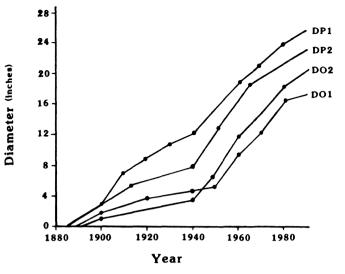
Figure 3.--Diameter growth (dbh) patterns of two dominant loblolly pines (DP1 and DP2) and two dominant cherrybark oaks (DO1 and DO2) from stand 3. There was a partial cut of loblolly pines in the early 1940's.

DISCUSSION
Pattern of Development

When cherrybark oaks grow in mixed stands with loblolly pines on these minor stream bottom sites in southwestern Arkansas, the pines eventually become taller than the oaks, even when the oaks are a few years older. Loblolly pines have a faster initial rate of height growth than cherrybark oaks, and the pines maintain this faster rate longer. As the pines increase their height advantage, they progressively influence and suppress more distant oaks. Thus the greater height growth rate of loblolly pines more than compensates for the initial height advantage of older oaks.

The only dominant cherrybark oaks on these sites were those that were approximately 8 or more years older than the planted pines, and had no pines growing adjacent to them. It is not known whether the growth advantage of these oaks resulted in the suppression and death of adjacent planted pines or if pines had not been planted close to these established oaks. The dominant oaks developed the attributes of open-grown trees: large crown volumes and short branch-free boles. Although pines will eventually be taller, the oaks will have larger diameters because they are older and/or their large crown volumes promote greater diameter growth.

Even though the pines are younger than adjacent oaks, their height and diameter growth patterns do not appear to be affected by the older oaks. For the first 34 years, height and diameter growth of dominant loblolly pines is almost linear. If pine coverage is adequate, pines will dominate the

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stand. Oaks dominate in those areas where they did not compete with pines. Removal of competing pines by thinning would be necessary to promote the retention and subsequent development of the oak component in these mixed stands.

Silvicultural Considerations

Data from this study suggest several silvicultural approaches for the establishment and management of loblolly pine and cherrybark oak mixtures. The fast initial height growth of pines and the slower overall growth of oaks indicate that these species should be widely spaced to keep oaks from becoming suppressed. Wide spacings would concentrate growth on the crop trees because the growth would not be restricted by adjacent trees. Although the rotation length for oak sawlogs would be shorter, there would probably be no intermediate harvests or income, and available growing space would be under-utilized early in the rotation. Rotations of 35 to 40 years under this even-aged unrestricted management approach would yield dominant cherrybark oaks and loblolly pines with average dbh's of 16 inches (figure 2). The unrestricted approach resembles the "free growth" technique, which has been used successfully with green pruning on oak stands in Great Britain to obtain high grade butt logs in a short time (Jobling and Pearce 1977).

If cherrybark oak and loblolly pine are closely spaced, the pines will eventually overtop and suppress the oaks. At least one thinning would be required to remove competing pines and favor oak growth. Distance to competing pines depends on when the thinning takes place, the size of competing pines that are removed, and whether more thinnings are planned. With close spacings, a two-stage system of timber harvest is possible in mixed oak-pine stands. The fast growing loblolly pine could be harvested in thinnings as pulpwood and small sawlogs, thus providing an intermediate income. The slower growing oaks would constitute the final harvest. This two-stage system is practiced in Europe with European oaks (Quercus spp.) and Norway spruce (Picea abies (L.) Karst.) or European larch (Larix decidua Mill.) (Penistan 1974).

Without silvicultural treatment to enhance the growth of cherrybark oak, most dominants will be loblolly pine. Oaks will either remain underneath pines in a suppressed condition or die. These oaks may respond to release if the overstory pines are harvested, as exhibited in stand 3. However, research with released cherrybark oaks after 5 years in east-central Mississippi suggested that intermediate and suppressed cherrybark oak trees are not good candidates for crop trees because of variable performance when released and because of reduced bole quality due to epicormic branches (Meadows 1988).

Bole Quality

Cherrybark oak requires strong lateral shading to develop long, straight, branch-free boles. The wide spacings required for cherrybark oak and loblolly pine mixtures on these minor stream bottoms promote cherrybark oak crown expansion at an earlier age and, therefore, shorter clear bole lengths. Lower branches are retained for a longer time, promoting larger branch diameters and making it more difficult for branch scars to heal once branches are shed, thus reducing log grade. Cherrybark oak log quality will improve somewhat with increased stem diameter; however, these logs will always have a core with large knots.

The height to th first live branch of dominant oaks in stands 1 and 2 averaged 25 feet, with many large surface knots and dead branch stubs on the lower bole. Additional clear bole length is diminished because of the retention of the large diameter lower branches. This reduced clear bole length is in contrast to cherrybark oak-sweetgum (Liquidambar styraciflua L.) stands, where sweetgum trees promote longer cherrybark oak clear bole lengths (to 50 feet), smaller branch diameters, and better log quality (Clatterbuck and Hodges 1988). Sweetgum acts as a "trainer" species that will naturally differentiate to crown strata below the oaks. There is no silvicultural reason to differentially harvest the sweetgum. In contrast, loblolly pine is a "competitor" species, similar to American sycamore (Platanus occidentalis L.) (Clatterbuck and others 1987), that competes vigorously with the oak crop trees.

A series of pine thinnings, if critically applied, could somewhat mimic conditions produced by trainer species. However, cherrybark oak under this scenario probably would not attain the exceptional bole quality associated with those grown with "true" trainer species.

SUMMARY
Cherrybark oak can be managed in mixtures with loblolly pine on minor stream bottom sites if initial spacings are wide or thinnings are planned to progressively harvest pines before the oaks become severely suppressed. Cherrybark oak requires ample growing space to develop, and because pine has a faster rate of height growth, pine tends to overtop and dominate the slower growing oaks at close spacings. Cherrybark oaks that were dominant had been open grown and had large crowns and short bole lengths. The pattern of stand development found on these sites may differ from other areas, depending on the physiology of the interacting species, their relative ages, the site, regeneration origin (seeds, sprouts, or advanced regeneration), initial spacing, and the age of the stand components.

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WILDLIFE

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WILDLIFE HABITAT QUALITY IN VARYING MIXTURES OF PINE AND HARDWOOD

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Abstract. — Five treatments, each replicated 3 times, were randomly assigned to fifteen 0.25 ha plots in a pine-hardwood stand on the Crossett Experimental Forest near Crossett, AR. Treatments consisted of mixtures of 100, 90, 80, 70, and 50 percent pine (Pinus spp.) growing stock with complementary proportions of hardwoods. All plots were thinned to 15 m²/ha basal area in 1983. From 1983 through 1985, annual production of total forage, woody plants, legumes, vines, and forbs did not differ by treatment. After hardwood regeneration was killed in 1985, annual production of ground-level vegetation (.5 m) was generally greater on the 100 percent pine plots than on the pine-hardwood mixtures. Forage production typically did not differ among the pine-hardwood mixtures during any year. Acorn production per oak (Quercus spp.) tree was not different among treatments. In 1988, percent cover of ground-level and shrub (1.5-5 m) layers was greatest in the 100 percent pine plots. Cover of midstory (5-10 m) and canopy (10 m) layers was greatest in the 50 and 70 percent pine plots favoring wildlife species dependent on these layers.

INTRODUCTION

Pine-hardwood forests are an important source of wildlife habitat in the United States, particularly in the South. About 40 percent of the nation's commercial forests are in the southern U.S and an estimated 15 percent of these 73.7 million ha are officially designated as mixed pine-hardwood stands (25 to 50 percent pine) (USDA Forest Service 1988). Yet, many upland southern forests have both pines and hardwoods present. In addition to providing wildlife habitat, these forests afford opportunities for recreational activities such as hunting, fishing, birdwatching, hiking, camping, and picnicking.

About 70 percent of the South's forests are owned by private, nonindustrial landowners (USDA Forest Service 1988), Although timber production is often the most important reason nonindustrial private landowners own forests (Porterfield and others 1978, Nabi and others 1983), most nonindustrial forest landowners have multiple-use ownership goals, with wildlife uses ranking high (Nabi and others 1983, Owen and others 1985). Multiple-use goals are reflected in the preference that many private, nonindustrial landowners have for pine-hardwood mixtures (Nabi and others 1983). Many publicly owned pine-hardwood forests are also managed for multiple resource values. For many landowners then, it is important to balance timber and wildlife values of pine-hardwood forests.

Although numerous studies have examined wildlife habitat in pine-hardwood stands (Schuster and

Halls 1963; Halls and Schuster 1965; Blair 1971; Blair and Brunett 1980; Hurst and others 1979; Fenwood and others 1984), there are few data evaluating habitat quality in stands with varying proportions of pine and hardwood. The objective of this study was to compare wildlife habitat quality in stands having a range of pine and hardwood compositions.

METHODS

The study area is located on the Crossett Experimental Forest near Crossett, AR. Using a completely randomized design, 3 replications of 5 treatments were assigned to 15 0.25-ha plots in a pine-hardwood stand. The stand is on a terrace adjacent to a small stream, and has a 50-year site index of about 30 m for loblolly pine (P. taeda). Loblolly and shortleaf (P. echinata) pines were dominant in the canopy and hardwoods were generally subordinate.

Treatments were 100, 90, 80, 70, and 50 percent merchantable (9 cm dbh) pine growing stock with complementary proportions of hardwoods (0, 10, 20, 30, and 50 percent). Merchantable-size trees on all plots were thinned to about 15 m2/ha BA during July 1983. In selecting hardwood trees to be left, oaks (Quercus spp.) were favored, and red oaks were favored 2 to 1 over white oaks. Many hardwood stems that were not merchantable-sized at the beginning of the study had become merchantable-sized by summer 1985. Therefore, during late summer 1985, hardwood trees in the 90, 80, 70, and 50 percent pine plots that were 2.5 cm dbh, but not marked as study trees, were killed by injecting with Roundup® herbicide. The 100 percent pine plots were treated with ground-applied Velpar® herbicide.

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Annually from 1983-1988, timber and wildlife habitat variables were measured on the interior 0.1 ha portion of each plot. Data were not collected on the 100 percent pine treatments during 1984 because of timber harvesting. The dbh of each tree was measured during fall or winter. Acorns were collected from oak trees 23 cm dbh from 1 September through 1 December using a bushel basket with a 0.15m2 opening was placed on the north side of each tree midway between the bole and the edge of the crown. During August, percent cover of ground-level (.5 m) vegetative species was estimated using 12 1-m2 subplots located on a grid in each 0.1 ha plot. Current-year growth (CYG) of woody plants, legumes, vines, grasses, forbs (including ferns and composites), and mushrooms was clipped on the subplots, oven-dried at 105 degrees C and weighed.

During August 1988, percent cover of ground-level, shrub (1.5-5 m), and midstory (5-10 m) layers were estimated at 30 sample points in each plot using 0.25m2, 2-m2, and 4-m2 subplots, respectively. Percent cover of the canopy (10 m) was estimated by taking 30 observations at each sample point with a spherical densiometer (Lemmon 1956). The percent cover of the ground, shrub, midstory, and canopy layers was used to calculate foliage height diversity (FHD) (MacArthur and MacArthur 1961) using the formula $H' = -\Sigma\ p_i\ \ln p_i$, where p_i = the proportion of cover in each layer.

One-way and two-way analysis of variance (with treatment and year as main effects) were used to evaluate differences in measured variables (Norusis 1988). Duncan's New Multiple Range Test was used to separate means. Analysis of covariance, with tree dbh as a covariate, was used to evaluate acorn production by treatment and year. Contingency table analysis and the chi-square statistic was used to evaluate associations between number of plant species, treatment, and year. Statistical significance was accepted at the 0.05 probability level.

RESULTS

During 1983, pines on the study plots averaged 42 cm dbh; hardwoods averaged about 25 cm dbh (table 1). By 1988, pines were about 46 cm dbh and hardwoods were about 27 cm dbh. Average dbh of pines and hardwoods did not differ by treatment during any year (p > 0.05). Tree growth on the plots is more fully described by Murphy and others (1989).

Ground-level vegetation

In each year of the study, the importance of individual ground-level species varied by treatment. However, the number of species categorized as woody, graminoid, legume, forb, and vine did not differ between treatments during any year

Table 1. Average stand characteristics for treatments after timber harvest in 1983 and 1988.

Stand characteristic	Percent pine basal area				
	100	90	80	70	50
	------------------ 1983 ------------------				
Pine					
no. trees/ha	98.5	108.5	63.6	74.8	41.2
dbh (cm)	46.6	39.1	47.8	45.5	48.5
basal area (m²/ha)	16.5	14.4	12.9	11.3	8.0
Hardwood					
no. trees/ha	3.7	71.1	78.6	116.0	205.8
dbh (cm)	3.1	21.4	24.9	24.9	22.3
basal area (m²/ha)	<0.1	2.9	4.5	5.9	8.5
	------------------ 1988 ------------------				
Pine					
no. trees/ha	89.8	104.8	63.6	74.8	41.2
dbh (cm)	49.5	42.0	51.1	48.5	51.1
basal area (m²/ha)	17.3	16.1	14.5	12.9	8.9
Hardwood					
no. trees/ha	3.7	71.1	78.6	116.0	187.1
dbh (cm)	3.7	24.0	27.5	28.1	25.2
basal area (m²/ha)	<0.1	3.7	5.4	7.3	9.9

Table 2. Average percent cover of ground-level (<1.5m) vegetative species over all treatments, 1983-1988.

Plant species[1]	Year					
	1983	1984	1985	1986	1987	1988
Woody Plants						
Acer rubrum	2.1	1.7	3.0	1.8	1.2	1.1
Callicarpa americana	0.7	0.6	1.8	3.0	1.0	1.0
Cornus florida	0.8	1.0	1.4	0.8	0.4	0.9
Liquidambar straciflua	1.5	1.1	1.1	0.9	<0.1	0.1
Nyssa sylvatica	1.2	0.6	2.0	0.8	0.3	0.2
Pinus spp.	0.1	2.7	1.6	1.9	5.2	3.4
Quercus alba	1.1	0.8	0.5	0.5	0.0	0.4
Q. falcata	0.0	1.0	0.1	<0.1	0.0	0.0
Q. nigra	1.1	0.0	0.0	0.0	0.0	0.1
Q. phellos	0.5	0.0	0.5	0.4	0.0	0.4
Quercus spp.	0.0	0.0	<0.1	0.5	0.8	0.4
Ulmus alata	1.3	1.3	0.5	0.4	0.5	0.3
Vaccinium spp.	4.8	1.9	3.5	2.0	1.0	2.1
Graminoids						
Chasmanthium sessiliflora	2.5	3.7	13.6	13.0	9.0	8.9
Panicum spp.	2.3	0.5	3.0	6.1	5.4	2.5
Vines						
Ampelopsis arborea	0.4	0.5	0.4	0.4	0.2	0.3
Berchemia scandens	1.6	0.9	1.0	0.9	1.4	1.0
Gelsemium sempervirens	0.6	0.2	0.3	0.4	0.9	1.1
Lonicera japonica	0.6	0.3	0.3	0.2	0.2	0.2
Parthenocissus quinquefolia	2.8	1.2	1.4	0.9	0.6	0.9
Rhus radicans	5.4	2.3	2.3	1.6	1.6	1.8
Rubus spp.	0.2	0.3	1.7	2.4	2.4	2.6
Smilax spp.	6.8	4.6	9.6	5.9	4.1	4.1
Vitis spp.	3.7	3.3	4.4	4.1	1.9	2.0
Forbs						
Elephantopus spp.	0.6	0.2	0.3	0.5	0.4	0.7
Erichtites hieracifolia	<0.1	0.3	0.4	1.5	0.4	0.4
Mentha spicata	0.1	0.0	0.1	0.5	0.6	0.4
Mitchella repens	1.9	0.7	0.7	0.4	0.8	1.1

[1] Includes only species with cover exceeding 0.5 percent during at least one year.

Species	Percent pine basal area				
	100	90	80	70	50
	----------- 1983 --------------				
Acer rubrum	1.7ab[2]	2.9b	2.9b	0.6a	2.2ab
Berchemia scandens	0.8a	4.2b	1.1a	0.8a	0.8a
Callicarpa americana	2.8b	0.1a	0.3a	0.1a	0.1a
Chasmanthium sessiliflora	4.6b	0.3a	2.3ab	0.4a	4.6b
Crataegus spp.	0.0a	0.7ab	0.8b	0.0a	0.1ab
Gelsemium sempervirens	0.0a	1.3c	0.8bc	0.7abc	0.1ab
Onoclea sensibilis	0.4b	0.0a	0.0a	0.0a	0.0a
Panicum spp.	2.1a	4.4b	1.4a	2.2a	1.5a
Sanicula canadensis	1.0b	0.3a	0.4ab	0.0a	0.4ab
Vitis spp.	7.4b	1.3a	3.6ab	1.9a	4.2ab
	----------- 1985 --------------				
Callicarpa americana	4.8b	1.5a	0.7a	0.9a	1.0a
Crataegus marshallii	0.0a	0.0a	0.6b	0.0a	0.0a
Elephantopus spp.	0.7b	0.7b	0.1ab	0.0a	0.1ab
Gelsemium sempervirens	0.8b	0.3ab	0.1a	0.0a	0.4ab
Panicum spp.	2.1a	1.1a	0.4a	10.1b	1.1a
Pinus spp.	1.9bc	0.7a	2.8c	0.9ab	1.8bc
Sassafras albidum	0.8b	0.0a	0.0a	0.0a	0.6ab
	----------- 1986 --------------				
Callicarpa americana	8.5b	2.1a	1.0a	2.7a	0.8a
Erichtites hieracifolia	6.0b	0.8a	0.1a	0.4a	0.1a
Galactia spp.	0.4b	0.0a	0.0a	0.0a	0.0a
Gelsemium sempervirens	1.5b	0.4a	0.0a	0.0a	0.1a
Oxalis spp.	0.4b	0.0a	0.0a	0.0a	0.0a
Panicum spp.	16.0b	2.8a	1.5a	8.3ab	1.7a
Pinus spp.	3.9b	0.7a	1.3a	2.1a	1.4a
Rhus radicans	2.6b	1.5a	1.1a	0.8a	1.7ab
Vaccinium spp.	4.9b	0.3a	2.2ab	0.8a	1.8ab
	----------- 1987 --------------				
Acer rubrum	0.7ba	1.3b	2.2c	0.5a	1.4b
Berchemia scandens	0.4a	1.9b	1.7b	1.4b	1.7b
Boehmaria spp.	0.0a	0.0a	0.2ab	0.7b	0.2a
Callicarpa americana	2.5b	1.2a	0.6a	0.5a	0.0a
Cassia spp.	0.2b	0.0a	0.0a	0.0a	0.0a
Cornus florida	1.5b	0.0a	0.7ab	0.0a	0.0a
Elephantopus spp.	0.8b	0.6ab	0.3a	0.3a	0.2a
Gelsemium sempervirens	1.1ab	1.4b	0.7ab	0.4a	0.8ab
Hamamelis virginiana	0.0a	0.0a	0.0a	0.0a	0.7b
Lespedeza spp.	0.3b	0.0a	0.1a	0.1a	0.0a
Mentha spicata	0.2ab	0.9bc	0.1a	1.3b	0.4ab
Mitchella repens	0.5a	0.8a	1.6b	0.4a	0.5a
Panicum spp.	10.6b	4.8a	3.1a	4.3a	4.1a
Parthenocissus quinquefolia	0.4a	1.2b	0.3a	0.6a	0.3a
Pinus spp.	7.1b	4.2a	5.3ab	4.7a	4.9a
Vaccinium spp.	2.8b	0.2a	1.1a	0.7a	0.1a
Zanthoxylem spp.	0.1a	0.3b	0.0a	0.0a	0.0a
	----------- 1988 --------------				
Berchemia scandens	0.2a	1.9c	1.3bc	0.8ab	0.8ab
Boehmaria spp.	0.0a	0.0a	0.1a	0.6b	0.0a
Callicarpa americana	2.6b	0.6a	0.7a	0.7a	0.4a
Cassia spp.	0.4b	0.1a	0.1a	0.0a	0.0a
Elephantopus spp.	1.2c	1.1bc	0.6abc	0.1a	0.4ab
Erichtites hieracifolia	0.7ab	0.9b	0.2a	0.2a	0.4a
Galium spp.	0.3b	0.1ab	0.1a	0.0a	0.1ab
Gelsemium sempervirens	1.7b	1.7b	0.8ab	0.7ab	0.5a
Hamamelis virginiana	0.0a	0.0a	0.0a	0.0a	1.3b
Hypericum spp.	0.2b	0.0a	0.2b	0.0a	0.0a
Mitchella repens	0.8ab	1.5bc	1.7c	0.2a	1.1abc
Osmanthus spp.	0.2b	0.0a	0.0a	0.0a	0.0a
Oxalis spp.	0.9b	0.3a	0.2a	0.0a	0.1a
Panicum spp.	4.8b	2.9ab	1.7a	2.6ab	0.6a
Quercus phellos	0.0a	0.7b	0.4ab	0.3ab	0.3ab
Quercus spp.	0.0a	1.8b	0.0a	0.0a	0.0a
Rhus radicans	3.4c	2.3bc	1.3ab	0.9a	1.3ab
Rubus spp.	5.9b	2.3a	2.5a	1.6a	0.9a
Vitis spp.	2.8b	1.6ab	3.2b	0.9a	1.6ab

[1] Ground cover did not differ for any species during 1984.

[2] Means with different letters within rows are different.

(p > 0.05). The number of ground-level species identified on each treatment also did not differ by year (χ^2 = 5.7, 16 df, p = 0.991).

During 1983, 46 species were identified on the study plots. In general, ground-level vegetation was dominated by greenbriars (Smilax spp.), poison ivy (Rhus radicans), blueberry (Vaccinium spp.), and grape (Vitis spp.) (table 2). Ground cover of 10 species differed by treatment (table 3). American beautyberry (Callicarpa americana) and sensitive fern (Onoclea sensibilis) covered greater ground area in the 100 percent pine plots than in the pine-hardwood mixtures. Cover of 8 species differed among the pine-hardwood mixtures. Rattan (Berchemia scandens), panic grass (Panicum spp.) and yellow jessamine (Gelsemium sempervirens) had greatest cover in the 90 percent pine plots. For the other 5 species there was no consistent pattern of differences among pine-hardwood treatments.

Although percent cover of individual species differed among treatments, production of total forage, woody plants, vines, legumes, forbs, fungi, and graminoids did not differ by treatment during 1983 (table 4). In general, production of total forage, woody plants, and graminoids was lower during 1983 than during other years. Legume production did not differ by treatment (p = 0.143) or year (p = 0.702), and averaged 0.7 kg/ha. Mushroom production was also not different by treatment (p = 0.839) or year (p = 0.767), and averaged 0.4 kg/ha. Mushrooms were found only on the 90, 80, and 50 percent pine plots and were found only during 1983 and 1987.

During 1984, after the plots were thinned, only 38 ground-level species were found. Greenbriars, Chasmanthium sessiliflora, grapes, and pines had greatest ground cover over all treatments (table 2). However, no ground-level species differed in cover between treatments. CYG of woody plants, vines, forbs, and graminoids also did not differ by treatment (table 4). Forb production was not different from production in 1983 (p < 0.01). CYG of woody plants, graminoids, and vines, and total forage, however, was greater than during 1983 (p < 0.05).

In 1985, graminoids, greenbriars, grapes, and blueberry dominated the plots (table 2). Over all treatments, Chasmanthium sessiliflora was the most important ground-level species, increasing 4-fold from 1984. Greenbriars doubled in cover compared to 1984. Although the number of species increased to 56, cover of only 7 differed among treatments (table 3). Cover of American beautyberry was greater in the 100 percent pine plots than in the pine-hardwood mixtures. Panic grasses were most abundant in the 70 percent pine plots. Hawthorn (Crataegus marshallii) was more abundant in the 80

percent pine plots than in other treatments. Production of total forage, woody plants, vines, forbs, graminoids, and legumes again did not differ by treatment (p < 0.05) (table 4). During 1985, CYG of total forage, woody plants, graminoids, and vines was greater than during 1984 (p < 0.05). Production of vines peaked during 1985.

Table 4. Average dry weight (kg/ha) of current-year growth for ground-level (<1.5 m) vegetation, 1983-1988.

Type of Vegetation	Percent pine basal area				
	100	90	80	70	50
----------------1983----------------					
Woody	19.4	50.3	65.3	50.0	52.2
Legumes	1.4	1.1	1.7	0.0	0.6
Graminoids	15.6	10.6	10.0	10.6	9.4
Forbs	4.4	5.6	4.2	3.9	3.9
Vines	85.8	43.3	133.1	85.8	86.7
Fungi	0.0	0.6	0.0	0.8	2.2
Total	126.7	111.4	214.2	151.1	155.0
----------------1984----------------					
Woody	--	75.3	74.4	42.5	141.1
Legumes	--	0.0	0.0	0.0	0.0
Graminoids	--	45.3	20.0	31.1	25.0
Forbs	--	2.5	2.8	0.0	4.4
Vines	--	157.5	88.1	111.9	168.1
Total	--	280.6	185.3	185.6	338.6
----------------1985----------------					
Woody	231.4	174.7	138.2	154.2	149.4
Legumes	0.9	0.8	0.0	0.0	0.8
Graminoids	191.6	201.7	106.1	289.0	311.8
Forbs	9.0	17.8	2.8	15.6	19.3
Vines	175.7	322.8	215.4	298.0	224.4
Total	606.9	717.8	462.4	756.3	705.7
----------------1986----------------					
Woody	467.9b[1]	108.0a	194.6a	114.8a	152.3a
Legumes	1.4	1.1	0.0	0.8	0.0
Graminoids	850.0b	245.0a	109.6a	274.4a	182.9a
Forbs	127.3b	23.5a	14.9a	10.9a	10.7a
Vines	245.7b	99.5a	160.0a	96.3a	131.9a
Total	1,692.4b	477.1a	479.1a	497.2a	477.8a
----------------1987----------------					
Woody	354.2b	63.6a	91.1a	45.8a	56.9a
Legumes	1.8	0.4	1.3	0.9	0.0
Graminoids	258.2	166.2	180.0	212.0	164.0
Forbs	16.4	25.8	17.3	42.7	14.7
Vines	86.7	98.7	88.4	50.2	62.2
Fungi	0.0	0.0	0.0	5.3	0.0
Total	717.3b	354.7a	378.2a	356.9a	297.8a
----------------1988----------------					
Woody	244.9b	111.1a	70.2a	41.3a	109.3a
Legumes	2.2	0.4	0.4	0.4	0.9
Graminoids	109.8b	58.2a	76.9ab	86.7ab	49.3a
Forbs	16.0	13.3	11.1	16.0	7.6
Vines	181.8b	118.7a	127.6ab	98.7a	91.1a
Total	554.7b	301.8a	286.2a	243.1a	258.2a

[1] Means with different letters within rows are different.

In 1986, following the injection and Velpar application, the number of species decreased to 49. In general, Chasmanthium sessiliflora, panic grass, greenbriar, grape, and American beautyberry were the dominant ground-level species. Cover of 9 species differed by treatment but no species differed in percent cover among the pine-hardwood mixtures (table 3). However, cover of pines, panic grass, American beautyberry, Galactia spp., fireweed (Erechtites hieracifolia), woods sorrel (Oxalis spp.), and yellow jessamine was greater on the 100 percent pine plots than on the pine-hardwood mixtures. CYG of total forage, woody plants, graminoids, forbs, and vines was also greater on the 100 percent pine plots than on the pine-hardwood mixtures (p < 0.05) (table 4). Forage production, however, did not differ among the pine-hardwood mixtures. CYG of total forage, woody plant, graminoids, and forbs peaked during 1986.

During 1987, graminoids, pines, and vines such as greenbriar, blackberry (Rubus spp.), grape, poison ivy, and rattan were dominant in terms of ground cover (table 2). Ground cover of 17 of the 62 species differed among treatments (table 3). Percent cover of flowering dogwood (Cornus florida), pines, American beautyberry, blueberry, lespedezas (Lespedeza spp.), partridge pea (Cassia spp.), panic grass, and elephant's foot were greatest on the 100 percent pine plots. Cover of only 6 species differed among the pine-hardwood mixtures. Ground cover of rattan, partridgeberry (Mitchella repens), Virginia creeper (Parthenocissus quinquefolia) and toothache-tree (Zanthoxylum americana) were greater on the 90 percent or 80 percent pine plots than on plots with less pine basal area. Coverage of witch-hazel (Hamamelis virginiana), spearmint (Mentha spicata), and false nettle (Boehmeria cylindrica) were greater on the 50 percent or 70 percent pine plots than on treatments with greater pine BA. CYG of total forage and woody plants was greater on the 100 percent pine plots than on the pine-hardwood mixtures (p < 0.05) (table 4); graminoid, forb, and vine production did not differ by treatment. Forage production did not differ among the pine-hardwood mixtures. Over all treatments, production of total, woody, forb, vine, and graminoid forage was lower than during 1986.

During 1988, Chasmanthium sessiliflora, greenbriar, pine, blackberry, panic grass, and blueberry were most prominent (table 2). Percent ground cover for 19 of 67 species differed by treatment (table 2). Cover for 7 of the 19 species was greatest on the 100 percent or 90 percent pine plots. Witch-hazel was the only species with greatest cover in the 50 percent pine treatment. Production of total forage and woody plants was greater on the 100 percent

pine plots than on the pine-hardwood mixtures (p < 0.05) (table 4). CYG did not differ among the pine-hardwood mixtures for any forage category. Graminoid, forb, and total CYG was less, but vine production was greater, than during 1987. Forage production in 1988 was, in general, not different from production during 1984.

Foliage height diversity

FHD during 1988 was greater in the 100 percent pine plots than in the pine-hardwood mixtures (p = 0.003) (table 5); FHD values did not differ among the pine-hardwood treatments. During 1988, ground cover was greater on the 100 percent pine treatment than on any of the pine-hardwood mixtures (p < 0.001). Ground cover also was greater on the 90 percent pine plot than on the 50 percent pine plot. Shrub cover was greatest on the 100 percent pine plots, but did not differ among the pine-hardwood mixtures (p < 0.001). The 100 and 80 percent pine plots had the least amount of midstory cover; midstory cover was greatest in the 50 and 70 percent pine treatments (p < 0.001). Cover of the canopy layer was greatest in the 50 percent pine treatment and least in the 100 and 80 percent pine treatments (p < 0.001).

Table 5. Foliage height diversity (FHD) and percent cover of forest layers by treatment, 1988.

| Forest Layer | Percent pine basal area | | | | |
	100	90	80	70	50
Percent cover:					
Ground (<1.5 m)	44.6c[1]	32.2b	31.9b	26.0ab	23.8a
Shrub (1.5-5 m)	47.6b	21.2a	30.9a	21.7a	28.8a
Midstory (5-10 m)	0.0a	5.9bc	3.8ab	11.0c	9.5c
Canopy (>10 m)	79.6a	85.9b	78.7a	86.6b	91.5c
FHD	0.67b	0.55a	0.58a	0.56a	0.55a

[1]Means with different letters within rows are different.

Acorn production

Acorn production per basket did not differ among treatments, but was different by year (p = 0.002). Production during 1983, 1984, 1985, and 1986 was 2, 1, 9, and 7 kg/ha, respectively. Acorn production during 1983 and 1984 was lower than production during 1985 and 1986. Because of poor mast crops, too few acorns were collected during fall 1987 and 1988 to conduct analyses.

DISCUSSION

In general, the quality of habitat for white-tailed deer (Odocoileus virginianus) and other species dependent on ground-level vegetation did not differ between the pine-hardwood mixtures. After hardwood regeneration was killed, however, production and cover of preferred forage species was greater on the 100 percent pine plots than on the pine-hardwood mixtures.

These results are consistent with other studies relating ground-level production to overstory and midstory characteristics. Understory production is typically inversely related to BA and the number of forest layers (Halls and Schuster 1965, Blair 1967, Blair and Enghardt 1976, Wiggers and others 1978, Hurst and others, 1979). In most southern forests, a dense multilayered midstory of hardwoods most inhibits forage growth (Schuster and Halls 1963, Blair 1969, Blair and Enghardt 1976, Blair and Feduccia 1977). A dense hardwood midstory may also cause undesirable changes in forage production by decreasing total number of species, the number of palatable species, and plant vigor (Schuster and Halls 1963, Blair 1967).

The FHD values suggest that, even with no midstory, the 100 percent pine plots offered the best habitat for songbirds. The high FHD value for the 100 percent pine was largely attributable to the high degree of cover in the ground and shrub layers. This vegetation, however, was pines, American beautyberry, and blackberry that were of sufficient height to be tallied in the shrub layer. This habitat would favor bird species more typically found in pine plantations than in pine-hardwood stands. Southern pine is most valuable for birds when mixed with hardwoods (Myers and Johnson 1978, Briggs and others 1982). The number of horizontal strata and development of the midstory and canopy is positively correlated with bird species diversity (MacArthur and MacArthur 1961, Myers and Johnson 1978).

For wildlife species dependent on acorn production, habitat quality was best in the treatments with the greatest BA in oaks. Acorn production per tree, however, did not differ among treatments, suggesting that growing conditions for oaks was similar across treatments. At BA 15m^2/ha, differences in acorn production might occur.

CONCLUSIONS

Generally, habitat quality did not differ among the pine-hardwood mixtures. Even 10 percent of BA in hardwoods, however, reduced forage production below levels in plots with 100 percent of BA in pine. For landowners seeking to favor wildlife, 50 percent of BA in pine provided forage production not different from the 90 percent pine plots. Additionally, on the 50 percent pine plots, acorn production and midstory development was greater than on the 90 percent or 100 percent pine plots. It should be noted, of course, that this study only evaluated habitat quality in stands with 15 m^2/ha BA. Further research is warranted to evaluate habitat in pine-hardwood stands with higher BA's.

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WILD TURKEY ACTIVITIES IN RELATION TO TIMBER TYPES ON THE FRANCIS MARION NATIONAL FOREST

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Abstract.–Fifty-five wild turkey (Meleagris gallopavo silvestris) hens and 20 gobblers were trapped, equipped with telemetry packages and released on site during 1981-84. Movements were monitored throughout the period to determine nesting habitat and general habitat preference during all seasons. The bald cypress (Taxodium distichum)/water tupelo (Nyssa aquatica) timber type was the most preferred habitat type for both gobblers and hens. Turkey hens preferred regenerated forest (10 years) and mixed pine/hardwood stands for nesting.

INTRODUCTION

A telemetry study of the nesting ecology and habitat utilization of an established population of eastern wild turkeys was conducted during 1981-84. We sought to determine the relationship of nesting with timber type and various stand characteristics. Preferred habitat types were to be identified for both sexes during all seasons.

This research project was part of an intensive effort to investigate the dynamics of a population that has been noted as one of the purest strains of eastern wild turkey. This population was the source for the successful restoration of wild turkey in the Piedmont and mountain areas of South Carolina.

METHODS AND MATERIALS

Study Area

The study area was the Waterhorn Hunt Unit (H.U.) and sections of the adjacent Northampton H.U. of the Francis Marion National Forest. Also included were in-holdings owned by timber companies or private individuals. The study area totals 18,940 ha in Berkeley and Charleston counties near Clellanville, South Carolina.

The Waterhorn H.U. is significant historically in that it was set aside by presidential proclamation as a wild turkey refuge in 1948 (Holbrook 1952). A hog-proof fence was constructed around 6,883 ha during the early 1950's and the area was managed intensively for wild turkeys to provide birds for restocking. During 1952, project personnel estimated a population of 800 to 900 birds on the refuge (Holbrook 1952).

Principal forest types on the study area included pine and swamp hardwood. The primary pine species on the study area were loblolly (Pinus taeda) and longleaf (P. palustris). During the study period, 3,901 ha (21 percent) of the study area were typed as longleaf and 6,747 ha (36%) as loblolly (excluding regeneration areas). Pine/hardwood or hardwood/pine (mixed stands) comprised only 765 ha (4 percent). A high percentage of the older timber stands on the study area was comprised of the bald cypress/water tupelo (BCWT) timber type which was often flooded. Silvicultural practices on the area included clearcutting and planting or seed tree cutting with natural regeneration for pine stands. Natural regeneration of hardwood sites occurred after clearcutting. Prescribed burning was common in the upland pine types. A tidal stream ran through the middle of the study area and many dikes and ditches associated with early rice culture were present.

The study area had a number of Forest Service roads which included approximately 61.3 km of rock surfaced road, 41.5 km of logging roads, 27.0 km of improved ditched dirt roads and 14.8 km of paved road. Many of the logging roads provide access to the 142 wildlife openings present on the study area.

Approach

Turkeys were captured by rocket-projected netting as described by Austin (1965) and Dill (1969) on sites baited with shelled corn during the months of January, February, and early March in 1981-84. Captured birds were weighed, aged, banded, and fitted with a solar- or battery-powered transmitter. Transmitters were attached to birds using harnesses of nylon-covered rubber tubing. A motion sensing feature of the transmitters allowed interpretation of animal activity.

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Birds were located at various times of the day at least 3 times a week. In addition, gobblers were monitored at 2-hour intervals at least 1 day a week to obtain representative daily activity patterns. On these days, readings began prior to birds leaving the roost each morning and continued until all birds flew to roost in the evening. Locations of turkeys were determined as described by Cochran and Lord (1973). Habitat utilization was analyzed using a modified TELEM program (Koeln 1980). A digitized computer map prepared by Westvaco Corporation from U. S. Forest Service compartment maps, aerial photographs and USGS maps was used to determine habitat types and preferences. All seasonal habitat utilization fixes were combined. Habitat use data were combined for all birds since the same habitat types were used by adult and juvenile birds. Dates were recorded when the transmitter activity sensor attached to hens indicated periods of inactivity and radio locations became clustered signifying nesting activity.

Initially, nest sites were located by flushing hens from nests. Since birds abandoned their nests after being flushed this method was terminated. Subsequently, nests were circled and flagged while the hen was on the nest, then located when the hen was away.

After hatching occurred, data collected at each nest site included adjacent understory and overstory vegetation, basal area and proximity to ditches and skid trails. Preferences of turkeys for different age and type timber stands were analyzed using methods derived by Neu and others (1974).

Standard U. S. Forest Service cover type guidelines were used to determine the timber composition of the area surrounding the nest and for each timber stand type on the study area. Stands in which 70 percent or more of the crowns in the dominant and codominant position were either softwoods or hardwoods were classified as a pure stand. Stands in which 51-69 percent of the crowns in the dominant and codominant positions were either hardwood or pines were classified as a mixed stand. While Forest Service type maps, prescriptions, etc. were used for habitat preference, actual overstory measurements were taken surrounding turkey nests. Therefore a nest located in a small patch of pine/hardwood type within a larger pure pine stand would be classified as having a mixed overstory.

RESULTS
Nesting Habitat

During the 4 years of the study, 37 turkey nests were located and evaluated. Of these, 28 were nests of study hens while 9 noninstrumented birds were located by U. S. Forest Service personnel during routine duties or by hunters. Of the 37 nests, 15 (40%) occurred in mixed stands, 11 (30%) occurred in areas of pine overstory, and 10 (27%) occurred in clearcuts ten years old or younger or seed tree cuts (table 1). One nest was found in a young pine stand (13 years old) which had been destroyed by wildfire. Nests often occurred in small mixed patches within larger stands that were typed as pine, or near stand edges or transition zones where mixed types were more prevalent. Basal area measurements for mixed and pine species surrounding nest sites averaged 8.73 and 6.59 square meters, respectively.

Stand type was significantly associated ($p \leq 0.10$) with the occurrence of nesting sites (table 1). Hens preferred regenerated stands (≤ 10 years) and mixed stands while avoiding pure pine and pure hardwood stands.

Stand age was also significantly associated ($p \leq 10$) with the occurrence of nesting sites (table 2). One nest occurred on private land where the age of the overstory was unknown and one nest was located in a stand that had been destroyed by wildfire.

Table 1.--Composition of overstory vegetation surrounding turkey nests on the Francis Marion National Forest, SC (1981-84)

Overstory type	Total hectares	Proportion of total area	Number of nests in area	Expected number observed	Proportion observed in each area	Confidence interval on proportion of occurrence 90%	Results[a]
Pine	10,919	0.577	11	21	0.297	0.122<pi<0.472	A
Hardwood	4,979	0.263	0	10	0.000	- <pi< -	A
Regeneration (10 years)	1,261	0.066	10	2	0.270	0.100<pi<0.440	P
Mixed	765	0.040	15	2	0.405	0.217<pi<0.593	P
Other	1,016	0.054	1	2	0.028	0.000<pi<0.091	R
Total	18,940		37	37			

[a]A=avoided; P=preferred; R=random

Table 2. Age class of overstory surrounding nests

Age class	Ha	Number of nests	Expected no. of nests (proportion)	Proportion observed in each age class	Confidence interval on proportion of occurrence (90% confidence coefficient)
0-10	1026.72	10	0.107	0.286	0.108<p<0.464
11-30	1340.89	5	0.140	0.142	0.005<p<0.281
31-50	1811.74	3	0.189	0.086	0.000<p<0.196
51-70	3038.87	14	0.317	0.400	0.207<p<0.593
>70	2363.16	3	0.247	0.086	0.000<p<0.196
0-10	Preferred				
11-30	Random				
31-50	Random				
51-70	Random				
>70	Avoided				

Thirty-five of the nests were located on U. S. Forest Service property where all stand age data were available. The statistical analysis was limited to these areas for the purpose of preference selection in table 2. Stands in the 0-10-year age class were preferred for nesting while stands greater than 70 years were avoided. Stands in other age classes were selected randomly with no statistical indication of preference or avoidance.

Habitat Utilization

Stand type was significantly associated ($p \leq 0.10$) with habitat utilization by both hens and gobblers (tables 3 and 4). Hens preferred the BCWT and other hardwood categories. Other hardwoods were comprised of several timber types which included laurel oak (Quercus laurifolia)-willow oak (Q. phellos), white oak (Q. alba)-red oak (Q. rubra)-hickory (Carya sp.) and scrub oak (Q. sp.). Hens also preferred the regenerated area (≤ 10 years). Hens avoided the following types: all pure pine stands, sweetgum (Liquidambar styraciflua)-water oak (Q. nigra)-willow oak and sweetbay (Magnolia virginiana)-swamp tupelo-red maple (Acer rubrum).

Gobblers avoided loblolly, randomly selected longleaf and preferred the slash (P. elliotta) and pond pine (P. serotina) category and the BCWT habitat type. The other hardwood and regenerated areas were randomly selected while the sweetgum-water oak-willow oak and sweet bay-swamp tupelo-red maple timber types were avoided.

Table 3.--Habitat preferences by wild turkey hens on the Francis Marion National Forest (1981-84)

Timber type	Area(ha)	Proportion of total area	Number of observations in area	Expected number observed	Proportion observed in each area	Confidence interval on proportion of occurrence 90%	Results[a]
Loblolly	6,747	0.356	974	1,210	0.286	0.266<pi<0.306	A
Longleaf	3,901	0.206	428	701	0.126	0.111<pi<0.141	A
Other pine	271	0.014	16	48	0.005	0.002<pi<0.008	A
Mixed	765	0.041	47	136	0.014	0.009<pi<0.019	A
Bald cypress-water tupelo	2,496	0.132	1,327	449	0.390	0.368<pi<0.412	P
Sweet gum-water oak-willow oak	1,141	0.060	62	204	0.018	0.012<pi<0.024	A
Sweet bay-swamp tupelo-red maple	816	0.043	37	146	0.011	0.006<pi<0.016	A
Other hardwoods (primarily oaks)	526	0.027	168	95	0.050	0.040<pi<0.060	P
Regenerated areas	1,261	0.067	294	228	0.086	0.074<pi<0.098	P
Other	1,016	0.054	48	184	0.014	0.009<pi<0.019	A
Total	18,940		3,401	3,401			

[a]A=avoided; P=preferred; R=random

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Table 4.--Habitat preferences by wild turkey gobblers on the Francis Marion National Forest (1981-84)

Timber type	Area(ha)	Proportion of total area	Number of observations in area	Expected number observed	Proportion observed in each area	Confidence interval on proportion of occurrence 90%	Results[a]
Loblolly	6,747	0.356	582	636	0.326	0.297<pi≤0.355	A
Longleaf	3,901	0.206	387	368	0.217	0.192<pi≤0.242	R
Other pine	271	0.014	70	25	0.039	0.027<pi≤0.051	P
Mixed	765	0.041	19	71	0.011	0.005<pi≤0.017	A
Bald cypress- water tupelo	2,496	0.132	460	236	0.257	0.230<pi≤0.284	P
Sweet gum- water oak- willow oak	1,141	0.060	20	107	0.011	0.005<pi≤0.017	A
Sweet bay- swamp tupelo- red maple	816	0.043	44	77	0.025	0.015<pi≤0.035	A
Other hardwoods (primarily oaks)	526	0.027	65	50	0.036	0.025<pi≤0.047	R
Regenerated areas	1,261	0.067	127	120	0.071	0.002<pi≤0.012	R
Other	1,016	0.054	13	97	0.007	0.002<pi≤0.012	A
Total	18,940		1,787	1,787			

[a]A=avoided; P=preferred; R=random

DISCUSSION

In this study nesting hens did not tolerate human disturbance. Only 1 hen of 8 (11%) returned to her nest after being flushed. Williams and others (1971) reported that 7 of 11 (64 percent) hens abandoned their nests after being flushed from their nests by investigators. Bidwell and others (1985) reported that most nest losses (61 percent, 8 of 13) in his study area were due to human disturbance. As turkey hunters and other resource users increase on the Francis Marion, the disturbance and abandonment of nests could affect turkey reproduction markedly.

The study suggests a need for mixed stand management for turkey nesting. Forty percent of the nests were located in areas where the overstory vegetation was mixed. These stands, however, comprised only 4 percent of the study area indicating a preference for nesting in mixed stands.

Turkeys also preferred clearcuts between the ages of 0-10 years and seed tree cuts for nesting. They avoided the older age classes (> 70 years) which were often flooded. Hens also preferred low to moderately stocked stands for nesting as evidenced by basal area measurements around the nest sites.

The preference of the BCWT type by hens and gobblers indicated the birds preferred a mature, undisturbed environment. The BCWT type generally was not harvested and provided an area relatively free of human activities, other than hunting. The majority of the BCWT timber type was found in a continuous strip along a tidal creek which bisected the study area. Turkeys often used this habitat type for roosting and made visits into other habitat types during the day. Ecotones appeared to be preferred as most turkeys were located only a short distance from the edge of the habitat type. The BCWT timber type has not been previously referenced as a preferred timber type for wild turkeys.

Other hardwoods, primarily mast producing oaks, and regenerated stands were preferred by hens and randomly selected by gobblers. Timber management prescriptions should allow for the interspersion of mast producing oaks within small regeneration areas.

ACKNOWLEDGEMENTS

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THE FOX SQUIRREL (SCIURUS NIGER) IN SOUTHEASTERN PINE-HARDWOOD FORESTS

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Abstract. — Southeastern fox squirrels have experienced significant declines in their distribution and numbers over the past 100 years. Their decline has been attributed to the decline and fragmentation of the mature pine-oak forests on which they depend. Thus, an understanding of the habitat relations of southeastern fox squirrels is necessary to manage and conserve these animals in the Southeast. We review what is presently known about 1) the habitat relations (species composition, habitat structure, and landscape aspects) of fox squirrels in the Southeast, 2) the food habits, nesting habits, and movement patterns of fox squirrels, and 3) how the resource requirements relate to fox squirrel habitat selection. Future research needs are also outlined.

