SO-75

United States
Department of
Agriculture

Forest Service

**Southern Forest
Experiment Station**

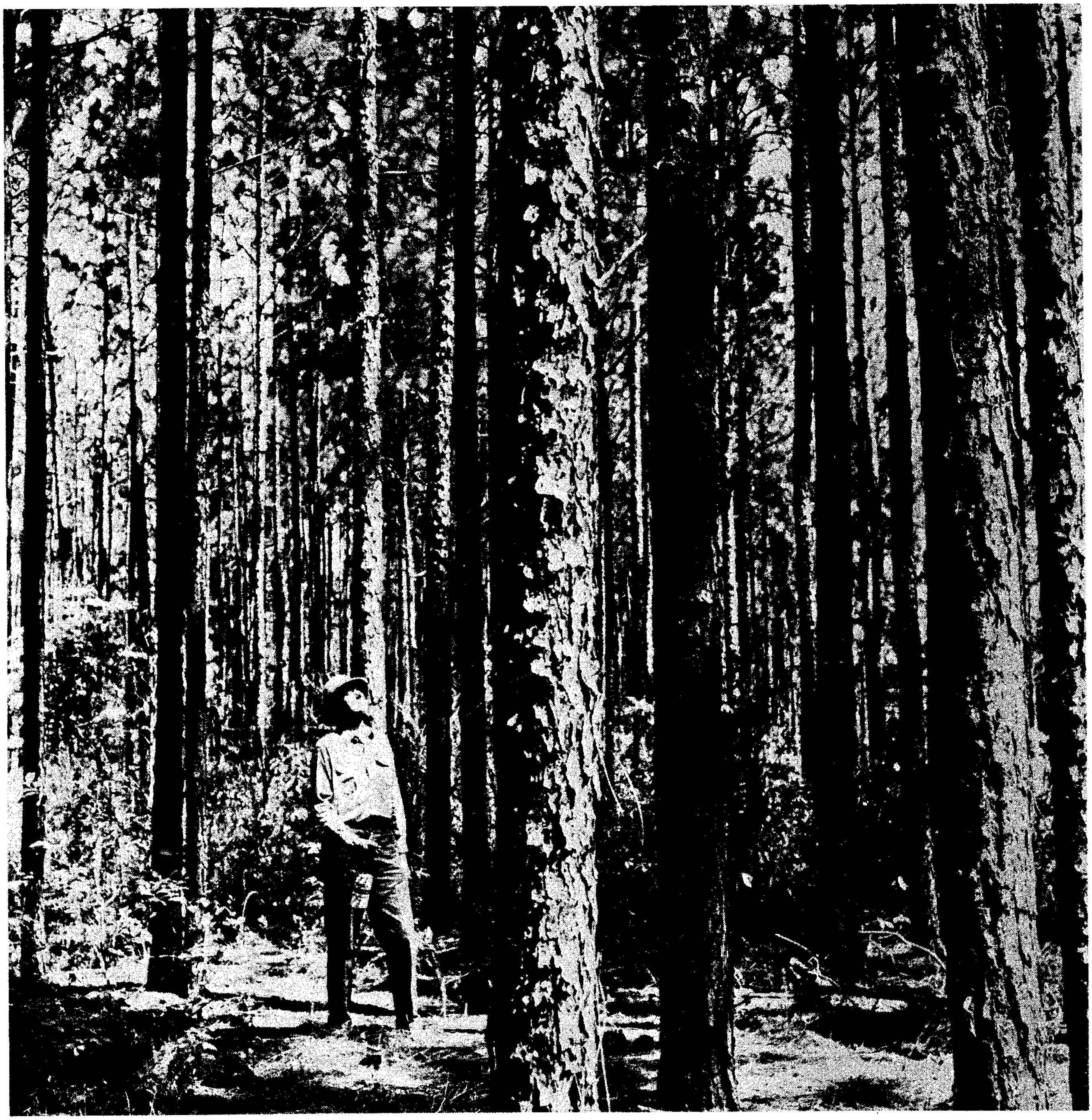
New Orleans,
Louisiana

General Technical Report
SO-75

Proceedings of the Symposium on the Management of Longleaf Pine

April 4-6, 1989

Long Beach, Mississippi



The cover photograph of Thomas C. Croker, Jr., author of the first paper in these proceedings, was taken in 1953 by Larry Walker while Tom was marking a longleaf stand for thinning in Compartment 95 of the Escambia Experimental Forest near Brewton in south Alabama.

Proceedings of the Symposium on the Management of Longleaf Pine

Edited by

Robert M. Farrar, Jr.

Long Beach, Mississippi
April 4-6, 1989

Sponsored by

School of Forest Resources
Mississippi State University

Mississippi Cooperative Extension Service

U.S. Department of Agriculture, Forest Service
Southern Forest Experiment Station
Southern Region, National Forest System
Southern Region, Cooperative Forestry

Society of American Foresters
Silvicultural Working Group

Published by

Southern Forest Experiment Station
701 Loyola Avenue, New Orleans, LA 70113

1990

PREFACE

The symposium on the management of longleaf pine leading to these proceedings was held on April 4 through 6, 1989, in Long Beach, MS, at the Gulf Park Conference Center of the University of Southern Mississippi. This conference was attended by approximately 170 land manag'ers, wildlife managers', researchers, educators, students, and others interested in longleaf pine. Nineteen papers were presented and an all-day'field trip was conducted for attendees during the two and one-half day meeting. Subject areas varied from longleaf pine facts and fallacies to the economics of managing its stands. Authors followed the review procedures of their organizations, supplied their papers in a requested format ready for reproduction, and the proceedings editor checked each paper for completeness, and reasonable format compliance.

The objectives of the symposium were to summarize current technology on regeneration, management, and utilization of longleaf pine, and to promote the species as an integral part of squthern forestry. Longleaf pine stands have been declining in acreage due in part to difficulties in regeneration. This symposium presented technology and operational examples of how those difficulties may be overcome or minimized. The subject matter should have particular application for the management forester and will have general application for researchers, educators, planners and administrators. The most recent previous conference on this subject was held on October 17-19, 1978, in Mobile, AL (USDA Forest Service. 1979. Longleaf Pine Workshop Proceedings. Tech. Publ. SA-TP3, S&PF-SA, Region 8, Atlanta, GA. 119 pp.).

The planning committee gratefully acknowledges the work of the authors and reviewers to provide up-to-date and informative presentations and the efforts of session moderators in adding pertinent comments and keeping the meeting on schedule. Special thanks are extended to the following:

Robert S. "Sid" Moss, State Forester of Mississippi, for his warm welcoming address.

Thomas H. Ellis, Director of the Southern Forest Experiment Station, for his opening remarks setting the stage for the symposium.

Albert G. Kais, Consulting Forester, Biloxi, MS, for his considerable efforts in planning and conducting the field tour.

Glenn A. Snow and Ronald C. Schmidtling, Southern Forest Experiment Station, Gulfport, MS, for their capable handling of the local meeting and social arrangements.

Thomas A. Monaghan and Andrew W. Ezell, Mississippi Cooperative Extension Service, for handling registration and otherwise facilitating the symposium and proceedings.

J. Lamar Beasley, Director of the Southeastern Forest Experiment Station, for his closing remarks defining the place of longleaf pine in the South's future forests.

Roger W. Dennington, Southern Region - Cooperative Forestry, for his interest, initiative, and drive which insured this symposium would take place.

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ITT Rayonier, Inc.

Ronald C. Schmidtling
Southern Forest Experiment Station
USDA-Forest Service

Glenn A. Snow
Southern Forest Experiment Station
USDA-Forest Service

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Session I
April 4, 1989

Moderator:

Stanley B. Carpenter
Louisiana State University

Longleaf Pine - Myths and Facts

Thomas C. Croker, Jr.

Abstract.--To set the stage for the longleaf pine symposium, three broad topics are discussed: historical considerations, silvical considerations, and technology transfer considerations.

INTRODUCTION

The purpose of this paper is to set the stage for the longleaf pine symposium. I will endeavor to do this by discussing three broad topics: historical considerations, silvical considerations, and technology transfer considerations.

A slide talk will be used to cover the historical aspects. The purpose will be to show how myths over the years have plagued the management of longleaf pine. Also the fallacy of myths in light of proven facts will be revealed.

Under silvics, I will present some silvical characteristics of the species that must be considered in developing technology.

In technology transfer considerations, I will briefly evaluate the limitations, as well as the value of the facts, presented in this symposium. Also the role of people, assets and liabilities of longleaf pine, and some philosophical concepts will be covered.

HISTORICAL CONSIDERATIONS

For the purpose of this discussion, a myth is defined as an unfounded opinion without any factual basis.

A story is told of strained relations between a pioneer housewife and her husband in the Blue Ridge Mountains of North Carolina that illustrates a myth. She had been persuaded by the mountaineer, reluctantly, to sign a Right of Way for a railroad to cross their land. Never having seen a train, she believed that they were letting a terrifying monster come and destroy their homestead,

On the first day when the train rumbled by her fears were not relieved. "Sure it did not harm us today," she admitted, "but it came through endwise," she pointed out. "Next time it'll come sidewise and wipe us off the face of the earth."

Thomas C. Croker, Jr., is a consulting forester specializing in Longleaf pine management and located at Route 4, Box 499 A, Greenville, TN 37743.

Ever since the white man crossed the Atlantic and came to America, he and his descendants have concocted unfounded beliefs about the longleaf pine forest.

Covering some 60 million acres, the magnificent virgin forest had grown without the help of man. Over the years, man-made myths have plagued the forest and threatened its destruction. Let's review some of the myths.

Longleaf pine trees were first faced for gum north of the Cape Fear River in North Carolina. Superstitious pioneers did not believe trees south of the river would run gum. This myth that could have destroyed the naval stores industry was soon discarded.

Lumbermen believed faced tree would produce inferior lumber and would not cut them until Bernard Fernow, a German Forester, proved they were wrong.

Early turpentiners cut deep streaks in faced trees contending that this was necessary to make the gum run. Also they cut deep cavities in the trees to collect the gum. 'This practice destroyed much valuable timber and severely weakened the trees.

W. W. Ashe and Charles Herty in the early 1900's proved that shallow bark chipping, combined with acid spray, produced even more gum.

Except for a few farsighted people like Henry Hardtner, most lumbermen believed conservative cutting of the virgin forest to produce a second crop was impractical. Ruthlessly they "cut out and got out" mining the timber like coal.

They criscrossed the uncut woods with railroad tracks and used powerful machines to remove every merchantable tree.

Clyde skidders drug heavy logs to landings, battering and banging smaller trees, leaving wanton destruction in their wake.

Huge band mills, sawing 100,000 board feet in a single 8-hour shift, converted the logs into a bonanza of yellow pine lumber.

Throngs of woods workers, needed to support the lumbering operation, were housed in crude shacks and sold supplies at company commissaries. Cash registers were ringing and there was rejoicing in the false prosperity.

Soon a day of reckoning came. The unwise policy of "cut out and get out" destroyed a magnificent forest leaving a desolate landscape and suffering and despair in the southland.

Early foresters, ignorant of the role of fire in the ecology of longleaf pine, preached a myth of total fire exclusion.

Determined to drive the fire demon from the forest they organized fire crews and got laws passed against woods burning. These were largely, ignored by the southerners.

Crude structures were erected to detect fires.

Where fire exclusion occurred, the site was invaded by hardwood brush and pines like loblolly and slash, destroying any chance for longleaf regeneration.

Fire exclusionists were dismayed when H. H. Chapman, a pugnacious advocate of controlled burning, challenged their myth of complete elimination of fire from longleaf pine forests.

Early foresters declared that fire would damage the range for woods grazing. S. W. Greene exploded that myth with careful research on the DeSoto National Forest in Mississippi where cattle did better on *burned* forest ranges.

On the Tall Timbers Research Station in Georgia, Herbert Stoddard, a world authority on quail, found that controlled fire was beneficial to the bird.

Research by the Southern Forest Experiment Station supported the control burners and destroyed the myth of fire exclusion. Prescribed burning became standard practice in the longleaf forest and has spread to many other forests in the United States.

But a dangerous myth has developed with prescribed burning, a belief that all fires are good. Much damage is done with carelessly executed fires. Even with longleaf pine, skill, experience, and caution are required for acceptable fire use. The myth that all prescribed fires are good must be rejected.

Miraculously when the virgin timber was clearcut well stocked stands sprang up on thousands of acres. Many unfounded theories were circulated to explain regeneration of these "topsy" stands.

Some foresters believed that a few scattered seed trees did the job. When this prescription, based on a myth, failed many decided that longleaf could not be regenerated naturally.

Unexpectedly, we discovered the secret of the "topsy" stand on the Escambia Experimental Forest in 1947. On a compartment scheduled for a seed tree cut, a wild fire established advance reproduction from the seed crop under an overstory that averaged about 30 square feet of basal area per acre.

We were surprised to note that much of the advance reproduction survived after a cut was made leaving scattered seed trees. So we staked these seedlings and compared them with those established later by the seed trees.

When the seed trees failed to produce seedlings, we removed them. This slide reveals the bare landscape after the seed trees were removed. Advance reproduction seedlings are hidden in the grass.

Seven years later from the same camera point is seen the advance reproduction that grew into sapling size. Building on this discovery, we investigated circumstances surrounding regeneration of many "topsy" stands.

Convinced that shelterwood was a promising way.to regenerate longleaf pine, we conducted several years of research to acquire the knowledge needed to apply the system. Foresters who had been indoctrinated with the myth that a shelterwood system would not work in southern pines were skeptical.

Thirty years of experience has destroyed that myth. Where the shelterwood system has been applied correctly, many well-stocked seedling stands have been regenerated with a substantial savings in cost over planting. It is convincing evidence that longleaf pine can be regenerated naturally.

Efforts to establish longleaf by direct seeding often failed and foresters believed that the method was too risky to use. Even Wahlenberg, in his 1946 monograph, condemned direct seeding.

Bill Mann and researchers in Louisiana proved they were wrong. Chemicals were discovered that repelled the seed predators, eliminating the main cause of failures.

Using treated seed, thousands of acres have been successfully regenerated - many by aerial seeding.

Some seeding was done in rows. These are five year old seedlings seeded with an H. C. Furrow Seeder on lands of T. R. Miller Mill Co., in south Alabama.

A planting myth seriously threatened the future of longleaf pine in the 1950s and 60s. Discouraged by repeated failures, most foresters concluded that the species could not be planted successfully and decided to convert their land to slash and loblolly pines. Thousands of stands, many well-stocked, were clearcut, and the land site-prepared with heavy machinery and planted. This dangerous trend threatened to completely eliminate longleaf pine as an important commercial species by the mid 1970s.

Alarmed, some foresters were determined to find the cause of planting failures - one problem was use of small, poor quality seedlings.

Seedlings were being weakened and killed in transit from the nursery to planting site by careless handling.

Seedlings were planted too shallow because of the myth that a little sand would kill the bud.

Heavy mortality occurred on trashy, unstable seedbeds. Competition-free, firm beds, without excessive erosion are a must for longleaf pine.

Without protection from hogs and heavy cattle grazing some successful plantations were destroyed.

Then there was a myth that seedlings, if they survived, would never make height growth.

This 3 year old seedling in a competition free environment is 74 inches high. Under proper conditions, not only can successful plantations be established but many seedlings will make height growth in the second growing season.

Growth studies in overstocked second growth stands and virgin timber generated the myth that longleaf pine would not grow fast enough for commercial management.

Growth studies since 1934 of properly managed stands by researchers like Bull, Farrar, Lohrey, Bailey, and others, have exploded this myth.

Longleaf stands can be thinned to medium densities throughout the rotation and produce satisfactory growth plus other benefits. Density regime depends on objectives of timber production and value of other forest uses.

Longleaf pine is an efficient producer of high quality wood products even on deep sandy sites.

It has supreme resistance to many of the hazards of the southern environment (e.g., fire, insects, disease) and has great esthetic appeal. The forest abounds with game and wildlife.

Many of the myths have melted away in the bright light of proven facts. The magnificent virgin forests are only a fond memory, but as long as trees grow and winds blow the gentle breezes will ripple the long straw crowns if the knowledge presented in this symposium is put into practice.

SILVICAL CONSIDERATIONS

Seed

Longleaf pine is a poor seed producer in comparison with other southern pines and the seed is more vulnerable to predator and seedbed conditions.

Seed is developed in the cone during three calendar years: bud year, flower year, and seed year. Initiation of seed primordia in the bud year is affected by three major factors: spring rainfall, fruitfulness and age and size of the seedtrees. Few seeds are produced in trees under 30 years old or under 10" d.b.h.

From summer of the bud year until ripening of the cones in the seed year the process is subjected to many hazards. Most important are freezing during the flower year, lack of pollination, and depredation by seed insects. Even after the cones mature many are destroyed by hungry squirrels.

During a short time in the spring both flowers and conelets are easily visible. Seed crop forecasts should be made at this time.

The large nutritious seeds are dispersed usually from late October to early December. Much of it is gobbled up by a host of predators; the most important being flocks of birds. Dispersal range is short, usually not more than one and a half times seed tree height.

There is a myth that longleaf pine produces a good crop every seven years. A scattered stand of seed trees may take 20 years to produce a useable crop. Where the seed trees are unfruitful, a good crop may never be produced. But a stand of reasonably fruitful seed trees with a density of 30 s.f. of basal area per acre will produce usable crops at 3 or 4 year intervals.

Since fruitfulness and quality are under strong genetic control this should be recognized in seed tree selection.

Establishment and growth

Special knowledge of the silvics of longleaf pine is required-to achieve successful establishment and growth. Seedbeds must be cleaned with fire or mechanical treatments so the large winged seed can reach mineral soil. And of course, there must be enough of it to feed the hungry predators and leave enough for regeneration.

Seeds germinate in the fall and will frost heave on heavy soils near the northern limits of the zone. Excessive populations of grazing rabbits can destroy marginal stands during the first winter. Flooded seedbeds are lethal to the seedlings.

After establishment growth occurs during four stages: grass-stage, height-growth, sapling, and large-tree stages. During the grass stage seedlings make rapid root growth but no height growth. Root growth makes them more drought resistant than loblolly or slash pines but they are dominated by pines and hardwoods that make rapid height growth. Competition severely retards start of height growth. The genetic makeup of the longleaf seedlings also affects the initiation of height growth. Seedlings resistant to brownspot and suprerior to their associates make faster height growth. Usually about 20 percent of seedlings in natural stands have this capacity. Height growth occurs when seedling root collar diameter reaches one inch. Because of the different makeup of natural stands they break up into strong crown classes. This makes them less likely to need precommercial thinning than other pines that tend to stagnate in overstocked stands.

During the sapling stage, longleaf growth compares favorably with slash and loblolly pine if it is not retarded by unwise prescribed fires that are worthless in controlling competition.

Beyond the sapling stage longleaf pine enjoys a growth factor that is often overlooked. Mortality from the hazards of fire, insects, and disease is much lower than for other pines and net growth is what counts. Also growth in terms of quality and specific gravity tend to favor longleaf pine.

Fire resistance

Longleaf pine is the most resistant of the southern pines to fire damage. However it can be severely damaged by unwise prescribed burning prescriptions. The forester must have a sound knowledge of the physical characteristics during the growth stages, the impact of fuels, weather, and burning strategy to avoid damage.

It is generally reported that grass-stage seedlings are resistant to fire damage when they reach three-tenths inch in diameter at the root collar, but this is misleading. Seedlings as small as one-tenth inch established on mineral soil, with the root collar at ground line, are safe from damage to low intensity fires; whereas those larger than three-tenths inch originating on duff layers with exposed root collars will be killed.

Height-growth seedlings with a protective sheath of green needles are much more resistant to damage than those without this protection, especially if their needles are infected with brownspot.

A slow moving backfire will do much more damage than a fast moving headfire to grass-stage and height-growth seedlings.

With a knowledge of seedling resistance and the effects of burning strategy a forester can prescribe fires that thin seedling stands killing the inferior and saving the better ones.

During the large-tree stage the amount and moisture content of fuels, wind velocity, temperature, and firing strategy are important factors.

For example, spring and summer burns can be safely done with headfire when the grass is green, the fuel largely composed of grass and pine needles, and drought periods are avoided.

On the other hand, a backing winter fire under low temperature, and calm winds can be disasterous if the stand is loaded with tons of dry freshly cured, logging slash.

Longleaf pine sites

The virgin longleaf pine forest covered a vast territory of 60 million acres. This is a strong evidence that it is ecologically adapted to many soil types. Competition rather than soil type is the main restricting factor.

But heavy soils near the northern limits of the zone cause frost heaving and are not suitable longleaf pine sites. Also,. as annual rainfall diminishes in Texas. the sites become unsuitable due to regeneration difficulties.

There has not been much intensive research to identify suitable longleaf pine sites but obsrvant foresters contend that the species is much more productive on the sterile sands than other species like loblolly and slash.

Where competition can be controlled longleaf pine can probably be safely grown on a wide range of soil types within its natural zone.

TECHNOLOGY TRANSFER CONSIDERATIONS

Facts

Symposium facts to be presented represent a wealth of accumulated knowledge. Intelligently used, they should significantly upgrade the management of longleaf pine forests.

But the wise forester should recognize the limitations of the data and adjust his management to the accumulation of new knowledge.

Much of the growth and yield data is based on average or better sites with little facts on the poor sandy soils, except for a few plots on Farrar's Regional growth study. Wood products are sold by weight rather than volume and we need more of the growth and yield knowledge translated in terms of weight.

Our knowledge of the important roles of genetics and mortality on growth and yields needs upgrading.

Forestry tools, chemicals, and equipment are rapidly changing so the forester must adapt his technology to the changes. For example, many are acquiring four-wheelers equipped with fire torches for prescribed burning. Use of such equipment is practical with headfire burning but perhaps not with backfire and strip headfire. Also fires are being set from the air with helicopters.

In summary, my advice is to make full use of the facts presented in this symposium but always be on the alert for improvement.

Assets and liabilities of longleaf pine

Longleaf pine, ecologically adapted to sixty million acres of southern pineland, has many assets. It is highly resistant to hazards that pose a serious threat to other pines: wildlife, tip moth, southern pine beetle,

fusiform rust, Fomes annosus root rot, and most other diseases except brownspot.

It it an efficient producer of high quality wood products, especially poles and piling.

A new industry is rapidly developing that uses **longleaf** pine straw that is much preferred over the straw of other pines.

Many people prefer a natural forest environment where they can enjoy sports like hunting and bird watching. **Longleaf** forests are ideally suited for such purposes.

Its major liabilities are difficult regeneration and delayed height growth. If the information covered in this symposium is used wisely these problems can be minimized.

People

A knowledge of the people that own the land is just as important as how to plant, regenerate, or otherwise manage **longleaf** pine forests. In order to "speak the language of the people" the forester should be familiar with their history, beliefs, even their prejudices. Some are emotionally attached to **longleaf** through family history, esthetics, or otherwise. This is a plus and should help get technology into practice. And don't forget the female factor. To paraphrase: "The hand that rocks the cradle" controls the management of much of our pineland.

Before trying to promote **longleaf** pine, the forester should become familiar with the landowner's stand conditions and his objectives. If he has a "topsy" stand reasonably well stocked with sawlog-size trees, is interested in a natural forest environment and production of high quality wood products, a sixty year rotation favoring natural regeneration might be suitable. Clear cutting and planting genetically improved stock might suit the needs of another.

Philosophy

In closing I want to offer a few philosophical concepts, not as a Doctor of Philosophy but as an Old Forester.

1. Computers, mathematics, and research findings are valuable tools but are just that. The human brain is much more sophisticated and must be used to achieve wise technology.

2. The written word is not necessarily more reliable than the spoken word. It all depends on the writer or the speaker.

3. So called scientific facts can be dead wrong. Keep in mind the myths I have presented.

4. Flexibility is the key to success. Education, experience, and an open mind are the essential ingredients.

5. The practice of forestry is an art. Proven facts must be used by the foresters, as an artist uses paint, to develop a solution to each management situation.

6. Finally, a forester who is a true professional, not just a technician, has a strong conservation ethic.

The Longleaf Pine Resource

John F. Kelly and William A. Bechtold[1]

ABSTRACT. Area of longleaf pine (*Pinus palustrius* Mill.) in the Southern United States has declined from 12.2 to 3.8 million acres over the past 30 years. Longleaf pine, which once dominated vast portions of the region, now accounts for only 3 percent of the total timberland acreage in the 8 States where the species is found. Longleaf growing-stock volume has decreased by 12 percent in the past decade. Reduced numbers of saplings and seedlings indicate that a reversal of this trend is unlikely in the near future. Existing stands are maturing, but many are poorly stocked. Future prospects depend on effective management of existing stands and improvement of an unfavorable growth-to-removals ratio.

INTRODUCTION

The forests of the lower coastal plain of the American South were once dominated by longleaf pine (*pinus palustris* Mill.). This species has been a major factor in the development of the timber industry and forestry in the South (Croker 1987). Despite the past importance of longleaf pine, its prevalence has dwindled over the years to the point where it is now only a minor southern timber species. Dennington and Sirmon (1987) point out that although this species is admired, it has not been widely propagated. The purpose of this paper is to describe the current longleaf pine resource in the South, as well as past trends involving this species.

Most of the information reported here has been compiled from forest inventory and analysis (FIA) data collected during ongoing forest resource surveys. Additional information from the latest inventories of each State is available in published resource bulletins (Sheffield and Knight 1986; Tansey and Hutchins 1988; Sheffield and Knight 1984; Brown and Thompson 1988; Rudis, et. al. 1984; Donner and Hines 1987; Rosson, et. al. 1988; McWilliams and Lord 1988). Authorized in 1928 by the McSweeney-McNary Act, the first of these statewide inventories were conducted during the 1930s. At present, the sixth survey cycle of southern forest resources is now underway. Because inventory definitions, standards, and procedures have changed substantially since the initial surveys, this report will focus primarily on trends since the mid-1950s.

AREA

FIA forest. type classification is based on the relative stocking of individual species. A designation of “pine type” requires at least 50 percent pine stocking; a specific type, such as longleaf pine, must have a plurality of pine stocking in the designated species. Oak-pine forest types are comprised of 25-49 percent pine stocking, with the balance in oaks and other hard-

[1]John F. Kelly is research forester, USDA Forest Service, Southern Forest Experiment Station; William A. Bechtold is research forester, USDA Forest Service, Southeastern Forest Experiment Station.

woods. Hardwood stands have less than 25 percent stocking in pine species. Even though longleaf pine occurs mainly in stands where it comprises a plurality of the stocking, it also occurs as a minor component of other pine forest types (mostly slash pine), as well as oak-pine and hardwood stands. The following descriptions of longleaf pine area refer to those acres dominated by longleaf stocking.