INTRODUCTION

Southeastern fox squirrels are the largest tree squirrels found in North America, ranging from 900 to 1200 g in weight. This group is comprised of 5 subspecies: Sciurus niger cinereus which is found on the Delmarva peninsula, S. n. niger whose range includes North Carolina, South Carolina, most of Georgia, and the panhandle of Florida, S. n. shermani which is found in the central portion of Florida, S. n. avicennia which is found on the southern tip of Florida, and S. n. bachmani which is found primarily in Alabama and Mississipi (Hall 1981). Southeastern fox squirrels are larger than midwestern fox squirrels (600 to 900 g) and more highly variable in color. The habitat associations of southeastern fox squirrels are also distinct. Unlike midwestern fox squirrels which are usually associated with open hardwood forests, often in small isolated woodlots and fencerows adjacent to agricultural fields (Flyger and Gates 1982), southeastern fox squirrels are usually associated with mature pine forests with an oak midstory. The longleaf pine-turkey oak (Pinus palustris-Quercus laevis) forests of the Coastal Plain and Sandhills Regions are considered the typical habitat of southeastern fox squirrels (Moore 1957; Weigl and others 1989) but, the loblolly pine (P. taeda) forests of the Piedmont Region may also provide good habitat.

Fox squirrels in the Southeast have experienced significant declines in their distributions and population numbers during the past century (Hamilton 1943; MacClintock 1970; Seton 1953). The Delmarva fox squirrel (S. n. cinereus) is a federally listed endangered species (U. S. Department of Interior 1970) and Sherman's fox squirrel (S. n. shermani) is considered to be of special concern by the state of Florida and is under consideration by the U. S. Fish and Wildlife Service for federal status (John Wooding, pers. comm.). The Big Cypress fox squirrel (S. n. avicennia) is also considered threatened by the state of Florida. The status of S. n. niger and S. n. bachmani is unknown, but Weigl and others (1989) and Wood (1988) suggested that the numbers of S. n. niger in North Carolina and South Carolina are declining and measures should be taken to manage and preserve suitable habitat to prevent further decline.

Knowledge of the habitat relations of any wildlife species is essential to effective management. Unfortunately, until recently southeastern fox squirrels have received very little study. The objectives of this paper are to review what is presently known about the habitat relations and resource requirements of southeastern fox squirrels and to outline what further knowledge is necessary before effective management of this species can be developed and implemented.

HABITAT ASSOCIATIONS OF SOUTHEASTERN FOX SQUIRRELS

The description of optimal habitat for any wildlife species should encompass at least three aspects: 1) the species composition of the habitat, 2) the structure of the habitat, and 3) landscape dimensions, including the juxtaposition of various habitat types. Fox squirrel habitat relations have been examined, to varying degrees, at all three of these levels. Use of nest-boxes and, particularly, radio-telemetry have been the most commonly used methods for investigating habitat relations of the fox squirrel.

Species Composition

Fox squirrel habitats in the Southeast usually contain both pines and hardwoods. Based on percent

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of radio-telemetry locations (Weigl and others 1989), fox squirrels in the Sandhills of North Carolina spend the majority of their time in pine-oak habitats (between 58 percent and 77 percent depending on sex and season), followed by edge habitats (22 percent to 40 percent), bottomland hardwoods (1 percent to 7 percent), and field and oak-scrub habitats (0 to 3 percent). Fox squirrels also use more nest boxes in longleaf pine-oak habitats. However, nest boxes in both longleaf pine-oak habitats and bottomland hardwoods are used in proportion to their availability.

In the Coastal Plain of Georgia fox squirrels spend the majority of their time in loblolly pine-oak habitats (66.0 percent), followed by loblolly pine pole (7 to 10 m tall) habitats which have virtually no oaks (15.3 percent), bottomland hardwoods (11.3 percent), longleaf pine-oak (5.2 percent), slash pine (P. elliottii) plantations (0.7 percent), and other habitats (1.5 percent) including old cuts, old fields, grass fields, food plots, and new cuts (Hilliard 1979). However, based on utilization versus availability, fox squirrels prefer loblolly pine-oak habitats (utilization/availability = 1.66) and bottomland hardwoods (1.71) and avoid the slash pine plantation (0.15) and other habitats (0.05). Loblolly pine pole and longleaf pine-oak habitats are used in proportion to availability (0.96 and 0.95, respectively) and thus, are neither preferred nor avoided. Loblolly pine-oak habitats are also used the most often for nesting (69.8 percent of nest locations) followed by loblolly pine pole (13.2 percent), bottomland hardwoods (9.4 percent), and longleaf pine-oak habitats (7.6 percent). In the case of nests however, loblolly pine-oak, bottomland hardwoods, and longleaf pine-oak habitats are all preferred (U/A = 1.76, 1.42, and 1.38, respectively) whereas the squirrels tend to avoid loblolly pine pole habitats for nesting (U/A = 0.83).

Edwards (1986) studied fox squirrels in an area characterized by stands of longleaf and loblolly pine stands bisected by narrow hardwood drains and cypress (Taxodium spp.) and gum (Nyssa spp.) swamps in the Coastal Plain of South Carolina. In this area, fox squirrels prefer carolina bay habitats, pine-hardwood stands, and drains of hardwood and mixed species composition. Marshes and areas containing pure pine in the overstory but at low densities are avoided. Hardwood runners are used most often for nesting (36 percent) followed by pine-hardwood habitats (21 percent), low density pine habitats (15 percent), mixed runners (14 percent), cypress (6 percent), medium density pine habitats (4 percent), and carolina bay (4 percent). However, 90 percent of the nests are within 60 m of a habitat boundary and are most often adjacent to low and medium density pine habitats.

Thus, studies using radio-telemetry to assess the amount of time spent in broad habitat categories (e.g., pine-hardwood vs. hardwood) indicate that pine-hardwood mixtures are important to southeastern fox squirrels. Using a different approach, Taylor (1973) and Dueser and others (1988) found that species composition had little to do with habitat suitability for Delmarva fox squirrels. These researchers compared sites with Delmarva fox squirrels to those where fox squirrels were absent but gray squirrels (S. carolinensis) were present. Areas that support fox squirrels have greater basal areas of American beech (Fagus grandifolia) and mixed hardwoods but do not differ significantly from areas that do not support fox squirrels in terms of loblolly pine, oak, or hickory (Carya spp.) basal areas. When multivariate statistics are applied to these data, species composition shows only a marginally significant difference between sites that support fox squirrels and those that do not, and only 19 percent of the variation in fox squirrel presence or absence is explained by species composition.

Habitat Structure

Habitat structure has often been suggested as a critical component in fox squirrel habitat selection in the Southeast. The density of the understory may be one of the most important factors. On the Delmarva peninsula, sites containing fox squirrels have an average understory cover of 29.7 percent whereas sites containing gray squirrels but not fox squirrels have an average understory cover of 71.5 percent (Taylor 1973). Suitable habitats for Delmarva fox squirrels also have a greater percentage of trees 30 cm dbh or greater, a greater percentage of overstory cover, and less percentage shrub-ground cover, (Taylor 1973; Dueser and others 1988). Taylor (1973) suggests that the apparent association of Delmarva fox squirrels with mature loblolly pine forests is due to the scarcity of understory growth in these stands and not to a reliance of fox squirrels on the pines themselves. Weigl and others (1989) also found that fox squirrels prefer to use nestboxes in open, mature, longleaf pine stands with little understory. The importance of mature pine stands with a sparse understory for fox squirrels was suggested by other researchers (Hilliard 1979; Kantola 1986; Moore 1957), but no data have been presented to support this conclusion.

Landscape Aspects

Landscape aspects of southeastern fox squirrel habitat relations have only been directly examined by Dueser and others (1988). Sites with fox squirrels do not differ significantly from sites without fox squirrels in terms of woodlot area, area of open

fields, percentage of forested area, forest edge, or forest shape. However, woodlots with fox squirrels are closer to the nearest woodlot than sites without fox squirrels. Thus, the degree of isolation may be an important aspect of fox squirrel habitat selection.

Although specific landscape variables have not been tested in other studies of fox squirrel habitat use, some conclusions about landscape dimensions have been made by various researchers based on patterns of habitat use. These studies have all found that edge or ecotonal areas may be significant to fox squirrels. Edwards (1986) concluded that ecotones are very important to fox squirrels in the Coastal Plain of South Carolina based on both the high number of nests and the high number of telemetry locations outside of nests which are within 30 to 60 m of habitat boundaries. Kantola (1986) also found more nests in ecotonal areas (4.7 nests/ha) than in upland longleaf pine stands (2.7 nests/ha). The ecotonal areas are downslope from uplands and are characterized by longleaf pines and turkey oaks interspersed with a variety of other oak species such as sand post oak (Q. stellata), live oak (Q. virginiana), laurel oak (Q. laurifolia), and bluejack oak (Q. incana), whereas the upland slopes have low productivity with longleaf pine and turkey oak being the predominant species. Kantola (1986) suggests that greater use of ecotones by fox squirrels may be due to a greater diversity of mast producing oaks, a higher mast production within the ecotone areas, and more material, particularly Spanish moss, for nest insulation. Weigl and others (1989) suggest that edge or ecotone habitats may be of importance seasonally. They describe a pattern of land use that is centered on the pine-oak forests with periodic shifts to the moister, cooler areas of edge (transition areas between the longleaf pine-oak habitats and the bottomland hardwoods) and bottomland hardwoods, particularly in summer.

RESOURCE REQUIREMENTS

To fully understand the habitat relations of fox squirrels, knowledge of their resource requirements is needed, i.e., what resources and in what amounts need to be contained in the habitat. The food habits, nesting habits, and movement patterns, including escape from predators, are three critical components of fox squirrel survival and are directly related to all three habitat dimensions.

Food habits

No quantitative data on the food habits of the fox squirrel have been published to date. However, based on observations of feeding and examination of some stomach contents, the diets of fox squirrels appear to be quite broad (Ha 1983; Moore 1957; Weigl and others 1989). Food items in the diets of

southeastern fox squirrels include the mast from a large variety of trees, pine buds, staminate cones, berries, hypogeous and epigeous fungi, insects, and longleaf pine seeds. Some of the important species in the diet of southeastern fox squirrels are turkey oak, southern red oak (Q. falcata), blackjack oak (Q. marylandica), bluejack oak, post oak, live oak, pecan (C. illinoensis), pignut hickory (C. glabra), Allegheny chinkapin (Castanea pumila), sweetgum (Liquidambar stryraciflua), and maple (Acer spp.).

Turkey oak acorns and longleaf pine seeds appear to be of particular importance, at least in the Coastal Plain and Sandhills Regions (Ha 1983; Kantola 1986; Moore 1957; Weigl and others 1988). Acorns are the major food items of southeastern fox squirrels during the fall, winter, and early spring. Further, reproduction of fox squirrels in the Southeast appears to be closely tied to the abundance of the fall mast crop (Kantola 1986; Weigl and others 1989) as it is in many other species of tree squirrels (see Gurnell 1983 for review). Thus, the fall mast crop provides an important source of energy and nutrients for both maintenance and production. Because the turkey oak is the most dominant oak in the Sandhills and Coastal Plain Regions, it has been assumed to be the most important. However, in areas where turkey oaks are not available (e.g., the Piedmont Region), other oaks probably take their place.

Longleaf pine cones are available for only a short period of time (1 to 3 months) but may still be a critical food source for fox squirrels in the Coastal Plain and Sandhills Regions. During late spring and early summer food supplies are very poor (Ha 1983; Moore 1957; Weigl and others 1989). Acorns from the previous fall have all been taken and few insects, buds, or flowers are available during this hot, dry period; squirrels often lose weight during this period and are in poor condition (Kantola 1986; Weigl and others 1989). This period of poor food supply ends with the ripening of the longleaf pine cones. Squirrels feed almost entirely on these seeds for approximately one to two months (Moore 1957; Weigl and others 1989). Each cone contains a large number of seeds (up to 150) and each seed has a very high energy content (Weigl and others 1989). Thus, longleaf pine cones may be significant to fox squirrels in being the major source of energy during an otherwise nutritionally stressful period. In the Piedmont Region of Georgia, loblolly pine cone seeds are also eaten during late summer (pers. obs.) but their importance relative to other foods is not known.

Nests

Fox squirrels utilize both cavities and outside leaf nests or "drays" for nesting (MacClintock 1970). However, in the Southeast, the frequency of cavity use is very low. In Georgia and Florida, only 7 percent of all nests utilized by fox squirrels are in cavities (Hilliard 1979; Kantola 1986) and in South Carolina, 20 percent of all nests are in cavities (Edwards 1986). However, Edwards (1986) found that cavity use varies by sex and season. Use of cavities by males is low throughout the year (0 to 9 percent) whereas cavity use by females varies from 0 percent in summer to 69 percent in winter. Weigl and others (1989) suggest that low cavity use by southeastern fox squirrels is due to low cavity availability. The relatively young pines in southeastern forests and the removal of large storm or fire damaged oaks during timber operations and for firewood presumably limit the number of available cavities.

Although cavity use may be low, the availability of cavities may still be critical to the survival of fox squirrel populations. Nestbox and cavity use increases considerably during cold or rainy weather (Kantola 1986; Weigl and others 1989) as well as during periods of low food supply (Weigl and others 1989). Further, Weigl and others (1989) suggest that cavities are important for rearing of young. Thus, cavities may be important for successful reproduction as well as a means of conserving energy during periods of low energy supply or high energetic demands.

A variety of tree species is used for leaf nest construction including loblolly pine, longleaf pine, slash pine, turkey oak, post oak, laurel oak, live oak, water oak (Q. nigra), willow oak (Q. phellos), red oak, blackgum, sweetgum, water tupelo, and cypress (Edwards 1986; Hilliard 1979; Kantola 1986; Moore 1957). While Edwards (1986) and Kantola (1986) found that nests are placed predominantly in hardwoods (85 percent and 81 percent, respectively), Hilliard (1979) found that pines (particularly loblolly pine) are the predominant nest tree (81 percent). In Georgia, tree species are used in proportion to their availability for nesting (Hilliard 1979) whereas in South Carolina, fox squirrels show a preference for nesting in oaks (Edwards 1986). Fox squirrels also show a preference for larger trees (Edwards 1986; Kantola 1979). Mean dbh of nest trees in South Carolina is 41.2 cm (Edwards 1986) and mean dbh of nest trees in Georgia is 39.1 cm (Hilliard 1979).

Movement and Spatial Relations

Fox squirrels are considerably more terrestrial than other tree squirrels (MacClintock 1970). In addition to spending much of their foraging time on the ground, they also run along the ground as a means of predator escape. The highly terrestrial nature of fox squirrels is probably due to their large size and consequent reduction in agility. The preference of fox squirrels for forests with sparse understories may be related to their terrestrial habits. An open understory allows for unhindered movement while on the ground as well as easier detection of predators (Taylor 1973).

Home range size of fox squirrels in the Southeast (based on the minimum convex polygon method) ranges from 9 ha to 19 ha for females and from 20 ha to 32 ha for males (table 1). These home range

Table 1.--A summary of estimated home range sizes of southeastern fox squirrels (Sciurus niger). All estimates were determined by the minimum convex polygon method except for the estimates for S. n. shermani which were determined by the 95 percent harmonic mean method.

	Location	Home Range Size (ha)	Source
S. n. cinereus	MD	29.9	Flyger and Smith 1980
S. n. niger--Males	NC	22.8	Weigl and others 1989
S. n. niger--Females	NC	16.2	"
S. n. niger--Males	SC	31.6	Edwards 1986
S. n. niger--Females	SC	19.3	"
S. n. niger--Males	GA	20.0	Hilliard 1979
S. n. niger--Females	GA	9.0	"
S. n. shermani--Males	FL	42.8	Kantola 1986
S. n. shermani--Females	FL	16.7	"

sizes are considerably larger than those reported for fox squirrels in the midwest (Ha 1983). Ha (1983) suggests that the large home range of fox squirrels in the Southeast is due to the lower, more patchy, and more unpredictable food supply found in southeastern forests.

At this time, there is no evidence to suggest that fox squirrels are territorial. Home ranges often overlap (Hilliard 1979; Kantola 1986; Weigl and others 1989) and concurrent and non-concurrent use of the same nest or nest box by 2 or more individuals has been observed (Hilliard 1979; Weigl and others 1989). However, Weigl and others (1989) suggest that close proximity among squirrels is rare and that they tend towards asocial behavior. Temporal spacing may thus be important in the spacing behavior of fox squirrels, and may also be an important factor in their large home range sizes.

FUTURE RESEARCH NEEDS
From the studies reviewed above, a sketch emerges of the habitat relationships of fox squirrels in the Southeast. The squirrels occupy habitats with large pines, sparse ground cover, and an association of mature, mast producing oaks. The oaks may occur as a midstory component of pine stands or as small patches of hardwood communities intersecting or intermixed with pine communities. Edges between upland pines and bottomland hardwoods may also be important, particularly on a seasonal basis, for nesting and foraging habitat. Hardwoods provide the bulk of the annual diet while pines appear to provide a seasonally important food source. A sparse understory allows for efficient movement on the ground and possibly easier detection of potential predators. The large home range size of fox squirrels suggests that large tracts of suitable habitat are necessary to satisfy the needs of the fox squirrel.

Our sketch of the habitat association of fox squirrels provides a generalized panorama of fox squirrel requirements, but it lacks the detail necessary to develop and prescribe management practices. Our current knowledge actually provides more questions than answers about fox squirrel ecology and management. What mixtures of pines and hardwoods provide optimum habitat for fox squirrels? Does it matter whether hardwoods occur as a mixture within pine stands or as hardwood stands adjacent to pine stands? Is stand or tree age an important factor versus some other attribute such as tree size or mast producing potential? What species of hardwoods and pines, are most important to fox squirrels? At what point can hardwood stocking become too high and begin to favor potential competitors such as the gray squirrel? Answers to these questions are essential for prescribing silvicultural practices and forest management strategies to favor fox squirrels.

The ultimate goal of management oriented research on fox squirrels should be to discover the factors which influence or limit the distribution and abundance of the species. This may seem an obvious goal common to the population ecology of any species (Elton 1927; Andrewartha and Birch 1982, 1984). Nonetheless, we feel it is important to explicitly restate the goal for this species to emphasize the research approach it implies. Understanding the fox squirrels' distribution and abundance requires understanding the species' innate capacity to increase in different environments. Too frequently we attempt to understand a species' ecology by studying either its environment or selected population parameters. However, population parameters are, in part, a function of, and vary among, different environments and the goal of management is to influence population dynamics primarily through modifications to the environment. Consequently, a comprehensive research approach must encompass both environmental parameters and population parameters and attempt to relate the two (Andrewartha and Birch 1982).

Determining the important environmental parameters to measure depends on a thorough knowledge and understanding of the food requirements and preferences, nest and nest site preferences, behavior patterns, and interactions with other species, particularly predators and competitors. Primary population parameters are birth and death rates, agents of mortality, and the age and sex structure of the population. Ultimately, habitat quality can be assessed by examining the population responses and behavior of fox squirrels in relation to environmental parameters (e.g., the availability of resources, the distribution of resources in space and time, and the abundance and distribution of competitors and predators). Thus, future research on fox squirrels should concentrate on determining their resource requirements and population dynamics under a wide variety of environmental conditions.

The above outline of research focuses on defining optimal habitat for fox squirrels. Additional research topics also need to be addressed. For example, accurate methods to estimate population abundance and density are needed to monitor population trends as well as to test population responses to habitat variables. Thus, census techniques for this large, relatively sparse, and widely ranging species need to be developed and tested.

Once these techniques are developed, monitoring of fox squirrel populations must be done to determine their status and population trends. Regional distributions should also be examined. The majority of fox squirrel studies in the Southeast have been conducted along the Atlantic Coast. It is necessary to determine the distribution and status of fox squirrels in the rest of the Southeast as well as to compare their ecologies with the fox squirrel populations in the Atlantic Coastal Plain and Sandhills Regions. Studies are now being conducted on S. n. niger in the Piedmont Region of Georgia by researchers from Clemson University and on S. n. bachmani in Alabama by researchers from the U. S. Fish and Wildlife Service and data from these studies will complement previous studies as well as data that are now being collected in the Sandhills of North Carolina by researchers from Wake Forest University and in Florida. However, more of these types of studies are needed. Studies on the taxonomy and evolutionary relationships of the five southeastern subspecies relative to the rest of the subspecies would also be highly informative in understanding the adaptations of fox squirrels to the environmental conditions of the Southeast.

Because there are many forest types both within and among physiographic regions in the Southeast, it is essential that habitats be defined clearly and precisely so that comparisons between areas and studies can be made. For example, the term pine-hardwood is defined for National Forests as a stand containing 50 percent to 70 percent pine as dominants or codominants. However, in several studies (Edwards 1986; Hilliard 1979; Weigl and others 1989) this term is used to describe habitats that have predominantly pine in the overstory but oaks and other hardwoods as the main component of the midstory. "Edge" and "ecotone" are also used in several studies but the precise definition of the habitat types they are describing are not given or are poorly defined. Differences in the use of terms to describe habitats or the poor definition of habitat terms is likely to lead to confusion and misunderstanding and thus ultimately, hinder our progress in fully understanding the habitat relationships of southeastern fox squirrels.

It is evident that a great deal of information is still needed before we fully understand the habitat relationships of fox squirrels in the Southeast and the importance of pine-hardwood mixtures to this species. However, the answers to the many questions about southeastern fox squirrels will not come from a few isolated studies. In order to determine the factors that limit the abundance and distribution of fox squirrels in the Southeast, studies covering a wide range of environmental conditions will be necessary. Further, due to both year-to-year variation in environmental parameters and the relatively long life span of this species, long-term studies are essential to the understanding of population responses to environmental variation and eventually, to environmental manipulation.

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AVIFAUNA OF THE PINE-HARDWOOD FOREST IN EAST CENTRAL MISSISSIPPI

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Abstract. — Birds in the interior of 3 mature (58 years old) pine-hardwood forests (PHF) and on edges of dirt roads (RDE) that traversed the PHF were studied in the Interior Flatwoods (Kemper County), Mississippi. Point counts (PT) and tape recorder counts (TR) were conducted from sunrise to 30 minutes later, from March-July 1972 and 1973. Number of males exhibiting territorial behavior was studied on 1 25 acre plot in a PHF in Spring 1973. Observations of birds in PHF and RDE were made during fall/winter 1972 and 1973. A total of 24 species, 23 by PT and 18 by TR was observed in PHF. Species with the highest frequency indices were cardinal, tufted titmouse, Carolina wren, summer tanager, blue jay, American crow, Carolina chickadee, yellow-billed cuckoo, chipping sparrow, white-eyed vireo, and wood thrush. Combined PT and TR observations found 48 species on RDE. Of this total, 26 species were not observed in the PHF. Seventeen species exhibited territorial behavior in the PHF. During fall/winter 35 species were observed in the PHF and 41 species were observed on RDE.

INTRODUCTION

Demand for wood products is increasing and the South is expected to produce more of the Nation's wood. One way to increase productivity, particularly pine (Pinus spp.), is to convert pine-hardwood forests to intensively managed pine plantations.

Birds are a major component of southern forests and interest in songbirds is increasing. Habitat conditions are altered by converting pine-hardwood forests to pine plantations (Dickson and Segelquist 1979, Darden 1980, Dickson and others 1980). The objective of this study was to document the avifauna of the pine-hardwood forest in east central Mississippi.

DESCRIPTION OF THE STUDY AREA

The study was conducted in the Interior Flatwoods land resource area (Kemper County) of the Southern Coastal Plain. The topography is flat and the area is poorly drained. Soils are clayey and acid. Mild winters and warm summers characterize the climate. Mean annual temperature is 60 degrees and average annual rainfall is 50 inches. The growing season averages 215 days (Pettry 1977).

As late as 1912 the flatwoods was a mixture of loblolly (Pinus taeda) and shortleaf (P. echinata) pine, which was harvested from 1912-1941. Flinkote Company bought a large tract in 1941 and practiced selective cutting until 1967. Weyerhaeuser Company bought the tract in 1967 and converted 100,000 acres of pine-hardwood forest to loblolly pine plantations.

Three study areas, each consisting of 640 acres, were located in the northern, central, and southern part of Kemper County, respectively. An 80-acre plot in each area was used for the bird study. The forests were homogeneous (Perkins 1973).

A pine-hardwood forest (PHF) occupied all study areas. The overstory contained 14 species and was dominated by pines. Post oak (Quercus stellata) was the dominant hardwood, followed by southern red oak (Q. falcata), white oak (Q. alba), hickories (Carya spp.), sweetgum (Liquidambar styraciflua), red maple (Acer rubrum), and winged elm (Ulmus alata). Pine basal area averaged 46 square feet per acre and hardwood averaged 53 square feet per acre. Average pine diameter at breast height (dbh) was 15.3 inches and hardwood averaged 10.2 inches. Dominant pine trees averaged 50 years old and averaged 73 feet tall. Hardwood trees averaged 57 years old.

The understory stratum contained 27 species, 14 of which were in the overstory. Post oak was the dominant species, followed by sweetgum, pines, and red oak. Pine basal area averaged 17 square feet per acre and hardwood averaged 53 square feet per acre. Pine dbh averaged 5.7 inches and hardwood 5.9 inches. Average pine age was 26 years and hardwood 44 years.

The transgressive stratum, woody stems between 5 feet high and 1 inch dbh, contained 32 species, 23 of which occurred in the understory. Sweetgum was dominant, followed by blackgum (Nyssa sylvatica), hickories, red maple, and pines.

The low woody stratum, stems below 5 feet tall, contained 36 species, 27 of which occurred in the transgressive stratum. Poison ivy (Rhus radicans),

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muscadine (<u>Vitis</u> <u>rotundifolia</u>), greenbrier (<u>Smilax</u> spp.) and red maple dominated this stratum.

The herbaceous stratum contained 55 species, 43 of which were forbs; 9 were grasses, and 3 were sedges. Of these species, 48 were perennials and 7 were annuals. Dioclea (<u>Dioclea</u> <u>multiflora</u>) was the dominant species, followed by spike-grass (<u>Uniola</u> <u>sessiliflora</u>), and nut-rush (<u>Scleria</u> spp.)(McKee 1972, Perkins 1973).

A company road traversed each study area. The forest on a 50-foot-wide strip was cleared, and a 26-foot-wide, dirt/gravel road was made. Road shoulders, about 12 feet wide, were left untended and a secondary successional plant community developed. All roads were bordered by PHF.

METHODS
Point Counts

Point counts (Verner 1985) were conducted at randomly established points in the 3 PHF. While remaining at the point, the observer recorded all birds seen or heard, from March-July 1972 and 1973. Counts began at sunrise and continued for 30 minutes. The 2 observers alternated between the 3 areas and a total of 10 counts was made. Points were at least 100 yards within a PHF, avoiding edges or other habitat types. Only birds thought to be on the sample area (not just flying over) were recorded. Binoculars and a spotting scope facilitated bird identification. A frequency index was calculated for each species (Kricher 1973). We did not estimate bird densities (Verner and Lyman 1985). Scientific names of bird species are listed in the Appendix.

Point counts were also conducted on edges of roads in the 3 PHF. Points along the roads were randomly selected and 12 counts were made during the same time and dates as PHF. Birds seen or heard on or near the road/PHF edges were recorded.

Tape Recorder Counts

Tape recorder counts were conducted by systematically placing a tape recorder (Sony TC 800B with Sony F-26s cardioid dynamic microphones or similar models) in the PHF. Tape recorder points were about 1/4 mile from observer points. The tape recorder was placed on the ground but the microphones were situated about 7 feet above the ground. Nine tape counts were made during the same time and dates as point counts. Tapes were played back and species vocalizations were identified and counted. A frequency index was calculated for each species.

Tape recorder counts (16) were also conducted on road edges. The recorder was placed near the edge of the road and the methods were the same as for those in PHF.

Breeding Bird Census Plot

One breeding bird census plot (Hall 1964) was established in 1 PHF. The plot (25 acres) was divided into 25 1 acre blocks and was censused 13 times in Spring 1973. Territory boundaries for each bird exhibiting territorial behavior were delineated and the size of the territory was measured. Number of territories for each species was counted. In addition, point counts (13) and tape recorder counts (9) were conducted on the plot in Spring/Summer 1973.

Fall/Winter Observations

Project personnel recorded all birds seen or heard in the PHF and road edges while working on other objectives in Fall/Winter (October/February) 1971-72 and 1972-73.

RESULTS
A total of 23 species was observed on point counts (PTS) in PHF. Species with the highest frequency indices (FI) were cardinal, Carolina wren, tufted titmouse, blue jay, summer tanager, and pileated woodpecker (table 1).

Tape recorder counts (TRS) detected 18 species in PHF. Species with the highest FI were cardinal, tufted titmouse, summer tanager, yellow-billed cuckoo, wood thrush, and chipping sparrow. Six species were observed at PTS that were not detected at TRS. The red-eyed vireo was detected at TRS but was not observed on PTS. Of the 24 species observed or recorded, 9 were summer residents and 15 were permanent residents.

On road edges (RDE) 38 species were observed by PTS and 38 were detected by TRS. Ten species were observed by PTS that were not detected by TRS, and 10 species were detected by TRS that were not observed by PTS. Species with the highest FI on PTS were cardinal, summer tanager, Carolina wren, mourning dove, wood thrush, and indigo bunting. Species with the highest FI at TRS were Carolina wren, tufted titmouse, cardinal, and barred owl.

A total of 48 species was observed or recorded by PTS and TRS on RDE. All species, except the red-eyed vireo, observed or recorded in the PHF were also seen or recorded on RDE. Twenty six additional species were observed or recorded on RDE. Of these 26 species, those with the highest FI were Kentucky warbler, chuck-will's-widow, barred owl, rufous-sided towhee, indigo bunting, and yellow-breasted chat. Twenty-one of the 26 species were summer residents.

Table 1. Frequency indices from point and tape recorder counts from the interior and road edges, Spring/Summer 1972 and 1973, and a breeding bird census plot, Spring 1973, in pine-hardwood forests, Kemper County, Mississippi

	Interior		Road edges		Breed. plot	
	Pt	TR	Pt	TR	Pt	TR
Species	cts	cts	cts	cts	cts	Cts
Cardinal	100.0	100.0	100.0	81.3	100.0	100.0
Carolina wren	90.0	33.3	75.0	100.0	76.0	33.3
Tufted titmouse	80.0	100.0	58.3	93.8	76.9	100.0
Blue jay	70.0	33.3	58.3	43.8	61.5	33.3
Summer tanager	60.0	100.0	91.7	50.0	92.3	100.0
Pileated woodpecker	60.0	33.3	41.7	56.3	23.1	33.3
American crow	50.0	33.3	25.0	37.5	7.7	33.3
Carolina chickadee	50.0	55.6	25.0	31.3	76.9	55.6
White-eyed vireo	50.0	22.2	50.0	31.3	53.8	22.2
Mourning dove	40.0	11.1	66.7	37.5	15.4	11.1
Yellow-billed cuckoo	40.0	77.8	58.3	25.0	84.6	77.8
Red-headed woodpecker	30.0	33.3	33.3	12.5	30.8	22.2
Wild turkey	30.0	11.1	8.3	25.0	7.7	11.1
Wood thrush	30.0	66.7	66.7	56.3	38.5	66.7
Red-shouldered hawk	20.0	--	16.7	12.5	--	--
Chipping sparrow	20.0	66.7	50.0	31.3	46.2	66.7
Blue-gray gnatcatcher	20.0	11.1	25.0	6.3	46.2	11.1
Red-bellied woodpecke	10.0	--	--	12.5	--	--
Cooper's hawk	10.0	--	--	--	--	--
Prothonotary warbler	10.0	--	--	6.3	--	--
Northern bobwhite	10.0	--	33.3	31.3	--	--
Great crested flycatcher	10.0	--	16.7	--	7.7	--
Yellow-throated vireo	10.0	11.1	41.7	50.0	15.4	11.1
Red-eyed vireo	--	22.2	--	--	46.2	33.3
Kentucky warbler	--	--	33.3	18.8	--	--
Gray catbird	--	--	8.3	--	--	--
Chuck-will's-widow	--	--	58.3	37.5	--	--
Ruby-throated hummingbird	--	--	8.3	--	--	--
Pine warbler	--	--	16.7	25.0	--	--
Barred owl	--	--	41.7	62.5	--	--
Ruby-crowned kinglet	--	--	8.3	--	--	--
Eastern wood-peewee	--	--	33.3	12.5	23.1	--
Black-and-white warbler	--	--	25.0	--	30.8	--
Rufous-sided towhee	--	--	25.0	43.8	--	--
Whip-poor-will	--	--	8.3	6.3	--	--
Chimney swift	--	--	8.3	--	--	--
Orchard oriole	--	--	16.7	--	--	--
Brown thrasher	--	--	8.3	--	--	--
Indigo bunting	--	--	66.7	18.8	--	--
Yellow-breasted chat	--	--	16.7	6.3	--	--
Blue grosbeak	--	--	8.3	--	--	--
Green heron	--	--	8.3	--	--	--
Brown-headed nuthatch	--	--	--	12.5	--	--
American robin	--	--	--	6.3	--	--
Northern flicker	--	--	--	6.3	--	--
Common grackle	--	--	--	25.0	--	--
Brown-headed cowbird	--	--	--	6.3	7.7	--
White-throated sparrow	--	--	--	6.3	--	--
Bewick's wren	--	--	--	6.3	--	--
Eastern bluebird	--	--	--	6.3	--	--

Table 2. Territory size and number of territories on a breeding bird census plot in a pine-hardwood forest, Spring 1973, Kemper County, Mississippi

Species	Territory size (acres)	Number of territories per 25 acres
Cardinal	3.50	3.5
Summer tanager	2.75	3.5
Tufted titmouse	3.75	3.5
Carolina chickadee	2.75	3.0
Blue-gray gnatcatcher	1.25	3.0
Black-and-white warbler	0.50	2.5
Chipping sparrow	2.25	2.5
Carolina wren	2.25	2.0
Blue jay	> 5.00	2.0
White-eyed vireo	1.50	2.0
Red-eyed vireo	2.25	2.0
Red-headed woodpecker	> 3.00	2.0
Yellow-throated vireo	1.50	1.5
Wood thrush	> 5.00	1.5
Eastern wood-peewee	1.25[a]	1.0
Pileated woodpecker	--	--
Mourning dove	--	--

[a] Not determined

Seventeen species exhibited territorial behavior on the plot (table 2). Most prominent were cardinal, summer tanager, and tufted titmouse, with 3.5 territories each. Territory size (5 acres) was largest for the blue jay and wood thrush.

A total of 22 species was observed by PTS and 18 by TRS on the breeding bird plot (table 1). The yellow-billed cuckoo had high FI on PTS and TRS but did not exhibit territorial behavior.

In the fall/winter, 35 species were observed in the PHF. No species was considered to be abundant, 14 species were common, and 21 species were rare. Only 9 species (dark-eyed junco, brown creeper, ruby-crowned kinglet, eastern phoebe, white-throated sparrow, hermit thrush, yellow-rumped warbler, palm warbler, and yellow-bellied sapsucker) were thought to be winter residents, the other species were transients.

Forty-one species were observed on RDE in the fall/winter. Ten species not seen in PHF were seen on RDE. Three species (chipping sparrow, field sparrow, and yellow-rumped warbler) were rated as abundant, 22 were common, and 16 were rare (Perkins 1973).

DISCUSSION

Twenty-four species were observed in PHF and twice as many (48) were observed on RDE in spring-summer. Twenty-six species were observed only on RDE. Lay (1938) reported that the edge of a forested area contained more birds and more bird species than areas within the forest. Similarly, Strelke and Dickson (1980) found that the number of breeding bird species, species diversity, and abundance were higher at or in pine-hardwood forest edges than in the forest interior or adjacent clearcuts in Texas. O'Meara and others (1985) found that the highest bird densities, in all seasons, occurred in edge habitats in Bradford County, Florida. The edges and early successional plant communities on road shoulders will be maintained by control burning the pine plantations and by removal of all pine trees (to a depth of 25 feet) on road edges.

In southern forests, 15 species were listed as preferring deciduous and coniferous (hardwood-pine) type forest for breeding (Shugart and others 1978). The cardinal was not on this list. Of the 15 species, only 1, the Carolina chickadee, was found to be breeding in the PHF in Mississippi. Dickson and others (1980) rated 15 species as Present, 12 as Regular, and 7 as Common in the pine-hardwood forest type. Our data agree with their ratings for Common species, except the Kentucky warbler was not common in our study areas in PHF.

A total of 17 species exhibited territorial behavior in the PHF. More species, such as hawks, owls, and wild turkey, undoubtedly nest in the PHF (Perkins 1973). Only 1 census plot was used. Myers and Johnson (1978) reported 20 breeding species in mesic PHF. Five species (blue-gray gnatcatcher, chipping sparrow, white-eyed vireo, red-headed woodpecker, and mourning dove) showed breeding behavior in PHF of Mississippi but were not listed by Meyers and Johnson (1978).

Dickson and Segelquist (1979) noted territorial behavior by 18 species in pine-hardwood forests (sawtimber, 65 years old) in east Texas. Their most numerous species were cardinal, red-eyed vireo, Carolina wren, and tufted titmouse. Eleven species were found both in Texas and Mississippi, but 6 were found breeding in Mississippi and 5 (4 warblers) in Texas that were not found in the other state.

Childers and others (1986) found 18 species of breeding pairs in second growth PHF in the central Piedmont of Virginia. The more abundant breeders were red-eyed vireo, ovenbird, scarlet tanager, and blue jay. Ten species were common to Mississippi and Virginia, with 8 in Virginia and 7 in Mississippi not recorded for the other state. The cardinal was not listed as a breeding species in central Virginia.

Noble and others (1980) reported that the highest breeding bird population (1888/100 acres) occurred in a PHF in Livingston Parish, Louisiana. This forest was uneven-aged, had many over-mature trees, and had not been disturbed for at least 50 years. They observed 32 species of breeding birds in this forest.

Only 9 of the 35 species observed in PHF were winter residents. Dickson and Segelquist (1978) reported 15 species in the PHF in east Texas from January-March (winter). Forty-one species were observed on RDE next to PHF. Most of these were also transients.

In the PHF, more species were observed by point counts than by tape recorder counts, and the FI changed for some species according to sample type. Tape recorders were thought to be more sensitive than human ears, were not distracted, were economical, and yielded an irrefutable record of bird vocalizations. However, tape recorders had mechanical problems, lacked subjectivity about bird location, and some persistent, vociferous birds received too much emphasis. A bird very close to the microphones could obliterate less vociferous birds. Tape recorders only detect singing birds, so they can not replace human sight/hearing.

No species was found to be unique to PHF (Perkins 1973). Several of the species were considered ubiquitous species (Dickson and others 1980). The only endangered species, red-cockaded woodpecker, was rarely seen in the PHF.

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Appendix Table 1. Scientific names of birds in the text.

Species	Scientific name	Species	Scientific name
Cardinal	Cardinalis cardinalis	American robin	Turdus migratorius
Carolina wren	Troglodytes ludovicianus	Northern flicker	Colaptes auratus
Winter wren	T. troglodytes	Common grackle	Quiscalus quiscula
Tufted titmouse	Parus bicolor	Brown-headed cowbird	Molothrus ater
Carolina chickadee	P. carolinensis	White-throated sparrow	Zonotrichia albicollis
Blue jay	Cyanocita cristata	Bewick's wren	Thryomanes bewickii
Summer tanager	Piranga rubra	Eastern bluebird	Sialia sialis
Scarlet tanager	P. olivacea	Yellow-rumped warbler	Dendroica coronata
Pileated woodpecker	Dryocopus pileatus	Acadian flycatcher	Empidonax virescens
American crow	Corvus brachyrhynchos	Ovenbird	Seiurus aurocapillus
White-eyed vireo	Vireo griseus	Hermit thrush	Catharus guttatus
Yellow-throated vireo	V. flavifrons	Red-cockaded woodpecker	Picoides borealis
Red-eyed vireo	V. olivaceus	Eastern phoebe	Sayornis phoebe
Mourning dove	Zenaida macroura		
Yellow-billed cuckoo	Coccyzus americanus		
Red-headed woodpecker	Melanerpes erythrocephalus		
Red-bellied woodpecker	M. carolinus		
Wild turkey	Meleagris gallopavo		
Wood thrush	Hylocichla mustelina		
Red-shouldered hawk	Buteo lineatus		
Chipping sparrow	Spizella passerina		
Field sparrow	S. pusilla		
Blue-gray gnatcatcher	Polioptila caerulea		
Cooper's hawk	Accipiter cooperii		
Prothonotary warbler	Protonotaria citrea		
Northern bobwhite	Colinus virginianus		
Great crested flycatcher	Myiarchus crinitus		
Kentucky warbler	Oporornis formosus		
Gray catbird	Dumetella carolinensis		
Chuck-will's-widow	Caprimulgus carolinensis		
Ruby-throated hummingbird	Archilochus colubris		
Pine warbler	Dendroica pinus		
Barred owl	Strix varia		
Ruby-crowned kinglet	Regulus calendula		
Golden-crowned kinglet	R. satrapa		
Eastern wood-peewee	Contopus virens		
Black-and-white warbler	Mniotilta varia		
Rufous-sided towhee	Pipilo erythrophthalmus		
Whip-poor-will	Caprimulgus vociferus		
Chimney swift	Chaetura pelagica		
Orchard oriole	Icterus spurius		
Brown thrasher	Toxostoma rufum		
Indigo bunting	Passerina cyanea		
Yellow-breasted chat	Icteria virens		
Blue grosbeak	Guiraca caerulea		
Green heron	Butorides virescens		
Brown-headed nuthatch	Sitta pusilla		
White-breasted nuthatch	S. carolinensis		

AVIAN COMMUNITIES OF PINE-HARDWOOD FORESTS IN THE SOUTHEAST: CHARACTERISTICS, MANAGEMENT, AND MODELING

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Abstract. —We used information on wildlife habitat relationships to predict the effects of forest management actions on avian species in southeastern pine-hardwood forests, and compared our predictions to published field studies. Pine-hardwood forests provide optimal or suitable habitat for more wintering bird species than loblolly-shortleaf pine or oak-hickory forests and for more breeding bird species than loblolly-shortleaf pine forests. If all the pine-hardwood stands in a forest were converted to loblolly-shortleaf pine or oak-hickory stands, up to 9 bird species probably would be extirpated from the forest. Generally, at least twice as many species were predicted to be negatively affected by clearcutting than positively affected for all combinations of stand age, time of effect, and season that were examined. A large number of bird species was predicted to be negatively affected immediately after burning, but this effect would only last about a year, and then many of these species were predicted to be positively affected for 5 to 10 years. There were many more species for which we could not predict the effects of thinning than for which a prediction could be made. A substantial number of bird species were predicted to be negatively affected by the removal of snags during clearcutting or thinning.

INTRODUCTION

Forest management that alters the composition or structure of forest vegetation will affect wildlife habitat and populations. In the past, forest managers usually considered the effect of forest management only on game species. However, many forest managers must now consider the effects of forest management on all wildlife. The National Environmental Policy Act of 1969 requires that the environmental impacts of any federally funded land management program be examined and evaluated. The Endangered Species Act of 1973 mandates that endangered and threatened species on Federal lands be protected and managed, and prohibits adverse impacts on critical habitat for endangered and threatened species. Also, the National Forest Management Act of 1976 directs National Forest managers to manage for biological diversity and maintain viable populations of all native and desirable exotic vertebrates. These and other laws and regulations have greatly increased the demand for information on the effects of forest management on all wildlife species.

The most reliable sources of information for evaluating the effects of forest management on wildlife are experimental field studies. However, very few of these studies have been done in pine-hardwood forests. Also, these studies often provide good information only for species that are most abundant and easiest to census. These may not be the most important species, and are certainly not the only species that need consideration.

Another approach to assess forest management is to use information on wildlife habitat relationships to predict the effects of forest management on wildlife. If we understand the habitat ecology of a species and we know how a forest management action affects the habitat, we should be able to predict the effect on the species. These predictions can provide managers with information for current planning and can be used by researchers as working hypotheses.

Our objective was to use wildlife habitat relationships to predict the effects of forest management actions on avian species in southeastern pine-hardwood forests. We examined the effects of clearcutting, controlled burning, and thinning on bird species that commonly use southeastern pine-hardwood forests. We then compared our predictions to the results of the few published field studies on the effects of forest management on birds in southeastern pine-hardwood forests. Pine-hardwood stands in the southeast often are converted to loblolly pine (Pinus taeda) and/or shortleaf pine (P. echinata) stands, or, because of lack of site preparation, regenerate to oak-hickory stands. Therefore, we compared the suitability of loblolly-shortleaf pine, oak-hickory, and pine-hardwood stands for birds.

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METHODS

We developed our models from an extensive review of avian habitat relationships on southeastern forest lands compiled by Hamel and others (1982). This review is a synthesis of the literature and expert opinions. Some of the information has not been empirically verified; however, it is the best comprehensive source of information about avian habitat relationships on southeastern forest lands presently available.

For each bird species that Hamel and others (1982) listed as commonly using pine-hardwood forests in the Southeast, we entered the following information into a computer data base: a habitat suitability rating of optimal, suitable, marginal, or unsuitable for each of 4 successional stages (grass-forb, shrub-seedling, sapling-pole timber, and sawtimber); whether the species uses bare soil, thick deciduous leaf litter, herbaceous ground cover, shrubs, midstory canopy, overstory canopy, or dead trees or limbs; and whether the species requires closed canopy, open canopy, snags, or slash. Hamel and others (1982) defined optimal habitat as habitat in which the species occurs in highest frequency, greatest numbers, or both. Suitable and marginal habitats were defined as habitats in which the species occurs in successively lower numbers and frequency. A habitat was considered unsuitable if the species was unlikely to occur in that habitat. All species information was separated into breeding and wintering habitat.

We examined the effects of clearcutting both pine-hardwood sawtimber and pole timber. The effects of clearcutting sawtimber were predicted for 3 time periods; immediate effects, short-term effects, and long term effects. To predict the immediate effects of clearcutting sawtimber we compared the habitat suitability rating of sawtimber to the habitat suitability rating of the grass-forb successional stage for each species. If the habitat suitability rating was greater for the grass-forb successional stage than for sawtimber, a positive effect was predicted (optimal suitable marginal unsuitable). If the habitat suitability rating was less for the grass-forb successional stage than for sawtimber, a negative effect was predicted. If the habitat suitability rating was equal in the grass-forb successional stage and in sawtimber, no effect was predicted. We used the same process to predict the short-term effects of clearcutting sawtimber except that the habitat suitability rating of the shrub-seedling successional stage was compared to the habitat suitability rating of sawtimber. To predict the long-term effects of clearcutting sawtimber, we compared the habitat suitability rating of the sapling-pole timber successional stage to the habitat suitability rating of sawtimber. We predicted

the immediate and short-term effects of clearcutting pole timber as defined above, except that pole timber was compared to the grass-forb and shrub-seedling successional stages.

The time period for each of the successional stages varies with site conditions. Therefore, the time periods associated with the immediate, short-term, and long-term effects of clearcutting are best determined by local managers.

We also examined the effect of snag removal during clearcutting. A species was predicted to be negatively affected by snag removal if the species required or used snags and the species had an optimal or suitable habitat rating in the grass-forb or shrub-seedling successional stages. Snag removal probably has little effect on species for which the habitat is marginal or unsuitable, and most snags left during clearcutting probably do not last past the shrub-seedling successional stage (Dickson and others 1983).