The natural range of longleaf pine extends from North Carolina to Florida and westward into Texas (Little 1971; Harlow and Harrar 1958). It is principally confined to the coastal plain portions of most States where it occurs, although the range does reach into the Appalachian foothills of Alabama and Georgia. Of the 4 major southern yellow pines, only slash pine (*Pinus elliottii* Engelm.) has a smaller natural range. Longleafpine is most commonly found on sandy coastal plain soils. The best sites are well-drained, although it also occurs on sandy sites which are underlain by hardpan (Harlow and Harrar 1958).

Within its natural range, the area of longleaf pine has been declining throughout the 20th century. Actually, the demise of longleaf forests began in earnest with the advent of widespread logging in the South during the late 19th century (Barrett 1980); McWilliams and Lord 1988). Logging of these old-growth forests continued until the early 1 930s in parts of the region. Early FIA data indicate that the area of longleaf pine continued to decline sharply between the mid-1930's and mid-1950s, the period when the second-growth forests of the South were established. Since 1955, area of longleaf pine has dropped from 12.2 to 3.8 million acres-a decrease of 69 percent in just 30 years (table 1). In the 8 states where longleaf presently occurs (North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana, and Texas), only about 3 percent of the total timberland area supports a longleaf forest type (table 2). Figure 1 shows the relative distribution of this acreage by county.

Table 1. -Area of longleaf pine forest type by State and year, 1955-1985

State	1955	1965	1975	1985
Alabama	1,370.2	989.5	749.8	679.3
Florida	4,389,4	2,298.7	1,371.2	1,034.4
Georgia	2,486.0	1,362.5	778.3	632.7
Louisiana	1,264.2	682.1	386.6	305.0
Mississippi	1,011.4	639.3	354.6	293.9
North Carolina	665.3	524.1	453.8	381.8
South Carolina	818.7	571.1	481.6	405.7
Texas	199.8	132.3	58.5	36.9
All states	12,205 .0	7,199.6	4,634.4	3,769.7

By ownership, the largest portion of longleaf pine acreage in the South is held by "other private" landowners (table 3). This category contains the largest share of longleaf pine acreage in all states except Florida, where public ownership is highest. Overall, other private owners account for 55 percent of the total longleaf area; public owners, 27 percent; and forest industry, including leased land, 18 percent.

About half of all longleaf pine stands occur on medium sites, which are capable of producing 50-84 cubic feet per acre per year when fully stocked (table 4). Another 31 percent are on sites with low productive potential (20-49 cubic feet per acre annually). The remainder, about one-fifth of the longleaf area, is located on superior sites able to produce at least 85

Table 2. -Timberland area by forest type and State where longleaf pine range occurs, latest survey cycle

State	All types	Longleaf pine	Other pine	Oak-pine	Hardwood
	Thousand acres				
Alabama	21,658.8	700.4	6,546.3	4,425.6	9,986.5
Florida	14,982.6	950.9	6,575.6	1,210.8	6,245.3
Georgia	23,733.7	676.4	10,762.5	2,959.6	9,335.2
Louisiana	13,872.6	313.2	4,653.2	1,913.3	6,992.9
Mississippi	16,981.6	270.2	4,493.1	3,477.6	8,740.7
North Carolina	18,450.3	389.0	5,955.9	2,276.7	9,828.7
South Carolina	12,178.8	396.5	5,040.6	1,543.7	5,198.0
Texas	11,565.3	34.7	4,181.8	2,401.8	4,947.0
All states	133,423.7	3,731.3	48,209.0	20,209.1	61,274.3

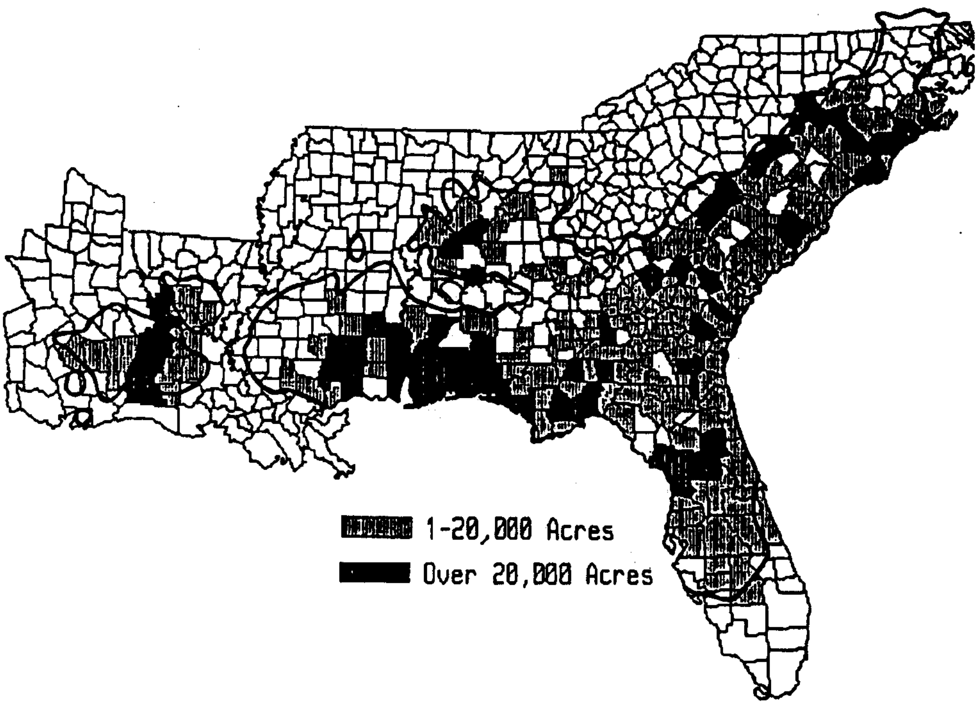

Fig. 1. -Counties with longleaf pine forest type. Natural range of longleaf pine indicated by dark line. (Light shading of counties indicates 1-20,000 acres; dark shading, over 20,000 acres.)

cubic feet per acre per year. The sandy sites where longleaf pine stands are commonly found are rarely highly productive sites. For example, in Alabama only 26 percent of the longleaf pine stands are in the high site classes. By contrast, 61 percent of all forest stands in Alabama are in these same high site classes.

Table 3. -Area of longleaf pine forest type by state and owner category, latest survey cycle

State	All owners	Public	Forest industry[1]	Other private
	------------Thousand acres------------			
Alabama	700.4	105.4	224.7	370.3
Florida	950.9	417.8	149.9	383.2
Georgia	676.4	46.7	83.2	546.5
Louisiana	313.2	73.7	109.7	129.8
Mississippi	270.2	101.5	37.3	131.4
North Carolina	389.0	141.4	44.8	202.8
South Carolina	396.5	120.1	22.7	253.7
Texas	34.7	6.1	11.4	17.2
All states	**3,731.3**	**1,012.7**	683.7	**2,034.9**

[1]Forest industry includes leased land.

Table 4. -Area of longleaf pine forest type by State and site class, latest survey cycle

State	All states	Site class, cubic feet/acre[1]				
		165 and greater	120-164	85-119	50-84	Less than 50
Alabama	700.4	12.0	6.2	164.8	386.7	130.7
Florida	950.9	---	---	34.1	473.1	443.7
Georgia	676.4	---	2.9	92.7	491.2	89.6
Louisiana	313.2	6.5	51.6	110.0	121.7	23.4
Mississippi	270.2	25.9	41.0	142.4	60.9	---
North Carolina	389.0	---	3.1	3.8	109.3	272.8
South Carolina	396.5	---	---	18.2	193.0	185.3
Texas	34.7	5.5	5.9	11.6	11.7	---
All states	**3,731.3**	49.9	110.7	577.6	**1,847.6**	**1,145.5**

[1]A classification of timberland based on potential yield in cubic foot per acre of mean annual growth at culmination of the increment in fully stocked natural stands.

The majority of longleaf pine stands are natural in origin, as only 9 percent of the area occupied by longleaf has been planted (fig. 2). The states leading in percentage of planted longleaf stands are Louisiana (18 percent), South Carolina (13 percent), and Mississippi (12 percent). Even in Louisiana, however, the percentage of planted longleaf pine stands is low compared to the percentage of all pine stands that are planted -- 30 percent.

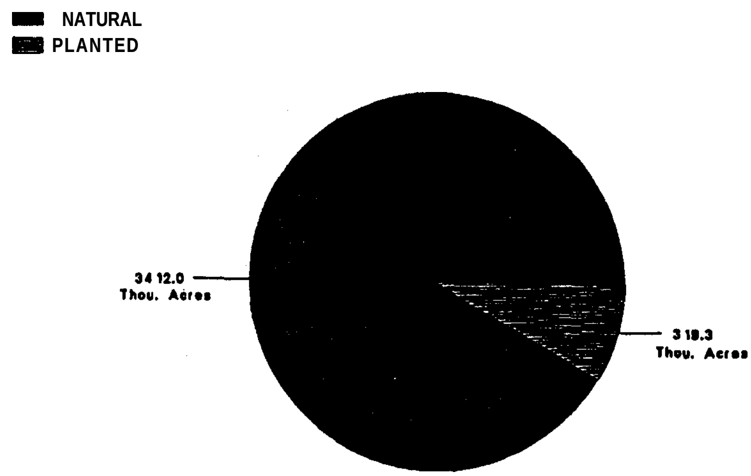

Fig. 2. -Area of longleaf pine stands by stand origin.

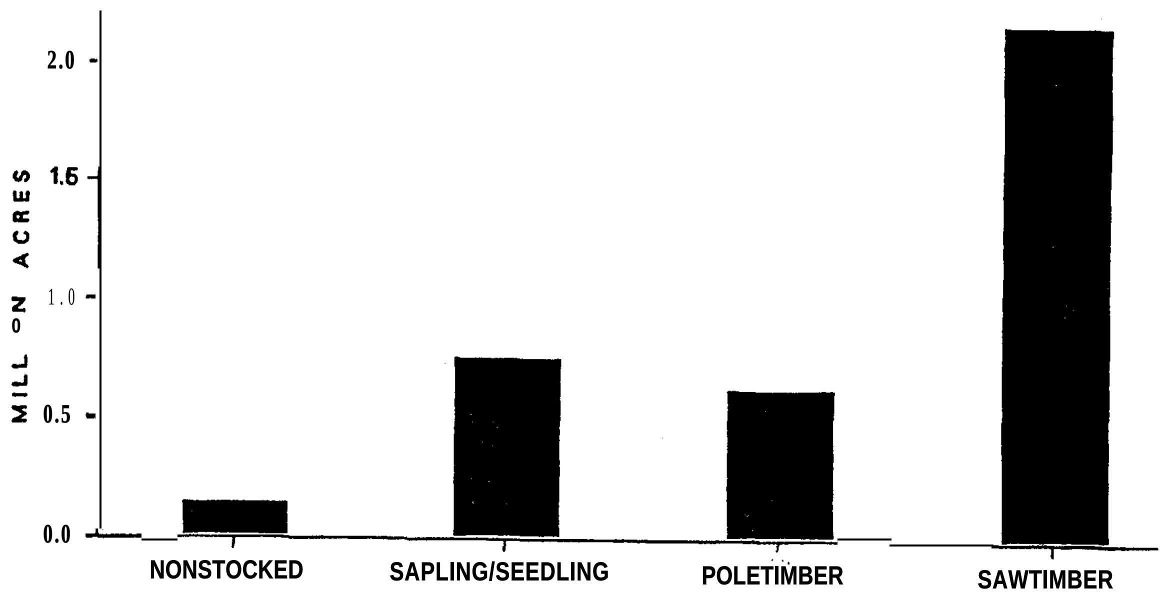

Fig. 3. -Area of longleaf pine stands by stand size.

About 58 percent of all longleaf pine stands are presently classified as sawtimber in size (fig. 3). Poletimber stands account for only 17 percent of the area, while sapling-seedling stands account for 20 percent. The remainder is nonstocked. The high ratio of sawtimber stands indicates that much of the resource is either mature or approaching maturity.

Even with the prevalence of sawtimber stands, only 24 percent of all longleaf pine stands are fully stocked (fig. 4). Although much of the area (40 percent) is medium stocked, a large amount - 36 percent - is poorly stocked. Fully stocked stands are at least 100 percent stocked, while the medium category ranges from 60-99 percent; poorly stocked stands are less than 60 percent stocked. Nonstocked stands, which are grouped with the poorly stocked stands in this comparison, are less than 16.7 percent stocked.

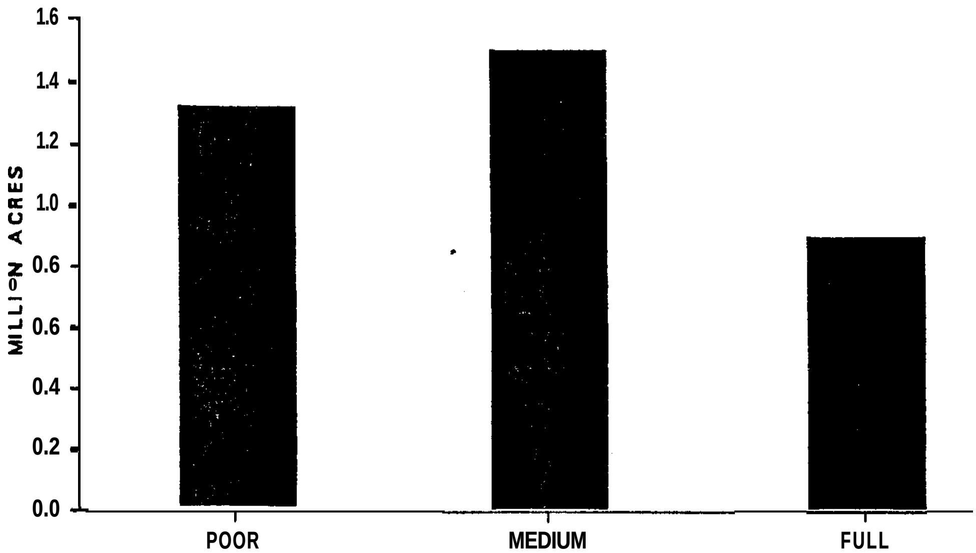

Fig. 4. -Area of longleaf pine stands by stocking class.

INVENTORY, GROWTH, AND REMOVALS VOLUME

Growing-stock volume in the 8-state area that bounds the natural range of longleaf presently totals 5.7 billion cubic feet (table 5, fig. 5). The States of Florida, Georgia, and Alabama are leaders in terms of total growing-stock volume. These 3 states account for 60 percent of all longleaf pine volume.

Table 5. -Growing-stock volume of longleaf pine by forest type and State, latest survey cycle

State	All types	Longleaf pine	Other pine	Oak-pine	Hardwood
	Million cubic feet				
Alabama	1,174.8	673.1	163.4	258.7	79.6
Florida	1,179.9	824.2	169.1	116.7	69.9
Georgia	1,050.1	678.3	246.0	81.6	44.2
Louisiana	438.2	261.8	145.4	27.3	3.7
Mississippi	604.5	296.7	132.8	147.1	27.9
North Carolina	442.6	322.2	73.7	32.7	14.0
South Carolina	659.0	463.3	112.8	57.5	25.4
Texas	108.0	54.3	40.9	8.7	4.1
All states	5,657.1	3,573.9	1,084.1	730.3	268.8

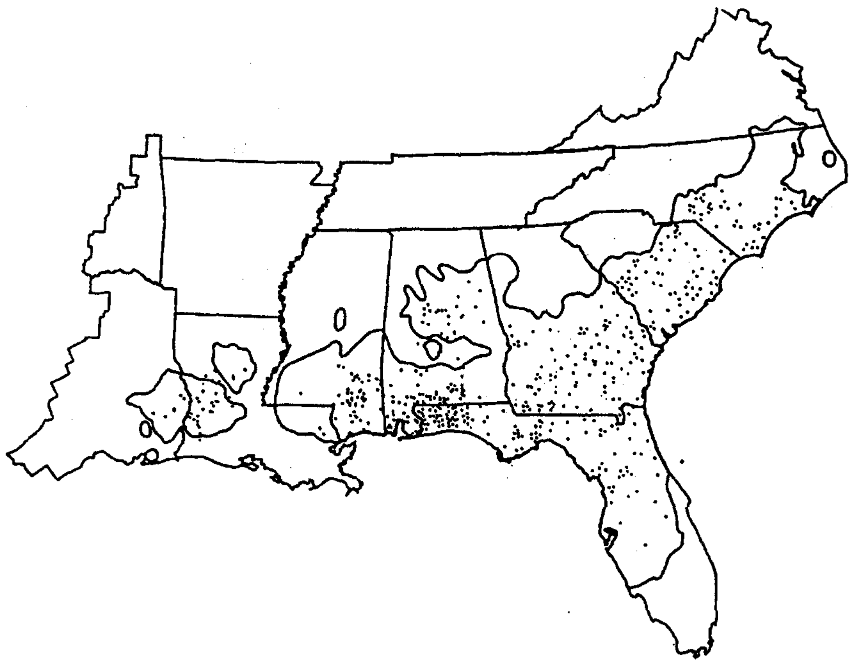

Fig. 5 -Volume of longleaf pine growing stock across the South. Each dot represents 10 million cubic feet. Natural range of longleaf pine indicated by dark line.

Most of the longleaf pine growing-stock volume - 63 percent - is found in stands specifically designated as a longleaf forest type. Other pine stands account for another 19 percent of the total longleaf volume. Oak-pine stands account for an additional 13 percent, while 5 percent is found in hardwood stands.

In the 10 years or so that mark the latest cycle of southern timber inventories, total longleaf pine volume has declined by about 12 percent. Notably, this decline has not been uniform across the range of diameter classes. Figure 6 indicates that for large trees - those 16.0 inches dbh and larger - volumes have actually increased. Volume in these large trees has increased 29 percent during the most recent cycle. They now contain more than one-fifth the total longleaf pine volume.

Sawtimber inventory of longleaf pine is 23.5 billion board feet (table 6). As with growing-stockvolume, Florida, Alabama, and Georgia lead the other states in total sawtimber. Again, most of this volume - 63 percent - is located in longleaf pine stands.

Recent surveys across the region indicate the net annual growth of longleaf pine growing stock totals 228.7 million cubic feet, and sawtimber totals 1.1 billion board feet (tables 7 and 8). Annual removals of longleaf growing stock total 326.9 million cubic feet (table 9), exceeding growth by 43 percent. This disparity between growing-stock growth and removals is reflected in the declining volume measured during the latest round of inventories.

Similar to the situation with total growing stock, longleaf pine sawtimber removals exceed growth by 19 percent. Annual removals of sawtimber surpass 1.3 billion board feet, compared to the 1.1 billion board feet of growth.

SUMMARY OF RESOURCE TRENDS AND OUTLOOK

The longleaf pine resource has continued to decline as long as forest surveys have been tracking trends. The forest type that once covered much of the southern coastal plain now

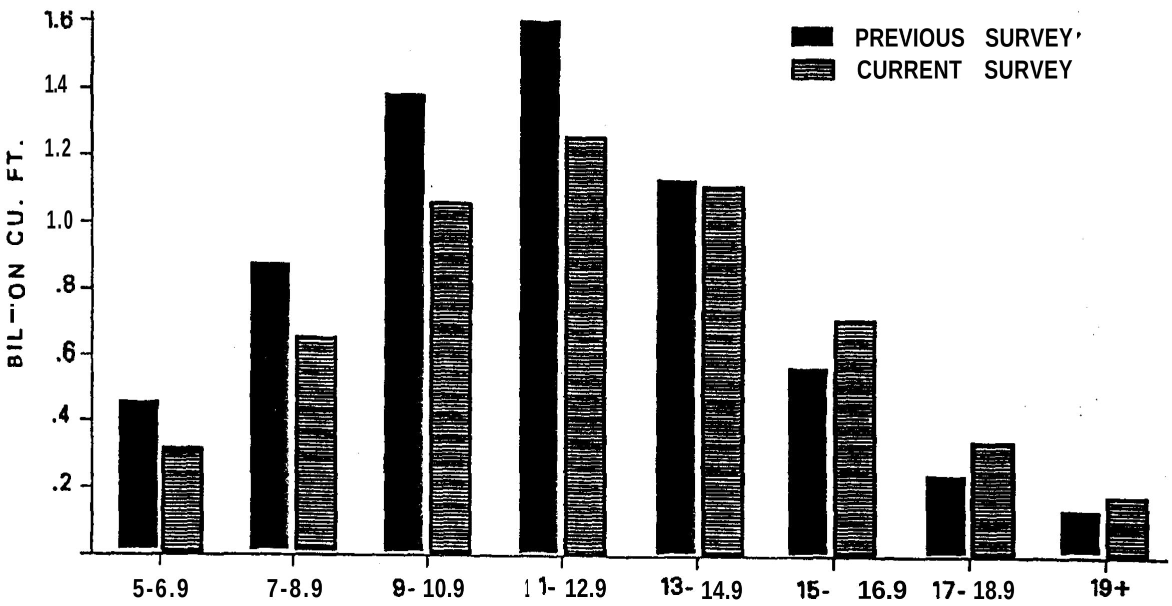

Fig. 6. -Growing-stock volume of longleaf pine by dbh class. Current and previous survey cycles.

Table 6. - Sawtimber volume of longleaf pine by forest type and State, latest survey cycle

State	All types	Longleaf pine	Other pine	Oak-pine	Hardwood
	Million board feet[1]				
Alabama	4,594.4	2,607.1	601.3	1,078.7	307.3
Florida	4,993.5	3,516.9	677.0	478.7	320.9
Georgia	4,445.3	2,889.0	999.8	359.4	197.1
Louisiana	1,666.8	970.5	567.1	116.8	12.4
Mississippi	2,716.1	1,326.1	598.5	661.8	129.7
North Carolina	1,776.0	1,254.9	326.6	136.7	57.8
South Carolina	2,833.8	1,950.7	503.6	261.2	118.3
Texas	508.4	252.9	193.8	43.4	18.3
All states	23,534.3	14,768.1	4,467.7	3,136.7	1,161.8

[1]International 1/4-inch rule.

Table 7. -Net annual growth of **longleaf** pine growing stock by forest type and State, latest survey cycle

State	All types	Longleaf pine	Other pine	Oak-pine	Hardwood
	Million cubic feet				
Alabama	45.4	22.2	8.1	9.5	5.6
Florida	35.8	23.7	5.4	4.1	2.6
Georgia	46.6	29.8	11.7	3.4	1.7
Louisiana	21.5	11.8	7.1	1.5	1.1
Mississippi	32.8	13.7	7.2	8.5	3.4
North Carolina	14.3	10.5	2.4	1.0	0.4
South Carolina	25.6	18.1	4.8	1.7	1.0
Texas	6.6	2.2	2.2	0.7	1.5
All states	228.7	132.0	48.9	30.4	17.4

Table 8. -Net annual growth of **longleaf** pine sawtimber by forest type and State, latest survey cycle

State	All types	Longleaf pine	Other pine	Oak-pine	Hardwood
	Million board feet[1]				
Alabama	221.4	103.5	37.7	51.2	29.0
Florida	204.0	132.2	32.2	23.6	16.0
Georgia	232.9	153.2	55.5	15.5	8.7
Louisiana	84.2	42.0	30.7	6.2	5.3
Mississippi	154.4	62.6	32.7	42.3	16.8
North Carolina	76.0	56.4	10.7	6.1	2.8
South Carolina	122.8	82.0	21.4	15.5	3.9
Texas	30.5	10.6	10.1	4.0	5.8
All states	1,126.2	642.5	231.0	164.4	88.3

[1]International 1/4-inch rule.

Table 9. -Annual removals of longleaf pine growing stock and sawtimber by State, latest survey cycle

State	Growing stock	Sawtimber
	million cu. ft.	million bd.ft[1]
Alabama	60.4 .	249.0
Florida	69.7	276.1
Georgia	72.7	295.4
Louisiana	26.1	106.0
Mississippi	35.0	153.1
North Carolina	21.6	87.7
South Carolina	30.7	121.8
Texas	10.7	48.1
All states	326.9	1,337.2

'International 1/4-inch rule.

occupies only 3.7 million acres. The longleaf acreage of today is only one-third of what it was just 30 years ago. The latest forest surveys show that longleaf growing-stock and sawtimber volume continues to diminish because of an imbalance between growth and removals.

Recent changes in numbers of trees imply that the protracted decline of longleaf pine is likely to continue. For the entire South, numbers of live longleaf pine trees are declining in all diameter classes except the largest - those 16 inches and larger in dbh (fig. 7). Generally,

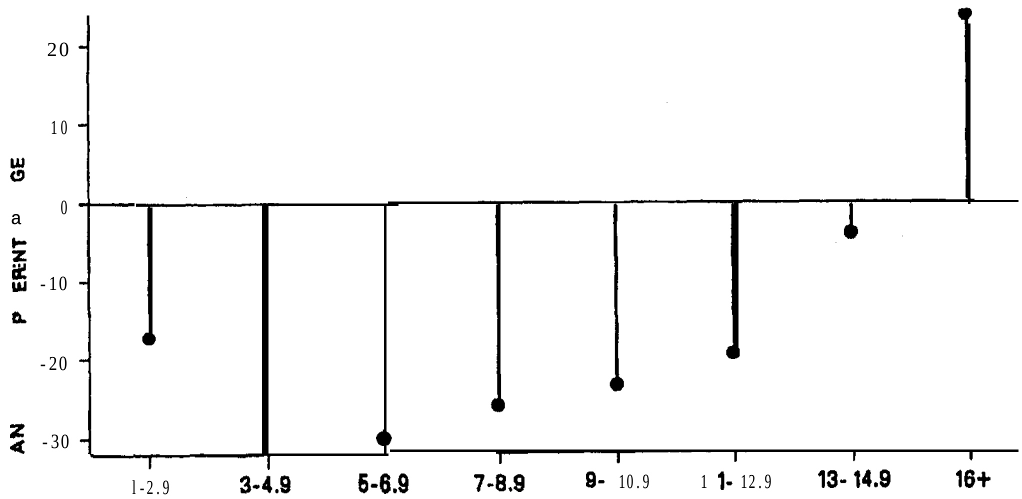

Fig. 7 -Percentage change in numbers of trees by dbh class from previous survey cycle.

this pattern holds true for individual states. In particular, a 23 percent decrease in trees below 5.0 inches dbh means that inventory volume can be expected to continue declining as a result of fewer trees available for ingrowth across the 5.0-inch volume threshold. Reductions in sawtimber volume can also be expected to steepen since numbers of poletimber trees (5.0-8.9

inches dbh) have also recently declined. These redistributions of trees by diameter class also imply that important stand structural changes are taking place. The buildup in large-diameter trees, combined with decreases in both volume and area of longleaf pine forest type, show that longleaf pine stands are generally advancing in maturity.

In addition to implicating a maturation of the resource, reductions in numbers of longleaf pine saplings support the acreage trends which indicate young stands are not replacing those now being harvested. For example, the area of longleaf pine in Mississippi declined by 31 percent between 1977 and 1987. This loss of acreage occurred principally because many harvested longleaf stands were not regenerated to longleaf. In many cases, forest managers replaced these harvested areas with slash pine plantations. Often, though, longleaf pine stands are partially cut with no effective regeneration; these areas then become mixed pine-hardwood or pure hardwood stands.