The effects of controlled burning and thinning were predicted based on habitat components that each species required or used. From a literature review we determined the effects of burning and thinning on habitat components. If a treatment increased 1 or more habitat components required or used by a species, the effect was predicted to be positive for that species. The effect was predicted to be negative for a species if a treatment decreased 1 or more habitat components required or used by that species. If a treatment increased and decreased habitat components required or used by a species, we could not predict the effect. We predicted the treatment would have no effect on species that did not require or use any of the habitat components affected by a treatment.

We determined that the immediate effects of burning are decreases in deciduous leaf litter, herbaceous ground cover, shrubs, slash, and snags and an increase in the amount of bare soil (Dickson 1981; Lander 1987; Lewis and others 1982; O'Halloran and others 1987; Van Lear and Johnson 1983; Wood and Niles 1978). Leaf litter, herbaceous ground cover, shrubs, snags, and slash are consumed by the fire, leaving more bare soil. These immediate effects usually last about a year, but the time period varies with site conditions. The short-term effects that follow are increases in herbaceous ground cover and shrubs, and a continued absence of slash (Cushwa and others 1969; Dickson 1981; Lander 1987; Lewis and others 1982; O'Halloran and others 1987; Resler 1972; Van Lear and Johnson 1983; Wood and Niles 1978). Fire stimulates the growth of herbaceous ground cover and shrubs, and after about a year they increase beyond the amount present before burning (Cushwa and others 1969; Dickson 1981; Lewis and

others 1982; Resler 1972; Van Lear and Johnson 1983; Wood and Niles 1978). Deciduous leaf litter returns to about the previous depth in 1 to 2 years (O'Halloran and others 1987). The increase in herbaceous ground cover and leaf litter restores the amount of bare soil to about the amount present before burning. Snags consumed by fire often are replaced within a few years by trees killed by fire (Lander 1987; Van Lear and Johnson 1983). However, slash consumed by fire usually is not replaced. The short-term effects of burning may last from 5 to 10 years; the time period depends on the site conditions.

We determined that thinning decreases overstory canopy and midstory canopy and increases herbaceous ground cover, shrubs, and slash (Dickson 1981; Hooper 1978; McComb 1982; Zeedyk and Evans 1975). The removal of trees decreases the overstory and midstory canopies which allows more light to reach the forest floor, which stimulates herbaceous ground cover and shrub growth (Dickson 1981; Hooper 1978; McComb 1982; Zeedyk and Evans 1975). Slash piles are usually created when trees are cut. The effects of thinning may last from 5 to 10 years; the time period depends on the site conditions. We also examined the effect of snag removal during thinning. A species was predicted to be negatively affected by snag removal if the species required or used snags.

We examined the effects of controlled burning on avian species in sawtimber, pole timber, and clearcuts (grass-forb successional stage) and the effects of thinning on avian species in sawtimber and pole timber, because these are likely management actions. Effects were predicted only for species with an optimal or suitable habitat rating in the successional stage under consideration. Habitat changes caused by burning or thinning probably have little effect on species for which the successional stage is marginal or unsuitable habitat.

We also used information from Hamel and others (1982) to compare the suitability of loblolly-shortleaf pine, oak-hickory, and pine hardwood stands for birds. We determined the number of breeding and wintering bird species that had an optimal or suitable habitat rating in each of the successional stages of pine-hardwood, loblolly-shortleaf pine, and oak-hickory forests. We also determined the number of breeding and wintering bird species that had an optimal or suitable habitat rating in 1 or more of the successional stages of pine-hardwood forests but did not have an optimal or suitable habitat rating in any successional stage of loblolly-shortleaf pine forests or oak-hickory forests.

Throughout the modeling, all bird species that were listed by Hamel and others (1982) as commonly using pine-hardwood forests in the Southeast were included. All the species may not be present in a particular forest. This should be considered when interpreting summaries such as the number of species positively affected by clearcutting sawtimber. Local managers need to determine which species are present in their forests. Hamel and others (1982) provide range maps and other information that is useful. Field guides, state data bases, and local birding clubs also may be helpful.

RESULTS AND DISCUSSION
Characteristics and Importance of Pine-Hardwood Forests

The number of bird species with an optimal or suitable habitat rating generally increased with the age of the successional stage in all 3 forest types (table 1). Sawtimber can provide optimal or suitable habitat for more than twice as many species as any other successional stage in all 3 forest types, except for wintering birds in the sapling-pole timber stage (table 1). A general increase in the number of breeding bird species present as ecological age increased, with mature forests having the greatest number of breeding bird species, was found in upland seres in Georgia (Johnston and Odum 1956) and Arkansas (Shugart and James 1973), and in oak-chestnut seres in North Carolina (Odum 1950). These results indicate the importance of mature forests to many bird species and to the maintenance of biological diversity.

Table 1.-- The number of breeding and wintering bird species with an optimal or suitable habitat rating in each successional stage and for all stages combined of pine-hardwood, loblolly-shortleaf pine, and oak-hickory forests in the Southeast (data compiled from Hamel and others 1982).

Season/forest type	Grass-forb	Shrub-seedling	Sapling-pole	Saw-timber	All stages
Breeding					
Pine-hardwood	12	14	16	43	62
Loblolly-shortleaf	10	11	13	29	46
Oak-hickory	13	17	15	49	73
Wintering					
Pine-hardwood	21	14	34	46	65
Loblolly-shortleaf	20	13	28	41	56
Oak-hickory	19	12	15	27	48

Pine-hardwood forests can provide optimal or suitable habitat for more wintering bird species than loblolly-shortleaf pine or oak-hickory forests and for more breeding bird species than loblolly-shortleaf pine forests (table 1). Pine-hardwood forests provide optimal or suitable habitat for 21 breeding species and 16 wintering species for which loblolly-shortleaf pine forests do not. Pine-hardwood forests also provide optimal or suitable habitat for 10 breeding species and 23 wintering species for which oak-hickory forests do not. Pine-hardwood

forests provide optimal or suitable habitat for 3 breeding species (long-eared owl [see appendix for scientific names], black-throated green warbler, and Bachman's sparrow) for which neither loblolly-shortleaf pine or oak-hickory forests provide optimal or suitable breeding habitat. Pine-hardwood forests also provide optimal or suitable habitat for 6 wintering species (turkey vulture, black vulture, ruffed grouse, chuck-will's-widow, black-and-white warbler, and ovenbird) for which neither loblolly-shortleaf pine or oak-hickory forests provide optimal or suitable wintering habitat.

These comparisons indicate the importance of pine-hardwood forests to avian species. Conversion of a pine-hardwood stand to a loblolly-shortleaf stand would likely decrease the number of bird species for which that stand can provide good habitat and can negatively affect a large number of bird species. Conversion of a pine-hardwood stand to an oak-hickory stand can also negatively affect a large number of bird species. If all the pine-hardwood stands in a forest were converted to loblolly-shortleaf pine or oak-hickory stands, up to 9 bird species would likely be extirpated from the forest. Therefore, to maintain biological diversity and populations of all native vertebrates, pine-hardwood stands should be maintained in forests where they naturally occur.

Clearcutting

The predictions of the effects of management practices on each species are in the appendix. Generally, at least twice as many species were predicted to be negatively affected than positively affected for all combinations of treatment, time period and season (table 2). Combining breeding and wintering species, the numbers of species predicted to be positively affected at some time (i.e. during at least 1 of the time periods) by clearcutting sawtimber and pole timber were 53 and 49 respectively and the numbers of species predicted to be negatively affected by clearcutting sawtimber and pole timber at some time were 85 and 80 respectively. Only 4 species that were predicted to be affected at some time by clearcutting, were predicted to be positively affected during 1 time period and negatively affected during another. Also, almost all the species predicted to be affected by clearcutting were predicted to be affected the same way by sawtimber and pole timber clearcutting. It is worth noting that the predicted long-term effect of clearcutting sawtimber is positive for far fewer species than for any other treatment and time period. This implies that pole timber provides better habitat than sawtimber for only a very few species.

Table 2.--Numbers of breeding and wintering bird species predicted to be positively affected (+), negatively affected (-), and unaffected (=) by clearcutting.

Treatment/time of effect	Breeding			Wintering		
	+	-	=	+	-	=
Clearcutting sawtimber						
Immediate	27	65	44	33	61	42
Short-term	20	57	59	22	52	62
Long-term	4	42	90	3	28	105
Clearcutting pole timber						
Immediate	27	52	52	32	57	47
Short-term	17	48	71	20	47	69

We found 2 published field studies of the effects of clearcutting on birds in pine-hardwood forests. Conner and others (1979) censused breeding and wintering birds in a 3-year-old clearcut, a 10-year-old clearcut, a 30-year-old stand, and a mature stand. They found more breeding and wintering bird species in the mature stand than in any of the other stands. The number of breeding species they found increased with stand age. Conner and others (1979) concluded that pileated woodpeckers, hairy woodpeckers, scarlet tanagers, red crossbills, pine warblers, and ovenbirds were associated with older stands. We predicted that clearcutting would have a negative effect on all these species. They also concluded that northern flickers, prairie warblers, indigo buntings, yellow-breasted chats, white-eyed vireos (Vireo griseus), and field sparrows were associated with the younger stands. We predicted that clearcutting would have a positive effect on all these species except northern flickers, for which we predicted a negative effect and white-eyed vireos, which were not listed by Hamel and others (1982) as commonly using southeastern pine-hardwood forests.

Strelke and Dickson (1980) censused breeding birds in 2 pine-hardwood stands (30 years old) and adjacent clearcuts (years old). There was no significant difference in the number of species that they found in the forests and the clearcuts but the mean number of species they found was 3.6 in each area. Strelke and Dickson (1980) concluded that yellow-billed cuckoos, blue jays, summer tanagers, tufted titmice, red-eyed vireos, pine warblers, and black-and-white warblers were associated with the older forest. We predicted that all these species would be negatively affected by clearcutting. They also concluded that blue grosbeaks, indigo buntings, yellow-breasted chats, and prairie warblers were associated with clearcuts, which we predicted would be positively affected by clearcutting.

The greater number of bird species negatively affected by clearcutting results because sawtimber provides the best habitat for more bird species than any other successional stage, and in the absence of sawtimber, pole timber provides the best habitat for more bird species than the earlier successional stages. The best habitat is provided by sawtimber for 42 breeding bird species and 27 wintering species (ie. sawtimber has a better habitat rating than any other successional stage for these species), by pole timber for 1 breeding species and no wintering species, by the shrub-seedling successional stage for 13 breeding species and 4 wintering species, and by the grass-forb successional stage for 20 breeding species and 24 wintering species. In the absence of sawtimber, pole timber provides the best habitat for 47 breeding species and 45 wintering species, but the number of species does not change for the shrub-seedling and grass-forb successional stages. Also, sawtimber can provide optimal or suitable habitat for more than twice as many species as any other successional stage, except for wintering birds in the sapling-pole timber stage (table 1).

There are a large number of bird species in southeastern pine-hardwood forests that are associated with sawtimber and, to a lesser degree, pole timber. For many of these species sawtimber provides optimal habitat, and pole timber provides suitable or marginal habitat, but the earlier successional stages provide only marginal or unsuitable habitat. Therefore, to maintain biological diversity, a large portion of any pine-hardwood forest should be sawtimber.

Considering species affected in the grass-forb and shrub-seedling successional stages, 5 breeding and 3 wintering bird species were predicted to be negatively affected by the removal of snags during clearcutting. Three of the breeding species and 2 of the wintering species were otherwise predicted to be positively affected by clearcutting. The removal of snags probably would make clearcuts unsuitable habitat for these species. Thus, the removal of snags during clearcutting is likely to decrease the number of species positively affected and increase the number of species negatively affected by clearcutting.

Dickson and others (1983) censused breeding birds in 4 plots with snags and 4 plots without snags in a pine-hardwood clearcut planted with loblolly pine. They found significantly more bird species in the plots with snags than in the plots without snags. They found red-headed, hairy, downy, and red-bellied woodpeckers, and Carolina chickadees almost exclusively on the plots with snags. We did not predict the effect of snag removal during clearcutting on these species because they did not have an

optimal or suitable habitat rating in clearcuts. The geographic location (Texas) or the planting of loblolly pine may have affected the habitat suitability for some species, and our examination of species only with optimal or suitable habitat ratings may have been too conservative. Dickson and others (1983) also found that Carolina wrens, northern cardinals, brown-headed cowbirds, and yellow-breasted chats were substantially more abundant or more detectable in plots with snags. We predicted that snag removal would negatively affect all of these species except northern cardinals, for which we made no prediction.

Our predictions and the study by Dickson and others (1983) indicate that the removal of snags during clearcutting will cause the clearcut to be unsuitable habitat for several species. Therefore, when possible, snags should be retained during clearcutting.

Controlled Burning

For all the successional stages considered, no species were predicted to be positively affected and a substantial number of species were predicted to be negatively affected immediately after burning (table 3). However, the short-term effect of burning was predicted to be positive for a large number of species and negative for 0 or 1 species in all the successional stages considered (table 3). The species for which the short-term effect of burning was predicted to be positive were those for which the immediate effect of burning was predicted to be negative or could not be predicted. These species all use herbaceous ground cover and/or shrubs which decrease immediately after burning but then increase. Most of the species for which the immediate effects of burning could not be predicted were species that use both bare soil, which increases, and herbaceous ground cover, which decreases. Many of these species also use shrubs or leaf litter, which decrease immediately after burning. Therefore, they probably would be negatively affected immediately after burning.

Table 3.--Numbers of breeding and wintering bird species predicted to be positively affected (+), negatively affected (-), and unaffected (=) by controlled burning; and for which the effect of controlled burning could not be predicted (?).

Treatment/ time of effect	Breeding				Wintering			
	+	-	=	?	+	-	=	?
Burning sawtimber								
Immediate	0	17	6	20	0	20	4	22
Short-term	28	1	13	1	33	1	10	2
Burning pole timber								
Immediate	0	7	0	9	0	15	3	16
Short-term	13	0	2	1	27	0	5	2
Burning clearcuts								
Immediate	0	7	0	5	0	7	0	14
Short-term	10	0	0	2	18	0	0	3

Pileated woodpeckers, the only species for which the short-term effect of burning was predicted to be negative, use slash, which are consumed by burning. The few species for which the short-term effect of burning could not be predicted also use slash. We found no published field studies of the effects of controlled burning on birds in southeastern pine-hardwood forests.

With the exception of a few species that use slash, the overall effect of controlled burning is likely to be positive for birds in pine-hardwood forests. Although a substantial number of species were predicted to be negatively affected immediately after burning, this effect would only last about a year and then many of these species would likely be positively affected for 5 to 10 years. Because the immediate effect of burning is negative, it would be best to burn areas that are as small as possible and to schedule burning so that adjacent areas are not burned during a short time period.

Thinning

There were many more species for which a prediction could not be made than for which a prediction could be made concerning thinning (table 4). Most of the species for which the effect of thinning could not be predicted feed in herbaceous ground cover and/or shrubs which increase, but they also feed, nest, or roost in the overstory and/or midstory canopies, which decrease. Patterns in the numbers of the relatively few species for which the effect of thinning could be predicted may not be representative of the large number of species for which the effect of thinning could not be predicted.

Table 4.--Numbers of breeding and wintering bird species predicted to be positively affected (+), negatively affected (-), and unaffected (=) by thinning; and for which the effect of thinning could not be predicted (?).

Treatment	Breeding				Wintering			
	+	-	=	?	+	-	=	?
Thinning pole timber	1	0	2	13	4	3	2	25
Thinning sawtimber	2	11	2	28	4	7	3	32

We found 2 field studies of the effects of thinning on birds in southeastern pine-hardwood forests. Mc-Comb and Noble (1980) censused birds for a year on a thinned plot and an unthinned plot in a pine-hardwood forest in Mississippi. They detected about the same number of species on each plot (47 on the thinned plot, 44 on the unthinned plot). They made conclusions for only 5 bird species. They concluded that Carolina chickadees, yellow-rumped warblers, white-throated sparrows, and northern cardinals were positively affected by thinning and that red-eyed vireos were negatively affected. Their conclusions agreed with our predictions for northern cardinals and red-eyed vireos. We could not predict the effects of thinning on the other 3 species.

Garrison (1986) censused breeding birds in a thinned and an unthinned pine-hardwood stand. He found significantly more eastern wood-pewees, wood thrushes, hooded warblers, and rufous-sided towhees and significantly fewer downy and hairy woodpeckers, great crested flycatchers, and red-eyed vireos in the thinned stand than in the unthinned stand. Our predictions agreed with his data for hairy woodpeckers, great crested flycatchers, and red-eyed vireos and disagreed for eastern wood-pewees. We could not predict the effects of thinning on the other 4 species. Because of the difficulty of predicting the effects of thinning on avian species using habitat relationships and the lack of field studies, there is a great need for research on the effects of thinning on avian species in southeastern pine-hardwood forests.

Fourteen breeding and 10 wintering bird species were predicted to be negatively affected by the removal of snags from sawtimber during thinning, and 5 breeding and 4 wintering species were predicted to be negatively affected by the removal of snags from pole timber during thinning. Many of these species require the presence of snags for suitable habitat. Sawtimber and pole timber are the only successional stages that can provide optimal or suitable habitat for most of these species. Therefore, the removal of snags from sawtimber and pole timber could extirpate some of these species from the area. Thus, to maintain biological diversity and populations of all vertebrate species, snags should not be removed from sawtimber or pole timber while thinning.

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Appendix.--Predicted effects of clearcutting, burning, and thinning on avian species in pine-hardwood forests

Species	H[a]	*Clearcutting[b]* 1	2	3	4	5	6	7	*Burning[c]* 1	2	3	4	5	6	*Thinning[d]* 1	2	3	4
Turkey vulture	B	-[e]	-	=	-	-			?	+	?	+			?	=	?	=
Cathartes aura	W	-	-	=	-	-			?	+	?	+			?	=	?	=
Black vulture	B	-	-	=	-	-			?	+	?	+			?	=	?	=
Coragyps atratus	W	-	-	=	-	-			?	+	?	+			?	=	?	=
American swallow-tailed kite	B	-	-	-	=	=												
Elanoides forficatus	W	=	=	=	=	=												
Mississippi kite	B	-	-	-	=	=												
Ictinia mississippiensis	W	=	=	=	=	=												
Sharp-shinned hawk	B	-	-	-	-	-			?	+					?	=		
Accipiter striatus	W	-	-	=	-	-			?	+	?	+			?	=	?	=
Cooper's hawk	B	-	-	-	-	-			?	+					?	=		
A. cooperii	W	-	-	=	-	-			?	+	?	+			?	=	?	=
Red-tailed hawk	B	-	-	-	=	=			?	+					?	-		
Buteo jamaicensis	W	-	-	-	=	-	-	-	?	+	?	+	?	?	?	-	?	-
Broad-winged hawk	B	-	-	-	=	=			?	+					?	=		
B. platypterus	W	=	=	=	=	=												
Rough-legged hawk	B	=	=	=	=	=												
B. lagopus	W	+	=	=	+	=	=						?	+				
Golden eagle	B	=	=	=	=	=												
Aquila chrysaetos	W	+	=	=	+	=												
Bald eagle	B	-	-	-	=	=												
Haliaeetus leucocephalus	W	-	-	=	-	-												
Northern harrier	B	=	=	=	=	=												
Circus cyaneus	W	+	=	=	+	=	=						?	+				
American kestrel	B	+	=	=	+	=	-						?	?				
Falco sparverius	W	+	+	=	+	+	-						?	?				
Ruffed grouse	B	-	=	+	-	-					?	+					?	=
Bonasa umbellus	W	-	-	=	-	-			?	+	?	+			?	=	?	=

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[a]B = breeding habitat, W = wintering habitat.
[b]Numbers represent age class and time of effect: 1 = sawtimber/immediate, 2 = sawtimber/short-term, 3 = sawtimber/long-term, 4 = pole timber/immediate, 5 = pole timber/short-term, 6 = snag removal/immediate, 7 = snag removal/short-term.
[c]Numbers represent age class and time of effect: 1 = sawtimber/immediate, 2 = sawtimber/short-term, 3 = pole timber/immediate, 4 = pole timber/short-term, 5 = clearcut/immediate, 6 = clearcut/short-term.
[d]1 = sawtimber, 2 = snag removal from sawtimber, 3 = pole timber, 4 = snag removal from pole timber.
[e]- indicates the species would be negatively affected; +, positively affected; =, unaffected, ?, can not predict; blank, the species had a marginal or unsuitable habitat rating in that successional stage.

Species	H	Clearcutting							Burning						Thinning			
		1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4
Northern bobwhite	B	+	+	=	+	+	=	=					?	+				
Colinus virginianus	W	+	+	=	+	+	=	=					?	+				
Ring-necked pheasant	B	+	=	=	+	=	=						?	+				
Phasianus colchicus	W	+	=	=	+	=	=						?	+				
Wild turkey	B	-	-	-	-	-			?	+					?	=		
Meleagris gallopavo	W	-	-	=	-	-			?	+	?	+			?	=	?	=
American woodcock	B	-	-	-	-	-			?	+					+	=		
Scolopax minor	W	-	-	-	=	=			?	+					+	=		
Upland sandpiper	B	+	=	=	+	=	=						-	+				
Bartramia longicauda	W	=	=	=	=	=												
Rock dove	B	+	=	=	+	=												
Columba livia	W	+	=	=	+	=												
Mourning dove	B	=	+	+	-	=	=	=	?	+	?	+	?	+	?	=	?	=
Zenaida macroura	W	=	=	=	=	=	=	=	?	+	?	+	?	+	?	=	?	=
Common ground dove	B	=	+	=	=	+												
Columbina passerina	W	+	+	=	+	+												
Yellow-billed cuckoo	B	-	-	=	-	-												
Coccyzus americanus	W	=	=	=	=	=												
Black-billed cuckoo	B	-	-	-	-	-												
C. erythropthalmus	W	=	=	=	=	=												
Common barn-owl	B	+	+	=	+	+	-						?	?				
Tyto alba	W	+	+	=	+	+	-						?	?				
Eastern screech-owl	B	-	-	-	-	-			?	+					?	-		
Otus asio	W	-	-	-	-	-			?	+					?	-		
Great horned owl	B	-	-	-	=	=			?	+					?	=		
Bubo virginianus	W	-	-	-	-	-			?	+					?	=		
Long-eared owl	B	-	-	-	-	-			?	+					?	=		
Asio otus	W	-	=	=	-	=												
Short-eared owl	B	=	=	=	=	=												
A. flammeus	W	+	=	=	+	=												
Northern saw-whet owl	B	=	=	=	=	=												
Aegolius acadicus	W	-	=	=	-	=												
Chuck-will's widow	B	-	-	-	-	-			-	=	-	=			=	=	=	=
Caprimulgus carolinensis	W	-	-	=	-	-			-	=	-	=			=	=	=	=
Whip-poor-will	B	-	-	-	-	-			-	=	-	=			=	=	=	=
C. vociferus	W	-	-	-	-	-			-	=	-	=			=	=	=	=
Ruby-throated hummingbird	B	-	=	=	-	=												
Archilochus colubria	W	=	=	=	=	=												
Northern flicker	B	-	-	-	-	-			?	+					?	-		
Colaptes auratus	W	-	-	-	=	=			?	+					?	-		
Pileated woodpecker	B	-	-	-	-	-			-	-					?	-		
Dryocopus pileatus	W	-	-	-	-	-			-	-					?	-		
Red-bellied woodpecker	B	-	-	-	-	-			-	=					-	-		
Melanerpes carolinus	W	-	-	-	-	-			-	=					-	-		
Red-headed woodpecker	B	-	-	=	-	-												
M. erythrocephalus	W	-	-	=	-	-												

Species	H	\(C\)1	2	3	4	5	6	7	\(B\)1	2	3	4	5	6	\(T\)1	2	3	4
Yellow-bellied sapsucker	B	=	=	=	=	=												
Sphyrapicus varius	W	-	-	-	-	-			-	+	-	+			?	-	?	-
Hairy woodpecker	B	-	-	-	-	-			-	=					-	-		
Picoides villosus	W	-	-	-	-	-			-	=					-	-		
Downy woodpecker	B	-	-	-	-	-			-	+	-	+			?	-	?	-
P. pubescens	W	-	-	-	-	-			-	+	-	+			?	-	?	-
Red-cockaded woodpecker	B	-	-	=	-	-												
P. borealis	W	-	-	=	-	-												
Eastern kingbird	B	+	=	=	+	=												
Tyrannus tyrannus	W	=	=	=	=	=												
Great crested flycatcher	B	-	-	-	-	-			-	=					-	-		
Myiarchus crinitus	W	=	=	=	=	=												
Eastern phoebe	B	=	=	=	=	=												
Sayornis phoebe	W	+	+	+	=	=	=	=	?	+	?	+					+	=
Acadian flycatcher	B	-	-	=	-	-												
Empidonax virescens	W	=	=	=	=	=												
Eastern wood-pewee	B	-	-	-	-	-			-	=					-	-		
Contopus virens	W	=	=	=	=	=												
Horned lark	B	+	=	=	+	=												
Eremophila alpestris	W	+	=	=	+	=												
Bank swallow	B	+	=	=	+	=												
Riparia riparia	W	=	=	=	=	=												
Barn swallow	B	+	=	=	+	=												
Hirundo rustica	W	=	=	=	=	=												
Cliff swallow	B	+	=	=	+	=												
H. pyrrhonota	W	=	=	=	=	=												
Purple martin	B	+	=	=	+	=												
Progne subis	W	=	=	=	=	=												
Blue jay	B	-	-	-	-	-			?	+					?	=		
Cyanocitta cristata	W	-	-	-	-	-			?	+	?	+			?	=	?	=
Common raven	B	-	=	=	-	=												
Corvus corax	W	=	=	=	=	=												
American crow	B	-	-	-	-	-			?	+	?	+			?	=	?	=
C. brachyrhynchos	W	-	-	-	=	-	-	=	?	+	?	+	?	+	?	=	?	=
Fish crow	B	-	-	-	-	-			?	+					?	=		
C. ossifragus	W	=	-	-	+	=	=		?	+		?	+		?	=		
Black-capped chickadee	B	-	-	=	-	-												
Parus atricapillus	W	-	=	=	-	=												
Carolina chickadee	B	-	-	-	-	-			-	+	-	+			?	-	?	-
P. carolinensis	W	-	-	-	-	-			-	+	-	+			?	-	?	-
Tufted titmouse	B	-	-	-	-	-			-	+	-	+			?	-	?	-
P. bicolor	W	-	-	-	-	-			-	+	-	+			?	=	?	=
White-breasted nuthatch	B	-	-	=	-	-												
Sitta carolinensis	W	-	-	=	-	-												
Red-breasted nuthatch	B	=	=	=	=	=												
S. canadensis	W	-	-	-	-	-			=	=	=	=			-	=	-	=

Species	H	Clearcutting							Burning						Thinning			
		1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4
Brown-headed nuthatch	B	-	-	=	-	-												
S. pusilla	W	-	-	=	-	-												
Brown creeper	B	=	=	=	=	=												
Certhia americana	W	-	-	-	-	-				=	=	=	=			-	=	-	=
House wren	B	=	=	=	=	=												
Troglodytes aedon	W	+	+	=	+	+												
Winter wren	B	=	=	=	=	=												
T. troglodytes	W	-	-	=	-	-				?	?	?	?			+	=	+	=
Bewick's wren	B	=	=	=	=	=												
Thryomanes bewickii	W	=	+	=	=	+												
Carolina wren	B	-	-	=	-	-			-	?	?	?	?			?	-	?	-
Thyothorus ludovicianus	W	-	-	=	-	-			=	?	?	?	?			?	=	?	=
Northern mockingbird	B	+	+	=	+	+												
Mimus polyglottos	W	+	+	=	+	+												
Gray catbird	B	-	=	=	-	=												
Dumetella carolinensis	W	-	=	=	-	=												
Brown thrasher	B	-	+	=	-	+			=										
Toxostoma rufum	W	-	+	=	-	+			=										
American robin	B	-	=	=	-	=												
Turdus migratorius	W	-	=	=	-	=												
Wood thrush	B	-	-	-	-	-				-	+					?	=		
Hylocichia mustelina	W	=	=	=	=	=												
Hermit thrush	B	=	=	=	=	=												
Catharus guttatus	W	-	-	=	-	-				-	+	-	+			?	=	?	=
Eastern bluebird	B	=	-	=	=	-												
Sialia sialis	W	=	=	=	=	=												
Blue-gray gnatcather	B	-	-	-	-	-				-	+					?	=		
Polioprila caerulea	W	-	-	=	-	-				-	+	-	+			?	=	?	=
Golden-crowned kinglet	B	=	=	=	=	=												
Regulus satrapa	W	-	-	=	-	-				-	+	-	+			?	=	?	=
Ruby-crowned kinglet	B	=	=	=	=	=												
R. calendula	W	-	-	=	-	-			=	-	+	-	+			?	=	?	=
Cedar waxwing	B	=	=	=	=	=												
Bombycilla cedrorum	W	-	=	=	-	=												
European starling	B	=	=	=	=	=												
Sturnus vulgaris	W	=	=	=	=	=												
Yellow-throated vireo	B	-	-	-	=	=												
Vireo flavifrons	W	=	=	=	=	=												
Solitary vireo	B	-	-	-	-	-				-	+					?	=		
V. solitarius	W	-	-	-	-	-				=	=	=	=			-	=	-	=
Red-eyed vireo	B	-	-	-	-	-			=	=						-	=		
V. olivaceus	W	=	=	=	=	=												
Black-and-white warbler	B	-	-	=	-	-												
Mniotilta varia	W	-	-	-	-	-			=	=						-	=		
Worm-eating warbler	B	-	-	=	-	-												
Helmitheros vermivorus	W	=	=	=	=	=												

Appendix.--Continued

Species	H	Clearcutting							Burning						Thinning			
		1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4
Golden-winged warbler	B	=	+	+	-	=												
Vermivora shrysoptera	W	=	=	=	=	=												
Blue-winged warbler	B	=	+	=	=	+												
V. pinus	W	=	=	=	=	=												
Orange-crowned warbler	B	=	=	=	=	=												
V. celata	W	=	=	=	=	=												
Northern parula	B	-	-	-	-	-			=	=					-	=		
Parula americana	W	=	=	=	=	=												
Yellow-rumped warbler	B	=	=	=	=	=												
Dendroica coronata	W	-	-	=	-	-			=	?	+	?	+		?	=	?	=
Black-throated green warbler	B	-	-	-	-	-			=	=					-	=		
D. virens	W	=	=	=	=	=												
Yellow-throated warbler	B	-	-	-	-	-			-	=					-	-		
D. dominica	W	-	-	-	-	-			-	=					-	-		
Chestnut-sided warbler	B	-	+	=	-	+	=											
D. pensylvanica	W	=	=	=	=	=												
Pine warbler	B	-	-	-	-	-			=	=					-	=		
D. pinus	W	-	-	-	-	-			-	+					?	=		
Prairie warbler	B	=	+	=	=	+	=											
D. discolor	W	-	=	=	-	=												
Palm warbler	B	=	=	=	=	=												
D. palmarum	W	+	+	+	=	+	=											
Ovenbird	B	-	-	-	-	-				?	+	?	+		?	=	?	=
Seiurus aurocapillus	W	-	-	-	-	-			?	=					=	=		
Louisiana waterthrush	B	-	-	-	=	=												
S. motacilla	W	=	=	=	=	=												
Kentucky warbler	B	-	-	-	=	=												
Oporornis formosus	W	=	=	=	=	=												
Common yellowthroat	B	+	+	=	+	+	=	=							-	+		
Geothlypis trichas	W	+	+	=	+	+												
Yellow-breasted chat	B	+	+	=	+	+	-											
Icteria virens	W	=	+	=	=	+												
Hooded warbler	B	-	-	-	-	-			-	+					?	=		
Wilsonia citrina	W	=	=	=	=	=												
House sparrow	B	+	=	=	+	=												
Passer domesticus	W	+	=	=	+	=												
Bobolink	B	+	=	=	+	=												
Dolichonyx oryzivorus	W	=	=	=	=	=												
Eastern meadowlark	B	+	+	=	+	+	=								-	+		
Sturnella magna	W	+	+	=	+	+	=								-	+		
Red-winged blackbird	B	+	=	=	+	=	=								-	+		
Agelaius phoeniceus	W	+	=	=	+	=												
Rusty blackbird	B	=	=	=	=	=												
Euphagus carolinus	W	-	-	=	-	-												
Brewer's blackbird	B	=	=	=	=	=												
E. cyanocephalus	W	+	=	=	+	=												

Species	H	Clearcutting							Burning						Thinning			
		1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4
Common grackle	B	-	-	=	-	-				?	+	?	+		?	=	?	=
Quiscalus quiscula	W	-	-	=	-	-												
Brown-headed cowbird	B	-	=	=	-	=			-	?	+	?	+		+	-	+	-
Molothrus ater	W	-	-	=	-	-												
Scarlet tanager	B	-	-	-	=	=			=	=					-	=		
Piranga olivacea	W	=	=	=	=	=												
Summer tanager	B	-	-	-	-	-			=	=					-	=		
P. rubra	W	=	=	=	=	=												
Northern cardinal	B	-	-	-	-	-				-	+	-	+		?	=	?	=
Cardinalis cardinalis	W	-	=	=	-	=			=	-	+	-	+		+	=	+	=
Blue grosbeak	B	+	+	=	+	+			=									
Guiraca caerulea	W	=	=	=	=	=												
Indigo bunting	B	=	+	=	=	+			=									
Passerina cyanea	W	=	=	=	=	=												
Dickcissel	B	+	=	=	+	=												
Spirza americana	W	=	=	=	=	=												
Evening grosbeak	B	=	=	=	=	=												
Coccothraustes vespertinus	W	-	-	-	-					?	+				?	=		
Purple finch	B	=	=	=	=	=												
Carpodacus purpureus	W	-	-	-	-					-	+	-	+		?	=	?	=
House finch	B	=	=	=	=	=												
C. mexicanus	W	+	+	=	+	+												
Pine siskin	B	=	=	=	=	=												
Carduelis pinus	W	-	-	-	-	=			=	?	+	?	+		?	=	?	=
American goldfinch	B	=	+	=	=	+												
C. tristis	W	+	+	=	+	+			=	=						?	+	
Red crossbill	B	=	=	=	=	=												
Loxia curvirostra	W	-	-	=	-	-												
Rufous-sided towhee	B	-	+	+	-	=			=	-	+	-	+		?	=	?	=
Pipilo erthrophthalmus	W	-	+	+	-	=			=	-	+	-	+		+	=	+	=
Savannah sparrow	B	+	=	=	+	=			=							-	+	
Passerculus sandwichensis	W	+	=	=	+	=			=							-	+	
Grasshopper sparrow	B	+	=	=	+	=			=							-	+	
Ammodramus savannarum	W	+	+	=	+	+			=							-	+	
Henslow's sparrow	B	+	=	=	+	=												
A. henslowii	W	+	=	=	+	=												
Le Conte's sparrow	B	=	=	=	=	=												
A. leconteii	W	+	=	=	+	=			=							-	+	
Vesper sparrow	B	+	=	=	+	=												
Pooecetes gramineus	W	+	=	=	+	=			=							?	+	
Bachman's sparrow	B	+	+	=	+	+			=									
Aimophila aestivalis	W	+	+	=	+	+												
Dark-eyed junco	B	=	=	=	=	=												
Junco hyemalis	W	-	-	-	-	=			=	?	+	?	+		?	=	?	=
American tree sparrow	B	=	=	=	=	=												
Spizella arborea	W	+	+	=	+	+			=							-	+	

Species	H	Clearcutting							Burning						Thinning			
		1	2	3	4	5	6	7	1	2	3	4	5	6	1	2	3	4
Chipping sparrow	B	=	=	=	=	=												
S. passerina	W	=	=	=	=	=												
Field sparrow	B	+	+	=	+	+	=	=					−	+				
S. pusilla	W	+	+	=	+	+	=	=					−	+				
White-crowned sparrow	B	=	=	=	=	=												
Zonotrichia leucophrys	W	+	+	=	+	+	=						?	+				
White-throated sparrow	B	=	=	=	=	=												
Z. albicollis	W	−	−	=	−	−			−	+	−	+			?	=	?	=
Fox sparrow	B	=	=	=	=	=												
Passerella iliaca	W	−	−	−	−	−			−	+	−	+			?	=	?	=
Swamp sparrow	B	=	=	=	=	=												
Meloszpiza georgiana	W	+	=	=	+	=												
Song sparrow	B	=	+	=	=	+												
M. melodia	W	+	+	=	+	+	=						−	+				

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GROWTH AND YIELD

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VOLUME GROWTH OF PINE AND HARDWOOD IN UNEVEN-AGED LOBLOLLY PINE - UPLAND HARDWOOD MIXTURES

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Abstract. — Results are reported from an exploratory investigation of stand-level periodic volume growth of uneven-aged mixed loblolly pine (Pinus taeda L.) - upland hardwood stands on good sites in southeastern Arkansas. A restricted set of replicated observations was extracted from an extensive CFI database involving varying pine-hardwood mixtures to form an array of plots with different levels of pines and hardwoods. Analysis was conducted of the 5-year periodic annual increment of the pine, the hardwood, and the total (pine plus hardwood) in relation to the stand density of the pine and hardwood components. Results show that at low to moderate pine basal area levels, an added hardwood component increases total stand growth but decreases total growth at higher pine levels. There seems to be little or no economic justification for mixed stands based on these growth predictions and current stumpage prices. The implications of these results and other factors regarding mixed stand management are also discussed.

INTRODUCTION

The information base on the growth of mixed southern pine - hardwood stands is quite limited and that for uneven-aged stands is particularly restricted. Most of the information deals with even-aged stands. Although the principles of species interactions in mixed stands are probably fundamentally similar in both even- and uneven-aged stands, the degree of the effect of one species upon another will probably be somewhat different in the two situations.

The general successional trend in the dominant woody vegetation on the southern uplands is toward hardwoods ultimately replacing pine unless the trend is interrupted or arrested by disturbances such as windstorms, fire, or forest management. Our southern pineries existed in the past essentially because catastrophes, principally wildfire, occurred at varying intervals and intensites over time and favored the light-seeded pioneering pines. Since we no longer allow fires to burn unchecked, the successional trend under these conditions is for hardwoods to generally invade pine stands at some stage of development and to eventually dominate without intervening treatment to favor pines. If our major economic interest is in pines, then the hardwoods must be kept at some tolerable level.

Most investigations on the effects of hardwoods on pine growth have dealt with the impacts of hardwoods overtopping or threatening to overtop pine regeneration in even-aged stands (Russel 1963, Clason 1978, Michael 1980, Hebb 1981) and early growth rates of pine stands are directly related to the intensity of hardwood control during stand establishment. Little information exists on the effects of hardwoods on pines in older stands. Some studies have shown a positive response of overstory pines to hardwood removal (Grano 1970, Pienaar and others 1983, Cain and Yaussy 1984). Burkhart and Sprinz (1984) show that as the percentage of hardwoods in the total stand increases in loblolly pine plantations, the survival, growth, and yield of the pine decreases. In even-aged shortleaf pine (Pinus echinata Mill.) stands, hardwood control increased growth rates of pines, particularly in dry years (Rogers and Brinkman 1965, Bower 1968). Grano (1970) has shown in uneven-aged loblolly-shortleaf pine stands that hardwoods can reduce the radial increment of pines by 30 to 40 percent in dry years. Other studies have not shown such responses (Russel 1961, Cain 1985, Boyer 1987). There may be a site-dependent threshold for hardwood density below which there is no appreciable effect of the hardwoods on the pine overstory and, from limited observations, the level appears to vary between about 10 to 30 square feet of basal area per acre (Boyer 1986). The level is probably toward the lower end for dry years and sites. Once a satisfactory pine sapling stand is established, there may be no strong economic reason to reduce hardwoods below this threshold during a rotation. However, it might be beneficial in reducing site preparation costs when the regeneration period is again reached. In uneven-aged pine stands the need to periodically secure regeneration and the restricted stand density range suitable for selection management are likely to call for a different strategy.

This paper deals with the periodic annual increment (p.a.i.) in merchantable cubic feet observed on a set of continuous forest inventory plots in natural stands in southeastern Arkansas. The stands are uneven-aged and composed principally of loblolly pine with varying admixtures of upland hardwoods

composed mostly of oaks (<u>Quercus</u> <u>sp.</u>). The purpose is to present information on the contribution of the pine and hardwood components to the total stand growth and to foster some appreciation of the contribution of the hardwoods in uneven-aged pine stands.

METHODS

Data

The inventory data come from 1/5-acre permanent plots located in uneven-aged loblolly-shortleaf pine stands with varying densities of pine and hardwoods on the lands of the Potlatch Corporation in southeastern Arkansas. The stands containing the plots have been periodically cut under a selection system. The site index is generally 80 to 90 feet for loblolly (base age 50 years). However, no age data are available. These plots were inventoried in 1966, 1971, and 1976 affording information on two 5-year growth periods. Each plot tree in the 5-inch class and larger was positively identified and the records included species, dbh to the nearest 0.1-inch, and tree history.

Merchantable cubic-foot volume and basal area were calculated for each tree. Tree volumes were calculated using local volume functions fitted to local tables for pine and hardwoods which contained average volumes per 2-inch dbh class. All volumes are in terms of merchantable cubic feet, outside bark (o.b.), for trees with dbh 4.5 inches, to a 4-inch, o.b., top. Stump heights were 1/2-foot for sub-sawtimber (dbh 9.5 inches) and 1-foot for sawtimber (dbh 9.5 inches). The tree volume functions fitted by least squares are:

$$PVol = -11.59 + 3.789(D) - .3912(D^2) + .03204(D^3) - .000502(D^4) \qquad (1)$$

$$n = 11, \quad R^2 = .9997, \quad RMSE = 1.113$$

$$HVol = 8.554 - 2.910(D) + .3327(D^2) - .00213(D^3) \qquad (2)$$

$$n = 11, \quad R^2 = .9997, \quad RMSE = .869$$

where

PVol = pine cubic-foot volume per tree
HVol = hardwood cubic-foot volume per tree
D = tree dbh in inches
n = number of 2-inch dbh classes
R^2 = coefficient of determination
RMSE = root mean square error

Volumes and basal areas were summed for each plot on an acre basis and the p.a.i. in volume was calculated for each plot for each of the two growth periods. The plots were then screened with the fol-lowing restrictions to obtain a homogenous data set for analysis that contained a minimum amount of extraneous variation:

1. Initial pine basal area is > 0.

2. Initial hardwood basal area is ≤ 50 percent of the total basal area.

3. Basal area of pines other than loblolly is ≤ 10 percent of the initial total basal area.

4. Basal area of oaks is ≥ 50 percent of the initial hardwood basal area.

5. Mortality during a period is ≤ 10 percent of the initial total basal area.

6. Ingrowth of pine or hardwood during a period is ≤ 10 percent of the initial basal area for pine or hardwood, respectively.

7. Periodic annual increment of pine or hardwood during a period is ≥ 0.

Although the growth values are actually net, we are essentially dealing with survivor cubic-foot volume p.a.i. of pine-hardwood stands with up to 50 percent of the density in hardwoods. Further, the hardwood density is at least 50 percent oak. This screening of several hundred plot observations resulted in selecting 58 observations on p.a.i. distributed by basal area of pine and basal area of hardwood as shown in table 1. No more than four replications per cell were chosen in an effort to extract a controlled experiment from uncontrolled data. The mean, minimum value, and maximum value for the variables and restrictions are shown in table 2. In this analysis data set, the following proportions by numbers of trees occur in the stands at the start of the 5-year growth periods:

1. 99 percent of the pines were loblolly and only 1 percent were shortleaf.

2. 67 percent of the pines were poletimber (≤ 9.5 inches dbh) and 33 percent were sawtimber (> 9.5 inches dbh).

3. 72 percent of the hardwoods were oaks composed of 44 percent red oaks and 28 percent white oaks.

4. The red oaks were principally southern red oak (Q. <u>falcata</u> Michx.), willow oak (Q. <u>phellos</u> L.), and water oak (Q. <u>nigra</u> L.) while the white oaks were principally post oak (Q. <u>stellata</u> Wangenh.) and white oak (Q. <u>alba</u> L.).

5. 18 percent of the hardwoods were gums, principally sweetgum (<u>Liquidambar styraciflua</u> L.), and the remaining 10 percent were miscellaneous hardwoods.

6. 71 percent of the hardwoods were poletimber and 29 percent were sawtimber.

Table 1.--Distribution of growth observations by pine and hardwood basal area classes.

Pine Basal Area Class sq. ft./ac.	Hardwood Basal Area Class					
	--------------- sq. ft./ac. -------------------					
	0	10	20	30	40	All
	------------------ no. of obs. ------------------					
20	3	2	1	-	-	6
30	4	1	2	-	-	7
40	4	2	-	4	-	10
50	4	-	1	-	3	8
60	2	1	-	-	-	3
70	4	1	1	1	-	7
80	1	2	-	-	1	4
90	4	2	-	-	-	6
100	2	1	-	-	-	3
110	2	-	-	-	-	2
120	2	-	-	-	-	2
Totals	32	12	5	5	4	58

Table 2.--Means and limits for variables and restrictions.

Item	n	Mean	Minimum	Maximum
Pine p.a.i.	58	107.3	25.1	242.7
Hardwood p.a.i.	58	11.9	0	47.0
Total p.a.i.	58	119.1	25.1	242.7
Pine basal area	58	59.4	15.6	121.3
Hardwood basal area	58	8.9	0	39.8
Percent of total basal area in shortleaf pine	58	0.7	0	9.6
Percent of total basal area in hardwood	58	13.1	0	48.9
Percent of hardwood basal area not oaks	32[a]	13.9	0	47.6
Mortality as percent of total basal area	58	1.6	0	8.6
Pine ingrowth as percent of pine basal area	58	2.4	0	9.7
Hardwood ingrowth as pct. of hardwood basal area	32[a]	2.6	0	10.5

[a]Twenty-six observations had no initial hardwood basal area.

Table 3.--Fit statistics[a] for prediction equations.

Equation	n	Mean	Bias	FI	RMSd	MABSd
6 (PPAI)	58	107.3	.3652	.6696	30.26	22.78
7 (HPAI)	58	11.9	-.1688	.8725	5.13	3.24
8 (TPAI)	58	119.1	.1964	.6028	31.15	23.62

[a] n = number of values

p = predicted value

o = observed value

Mean = $\Sigma(o)/n$

Bias = $\Sigma(p-o)/n$

FI = $1 - [\Sigma(p-o)^2/\Sigma(o-\Sigma(o)/n)^2]$

RMSd = $[(\Sigma(p-o)^2)/n]^{1/2}$

MABSd = $\Sigma|p-o|/n$

Analysis

The analysis consisted of regression analysis to relate the pine, hardwood, and total (combined pine + hardwood) p.a.i. to the pine and hardwood basal area at the start of the growth period. We investigated and evaluated several systems of linear equations in which pine, hardwood, and total p.a.i. are each predicted. We also tried non-linear systems in which the total p.a.i. is predicted, pine p.a.i. is predicted as a proportion of the total p.a.i., and hardwood p.a.i. is obtained by subtraction. We finally converged on the following system of non-linear models due to reasonable trends and goodness of fit:

$$PPAI = f1(PBA, HBA) \tag{3}$$

$$HPAI = f2(PBA, HBA) \tag{4}$$

$$TPAI = PPAI + HPAI \tag{5}$$

where

PPAI = 5-year pine p.a.i., cu. ft./ac./yr.

f1, f2 = functions of similar form

PBA = pine basal area, sq. ft./ac.