In addition to the problems associated with the shrinking longleaf land base, loss of longleaf inventory volume is intensified by the fact that such a high ratio of the remaining stands are producing far below potential due to inadequate stocking. Thirty-six percent of all longleaf stands are currently poorly stocked. This represents a sizeable treatment opportunity for existing stands.

Despite the unfavorable outlook for longleaf, there is some evidence of conscious longleaf pine management. Although accounting for a scant 9 percent of the total longleaf pine resource, the 319,300 acres of plantations undoubtedly represents a substantial investment for some landowners. There are some well-stocked natural stands as well. The future of the longleafpine resource will depend on the conscientious management of existing and harvested stands to change the current unfavorable growth-to-removals ratio. The continuance of past trends does not bode well for a species many southerners profess to admire.

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Identifying Longleaf Pine Sites

Eugene Shoulders

ABSTRACT. In its natural environment, longleaf pine (*Pinus palustris* Mill.) is a pioneering species, inexacting in its soil requirements but intolerant of competition and flooding, especially during its grass stage. Historically, fire and moisture were the principal factors controlling longleaf distribution within its natural range. The longleaf pine type became established and persisted on sites where frequent fires reduced exposure of seedlings to the brown-spot needle blight fungus (*Scirrhia acicola* [Dearn.] Siggers) and held back the competing vegetation, and where flooding was infrequent and/or of short duration. In a managed ecosystem within its natural range, longleaf pine has the potential to compete favorably in yields with other major southern pines on a wide range of site conditions if appropriate measures are taken to assure prompt emergence of well-stocked stands from the grass stage.

INTRODUCTION

The concept of species-site associations is rooted in the ecological principle that plants are adapted to certain combinations of biotic and abiotic factors that enable them to grow and reproduce in some local environments but not in others. While the principle is generally accepted, identifying Longleaf pine (*Pinus palustris* Mill.) sites is not as straightforward as a casual student of plant ecology might assume. In the virgin forest, longleaf existed in pure stands or in association with other species under a wide variety of environmental conditions (Wahlenberg 1946). In managed ecosystems, however, longleaf has often failed to perform as well as other southern pines, even on sites where it once existed in pure stands (Mann 1969). At best, foresters' past attempts to manage the species have produced erratic results. As a consequence, the area of longleaf pine type (Eyre 1980) in the South has declined from some 30 to 60 million acres in colonial times (Wahlenberg 1946) to less than 4 million acres today.[1/]

Eugene Shoulders is principal silviculturist, Southern Forest Experiment Station, USDA Forest Service, Pineville, LA 71360.

1/ Estimate in a longleaf pine technology transfer plan based on forest survey data from USDA FS Southern and Southeastern Forest Experiment Stations.

The disappearance of longleaf pine from much of the area and many of the sites that it once occupied caused me to take an indirect approach in this paper to identifying longleaf pine sites. First, the ecological niche that longleaf pine once occupied is described. Survival and growth of longleaf pine are then compared with those of other southern pines on a variety of sites. Finally, the site conditions are described under which longleaf pine should perform as well as, or better than, other southern pines, if the knowledge gained through research on its cultural requirements for success (Farrar and White 198.3, Kais et al. 1981, Marx and Hatchell 1986, Schmidtling 1987, Shoulders 1963) were faithfully applied.

ECOLOGICAL CHARACTERISTICS OF LONGLEAF PINE SITES

The natural range of longleaf pine extends from southeastern Virginia to east Texas in a belt approximately 150 miles wide adjacent to the coasts of the Atlantic Ocean and the Gulf of Mexico (fig. 1). It dips as far south as central Florida and widens northward into west central Georgia and east central Alabama. It occupies portions of three physiographic provinces: the Southern Coastal Plain, the Piedmont, and the Appalachian foothills.

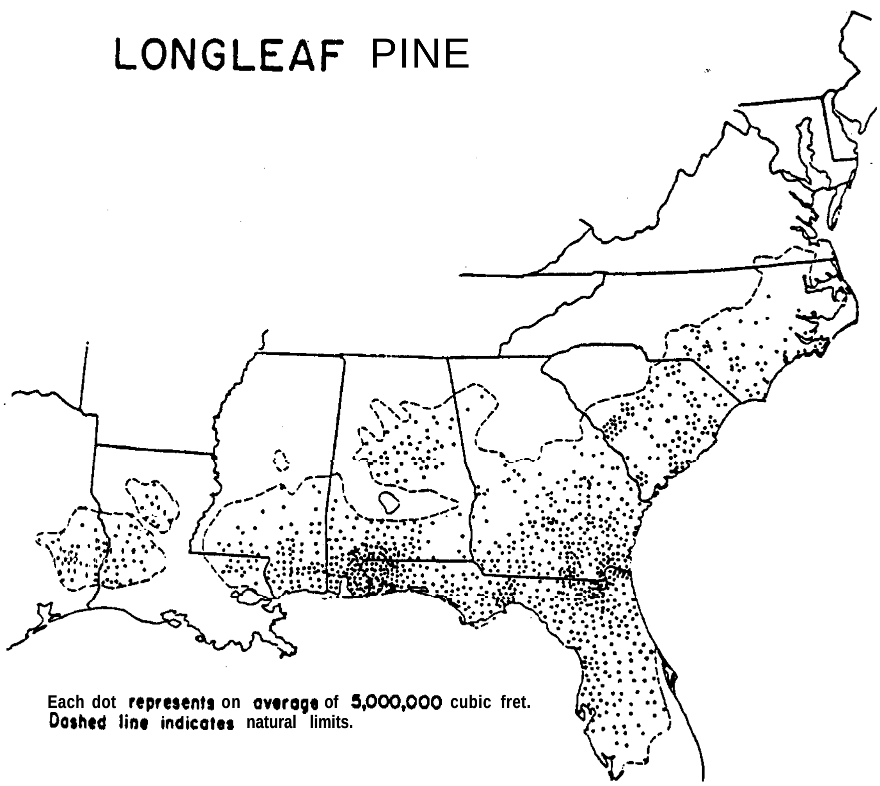

Figure 1.--The range and volume of longleaf pine (from Sternitzke and Nelson 1970).

Mean annual temperatures vary from 63 to 73°F, while minimum and maximum average temperatures range from -10 to 108°F (Wahlenberg 1946). The frost-free period averages about 200 days in the northern part of the range and 300 days in the southern part (Fowells 1965).

Mean annual rainfall varies within the region from about 45 to 65 inches. Moreover, there are variations in seasonal distribution of rainfall, with spring and summer droughts being more common in the western than in the eastern portion of the range (USDA Forest Service 1969).

Longleaf pine's reputation of being a species of drier and better drained sandy upland sites belies its edaphic plasticity. The species tolerates a wide variety of soil conditions (Wahlenberg 1946) and is less sensitive than other major southern pines to variations in soil fertility. Moreover, in addition to being the characteristic type of better drained and drier soils within its range, longleaf pine originally occupied extensive areas of poorly and imperfectly drained flatwood soils in Texas, Louisiana, and the southeast. Longleaf was rarely found on flood-prone sites, because longleaf seedlings do not survive prolonged submergence during their grass stage.

Longleaf pine is neither a climatic nor an edaphic climax type on the sites it occupies; it is a successional stage in the ecological progression toward a mixed hardwood climax forest. It owed its existence in pure stands in the primeval forest to frequent occurrence of fires, which created a favorable environment for the establishment of longleaf seedlings, reduced exposure of grass-stage seedlings to the brown-spot needle blight fungus (<u>Scirrhia acicola</u> [Dearn.] Siggers), and discouraged development of hardwoods and other pines. Freedom from excessive competition during its grass stage was, and continues to be, critical to successful regeneration of longleaf pine.

In its natural environment, then, longleaf pine is a pioneering species, inexacting in its soil requirements but intolerant of competition and flooding, especially during its grass stage. Longleaf became established and has persisted on sites where frequent fires held back the competing vegetation and where flooding was infrequent and/or of short duration.

PERFORMANCE OF LONGLEAF PINE IN SPECIES COMPARISONS

<u>An In-depth Study</u>

<u>Methods</u>.--Experimental plantings in which the species of interest are established on uniform sites provide the most reliable information on the relative adaptability of individual species to particular site conditions. Such an experiment was established in Louisiana and southern Mississippi in the 1950's to compare performance of the major southern pines over a wide array of site conditions. Three plots each of loblolly (p. <u>taeda</u> L.), longleaf, and slash pine (<u>P. elliottii</u> Engelm. var. <u>elliottii</u>) were planted in a randomized block design at 113 locations (Shoulders and Walker 1979). Three plots of shortleaf pine (<u>P. echinata</u> Mill.) were included in installations at about

half of the locations. Extraneous factors, unrelated to species performance, reduced the number of installations that existed at 10 years from 113 to 106. By age 20, species failures and further extraneous losses reduced the number of installations containing 2 or 3 plots each of longleaf pine and 1 or more of the other species to 35 (Shoulders 1985).

The site at each location was classified as wet, intermediate in moisture characteristics, or dry, based on soil properties. Wet site soils lacked abrupt changes in either color or texture within the first 3 to 4 feet of the soil profile. These soils remain submerged or saturated with water during wet periods, especially in winter. They range in internal drainage from very poor to moderately good. The main distinguishing characteristic of intermediate sites was that the soils had well-defined horizons that differed from each other in both texture and color. These soils are moderately well to well drained. The dry sites had a surface layer, at least 3 feet thick, of.coarse sand to sandy loam soil, with good to excessive internal drainage and a very limited capacity for storing readily available moisture.

Additional details on establishment and conduct of the study are given in Shoulders and Walker (1979) and Shoulders (1983, 1985). Only the performance of longleaf pine relative to the performance of the other three species is considered in this paper. Four parameters are discussed: (1) first-year survival, (2) stocking at 10 years, (3) average height of dominant and codominant trees at 20 years, and (4) average total yields in cubic feet (o.b.) at 20 years.

First-year survival.--One year after planting, longleaf pine survival averaged 21 to 26 percentage points lower than survival of loblolly pine, 13 to 17 percentage points lower than survival of slash pine, and 12 to 41 percentage points lower than survival of shortleaf pine (table 1). These differences were largely independent of site, as longleaf survival was significantly less than survival of one or more of the other species in 63 percent of wet site installations, 82 percent of intermediate site installatins, and 70 percent of dry site installations (table 2).

Table 1.--First-year survival of major southern pine species by site condition (adapted from Shoulders and Walker 1976).

Site condition	Longleaf pine	Loblolly pine	Slash pine	Shortleaf pine
	Percent			
Wet	63	84	76	75
Intermediate	52	77	68	80
Dry	32	58	49	73
All	54	77	69	78

Table 2.--Difference between longleaf and other southern pines in first-year survival by site condition.

Comparison	Site condition		
	Wet	Intermediate	Dry
	--Number (percent) of installations--		
Longleaf vs. loblolly			
Longleaf sig. greater	0 (0)	0 (0)	0 (0)
No sig. difference	14 (37)	16 (26)	3 (30)
Loblolly sig. greater	24 (63)	45 (74)	7 (70)
Longleaf vs. slash			
Longleaf sig. greater	4 (11)	3 (5)	1 (10)
No. sig. difference	19 (50)	22 (36)	5 (50)
Slash sig. greater	15 (39)	36 (59)	4 (40)
Longleaf vs. shortleaf			
Longleaf sig. greater	0 (0)	0 (0)	0 (0)
No. sig. difference	5 (62)	5 (18)	2 (33)
Shortleaf sig. greater	3 (38)	23 (82)	4 (67)

__Stocking at 10 years.__--Part of, but not all, the differences between species in first-year survival were eliminated by replanting entire plots or individual failed positions within plots after the first-growing season. Moreover, an attempt was made to minimize the effects of brown-spot needle blight on longleaf survival by spraying seedlings twice annually (spring and fall) for 5 years with Bordeaux mixture--a fungicide recommended for control of brown-spot infections in plantations (Wakeley 1954).

Despite these efforts to obtain well-stocked stands of all species, two-thirds of the installations contained fewer than 250 longleaf seedlings/acre that had emerged from the grass stage by age 10 (table 3). Only 3 installations were stocked with fewer than 250 loblolly or slash pine trees/acre. Shortleaf stocking exceeded 500 trees/acre in all installations where it was included. Individual plots containing fewer than 250 surviving trees/acre at 10 years were considered failures and were dropped from the study.

On wet sites where longleaf succeeded, stocking at 10 years averaged 809 trees/acre, as against 1,010 to 1,123 trees/acre for the other species in the same installations (table 4). Longleaf stocking on successful intermediate site plots averaged 104 to 302 fewer trees/acre than the other species. Successful dry site installations averaged about one-third fewer longleaf trees/acre than other species. In general, the proportion of installations where longleaf was at least marginally successful increased with decreasing wetness of the site. In the installations where longleaf succeeded, however, average stocking of trees in active height growth declined as sites became drier.

Table 3.--Summary of stocking at 10 years by species and site condition.

Species	Stocking at 10 years	Site condition: Wet	Intermediate	Dry
	Trees/acre	Number (percent) of installations		
Longleaf pine (all trees)	<250	14 (44)	15 (23)	3 (30)
	250-500	5 (16)	8 (13)	2 (20)
	>500	13 (40)	41 (64)	5 (50)
Longleaf pine (trees ≥0.6 inch in dbh)	<250	25 (78)	41 (64)	5 (50)
	250-500	2 (6)	8 (13)	2 (20)
	>500	5 (16)	15 (23)	3 (30)
Loblolly pine	<250	1 (3)	1 (2)	0 (0)
	250-500	3 (9)	3 (4)	1 (10)
	>500	28 (88)	60 (94)	9 (90)
Slash pine	<250	0 (0)	1 (2)	0 (0)
	250-500	0 (0)	4 (6)	0 (0)
	>500	32 (100)	59 (92)	10(100)
Shortleaf pine	<250	0 (0)	0 (0)	0 (0)
	250-500	0 (0)	0 (0)	0 (0)
	>500	'5 (100)	30 (100)	6(100)

Table 4.--Average stocking at 10 years by site condition and species in installations having at least 250 longleaf, trees/acre ≥ 0.6 inch in dbh.

Species	Site condition: Wet	Intermediate	Dry
	Trees/acre		
Longleaf pine			
All trees	809	744	663
Trees ≥0.6 inch dbh	637	607	578
Loblolly pine	1123	932	925
Slash pine	1010	848	894
Shortleaf pine	1086	1046	1076

Height at 20 Years.--Average heights of dominant and codominant trees of each species at 20 years were: longleaf, 23 to 59 feet; loblolly, 11 to 71 feet; slash, 30 to 70 feet: and shortleaf, 27 to 57 feet. The shortest trees of all species were found on wet sites and the tallest trees on intermediate sites.

Scattergrams contrasting heights of dominant and codominant trees (fig. 2) show that longleaf was usually shorter than either loblolly or slash but was usually taller than shortleaf. Other impressions that one gets from the scattergrams are that there were several installations where differences between species were not great and that the proportion of installations where differences were small increased as sites became drier. These observations were borne out in statistical analyses of the data for individual installations (table 5).

Table 5.--Differences in average height of dominant and codominant longleaf and other southern pine trees at 20 years by site condition (adapted from Shoulders 1983).

Comparison	Site condition: Wet	Intermediate	Dry
	-Number (percent) of installations-		
Longleaf vs. loblolly			
Longleaf sig. taller	0 (0)	0 (0)	0 (0)
No sig. difference	6 (67)	15 (75)	4 (100)
Loblolly sig. taller	3 (33)	5 (25)	0 (0)
Longleaf vs. slash			
Longleaf sig. taller	0 (0)	0 (0)	0 (0)
No sig. difference	2 (22)	9 (45)	2 (40)
Slash sig. taller	7 (78)	11 (55)	3 (60)
Longleaf vs. shortleaf			
Longleaf sig. taller	1 (50)	3 (27)	0 (0)
No sig. difference	1 (50)	8 (73)	3 (100)
Shortleaf sig. taller	0 (0)	0 (0)	0 (0)

Actual yields at 20 years.--At 20 years, actual yields per acre in the 35 installations were: longleaf, 521 to 4,874 ft^3; loblolly, 654 to 5,644 ft^3; slash, 2,359 to 5,959 ft^3; and shortleaf, 1,065 to 5,313 ft^3. Yield data for individual installations are displayed in figure 3.

Overall, longleaf yields equaled (i.e., were not significantly different from) those of loblolly in 33 percent of the installations, slash in 26 percent of the installations, and shortleaf in 69 percent of the installations, where comparisons

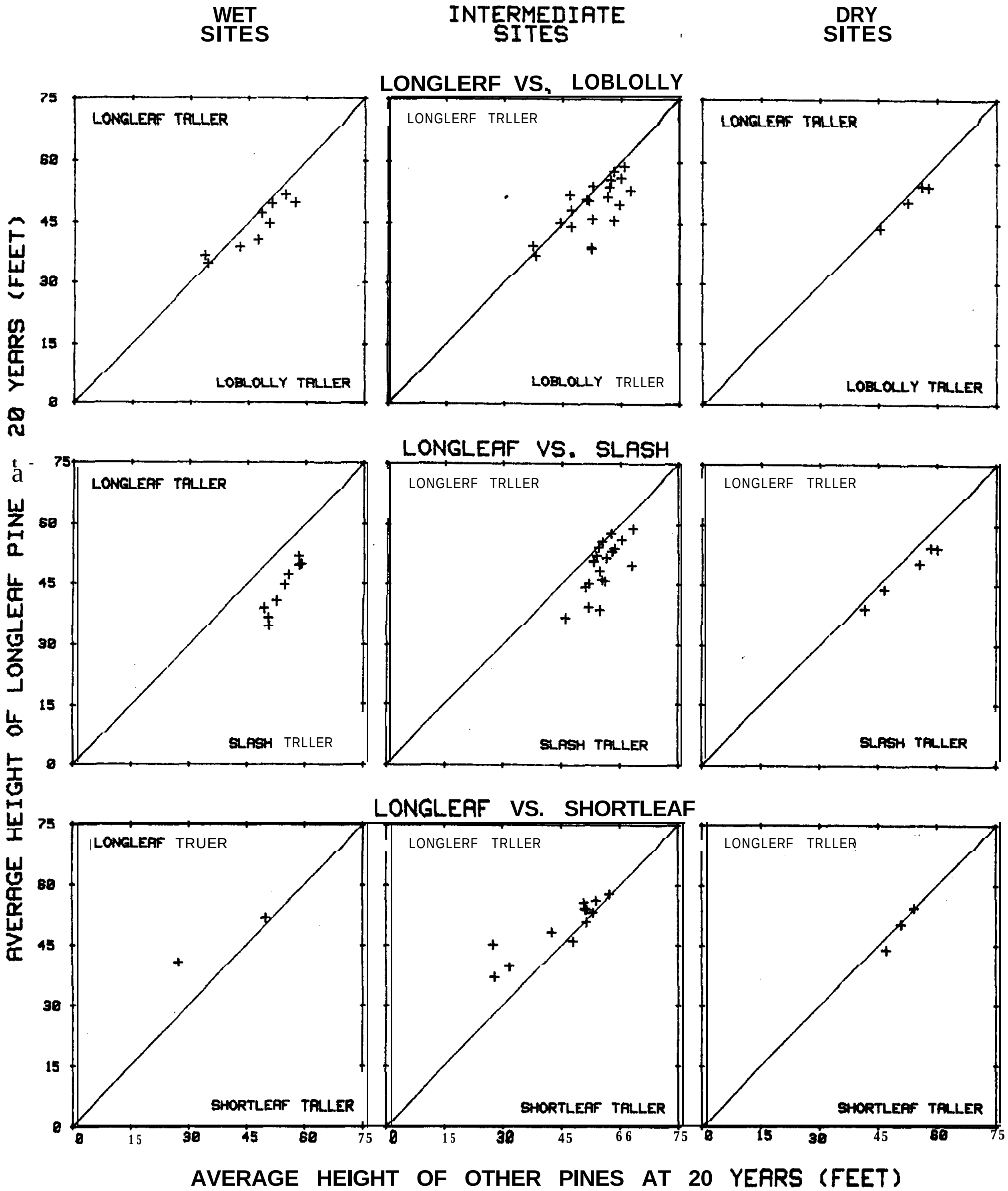

Figure 2. Comparisons of total heights of dominant and codominant longleaf and other southern pine trees at 20 years by site condition. Diagonal line represents equal performance of the two species in the comparison (redrawn from Shoulders 1983).

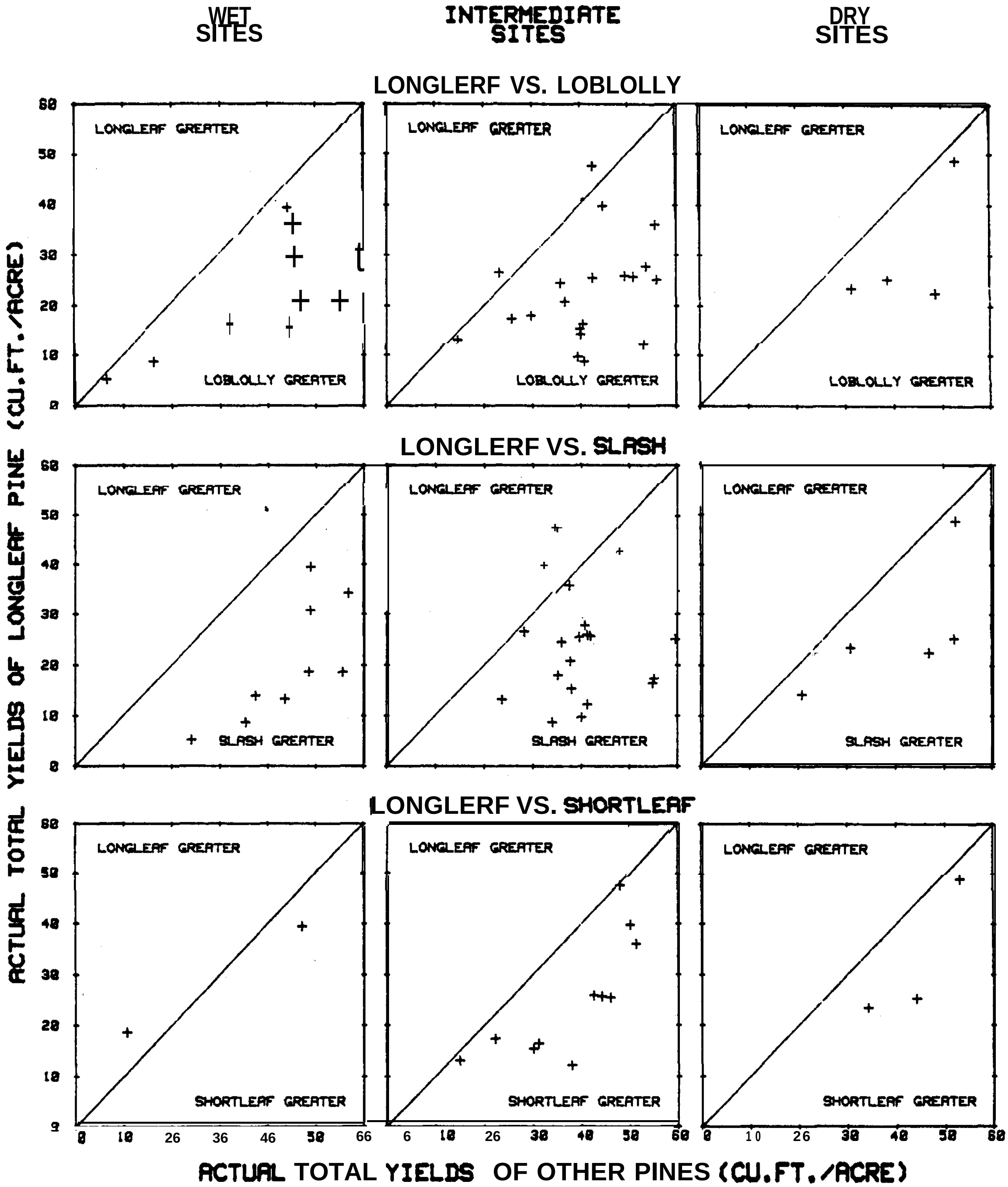

Figure 3. Comparisons of actual **longleaf and other** southern pine yields (o.b.) at 20 years by **site condition.** Diagonal line represents equal performance of the two species in the comparison (redrawn from Shoulders 1983).

between individual species were possible (table 6). The proportions of installations where actual longleaf yields equaled or exceeded those of loblolly and slash increased as sites became drier, whereas the proportions of installations where longleaf yields equaled or exceeded shortleaf yields decreased.

Table 6.--Difference in actual longleaf and other southern pine yields at 20 years by site condition (adapted from Shoulders 1985).

Comparison	Site condition		
	Wet	Intermediate'	Dry
	-Number (percent) of installations-		
Longleaf vs. loblolly			
Longleaf sig. greater	0 (0)	0 (0)	0 (0)
No sig. difference	3 (33)	5 (25)	3 (75)
Loblolly sig. greater	6 (67)	15 (75)	1 (25)
Longleaf vs. slash			
Longleaf sig. greater	0 (0)	1 (5)	0 (0)
No sig. difference	0 (0)	6 (30)	3 (60)
Slash sig. greater	9 (100)	13 (65)	2 (40)
Longleaf vs. shortleaf			
Longleaf sig. greater	1 (50)	0 (0)	0 (0)
No sig. difference	1 (50)	8 (73)	1 (33)
Shortleaf sig. greater	0 (0)	3 (27)	2 (67)

Studies in the Sandhills

Hebb (1982) and Brendemuehl (1981) reported 15- or 20-year results of four pine species trials on infertile, excessively drained sands in Florida, Georgia, and South Carolina. Longleaf pine, loblolly pine, slash pine, Ocala sand pine (*P. clausa* var. *clausa* [Chapm.] Vasey) and Choctawhatchee sand pine (*P. clausa* var. *immusinata* D. B. Ward) were planted at all locations. Virginia pine (*P. virginiana* Mill.) and shortleaf pine were also included in the Florida trials.

Data from Florida (fig. 4) are representative of the species' relative performance at all locations. Both Hebb (1982) and Brendemuehl (1981) recommended Choctawhatchee sand pine over the other pines for planting on infertile sandhill sites where the primary goal of management is maximum fiber production in short rotations. Poor survival and susceptibility to disease of Ocala sand pine caused both authors to consider it a poor choice for sandhill reforestation.

Longleaf pine was the only other option for pine management on typical sandhill sites. Brendemuehl wrote that, "Longleaf pine is suited to sandhill forest management programs which can accept long rotations (50 or more years) [and] comparatively low yields (SI 60 or less)..." No supporting data were given for this conclusion other than the observation that longleaf stands eventually attain merchantable size on sandhill sites and may appeal to landowners because of recreation, wildlife, and esthetic values.