HBA = hardwood basal area, sq. ft./ac.

HPAI = 5-year hardwood p.a.i., cu. ft./ac./yr.

TPAI = total p.a.i. = (PPAI + HPAI)

Equations 3 and 4 in this model set were formulated and fitted via non-linear least-squares utilizing "seemingly unrelated regression" procedures (SAS 1984). Solution of equation 5 is obtained by summing fitted equations 3 and 4. All three equations were then evaluated regarding goodness-of-fit.

RESULTS AND DISCUSSION

The fitted equations for the system are as follows:

$$PPAI = 2.70100(PBA)e^{\{A\}}, \tag{6}$$

where: $\{A\} = -0.0046892(PBA) -0.0085694(HBA)$

$$HPAI = 4.24869(HBA)e^{\{B\}}, \tag{7}$$

where: $\{B\} = -0.0087526(PBA) -0.0313041(HBA)$
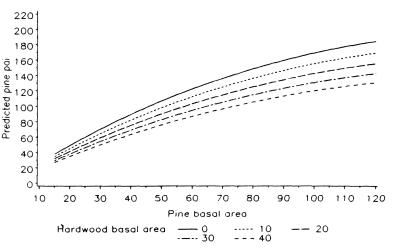
$$TPAI = PPAI + HPAI \tag{8}$$

The goodness of fit statistics for this set are shown in table 3. The amount of variation in the dependent variables accounted for by the system is not outstanding but is probably about as much as could

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be expected from such a database not controlled for research purposes. The unusually good fit index (FI) for HPAI is partly due to 18 of the 58 observations being zero and thus having zero deviations from the predicted value. The lower RMSD for HPAI reflects the lower p.a.i. of the hardwood component compared to the pine.
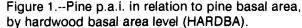
The predicted response of pine and hardwood for typical selection stand densities is shown in table 4. We see that increasing hardwood basal area decreases pine p.a.i. at any pine density level. This is similar to the response found by Burkhart and Sprinz (1984) in loblolly pine plantations. In a like manner, hardwood p.a.i. declines with increasing pine basal area at any hardwood density level. Both responses are also illustrated in figures 1 and 2.
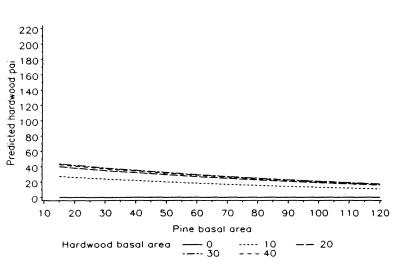
Except at the lowest HBA levels, the effect of the pine basal area on pine p.a.i. is somewhat more than directly proportional. For example, in table 5 a total basal area of 60 square feet per acre is partitioned into varying proportions of pine and hardwood basal area. Here, we see that where PBA is 90 percent of TBA, the PPAI is 89 percent of TPAI. But, where PBA is 70 percent of TBA, the PPAI is 73 percent of TPAI. As the PBA decreases to 50 percent, its contribution to TPAI increases to 58 percent. Also, the effect of hardwood basal area on hardwood p.a.i. peaks at about 30 square feet (figure 2) at any pine basal area level and does not vary much above 20 square feet of HBA.
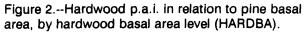
The effect of pine and hardwood basal area on total p.a.i. is shown graphically in figure 3. At low pine densities the hardwood density contributes to total growth. But, as PBA increases above about 50 to 80 square feet, HBA reduces the total growth. At the upper pine densities total growth reduction increases as HBA increases. These responses imply that, at lower pine densities, the pine component does not fully utilize the site's resources and the additional hardwood component makes a net contribution to total growth but pine growth alone decreases (table 4). In contrast, at the upper pine density levels, adding hardwood density results in a net competitive effect and the total growth is reduced. The reduction in total growth here is directly related to the hardwood density level.

An interesting aspect of these relationships is the implied growth/density efficiencies. If we define efficiency as the ratio of p.a.i. to basal area and plot it on the ratio of pine basal area to total basal area, we get the efficiency trends depicted for pine, hardwood, and total in figures 4 through 6. Each figure shows the calculated efficiency as plotted for three levels of total basal area normally encountered in selection stands - 45, 60, and 75 square feet. In all cases the lowest total basal area

Figure 1.--Pine p.a.i. in relation to pine basal area, by hardwood basal area level (HARDBA).

Figure 2.--Hardwood p.a.i. in relation to pine basal area, by hardwood basal area level (HARDBA).
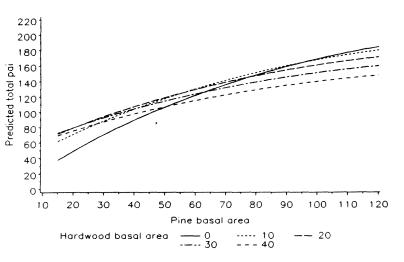

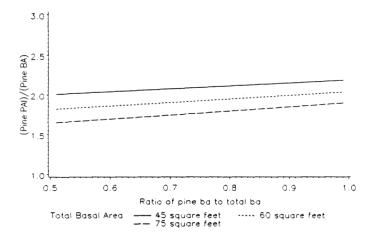Figure 3.--Total p.a.i. in relation to pine basal area, by hardwood basal area level (HARDBA).

Figure 4.--Pine growth efficiency in relation to the proportion of pine in the total basal area, by three total basal area levels.
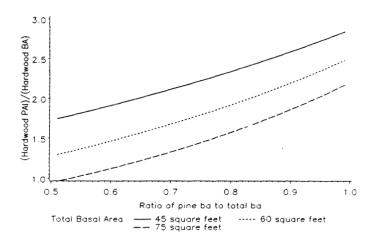
Figure 5.--Hardwood growth efficiency in relation to the proportion of pine in the total basal area, by three total basal area levels.
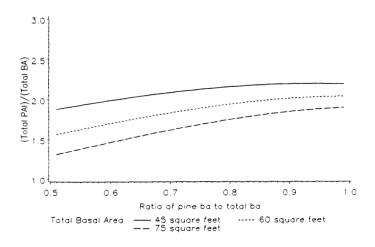
Figure 6.--Total growth efficiency in relation to the proportion of pine in the total basal area, by three total basal area levels.

class has the highest efficiency and all efficiencies increase as the proportion of pine basal area increases. For pine and the total stand the increase in efficiency is gradual as the proportion of pine basal area increases but for hardwood the increase is relatively steep. Efficiencies range from about 1.6 to 2.2 cubic feet per square foot for pine, from about 1.0 to 2.9 for hardwood and from about 1.3 to 2.2 for total. At higher proportions of pine basal area, hardwood efficiency greatly exceeds that of pine, indicating that the hardwoods are much more tolerant in this situation. Although hardwood efficiency is greatest at higher proportions of pine density, this does not result in greatly increasing total efficiency (figure 6). Hardwood levels are so low at higher pine proportions that total efficiency tends to become asymptotic when the pine basal area proportion is above 80 to 90 percent.

Table 4.--Predicted p.a.i. by pine and hardwood density levels.

PBA	HBA	PPAI	HPAI	TPAI
-sq. ft./ac.-		--------	cu. ft./ac./yr.	---------
45	0	98	0	98
45	10	90	21	111
45	20	83	31	114
45	30	76	34	110
60	0	122	0	122
60	10	112	18	131
60	20	103	27	130
60	30	95	29	124
75	0	143	0	143
75	10	131	16	147
75	20	120	24	144
75	30	110	26	136

These growth predictors can be used to obtain crude estimates of the monetary impact of pine-hardwood mixtures. For example, look at the situation in table 4 where a stand has 60 square feet of TBA with PBA varying from 100% to 50%. Assume that a cord contains 90 cubic feet (o.b.) and that stumpage is $15 per cord for pine and $5 per cord for hardwood. The resulting scenario illustrated in table 5 shows that 10 percent hardwood decreases the total stumpage only by a dollar or two, but 50 percent hardwood decreases stumpage by nearly half. Even if stumpage prices were equal for pine and hardwood, the mixed stand value growth will be less than that for pure pine. However, in some cases (table 4) equal stumpage prices could result in a slight monetary advantage if total basal areas are in the sustainable range under selection management.

Table 5.--Predicted p.a.i. for 60 square feet of total basal area composed of varying percentages of pine and hardwood basal area.

PBA	HBA	PPAI	HPAI	TPAI
---------------- pct --------------------				cu. ft./ac./yr.
100	0	100	0	122
90	10	89	11	121
80	20	80	20	116
70	30	73	27	110
60	40	66	34	102
50	50	58	41	93

OTHER CONSIDERATIONS

Aside from the growth and stumpage aspects, a number of other considerations must be dealt with in managing mixed pine-hardwood stands. It is probably true that if we wish to expend sufficient energy and ignore costs we could manage almost any conceivable mixture of pines and hardwoods. But, we also think that where economical timber production is the primary goal, on suitable uplands it will be best to manage pine in pure stands and any desired hardwood component will best be managed separately as inclusions of whatever size is deemed suitable. These could be patches of a few tenths to an acre or so, the borders of drainages, and/or the stream bottoms. This allocation may complicate inventory and record-keeping but will largely prevent long-term management problems. In general, hardwoods should be grown on the sites best suited to them, which will usually be the minor to major stream bottoms in the Southern Coastal Plain. Whether pine or hardwood is to be managed, we think that both will be most efficiently managed as essentially pure stands due to the silvical nature of these species groups, management considerations, and general successional trends.

In selection or uneven-aged pine management, it seems imperative that stands be kept as "pure" as feasible. The basal area "window" for pine selection management is fairly narrow - about 45 to 75 square feet - and all needs to be in pine for adequate production. The addition of a hardwood component to the pine component may push the density above the level where development of pine regeneration and recruitment into the stand can be sustained. This level has not been well quantified but observations strongly suggest that it is no higher than 80 square feet at the end of a cutting cycle for uneven-aged loblolly pine stands in southeastern Arkansas. Until this level is better defined, the safest option is to allow practically no hardwoods in uneven-aged pine stands.

If the hardwood component is added in place of pine, the pine growing stock is reduced, which generally lowers total production and profits. Furthermore, hardwood density, due to its much

denser shade, generally retards pine reproduction more than an equivalent amount of pine density (Wahlenberg 1960). Pine will regenerate and develop to some extent under the shade of a given moderate pine basal area but not to any useful extent under the shade of an equivalent basal area of hardwood. This is based on observation and implied by work by Wahlenberg (1948) and Bormann (1956). At every cutting cycle, there is essentially a need to obtain some pine regeneration to sustain the system. If hardwoods are continually present they have the potential to interfere with pine reproduction and capture pine growing space.

There is also the danger that a seemingly small amount of hardwood in a selection stand may, by default, increase to a major proportion simply because the volume and growth is not sufficient for it to be operationally reduced at each cutting cycle. It may take two or three cutting cycles to build enough hardwood volume for an operational cut and during this time it can seriously affect both pine growth and reproduction if some action, such as a periodic non-commercial reduction, is not taken. For example, we see in table 6 that 6 square feet of hardwood produces a p.a.i. of only 13 cubic feet. At this rate, if 2 cords/acre is a minimum operable cut, it will take about 14 years to produce a commercial cut and leave the initial hardwood density. There might be some small increase in hardwood production due to increasing hardwood density during this period but this would likely be offset by reduced pine production and, more importantly, increased interference with pine reproduction.

Table 6.--Estimated stumpage value[a] of the p.a.i. for a stand with 60 square feet of total basal area composed of varying proportions of pine and hardwood basal area.

PBA	HBA	PPAI	HPAI	TPAI	VALUE
-sq. ft./ac.-		------ cu. ft./ac./yr -----			dollars
60	0	122	0	122	20.33
54	6	108	13	121	18.69
48	12	93	23	116	16.76
42	18	80	30	110	15.03
36	24	67	35	102	13.15
30	30	54	38	93	11.11

[a] Assuming 90 cubic feet, o.b., per cord, $15 per cord for pine, $5 per cord for hardwood.

The even-aged situation is not quite so critical because here the hardwoods can be dealt with more easily. The general principle that the hardwoods will not grow as well as pines on upland Coastal Plain sites still holds. Thus, mixtures of reasonable densities will not grow as much as pure pine at the same densities. But, because the densities in even-aged stands are usually maintained at higher levels than in uneven-aged stands, one can tolerate a certain amount of hardwood and still maintain satisfactory pine densities and production. For example,

10 to 20 square feet of hardwood might be acceptable in even-aged stands containing 60 to 100 square feet of pine.

Another major reason why mixed even-aged stands are more acceptable is that there is no need for periodically recurring pine regeneration. At the end of each rotation, necessary steps are taken during the regeneration period to insure an acceptable level of pine reproduction, a tolerable level of hardwood reproduction is also accepted, and regeneration is not a concern again until the end of the rotation. The two components grow up together and, depending upon growth and values, are thinned as desired during the rotation and harvested at the end. Some hardwoods may actually act as valuable trainers to the pines and improve their pruning and form (Paul 1933) although at a cost of reduced pine production. Also, some landowners may accept even-aged mixed stands containing a relatively large hardwood component because they cannot afford expensive site preparation or pine release work. They may not get maximum production or returns but they will not have large investments and can exercise this option, which may not be available in uneven-aged stands due to adverse effects of hardwoods on pine regeneration.

Aside from taking up pine growing space in even-aged stands, a hardwood component can interfere with area-wise stand treatment prescriptions such as herbicide treatments for cleanings and weedings and prescribed fire use to control undesirable vegetation. In cleanings or weedings, the individual desirable hardwood stems will need to be marked to prevent their destruction and treatments will have to be stem-wise. It will be difficult to burn and discriminate between desirable hardwoods and undesirable brush. Fires are likely to be irregular in intensity and coverage and they may promote decay in the desired hardwood component. Also, the amount of hardwood may be so small and dispersed that it will not even be an asset to non-timber values. Thus, from a timber production standpoint, the maintenance of mixed pine-hardwood stands is likely to be more costly than maintenance of pure stands, especially in the uneven-aged situation where it may be prohibitively costly.

CONCLUSION

There are conditions in uneven-aged stands where a hardwood component in addition to the pine component can increase the total growth of the stand. These conditions are usually where pine basal area is less than about 60 square feet per acre. Above this level the addition of hardwoods decreases the total growth. Although the density is within the range suitable for selection management, the added growth due to the hardwoods usually does not appreciably increase the total stumpage value. A hardwood component usually decreases total stumpage because its growth and value are generally much less than that for pine. For these and other reasons, it is suggested that a hardwood component is best accomodated as separate pure aggregations or stands rather than dispersed throughout the pine stand.

The stand-level models developed here provide some useful insight into the function of mixed stands. However, they are limited in their ability to explain mixed stand growth and constitute little more than a primer. They do not take into account the impact of a number of additional possible factors such as differential rates of growth, ingrowth, and mortality among species; the distribution of species and stems vertically in the understory, midstory, and overstory; distribution of species and stems laterally over area; and inter-tree influences. Evaluation of these effects is largely beyond the capability of stand-level growth prediction systems and individual-tree systems will be required to quantify these effects.

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INDIVIDUAL TREE GROWTH RELATIONSHIPS IN PINE-HARDWOOD MIXTURES

Paul A. Murphy, Robert M. Farrar, Jr. and R. Larry Willett[1]

Abstract. — A study was established in southeast Arkansas in 1983 in which 5-year growth data were used to examine the relationship between pine and hardwood tree basal area growth and various tree and stand variables. Separate analyses were made for each species. A comparison was also made between distance-independent measures and a distance-dependent measure (area potentially available, APA) of competition. The APA did not make any additional statistical contribution to regressions of tree basal area growth in the presence of other stand variables. An analysis was made of a set of inventory data from south Arkansas for comparison. Regressions using these data indicate that basal area component variables (by rank and species) have good predictive power. The results should be useful to modelers investigating growth relationships and to researchers who are contemplating installation of similar studies.

INTRODUCTION

The growth of an individual tree is affected by its neighbors. How this competition is described depends upon whether the spatial arrangement of the trees is taken into consideration. If these data are not considered, then competition must be described by models employing some aggregate stand variables--such as number of trees, basal area, or quadratic mean diameter. These models have been traditionally called distance-independent models. If the spatial arrangement of the trees is considered, then a host of intertree competition measures have been proposed — crown overlap, Hegyi's index, and area potentially available (APA) to name just a few. Models employing these measures have been termed distance-dependent, and this modeling activity has been applied almost exclusively to even-aged, single-species stands.

The effect of competition by other trees on growth of the subject tree is more complex in uneven-aged and mixed-species stands. It is questionable whether some of the techniques developed for simpler conditions can be applied to these stands. If the subject tree is a loblolly pine, will the competitive effect of a pine neighbor be the same as that of a hardwood of similar height and diameter? The problem is especially acute in uneven-aged pine-hardwood mixtures.

In this paper we discuss an effort to describe inter-tree competition and its effect on individual tree growth in uneven-aged loblolly-shortleaf pine-upland hardwood stands. Both distance-independent and distance-dependent models are used.

The data are from a study installed on the Crossett Experimental Forest and a permanent plot inventory system maintained by Potlatch Corporation on their lands in south Arkansas.

STUDY AND DATA DESCRIPTION
Pine-Hardwood Study

A study was installed on the Crossett Experimental Forest in south Arkansas in 1983 to investigate volume growth and wildlife habitat suitability of uneven-aged pine-hardwood stands composed of different percentages of loblolly-shortleaf pine and hardwoods. The study area is located on a terrace adjacent to a small stream, and the soil is predominantly a Bude silt loam with some Providence silt loam. The site index is about 90 feet for loblolly pine at 50 years (U.S. Department of Agriculture, Forest Service 1976).

Fifteen 0.62-acre square plots, each with an interior square measurement plot area of 0.22 acre, were established in a pine-hardwood stand. Five treatments were applied that would leave a residual basal area of 65 square feet per acre in stems 3.6 inches in dbh and larger in the following pine-hardwood proportions: (1) 100 percent pine, (2) 90 percent pine and 10 percent hardwood, (3) 80 percent pine and 20 percent hardwood, (4) 70 percent pine and 30 percent hardwood, and (5) 50 percent pine and 50 percent hardwood. Preference was given to oaks in selecting the hardwoods because they are hard mast producers; the red oaks were favored over the white oaks in a 2 to 1 ratio insofar as possible because of their more reliable mast production. Three replications of the five treatments were installed in a completely randomized design--subject to the constraint of being able to impose a given treatment on a plot. The plots were cut to attain these treatments during the 1983-84 dormant season.

All remaining trees on the plots were assigned a tree number. Tree measurements were taken and consisted of species' identification and measuring dbh to the nearest 0.1-inch at the uphill ground level during the 1983-84 dormant season after cutting. In January 1987, all live trees were mapped by measuring the azimuth to the nearest degree and distance from plot center to tree center to the nearest 0.1 foot. The azimuth and distance of trees that had died after the study was begun were also determined. During October 1988, dbh's of all trees were remeasured. Only species having at least 14 surviving trees were included in the analysis (table 1). They were loblolly pine (Pinus taeda L.), shortleaf pine (P. echinata Mill.), southern red oak (Quercus falcata Michx.), water oak (Q. nigra L.), white oak (Q. alba L.), and post oak (Q. stellata Wangenh.). Details about the measurement of mast, herbaceous, and browse production are described by Wigley and others (1989).

Table 1.--Summary statistics for fifteen 0.22-acre plots of a pine-hardwood study on the Crossett Experimental Forest, 1983-1988.

| Species | Number of trees | Average annual dbh growth | 1983 Diameter | |
			Mean	S.D.
		---------------inches------------		
Shortleaf pine	14	0.12	15.1	5.9
Loblolly pine	86	0.22	17.4	6.2
White oak	33	0.21	10.0	4.5
Southern red oak	18	0.19	9.0	2.5
Water oak	24	0.27	11.2	3.6
Post oak	16	0.23	9.2	2.4

Inventory Data

The inventory data are from 0.2-acre circular plots located in uneven-aged loblolly-shortleaf pine stands on Potlatch Corporation lands. These plots also had a varying hardwood component. Measurements were conducted in 1966, 1971, and 1976. Information was maintained for each individual tree 5.0 inches and larger in dbh. Pertinent information used for this analysis were: (1) dbh to the nearest 0.1 inch, (2) species, and (3) tree history. No data were used from plots that had been logged or that had received any other disturbance during a measurement period. Each plot had the potential of yielding two growth observations per tree. Only species having at least 200 growth observations were included in the analysis (table 2); these were loblolly pine, shortleaf pine, southern red oak, water oak, post oak, and sweetgum (Liquidambar styracifua L.).

Table 2.--Summary statistics for inventory data from Potlatch Corporation stands in south Arkansas, 1966-1976.

| Species | Number of trees | Average annual dbh growth | Initial diameter | |
			Mean	S.D.
		------------ inches ----------		
Shortleaf pine	1027	0.23	9.9	3.0
Loblolly pine	5860	0.29	10.1	3.8
Southern red oak	336	0.26	10.6	3.7
Water oak	204	0.27	10.7	4.2
Post oak	256	0.14	9.2	3.1
Sweetgum	473	0.14	9.6	3.3

ANALYSIS
Pine-Hardwood Study

The objectives of this analysis were (1) to identify two variables that could be used for modeling individual tree basal area growth in a distance-independent context, (2) to investigate the use and modification of the APA index for describing individual tree basal area growth and how it might be modified, and (3) to measure the contribution of APA to explaining tree growth when used in conjunction with other variables.

We assumed that the growth response of a tree varies according to the size and species composition of its competitors. Therefore, all stand variables were summarized separately for the two taxonomic classes. Furthermore, we assumed that a tree will react according to its stand hierarchy and the species composition (pine or hardwood) of the hierarchy. This hierarchy can be based on any number of variables; we chose basal area and diameter. To express this hierarchy, we partitioned basal area and diameter according to the amount above and below the tree in rank. Thus these variables are unique for each tree; the basal area or diameter of a tree is not included when it is the subject tree. Using these assumptions, we came up with a total of 17 variables for testing. In addition to the initial subject tree diameter, each of the following variables was tested for both pine and hardwood components:

(1) Quadratic mean diameter
(2) Number of trees
(3) Basal area
(4) Sum of diameters
(5) Sum of diameters of trees larger than subject tree
(6) Sum of diameters of trees smaller than subject tree
(7) Sum of basal areas of trees larger than subject tree
(8) Sum of basal areas of trees smaller than subject tree.

All the variables were calculated using the 1983 measurement and expanded to a per-acre basis where appropriate. We first conducted regression analyses by pine and hardwood to determine which two variables were best for modeling (using R^2 as the criterion). Using these results, a separate analysis was then done for each species.

The use of APA was also investigated. The APA method was first proposed by Brown (1965). In the original application, a convex polygon was constructed around the subject tree by drawing a set of lines that are perpendicular bisectors of other lines drawn from the subject tree to its neighbors. However, this only considered intertree distance and not tree size in constructing the polygons. Thus correlations between growth and APA were not high. Moore and others (1973) modified the construction so that the perpendicular bisector was located at a point that was determined by the sizes of the subject and competitor tree:

$$l_{ij} = D_i^2 L_{ij} / (D_i^2 + D_j^2), \qquad (1)$$

where:

l_{ij} = distance from subject tree i to the weighted point between tree i and its competitor j,
L_{ij} = distance between the subject and competitor tree, and
D = tree diameter.

In this case, the weight is D^2. Other weighting factors can be used as well. Daniels and others (1986) compared several competition measures and found that only APA and another distance-dependent competition index contributed to growth predictions in conjunction with using distance-independent variables. There was still a problem with the technique, however, when gaps occurred in the stand. Thus, more APA might be allocated to a tree adjacent to the gap than what it could effectively utilize. Nance and others (1988) solved this problem by constraining the distance l_{ij} to being no more than some percentage of the crown radius of an open-grown tree of equivalent diameter. If:

$$l_{max,i} = (C_{bar}/C_{max})(b_0 + b_1 D_i) \qquad (2)$$

where:

$l_{max,i}$ = constrained distance for tree i,

C_{bar} = mean crown ratio of all trees in stand,
C_{max} = maximum attainable mean crown ratio for stands of same species,
b_0, b_1 = species dependent coefficients, and

$(b_0 + b_1 D_i)$ = crown radius of an open-grown tree of same species and diameter.

Then:

$$l_{i,j}* = \text{minimum } \{l_{i,j}, l_{max,i}\} \qquad (3)$$

where:

$l_{i,j}*$ = distance between subject tree i and competitor tree j.

APA was formulated for single species, even-aged stands, and it may not be suited to multiple-species, uneven-aged conditions in which crowns occupy different levels in the canopy layer and where there can be crown overlap such that a small tree may occur beneath a large one. However, Moore and others (1973) used uneven-aged mixed hardwood data in their development of weighted APA. A possible adaptation of APA for different species might be to weight the tree diameters according to species in the following manner,

$$Z_{ij} = w_i D_i^2 L_{ij} / (w_i D_i^2 + w_j D_j^2), \qquad (4)$$

where:

w_i = weight for the subject tree,

w_j = weight for the competitor tree, and

Z_{ij} = the distance between the subject tree and the weighted point between the subject and competitor trees, and

$w > 0$.

Ideally, equation (4) would be constrained using a separate crown radius equation for each species. However, few species-specific crown radius (or diameter) equations for open-grown trees exist for the species represented here. A graphical comparison (crown radius or diameter vs. dbh) of equations for upland oaks (Minckler and Gingrich 1970), shortleaf pine (Rogers 1983), and the equation for loblolly pine used by Nance and others (1988) showed little difference between the oaks and loblolly pine, while the crown radius of shortleaf pine graphed slightly below the oaks and loblolly pine. Therefore, the loblolly pine equation was used for all species. Equation (2) was changed to read,

$$Z_{max,i} = r(2.0 + 0.8D_i), \qquad (5)$$

where:

$Z_{max,i}$ = constrained distance for tree i,

r = crown radius constraint ($r > 0$), and
$(2.0 + 0.8D_i)$ = crown radius (ft) of open-grown tree (loblolly pine).

The actual distance between the subject and the competitor tree is now:

$$Z_{i,j}* = \text{minimum } \{Z_{ij}, Z_{max,i}\} \qquad (6)$$

The APA's were calculated using software developed developed by Nance and others (1988). They were correlated with tree basal area growth by letting the weight for pine equal 1 as the weight for hardwood (w) varied from 0.1 to 4.0 in increments of 0.1. The crown constraint was also tested by letting r in equation (5) vary from 0.05 to 1.0 in increments of 0.05.

The final step in the analysis was to test whether or not the addition of APA to distance-independent variables already in a regression significantly explains tree basal area growth. This was done for each species.

Inventory Data

In this analysis, we were interested in specifying a single model for the different species and observing model performance and consistency of the coefficients for each species. We were interested in specifying an equation in which the competitive position of the tree is portrayed. This competitive position must also take into account species groups. The equation we selected was,

$$BAG = a_0 + a_1(DBH) + a_2(PBAB) + a_3(PBAA) + a_4(HBAB) + a_5(HBAA),$$

where:

BAG = tree basal area growth (sq ft),

DBH = initial tree diameter (in)

PBAB = basal area (sq ft/ac) in pine trees smaller than the subject tree,

PBAA = basal area (sq ft/ac) in pine trees larger than the subject tree,

HBAB = basal area (sq ft/ac) in hardwood trees smaller than the subject tree,

HBAA = basal area (sq ft/ac) in hardwood trees larger than the subject tree, and

a_i = coefficients to be estimated.

It should be noted that the sum of the basal areas plus the basal area of the subject tree equals the total basal area.

RESULTS
Pine-Hardwood Study

The best variables (based upon R^2) for loblolly and shortleaf pine were individual tree diameter and the quadratic mean diameter of pine; individual tree diameter and the pine basal area above the subject tree were the best variables for hardwoods. The R^2 for loblolly pine was not high (table 3), and the low value may reflect the older ages and larger sizes of the loblolly trees; their growth has culminated and

they may be in a senescent stage of their development. The fit for shortleaf pine is much better; the shortleaf trees may be either younger or capable of longer sustained growth.

Table 3.--Statistical evaluation of tree basal area growth models for a pine-hardwood study on the Crossett Experimental Forest.

Species	Two-variable regressions[a]	APA alone[b]	Two-variable regression plus APA[c]
	---------R^2----------		F-value (probability level)
Loblolly pine	0.45	0.39	0.95 (0.33)
Shortleaf pine	0.72	0.62	1.14 (0.31)
White oak	0.42	0.34	0.04 (0.84)
Southern red oak	0.49	0.48	0.28 (0.61)
Water oak	0.63	0.33	0.08 (0.78)
Post oak	0.43	0.50	2.56 (0.14)

[a]The independent variables for loblolly and shortleaf pines were initial diameter and quadratic mean diameter of pines; the independent variables for hardwoods were initial diameter of subject tree and basal area in pine trees larger than the subject tree.

[b]The APA (area potentially available) values were calculated with a crown radius constraint of 0.4 and equal weights for pine and hardwood.

[c]The F-values are type III sums of squares (SAS Institute 1986) or the sums of squares attributable to APA, given that the other independent variables are already in the model.

The apparent usefulness of the pine basal area above the subject tree for describing hardwood basal area growth was a surprise. However, on these plots the hardwoods were smaller than the pines and had subordinate canopy positions. Therefore, this variable probably reflects the competitive position of the hardwoods. If the hardwoods had occupied both superordinate and subordinate canopy positions, the variable selection might have been different. Except for water oak, the R^2's for the hardwoods were similar to the one for loblolly pine (table 3).

Figures 1-4 show the effect of the hardwood weights (w) and selected crown radius constraints (r). Each graph depicts the root mean square errors (RMSE's) resulting from using APA in a simple linear regression model with tree basal area growth as the dependent variable. Weighting the hardwood diameters did not seem to affect RMSE's that much, and the strategy of giving equal weighting to all species appears to be as good as a more complicated weighting scheme.

To isolate the effect of the crown radius constraint, we gave equal weighting to both pine and hardwood and allowed the crown constraint to vary from 0.05 to 1.00 in increments of 0.05. The results (figure 5) are not consistent over species. Some have definite minimum RMSE's (e.g., post oak), while other RMSE's consistently increase as the crown radius constraint is relaxed.

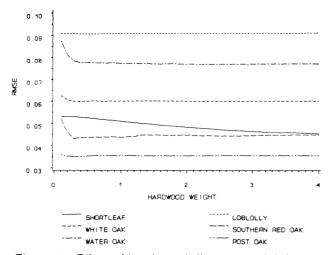Figures 6 to 8 show maps of tree polygons on a representative plot for different crown radius con-

Figure 1.--Effect of hardwood diameter weighting and a crown radius constraint of 0.1 on root mean square error (RMSE) of the regression of tree basal area growth as a function of APA, by species.
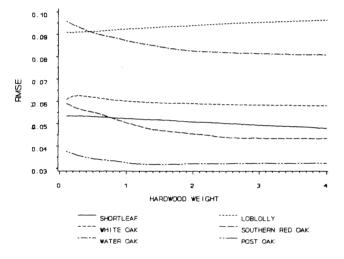

Figure 2.--Effect of hardwood diameter weighting and a crown radius constraint of 0.4 on root mean square error (RMSE) of the regression of tree basal area growth as a function of APA, by species.

Figure 3.--Effect of hardwood diameter weighting and a crown radius constraint of 0.7 on root mean square error (RMSE) of the regression of tree basal area growth as a function of APA, by species.

Figure 4.--Effect of hardwood diameter weighting and a crown radius constraint of 1.0 on root mean square error (RMSE) of the regression of tree basal area growth as a function of APA, by species.

straints. The crown radius constraint affects larger, isolated trees most dramatically. Even when the constraint is 1.0, the polygons do not completely occupy the growing space, which is a reflection of the residual density of only 65 square feet per acre.

To test the effect of using APA in conjunction with other variables, the APA's were calculated with w = 1.0 and r = 0.4. The constraint of r = 0.4 represents a compromise choice based on the conflicting behavior of the RMSE's in figure 5. Table 3 shows the effect of adding APA to the two-variable regression. The APA did not make a significant contribution to the model for any species. Perhaps a straightforward application of APA to mixed-species, uneven-aged conditions does not work, and some refinement is necessary.
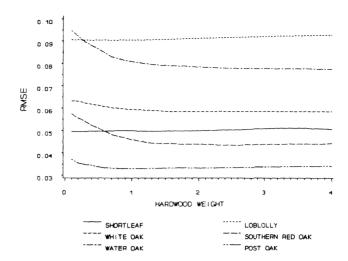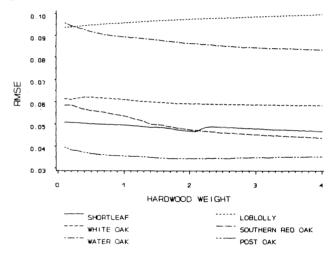
Inventory Data

The R^2's for the growth model using the basal area components range from 0.29 for sweetgum to 0.61 for post oak:

Species	R^2
Loblolly pine	0.55
Shortleaf pine	0.50
Southern red oak	0.54
Water oak	0.50
Post oak	0.61
Sweetgum	0.29

In all cases, the sign of the coefficient for initial dbh was positive, and the sign of the coefficients for the basal area variables were negative. Thus the results
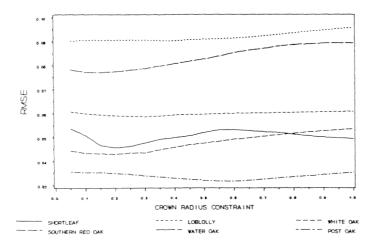
185

Figure 5.--Effect of crown radius constraint on root mean square error (RMSE) of the regression of tree basal area growth versus APA with equal weighting of pine and hardwood, by species.
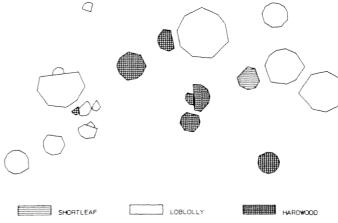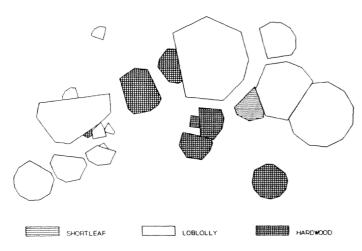

Figure 6.--Map of tree polygons for plot 31 of the pine-hardwood study located on the Crossett Experimental Forest with crown radius constraint of 0.4.

Figure 7.--Map of tree polygons for plot 31 of the pine-hardwood study located on the Crossett Experimental Forest with crown radius constraint of 0.7.

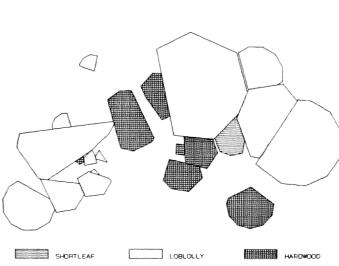Figure 8.--Map of tree polygons for plot 31 of the pine-hardwood study located on the Crossett Experimental Forest with crown radius constraint of 1.0.

are consistent. High probabilities ($p > 0.10$) occurred four times (table 4). Three of these were for basal area components below the subject tree. The results indicate what degrees of fit might be expected for inventory data and are a baseline for results from controlled studies.

CONCLUSION
The results from this study are indicative, not conclusive. The APA and other distance-dependent competition indexes probably need modification if they are to be used for mixed-species or uneven-aged conditions. These indexes were developed for single-species even-aged stands with a single canopy layer and need refinement before they are applied to multiple canopied situations where crown overlap is a common occurrence.

In the present study the hardwoods generally occupied subordinate canopy positions. If some hardwoods can compete successfully with pines and occupy the same canopy layer, then study plots should have hardwoods in both superordinate and subordinate positions relative to the pines.

While cognizant of the fact that different models were used, the goodness-of-fit statistics for the controlled study were somewhat disappointing compared to those from the inventory data. It indicates that perhaps the study design could be improved. The poor fit for loblolly pine was probably the result of advanced tree ages. Locating plots in vigorously growing stands with relatively young trees might assure a better growth response as well as lengthening study life if even-aged conditions are being

Table 4.--Statistical evaluation of tree basal area growth model for inventory data from Potlatch Corporation stands in south Arkansas.

Species	Variable[a]				
	DBH	HBAA	HBAB	PBAB	PBAA
	----------F-value (probability level)[b]--------				
Loblolly pine	2233.25 (0.0)	80.59 (<0.01)	0.0 (0.96)	220.27 (<0.01)	1018.84 (0.0)
Shortleaf pine	355.42 (0.0)	4.58 (0.03)	7.86 (0.01)	30.14 (<0.01)	172.18 (<0.01)
Southern red oak	172.61 (<0.01)	19.37 (<0.01)	6.84 (<0.01)	9.99 (<0.01)	2.41 (0.12)
Water oak	25.53 (<0.01)	31.62 (<0.01)	10.92 (<0.01)	1.44 (0.23)	23.70 (<0.01)
Post oak	177.95 (<0.01)	13.72 (<0.01)	1.11 (0.29)	17.09 (<0.01)	5.04 (0.03)
Sweetgum	102.54 (<0.01)	22.02 (<0.01)	24.52 (<0.01)	29.05 (<0.01)	3.82 (0.05)

[a]DBH is the initial diameter, HBAA is the basal area in hardwood trees larger than the subject tree, HBAB is the basal area in hardwood trees smaller than the subject tree, PBAB is the basal area in pine trees larger than the subject tree, and PBAA is the basal area in pine trees smaller then the subject tree.

[b]The F-values are type III sums of squares (SAS Institute 1986) or the sums of squares attributable to APA, given that the other independent variables are already in the model.

studied. The species range of the hardwoods should also be restricted and confined to those with similar growth rates, so that differences in hardwood species can be minimized.

Competition studies have a rich history in plant population ecology, and the study design implemented here is termed a "replacement series experiment" in which the total density is constant but where the species proportion is varied (Silverton 1987). A second study design is an "additive experiment" in which the density of one species is fixed while the density of the other is varied. A third is called an "additive series experiment," and it is essentially a combination of the other two and is the most comprehensive. We heartily recommend this last design to anyone contemplating a pine-hardwood density experiment. To illustrate how it can be implemented in an uneven-aged pine-hardwood stand, we might consider the following density levels:

Pine basal area (ft^2/acre)	Hardwood basal area (ft^2/acre)		
	0	10	20
----(Total ft^2/acre)-----			
50	50	60	70
60	60	70	80
70	70	80	90

For a given level of pine, one can assess the impact of different levels of hardwood and vice versa. Also there are contrasts that can be made on diagonal elements of the table where the total basal area is constant but the proportions vary. The additive series design allows a more comprehensive analysis than the replacement series and simple additive designs.

Our knowledge of the growth and development of pine-hardwood mixtures is very rudimentary. But it is encouraging to note that well designed studies should contribute greatly to our future understanding.

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RELATIVE BASAL AREA AS IT APPLIES TO PINE-HARDWOOD MIXTURES IN THE UPPER COASTAL PLAIN

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Abstract. — In the late 1930's, three studies were established in natural pine-hardwood stands in southern Arkansas to investigate the long-term growth of merchantable-size stems. With no management or low-intensity management, relative density of merchantable-size pines tended to be negatively related to relative density of merchantable-size hardwoods, whereas relative basal area of pines and hardwoods remained nearly constant through time. With more intensive management, as in using periodic improvement cuts and hardwood control, pines benefited by increasing in relative density and relative basal area compared to hardwoods. It appears that there is a rather narrow range in relative basal area for merchantable-size pines and hardwoods that may perpetuate the productivity of pine-hardwood mixtures.

INTRODUCTION

A vast resource of pines has been perpetuated in the South over the last 50 years as a result of biological, economic, and social forces (Boyce and Knight 1980). Compared to most hardwood species on Upper Coastal Plain sites, pines tend to have faster growth, are in greater demand by forest industry, and usually bring a better price to land-owners. In order to increase pine production, forest managers have discouraged hardwood management. This has been necessary because hardwoods on upland pine sites not only compete with pines, but also are often slow growers, scarred with short and crooked boles, and highly variable in species' composition. If forest managers decide to harvest these hardwoods, they usually obtain low volumes per acre that tend to increase harvesting costs (Karchesy and Koch 1979).

Even though the management emphasis has been on pine productivity, many private nonindustrial forest landowners (PNIFL's) do not perceive timber production as their principal ownership goal (Porter-field 1984). These landowners, who control more than 70 percent of the forest land in the South, have a variety of reasons for woodland ownership. In addition to timber production, these reasons may include aesthetics, recreation, wildlife, private retreat, and firewood. Because of such varied interests, many PNIFL's would be better served by pine-hardwood mixtures rather than by pure pine or pure hardwood forests.

Knowledge of successional patterns relative to various levels of stand disturbance is important for the successful management of a mixed pine-hardwood forest. Data from three long-term inves-

tigations in natural stands under various levels of management are presented in this paper. These data suggest that relative basal area of the pine and hardwood components may provide a potential management strategy for sustaining pine timber productivity from mixed pine-hardwood stands.

METHODS

Study Area

Study plots were located on the Crossett Experimental Forest in Ashley County, Arkansas, at 33°02'N mean latitude and 91°56'W mean longitude. Annual precipitation averages 55 inches, with extremes being wet winters and dry autumns. Elevation of the area is about 175 feet, with nearly level topography. Soils are Bude (Glossaquic Fragiudalfs), Providence (Typic Fragiudalfs), and Arkabutla (Aeric Fluvaquents) silt loams (USDA 1979). Bude and Providence soils were formed in thin loessial deposits and have an impervious layer at 18 to 40 inches that impedes internal drainage. The Arkabutla soil was formed in silty alluvium and is subject to flooding in late winter and early spring. These soils have an excellent potential for the growth of commercially important hardwoods and pines. Site indices (S.I.) at 50 years are as follows: cherrybark oak (Quercus falcata var. pagodifolia Ell.), S.I. = 90 to 105 ft; sweetgum (Liquidambar styraciflua L.), S.I. = 85 to 100 ft; shortleaf pine (Pinus echinata Mill.), S.I. = 80 to 90 ft; and loblolly pine (P. taeda L.), S.I. = 85 to 100 ft. Old-growth pine timber on the forest was cut before 1915 to a 12-inch d.b.h. limit. There were recurrent wildfires until fire protection began in the 1930's.

Study History

Three long-term investigations had been initiated on the Experimental Forest during the late 1930's and early 1940's. These investigations included an unmanaged stand, a pine release study, and a

methods-of-cut study. Periodic inventories were made of the number of merchantable-size trees (stems 3.6 inches in d.b.h. and larger) to provide a record of pine and hardwood productivity through time. Different silvicultural practices were utilized in the management of these three studies as follows:

Unmanaged stand. In 1935, an 80-acre stand was set aside to be kept from future management. With the exception of fire protection and occasional cut-and-leave or salvage of small bark beetle infestations, no management practices have been undertaken in this stand. In 1937, density of pines and hardwoods 4 inches in d.b.h. and larger averaged 130 and 41 trees per acre respectively.

Pine release study. This investigation was initiated to determine if suppressed pine seedlings would respond to release from a pine-hardwood overstory. In 1939, there was an average of 75 merchantable-size pines and 54 merchantable-size hardwoods per acre in this 16-acre study area. About 1,400 pines per acre were of submerchantable size, and about 6,000 hardwood trees and shrubs per acre were less than 4 inches in d.b.h. Three intensities of pine release were tested: remove overstory hardwoods; remove midstory and overstory hardwoods; and remove midstory, overstory, and some understory hardwoods. Each treatment was replicated four times and hardwoods were removed by cutting. In 1955, there was partial repetition of each treatment using the herbicide 2,4,5-T. Harvesting of merchantable pines and hardwoods was done using the single tree selection system in 1939, 1949, 1955, 1960, and 1965 (when management ceased). The only silvicultural treatment applied since 1965 was a prescribed burn over the entire area in 1980 for fuel hazard reduction.

Methods-of-cut study. This study was initiated to determine the effectiveness of four different reproduction cutting methods--selection, diameter-limit, heavy seed-tree, and patch clearcutting--for obtaining adequate pine regeneration, for enhancing pine growth and yield, and for dealing with low-quality hardwoods. The study was installed as two series. The first series was established in 1937 and the second series in 1942. All four treatments were replicated three times in each series on 4.4-acre plots. The initial density of the merchantable component averaged 136 stems per acre for pines and 73 stems per acre for hardwoods.

In the selection method, merchantable pines were harvested as single trees or small groups on a 5-year cutting cycle. Merchantable hardwoods were harvested when the study began and all remaining hardwoods larger than 4 inches in d.b.h. were cut about 3 years later. Harvesting of pines and hardwoods ceased after 1968.

In the diameter-limit method, all pine sawtimber larger than 11.5 inches in d.b.h. and all merchantable hardwoods were harvested when the study began. All remaining hardwoods larger than 4 inches in d.b.h. were cut about 3 years after the initial harvest to release pine regeneration. Subsequent pine diameter-limit cuts were conducted at 5- to 10-year intervals until 1968 when harvesting ended.

In the heavy seed-tree method, all merchantable pines and hardwoods were harvested when the study began except that 15 to 20 pine seed trees were left per acre. Pine regeneration was released about 3 years after the initial harvest by cutting remaining hardwoods larger than 4 inches in d.b.h. Seed trees were removed about 15 years after the initial cut and there was no further activity.

In the patch clearcut method, all merchantable pines and hardwoods larger than 5.5 inches in d.b.h. were harvested when the study began. Prescribed burning was used shortly after to reduce logging slash, to prepare a seed bed for natural pine regeneration, and to control small hardwoods. Residual hardwoods larger than 4 inches in d.b.h. were cut about 3 years after the initial harvest.

Study Measurements
Unmanaged stand. Periodic inventories of all trees 4 inches in d.b.h. and larger were conducted between 1937 and 1983 at 5- to 10-year intervals. Inventories before 1983 recognized three species' groups: pines (Pinus L. spp.), oaks (Quercus L. spp.), and other hardwoods. All stems were recorded by 1-inch d.b.h. classes. In 1983, a fourth group, gums (Liquidambar L. and Nyssa L.), was added to the inventory.

Pine release study. Prior to release treatments in 1939, all pines and hardwoods 4 inches in d.b.h. and larger were inventoried by 1-inch d.b.h. classes on a plot-by-plot basis. Hardwoods were categorized as red oak, white oak, gum, and others. Records of harvested trees were kept by species' groups and number of trees cut by 1-inch d.b.h. classes. The most recent inventory on these plots was conducted in 1986.

Methods-of-cut study. All trees 4 inches in d.b.h. and larger were measured before and after each cut and categorized by 1-inch d.b.h. classes on a plot-by-plot basis. Species' classification was either pine or hardwood. The last inventory for purposes of this investigation was done in 1979.

Data Analysis

For all three studies, pine volumes were determined from loblolly-shortleaf volume equations (Farrar and others 1984). Hardwood volumes were obtained from a hardwood volume table for the Crossett Experimental Forest (Reynolds 1959). Volume production was determined as follows:

Residual volume + cut volume - initial volume = volume production.

In both the release study and the methods-of-cut study, analysis of variance was used to evaluate treatment differences for pine and hardwood. Duncan's multiple range test was used to partition mean differences among treatments. All analyses were conducted at the 0.05 level of significance.

RESULTS AND DISCUSSION

Timber Production

Where pure pine was the principal goal of management, pine volume production tended to increase in all three investigations whenever competing hardwoods were effectively controlled (table 1). In the unmanaged stand, where there was no hardwood control, annual pine volume production averaged 43 percent less than the next lowest annual production, which was found in the pine release study. That lower volume in the pine release study occurred where the least intensive treatment involved cutting of only those overstory hardwood trees that were overtopping pine seedlings. The largest average annual sawlog produc-

tion was in the methods-of-cut study using the selection system, which is rather intensive management by cyclic cuts at regular intervals.

The highest average annual hardwood production on these upland pine sites occurred in the pine release study with a mean of 21 cubic feet per acre across the three treatments (table 1). Even though increasing intensity of pine release significantly improved the cubic-foot production of pines in that study, there were no statistically significant differences in hardwood production between treatments after 47 years. Because there were no sales of hardwood timber and thus no hardwood removal in the unmanaged stand, annual hardwood production was 71 percent less than the mean in the pine release study during a similar time interval.

Hardwood production data from the pine release study corroborate results of other investigations that have demonstrated the ability of indigenous hardwoods to rebound after repeated efforts at control (Cain and Yaussy 1983, 1984; Cain 1985). Such resilience provides landowners with an opportunity to manage their forest properties for both pines and hardwoods if their objective is the development of mixed stands. For example, in the

Table 1.--Merchantable volume production from three long-term investigations in mixed pine-hardwood stands

Study designation and treatments	Time interval	Mean volume production/acre·year[a]		
		Pine		Hardwood
	Years	Board feet[b]	Cubic feet	Cubic feet
Unmanaged Stand[c]	46	120	32	6
Pine Release[d]	47			
ROH		227a	56a	22a
ROMH		279a	75 b	20a
ROMUH		276a	77 b	21a
Error mean square		1,202	45	15
Methods-of-Cut[e]	36			
Selection		377a	84 b	--
Diameter limit		330a	107a	--
Heavy seed tree		362a	117a	--
Patch clearcut		260 b	93 b	2
Error mean square		766	46	--

[a]/Production = Residual + cut - initial. Means within columns by treatment and study are not significantly different at the 0.05 level when followed by the same letter.

[b]/Doyle scale.

[c]/Production data from Baker and Bishop (1986).

[d]/ROH = Remove overstory hardwoods; ROMH = Remove overstory & midstory hardwoods; ROMUH = Remove overstory, midstory & some understory hardwoods.

[e]/Production data for plots established in 1942 (Baker and Murphy 1982).

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more intensively managed methods-of-cut study, the only increase in hardwood production in 36 years was in the patch clearcut method, which was the only treatment to receive prescribed burning. Other studies have shown that single and periodic prescribed fires in natural stands of southern pines will increase the density, and therefore future productivity, of the hardwood component (Oosting and Livingston 1964; Cain 1985).
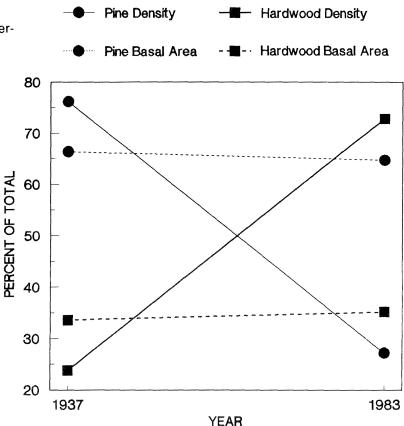
Where management of the merchantable stand component was most intensive in these three studies, there was a general increase in submerchantable (stems less than 3.6 inches in d.b.h.) pine density. For example, all four treatments in the methods-of-cut study averaged about 3,000 stems per acre of pine reproduction 5 years after the initial harvest (Grano 1954). In the pine release study, the two most intensive treatments increased the number of free-to-grow pine seedlings so that ingrowth to merchantable size resulted in long-term pine volume gains (Cain 1988). In contrast, shade tolerant hardwoods predominated the submerchantable component of the unmanaged stand in the absence of disturbance (Cain 1987).

Relative Density and Basal Area

All three investigations presented in this paper were within 1 mile of each other on good sites in the Upper Coastal Plain. Although forest stocking levels were generally determined by the degree of management imposed, data from these three investigations emphasize the wide range in density and basal area that is possible from mixed pine-hardwood stands in a small geographic area where site conditions are uniform. For example, merchantable pine plus merchantable hardwood basal area ranged from a low of 29 square feet per acre on one treatment of the pine release study in 1939 to a high of 147 square feet per acre in the unmanaged stand in 1983. Similarly, merchantable pine plus hardwood density varied from 101 stems per acre in 1939 on the least intensive treatment of the pine release study to 281 stems per acre in 1979 on the clearcut treatment of the methods-of-cut study.

Because of such variability, some measures of density or stocking are needed, measures that are not site specific, to serve as guides to forest managers who wish to achieve modest pine productivity from mixed pine-hardwood stands. Relative basal area of the pine and hardwood components might provide a useful stocking guide. To test that assumption, long-term trends from the present investigations were illustrated graphically by plotting relative basal area and relative density (trees per acre) of both the pine and hardwood components over time (figures 1 through 3). The most dramatic trend was found in the unmanaged stand (figure 1). Relative basal area of pines (65 percent) and

Figure 1.--Relative density and basal area for merchantable-size pines and hardwoods in an unmanaged stand between 1937 and 1983.
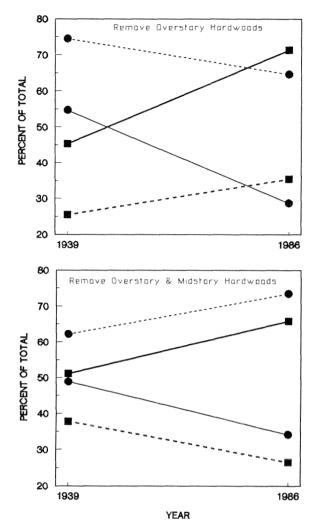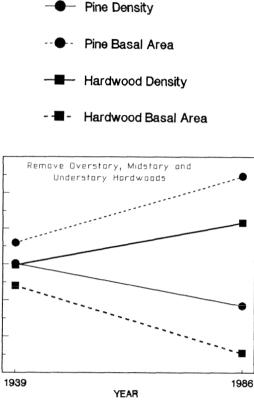
Figure 2.--Relative density and basal area for merchantable-size pines and hardwoods between 1939 and 1986 by intensity of pine release.
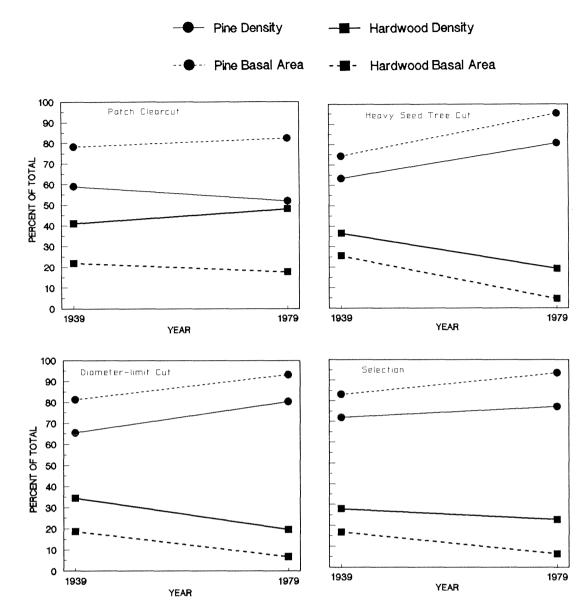
hardwoods (35 percent) remained nearly stable over a 46-year period, but relative hardwood density increased with a concomitant decrease in relative pine density. The intolerant pines could not regenerate in competition with the more shade-tolerant hardwoods in the absence of disturbance, but established pines continued to increase in diameter and maintain their basal area level.
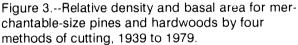
Similar trends in relative basal area were apparent in the pine release study where both pines and hardwoods were periodically harvested between 1939 and 1965. Although pine production was improved with more intensive release (table 1), relative hardwood basal area, before release and 47 years later, had a narrow range of from 26 percent to 45 percent of the total (figure 2). The midpoint of that basal area range corresponds to the relative hardwood basal area (35 percent) in the unmanaged stand during a 46-year interval.

Pretreatment relative basal area for hardwoods in all plots of the methods-of-cut study averaged about 20 percent (figure 3). In that study, pine production was the principal goal of management. For the

clearcut treatment, however, where there was no disturbance from management activities for 40 years, relative hardwood basal area still averaged about 20 percent in 1979. Site disturbance from periodic harvesting at 5- to 15-year intervals in the heavy seed-tree, diameter-limit, and selection cutting methods resulted in a reduction of relative hardwood basal area to about 6 percent of the total in 1979.

Long-term trends from these three investigations tend to support the following hypothesis. Relative basal areas between 20 and 45 percent for the hardwood component and between 55 and 80 percent for the pine component occurred in conjunction with different silvicultural treatments. Therefore, these relative basal area levels may provide a basis for perpetuating mixed pine-hardwood stands where pine is the principal component.

This hypothesis can be substantiated from published investigations within and outside the Upper Coastal Plain of the Southern United States. In southern Arkansas, for example, Cain (1985) ex-

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Figure 3.--Relative density and basal area for merchantable-size pines and hardwoods by four methods of cutting, 1939 to 1979.

amined the long-term consequences of hardwood control that began in 1954 in a 49-year-old, even-aged, natural stand of loblolly-shortleaf pines. Hardwoods were intensively controlled with prescribed fire or herbicides (cut-stump treatment or foliar application) between 1954 and 1961. Before treatment, total basal area had averaged 90 square feet per acre with 14 percent in hardwoods and 86 percent in pines. In 1983, or 23 years after treatments ended, relative hardwood basal area averaged 22 and 21 percent respectively on the check and burn plots but only 6 percent on the herbicide treated plots.

Halls and Homesley (1966) described the composition of a mature pine-hardwood forest in the Coastal Plain of east Texas. An even-aged stand of loblolly-shortleaf pines had developed after old-growth pine timber was cut in the 1890's. There were recurrent wildfires until the 1930's, and larger hardwoods were cut or killed between 1938 and 1950; otherwise the forest was undisturbed. When an inventory was conducted in 1963, pines were 70 years old, and total basal area for pines and hardwoods was 125 square feet per acre with 73 percent in pines and 27 percent in hardwoods.

Schuster (1967) characterized the structure of another natural, loblolly-shortleaf, pine-hardwood forest in east Texas. The virgin timber was cut around 1900, and salvage cuts of merchantable pines and hardwoods were conducted in 1940,

1943, and 1946. In 1949, clearcut, selection, and shelterwood cutting methods were initiated for comparison with uncut areas. Ten years later, total pine and hardwood basal area ranged from 26 square feet per acre on the clearcut treatment to 96 square feet per acre on the uncut plots. Relative basal area for hardwoods was 30, 43, 36, and 77 percent of total on the uncut, shelterwood, selection, and clearcut plots respectively.

Based on a 1938 inventory of a shortleaf-Virginia pine (P. virginiana Mill.) stand in the Appalachian Highlands of Tennessee, Lange (1951) found that the area contained a 26-year-old, even-aged mixture of pines that developed through a 41-year-old hardwood understory as a result of fire. Basal area of pines and hardwoods averaged 107 square feet per acre with 72 percent of that in pines and 28 percent in hardwoods.

Oosting and Livingston (1964) studied the effects of a single ground and crown fire 29 years after the burning of a 35-year-old natural stand of loblolly pine in the southeastern Piedmont of North Carolina. At the time of their assessment, the unburned portion of the stand was 64 years old with no management before or after the fire. Relative basal area for stems 1 inch in d.b.h. and larger averaged 81 percent for pines and 19 percent for hardwoods, regardless of whether the plots were unburned or had been subjected to a ground- or crown-fire.

In 1947, a study was initiated in the Cumberland Plateau of northern Alabama to appraise the effects of stand improvement in pine-hardwood forests that had been depleted by cutting and fire (Smalley 1974). Before treatment, the merchantable portion of the stands consisted of 47 square feet of basal area per acre with 28 percent in pines and 72 percent in hardwoods. A combination of cleanings, improvement cuts, liberation, salvage, and a few thinnings, all based on individual tree selection, rehabilitated the depleted stands so that relative hardwood basal area decreased from 72 percent of the total to less than 30 percent of the total within 19 years.

There is a common thread that binds all of these investigations together. Relative hardwood basal area in mixed pine-hardwood stands across the South tended to range between 20 and 45 percent of the total basal area. These relative basal area levels were not achieved as quickly when merchantable timber was depleted or when there was intensive use of herbicides for hardwood control to enhance pine production. On the other hand, these levels were achieved on a variety of sites where there were periodic disturbances from harvesting activity or recurrent fires. Forest managers should therefore capitalize on any phenomenon that tends to perpetuate productivity from mixed stands. Forest management is needed to maintain stand conditions so that pines can survive and coexist with the more aggressive hardwood species. If management by man is excluded from pine sites in the Southeast, and if succession proceeds without disturbance, hardwoods will eventually replace the pines, thus culminating in an oak-hickory climax forest (Oosting 1956).

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DYNAMICS OF MIXED PINE-HARDWOOD STANDS THAT DEVELOP FROM HARDWOOD ENCHROACHMENT IN PINE PLANTATIONS

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Abstract. — Interest in the management of mixed pine-hardwood stands has increased the need for the development of growth and yield models for mixed stands. Smith and Hafley (1987) used a simulation approach based on independently developed pine plantation and natural hardwood models to develop a model for such stands. Output from the model supported by long-term measurements from permanent plots in pine plantations that contain a significant hardwood component are used to evaluate the changes in species composition over time.

INTRODUCTION

Interest in modeling the growth and development of pine plantations that have a significant hardwood component has increased greatly in recent years. Assessing the economic impact of hardwood encroachment on pine production was the initial motivation. But increased recognition of the nontimber amenities of mixed stands has expanded this interest.

Evaluation of the productivity of timber and nontimber products from mixed stands is facilitated by the use of growth and yield models. Development of such models requires (1) an understanding of stand growth and ecology, both as pure stands and in mixtures, (2) the development of mathematical functions that describe the biological relationships, and (3) long-term measurement of mixed stands to estimate model parameters. Unfortunately, very little data exist on the growth of pine plantations with a hardwood component. Although many studies have been established to assess the impact of hardwood on pine growth, very few provide information on either the initial hardwood composition or its subsequent development over time. This limits the development of an understanding of stand growth and ecology and makes the direct estimation of parameters for growth equations difficult.

Smith and Hafley (1987) used a simulation approach based on independently developed planted pine and natural hardwood models to model the development of such stands. The pine plantation component was the North Carolina State University Plantation Management Simulator, and the hardwood component was developed by Zahner and Myers (1984) for young Piedmont oak stands of sprout origin. Results of the model, as presented

in figure 1, indicate that hardwood composition decreases dramatically after the initial period of encroachment and then increases over time. This behavior, as will be discussed later, is expected given basic ecology and the relative growth habits of the species.
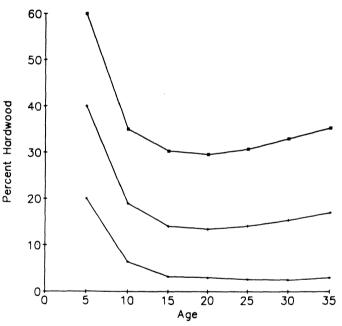
Figure 1.--Predicted percent hardwood basal area over time from the NCSU model.

Details of the model development and preliminary verification using a 24-year-old site preparation study located at Fayette, Alabama provided by the Auburn University Silviculture Herbicide Cooperative are contained in the papers cited. However, in the Fayette data the first measurement of hardwood composition was not made until age 12, after the most significant changes in composition take place, and no other measurements were made until age 24. The Virginia Department of Forestry (VDF) established a series of paired plots in pine plantations

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on cutover sites. Average age at the initial measurement was 3 (ages 2 to 4) and the plots were remeasured at 4-year intervals. Final measurement was a age 19 (ages 18 to 20). In this paper the results of VDF plots are used to examine the dynamics of hardwood encroachment into pine plantations and to verify empirically the change in species composition exhibited by the model.

ECOLOGY AND DEVELOPMENT OF PINE-HARDWOOD STANDS

Although knowledge in the development of hardwood encroachment into pine plantations is limited, the development of natural pine-hardwood stands that result from old field succession is a fundamental concept of plant ecology. The gradual change from pine to hardwood is presented in table 1 from Oosting (1942). Percent hardwood increases over time until, if undisturbed, a pure climax hardwood forest develops. The pattern, however, that develops in pine plantations established after harvesting a mixed natural stand without intensive site preparation is considerably different. The change in species composition, predicted by the model (figure 1), indicates a rapid decline in percent hardwood until about age 10, it reaches a minimum at about age 20, and then increases thereafter.

Table 1.--Change in hardwood composition over time from old field succession (data taken from Oosting 1942).

Age of stand	Percent total density	Percent total basal area
11 years	0.0	0.0
22 years	34.7	3.7
31 years	48.5	2.2
34 years	63.2	11.7
42 years	23.4	1.9
75 years	77.9	6.2
110 years	93.4	12.0
Post climax	98.5	99.3

Percent hardwood composition in six of the check plots from the VDF data is plotted against age in figure 2. Average hardwood composition at the time of the initial measurement, age 3, was 91.2 percent, however 4 years later it had declined to 58.5 percent and by the last measurement, age 19, to 43.1 percent. This behavior is in agreement with the change in hardwood percent (presented in table 2) observed at the Fayette Alabama study. The average percent decline in percent hardwood from age 12 to 24 in the Fayette study was 16 percent. Over a similar period in the VDF study, age 9 to 15, the decline was 20 percent. Although data in plantations does not exist to verify the increase in percent hardwood in later years as is indicated by the model and as occurs in old field succession, it was not unexpected given the normal growth habit of oak. In general, oak reaches the rapid growth stage after the growth of pine culminates.
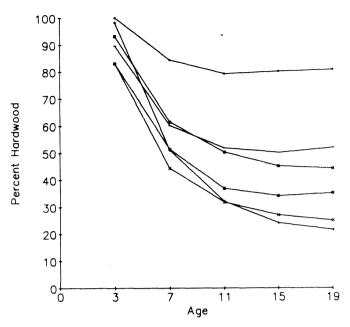
Figure 2.--Actual hardwood basal area over time for the check plots from the VDF data.
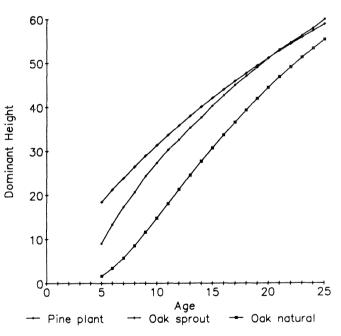
Figure 3.--Comparison of dominant height of planted loblolly pine with oak from seedling and sprout origin.

Table 2.--Change in hardwood composition from age 12 to 24 for the Fayette, Alabama Study

Site preparation treatment	Percent hardwood age 12	Percent hardwood age 24
Bulldozed	10.0	9.0
Injection	23.0	14.0
Hand Girdled	40.0	38.0
Ax Frill	21.0	9.0
Check	83.0	84.0

Data provided by Auburn University Herbicide Cooperative

This difference in growth pattern between mixed stands that develop by old field succession and hardwood encroachment in pine plantations established on cutover sites is explained by the origin of the hardwoods. On old fields the hardwoods develop from seed origin while on cutover sites the hardwoods develop from sprouts or advanced regeneration. The comparative height growth of natural oak (Olson 1959), oak of sprout origin, and planted loblolly pine (Golden and others 1981) on loblolly pine site index 60 base 25 are presented in figure 3. The equivalent base age 50 is site 92 for pine and site 84 for oak. The natural oak curve exhibits the slow early height growth, 3 feet at age 5, typical of oak seedlings while the sprout curve demonstrates the rapid early growth of oak stems of sprout origin. In old field succession the pine is much taller than the oaks of seedling origin and oak will not dominate the site until after senescence of the pine. In contrast the planted pine is much shorter than the oak sprouts at age 5. The pine will catch up to the oak by age 20 and will, as indicated by the difference in site index base 50, exceed the height growth of the oaks. The development of VDF data is consistent with this pattern. Dominant height of oak, although measured on only one plot, was 40 feet at age 19 compared with 37 feet for pine.

COMPARISON OF THE MODEL WITH THE VDF DATA

A comparison of the model predictions with the observed results from the VDF study are presented in table 3. Predictions were based on the initial and projected to age 19.

Table 3.--Comparison of model projection from stand conditions at age 7 to age 19 with actual for 15 plots from the VDF data.

Variable	Average Difference	Range	Average Absolute Difference	Percent Explained Variation
Pine T/A	7.0	-99 to 217	56.0	75.2
Pine Dbh (in)	.0	-.6 to .6	.4	69.3
Pine BA (sqft)	-3.4	-28 to 16	10.8	88.0
HdwdBA (sqft)	3.5	-9 to 16	6.5	83.2
Percent Hdwd	1.1	-20 to 13	5.4	88.0

Difference = Observed - Predicted
Percent Explained Variation = 1 - Difference Squared/Total
Adjusted Sum of Squares
Expressed as a Percent

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

The most significant result obtained from the VDF data is additional verification of the predicted change in hardwood composition by the model. The importance in recognition of this behavior in yield forecasting is demonstrated in table 4. The projected total yield of both pine and hardwood using the model is compared with a growth projection based on the assumption that the percent

hardwood is constant over time. The error in prediction when percent hardwood is assumed constant ranged from 20 to 60 percent underestimates of pine volume and corresponding overestimates of hardwood volume. It is of equal importance when making management prescriptions. Changes are most rapid at young ages when manipulation of species compostion is most effective.

Table 4.--Comparison of projected volume at age 30 given percent hardwood at age 5 with projected volume assuming no change in percent hardwood.

Percent Hardwood age 5	Percent Hardwood age 30	Volume (cf/ac) age 30		Volume (cf/ac) age 30 no change in Percent Hardwood	
		Pine	Hdwd	Pine	Hdwd
0	0	3617	0	3617	0
20	3	3259	65	2574	461
40	15	2689	348	1646	797
60	33	2048	741	861	956

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DEVELOPMENT AND APPLICATION OF A VARIABLE DENSITY YIELD MODEL FOR MIDSOUTH PINE-HARDWOOD STANDS

John F. Kelly[1]

Abstract.—The development and application of a recursive equation system to predict future volumes for mixed-aged, pine-hardwood stands is described. The model was developed using data from permanent plots remeasured as part of the ongoing forest survey of the USDA Forest Service in Midsouth states. Coefficients are presented for 3 different site classes in the East Gulf Coastal Plain region. Application of the model requires the basal area and number of growing-stock trees, saplings, cull trees, and the percent of pine basal area. The model accounts for the average amount of mortality; stands with declining volumes were excluded from model development.

INTRODUCTION

A large portion of the Midsouth's forests is comprised of mixed, uneven-aged stands. Almost one-fifth of the timberland in the 7-state Midsouth area is classified as mixed pine-hardwood forest type, where pine comprises 25-49 percent of the stocking (Birdsey and McWilliams 1986). In addition, there are large portions of natural pine and upland hardwood forest types that have a significant component of hardwood, or pine, respectively. Currently, there are 44 million acres of upland pine sites in the 7 Midsouth states that support mixed-aged stands (table 1). These stands have two or more distinct age classes that are at least 10 years apart. This estimate excludes upland hardwood sites not favorable for pine growth.

Table 1.--Timberland area, in the Midsouth, of mixed-aged stands on pine sites, by State, latest survey.

State	Date of survey	Timberland area
		Thousand acres
Alabama	1982	12,638.5
Arkansas	1988	8,238.8
Louisiana	1984	4,898.4
Mississippi	1987	7,931.2
Oklahoma	1986	1,655.1
Tennessee	1980	3,267.4
Texas	1986	5,541.3
All States		44,170.7

Although the development of mixed-aged, pine-hardwood stands may not be a goal of forest managers, information about the growth of these stands is important. This importance stems not only from the wide area covered by these stands, but also due to the increasing interest of forest managers in applying economically sound silvicultural practices. Often, the maintenance of mixed-aged, pine-hardwood stands may be an important

opportunity cost if their conversion to natural pine or pine plantations is considered. The updating and projection of forest inventories is an important issue both regionally and nationally; due to the large area they occupy, mixed stands must be effectively dealt with to insure the validity of these procedures.

There have been several studies of growth and yield applicable to the South, but most have dealt with even-aged pine stands. Some studies have concerned hardwoods as well, but there has been a lack of stand-level models dealing with mixed-age, pine-hardwood stands.

The nation-wide forest inventory and analysis (FIA) was established as a responsibility of the USDA Forest Service originally in 1928 by the McSweeney-McNary Act. Subsequent laws have continued and extended this function. Over the years, FIA plots have been installed and remeasured, primarily to determine volume and changes in the timber resource. These plots also provide an opportunity to develop information on growth and yield for a variety of stand conditions. Murphy (1982, 1983) and Murphy and Beltz (1980) have used these data for yields of even-aged stands of loblolly pine and shortleaf pine. Studies in other regions have used FIA data to develop yield information in tabular form, such as Hahn and Stelman (1984), and McClure and Knight (1984).

A number of factors make pine-hardwood stands in the South more difficult to analyze than others. Chief among these factors are (1) stand structures, which are often neither even-aged, nor uneven-aged (characterized by having 3 or more age classes distributed in an orderly fashion); and (2) the heterogeneity of species. Data from remeasured FIA plots in the Midsouth offers an opportunity to explore the development of a volume-prediction

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model for these typical stands. The purpose of this paper is to develop a volume prediction model for mixed-aged pine-hardwood stands using data from remeasured FIA plots in the Midsouth.

FOREST INVENTORY PROCEDURES

The Southern Forest Experiment Station, Forest Inventory and Analysis unit (SO-FIA) remeasures permanently established plots on a periodic basis. SO-FIA procedures include classification of trees as either growing stock or cull with volume calculations accomplished for growing-stock trees at least 5.0-inches diameter at breast height (dbh). Basal area is calculated for trees 1.0-inches dbh and larger.
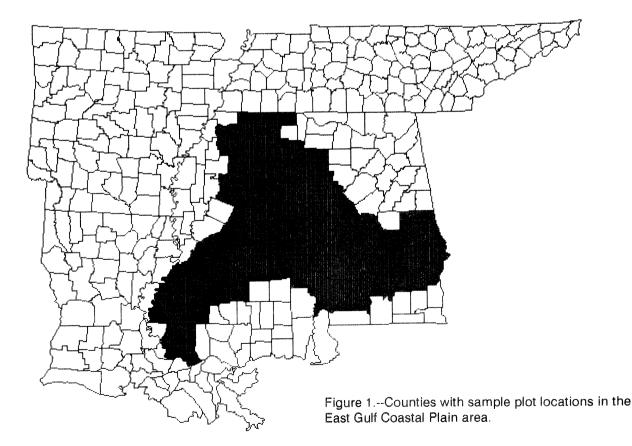
Forest sites are classified by productivity class, based on the best site index trees available - regardless of species. Sites are also classified according to physiography and potential for pine growth; the specific categories for this classification are pine sites, upland hardwood sites, and bottomland hardwood sites. Only pine sites were used in this study.

SO-FIA cruisers assign an age to individual stands - but only if a single tree age is present. The presence of 2 or more distinct age classes will result in a mixed age classification.

As plots are remeasured, a tree history code is used to account for individual trees tallied in the initial survey. These tree history codes indicate trees that have been cut, died, or survived during the inter-survey period. Accounting for trees in the initial measurement thus allows the calculation of change data, such as growth, removals, and mortality; the records also maintain information about the stand at both the initial and final periods.

DATA FOR MODEL DEVELOPMENT

SO-FIA data were selected for model development to include plots in the East Gulf Coastal Plain; areas in the predominantly longleaf-slash pine region near the coast were excluded (figure 1). These plots were screened to include only mixed-aged stands on upland pine sites. Furthermore, plots with the following characteristics were excluded: stands with any eastern redcedar component; plots with any timber removals over the survey cycle; and plots that were otherwise showing a decline in volume. Finally, plots were required to have at least 10 square feet basal area of growing stock. The plots selected range from pure hardwood stands to pure pine stands, with the vast majority having some mix of pine and hardwood.

Portions of Alabama, Mississippi, and Louisiana were included in the study. SO-FIA data are avail-

Figure 1.--Counties with sample plot locations in the East Gulf Coastal Plain area.

able for these states covering 3 surveys. Data for Alabama are available for surveys in 1963, 1972, and 1982; Louisiana data are available for 1964, 1974, and 1984; and Mississippi data covers 1967, 1977, and 1987. The data were assembled so that attributes could be gauged over an approximate 20-year period for qualifying plots - those with at least 10 square feet of initial basal area, no timber removals during the interim, etc. The data from the 20-year period were then pooled with the data from the most recent 10-year period in order to provide differential time periods. In actuality, the elapsed time between measurements for the short-cycle data ranged from 8.1-10.6 years, while the elapsed time for the long-cycle data ranged from 17.5-21.2 years.

A total of 672 plots was utilized, with about half (320) remaining undisturbed over the 2 survey periods. For the pooled data set, initial basal area of growing stock ranged from 11 to 183 square feet per acre, with an average of 61. Pine basal area as a percent of total pine basal area averaged 36 percent. Initial quadratic mean dbh of growing-stock trees averaged 5.4 inches. Table 2 shows the distribution of plots in the pooled data set by site, mean diameter of volume trees, and basal area of growing-stock trees.

Since a variety of species was used to determine site quality, the standard FIA site class variable was used. To facilitate model development, 3 sites were designated: low, representing potential productivity for fully stocked natural stands of 50-84 cubic feet per acre per year; medium, representing potential productivity of 85-119 cubic feet; and high, 120

cubic feet and higher. Loblolly pine site indexes (50-year basis) correspond approximately to these site classes as follows: low, 60-79; medium, 80-94; and high, 95 and above. In order to concentrate on stand conditions influencing stand growth, separate models were estimated for these 3 site classes.

MODEL DEVELOPMENT
Most stand-level yield models deal with even-aged stands through estimation of growth-rate equations integrated over a specified time period (age). An example of these models is Clutter (1963); other studies have used a modification of this approach. Moser and Hall (1969) have modelled growth in un-even-aged stands. This latter model uses periodic change in both basal area and volume as predictor variables for yield over an elapsed time, instead of age. The model was applied to a single stand of mixed hardwood in Wisconsin.

Mixed-aged, pine-hardwood stands are composed of many species differing greatly in their tolerance. The pines are intolerant and may be somewhat tolerant at early age; the hardwoods vary widely in their tolerance by species. Moreover, this stand classification is often used for stands that do not fit more precisely defined categories. This classification is thus a bewildering collage of stands comprised of widely varying species compositions and stand structure conditions.

Due to this complexity, yield functions consisting only of growth-rate equations which are integrated over an elapsed time may not account for potential variability from stand to stand. Additional information relating to specific stand structure and species

Table 2.--Sample plot distribution by site, mean diameter, and basal area at initial period.

Site[a]	Mean diameter[b]	Basal area per acre [c]					
		10-25	25-50	50-75	75-100	100+	Total
Low	No trees	7	3	0	0	0	10
	5-10	25	53	38	16	5	137
	10 +	6	12	14	3	0	35
	Total	38	68	52	19	5	182
Medium	No trees	0	2	0	0	0	2
	5-10	36	77	81	56	26	276
	10 +	11	24	20	18	12	85
	Total	47	103	101	74	38	363
High	No trees	1	1	0	0	0	2
	5-10	29	63	86	57	39	274
	10 +	10	32	40	45	30	157
	Total	40	96	126	102	69	433

[a]Site quality is based on culmination of mean annual growth in fully stocked natural stands as follows: low sites, 50-84 cubic feet per acre per year; medium sites, 85-119; and high sites, 120 and higher.

[b]Mean diameter of tree of average basal area for trees at least 5.0-inches dbh.

[c]Includes growing-stock trees at least 1.0-inches dbh.

composition may be more effective. An effective model would be able to deal with varying stand structures and the mix of species.

The first step in developing a volume prediction model deals with selecting an equation to estimate

$$E(V_2) = a_0 + a_1 B_2 + a_2 D_2 \qquad (1)$$

where:

$E(V_2)$ = expected (predicted) cubic foot volume, inside bark, of growing-stock trees at least 5.0 inches dbh, on a per acre basis for final time period:

B_2 = basal area, in square feet per acre, of growing-stock trees at least 5.0 inches dbh

D_2 = dbh of the tree of average basal area, for trees at least 5.0 inches dbh; also know as quadratic mean diameter

a_0, a_1, a_2 = regression coefficients to be estimated.

This stand volume equation is related to the diameter-diameter squared individual tree volume equation suggested by Cunia (1964).

Obviously, B_2 and D_2 must now be estimated in order to predict V_2. The following equations were formulated to account for the silvical factors affecting changes of B_2 and D_2 over time:

$$E(B_2) = b_0 + b_1(BGS_1) + b_2(PPN_1) + b_3(1/T) \qquad (2)$$

$$E(D_2) = c_0 + c_1 D_1 + c_2(TS_1) + c_3(BLV_1) + c_4(1/T) \qquad (3)$$

where:

BGS_1 = basal area, in square feet per acre, of growing-stock trees at least 1.0 inches dbh for the initial period

PPN_1 = proportion of pine basal area relative to total live basal area (including cull trees) for all trees 1.0 inches dbh and larger

D_1 = quadratic mean diameter for growing-stock trees 5.0-inches dbh and larger

TS_1 = number of sapling growing-stock trees (1.0-4.9 inches dbh)

BLV_1 = basal area of all live trees at least 1.0-inches dbh

T = elapsed time, in years, of the volume prediction period.

b_i, c_i = regression coefficients to be estimated.

Variables BGS_1, TS_1, and BLV_1 deal with stand structure, as it relates to survivor growth, potential ingrowth of volume trees, and total stocking. PPN_1 accounts for the relative presence of pine. Site is not included as a variable, since the discreet site

classes used by SO-FIA would be inappropriate for direct incorporation in a linear model; separate estimations were accomplished for each site class.

Equations (1), (2), and (3) thus form a recursive system of equations that may be used to predict stand volumes for a specified elapsed time. The system contains 3 endogenous variables (V_2, B_2, and D_2), and 6 predetermined variables (BGS_1, PPN_1, D_1, TS_1 and BLV_1, and T). Ordinary least squares may be applied to each equation separately to solve a recursive system (Gujarati 1978). Thus, equations (2) and (3) are first solved, then the results are used to solve equation (1).

RESULTS
The results from the regression analysis are shown in table 3; separate coefficients are provided for low, medium, and high site classes. The plotting of

Table 3.--Estimates of model coefficients and their standard errors for low, medium, and high sites.

Parameter	Estimate [a]	Standard error
	Low sites	
a_0	-1780.570000	322.073715
a_1	23.881840	2.080409
a_2	171.229677	36.598444
b_0	43.424859	5.918468
b_1	0.708188	0.056004
b_2	11.403940	4.837138
b_3	-276.858000	59.265759
c_0	7.540647	0.783882
c_1	0.294168	0.059957
c_2	-0.001385	0.000355
c_3	0.022649	0.005071
c_4	-18.018200	5.793460
	Medium sites	
a_0	-1821.490000	295.333940
a_1	28.343664	1.505178
a_2	141.879423	29.414931
b_0	49.597569	4.486295
b_1	0.652402	0.038251
b_2	18.490549	3.821802
b_3	-263.230000	44.032006
c_0	6.388632	0.432705
c_1	0.469200	0.040207
c_2	-0.000910	0.000203
c_3	0.011827	0.002785
c_4	-12.586200	3.253608
	High sites	
a_0	-2496.190000	234.969557
a_1	33.698729	1.462825
a_2	167.449396	20.807730
b_0	59.799143	3.577081
b_1	0.578900	0.029587
b_2	17.479120	3.500136
b_3	-291.454000	36.109863
c_0	5.786932	0.444331
c_1	0.611919	0.037755
c_2	-0.000634	0.000192
c_3	0.008523	0.002327
c_4	-14.313900	3.062363

[a] All parameter estimates are significant at the .05 probability level.

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residuals indicated no discernable violations of assumptions inherent in the linear model. Possible collinearity between explanatory variables in the equation system was investigated by linear regression. The strongest linear correlation was between D_1 and TS_1 in equation (3), but this was deemed weak; furthermore, the variables actually represent separate parameters of different, albeit related, components in the stand.

The effectiveness of the equation system is indicated in table 4. Deviations from the mean predicted values are presented as root mean square errors and coefficients of variation.

Table 4.--Model estimation errors.

Site	Equation and variable	Mean[a] value	Root mean[a] square error	Coefficient of variation
				(Percent)
Low	(1) - V_2	1,169	493	42.2
	(2) - B_2	56.5	19.2	34.0
	(3) - D_2	9.3	1.8	19.6
Medium	(1) - V_2	1,650	575	34.8
	(2) - B_2	72.6	20.5	28.2
	(3) - D_2	10.0	1.5	15.0
High	(1) - V_2	2,034	594	29.2
	(2) - B_2	80.5	18.9	23.4
	(3) - D_2	10.9	1.6	14.6

[a] V_2 is in cubic feet; B_2 in square feet; and D_2 in inches dbh.

These equations accounted for the following percent of the variation in stand volumes at the final period: low sites, 54.5; medium sites, 54.4; and high sites, 62.2.

APPLICATION OF THE MODEL

Application of the model requires current stand data for the following items: (1) total basal area and number of merchantable growing-stock trees those at least 5.0-inches dbh; (2) total basal area of growing-stock trees at least 1.0-inches dbh, for both pine and all other species; (3) the number of sapling growing-stock trees (1.0-4.9 inches dbh); and (4) the basal area of cull trees at least 1.0-inches dbh. These data are then used to develop the explanatory variables in equations (2) and (3). The quadratic mean diameter of merchantable growing-stock trees (D1) is computed as a function of basal area and number of trees.

For application of the model on medium sites, basal area and mean diameter are predicted with the following equations:

$B_2 = 49.597569 + 0.652402 \ (BGS_1)$
$\quad + 18.490549 \ (PPN_1) - 263.230000 \ (1/T)$ (4)

$D_2 = 6.388632 + 0.469200 \ (D_1) - 0.000910(TS_1)$
$\quad + 0.011827 \ (BLV_1) - 12.586200 \ (1/T)$ (5)

After computing estimated values for B_2 and D_2, the projected volume is calculated by the following equation:

$V_2 = -1821.49 + 28.343664 \ (B_2)$
$\quad + 141.879423 \ (D_2)$ (6)

As an example, suppose a predicted volume for 20 years hence is needed for a stand on a medium site (loblolly pine site index 80-94, 50-year basis) with the following characteristics on a per acre basis: 50 square feet of total live basal area, consisting of 5 square feet of cull trees, 15 square feet of pine and 38 square feet of basal area in merchantable growing-stock trees (at least 5.0-inches dbh); the stand has 125 growing-stock trees of merchantable size, and 150 growing-stock trees of sub-merchantable size. Initial volume is estimated at 200 cubic feet per acre. First, the quadratic mean diameter of the current volume trees (D_1) should be calculated. This is done as follows:

$D_1 = [(38 \text{ sq ft}/125 \text{ trees})/0.005454]^{0.5}$

$\quad = 7.5\text{-inches dbh}$

The proportion of pine growing stock is also determined:

$PPN_1 = 15/50 = 0.30$

Then, equations (4) and (5) are solved:

$B_2 = 49.597569 + 0.652402 \ (45) + 18.490549$
$\quad (0.30) - 263.23 \ (1/20)$

$\quad = 71.34 \text{ sq. ft./acre}$

$D_2 = 6.388632 + 0.469200 \ (7.5) - 0.000910(150) +$
$\quad 0.011827 \ (50.0) - 12.586200 \ (1/20)$

$\quad = 9.7\text{-inches dbh}$

Finally, the predicted volume equation is solved:

$V_2 = -1821.49 + 28.343664 \ (71.34)$
$\quad + 141.879423 \ (9.7)$

$\quad = 1,577 \text{ cubic feet/acre}$

Given the initial volume of 200 cubic feet per acre, the stand has produced 1,377 cubic feet in 20 years, for an annual average growth of 69 cubic feet per acre.

Other equation coefficients presented in table 3 may be used similarly to provide estimates of volume for low and high sites. It should be noted that the V_2 equation is to be used to estimate predicted volumes, not current estimates.

Figure 2 shows the relationship of predicted values to elapsed time for average stand conditions existing at the time of initial measurement for the 3 site classes. Table 5 shows the average stand conditions for plots in the data set.
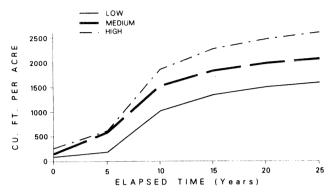

Figure 2.--Relationship of predicted volumes to elapsed time for average stand conditions at initial measurement, by site class.

Table 5.--Mean values for stand variables for plots in the data set, by site class.

Variable and unit	Site class		
	Low	Medium	High
BGS_1 (sq. ft/ac.)	47.6	59.4	67.8
PPN_1	0.36	0.37	0.35
D_1 (inches dbh)	8.2	8.9	9.5
TS_1 (numbers)	437	451	435
BLV_1 (sq. ft./ac.)	60.8	72.8	83.4
V_1 (cu. ft./ac.)	92	154	268

The model does not provide separate estimates of pine and hardwood volume; an extension of the model is planned that will accomplish this. Users may, however, make independent estimates of the proportion of pine volume at the predicted time.

CONCLUSION

The model presented here for prediction of future timber volumes for mixed-aged stands on upland pine sites accounted for 54-62 percent of the variation in stands located in the East Gulf region of the Coastal Plain. Other models dealing with even-aged pine stands typically account for more variation; they should be used where applicable. Since observations for the stands included in the study were accomplished for only 3 time periods covering a minimum of 8 years and a maximum of 21 years, the model is valid only for limited projection periods - perhaps a span of 5-25 years.

It should be noted that the models account for an average amount of mortality. However, stands declining in volume - showing a negative growth

rate - were excluded from the data and model estimation. The presence or absence of large amounts of mortality could be a major factor in actual volume yields.

Further development does need to be done before it is fully satisfactory in many situations. The model needs to be extended to estimate pine and hardwood volumes separately. Also, as forest surveys continue across the Midsouth, additional data may be incorporated to strengthen the parameter estimates, especially over longer periods of time.

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LINKING STAND-LEVEL AND INDIVIDUAL-TREE GROWTH
SIMULATORS FOR MIXED SPECIES STANDS

F. Thomas Lloyd[1]

Abstract. — Growth and yield information will be needed to manage the pine--hardwood type. This paper reports on the early stages of a major research effort to develop a growth and yield forecasting system for pine-hardwood mixtures and outlines the steps being taken to develop supporting data bases needed to calibrate the system. It is not a discussion of a working model. Rather, it lays out principles on which the research is being built and describes in broad terms how modeling will proceed.

INTRODUCTION

Various mixtures of yellow pine and hardwood are recognized as common stages of succession following forest disturbance in the South. Traditionally, silviculturalists have viewed these stands as prime candidates for conversion to pure pine. As a result, pine-hardwood mixtures have not been studied as a management type. Papers at this symposium demonstrate that there are a lot of reasons for considering management of pine-hardwood mixtures and that such management will require certain kinds of research.

One pressing need is for information on growth and yield of pine-hardwood mixtures. Very little information is available in the literature, and what has been published has come from pine management studies that either by chance or design had hardwoods relegated to an understory status (e.g., Burkhart and Sprinz 1984, Smith and Hafley 1987). Studies have not been designed to evaluate growth characteristics in overstory mixtures of even-aged pine and hardwood. The goal of the research I propose is to develop a suitable system for forecasting growth and yield of mixed stands. In this paper I discuss the envisioned modeling approach and briefly describe initial field studies. By necessity, the exposition glosses over specific model constructs and associated calibration details. I also recognize that what apparently are viable assumptions and approaches may prove to be false or unworkable.

MODEL PRECEPTS

Rotation-length growth and yield models traditionally predict stand-level attributes such as mean stand diameter, total basal area, volume, and the number of surviving trees for species monocultures. Considerable research has also gone into breaking down these stand-level statistics into diameter class frequency distributions. Even for monocultures, the complexity of this disaggregation process is considerable, and it is greater when modeling mixed species stands because of the need to predict by species group. The selection of appropriate groupings is an early requirement. **Precept one is that species grouping will be based on a combination of shade tolerance, joint occurrence, on specific site types, and the similarity of growth patterns within groups.** Final refinements to group composition will be determined by prediction objectives. For example, development of the pines is important because of their high stumpage value, so pine might be split from a broader group of intolerant species.

Site-specific differences in height growth are anticipated and will be among the growth criteria used in species group formation. For example, early height growth of hardwoods generally increases more than pine height growth as site type progresses from xeric to mesic conditions. Composition of the hardwoods also changes across the moisture gradient, so species groups probably will differ between site types. It is difficult to incorporate all height complexities found over the range of site conditions being considered because of limits to the flexibility of the mathematical constructs needed to describe the process. **Precept two is that modeling can be simplified by building separate sets of height growth curves for specific site types defined across a moisture gradient.** A description of the classification system that will identify the site-quality gradient to be used in this research is given by Jones (1989).

Precept three is that at any given time growing space used by one species or species group in a mixed stand is not available for other species or species groups. The challenge here is not in accepting the validity of this foundational concept, but rather in quantifying its effects. The model constructs must mimic annual growth trends brought

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about by crowding. A sound basis for incorporating these trends is contained in the limiting size boundary of the -3/2-power rule. This rule (or law-like constraint) says that over time competition for growing space will increase, mortality (or self-thinning) will begin as competition intensifies, and growth in average tree size will slow precipitously if self-thinning is allowed to progress undisturbed.

Rotation-length models estimate stocking with poor precision and/or contain bias due to the irregularity of mortality. The problem is considered inconsequential when performing broad forest management decision analyses and regional economic evaluations over large areas. However, similar analyses for forestry enterprises and individual forest landowners require more precise and accurate growth and yield projection. A frequently used alternative approach to improving precision is to inventory stands for up-to-date stocking estimates and then project growth of the sample tree lists over a relatively short (relative to forestry decisions) time period, say 5 to 15 years. Both approaches have valid applications and are widely used, so **precept four is that periodic growth estimates from both stand table projection and rotation-length prediction systems must be the same when site quality, basal area, and stand age are equal.**

MODEL ELEMENTS
The standard approach to growth and yield investigation is to establish plots over the range of conditions to be modeled, remeasure the plots over time, and mathematically describe the data. As an adjunct to this process, I believe we need to use more of what we know in general about stand dynamics to creatively expand the range of data we draw upon and the way that data are used to fit models. One emphasis in this investigation will be on how stands behave at biological limits (e.g., at the carrying capacity density and biological rotation age) and how selected model constructs function when used to describe this behavior. With this strategy, modeling can provide understanding and direction for further study, rather than only another model with a limited scope and capability.

The model parameters that control behavior will be set using a variety of information and fitting strategies (from nonlinear estimation to best guesses). Accurately characterizing stand behavior at the biological limits will allow greater flexibility in the way other information is used to describe model behavior. One cost of such an approach is accepting some model bias and the challenge of deciding how much can be permitted without damaging model performance.

The plan is to build a two-phase model: (1) an establishment phase (before stand closure) and (2) a competition phase describing stand development after stand closure, or after some preselected young stand age very near stand closure. The establishment phase will be characterized by rapid change, the results of which will determine the success or failure of pine establishment. Driving variables in the establishment phase model will include the amount, type, and condition of natural regeneration; relative height development of pine to other species; and, perhaps, some measure of free-to-grow-status of pines (such as percent), type and timing of harvest, and preharvest species composition. The primary output from the establishment phase model will be an estimate of overstory species composition at crown closure (say percent basal area by species group). After closure, competition for growing space becomes a major driving force in stand development, characterized by self-thinning and reduced rates of change in mean tree size, stand volume, and basal area. The two phases will be linked via the estimate of overstory composition at crown closure. The competition phase of the model can also be used for growth simulation by not using the establishment phase model and simply choosing species composition at the linkage age.