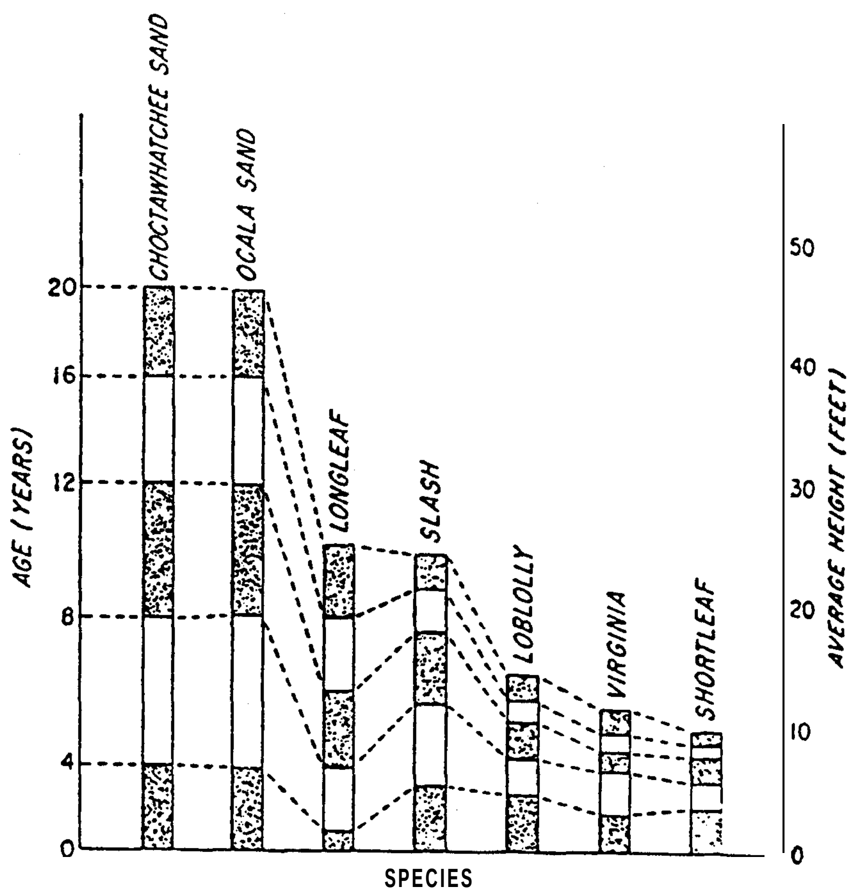

Figure 4. Average height of southern pines in species trials on Florida sandhills (from Brendemuelh 1981).

LONGLEAF'S POTENTIAL UNDER IDEAL CONDITIONS

Research since the 1950's has provided more reliable techniques for establishing and managing longleaf pine. It is now possible to obtain satisfactory survival of longleaf pine and to have the trees initiate rapid height growth in 3 or 4 years by planting vigorous seedlings on well-prepared sites (Mann 1969, Farrar and White 1983, Kais et al. 1981).

Prompted by these developments, Shoulders (1985) recomputed 20-year yields of 35 of the site-species trials in Louisiana and Mississippi, based on the assumptions that longleaf attained an average height of 4 feet by age 4 and that plots of all species supported stands of equal basal area stocking at 20 years. Procedures used to adjust yields are described in Shoulders (1985).

After adjustment for slow emergence of longleaf from the grass stage and for unequal density among species at 20 years, yields per acre ranged from 1,135 to 4,991 ft^3 for longleaf, 974 to 5,109 ft^3 for loblolly, 1,311 to 5,433 ft^3 for slash, and 1,542 to 5,167 ft^3 for shortleaf pine.

Scattergrams of adjusted values for individual installations showed remarkable agreement between longleaf yields and yields of other species at 20 years (fig. 5). Statistical analyses of these data indicated that potential yields of longleaf equaled or exceeded those of loblolly in 97 percent of the installations and of slash in 85 percent (table 7). Longleaf yields should have equaled or exceeded those of shortleaf on all sites where both species were planted and survived. Moreover, there were no large differences among wet, intermediate, and dry sites in the proportion of installations'where potential longleaf yields equaled or exceeded those of the other species.

Table 7.--Difference in potential longleaf and other southern pine yields at 20 years by site condition (adapted from Shoulders 1985).

Comparison	Site condition		
	Wet	Intermediate	Dry
	--Number (percent) of installations--		
Longleaf vs. loblolly			
Longleaf sig. greater	3 (33)	3 (15)	1 (33)
No sig. difference	6 (67)	16 (80)	3 (67)
Loblolly sig. greater	0 (0)	1 (5)	0 (0)
Longleaf vs. slash			
Longleaf sig. greater	0 (0)	0 (0)	0 (0)
No sig. difference	7 (78)	15 (75)	3 (60)
Slash sig. greater	2 (22)	5 (25)	2 (40)
Longleaf vs. shortleaf			
Longleaf sig. greater	1 (50)	3 (27)	0 (0)
No sig. difference	1 (50)	8 (73)	3(100)
Shortleaf sig. greater	0 (0)	0 (0)	0 (0)

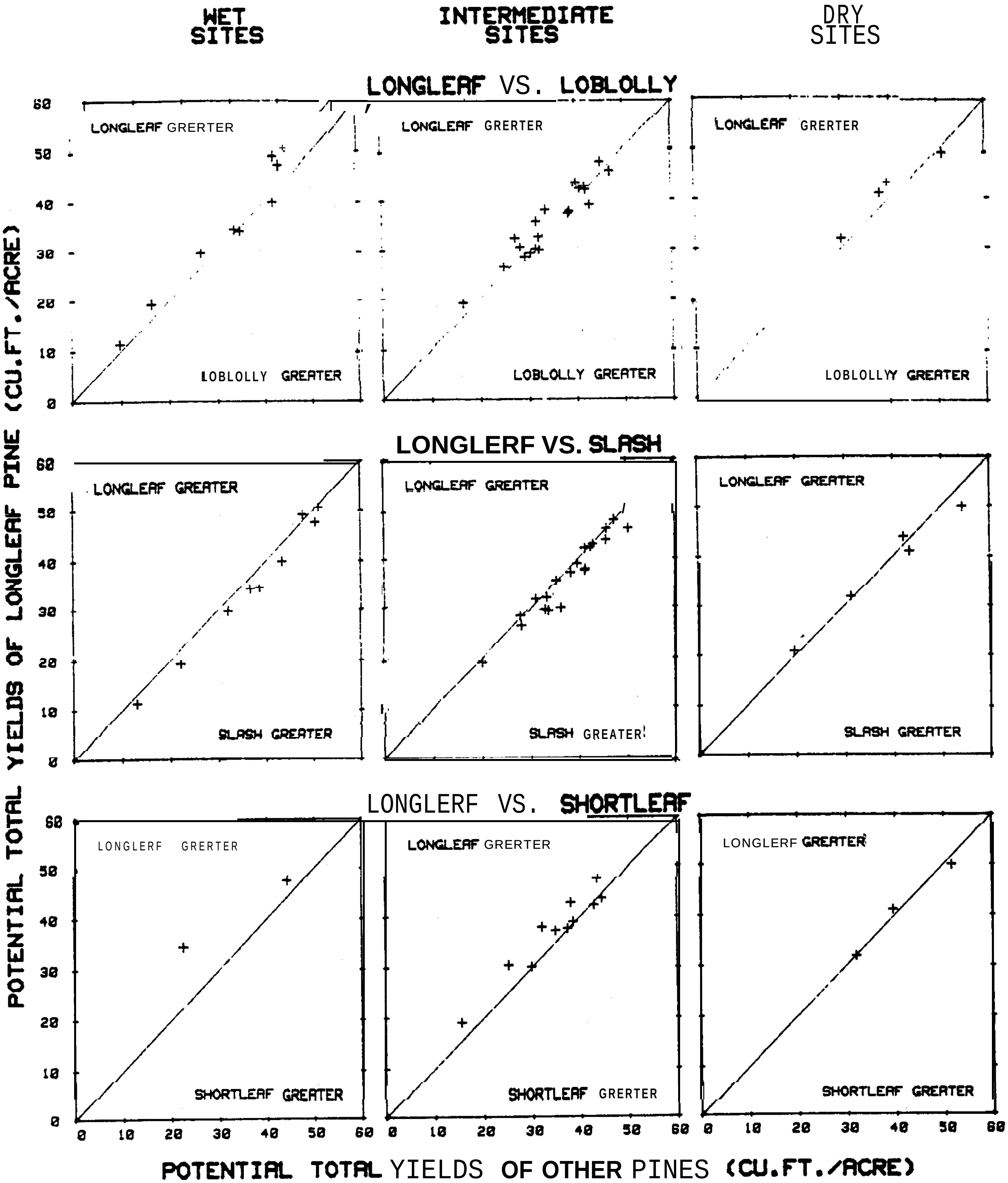

Figure 5. Comparisons of potential longleaf and other southern pine yields (o.b.) at 20 years by site condition. Diagonal line represents equal performance of the two species in the comparison (redrawn from Shoulders 1983).

It should be noted that these comparisons give no advantage to longleaf pine for its greater resistance to fusiform rust infection than loblolly and slash pine (Czabator 1971). Nor do they reflect the fact that longleaf has greater potential than other southern pines for being merchantable as high-quality poles and pilings (Anon. 1986). These attributes of longleaf pine make it an even stronger competitor for planting on a particular site than adjusted yield values indicate.

SUMMARY AND CONCLUSIONS

In the classical interpretation of ecological niche, there is no unique combination of climate and soil that assures perpetual dominance of longleaf pine over other species of trees on any site. Within its natural range, fire and moisture regime were the primary factors controlling the distribution of longleaf in the original forests of the South.

Historically, longleaf pine was the characteristic type of the better drained and drier sites within its natural range. It existed there in pure stands because the fortuitous occurrence of wildfires allowed it to compete successfully with other vegetation for dominance on these sites. It also grew in pure or mixed stands on extensive areas of poorly and imperfectly drained flatwood soils. But longleaf is neither a climatic nor an edaphic climax type on the sites it occupies and eventually is replaced by a mixed hardwood forest if fire is excluded.

Longleaf pine is inexacting in its soil requirements, but is intolorent of flooding and competition especially during its grass stage.

In a managed ecosystem within its natural range longleaf pine has the potential to compete favorably in yields with other major southern pines on a wide range of site conditions, and moisture regimes, if appropriate measures are taken to assure prompt emergence of well-stocked stands of longleaf pine from the grass stage.

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Nursery Culture of Bare-root Longleaf Pine Seedlings

Charles E. Cordell, Glyndon E. Hatchell, and Donald H. Marx

ABSTRACT. Recent studies have identified key components in an integrated system that increases field survival, disease protection, and growth of planted longleaf pines. Biological, chemical, and cultural practices in the nursery and the field are coordinated to increase seedling root development, ectomycorrhizae, and stem diameter: decrease nursery and field planting site pest problems; and maintain seedling quality beyond the nursery packing shed. Factors that must be controlled in nurseries include seed quality, soil and mulch fumigation, sowing dates, seedbed density, seedling root pruning, and seedling lifting, handling, and storage. Recent nursery developments are precision sowing of seedbeds, inoculations of seedbeds with the ectomycorrhizal fungus Pisolithus tinctorius (Pt), and treatment of roots with the systemic fungicide benomyl. Successful longleaf pine planting requires continuous application of all of the required practices in nurseries and in the field.

INTRODUCTION

Longleaf pine (Pinus palustris Mill.) was once the dominant tree species on 60 million acres of virgin forests of the Southern Coastal Plain and on the sandhills of the fall-line region of Georgia and North and South Carolina (Croker 1987). It is well adapted to these sites, is relatively resistant to fusiform rust, Cronartium quercuum f. sp. fusiforme (the most destructive disease of slash, P. elliottii, and loblolly, P. taeda, pines), and is a valuable timber species (Wahlenberg 1946). However, there are only about 5 million acres currently forested in longleaf pine, and the species accounts for only about 2.5 percent of annual southern pine seedling production. Longleaf plantings have usually failed because of combined problems of inferior seedling quality, protracted slow growth in the characteristic "grass stage," and the extreme susceptibility of seedlings to brown-spot foliage blight (caused by Scirrhia acicola) during the grass stage (Cordell et al. 1989). Seedlings are considerably less susceptible to the disease after they grow out of the grass stage. Initiation of height growth of longleaf pine seedlings apparently is correlated with stem diameter and seedling vigor (Wahlenberg 1946). Consequently, improving seedling quality in the nursery reduces both the duration of the grass stage and the effects of brown-spot foliage blight.

The following characteristics, which represent an expansion of Wakeley's (1954) seedling grades for this species, have been associated with high-quality longleaf pine bare-root nursery seedlings:

Charles E. Cordell is Nursery Pest Specialist, USDA Forest Service, Region 8, Forest Pest Management, Asheville, NC; Glyndon E. Hatchell is Research Forester, (Retired), USDA Forest Service, Institute for Mycorrhizal Research and Development, Southeastern Forest Experiment Station, Athens, GA; Donald H. Marx is Director and Principal Plant Pathologist, USDA Forest Service, Institute for Mycorrhizal Research and Development, Southeastern Forest Experiment Station, Athens, GA.

1. Root collar diameter of at least 10 mm or 0.4 in.

2. At least six primary lateral roots 2 mm or more in diameter.

3. A highly fibrous root system .

4. A minimum of 25 percent total feeder root ectomycorrhizae.

5. A well developed, stout taproot at least 15 cm or 6 in. long. If the taproot has been severed by root pruning, the severed end should be callused over.