Volume curves will be formed from two basic model components: (1) the height models described above and (2) expressions of mean size (S) as functions of surviving trees per unit area (N) and stand age. Mean size (S) will be bounded above by the maximum limiting size (Sm), where

$$S_m = gN^{-3/2} \qquad (1)$$

A limiting size expression like Equation (1) will be established for each species group and the value of parameters (g) will be adjusted for the proportion of the stand each species group occupies. Growth curves that express quadratic mean diameter as a function of the number of trees in groups will be bounded from above by limiting expressions like Equation (1) by partitioning the level parameter (g) for the total stand model.

Survival is a key variable in this modeling effort, but relevant data have not been gathered and planned permanent plot installation is just beginning. Furthermore, new observations from planned studies will be restricted to periodic mortality in existing stands ranging from 10 to 35 years of age. Non-standard methods of developing survival curves are being formulated. One approach will plot mean size (quadratic mean diameter or stem volume) over number of surviving trees from our initial plot

measurements (i.e., before repeat measurements are available). An approximation for Equation (1) will be established by choosing the theoretical value for the exponent parameter (-3/2 for stem volume and -1/2 for quadratic diameter) and estimating the level parameter (g) either by eye using a graph or by fitting a model that describes mean size using nonlinear estimation (see Lloyd and Harms, 1986). In its present form, Lloyd and Harms' model requires the number of trees at the linkage age (approximate stand closure). The strategy here will be either to use ocular estimates from graphs based on where the observed data point is in relation to the limiting size line defined by Equation (1) or to modify the model so that only the present number of surviving trees is needed. Survival curves will then be derived using the fitted stand trajectory model and a set of harmonized curves obtained by plotting mean size over basal area. Each curve comprising the harmonized set represents a different number of surviving trees.

General knowledge of stand development suggests the working hypothesis that height growth can be a major driving variable in the growth and yield model for pine-hardwood stands. Height growth will be incorporated as a driving variable based on its relationships with diameter growth, leaf biomass, crown volume, relative mean size, competitive status, and survival rates. The height information will come from stem analyses of key species from a range of sites. Separate sets of height/age curves will be developed for each species-group and site-type combination.

The stand table projection method will use individual-tree, distance-independent technology like that in the STEMS models that are so successfully applied to mixed northern hardwood stands. In this component of the system, a diameter growth model similar to the maximum potential growth and modifier approach as presented by Belcher and others (1982) will be used, but the modifier function will be designed so that total basal area growth from the stand-level model will be distributed according to tree size (diameter) ranking in the tree list, thus linking the two model types. Height growth will come from the models for the stand-level system described above. Mortality will also come from the stand-level model, but the effect of mortality will be imposed by adjusting growth on all trees in the list, rather than trying to decide which trees to remove (i.e., "kill") from the list. The adjustments to growth designed to compensate for mortality will be proportionally greater at the small end of the diameter rankings, decreasing to nearly zero for the largest trees.

DATA

Existing data are limited. However, in a completed 35-year study of natural loblolly pine regeneration, one of the treatments was to follow the natural stand that developed after harvesting a mixed pine-hardwood overstory. A second treatment in the same study produced a mixed pine-hardwood stand by killing the large residual hardwoods. This study, therefore, is a good starting point even though the data are of limited scope and the hardwood component was not measured the same way as the pine.

Two new studies are being installed on Piedmont sites in South Carolina and Georgia that will be used in developing the competition phase model. In one study, stem analyses will be used to develop the height models mentioned above. The second is a large permanent plot growth study in 10- to 35-year-old, even-aged, pine-hardwood stands on National Forest lands. About 150 plots will be established. Data for the establishment phase of the model will come from four regeneration studies now in place and others that are planned. Other sources of data include areas of pine-hardwood regeneration established on a production basis on the Sumter National Forest for the last 10 years.

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PINE-HARDWOOD FORESTS IN NORTH-CENTRAL MISSISSIPPI: AN ECOLOGICAL AND ECONOMIC PERSPECTIVE

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Abstract.—Overstory and understory characteristics of 19 pine-hardwood forests in north-central Mississippi were studied. Stands were naturally regenerated and had not been disturbed. Overstory variables including diameter, basal area, total and merchantable height, species composition, density, radial growth, and site index were studied. Understory variables including relative species abundance and white-tailed deer (Odocoileus virginianus) summer forage production were evaluated in relation to diversity, temporal dynamics, deer carrying capacity, and timber production. Stand characteristics varied with topographic position and soil classes. Only pine basal area was greatest on upland sites while site index, hardwood basal area, pine and hardwood height, and pulpwood production were greatest on bottomland sites. The hardwood component was more prevalent in the Interior Flatwoods (IFW) where hardwood sawtimber and pulpwood yield was greatest. Pine dominance decreased with stand age, with a corresponding increase in hardwood basal area, yield of sawtimber and pulpwood, and density. Diameter class distributions and understory tree composition indicated a shift to a more mixed pine-hardwood overstory as stands matured. Summer forage yield was independent of age with an average standing crop of 96.3 kg/ha. Pine was the dominant component in all stands sampled. A constant value of hardwood sawtimber, more predictable summer forage yield, greater overstory and understory species diversity, increased hard and soft mast production, and greater recreational value when contrasted to pine monocultures make natural pine hardwood forests desirable. This is more applicable to private, non-industrial landowners with multiple use goals.

INTRODUCTION

The pine-hardwood forest type occupies approximately 20 percent of forested land in Arkansas, Alabama, Texas, and Mississippi. In Mississippi, over 11 percent of the state's land mass or 22 percent of all forested land is comprised of mixed pine-hardwood stands (U.S. Forest Service 1985). Additionally, over 70 percent of the pine-hardwood stands in Mississippi are privately owned (U. S. Forest Service 1985) and are not intensively managed. This fact is important because for every acre of pine (Pinus spp.) plantation in Mississippi there are 2 acres of pine-hardwood forest.

Pine plantation acreage is increasing whereas acreage of the pine-hardwood forest type is decreasing. This result is due to higher anticipated yields from intensively managed pine plantations (Miller 1954). Additionally, regeneration costs are often prohibitive to the non-industrial land owner (Phillips and Abercrombie 1987), who simply permits natural regeneration. However, regeneration costs are not the sole reason why many private landowners choose natural regeneration methods because projected mixed-pine stands meet multiple use objectives (Royer 1979). Only 30 percent of

Mississippi's non-industrial forest landowners indicated that timber production has been a major goal, although other goals including grazing, wildlife, and recreation were also important (Porterfield and Moak 1977).

Thus, a majority of forested lands in the Southern United States are represented by the pine-hardwood forest type and are owned by private, non-industrial owners. Most of these stands are regenerated naturally because of high cost and multiple use goals as well as owner indifference. Within this context, this paper will describe the overstory and understory characteristics of naturally regenerated pine-hardwood stands found in north-central Mississippi and relate these characteristics to multiple use management goals (timber and wildlife management).

STUDY AREA

Nineteen pine-hardwood stands (figure 1) were sampled. Stands were considered for sampling if they were naturally regenerated, had not had any timber stand or wildlife habitat improvement prior to sampling, especially within the last 20 years, and were at least 80 contiguous acres. Stands were selected to provide a wide range of ages (30 - 100 years) and thus a wide range of overstory and understory characteristics. Stands 1-11 were sampled in 1978-79, stands 12-15 in 1974-75, and the remaining stands, 16-19 in 1980-81.

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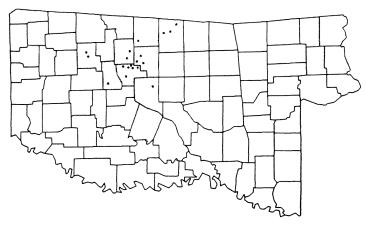
Figure 1.--Location of nineteen naturally regenerated pine-hardwood forests sampled between 1974-1981 in north-central Mississippi.

Sampled stands were within one of two land resource areas (Pettry 1977) and included the IFW and the Upper Coastal Plains (UCP). The IFW is underlain with a highly acidic layer of shale with soils developed in a silty and clayey material. Soils are low in plant nutrients and waterlogged conditions are common during the winter and spring. Topography is mostly flat with little topographic relief. Soils of the UCP are derived from loamy, clayey, and sandy coastal plain sediments which are generally deep, well-drained to moderately well-drained with fragipans and clayey subsoils. Topography ranges from level to steep hill sides that are eroded, low in fertility, and acidic.

The general climate for both regions is very similar with annual precipitation ranging from 130 to 150 cm, concentrated during the winter and spring (McWhorter 1962). Mean annual temperature ranges from approximately 17.2 to 18.3° C with winter temperatures averaging from 4.4 to 7.2° C and summer temperatures from 27.2 to 28.8° C.

MATERIALS AND METHODS

Measured Variables

Overstory stand measurements. For stands 1-15, 12 one-fifth acre circular plots were sampled to determine overstory and understory characteristics. But for stands 16-19, only 9 one-fifth acre plots were sampled in each stand. Growing stock was described by measuring all individual trees [0.5 in. diameter breast high at 4.5 feet (dbh)], total and merchantable height (4.6 inches dbh; co-dominant and dominant trees), age, number of layers in the canopy and stand density. Merchantable timber was determined either as number of 10 foot bolts for pulpwood (dbh 3.6, 3.6 top) or 16 foot bolts for sawlogs (hardwood: dbh 11.6, 9.6 inch top; pine:dbh 9.6, 7.6 inch top). Age of at least 2 red

oaks, 2 white oaks, and 4 pine (preferably 2 loblolly, 2 shortleaf) was measured. For pine, radial growth for the previous 5 and 10 years was also measured. Site index and basal area were calculated from these data.

Understory stand measurements. Understory vegetation below 4.5 inches dbh was sampled using two methods. Species specific frequency and occupancy were estimated using 100 foot line transects with 0.10 foot sampling intervals. To estimate species specific summer forage yield, ranked-set sampling (Dell and Clutter 1972) was used. Nine, 9.62 foot^2, circular plots were located 25 feet from plot center at 40 degree intervals clockwise from North. All plants 4.5 feet in height and less than 0.55 inches in diameter were clipped. Plants were classified as desirable or undesirable deer browse (Crawford and others 1969, Mawk 1976, Warren 1980). Clipped samples were oven-dried at 70° C for 72 hours. Individual understory species were classified as either grass, forb, vine, or woody.

Computed Stand Measurements

Total pine and hardwood basal area were computed using measured tree diameters. Pine and hardwood pulpwood (cords/acre) and sawtimber (board feet) were computed using a local volume table, International 1/4 inch rule. Diversity of understory vegetation was determined using the Shannon-Wiener Function and standardized as a relative index by dividing it by its theoretical maximum (Zar 1984:32-34). Site index was derived only for loblolly pine (Pinus taeda).

Statistical Analyses

Simple linear regression analysis was used to assess temporal changes in stand overstory conditions. To determine differences in stand characteristics regarding topographic position, nonparametric Mann-Whitney two sample tests for differences in medians were employed. A similar analysis with the Mann-Whitney test was applied to test for differences in overstory characteristics with respect to the land resource areas.

RESULTS

Overstory Characteristics

General. Species composition varied with individual stands but 13 oaks (Quercus spp.), 2 pine, 8 hickories (Carya spp.), 4 ash (Fraxinus spp.), 3 elm (Ulmus spp.) and 63 other species were identified. Predominant tree species (comprising 5 percent of any individual stand) included loblolly pine,

shortleaf pine (P. echinata), post oak (Q. stellata), southern red oak (Q. falcata), white oak (Q. alba), water oak (Q. nigra), mockernut hickory (C. tomentosa), blackgum (Nyssa sylvatica), sweetgum (Liquidambar styraciflua), flowering dogwood (Cornus florida), red maple (Acer rubrum), tree sparkleberry (Vaccinium arboreum), eastern red cedar (Juniperus virginiana), sourwood (Oxydrendrum arboreum), winged elm (U. alata), and yellow-poplar (Liriodendron tulipifera).

Overstory characteristics varied greatly within stands with respect to topographic position as well as between stands with respect to land resource areas (tables 1 and 2). Pine age ranged from 36 to 99 years but age of hardwoods ranged between 51 to 106 years providing a wide range of stand conditions. Dominant and co-dominant hardwoods were generally 10-30 years older than pines of similar stature, particularly in the young to intermediately aged stands (30-60 years old).

Loblolly pine site index also varied, ranging from 72 to 98. Pine basal area was highly variable and extended from a minimum of 2 to a maximum of 144 feet2. Density of hardwoods generally, except for stand 12, exceeded that of pine independent of soil group or topographic position (bottom vs. upland).

However, although more dense, hardwood dbh was generally significantly lower than pine with only one exception (Stand 14), indicating that maturing stands consisted of fewer but older pines with an understory comprised primarily of hardwood species. Total tree height differed between pine and hardwoods, with height of dominant and co-dominant pine always exceeding that of the hardwood overstory.

Contrasting merchantable timber for all stands followed the same pattern as for basal area, tree height, and diameter at breast height. Pine sawtimber greatly exceeded that of hardwood, often with a 20:1 ratio. Maximum pine sawtimber measured almost 25,000 board feet contrasted to a maximum hardwood sawtimber of 8,500 board feet. Conversely, hardwood pulpwood, except in stands 11, 16, and 17, generally exceeded pine with a 3:1 ratio which is understandable since many hardwood stems were in the smaller diameter classes. Finally, growth of pine varied from 4.2 to 10.7 inches/year.

Effects of topographic position. Overstory characteristics differed greatly with respect to topographic position. Only average pine density (P = 0.006) was greater in plots located on upland sites. Conversely, site index (P < .001), hardwood basal area

Table 1.—Characteristics of 11 natural, pine-hardwood stands with respect to topographic position (hill and bottom) sampled in 1978-1986 of the Upper Coastal Plain land resource area in north-central Mississippi

Stand Measurement	Stand #3			Stand #4			Stand #5			Stand #7			Stand #8		
	Bot.	Hill	Total	Bot.	Hill	Total	Bot.	Hill	Total	Bot.	Hill	Total	Bot.	Hill	Total
Age															
Pine	38.0	64.0	59.7	60.3	60.3	60.2	45.4	60.2	56.5	52.2	63.3	61.3	57.4	45.6	49.9
Hardwood	----	86.2	86.2	66.0	74.5	70.2	38.0	69.7	65.1	87.0	74.5	78.7	57.5	46.0	51.1
Site Index	101.0	87.7	89.8	82.5	70.0	72.1	91.0	79.4	82.3	95.0	79.0	81.7	79.2	72.1	74.7
Basal Area															
Pine	67.7	86.6	83.4	56.7	76.8	73.4	68.5	96.9	89.8	83.8	84.4	84.3	42.6	83.5	66.4
Hardwood	66.6	37.9	42.7	43.2	24.1	27.3	56.4	27.5	34.7	48.7	33.0	35.6	76.3	23.2	45.3
Density															
Pine	50	285	246	97	224	203	128	438	360	87	334	293	78	253	180
Hardwood	600	738	715	480	470	472	890	522	614	945	701	742	721	515	601
Diameter															
Pine	14.5	7.8	8.9	9.4	8.3	8.5	13.3	7.1	8.6	12.5	6.7	7.8	10.6	7.4	8.6
Hardwood	4.4	3.0	3.2	2.9	3.0	3.0	3.4	2.9	3.0	3.0	2.7	2.8	4.0	2.8	3.3
Height															
Pine	88.1	58.9	63.8	59.0	54.5	55.3	79.0	58.3	63.5	77.2	60.1	63.2	66.1	52.0	57.1
Hardwood	53.6	41.6	43.6	33.0	30.4	30.8	44.2	35.3	37.5	50.0	41.5	42.9	46.2	37.3	41.0
Growth Inc.															
5 year	19.2	11.3	12.6	15.9	10.6	11.5	16.1	13.4	14.1	16.7	11.2	12.1	10.0	17.0	14.1
10 year	33.7	22.4	24.3	26.1	20.2	21.2	32.6	23.3	25.6	31.7	22.2	23.7	19.2	25.8	23.1
Sawtimber															
Pine	12931	11435	11684	7414	8362	8204	10659	10362	10436	12831	9247	9845	5091	5961	5599
Hardwood	3897	1494	1894	0	300	250	1288	423	639	888	1471	1373	4035	536	1994
Pulpwood															
Pine	27	203	173	61	79	76	48	198	161	137	171	165	75	264	185
Hardwood	727	337	402	411	273	296	458	393	409	1029	440	538	651	230	405

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Table 1.—(continued) Characteristics of 11 natural, pine-hardwood stands with respect to topographic position (hill and bottom) sampled in 1978-1986 of the Upper Coastal Plain land resource area in north-central Mississippi
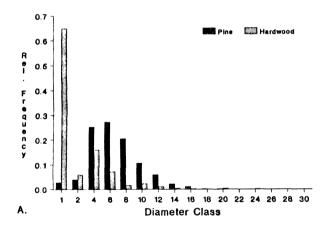
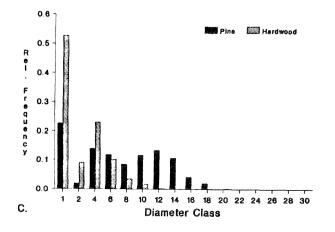| Stand Measurement	Stand #9 Bot.	Hill	Total	Stand #11 Bot.	Hill	Total	Stand #16 Bot.	Hill	Total	Stand #17 Bot.	Hill	Total	Stand #18 Bot.	Hill	Total	Stand #19 Bot.	Hill	Total
Age																		
Pine	46.5	43.7	44.4	35.5	36.0	35.9	33.7	37.6	36.7	37.2	41.3	40.3	64.5	57.8	59.5	80.2	65.4	69.1
Hardwood	43.7	62.3	54.9	52.8	53.9	53.5	----	----	----	----	----	----	----	----	----	----	----	----
Site Index	84.7	77.0	78.9	90.7	77.7	80.9	100.5	75.0	81.4	100.0	77.2	82.9	111.0	94.2	98.4	105.0	80.2	83.7
Basal Area																		
Pine	53.3	76.1	70.4	136.2	113.2	119.0	180.8	131.8	144.1	143.6	130.0	133.4	162.4	116.0	127.6	77.2	101.8	95.6
Hardwood	58.8	28.6	68.7	36.5	30.7	32.2	41.2	27.3	30.8	53.2	25.2	32.2	62.0	60.6	60.9	62.5	44.8	49.2
Density																		
Pine	68	220	182	332	451	421	355	552	502	205	572	481	132	136	135	52	192	157
Hardwood	640	372	439	930	546	642	902	511	609	1550	800	987	1382	1622	1562	987	1054	1037
Diameter																		
Pine	13.1	9.0	10.0	8.3	6.8	7.1	9.4	6.5	7.2	10.7	5.8	7.0	14.9	11.9	12.7	16.1	8.9	10.7
Hardwood	3.9	3.1	3.3	2.6	3.1	3.0	2.2	2.5	2.5	2.0	1.8	1.8	2.2	2.0	2.1	2.5	2.1	2.2
Height																		
Pine	74.7	56.8	61.3	63.8	51.4	54.5	70.6	53.1	57.5	74.7	53.9	59.1	109.3	83.7	90.1	90.4	75.1	79.0
Hardwood	45.5	42.9	43.5	44.7	40.4	41.5	44.7	42.8	43.3	48.0	41.8	43.4	53.2	46.9	48.5	51.5	41.9	44.3
Growth Inc.																		
5 year	19.7	17.4	18.0	22.5	19.5	20.3	19.9	13.8	15.3	18.2	14.7	15.6	13.5	13.5	13.5	8.1	8.3	8.3
10 year	25.7	31.6	30.2	39.7	36.3	37.2	35.4	23.6	26.5	34.0	26.8	28.6	24.4	24.4	24.4	15.8	15.6	15.7
Sawtimber																		
Pine	6476	8197	7767	9686	5275	6377	9737	4969	6161	17404	6079	8910	33051	22246	24947	15854	17393	17008
Hardwood	1825	961	1177	1168	994	1037	0	65	49	57	388	305	391	304	326	1916	779	1063
Pulpwood																		
Pine	76	1234	112	712	523	570	670	755	734	378	552	508	145	96	108	61	48	51
Hardwood	817	234	402	408	445	436	529	331	380	533	149	245	591	376	430	658	264	363

Table 2.—Characteristics of 8 natural, pine-hardwood stands with respect to topographic position (hill and bottom) sampled in 1978-1986 of the Interior Flatwoods land resource area in north-central Mississippi

Stand Measurement	Stand #1 Bot.	Hill	Total	Stand #2 Bot.	Hill	Total	Stand #6 Bot.	Hill	Total	Stand #10 Bot.	Hill	Total	Stand 12	Stand 13	Stand 14	Stand 15
Age																
Pine	45.5	50.3	48.5	61.4	60.0	60.2	108.8	93.9	99.3	40.9	40.5	40.6	75.0	75.0	75.0	80.0
Hardwood	85.8	85.8	85.8	94.7	78.7	81.9	111.3	103.2	105.6	74.3	80.9	79.2	-----	-----	-----	-----
Site Index	83.2	78.5	80.1	95.0	92.5	92.9	86.7	79.1	81.7	84.7	82.6	83.1	-----	-----	-----	-----
Basal Area																
Pine	74.1	48.5	57.0	67.4	110.7	103.5	63.2	44.8	51.0	57.5	66.8	64.5	44.7	28.4	49.0	2.0
Hardwood	53.7	62.3	59.4	68.7	44.2	48.3	64.8	76.6	72.7	60.8	54.1	55.8	42.4	56.6	67.0	84.4
Density																
Pine	229	410	350	90	114	110	29	35	33	142	165	159	120	56	62	2
Hardwood	590	488	522	530	557	553	747	765	759	888	794	818	107	157	91	165
Diameter																
Pine	7.5	4.6	5.5	10.9	13.0	12.6	19.3	13.6	15.5	8.8	8.1	8.3	7.5	8.6	11.0	18.0
Hardwood	4.3	4.7	4.6	4.3	3.6	3.7	3.7	3.8	3.8	3.2	3.1	3.1	7.7	7.3	11.2	8.4
Height																
Pine	68.1	61.2	63.7	75.2	83.8	82.3	100.3	78.4	85.7	61.5	57.7	58.6	-----	-----	-----	-----
Hardwood	64.4	62.7	63.3	57.5	48.4	49.9	44.3	45.8	45.3	48.2	47.1	47.4	-----	-----	-----	-----
Growth Inc.																
5 year	-----	-----	-----	13.1	10.1	10.6	9.9	9.8	9.8	21.1	20.8	20.9	-----	-----	-----	-----
10 year	50.9	37.9	42.2	26.2	19.8	20.9	19.6	18.4	18.8	39.7	39.9	39.9	-----	-----	-----	-----
Sawtimber																
Pine	5695	3062	3940	9812	18377	16949	15441	8502	10815	4708	5034	4952	4510	3428	6518	370
Hardwood	1786	2261	2103	5344	1705	2312	2296	4649	3865	3124	2798	2879	2493	2873	5025	8500
Pulpwood																
Pine	329	152	211	186	144	151	0	23	16	238	271	263	396.8	179.2	141	0
Hardwood	679	677	678	214	492	445	838	760	786	765	373	471	448.0	550.4	486	550

(P = 0.006), pine diameter (P = 0.002), pine (P = 0.004) and hardwood (P = 0.013) height, and hardwood pulpwood production (P = 0.003) were greatest on bottomland sites. Sawtimber production and pine basal area varied greatly among stands and site but were independent of topographic position. Hardwood diameter was equal (P = 0.32) for topographic positions because most hardwood stems were less than 3.6 inches dbh.

Effects of soil regime. Many overstory characteristics differed greatly with respect to land resource area. Pine basal area (P = 0.003), pine density (P = 0.004), hardwood density (P = 0.05), and pine sawtimber (P = 0.05) were greater for the UCP when contrasted to the IFW. Conversely, hardwood basal area (P = 0.019), hardwood diameter (P = 0.001), average hardwood height (P = 0.011), hardwood sawtimber (P = 0.001), and hardwood pulpwood production (P = 0.001) were greater for the IFW. Variables that were not significantly different between the two land resource areas included site index, pine diameter, pine height, and radial growth (mm/year).
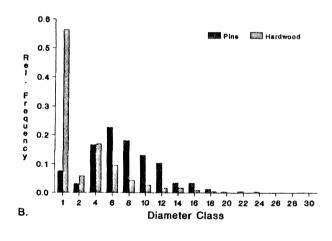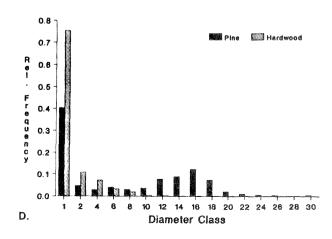
Diameter class (age) distribution. Pine and hardwood diameter class distributions were developed for stands 1-11 and 16-19. Diameter class 1 represented number of stems 3.55 inches dbh, whereas all subsequent diameter classes represent 2 inch diameter increments.

Generally, a consistent pattern was found where pine diameter distribution formed a "bell-shaped" curve or was slightly skewed to the left. Differences did exist and were primarily in location of the mode, increasing as age increased (figures 2 and 3). Hardwood diameter distributions were significantly different from pine, with most individuals in the smaller diameter classes which supports earlier observations regarding hardwood diameter relationships. Additionally, the modal diameter for hardwoods did not shift significantly when contrasted to pine (figures 2 and 3)

Figure 2.--Diameter class distributions for naturally regenerated pine-hardwood forests sampled between 1974-1981 in the Upper Coastal Plain land resource area of north-central Mississippi.
A = Stand 11; B = Stand 8; C = Stand 4; D = Stand 19.
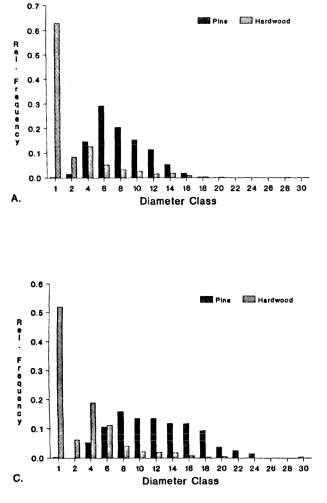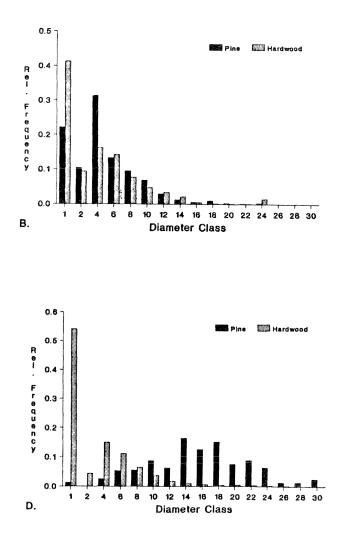
A.

B.

C.

D.

Figure 3.--Diameter class distributions for naturally regenerated pine-hardwood forests sampled between 1974-1981 in the Interior Flatwoods land resource area of north-central Mississippi. A = Stand 10; B = Stand 1; C = Stand 2; D = Stand 6.

Temporal overstory dynamics. Simple linear regression analyses were performed to assess changes in overstory parameters with respect to age (table 3). Age was positively related to hardwood basal area ($P = 0.001$), average pine ($P = 0.001$) and hardwood ($P = 0.009$) diameter, hardwood sawtimber ($P = 0.004$) and hardwood pulpwood ($P = 0.007$) production. Pine basal area ($P = 0.002$), pine density ($P = 0.001$), pine growth (mm/yr) ($P = 0.004$), percentage pine sawtimber production ($P = 0.026$), and pine pulpwood volume ($P = 0.002$) were inversely related to stand age.

Stand age was regressed with total sawtimber for red oak, white oak, and other hardwoods. Only red oak sawtimber significantly increased with age ($P = 0.0295$).

Regressions were performed relating stand age with total basal area of hard, soft, and total mast producing trees. Hard mast producers included oaks and hickories but soft mast producers included flowering dogwood, blackgum, huckleberries (Vaccinium spp.), hawthorn (Crataegus spp.) and grape (Vitus spp.). Basal area of soft, hard, and total mast producing trees remained relatively constant with respect to stand age (slope not significantly different from 0.0, $P > 0.05$).

Understory Characteristics

Species diversity and richness. Relative frequency of understory species was derived from the line transect data. A total of 261 was identified from line transects. This total included 25 grasses, 104 forbs, 23 vines, 28 shrubs, 52 trees, 7 ferns, 12 sedges, 9 bryophtes, 1 mushroom, and 1 liverwort. Species occurring most frequently (percentage occurrence exceeding 2.5 percent) included southern red oak, poison ivy (Rhus radicans), greenbriar (Smilax glauca), grape (V. rotundifolia), sweetgum, flowering dogwood, and red maple. Most species were tree species.

TABLE 3.— Selected correlation coefficients (r) relating stand age (pine) and overstory and understory stand characteristics for natural pine-hardwood forests sampled in 1978-1985 in north-central Mississippi

Stand Characteristic	Stand Age (Pine)		
	r	P-Value	Regression Coefficient
Overstory			
Pine Basal Area	-0.631	0.002	-1.390
Hardwood Basal Area	0.646	0.001	0.608
Total Basal Area	-0.442	0.056	-0.778
Pine Density	-0.772	0.001	-6.89
Hardwood Density	-0.278	0.125	-5.93
Total Density	0.505	0.028	-12.80
Pine Diameter	0.665	0.001	0.124
Hardwood Diameter	0.538	0.009	0.082
Pine Growth (10 yrs)	-0.662	0.004	-0.316
Pine Sawtimber	0.053	0.414	18.000
% Pine Sawtimber	-0.453	0.026	-0.006
Hardwood Sawtimber	0.594	0.004	71.600
Total Sawtimber	0.292	0.176	89.700
Pine Pulpwood	-0.638	0.002	-7.43
Hardwood Pulpwood	0.557	0.007	4.13
Total Pulpwood	0.288	0.180	-3.30
Understory Forage Yield			
Grass	0.254	0.148	0.158
Forb	0.057	0.407	0.060
Vine	-0.372	0.059	-0.426
Woody	-0.144	0.278	-0.198
Total Desirable	-0.166	0.247	-0.407

Relative species diversity (grass, forb, vine, shrub, tree) ranged from 0.35 to 0.85 and was independent of stand age (P > 0.05). Species richness (total number of species within each life form) of the overstory varied from as many as 58 species to as few as 21. Similar to diversity, understory species richness was independent of stand age. For example, for stand 9 (age 99), species richness was 44 contrasted to stand 16 (age 37) with a species richness of 50. Similarly, species richness of the understory was also independent of stand age, ranging from 78 to 130 species.

Deer Summer Forage Yield

Total yield was extremely variable ranging from 38.0 to 198.0 kg/ha, with an average of 97.2 kg/ha (table 4 and 5). Grass production ranged from 0.40 to 35.3 kg/ha with an average of 11.6 kg/ha. An average forb forage production of 15.1 kg/ha, ranging from 1.3 to 58.7. Production of vine browse was similar to forb, ranging from 4.5 to 79.2 and averaging 30.5. Woody browse production was greatest, averaging 40 kg/ha and ranging between 10.9 to 120.2 kg/ha.

TABLE 4.—Deer forage yield (kg/ha) for natural pine-hardwood forests sampled in 1978-1985 of the Upper Coastal Plain land resource area in north-central Mississippi

Stand	Lifeform				
	Grass	Forb	Vine	Woody	Total
Stand 3					
Bottom	1.0	0.8	46.4	30.6	78.8
Hill	17.1	10.8	10.8	38.1	76.8
Composite	14.5	9.1	16.8	36.9	77.3
Stand 4					
Bottom	18.6	33.7	13.7	55.7	121.7
Hill	38.6	63.7	18.9	76.7	197.9
Composite	35.3	58.7	18.0	73.2	185.2
Stand 5					
Bottom	35.9	33.3	54.0	68.6	191.8
Hill	14.7	25.1	23.4	113.3	176.5
Composite	20.0	27.1	31.0	120.2	198.3
Stand 7					
Bottom	87.3	21.0	32.0	17.9	158.2
Hill	21.8	21.1	30.0	49.7	122.6
Composite	32.7	21.0	30.3	44.4	128.4
Stand 8					
Bottom	2.1	4.5	89.8	56.4	152.8
Hill	0.3	8.8	60.5	27.9	97.5
Composite	1.0	7.0	72.7	39.8	120.5
Stand 9					
Bottom	1.1	1.6	62.0	71.9	136.6
Hill	15.9	4.4	51.1	32.6	104.0
Composite	12.2	3.7	53.8	42.4	112.1
Stand 11					
Bottom	0.1	2.3	198.9	18.0	219.3
Hill	0.9	4.4	39.3	38.0	82.6
Composite	0.7	3.9	79.2	33.0	116.8
Stand 16					
Bottom	0.1	0.0	59.1	52.1	111.3
Hill	0.5	3.1	18.8	47.0	69.4
Composite	0.4	2.4	28.9	48.3	80.0
Stand 17					
Bottom	0.0	0.1	16.5	7.7	24.3
Hill	2.5	18.9	14.0	64.7	100.1
Composite	1.9	14.2	14.7	50.5	81.3
Stand 18					
Bottom	0.0	0.1	16.6	14.0	30.7
Hill	3.6	1.6	11.5	51.7	68.4
Composite	2.7	1.3	12.7	42.3	59.0
Stand 19					
Bottom	4.1	1.1	2.2	17.9	25.3
Hill	12.8	4.9	5.2	44.5	67.4
Composite	10.7	3.9	4.5	37.8	56.9

Contrasting total deer summer forage yield (dry weight kg/ha) with respect to topographic position indicated no significant differences (P = 0.836). Similarly, total deer forage yield was not significantly different with respect to land resource area (P = 0.231). Finally, regressing stand age with deer forage yield indicated that forage yield was independent of stand age (P > 0.05) (table 3).

To estimate an approximate number of deer that the pine-hardwood forests may sustain, several assumptions must be made. Jacobson (1984) found that a deer consumed an average of 1.306 kg/day, dry weight basis. Additionally, if we assume that to

TABLE 5.--Deer forage yield (kg/ha) for natural pine-hardwood forests sampled in 1978-1985 of the Interior Flatwoods land resource area in north-central Mississippi

			Lifeform		
Stand	Grass	Forb	Vine	Woody	Total
Stand 1					
Bottom	21.4	40.6	47.9	20.8	130.7
Hill	11.6	64.2	30.1	40.7	146.6
Composite	14.9	56.4	36.0	34.1	141.4
Stand 2					
Bottom	7.2	4.4	32.3	15.1	59.0
Hill	0.8	2.7	20.1	10.0	33.6
Composite	1.9	3.0	22.2	10.9	38.0
Stand 6					
Bottom	2.0	8.7	30.0	43.0	83.7
Hill	1.4	0.9	31.5	74.0	107.8
Composite	1.6	3.5	31.0	63.7	99.8
Stand 10					
Bottom	11.7	3.3	23.4	28.5	66.9
Hill	2.8	1.0	27.1	28.0	58.9
Composite	5.0	1.6	26.1	28.1	60.8
Stand 12					
Composite	14.2	15.8	20.9	11.8	62.7
Stand 13					
Composite	16.6	14.4	33.4	16.3	80.7
Stand 14					
Composite	18.6	5.7	28.9	11.4	64.6
Stand 15					
Composite	15.4	34.6	18.9	14.1	83.0

maintain plant vigor, only 50 percent of available yield may be consumed and assuming a 92 day period (summer), the following formula may be used:

$$Y = \frac{0.50 \times \text{forage production (kg/ha)}}{1.306 \text{ kg/deer/day}} \times \frac{1}{92 \text{ days}}$$

where Y = number of deer/hectare.

This yields a range in summer deer carrying capacities of 0.158 - 0.824 deer/hectare, with an average of 0.401 deer/hectare or a stocking density of 1 deer/2.5 hectares.

Overstory Reproduction. We compared percentage occurrence of major overstory species (identified on 1/5 acre plots) and percentage occurrence of understory species (line transect data). Tree species examined included loblolly and shortleaf pine, white oaks, red oaks, sweetgum, hickories, ash, red maple, blackgum, magnolias (Magnolia spp.), elms, black cherry (Prunus serotina), eastern red cedar, persimmon (Diospyrus virginianus), and beech (Fagus grandifolia).

Generally pine dominated the overstory but was scarce to absent in the understory (figures 4 and 5). However, as expected, percentage occurrence of hardwoods was greatest within the understory contrasted to overstory abundance. One exception did occur, sweetgum occurrence in the understory was equal to or less than occurrence in the overstory. Red oaks were always more predominant in the understory whereas white oak was more predominate in the overstory in two stands, equal in four stands, and more abundant in the understory for the remaining five stands.

DISCUSSION

Naturally regenerated pine-hardwood forests sampled in north-central Mississippi were extremely complex regarding plant species diversity, overstory/understory species composition, composition changes with respect to time, yield of deer forage, and timber production. Additionally, within stands, site differences (upland vs. bottom) and the effects of soil were also evident.

Several past studies demonstrated that intensively managed pine plantations produce a large amount of deer browse when compared to forest stands not intensely managed (Schuster 1967, Halls 1970, Blair and Enghardt 1976, Hurst and Warren 1980, Cutler 1986). However, biomass of browse may not be completely sufficient if diversity of the understory is also desired. Intensive forest management generally results in apparent loss of spatial, temporal, and vertical ecosystem diversity which is considered essential for a variety of wildlife, esthetics, and ecosystem stability (White 1975). Relative stand diversity of the overstory ranged from 0.244 to 0.781 which would not be the case for intensively managed monocultures. Concerning the understory, relative diversity of four, 10 year old bedded and four, 8 year old tree injected pine plantations was 0.603 and 0.614 respectively (Warren, unpublished data) which is approximately equal to species diversity computed for our stands. Additionally, only 43 species were identified on the line transects for both bedded and tree-injected plantations. Finally, unmanaged pine plantations older than 11 years provide little deer forage yield (Cutler 1980) whereas deer forage yield for the natural pine-hardwood forest, although significantly lower than in pine plantations, remained constant and therefore predictable, over all age classes (P > 0.05).

Another component of the pine-hardwood forest is mast production. Several wildlife species are noted for their use, if not need, of hard and soft mast to ensure winter survival and possibly optimal productivity the following spring. White-tailed deer (Segelquist and Green 1968) and wild turkey (Gardner and Arner 1968, Billingsley and Arner 1970, Beasom and Pattee 1980) are two such species. We computed total basal area for hard and soft mast producers and found that total basal area for hard mast producers ranged from 0.9 to 64.1 feet^2 and 0.6 to 13.9 feet^2 for soft mast producers.

A. Species or Species Group

B. Species or Species Group

C. Species or Species Group

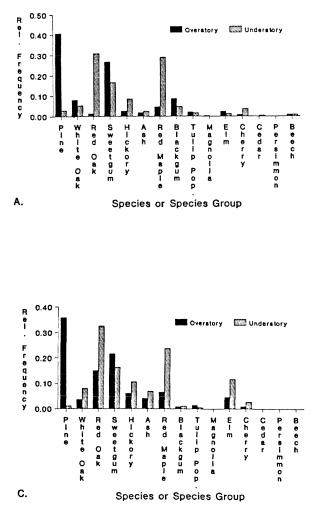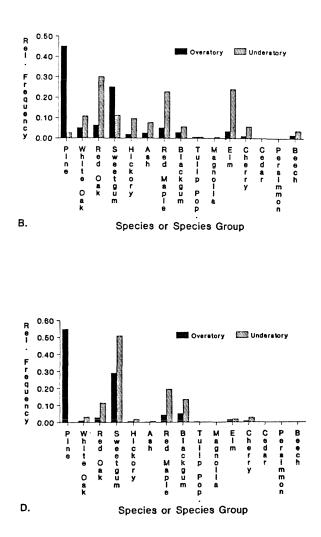**D.** Species or Species Group

Figure 4.--Percentage occurrence of selected tree species within the overstory and understory for naturally regenerated pine-hardwood forests sampled between 1974-1981 in the Upper Coastal Plain land resource area of north-central Mississippi. A = Stand 4; B = Stand 9; C = Stand 8; D = Stand 11.

When mast production is added to deer forage yield, the value of pine-hardwood forests for forage increases and possibly exceeds that of older (5 year old) pine plantations (Hurst and Warren 1980).

Average total stand sawtimber volume differed slightly from the UCP to the IFW, 11.5 MBF and 10.1 MBF respectively. However, the UCP stands were significantly different when species composition of sawtimber is compared with IFW stands. The UCP stands were 95 percent pine and 8 percent hardwood by volume while the IFW stands were only 65 percent pine and 37 percent hardwood by volume. Since all study stands were chosen on the basis of a non-disturbance criterion, the very real influence of site condition on species composition was observable. The UCP sites are usually defined as pine management sites, whereas

the IFW sites, on average, are of a higher productive potential and thus able to maintain hardwoods into dominate and co-dominant positions in the stand. This fact becomes important when sawtimber value is considered.
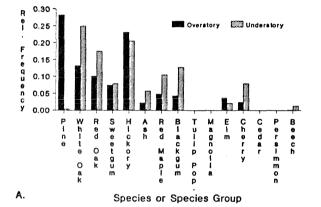
Changes in sawtimber value with time are observable when the 1978 inventory is priced at 1978 and 1989 stumpage prices as reported by Timber Mart South. Recent increases in hardwood sawtimber prices do make an impact on value distribution (table 6). In this case, although it may seem that

Table 6.--Volume and value distribution by site (Upper Coastal Plain and Interior Flatwoods, Mississippi) and price reporting years for natural pine-hardwood stands in north-central Mississippi.

		Year	
		1978	1989
Land Resource Area	% Volume	% Value	% Value
Upper Coastal Plain			
Pine	92.0	97.0	93.0
Hardwood	8.0	3.0	7.0
Interior Flatwoods			
Pine	63.0	83.0	68.0
Hardwood	37.0	17.0	32.0

pine sawtimber dominates the pine-hardwood stands, the increase in value per unit of timber is greater for hardwoods and thus decreases the margin of difference between pine and hardwood.

A more critical management issue is the amount of value growth required to carry either group of stands for another growing season. If a 10 percent alternate rate of return is required, then a decision variable may be identified for each stand. For the UCP pine stands, annual volume growth must be 0.5 MBF/acre if stumpage prices of $200/MBF are assumed. Not many of these stands will reach this level of growth under conditions as described. Essentially, the same holds true for the IFW stands. Since these stands have a higher proportion of hardwood, growth would likely be lower. But the lower volume growth may be offset by higher values associated with selected hardwood species. This

would result in managers being more likely to reduce the pine component volume and value on both site groups. A normal scenario would be to begin cutting pine volume when the larger sized trees were saleable for small sawlogs. This diameter limit cut is frequently applied to unmanaged stands in the South. The end result is to convert the stand from a pine-hardwood type to a mixed species type where pine is a minor species. Uninformed managers frequently make timber sale decisions which drastically and negatively impact on future revenue flows from the timber resource.

This study supports the concept of managing pine-hardwood stands to optimize pine timber production as an effective deer management treatment. There is no significant difference between deer forage yield between the stands or land resource

A.

B.

C.

D.

Figure 5.--Percentage occurrence of selected tree species within the overstory and understory for naturally regenerated pine-hardwood forests sampled between 1974-1981 in the Interior Flatwoods land resource area of north-central Mississippi. A = Stand 10; B = Stand 1; C = Stand 2; D = Stand 6.

area. Yet, there is a significant difference in average volume of pine sawtimber on the UCP (10.6 MBF/acre) and the IFW (6.4 MBF/acre).

Landowners must integrate species and site capability in choosing a management system. In many instances, Mississippi forest sites are much better suited for pine production. However, pine-hardwood forests offer more than timber production values. Revenue/acre for hunting leases are growing. An annual hunting lease which pays $10/acre would return income equivalent to the value of 50 board feet of pine sawtimber growth/acre when this growth is valued at $200/MBF. If pine sawtimber growth potential is reduced by 100 board feet/acre/year, then the annual hunting lease returns should equal $20/acre. Additionally, pine-hardwood forests offer additional values not readily available in intensively managed pine plantations including bird-watching, hiking, watershed values, fishing, and a greater diversity of hunting opportunities (squirrels, turkey, white-tailed deer). Therefore, forest management must be tempered to meet multiple use goals and within the pine-hardwood forest type, reduced timber yields may be acceptable when other values are desired, particularly by the non-industrial, private landowner.

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PINE AND HARDWOOD REGENERATION OPTIONS ON A CUMBERLAND PLATEAU SITE: AN ECONOMIC PERSPECTIVE

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Abstract. — In a study conducted by the U.S. Forest Service near Sewanee, TN, 11 year performance data were available on several low cost regeneration options implemented following the shear harvest of an upland mixed hardwood stand. We evaluated the options to allow natural development, to plant loblolly pine, and to plant loblolly pine following herbicide injection treatments of residual hardwoods. The YIELDplus and HDWD software packages were used to project existing stand conditions forward to rotation age. Cost data and stumpage market assumptions were used to simulate the financial profitability for a full rotation cycle of each regeneration option. Results should be relevant to the owners of moderate quality upland sites in the South desiring to generate some forestry income with minimum capital investment.

INTRODUCTION

The Cumberland Plateau area of Tennessee abounds with low-quality hardwood trees (i.e., poor form, relatively small, low value sawtimber species). The primary reason for this condition is past logging practices, which over many years removed the higher grade growing stock. Other reasons behind the profusion of low-quality hardwood stands include the moderately low site quality typical for this region, fire and weather related damage, and insect and disease problems (McGee 1982). Non-industrial private landowners control forest management activities on the bulk of these lands. The long established pattern of irregular harvests which "take the best and leave the rest" continues today as dictated by personal financial need. Although pine plantations earn a respectable return on investment, conversion costs form a barrier which few landowners are willing or able to overcome. Costs for conversion can be reduced considerably if first, a mixture of pine and hardwood is considered acceptable, and second, markets for low-quality hardwoods develop to the point that intensive (i.e., multi-product, mixed species) harvesting becomes economically feasible. Ironically, the prospect of rising hardwood stumpage prices, relative to pine, also raises the possibility that intentional development of a pine component is not warranted.

Markets for low value hardwood trees are evolving, thus sparking new hope for better management of the region's low-quality hardwood stands. Domestic paper manufacturers increasingly are substituting hardwood for pine when expanding mill capacity (Skog and others 1988). The export market for hardwood chips is also growing. Current trends indicate that intensive harvest of Cumberland Plateau hardwoods may become economica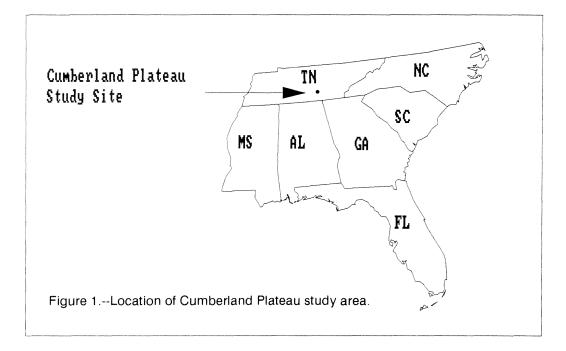lly feasible within a decade. Intensive harvesting of low-quality hardwood stands effectively clears the site of trees and creates a number of options for regenerating new stands. The purpose of this paper is to project the growth, yield, and economic performance of 3 possible low-cost regeneration options following a shear harvest which removes all material down to a 4" diameter breast high (dbh) limit. The regeneration options are:

1) allow natural development

2) plant loblolly pine

3) inject residual hardwoods with herbicide and plant pine

We use simulation results to speculate on which regeneration option is the most financially attractive. We also contrast financial returns for these 3 low cost regeneration options with those for a fourth, an intensively site prepared pine plantation.

CUMBERLAND PLATEAU STUDY

The 40 acre study area is located on the University of the South Domain near Sewanee, Tennessee (figure 1) and is typical of Cumberland Plateau land which has been logged and burned at irregular intervals (McGee 1980; McGee 1986). Prior to a shear harvest, the area was fully stocked with low-quality hardwood trees. Oak site index averaged 60-65 feet (base 50). After harvest, the area was divided into 1 acre plots. Six plots were planted to loblolly pine on an 8 x 10 spacing (545 stems/acre). Three of these 6 plots received herbicide injection treatments for residual trees greater than 4 1/2 feet tall followed by re-treatment within the year of trees which escaped injection on the first pass. Three additional plots served as controls. The remaining plots received other treatments which are not relevant to this discussion.

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Figure 1.--Location of Cumberland Plateau study area.

Eleven year growth and yield performance data were collected and summarized for the 9 plots used for this paper. McGee (1989) provides a full accounting of these results. The plot data summary (table 1) show that herbicide injection treatments boost the height growth, survival, and basal area development of the planted pine. Data for regeneration options number 2 and 3 refer to the pine component only. Spatially, the pine component has evolved into clumps throughout the plots where pine was planted. Visual inspection of the plots reveals planting rows where nearly every pine tree has survived alternating with areas where no pine trees are visible.

Table 1.--Average performance values per acre by regeneration option measured 11 years following treatment (McGee 1989)

Regeneration Option	Site Index		Number Stems	Basal Area
1) Natural	65 (base 50)	oak	666	--
2) Plant pine	53 (base 25)	loblolly	403	32 ft^2
3) Inject residuals, plant pine	57 (base 25)	loblolly	458	65 ft^2

ASSUMPTIONS

Various assumptions must be made in order to seed the growth and economic projection models. They are grouped into categories for cultural practice costs, stumpage prices, and growth and yield simulation procedures.

Cultural Practice Costs

Cultural practice costs were incurred on the study site for herbicide injection treatments and for hand planting of pine. An intensively site prepared plantation would entail costs for chopping, burning, and machine planting. Although an intensively site prepared pine plantation was not established on the study site, the estimated costs and returns are considered here for comparison purposes (regeneration option number 4). Southwide average costs were selected for all treatments so that the simulation results would be more generally applicable (table 2). Table 3 summarizes the cultural practice costs assumed for each of the four regeneration options.

Table 2.--Southwide average cultural practice costs (Straka, Watson, and Dubois 1989)

Cultural Practice	Cost (dollars/acre)
Herbicide Injection Site preparation	48
Hand Planting Cutover land following less than intensive site preparation	40
Machine Planting Cutover land following intensive site preparation	35
Loblolly Pine Seedlings (545/acre) Tennessee Division of Forestry	13
Double Chop	113
Burn Chopped Areas Ground drip torch	10

Table 3.--Total cultural practice costs by regeneration option

Regeneration Option	Cultural Practices	Cost (dollars/acre)
1) Natural	None	0
2) Plant pine	Hand planting, loblolly pine seedlings	53
3) Inject residuals plant pine	Herbicide injection, hand planting, loblolly pine seedlings	101
4) Chop, burn, and plant pine	Double chop, burn chopped area, machine plant, loblolly pine seedlings	171

Stumpage Prices

Prices for Tennessee pine and hardwood timber fluctuate widely according to location and quality. The average prices reported in table 4 show that oak sawtimber stumpage values have been rising briskly in recent years (Neal and Norris 1989). Mixed hardwood sawtimber values average less than those for pure oak. When we questioned several foresters operating in the Cumberland Plateau region of Tennessee, they indicated that the hardwood pulpwood market had not emerged yet in their vicinity. They also mentioned that "Plateau oak" sawtimber stumpage values run considerably less than those reported in table 4. Pine pulpwood prices currently range from $12/cord or more in the southern portion of the State where paper mills are in close proximity, to virtually no value in the northern portions of the State. Since future prices are impossible to predict, we used the 1977-1987 average prices as a starting point for the simulation analysis.

Table 4.--Stumpage prices per cord and per Mbf (thousand board feet) for Tennessee (Neal and Norris 1989)

| Year | Southern Pine | | Oak | |
	Cord	Mbf (Scribner)	Cord	Mbf (Doyle)
		-dollars-		
1977	5.60	44.00	1.50	81.00
1978	6.00	57.00	1.50	107.00
1979	5.90	67.00	1.50	98.00
1980	5.50	62.00	1.50	86.00
1981	5.40	64.00	2.00	78.00
1982	3.80	60.00	2.20	62.00
1983	6.50	86.00	2.50	65.00
1984	7.50	88.00	2.50	110.00
1985	8.70	76.00	2.60	100.00
1986	8.70	84.00	2.70	100.00
1987	8.65	63.00	2.50	107.00
Average	6.57	68.27	2.09	90.36

Growth and Yield Simulation

Stand dynamics for pine and hardwood mixtures are not well understood. Fortunately, the 11 year performance data establish trends which afford some indication of future stand development.

However, bold assumptions about future stand growth must be made before a model is used to perform a projection. The YIELDplus: Timber Yield Forecasting and Planning Tool (Hepp 1987) and HDWD (Burkhart and Sprinz 1984) computer programs were selected for performing growth projections and financial analyses. YIELDplus relies on a variety of published growth and yield models for single species, evenaged stand types. The HDWD model is designed to estimate future volumes in loblolly pine plantations which have a significant hardwood component. In HDWD, the user must specify the percent or amount of basal area in hardwood in the main canopy. This percent is then assumed to remain constant.

The pine-hardwood mixtures examined in this study required some innovative applications of the models. Initially, the YIELDplus cutover site loblolly pine plantation simulator was selected for projecting development of the chop, burn and plant pine regeneration option. However, yields estimated from the simulator compared with the 11-year data for the inject residuals, plant pine regeneration option revealed an inconsistency. Apparently, the mediocre site quality of the Plateau region results in significantly less hardwood competition than is typical for the South, given equal levels of site preparation intensity. Therefore, the YIELDplus oldfield loblolly pine simulator was judged more appropriate to simulate the chop, burn and plant pine option. This simulator enjoys the added benefit of being based upon data collected from loblolly pine plantations located in the region (Smalley and Bailey 1974). Table 5 summarizes the model selected and other considerations made for simulating the growth and yield performance of each regeneration option.

Table 5.--Assumptions for projecting growth and yield by regeneration option

Regeneration Option	Model	Calibration Assumptions
1) Natural	YIELDplus (Upland oak)	[a]Age 20 basal area 87 ft^2/acre, 782 stems/acre
2) Plant pine	HDWD	Hardwood is 40 percent of total basal area
3) Inject residuals, plant pine	HDWD	Hardwood is 13 percent of total basal area
4) Chop, burn, and plant pine	YIELDplus (Oldfield loblolly pine)	Plant 545 stems/acre, site index 57(base 25)

[a]Based on full stocking level for 666 stems at age 11 (Gingrich 1964) and projecting forward 9 years using the YIELDplus upland oak simulator (Dale 1972).

All financial analyses were conducted using YIELDplus. Valuation of the hardwood component in pine-hardwood mixtures posed a challenge. For lack of a better approach, the assumption inherent to HDWD that the proportion of hardwood basal

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area remains constant over time following crown closure, was expanded to include volume. The Soil Expectation Value (SEV) (Faustmann 1849) was used as the financial criterion for relative comparison of financial returns. SEV is expressed in real, after tax, dollars using a 4 percent, before tax, discount rate and a 28 percent income tax rate. Applicable reforestation income tax incentives were used to adjust cash flows prior to SEV calculations. The average stumpage prices cited in table 4 were used to translate sawtimber and pulpwood volume estimates into value estimates.

SIMULATION RESULTS

The YIELDplus and HDWD models were used to determine the SEV's for each regeneration option across a range of rotation ages. Thinnings were not considered in the projections to avoid excessive complexity. The inject residuals, plant pine regeneration option showed the highest simulated SEV (figure 2), followed closely by the chop, burn and plant pine option. By comparison, both the natural and plant pine regeneration options performed poorly despite their no or low investment costs. The after tax internal rate of return for the inject residuals, plant pine regeneration option was 5.1 percent using a 40 year rotation age. However, the chop, burn, and plant pine option performed nearly as well for the assumed stumpage price levels. When risk of failure for the pine to survive is accounted for, the chop, burn, and plant pine option appears to be the overall best.

The rotation age which maximized SEV for each regeneration option was used for subsequent analyses. The regeneration options and the respective rotation ages are:

1) natural, age 80

2) plant pine, age 45

3) inject residuals, plant pine, age 40

4) chop, burn, and plant pine, age 45.

Undoubtedly, thinning regimes would change the rotation ages, particularly if the pine and hardwood components were treated separately. Figure 3 illustrates the mixture of simulated pine and hardwood sawtimber production for each regeneration option. The volumes reported reflect differences in log rules and rotation ages.

Future stumpage prices cannot be predicted with certainty. Real appreciation rates in sawtimber stumpage values for pine versus hardwood are subject to speculation. Figure 4 shows how SEV varies across a range of hardwood sawtimber stumpage values, while holding the value of pine sawtimber

constant at $68.27/Mbf (Scribner). Conversely, figure 5 shows how SEV varies by changing pine sawtimber stumpage values when hardwood sawtimber values are held constant at $90.36/Mbf (Doyle).

Figure 4 indicates that increasing hardwood sawtimber stumpage prices do not compensate well for the slow growth rate of hardwood relative to pine. Figure 5 implies that if pine sawtimber stumpage prices exceed approximately $80/Mbf (Scribner) while holding hardwood prices constant at $90.36 (Doyle), then intensive site preparation and planting is justified. When pine ranges between $50 and $80/Mbf, the inject residuals, plant pine option is somewhat better. In a weak pine sawtimber market, no investment in pine generation (i.e., natural option) is about as good as any other option.

CONCLUSIONS

Pine-hardwood stand dynamics are poorly understood. The simulation procedures in this analysis should be interpreted with considerable caution. The conditions for the study site may not be representative for the Cumberland Plateau in general and conclusions should not be extrapolated to other regions. However, some useful inferences probably can be safely drawn from the results. They are:

- Intensive harvest of low-value hardwood stands in the Cumberland Plateau region would create an assortment of regeneration options. The economically superior option depends heavily upon future prices for hardwood and pine sawtimber.

- The superior growth rate of pine relative to hardwood for this site is sufficient to compensate for high pine establishment costs and low sawtimber stumpage prices for pine.

- The mediocre site quality of the Plateau region apparently allows for successful establishment of a loblolly pine plantation with relatively less intensive site preparation than is possible for the South in general. Further replications of this study are required to verify this claim.

- Overall investment returns from pure pine or pine-hardwood culture on the Cumberland Plateau may not compete favorably with non-timber investment opportunities. A 5.1 percent after tax, real, internal rate of return is attractive. However, risk, liquidity, and capital formation may still pose a barrier for many landowners. The risk associated with uncertain future prices, pine seedling mortality, and pests cannot be ignored.
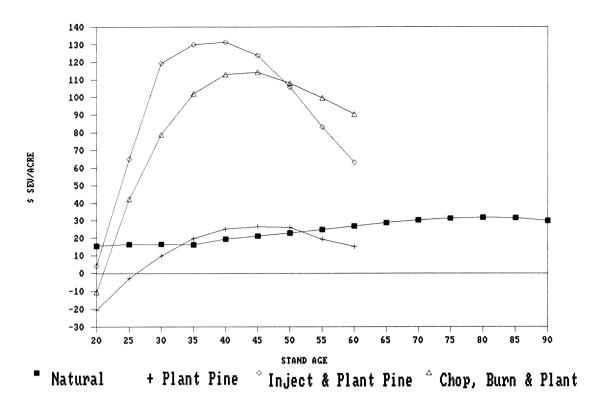
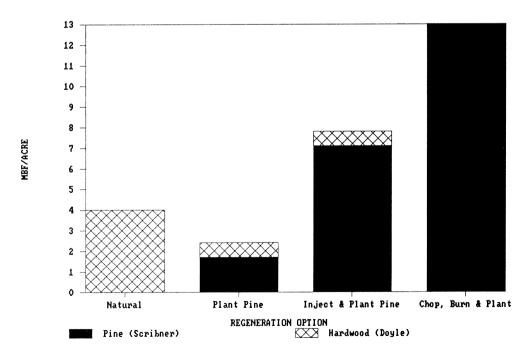Figure 2.--SEV plotted over rotation age by regeneration option.

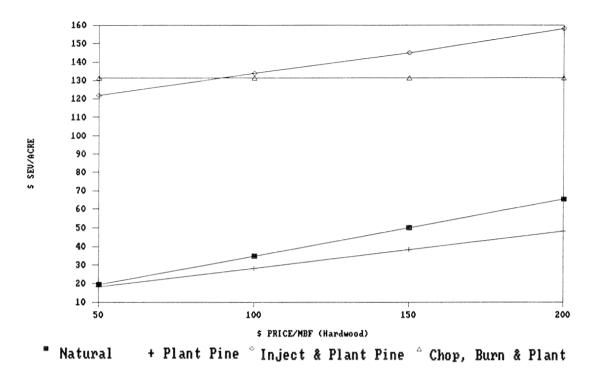Figure 3.--Sawtimber volume yield by regeneration option.

Figure 4.--SEV plotted over hardwood sawtimber
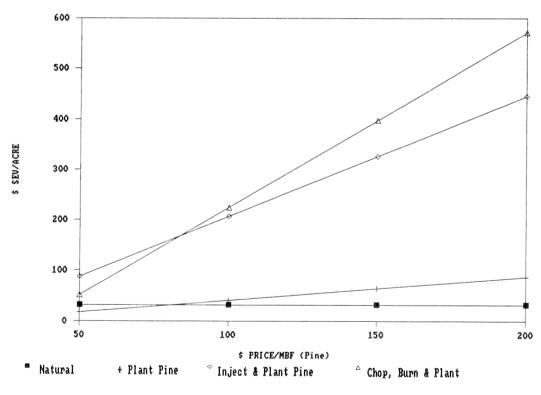stumpage price by regeneration option.

Figure 5.--SEV plotted over pine sawtimber
stumpage price by regeneration option.

• Expanding hardwood pulpwood demand may result in only moderately intensive harvesting if tree length logging is employed. This is because tree length loggers commonly cut down to a 6-8 inch dbh minimum. Therefore, a substantial amount of residual hardwoods may remain to inhibit regeneration efforts. Costs for residual control may be higher than those assumed for this analysis.

Intensive harvest of low-value hardwood stands in the Cumberland Plateau region is a means to an end. For private landowners interested in forest management, that end generally is the culture of a new crop of sawtimber stumpage products. An emerging hardwood pulpwood market may lead to a partial "cleaning of the silvicultural slate." However, speculation on future pine and hardwood sawtimber stumpage prices should drive the next decision, choosing a regeneration option. Our analysis showed that introduction of a loblolly pine component boosts volume yield and net economic returns relative to pure hardwood culture. Moreover, a pine component can be established following a shear harvest for about $100/acre before subsidies and reforestation income tax refunds. Considering the financial constraints faced by typical private landowners, however, this author believes that most lands harvested to meet growing hardwood pulpwood demand will be allowed to evolve naturally. Revenues from the sale of previously non-merchantable trees combined with increased growing space for desirable hardwood sprouts should mark a modest improvement over past conditions.

ACKNOWLEDGMENTS

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MANAGED MIXED PINE-HARDWOOD STANDS CAN YIELD
HIGH RATES OF RETURN ON INVESTMENT

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Abstract. — A simulation model was used to predict yields of natural stands of pure loblolly pine, mixed pine-hardwood, and a mixture of hard and soft hardwoods. A second model was used to predict yields of loblolly pine plantations with four levels of encroaching hardwood competition. Yields were predicted with and without thinning in all cases. Yields from a 30-year rotation were merchandized and analyzed economically in terms of internal rate of return and annual equivalent yield. Natural stands with 50 percent or less hardwood component were more profitable than artificially seeded stands of pure pine. Natural stands with 75 percent or less hardwood, and seeded stands with 50 percent or less hardwood exceeded the rate of return of the best plantation option. While natural and seeded stands of pine and mixed pine-hardwood had the highest rates of return, financial yields of several plantation options were high enough to be acceptable to many investors, even with some hardwood encroachment. There are many sites on which natural or seeded stands will not give favorable results. But where such stands will develop, they can be highly profitable. Mixed pine-hardwood stands are even more valuable where wildlife and aesthetic resources contribute to overall management goals.

INTRODUCTION

Economic criteria by which the quality of an investment is judged vary widely depending on differing investment objectives. Forest industry often sets a quota of wood to be produced at the lowest possible capital cost and may therefore elect to maximize volume per acre. A slightly differing scenario is characteristic of the private forest landowner with a fixed land base. Such an owner typically owns land for personal use such as recreation, estate building, and periodic income. This owner often elects to manage to maximize the value of benefits per acre including timber, and therefore the present net worth concept of investment quality may be appropriate.

A third type of investor is one who looks primarily at return on investment as a measure of investment quality. The alternative rate of return (ARR) of the best investment available is often used as a test criteria. This type of "pure" investor seldom choses timber growing investments. Within the last ten years institutional investors such as pension funds and insurance underwriters have sampled forest resource production investments. Individual investors responded vigorously for a time in the early 1980's to certain limited partnerships offered by forest industries and nationally known investment firms. Certain forest management options may be financially attractive based on the "pure" investors' criteria, therefore it may be possible to attract substantial amounts of new capital into forest resource production.

The objective of this study was to compare the internal rates of return (IRR) of natural, artificially seeded, and plantation stands of pure pine, mixed pine-hardwood and pure hardwood. Stands were grown using computer simulation with and without thinning, and with a wide range of typical establishment costs.

METHODS

Stand Growth and Yield Simulation

Natural stand growth was simulated using the NC State University Natural Stand Simulator (Smith and Hafley per comm.) with and without thinning at age 20, and with final harvest at age 30. Plantations were simulated using the NC State University Plantation Management Simulator (Smith and Hafley 1986), with and without thinning at age 15, and with final harvest at age 30. All pine was loblolly, while hardwood represented an equal mixture of decurrent (oak) and excurrent (sweetgum) hardwood species. Site indices (base age 50) were 100 for loblolly pine, and 94 for mixed hardwood. Natural stands ranged from 100 percent hardwood to 100 percent pine by 25 percent increments based on basal areas of typical natural stands of the pure species at age 20. The typical pure loblolly pine natural stand contained 309 trees per acre (tpa) with 123 square feet of basal area (ft^2 ba) at age 20 (Schumacher and Coile 1960). By contrast, the typical pure hardwood natural stand contained 681 tpa and 115 ft^2 ba at age 20 (Gardner and others 1982).

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Table 1.--Stand characteristics and yields at age 20 of mixed loblolly pine-hardwood natural stands, site index (base age 50) pine: 100, hardwood: 94, with proportions of stocking based percentages of basal area of typical pure natural stands of pine and hardwood[a]

Treatment	Proportion of Hardwood (pct BA)	Mean Height Pine ft	Mean Height Hdwd ft	Total Trees/Acre Pine (n)	Total Trees/Acre Hdwd (n)	Diameter Breast Height Pine (in)	Diameter Breast Height Hdwd (in)	Basal Area/Acre Pine (ft^2)	Basal Area/Acre Hdwd (ft^2)	Total Yield Pine (cd/a)	Total Yield Hdwd (cd/a)
Unthinned	0	56	-	309	-	8.5	-	123	-	32.0	-
	25	56	53	232	170	8.5	5.6	92	29	23.9	6.1
	50	56	53	154	340	8.6	5.6	62	58	16.1	12.2
	75	56	53	77	511	8.6	5.6	31	86	8.1	18.1
	100	-	53	-	681	-	5.6	-	115	-	24.3
After Thinning	0	59	-	187	-	9.4	-	90	-	25.0	-
	25	57	53	156	123	9.0	5.6	68	21	18.3	4.4
	50	56	53	112	246	8.6	5.6	45	42	11.7	8.9
	75	56	54	55	340	8.6	5.8	22	63	5.7	13.7
	100	-	55	-	411	-	6.1	-	84	-	19.9

[a]Smith and Hafley (1986); Gardner and others (1982).

Thus the 50 percent pine-hardwood mixture contained half of a typical natural pine stand (154 tpa and 62 ft^2 ba) plus half of a typical natural hardwood stand (340 tpa and 58 ft^2 ba) (table 1).

Natural hardwood stands were thinned at age 20 to a residual basal area of 84 ft^2. Natural pine stands were thinned to a residual basal area of 90 ft^2. Residual stockings after thinning of mixed natural stands were proportions of the original stocking of each pure pine or hardwood type, therefore the residual stocking of the 50 percent hardwood mixture was 45 ft^2 of pine and 42 ft^2 of hardwood (table 1).

The natural stand simulator requires a parameter called the after/before diameter ratio. It is the ratio of the diameter after thinning divided by the diameter before thinning. Typical sizes are 1.0 (no change) to 1.1 (relatively large change). In this study, 1.1 was used for the pure natural stands. For the dominant species at 75 percent, 1.05 was used, and ratios at 50 and 25 percent were 1.0.

Plantations were simulated with 0, 15, 30, and 45 percent encroaching hardwood competition based on total basal area at age 15. Initial pine stocking was 700 tpa with 85 percent survival, leaving 595 tpa established. Pine was thinned to a residual basal area of 71 ft^2 at age 15. The proportion of hardwood removed equaled the proportion of pine removed when hardwood was present (table 2). Note that with 45 percent hardwood, only 7 ft^2 ba was removed leaving residual basal area at 51 ft^2, 20 ft^2 below the stands with higher pine stocking (table 2). Height over age curves used were by Smalley and Bower (1971).

Stand characteristics at age 30 in terms of basal areas and yields were generally proportional to stand characteristics at age of thinning, reflecting the proportional thinning of each type, and program logic which generally maintained proportional stocking through age 30. Comparison of mean and current annual increments indicated that all stands were close to volumetric culmination by

Table 2.--Stand characteristics and yields at age 20 of loblolly pine plantations with four levels of hardwood competition, site index (base age 50) pine: 100, hardwood: 94, with 595 pines established to grow

Treatment	Proportion of Hardwood (pct BA)	Average[a] Height Pine ft	Trees/Acre Pine (n)	DBH Pine (in)	Basal Area/Acre Pine (ft^2)	Basal Area/Acre Hdwd (ft^2)	Total Volume Pine (cd/a)	Total Volume Hdwd (cd/a)
Unthinned	0	45	554	6.8	141	-	28.4	-
	15	45	471	6.6	112	20	22.4	3.4
	30	44	387	6.3	83	36	16.7	6.2
	45	44	304	5.9	58	47	11.5	8.3
After Thinning	0	47	217	7.7	71	-	15.0	-
	15	47	244	7.3	71	12	14.8	2.3
	30	46	293	6.6	71	30	14.6	5.4
	45	45	240	6.2	51	41	10.4	7.5

[a]Dominant height of pine was 49 ft. in all cases.

age 30 (table 3). Yields were merchandized for economic analysis. In plantations, the following minimum dimensions were used:

Pine Sawtimber - small end dib^2 = 8 inches
Pine Chip-n-saw - small end dib = 6 inches
Pine Pulpwood-small end dib = 4 inches
Hardwood Sawtimber - DBH^3 = 11 inches
Hardwood Pulpwood - DBH = 5 inches

In natural stands, the following minimum dimensions were used:

Pine Sawtimber and Chip-n-saw - DBH = 9 inches
Pine Pulpwood - DBH = 5 inches
Hardwood Sawtimber - DBH = 11 inches
Hardwood Pulpwood - DBH = 5 inches

Conversion of cubic foot volume to cords and board feet were according to equations by Schumacher and Coile (1960), with substitution of appropriate coefficients for hardwoods (Hafley, per comm.)

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[2] Diameter Inside Bark.

[3] Diameter Breast Height (4.5 feet above ground line)

Economic Analysis

Transaction costs for various site preparation activities, sowing and planting, timber marking, taxes, fire protection and insurance were representative of average values in the southeast for the Piedmont and Coastal Plain (Straka and others 1989). All values are in 1988 dollars/acre (table 4).

Five different stand establishment scenarios were evaluated based on appropriate combinations of costs, with and without thinning costs, and including an annual maintenance cost of $3.12/acre/year (table 4). Unit prices for products were 1988 acreage prices for the Piedmont of North Carolina as reported in Timber Mart-South (Norris, 1988) (table 5). No inflationary or real price increases were assumed, so all inputs and results are in 1988 dollars.

Economic analyses were done using Quick Silver (Vasievich and others 1984). Parameters calculated were internal rate of return (IRR) and annual equivalent value (AEV) per acre. The IRR is the yield rate at which present value of costs equals present value of gains with intermediate cash flows

Table 3.--Stand characteristics and yields of mixed pine-hardwood natural stands and plantations at final harvest age 30, without or with thinning at age 20 for natural stands, and age 15 for plantations

Stand Type	Proportion of Hardwood	Mean Height		Total Trees/Acre		Diameter Breast Height		Basal Area		Mean Annual Increment		Current Annual Increment	
	(pct BA)[a]	Pine ft	Hdwd ft	Pine (n)	Hdwd (n)	Pine (in)	Hdwd (in)	Pine (ft^2)	Hdwd (ft^2)	Pine cds/ac/yr	Hdwd cds/ac/yr	Pine cds/ac/yr	Hdwd cds/ac/yr
NATURAL Unthinned	0	72	-	205	-	11.5	-	149	-	1.8	-	1.5	-
	25	72	68	153	160	11.5	6.4	111	36	1.3	0.3	1.1	0.3
	50	72	68	101	339	11.6	6.4	74	75	0.9	0.7	0.7	0.8
	75	72	68	50	508	11.6	6.3	37	111	0.4	1.0	0.3	1.1
	100		68	-	657	-	6.3	-	143	-	1.3	-	1.2
NATURAL Thinned	0	75	-	133	-	12.9	-	121	-	1.5	-	1.6	-
	25	74	68	110	108	12.3	6.7	91	27	1.1	0.2	1.2	0.3
	50	72	68	79	237	11.8	6.7	60	58	0.7	0.5	0.7	0.6
	75	72	69	38	340	11.8	6.9	29	88	0.3	0.8	0.3	1.0
	100	-	71	-	415	-	7.2	-	116	-	1.1	-	1.3
PLANTATION Unthinned	0	69	-[b]	403	-[b]	9.4	-[b]	195	-	2.0	-	2.2	-[b]
	15	69	-	330	-	9.3	-	157	32	1.6	0.3	1.8	-
	30	69	-	258	-	9.2	-	120	64	1.2	0.7	1.4	-
	45	69	-	187	-	9.1	-	85	86	0.9	0.9	1.0	-
PLANTATION Thinned	0	73	-	198	-	11.4	-	141	-	2.0	-	2.0	-
	15	72	-	211	-	10.4	-	136	22	2.0	0.3	2.0	-
	30	71	-	228	-	10.1	-	126	57	1.8	0.8	1.7	-
	45	71	-	180	-	10.0	-	98	79	1.4	1.1	1.4	-

[a] For natural stands - percent BA of typical hardwood stand on site 94 at age 20 (Gardner and others 1982). For plantations - percent of total BA (pine plus hardwood) at age 15.
[b] The hardwood component simulator is driven by basal area and does not generate charcteristics of individual trees, or current annual increment.

Table 4.--Present and future transaction costs for investments in natural stands and plantations (1988 dollars)

Activity	Cost	Stand Establishment Scenario	Cost
	($/a)		($/a)
Site Preparation by:		Natural	0
Shear-Rake-Pile	124.67	Direct Seeded	25.00
Chop	65.47		
Burn		Burn-Plant	49.60
Piles	5.00		
Chopped or slash	9.70	Chop-Burn-Plant	115.07
Seeding (all inclusive)	25.00		
		Shear-Rake-Pile	
Plant after:		Burn-Plant	168.36
Shear-Rake-Pile-Burn	38.69		
Chop-Burn	39.90		
Burn	39.90		
Maintenance:			
Insurance	.15		
Ad Valorum Taxes	1.25		
Fire Protection	1.72		
TOTAL	3.12		
Mark Thinning in:			
Natural Stands	7.24		
Plantations	11.58		

Table 5.-- Unit prices for products harvested from mixed-pine hardwood natural stands and plantations[a]
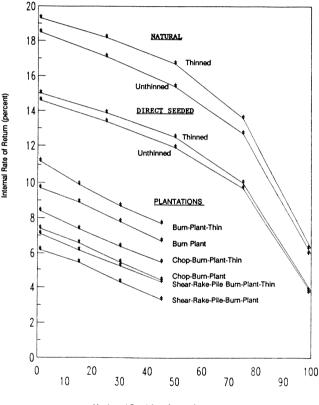
Product	Price	Unit
	$/unit	
Pine		
Pulpwood	11.63	cords
Chip-n-saw	29.50	cords
Sawtimber	129.00	MBF (Scribner)
Hardwood		
Pulpwood	4.58	cords
Sawtimber	56.98	MBF (Scribner)

[a]Timber Mart-South (Norris, 1988).

invested at the IRR. The AEV is the net worth of the scenario paid in equal annual annuity payments over the entire rotation. The IRR is independent of any discount rate in its calculation. It indicates the ARR at which the value of the enterprise is 0. If the ARR is less than the IRR, the enterprize is profitable. If the ARR exceeds the IRR, the enterprise is not profitable. How profitable or unprofitable is indicated by the AEV at a specified ARR.

RESULTS

All natural stands with up to 75 percent hardwood exceeded the profitability of the best plantation scenario (Burn-Plant-Thin), as did all seeded stands with up to 50 percent hardwood (table 6, figure 1). Thinned stands always exceeded unthinned stands in IRR. Relatively more benefit was obtained from thinning plantations and natural stands than from thinning seeded stands (figure 1). The rate of decrease in profitability was much higher for plantation scenarios than for natural stands as proportions of hardwood basal area increased up to 50 percent. From 50 percent on, natural stands had equal or higher sensitivity to increasing proportions of hardwood than plantations, as measured by IRR (figure 1).

Figure 1.--Internal rates of return for investments in thinned and unthinned natural stands and plantations of pure pine and hardwood, and pine-hardwood mixtures with differing establishment costs and an annual carrying cost of $3.12/acre/yr through a 30-year rotation.

DISCUSSION

What rate of return on investment is likely to attract new capital to management of forest resources? One place to look for alternative rates is the government guaranteed, mortgage backed securities offered by the Government National Mortgage

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Table 6.-- Economic charactieristics of investments in mixed pine-hardwood natural stands and plantations, thinned and unthinned, with differing establishment costs and an annual maintenance cost of $3.12/ac/yr through a 30-year rotation

Stand Type	Internal Proportion of Hdwd (pct BA)[a]	Rate of Return (pct)	Annual Equivalent Value ($/a) at Discount Rate of:				
			(4 pct)	(6 pct)	(8 pct)	(10 pct)	(12 pct)
NATURAL							
Thinned	0	19.3	48	34	23	16	10
	25	18.2	35	25	17	11	7
	50	16.7	24	17	11	7	4
	75	13.6	12	8	5	3	1
	100	6.2	1	0	-1	-2	-2
Unthinned	0	18.5	48	34	23	15	9
	25	17.1	36	25	17	11	6
	50	15.4	24	17	11	6	3
	75	12.7	13	8	5	2	0
	100	5.9	1	0	-1	-2	-2
DIRECT SEEDED							
Thinned	0	15.0	44	30	19	11	6
	25	13.9	32	22	14	8	3
	50	12.5	21	14	8	4	1
	75	9.9	10	6	3	-0	-2
	100	3.8	0	-2	-3	-4	-5
Unthinned	0	14.6	44	29	19	11	5
	25	13.4	32	21	13	7	2
	50	11.9	22	14	8	3	0
	75	9.6	11	6	2	-1	-3
	100	3.7	0	-2	-3	-4	-5
PLANTATIONS							
Burn Thinned	0	11.2	21	13	7	2	-1
	15	9.9	16	9	4	0	-3
	30	8.7	12	6	1	-2	-3
	45	7.7	8	3	0	-4	-6
Unthinned	0	9.7	17	10	4	-1	-4
	15	8.9	13	7	2	-2	-5
	30	7.8	8	3	0	-3	-6
	45	6.7	5	1	-2	-5	-7
Chop-Burn Thinned	0	8.4	17	8	1	-5	-9
	15	7.4	13	5	-2	-7	-12
	30	6.4	8	1	-4	-9	-13
	45	5.5	5	-1	-6	-10	-14
Unthinned	0	7.4	13	5	-2	-7	-12
	15	6.6	9	2	-4	-9	-13
	30	5.5	5	-1	-6	-10	-14
	45	4.5	1	-4	-8	-12	-15
SHEAR-RAKE- PILE-BURN Thinned	0	7.1	14	5	-3	-10	-16
	15	6.2	9	1	-7	-13	-18
	30	5.3	5	-3	-9	-15	-20
	45	4.4	2	-5	-11	-16	-21
Unthinned	0	6.2	10	1	-7	-13	-19
	15	5.5	6	-2	-9	-15	-20
	30	4.4	2	-5	-11	-16	-21
	45	3.4	-2	-7	-13	-17	-21

[a]For natural stands - percent of BA of typical hardwood stand on site 94 at age 20 (Gardner and others 1982).
[b]For plantations - percent of total BA (pine plus hardwood) at age 15.

Association (GNMA). Average net yields to investors based on prepayment in 12 years on pools of 30-year-FHA/VA mortgages from 1983 to early 1986 ranged from 13.1 to 9.4 percent (Wiedemer 1987). If the inflation rate is about 3 percent, then an investor may be willing to accept a minimal average real rate of return of about 8 percent. In our recent experience with investors in partnerships minimum ARR's were 11 to 12 percent, so the 8 percent real rate minimum seems realistic.

Thinned natural stands were the best performers based on investment criteria under the conditions and assumptions of this study. Even with 50 percent hardwood, thinned natural stands exceeded the profitability of direct seeded and thinned pure loblolly pine (figure 1). Of course to accomplish this high rate of return, high proportions of pine must become established in naturally developing stands. A pine seed source must be present, otherwise direct seeding is the next lowest cost option. A seed bed must be prepared by preharvest fire or scarification during logging, and the harvest must be timed to catch the seed fall.

When mixed pine-hardwood stands develop with 50 percent or more pine the highest rates of return may be enjoyed (figure 1). However, one may be well advised to do one or more of the activities suggested above to help in obtaining a natural stand with a high proportion of pine. But with 75 percent hardwood, the natural stand IRR was about equal to that of a $25/acre investment in direct seeding resulting in 25 percent hardwood. Therefore, the amount of investment in such activity must be conservative. The most important thing is to recognize those stand and site combinations which will respond well to low cost approaches, and do not attempt such approaches on stands and sites which will not. The investor seeking high yields in the range of 10 to 12 ARR, will be limited to those stand and site combinations which respond favorably to low cost approaches.

Only the highest yielding plantation options exceeded an 8 percent IRR. Therefore most plantation options will yield either negative or very low profits at an 8 percent alternative rate of return. In fact, the highest yielding plantation scenario yielded $7/acre/year at 8 percent alternative rate of return (table 6). This resulted from an IRR of 11.2 percent, obtained in a burned only, thinned, pure pine plantation (figure 1). Therefore, under the conditions and assumptions of this study we conclude that the investor will be limited to the lowest cost plantation options, and that profits will be modest at best.

However, plantations deserve a second look from the point of view of the investor in typical certificates of deposit or common stocks which have yields in the range of 9 to 11 percent. Substracting 3 percent for inflation, this is equivalent to a 6 percent minimum real rate of return. Most plantation scenarios exceeded 6 percent in IRR (figure 1). Profit from the best plantation scenario at 6 percent ARR was $13 per acre/year (table 6). Very substantial improvements in yield rates for plantations can be obtained with cost-sharing. For example, the yield rate of chop-burn-plant with 60% cost-share is about equal to the yield rate of burn-plant, a net increase of about 2.8 points. Therefore, plantation options deserve consideration by some forest resource investors.

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HARDWOOD MATERIAL USE: PAST, PRESENT, AND FUTURE

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Abstract. — There have been dramatic changes in the consumption of hardwood products over the last 30 years. Production of hardwood pallets and kitchen cabinets have soared while production of household wood furniture has shown less growth. There also has been major growth in the production of lower value hardwood pulpwood and the exportation of higher value hardwood lumber, logs, and veneer. Trends in domestic consumption, economic activity in Europe and Asia, and concerns over clearing and logging activities on tropical land indicate that demands for hardwood products should continue to increase through the remainder of this century.

INTRODUCTION

Over the last 30 years there have been dramatic changes in the consumption of hardwood products. Pallets, kitchen cabinets, and exports have grown from minor importance to become three of the top five markets for hardwood lumber. Hardwood pulpwood has become one of the top two markets for hardwood industrial roundwood. This paper examines these changes and discusses future use of hardwood products in major end markets.

Specific topics examined in this paper are domestic hardwood lumber use, hardwood product exports, and pulpwood production. The domestic markets for hardwood veneer and plywood have been excluded due to the lack of consistent historical data.

DOMESTIC HARDWOOD LUMBER USE

Hardwood lumber probably is the single most important product derived from the eastern hardwood forest on a value basis. One difficulty encountered in making an absolute statement on the importance of this product is that official estimates of hardwood lumber production appear low. Estimates of total hardwood lumber use by Cardellichio and Binkley (1984) based on a use-factor approach and estimates of hardwood lumber production (Luppold and Dempsey, in press) are consistently higher than hardwood production estimates reported by the U.S. Bureau of the Census (Current Industrial Reports) (figure 1).

Estimates of industrial hardwood lumber use derived from the Census of Manufactures indicate that industrial consumption alone has been greater than reported production since the early 1970's (table 1). Also, the information in table 1 indicates that hardwood lumber consumption by major industrial user has increased dramatically in the 1980's. The most striking increase in demand was
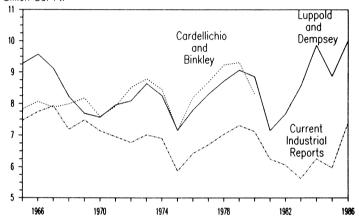
Figure 1.--Comparison of Current Industrial Reports hardwood lumber production volumes to Cardellichio and Binkley usage volumes and Luppold and Dempsey production volumes.

by the pallet and container industries. The estimates provided in table 1 combined with the information in figure 1 indicate that pallet and container industries used more than 40 percent of the lumber apparently consumed in 1986.

Another major shift indicated in table 1 is that, after 25 years of relatively stable demand, use of lumber in the furniture and cabinet industry seems to be increasing. Although the wood household furniture industry is still the largest single user of hardwood lumber, the cabinet industry has shown the greatest increase in level of employment and apparent demand.

Production of hardwood dimension and flooring also has increased substantially during the 1980's. The increase was due to both a 20-percent increase in wood furniture production and a 96-percent increase in wood flooring production between 1982 and 1986 (Nolley 1988). It should be noted that

Table 1.--Hardwood lumber consumption by major end-use products, selected years[a]

User	1958	1963	1967	1972	1977	1982	1986
			Million board feet				
Furniture and cabinets	1606	1986	1970	1970	2096	1987	2454[b]
Dimension and flooring[c]	1502	1790	1503	1452	1384	1149	1660[b]
Millwork	245	242	354	534	472	500	780[b]
Plywood, structural members, and prefab buildings	177	113	147	399	478	440	440[d]
Wooden boxes, pallet containers, and wood products NEC[c]	987	1746	2443	2418	2627	3184	4680[b]
Rail ties[e]	775	500	650	850	1000	834	548[f]
Exports	235	131	164	237	240	357	498
Total consumption	5527	6508	7231	7860	8297	8451	11060
Total production[g]	5920	7154	7430	6770	6701	5061	7184

[a] Except where noted, figures are from Luppold 1987.
[b] Estimated from the change in deflated value of shipments from U.S. Department of Commerce, International Trade Administration's 1986 U.S. industrial outlook and change in employment from unpublished U.S. Department of Labor data.
[c] Includes lumber produced within the plant.
[d] No attempt made to estimate 1986 use, so 1986 figures are included for accounting purposes.
[e] Railroad tie lumber-usage level developed from Cardellichio and Binkley's 1984 estimates for 1963-82.
[f] Developed from rail ties production estimates (American Wood Preservers' Association 1986).
[g] U.S. Department of Commerce, Bureau of the Census, Current Industrial Reports.

even after the tremendous increase in wood flooring production in the 1980's, flooring production is just 25 percent of the level produced in the early 1960's (U.S. Department of Commerce, Bureau of the Census 1987).

Even though table 1 indicates that apparent usage is greater than estimated production, these demand estimates still are lower than estimates by Luppold and Dempsey (in press) of eastern and central lumber production adjusted for changes in millstocks, western productions, and imports (table 2). The differences between the latter estimates and estimates of apparent usage probably stem from nonindustrial uses and nonreported industrial uses.

Home and farm-building construction probably was the largest nonindustrial use prior to 1970. Nonreported industrial uses include dunnage, blocking, mine timber, and other industrial products purchased directly from sawmills. Most of these nonindustrial or hidden industrial uses apparently have subsided with the introduction of alternate material or alternate manufacturing and transportation processes.

The negative difference between total apparent consumption and industrial consumption that occurred in 1982 could be due to the inaccuracy of the estimation techniques employed. It also might be explained by the reductions in lumber inventories held

Table 2.--Comparison of hardwood consumption against Luppold and Dempsey's hardwood production estimates

Year	Luppold and Dempsey (in press)	Change[a] in mill stocks	Western production	Imports	Total apparent consumption	Consumption by industry users--1987	Difference
				Million board feet			
1967	9114	-200	197	342	9453	7231	+2222
1972	8091	251	139	449	8930	7860	+1070
1977	8317	134	183	343	8977	8297	+680
1982	7768	74	329	211	8382	8451	-39
1986	10749	-83	386	347	11399	11060	+339

[a] Estimated by taking the product of the Luppold-Dempsey multipliers times the U.S. Department of Commerce, Bureau of the Census estimate of millstocks.

by brokers or furniture plant lumber yard stocks in the early 1980's. These reductions resulted from the high interest rates and slack business conditions during this period. Conversations with wood buyers indicate there was a significant reduction of inventories by hardwood-using and distributing industries in the early 1980's. Low inventory levels persist today as firms try to minimize inventory costs.

HARDWOOD PRODUCT EXPORTS

Exports of hardwood logs, lumber, and veneer have increased during the last 30 years. Of the three major hardwood products exported in 1986, hardwood lumber was the most important, accounting for 66 percent of the total value and 77 percent of the total volume on a board-foot basis (Luppold and Araman 1988). Between 1960 and 1972, exports of hardwood lumber fluctuated between 110 and 170 million board feet (MMbf) per year (figure 2). Between 1972 and 1986, exports of hardwood lumber increased from 160 to 549 MMbf.

MM bf
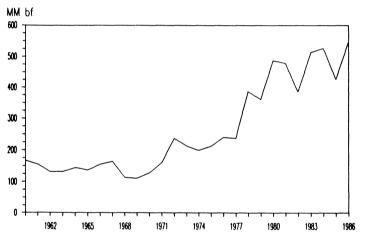
Figure 2.--Hardwood lumber exports, 1960-1986.

Analysis of hardwood lumber exports during the last 15 years shows three distinct periods of market change (figure 2). During the 1970's, exports to Europe increased rapidly due to the devaluation of the U.S. dollar and increased economic activity in Europe (Luppold 1984). In the early and mid-1980's, the dollar increased against European currencies and exports to Europe dropped. However, total exports of hardwood lumber stabilized during the early 1980's because the drop in European exports was matched by an increase in shipments to Japan and Taiwan. Since 1986, exports have increased substantially to all major markets.

Oak has consistently been the major hardwood species of lumber exported in the post-World War II era. In 1986, nearly 50 percent of the hardwood lumber exports were red oak and 18 percent were white oak (Ulrich 1988). Since exports contain relatively large volumes of higher grade lumber, the surge in exports has caused a dramatic increase in the prices of higher grade oak, ash, and cherry lumber. These price increases apparently have caused an increase in demand for high-grade logs and timber sites containing a high proportion of these species.

Hardwood logs are the second most important hardwood exported product, accounting for 18 percent of the dollar value and 19 percent of the volume of total hardwood product exports in 1986 (Luppold and Araman 1988). Unlike lumber exports, log exports increased gradually during the post-World War II period, with noticeable increases in the 1960's, 70's and 80's (figure 3).

MM bf
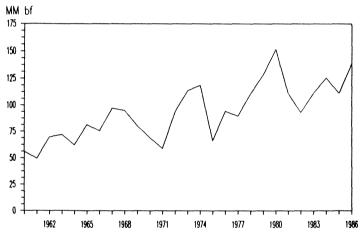
Figure 3.--Hardwood log exports, 1960-1986.

Apart from physical- or dollar-volume trends, log exports over time can only be generalized. In the 1950's and 60's, black walnut was the most important log species exported on a dollar-value basis. In the 1970's, black walnut still accounted for 76 percent of the dollar value and 25 percent of the physical volume of log exports. The increase in oak lumber exports to Europe in the mid- and late-1970's coincided with an increase in oak log exports. By 1979, shipments of oak made up 47 percent of the physical volume while shipments of black walnut dropped to 5 percent of the physical volume (Ulrich 1988).

Hardwood veneer exports accounted for 4 percent of the total board-foot volume and 17 percent of the dollar value of total hardwood product exports in 1986 (Luppold and Araman 1988). Similar to lumber exports, veneer exports to Europe increased

rapidly in the early 1970's. Similar to the log market, oak veneer exports surpassed walnut veneer exports as a result of the surge in European demand for oak. In 1970, 60 percent of the veneer exports were walnut while 39 percent were oak and other species. By 1980, 11 percent of the veneer exports were walnut while 59 percent were oak. Unlike lumber, white oak accounted for 40 percent of the veneer shipments while red oak accounted for 24 percent (Ulrich 1988). This difference between the lumber and veneer markets was caused by the large impact of German demand for white oak veneer.

HARDWOOD PULP DEMAND

Since hardwood fibers are shorter and less flexible than softwood fibers, paper products containing mostly hardwood pulp tend to be weaker than their softwood counterparts. Historically, this made hardwood pulp less preferred than softwood pulp in many paper-making activities. However, the combination of new technologies, changing paper product markets, and the relatively low price of hardwood pulpwood has caused the consumption of hardwood pulp to expand.

Between 1956 and 1986, hardwood increased from 17 percent of the demand for pulped material to 30 percent of the total market (Ulrich 1988). This represents a 370-percent increase in hardwood pulpwood production compared to a 172-percent increase in softwood pulpwood production during the same period. However, the increase was not uniform across regions (table 3). The largest amount of increase was in the South. On a percentage basis, however, the West experienced the largest percent increase in hardwood pulpwood production.

In absolute terms, nearly 80 percent of the total U.S. increase in hardwood pulpwood consumption was in the South. Some of this change can be attributed to the growth of the southern pulp industry in general, but overall hardwood usage has increased by more than 500 percent while softwood usage has increased by less than 150 percent. These trends have increased hardwood's share of the southern pulpwood market from 14 percent in 1956 to nearly 30 percent in 1986 (Ulrich 1988).

Production of northern hardwood pulpwood also has increased dramatically over the last 30 years. In absolute terms, hardwood pulpwood production increased by more than 6 million cords while softwood production increased by slightly more than 1 million cords (Ulrich 1988). These changes in production increased hardwood pulpwood's market share from 41 percent in 1956 to 63 percent in 1986.

The variation of hardwood pulp production for specific products is quite marked between regions (table 3). A large share of hardwood pulpwood produced in the South is consumed in semi-chemical (paperboard) newsprint production (Ince and others, in press). For these and other products, increasing amounts of hardwood pulp (17 to 18 percent) are combined with softwood pulp to make products that were mostly softwood pulp 20 years ago. The majority of hardwood pulp produced in the northern region is used to produce writing paper and tissue.

WHAT DOES THE FUTURE HOLD?

Given current information, hardwood lumber usage, export demand, and hardwood pulpwood production can be expected to increase through the remainder of this century.

One major factor that will influence future demand for higher quality hardwood lumber is the maturing of the baby boomers matched with the apparent

Table 3.--Hardwood and softwood pulpwood production in 1956, 1966, 1976, and 1986, by region (Ulrich 1988)

Species group and region	Production				Percentage change in production
	1956	1966	1976	1986	
	Million cords				
Hardwood					
North	3.0	5.9	7.4	9.5	217
South	2.9	7.7	11.2	17.9	517
West	0.2	0.6	0.7	1.3	550
Total	6.1	14.1	19.3	28.7	370
Softwood					
North	4.4	4.4	4.8	5.7	30
South	17.4	25.4	36.2	42.7	145
West	7.3	12.2	17.1	16.3	123
Total	29.1	42.0	58.1	64.7	122

quality appeal of hardwood products. The furniture, cabinets, dimension, flooring, and millwork industries used nearly 5 billion board feet of hardwood lumber in 1986, an increase of 1 billion board feet over 1977. This increase coincided with the increase in the 25- to 44-year-old population (figure 4). As this age group is increasingly tied to home activities, demand for such products as furniture, fancy wood fixtures, and cabinets can be expected to increase. A striking example of the influence of this population group is the resurgence in the use of wood flooring.

Millions
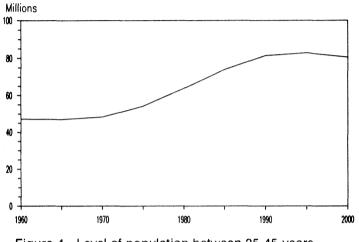
Figure 4.--Level of population between 25-45 years of age, (actual and projected), 1960-2000.

Increased use of low-grade hardwood lumber by the pallet industry also can be expected. Pallets are a low-cost part of capital-intensive material handling systems (Luppold and Anderson 1986). As industrial production and labor costs increase, the installation of systems utilizing hardwood pallets also can be expected to increase. On the other hand, if a more functional pallet exchange system is developed utilizing a more durable pallet, lumber use could decrease while pallet use continues to increase.

Factors that indicate an increase in hardwood product exports include: (1) the continuing high U.S. trade deficit that will keep the value of the U.S. dollar low relative to European and Asian currencies; (2) environmental concerns over clearing and logging activities on tropical land combined with limited supplies of temperate timber outside of the United States; (3) the development of consumer-based versus producer-based economies in Japan and other Asian countries; and (4) an expanded European economy resulting from the dropping of all inter-Common Market trade barriers in 1992.

Some factors that may hinder exports of hardwood products are: (1) the liquidation of forest resources by Third World countries to reduce their indebtedness; (2) escalation of trade tension with European and Asian nations leading to trade wars; and (3) a major interruption of international financial markets leading to decreased worldwide economic activity. It is difficult to say whether the factors facilitating trade will outweigh the factors that may hinder it.

As demand for hardwood lumber increases, so will the availability of low-cost hardwood pulp material. Projections by Ince and others (in press) indicate substantial increases in hardwood pulpwood consumption in all U.S. regions and for most paper and board products. Hardwood pulpwood will continue to displace softwood pulpwood production in the North, while hardwood pulpwood production will grow at a faster rate than softwood pulpwood production in the South.

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MANAGEMENT OPTIONS WHEN LOBLOLLY PINE REPRODUCTION INVADES A CLEARCUT INITIATED FOR HARDWOODS

Roger W. Dennington[1]

Abstract. — In south Mississippi loblolly pine seeded into stream bottom clearcuts where hardwoods were the preferred forest type. Analysis of data collected nine years following site preparation treatments shows that several management options are available which will accommodate a range of management objectives. Three basic management options are presented: (1) optimized wildlife benefits with a hardwood forest type, (2) optimized timber revenues with a loblolly pine forest type, and (3) a compromise between option one and two with a pine-hardwood forest type at a level where both wildlife benefits and timber revenues produce acceptable outputs. All three options can be accomplished at low investment cost and with high returns.

INTRODUCTION

Foresters and wildlife biologists on the DeSoto National Forest in south Mississippi expect the stream-bottom sites to produce much of the hard mast needed to carry desired wildlife populations. These sites represent only 11 percent of the total commercial forestland (CFL) acres on that national forest. The remaining 89 percent of CFL on this 500,000 acre public forest is deemed best suited for growing the longleaf, slash, and loblolly pine forest types. Past management practices and wildfires have made the hardwood timber quality and hard mast production on the bottomland sites less than optimum. The most effective way to increase the hard mast production of these stands is to regenerate them and favor the oak component as the future stand develops. In the mid 1970's one of the DeSoto National Forest districts embarked on a hardwood regeneration initiative. The Chickasawhay District in Greene, Jones and Wayne Counties has approximately 27,000 acres of bottomland sites out of its 150,000 acre total. An average of 130 acres of the bottomland sites were regenerated each year. Stand size averaged 20 acres.

In order to concentrate regeneration efforts on the least mast productive sites first, a regeneration protocol was established (table 1). Often stands containing a high component of loblolly pine were harvested for the purpose of regenerating a hardwood stand. This paper reports on two such stands nine years following the harvest cut and site preparation. Management options are suggested that may be suited to both public and private forest landowners.

Table 1. Regeneration priority for hardwood sites on the Chickasawhay District - DeSoto National Forest

Priority	Pre-harvest condition
1	Sparse hardwood growing stock
2	Low-quality hardwood growing stock
3	Stands with high components of pine
4	Over mature hardwood

NOTE: Stands averaging < 30 square feet basal area per acre of acceptable hardwod growing stock not eligible to regenerate.

DESCRIPTION OF THE AREA

The two stands forming the basis of this paper are located on Trebloc soils characterized by poorly drained soils that formed in moderately fine textured alluvial sediment in stream terraces and flood plains. Slopes are 0 to 2 percent. The soils of the Trebloc series are fine-silty, siliceous, thermic Typic Paleaquults.

No detailed stand composition data were collected prior to harvest. It is reasonable to assume that the original stand is represented by adjacent uncut stands on the same soils. Here loblolly pines in large 18-inch plus diameters are scattered and clumped over a mid-story of laurel oak, water oak, blackgum, red maple, and southern magnolia. The pine basal area ranges from 10 to 100 square feet per acre. Dominant pines average 20 inches DBH and 100 feet in height. Few pines under 16 inches are a component of these stands. Hardwoods are smaller in diameter and height. Based on height over age curves for natural loblolly pine, on-site measurements suggest the site index (base 50 years) for loblolly pine is 100. Soil-site conditions

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were measured using Baker and Broadfoot's guide to determine the site quality rating (SQR) for water oak to be 70 to 75 (Baker and Broadfoot 1979).

After all merchantable pine and hardwood stems were removed in a commercial clearcut in 1978, the stands were site prepared by shearing in October, 1979. The shearing was accomplished with a V-blade on a crawler tractor in the Forest Service fleet. Soil disturbance and hardwood root damage was minimized by keeping the blade 2 to 3 inches above the ground. Tractor production averaged 4 to 5 acres per hour. Based on competitively bid contracts of site preparation by shearing in similar conditions, the cost would have been $35 to $45 per acre.

RESULTS

Nine years after site preparation the stands were inventoried using a series of randomly located 1/100 acre plots. As had been anticipated, loblolly pine seeded in from adjacent uncut stands and was clearly the dominant species of the new stand. Loblolly pine composed over 90 percent of the total biomass (table 2). The maple group folowed with 5 percent and the important oak group with 1.6 percent. Species were lumped into five groups for purposes of discussion (table 3).

Table 2. Species group biomass at age 9

Species group	Percent of woody biomass
Pine	90.9
Maple	5.0
Gum	2.3
Oak	1.6
Other	0.2

The stand composition was dominated by maple and loblolly pine with 1,938 and 1,908 trees per acre (TPA) respectively (table 4). Gum followed with 369 and the oaks with 316 TPA. Total TPA averaged 4,762.

Loblolly pine was the most dominant in size of all species. It averaged 4.1 inches DBH and 25.0 feet in total height on dominants and co-dominants at the time of inventory (table 5). Most of the dominant pines were 7 to 8 years old. Oak stems that were largest averaged 1.5 inches DBH and 17.1 feet total height.

Table 3. Species groupings

Group	Species
Pine (negligible)	Loblolly Pine Spruce Pine
Maple	Red Maple
Gum	Blackgum
Oak	Water Oak Laural Oak Post Oak White Oak (alba)
Other	Sassafrass Black Cherry Persimmon Sweet Bay Dogwood

Table 4. Stand composition 9 years after site preparation

Species Group	Trees per acre
Pine	1,908
Maple	1,938
Gum	369
Oak	316
Others	231
Total	4,762

Table 5. Size of dominants and codominants 9 years after site preparation

Species Group	DBH	Total Height
	-in-	--ft--
Pine	4.1	25.0
Maple	1.2	16.2
Gum	1.8	17.3
Oak	1.5	17.1
Other	0.8	12.7

It was apparent from the range of sizes and increment borings that the loblolly pines came from three or four seed years. The larger stems originated from the earlier seed crops and smaller seedlings, in the 2 to 3 foot height class, from subsequent crops.

MANAGEMENT OPTIONS

Several management options are available at this time in the life of these young stands. As time progresses, some options will be more difficult to execute and capture the full benefits. Ideally, managers should select their long-term objectives within the first years of the stands' establishment. For simplification, three options are presented: (1) managing to maximize wildlife habitat, (2) managing to maximize financial returns from timber receipts, and (3) managing to blend the wildlife and financial benefits without overly compromising either.

Wildlife Habitat Option

In the context of total forest management, these stands will contribute the most to wildlife habitat if managed for hardwood forest types. Optimum native game habitat for most preferred species should contain hard mast capacity.

Deer, turkey, and squirrel are major wildlife groups that benefit from a hard mast component in their diets. At this point in time with the two stands in question, something must be done to lessen the dominance of the pine and increase the presence of the mass producers, the oaks and gums. Blackgum is a desirable stand component because of its soft mast production and tendency to produce nesting cavities sooner and more frequently than most other species.

Because of the rapid growth of the pine, a commercial cleaning is needed by age 12 to 15. By then dominant pine stems should average 6 to 8 inches DBH. The cleaning procedure, which could also be considered a release treatment or a thinning from above, should be designed to remove pines that overtop desirable hardwoods. This procedure will need to be repeated every 8 to 12 years until the pine has been converted from the major component to a subordinate or minor component of the stand. Merchantable pine stems that do not compete or are not expected to compete with desirable hardwood stems should be left. This keeps the entire site fully occupied with either pine or desirable hardwood. On each subsequent entry, each pine stem must be judged again as to its removal or retention.

The removal of pines is a delicate operation which will require the greatest of sale administration skills. Directional felling, carefully located skidding lanes, and complete limbing before skidding are but some of the techniques that must be employed to prevent unacceptable damage to the hardwoods. Pines to be removed should come out of the stand as early as possible to minimize hardwood damage.

But what about the small size and slow initial growth of the oaks during the first 9 years? Will the oaks do better? How will they fare with the other hardwoods? Must other hardwoods be removed by some release and weeding operation to favor the oaks? Clearly the oaks will never overcome the aggressiveness of the pines without help in the form of pine removal. Stand dynamics varies by site and species, but generally oak is a slow starter that begins to move from a subordinate to a dominant crown position by age 20 to 25 (Clatterbuck and Hodges 1988). This is especially true when the competitors are gum and maple.

The quality of wildlife habitat is generally enhanced if a few scattered or clumped pines remain in the stand throughout its tenure. Fifty years into the management period the stand profile might appear like the hardwood option (H) in figure 1.

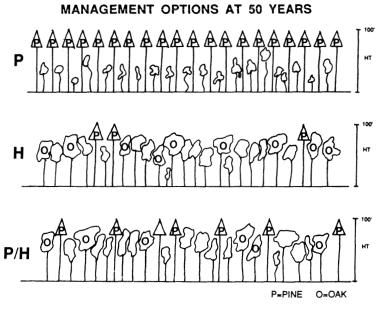**MANAGEMENT OPTIONS AT 50 YEARS**

P-PINE   O=OAK

Figure I.- - Stand profiles of three management options at age 50.

Pine stocking in the initial regeneration of these stands should be discouraged by a series of preplanned alterations in regeneration procedures. Included alterations are (1) minimize soil disturbance and exposure, (2) reduce or eliminate the pine seed source around the perimeter of the stand, (3) initiate site preparation during years of weak

pine seed crops, (4) avoid small stand sizes that have a high percent of the area within the seeding distance of adjacent pines, and (5) delay site preparation treatments until loblolly pine seed-in-place have germinated. Hardwood stocking of preferred species could be increased by (1) injecting undesirable hardwoods with herbicides either before or after logging, (2) enrichment plantings or direct seeding, and (3) retention of hardwood seed trees.

Optimized Timber Revenues

Managing the loblolly pine from natural regeneration origin is an attractive financial option. With low initial investments and a high potential volume yield the loblolly pine will produce a high rate of return (ROR) in a 30 to 40 year investment period. Investors should make their own analyses and assumptions, but this option should produce ROR percentages in the high teens.

In south Mississippi, pine sawtimber stumpage averages 3 to 4 times as high as the utility grade hardwood sawlogs this site will produce. Pulpwood stumpage differentials are about the same. Similar sites at age 50 can conservatively be expected to yield between 20-25 MBF per acre of pine sawtimber when the stand is thinned properly. Hardwood product volumes will average 60 to 70 percent less over the same period of time (figure 2).

Estimated Empirical Volumes at Age 50
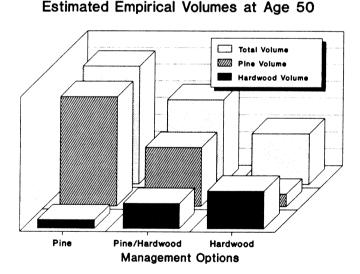
Figure 2. - - Estimated empirical volumes at age 50.

To apply this option to the two case-study stands, managers should thin from below early and often. The initial thinning could occur at age 15 and reoccur at age 20-22. Thinning objectives should be to retain 70 to 80 square feet of basal area in the largest and best pine stems and to move them into the sawtimber product class as soon as possible.

Little regard should be given to saving or preventing damage to the hardwood stems during logging. Hardwoods are expected to fall farther behind into intermediate and suppressed crown classes as the pine grows to the full height of its site class potential.

These are moderately high risk sites for Southern Pine Beetle because of the poor internal drainage of the soil and loblolly pines' inherent high susceptibility. To minimize losses to this pest, logging should occur during dry seasons when rutting and root damage will be less. Also, as always, mechanical damage to the pine boles should be avoided.

Forest managers who favor high financial returns on these sites should at stand establishment encourage the regeneration of loblolly pine. This can be done by (1) timing the site preparation treatments to occur just before good to bumper loblolly seed crops, and (2) providing a receptive seedbed by exposing mineral soil.

The Pine-Hardwood Option

Forest managers desiring both high financial and wildlife yields should consider molding a mixture of pine and hardwood. It may be one of the few places where they can enjoy the "best of two worlds". To exercise this option, managers should (1) encourage the establishment of natural pine seedlings, and (2) carefully select species and levels of species groups to remove (and favor) in the first 3 to 4 cleaning/thinning operations.

CONCLUSIONS

The dynamics of forest stands during establishment and subsequent growth periods provide forest managers with a variety of options. This is especially true on stream bottom sites when loblolly pine is a component. The preferred option should ideally be determined before the regeneration process begins. Managers should modify their practices to shape initial species composition. Ten to fifteen years and following after establishment the mixtures of species can be altered by thinnings and cleanings.

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LOWER COASTAL PLAIN PINE-HARDWOOD STANDS: MANAGEMENT OF TWO DISTINCTLY DIFFERENT SITE TYPES

Donald J. Lipscomb and Thomas M. Williams[1]

Abstract. — Pine-hardwoods on the lower Coastal Plain occur on two distinct site types. The ridge pine-hardwood site type occurs on well-drained soils near well developed drainage systems. On this type pines are associated with red oaks and water tables are more than 4 feet below the surface. Management of this site type will differ little from techniques used in the upper Coastal Plain or Piedmont. The flatland pine-hardwood site type occurs on poorly drained soils of lower elevation or on broad inter-stream divides. On this type pines are associated with sweetgum and blackgum and water tables seldom are deeper than 3 feet with saturated conditions occurring every year. Management of this site type will be hampered by limitations on heavy equipment, possible wetland regulations, and difficulty in using prescribed fire.

INTRODUCTION

South Carolina has, and will continue to have, a significant area of its forest in mixed pine-hardwood types (Baumann and others 1988). In 1978 South Carolina had 1.7 million acres in the oak-pine type with a significant portion being regenerated to pine-hardwood (Knight and McClure 1979). In 1979 Knight and McClure forecasted a 57 percent increase in available hardwood cut for the coming thirty-year period. Baumann and others (1988) also point to an expected forty percent increase in the harvest of hardwood in the next thirty years. This increased hardwood harvesting reinforces the need to begin now to plan the management and wise use of all sites that grow hardwoods.

Mixed pine-hardwood forests are generally treated under silvicultural recommendations for the group known as the oak-pine cover type (Burns 1983). In the oak-pine type upland oaks and other hardwoods comprise more than fifty percent of the stocking and pines the remainder. A number of cover types defined by the Society of American Foresters (Eyre 1980) are included in this general type. Longleaf Pine-Scrub Oak (type 71) and Loblolly pine-hardwood (type 82) are most common in South Carolina. Both of these types are prominent in the lower Coastal Plains.

The loblolly pine-hardwood (type 82) occupies two distinct sites in the lower Coastal Plain. The first site type is on moderately well- to well- drained soils on high topographic positions or near well developed drainages. The second site type is located on lower topographic positions or on broad inter-stream divides and has poorly- to very poorly- drained soils. The latter site type may be incorporated into the type definition of some hardwoods, but in such a way that these pine-hardwood mixes become a part of the oak-pine type. For example, Sheffield (1978) defines the oak-gum-cypress type as follows: "Bottomland forests in which tupelo, blackgum, sweetgum, oaks, or southern cypress, singly or in combination, comprise a plurality of the stocking, except where pines comprise 25 to 50 percent, in which case the stand would be classified oak-pine (common associates include cottonwood, willow, ash, elm, hackberry, and maple.)". The sweetgum-yellow poplar (type 87) described by the Society of American Foresters similarly incorporates a possible pine component.

These definitions include the flatland pine-hardwoods along with the ridge pine-hardwoods as a transitional succession stage. The flatland site type is not separated from the oak-pine type for management considerations.

Regulatory agencies with jurisdiction over wetlands are mapping flatland pine-hardwoods as palustrine, forested, broad-leaved deciduous (Cowardin and others 1979). This site type would most logically fit into the "wetflat" definition in the "Best Management Practices for South Carolina's Forest Wetlands " (S.C. Comm. of For. 1988). Because of the increasing emphasis on wetlands management practices, it will become necessary to distinguish these two site types in the Coastal Plain and consider them under separate management and silviculture assumptions.

The purpose of this paper is to discuss the basic characteristics which distinguish these two site types and some possible differences in management considerations.

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METHODS

The study was conducted on Hobcaw Barony, located in the lower Coastal Plain near Georgetown, South Carolina. The 7,500 acre forested portion of the Barony was type mapped prior to an inventory in 1976. Pine-hardwood stands were classified into ridge pine-hardwood and flatland pine-hardwood site types based on topographic positions. During 1986 all pine-hardwood stands were re-inventoried using point sampling with a 10 factor prism. A 10 percent sample was attempted on each stand delineated. Twenty stands (tracts) containing 239 sample points typed as ridge pine-hardwoods were processed using the Tennessee Valley Authority Inventory processor (TVAIP version 4.0). A unit summary showing total stems by species was used to develop a table representing all twenty tracts. Similarly 561 sample points were summarized from 15 stands of the flatland pine-hardwood site type. The TVAIP employs grouping of some species of lesser economic interest, but we feel the tables are pretty accurate indices of species associations and composition. These 35 stands, representing 69 percent of the ridge pine-hardwood and 78 percent of the flatland pine-hardwood type, were selected to represent the greatest area with the smallest number of stands since each stand required a separate computer run.

Data to evaluate water table positions of the proposed site types were collected from a series of water table wells located on the forest. A series of 45 wells was installed into the water table aquifer in the summer of 1975. These wells consist of plastic or asphalted paper pipes inserted from 6 to 15 feet into the aquifer. All wells are open bottomed and screened throughout their length with 1/4" holes. Water table elevation has been measured in each well weekly since July 1975. Seven wells fell in pine-hardwood stands. One was located along a site type boundary but three wells were located in each site type (figure 1).

Monthly average water table depths for each site type were determined by averaging depths in the three wells in each site type. For each month from 1976 through 1988 weekly elevations were averaged for the three wells. Means and standard errors were calculated from the 12 or 15 depth readings for each month. These means and error estimates (expressed as 95 percent confidence intervals) are presented in figure 2.

RESULTS

Ridge pine-hardwoods and flatland pine-hardwoods are distinct site types on the South Carolina coast. Water table depth data clearly separate these two
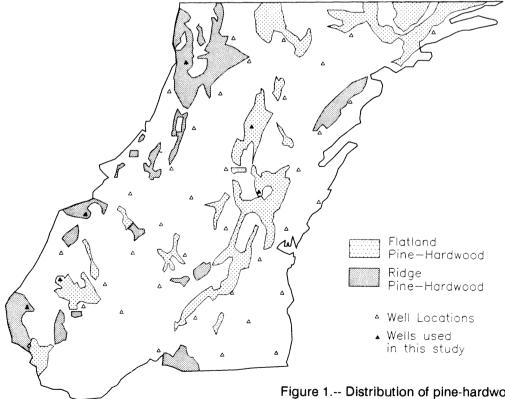

Figure 1.-- Distribution of pine-hardwood types on Hobcaw Forest. Locations of measured wells and those for which records were averaged to determine water tables in pine-hardwood site types.

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site types. Water tables in the flatland pine-hardwood type remained less than 4 feet below the surface for the entire 12 year record. In the ridge pine-hardwood type the water table seldom rose to within 5 feet of the surface. The water table in the ridge pine-hardwood stands was generally 4 to 5 feet deeper than in the flatland pine-hardwood stands at any time. Water tables in both types responded similarly to the balance of rainfall and evaporation with highest water tables in late winter and lowest in fall to early winter.

Although timber species are similar there are distinct species in each type (table 1 and 2). Ridge pine-hardwood stands are predominately oak-pine species associations, however, loblolly pine-hardwood types (SAF type 82) on poorly drained sites do not easily separate into the flatland pine-hardwoods on the basis of species associations alone. Tables 1 and 2 show composition of stands from each site type combination in the lower South Carolina Coastal Plain. The species lists are similar and both fit SAF type 82, but the relative frequencies of the hardwood components must be examined to distinguish the sites. On the dry ridge pine-hardwood sites, fire and drainage appear to affect species association survival.

Table 1 shows the flatland pine-hardwood stands with the gums and wet site oaks dominating the hardwood species component. Again the dominance of these fire-susceptible, wet site-adaptable species distinguishes the type from its ridge counterpart, but the difference is in stem count and basal area, and cannot be determined from the species association lists alone.

The ridge pine-hardwood site type conforms with descriptions for the oak-pine type (Burns 1983) (table 2). It is found on moderately well- to well-drained soils with water tables ranging from 4 to 10 feet below the surface (figure 2). It generally occurs at elevations greater than 10 feet above sea level and is found along banks and ridges near well developed water courses. The depth of water table clearly distinguish this site. In these stands all microsites are available to all species and species distributions are primarily due to natural disturbance or management.

The flatland pine-hardwood site type has similar species associations; however, the site is found in a different topographic position and is consistently wetter than its ridge pine-hardwood counterpart. Soils are poorly- to very poorly-drained and the water table remains relatively shallow throughout the year (figure 2). This site type is usually found on broad flats located some distance from well developed stream courses. On this site pines are restricted to specific dry microsites. Hardwoods occupy all remaining areas with little disturbance due to fire.

Table 1. Flatland Pine-Hardwood[1]

Species Group	Trees/Ac[2]	Pct	BA[3]	Pct
Ash	1.922	2.24	1.2	1.79
Black gum	10.061	11.71	8.1	12.05
Black oak	0.065	0.08	0.1	0.15
Cypress	2.303	2.68	2.3	3.42
Elm	0.263	0.31	0.2	0.30
Hickory	0.208	0.24	0.3	0.45
Holly	1.259	1.46	0.5	0.74
Loblolly pine	31.921	37.14	21.5	31.99
Misc red oaks	0.420	0.49	0.3	0.45
Misc yellow pines	1.064	1.24	0.9	1.34
Post oak	0.119	0.14	0.2	0.30
Red maple	1.672	1.95	1.3	1.93
Southern red oak	0.152	0.18	0.2	0.30
Sweet gum	18.199	21.17	13.5	20.09
Water oak	5.108	5.94	4.1	6.10
White oak	0.133	0.15	0.1	0.15
Laurel oak	8.881	10.33	9.8	14.58
Yellow poplar	0.375	0.44	0.8	1.19
Longleaf pine	0.544	0.63	0.9	1.34
Swamp chestnut oak	0.621	0.72	0.6	0.89
Magnolia	0.027	0.03	0.0	0.00
Misc hardwoods	0.067	0.08	0.1	0.15
Sweet bay	0.424	0.49	0.2	0.30
Persimmon	0.95	0.11	0.0	0.00
Swamp white oak	0.050	0.06	0.0	0.00
Totals	85.953	100.00	67.20	100.00

[1] Fifteen representative stands, occupying 718 acres, were selected for the flatland pine-hardwood site type; 561, 10 BAF point samples were recorded and then summarized as a TVAIP unit.

[2] Stems per acre of all trees 4 in. DBH and larger of the labeled species.

[3] Basal area (ft2/ac) of all trees 4 in. DBH and larger of the labeled species.

Table 2. Ridge Pine-Hardwood[1]

Species Group	Trees/Ac[2]	Pct	BA[3]	Pct
Ash	0.053	0.05	0.0	0.00
Black cherry	0.049	0.05	0.0	0.00
Black gum	0.699	0.70	0.6	0.89
Cypress	0.042	0.04	0.1	0.15
Dogwood	0.177	0.18	0.1	0.15
Eastern red cedar	1.020	1.02	0.4	0.59
Hickory	5.484	5.46	2.9	4.30
Holly	0.445	0.44	0.1	0.15
Loblolly pine	37.586	37.40	30.9	45.78
Misc hardwoods	0.052	0.05	0.1	0.15
Misc red oaks	12.791	12.73	3.9	5.78
Live oak	16.185	16.11	12.5	18.52
Post oak	0.241	0.24	0.1	0.15
Red maple	0.051	0.05	0.0	0.00
Shortleaf pine	3.400	3.38	1.9	2.81
Southern red oak	4.667	4.64	2.9	4.30
Sweetgum	3.349	3.33	1.9	2.81
Water oak	3.439	3.42	2.3	3.41
White oak	0.162	0.16	0.1	0.15
Laurel oak	9.734	9.69	6.3	9.33
Yellow poplar	0.010	0.01	0.0	0.00
Longleaf pine	0.850	0.85	0.4	0.59
Totals	100.486	100.00	67.50	100.00

[1] Twenty representative stands, occupying 445 acres, were selected for the ridge pine-hardwood site type; 239, 10 BAF point samples were recorded and then summarized as a TVAIP unit.

[2] Stems per acre of all trees 4 in. DBH and larger of the labeled species.

[3] Basal area (ft2/ac) of all trees 4 in. DBH and larger of the labeled species.
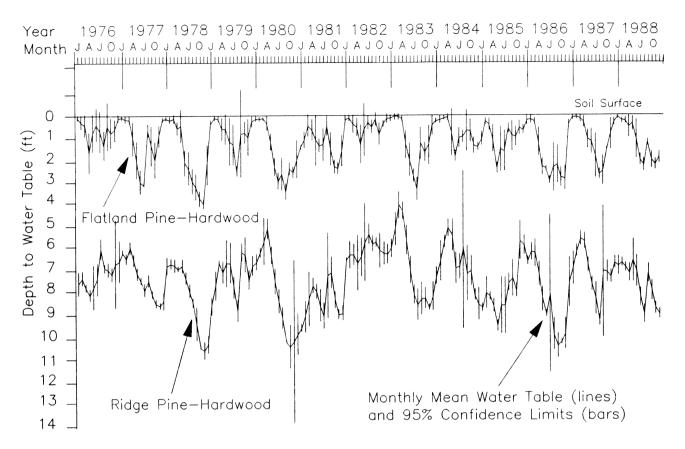
Figure 2.-- Monthly mean water table elevations and 95 percent confidence limits for wells located in pine-hardwood site types.

MANAGEMENT IMPLICATIONS

Some differences in management considerations become readily apparent when these two site types are separated. By most definitions the site type labeled flatland pine-hardwood will be a wetland (Cowardin and others 1979, S.C. For. Comm. 1988). Stand conversion to pine plantation will be much more difficult on these poorly drained sites and may often involve a degree of site conversion by drainage. A close look at figure 1 reveals potential access difficulties for operations that require heavy equipment. There were only 3 years out of 13 when equipment could have worked on the flatland pine hardwood sites monitored, if we assume a water table depth of 1.5 to 2 feet is required to avoid severe compaction and rutting. To further complicate this problem, removal of a significant portion of the timber will cause a rise in the summer and fall water table (Williams and Lipscomb 1981).

Fire can readily be employed on the ridge-pine-hardwood site type for a number of silivicultural objectives (Ferguson 1961; Sanders and others 1987; and Waldrop and others 1985). However, application of prescribed fire to flatland pine-hardwood site types will be very restricted. Stands on these sites will not carry fire during most years; thus, spot ignition of the pine micro-sites will prove less effective and more costly than normal prescribed burning.

The pine component in flatland pine-hardwood stands often provide economic motivation for management, especially where it approaches fifty percent of stand composition. However, the hardwood component is not usually composed of high quality or high value species and therefore does not justify costly stand improvement or harvesting operations (table 1). The ridge counterpart offers the same problem with relation to the hardwoods (table 2); however, it has more site available to favor the perpetuation of the pine component. Future markets may make management of the hardwood component more attractive and cost effective.

RECOMMENDATIONS

The flatland pine-hardwood site type will need to be distinguished in the development of pine-hardwood management prescriptions. The flatland pine-hardwood sites are characterized by near saturated conditions for several months of each year. Management of this type may be restricted under wetlands regulations. Wet conditions will limit the use of heavy equipment and limit effectiveness of some herbicide treatments. Techniques to identify and map the flatland pine-hardwood sites will need to

be developed for the Lower Coastal Plain. The initial differentiation of site types on Hobcaw was based on qualitative estimates of landscape position. The data on water table position indicates that field identification may be easily done by locating a water table near the ground surface. The relatively similar vegetation of the two types may limit mapping of the types by remote sensing techniques, although computerized geographic information systems may be useful in such mapping. The water table differences between the site types are quite distinct and will be reflected in soil series differences. A computerized mapping system can overlay maps of poorly drained soils series on a vegetation type map. The resulting union could distinguish flatland pine-hardwood site types.

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POSTER ABSTRACTS

NITROGEN GAINS AND LOSSES ASSOCIATED WITH SITE-PREPARATION BURNING IN SOUTHERN PINE-HARDWOOD FORESTS

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ABSTRACT

High-intensity site-preparation burning on Piedmont sites may result in excessive losses of forest floor organic matter and nitrogen. Nitrogen losses may range from 50-300 kg N ha^{-1} yr^{-1} from burning logging slash. Few case studies have closely examined losses from burning forest floor organic matter, erosion of residual ash and litter, or rapid microbial transformation and leaching of residual organic nitrogen. Losses resulting from burning coarse woody debris (slash), which may serve as a substrate for free-living nitrogen-fixing bacteria, must also be considered.

Nitrogen losses due to site-preparation burning may be extensive, but there are sources of replenishment to the site. Nitrogen fixation by free-living bacteria in the forest floor is generally < 3.7 kg N ha^{-1} yr^{-1}. Atmospheric inputs of nitrogen may range from 5-12 kg N ha^{-1} yr^{-1}.

One additional source of replacement is symbiotic nitrogen fixation by understory legumes, < 1-10 kg N ha^{-1} yr^{-1}, which are abundant in frequently burned forest ecosystems. These legumes generally deposit nitrogen-rich leaf litter to the forest floor. Substrate quality analyses indicate that this litter may have rapid to moderate decomposition and mineralization rates.

All of these nitrogen inputs may be highly variable over space and time, and more detailed information on these processes is needed. Estimated nitrogen losses during and following intensive burning must be balanced by gains over the length of a forest rotation.

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DEVELOPING FEEDBACK THINNING POLICIES FOR UNEVEN-AGED MANAGEMENT WITH STOCHASTIC PRICES

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Abstract

Two questions that this study begins to address are: (1) What are the effects of uncertain biological and economic parameters on the returns from uneven--aged management and (2) Is it possible to devise management strategies that mitigate the effects of these uncertainties? Most modeling studies that evaluate the efficiencies of alternative silvicultural systems use point estimates of financial performance and ignore the uncertainties in both biological and economic model parameters. Stochastic simulation has been used to study the effects of uncertain economic parameters on the performance of management systems in a range of timber types. Although stochastic simulation measures the impact of uncertainty on the performance of a given strategy, it does not devise management strategies that perform better in the face of parameter uncertainty.

One way to mitigate the negative effects of uncertainty when analyzing uneven--aged management is to employ feedback thinning policies. A feedback thinning policy is a conditional set of actions where thinning intensity at each decision point is a function of the stand state at that point. Let $x(t)$ be the stand state at the beginning of each time period t in which management action is considered. When future stumpage prices are uncertain, a flexible feedback thinning policy can be constructed by letting the number of trees harvested $H(t)$ be a function of stand value $V[x(t)]$:

$$H(t) = \begin{cases} b_1\{V[\mathbf{x}(t)] - b_2\}^{b_3} & \text{if } V[\mathbf{x}(t)] > b_2 \\ 0 & \text{otherwise} \end{cases}$$

where $b_1 \geq 0.0$ and b_2 is unrestricted. Depending on the value of b_3, the harvest level is either constant or an increasing function of stand value. When $b_3 = 0.0$, $H(t) = b_1$; a constant harvest is taken each period. When $b_3 = 1.0$, $H(t) = b_1\{V[x(t)]-b_2$; the cut increases linearly with stand value. When $b_3 = 0.5$, $H(t) = b1\{V[x(t)]-b2^{0.5}$; the cut increases with stand value at a decreasing rate. Diameter class thinning rates are obtained by proportioning the total harvest among the diameter classes according to some thinning type rule (e.g., thin from above). The uneven--aged management problem involves determining optimal values for the feedback function parameters b_1, b_2, and b_3.

Using this feedback function, optimal thinning strategies are developed for an uneven-aged white fir stand in California. The planning horizon is 100 years, the cutting cycle is 20 years, and the objective is to maximize present value. With deterministic prices, constant cut and linear feedback thinning policies give almost the same present value as the optimal (openloop) diameter--class thinning regime. With stochastic prices, the optimal feedback thinning policy is an increasing, nonlinear function of stand value. Based on Monte Carlo simlulations, the nonlinear feedback thinning policy provides a greater expected return than do either the openloop or feedback thinning policies from deterministic optimization. These methods are being extended to management problems involving mixed pine-hardwood stands in the South.

WORKING WITH NATURE: PINE-HARDWOOD MIXTURES

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ABSTRACT

This videotape describes a method of regenerating low-quality mixed pine-hardwood stands on medium sites to stands of higher quality trees through natural sprouting of hardwoods and enrichment planting of genetically improved pine seedlings. Sites are prepared using the fell-and-burn technique developed by James A. Abercrombie. The method has worked well in the Ouachita Mountains of Arkansas and the Appalachian Mountains of South Carolina. The steps taken are:

1. A suitable stand on a medium site is selected.

2. The stand is clearcut.

3. Some remaining trees are cut for firewood by local people.

4. All residual stems are felled in late spring at 3/4 to full leafout using a chainsaw or brushcutter.

5. The area is broadcast burned in mid-summer after nesting season.

6. Improved pine seedlings are interplanted among the hardwood stumps at wide spacing the following planting season.

This method of regenerating pine-hardwood mixtures is being tested in the Piedmont regions of South Carolina and Georgia. Many questions remain. Research is being conducted by the Pine-Hardwood Silviculture Research Work Unit of the USDA Forest Service.

This videotape runs 15 minutes and 45 seconds. A copy may be obtained by sending a blank tape (1/2 inch, 20-minute VHS) to: Dr. Jacqueline L. Haymond, Department of Forestry, Clemson University, Clemson, SC 29634.

NUTRIENT RESPONSE TO OVERSTORY REMOVAL AND WINTER PRESCRIBED FIRE VERSUS CLEARCUTTING AND SUMMER SITE PREP BURNS IN OKLAHOMA OUACHITA MOUNTAINS

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ABSTRACT

Nutrient response of elmleaf goldenrod (Solidago ulmifolia), stiffleaf sunflower (Helianthus hirsutus), greenbriar (Smilax bona-nox), winged sumac (Rhus copallina), and winged elm (Ulmus alta) to various levels of overstory removal and winter prescribed fire versus clearcutting and summer site preparation burn was studied in the Ouachita Mountains of eastern Oklahoma. Differences ($p < 0.10$) due to treatments were noted in percent crude protein, calcium, phosphorous, Ca:P ratio, ash, magnesium and potassium. Acid detergent fiber and total digestible nutrients did not differ among treatments. Nutrient levels varied by treatment and among species of preferred deer (Odocoileus virginianus) foods. Early fall forage nutrient levels were correlated with overstory basal area, canopy closure, and to a lesser extent presence or absence of fire. Crude protein and phosphorous values decreased as basal area and overstory cover increased. Conversely, calcium and Ca:P ratios increased as basal area and overstory cover increased. Winter rough reduction burns elevated phosphorous, magnesium and potassium values and depressed crude protein and calcium levels, but not significantly in most cases. Overstory removal and fire together increased crude protein, phosphorous, and magnesium, while ash, calcium and Ca:P ratios were reduced. Not all parameters of all forages showed significant differences due to treatments. Overstory removal by harvesting shortleaf pine (Pinus echinata), selectively injecting hardwoods and winter prescribed burning resulted in greater nutrient concentrations and more differences across the range of nutrient parameters and forages than other treatments. Mean nutrient levels of forages from the overstory removal and winter prescribed burn treatment were not in most cases significantly different from the clearcut and summer site prep burn treatment. The uncut unburned control had the lowest nutrient response of all treatments. Findings aid in developing wildlife andorest management techniques that maximize early fall nutrient levels in preferred deer foods.

A GROWTH PROJECTION SYSTEM FOR MIXED-SPECIES STANDS

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ABSTRACT
Efforts have been underway at Auburn University since the early 1980's to develop models that predict tree growth in the South. The general direction of this research is to develop a growth projection system capable of predicting the development of major forest types throughout the South. This work has concentrated on model building, and has relied on the TWIGS projection system for the computer framework for model implementation. Recent efforts have concentrated on two major projects. The first is a growth projection system based on the state of Georgia (GATWIGS). This system is currently under validation and verification. The second project is to improve on GATWIGS and build a much broader system (for Alabama, Georgia, and South Carolina) which can be used throughout much of the Southeast (SET). These projection systems are distance-independent individual tree models, which were developed from U. S. Forest Service survey data. Crown ratio, total height, diameter increment, and survival models have been developed for clusters of observations based on physiographic region, species, and forest type. A brief description of the resource and data base is followed by a discussion of model development. Both of these products will be available through the Forest Resources Systems Institute upon their completion.

PHOTOS FOR ESTIMATING RESIDUE LOADING BEFORE AND AFTER BURNING IN SOUTHERN APPALACHIAN MIXED PINE-HARDWOOD STANDS

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ABSTRACT

Harvested stands in the Southern Appalachians contain large volumes of woody debris following spring clearfelling of nonmerchantable, residual trees. Knowledge of the fuel loading, distribution, and characteristics of this residue is needed to effectively prescribe fuel treatments for site preparation and reforestation. The planar intersect technique was used to estimate fuel loadings before and after high-intensity summer boradcast burning. Weight of woody slash, litter, duff, and live fuels was estimated. A photo series describing the range of fuel loadings on clearcut sites in the Southern Appalachians was developed by establishing eight triangular photo plots in areas with slash fuel loadings of 16, 18, 22, 28, 31, 33, 43, and 52 dry tons per acre. Burning reduced slash fuel an average of 52 percent. Woody slash less than 3.0 inches in diameter was reduced an average of 78 percent by burning, thereby facilitating planting operations and reducing the potential for unplanned ignitions.

THE EFFECTS OF FIRE ON TABLE MOUNTAIN PINE COMMUNITIES

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ABSTRACT

In a study still in progress on Bote Mountain in the Great Smoky Mountains National Park, regeneration of table mountain pine (Pinus pungens Lam.) following an April 1986 fire is most successful where fire intensities were high. The high intensities most successfully produced the conditions needed for table mountain pine regeneration: opening of serotinous cones, mineral soil seedbed, and opening of the stand to full sunlight.

Of the 20 plots 0.4 hectare in size, seven were located where fire intensities were low (surface fire only), six where intensities were moderate (surface fire with some scorching and torching of individual trees), and seven where intensities were high (crown fire). Within each plot, 64 .25 sq.m subplots were sampled (1280 total) in which the depth of residual organic matter and the number of table mountain pine seedlings germinating since the fire were recorded.

A total of 366 table mountain pine seedlings were counted in the 1280 subplots for an overall density of 11,437.5 seedlings/ha. In the low fire intensity plots, only 14 seedlings were counted for a density of 1250/ha. In the moderate intensity areas, the density was 15,312/ha, and in the high intensity areas, the density was 18,304/ha.

Of the 366 seedlings recorded, 276 (75.4%) were found growing where the organic matter depth was less than 1 cm. Of the subplots sampled with less than 1 cm of residual organic matter, 198 of 494 (40.0%) contained at least one table mountain pine seedling. The occurrence on subplots with residual organic matter of 1-5 cm was 18.1% (73 of 404), and 0.7% (2 of 282) where the organic matter was 6-10 cm deep. There was no occurrence of seedlings on any of the 99 subplots with organic matter depths greater than 10 cm.

Current indications show that serotinous cones were opened by the heat in the moderate and high intensity areas, but there was less residual organic matter (i.e., more mineral soil exposed) in the high intensity areas. Of the subplots sampled in the high intensity areas, 61.9% had less than 1 cm of residual organic matter (i.e., exposed mineral soil). In the moderate intensity areas, the rate was 33.6%, and in the low intensity areas, only 19.9%.

Expected completion date on the project is September, 1989.

EARLY REGENERATION RESPONSE IN A NORTH CAROLINA PIEDMONT MIXED PINE-HARDWOOD STAND

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ABSTRACT

In order to predict the number and distribution of both the pine and hardwood component in mixed stands, and the subsequent pine and hardwood basal areas from which stand projections can be made, a long term study is being installed to determine initial stand composition based on composition of the prior stand, the composition of harvest residuals, the method of regeneration and site preparation, and site type and quality.

The study was designed as a randomized complete block for plot layout with a 2 by 2 by 2 factorial design. Two harvest treatments, two site preparation treatments, and two pine regeneration treatments are used in the study. The two harvest treatments are clearcutting and a commercial clearcut where only merchantable stems will be removed. The site preparation treatments are with and without preharvest burning. The regeneration treatments will be planting loblolly pine at a 15 by 15 foot spacing and seed-in-place. Each replication consists of eight, 1 acre treatment plots surrounding a centered 1/4 acre square measurement subplot. Each subplot is divided using a 4 by 4 grid to create 16 contiguous quadrats/subplot. A preharvest inventory of all trees 1.0 inches dbh and a milacre sample of advanced reproduction is made on each of the quadrats. A 100 percent inventory of regeneration will be made one and two years after harvest, and at longer intervals thereafter. Greig-Smith's (1964) blocked quadrat variance (BQV) procedures will be used to determine spatial distribution of initial stand parameters and the subsequent regeneration response.

Two replications of the study were installed during 1988 in Chatham County, North Carolina. Four to six replications will be installed during 1989 at other North Carolina Piedmont locations.

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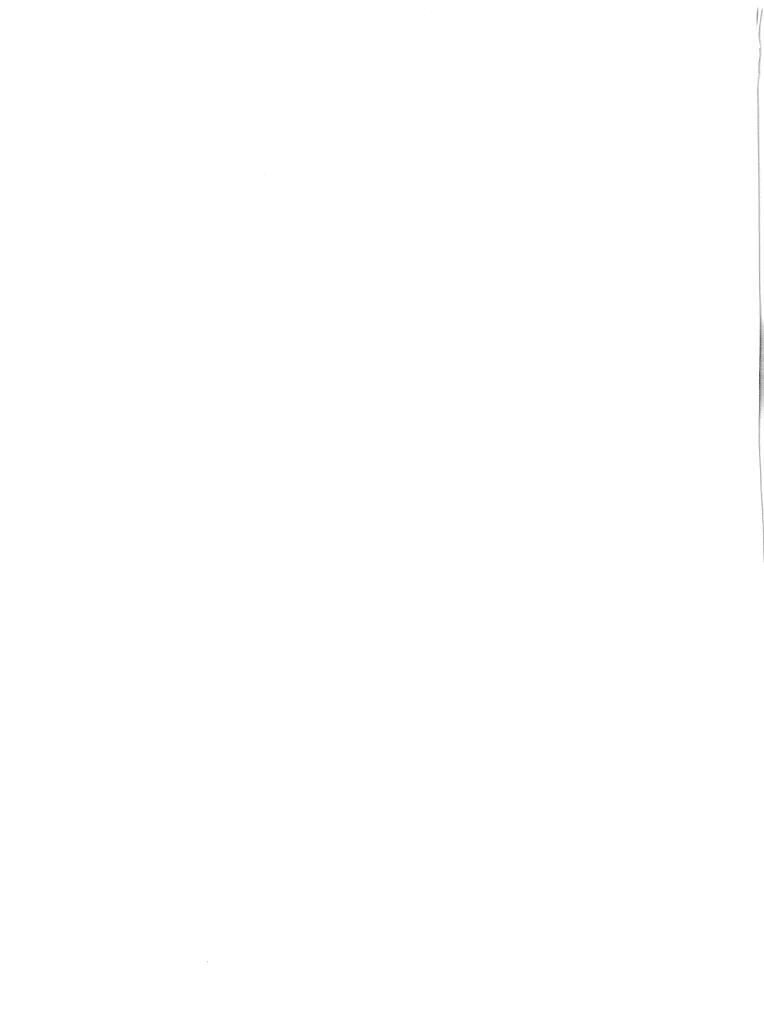P.O. BOX 238
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