6. A well-developed winter bud with scales.

7. Normal amount, length, and green color of foliage.

8. No evidence of pest problems, such as brown-spot disease or rhizoctonia blight on foliage, fusiform rust swellings at root collar, or root rot.

Recently, longleaf pine reforestation has received considerable attention, particularly since many plantings of slash and loblolly pines on deep sands have stagnated or succumbed to fusiform rust. Recent extensive nursery and field studies have identified key components of longleaf seedling quality and developed an integrated nursery management approach to produce higher quality. seedlings for increased field survival, disease protection, and growth (Mann 1969; White 1981; Hatchell 1985a; Kais et al. 1986; Lauer 1987). Nursery and field forestation practices are coordinated to: (1) increase seedling root development, ectomycorrhizae, and stem diameter: (2) decrease nursery and field planting pest problems; and (3) maintain seedling quality beyond the nursery packing shed. Seed quality, soil and mulch fumigation, sowing date, seedbed density, seedling root pruning, and seedling lifting, handling, and processing can affect longleaf pine seedling vigor significantly. Maximum potential increases in seedling quality are obtained by inoculation of prefumigated seed-beds with the ectomycorrhizal fungus Pisolithus tinctorius (Pt) (Kais et al. 1981), precision sowing of longleaf seeds for optimum seedling spacing and density, and lateral and horizontal pruning of roots for increased feeder root and ectomycorrhizae development (Hatchell 1985b). Root treatment of longleaf pine seedlings, either at the nursery or planting site, with the fungicide benomyl has controlled brown-spot disease (Kais et al. 1986) and increased tree survival and growth in field plantings (Barnett et al. 1988). Failure to properly use and coordinate these management practices can have significant negative effects on seedling quality and field performance.

SEED SOURCE AND QUALITY

Longleaf pine seeds should be obtained from the appropriate geographic source (Lantz and Kraus 1987). Whenever available, the most recently collected seeds from the local source should be utilized. Seed purity and germination should be as high as possible. For effective and efficient precision sowing, the seeds should have 95 percent or greater purity and a minimum of 75 percent germination. Wings should be removed with a dry dewinger, using special effort and precaution to remove as much as possible of the wings without damaging the seed. As with other southern pines, longleaf seeds should be stored at low seed moisture levels (5 to 10 percent) and low temperature (25 to 37 °F).

Seed stratification may increase the amount and rate of longleaf pine seed germination. However, the effects of stratification vary with different seedlots, and the seeds should never be stratified for more than 15 days.

NURSERY BED LOCATION

The selection of a nursery seedbed is one of the most significant factors affecting quality longleaf pine seedling production. Soil factors such as texture, drainage, fertility, and pH are important. The majority of the pine nurseries in the Southern United States have been established on sandy or loamy sand soils with a maximum of about 15 percent clay and/or silt (May 1984a). Fine-textured soils with higher amounts of clay and silt are not suitable for longleaf pine seedlings. The coarse-textured soils are characteristically well-drained, but also have relatively low moisture and nutrient retention capabilities. A higher incidence and damage by Rhizoctonia foliage blight disease has also been observed on the coarse-textured sandy soils (Gilly et al. 1985).

Perhaps the most significant soil factor affecting seedling quality is pH, which reflects the relative soil acidity or alkalinity. Soil pH affects nutrient availability and ectomycorrhizal development, along with seedling growth and quality. Soil pH values between 5.0 and 6.0 should be maintained for the sustained production of quality longleaf pine seedlings. pH levels above 6.0 may increase the hazard of damping-off diseases and decrease ectomycorrhizae development. A soil pH of 6.5 or above can have severe negative effects on the development of Pt ectomycorrhizae on longleaf pine seedlings following artificial nursery seedbed inoculations.

INTEGRATED PEST MANAGEMENT

An integrated nursery pest management (INPM) program is recommended as the most effective and efficient means of maintaining pest problems at tolerable levels in longleaf pine nurseries. This approach involves a combination of cultural, biological, and chemical nursery pest management practices (Cordell and Filer 1984). Cultural and biological pest management practices should be emphasized whenever possible. Chemical treatments should be primarily aimed at the more hazardous pests and where the cultural and biological treatments either have failed or are not feasible. The selection of the most effective, practical, and environmentally safe combination of INPM practices for the target pest problems is the key to successful pest management in longleaf pine nurseries. This subject is presented in a separate pest management section at this symposium.

SOIL AND MULCH FUMIGATION

Practically all southern nurseries fumigate seedbeds to control certain weeds, soil-borne insects, nematodes, and soil-borne diseases, such as Cylindrocladium root rot (caused by Cylindrocladium sp.) or charcoal root rot (caused by Macrophomina phaseolina [Tassi] Goid., Tassi, [Maubl.] Ashby) (Seymour and Cordell 1979). Soil fumigation is also effective for the control of soil-borne diseases, such as Rhizoctonia blight (caused by Rhizoctonia spp.), a very serious disease on 1-0 longleaf pine seedlings in southern bare-root nurseries. Gilly et al. (1985) describe an integrated pest management approach for controlling Rhizoctonia blight in longleaf bare-root nurseries. Both Rhizoctonia blight and brown spot can also be introduced into nurseries through unfumigated mulch, particularly longleaf pine straw. To control these and other potential nursery pest problems, both soil and mulch should be fumigated (Seymour and Cordell 1979).

Soil should be fumigated shortly before it is inoculated with Pt (Cordell et al. 1987). To maximize the benefit of artificial Pt inoculation, all soil organisms, including naturally occurring ectomycorrhizal fungi, must be eliminated, at least temporarily. Spring fumigation of soil and mulch material followed as soon as possible by Pt inoculation and seed sowing have provided the most consistent and effective artificial Pt inoculation results. Recent results obtained from studies at Taylor State Nursery, S.C., and International Paper Company Nursery, Selma, Ala., indicate that fall-fumigated nursery seedbeds and fall-sown longleaf pine seedlings can be successfully inoculated with Pt the following spring (Marx and Cordell 1989b). A prototype machine designed to apply Pt vegetative inoculum between established nursery seedling rows has performed well at an International Paper Company nursery.

ECTOMYCORRHIZAL FUNGUS MANAGEMENT

Numerous studies have shown that effective Pt ectomycorrhizal inoculation improves longleaf pine seedling quality by increasing the amount of fibrous feeder roots and ectomycorrhizae (Hatchell 1985a, Hatchell 1985b). Standard bare-root longleaf seedlings often have relatively few ectomycorrhizae and very few fine feeder roots and secondary lateral roots when harvested (Kais et al. 1981). Artificial inoculation with Pt improves development of root systems and ectomycorrhizae, increasing stem diameters and improving field performance (Table 1). Longleaf pine field survival and early height growth (emergence from grass stage) have been increased significantly in over 10 comparative Pt inoculations in field plantings in 7 Southern States (Hatchell 1985, Hatchell and Marx 1986, Kais et al. 1981, Cordell et al. 1989). Increases in tree survival, early height growth, and plot volume of Pt-inoculated longleaf seedlings after 3 years in the field in 4 Southern States averaged 17, 13.7, and 177 percent, respectively (Figures 1, 2, and 3).

Table 1. Effects of selected nursery cultural practices on longleaf pine seedling survival and growth after 4 years in the field

		Survival (%)	X Height (ft)	Relative Plot Volume
No lateral root pruning No Pt ectomycorrhizae	12 seedlings/ft^2	53	2.4	1.3
	15 seedlings/ft^2	40	2.4	1.0
Lateral root pruning Pt ectomycorrhizae	12 seedlings/ft^2	83	2.8	2.5
	15 seedlings/ft^2	81	2.5	2.3

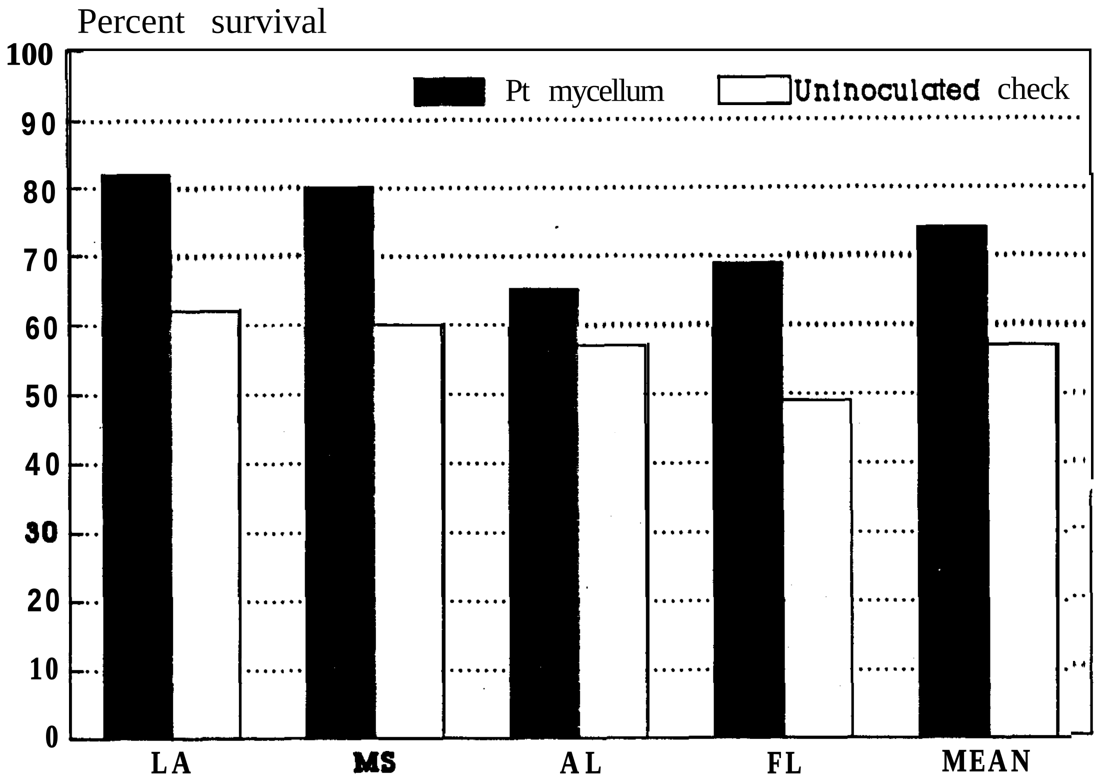
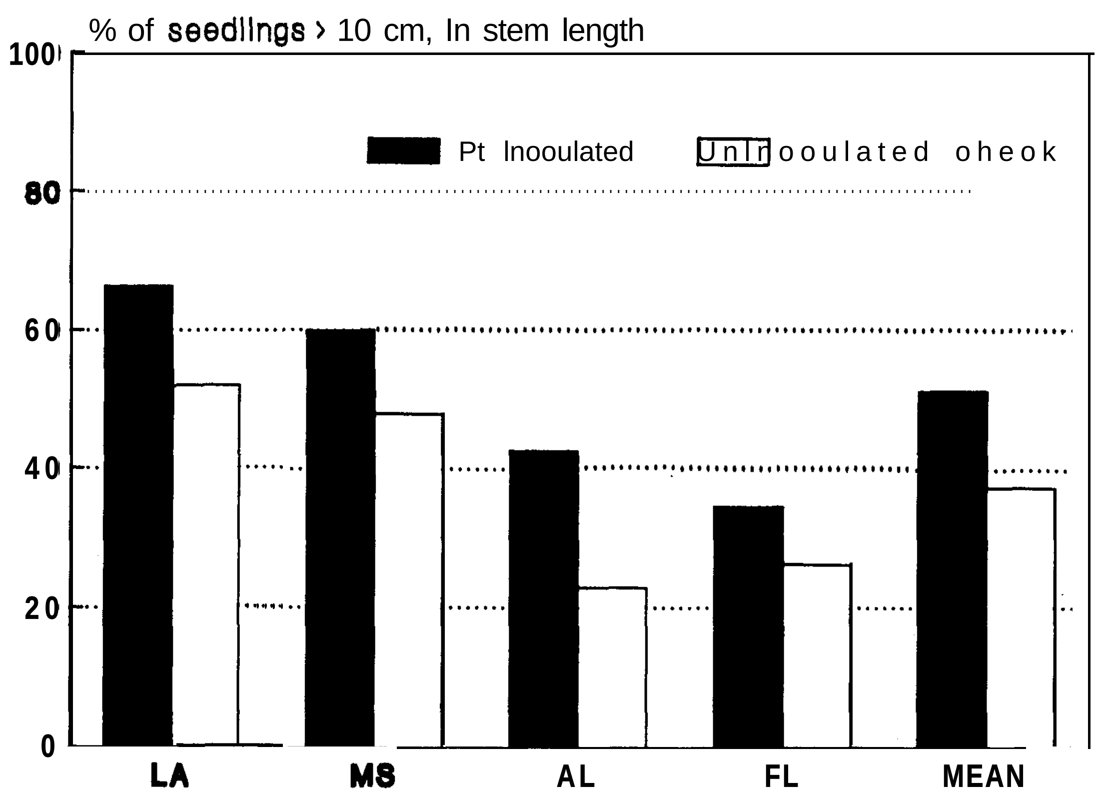


Figure 1. Effect of Pisolithus tinctorius (Pt) nursery seedbed inoculations on survival of longleaf pine after 3 years in the fleld.



Flgure 2. Effeot of Plsollthus tlnctorlus (Pt) eotomyoorrhlzae on Initial height growth of longleaf pines after 3 years In the fleld.

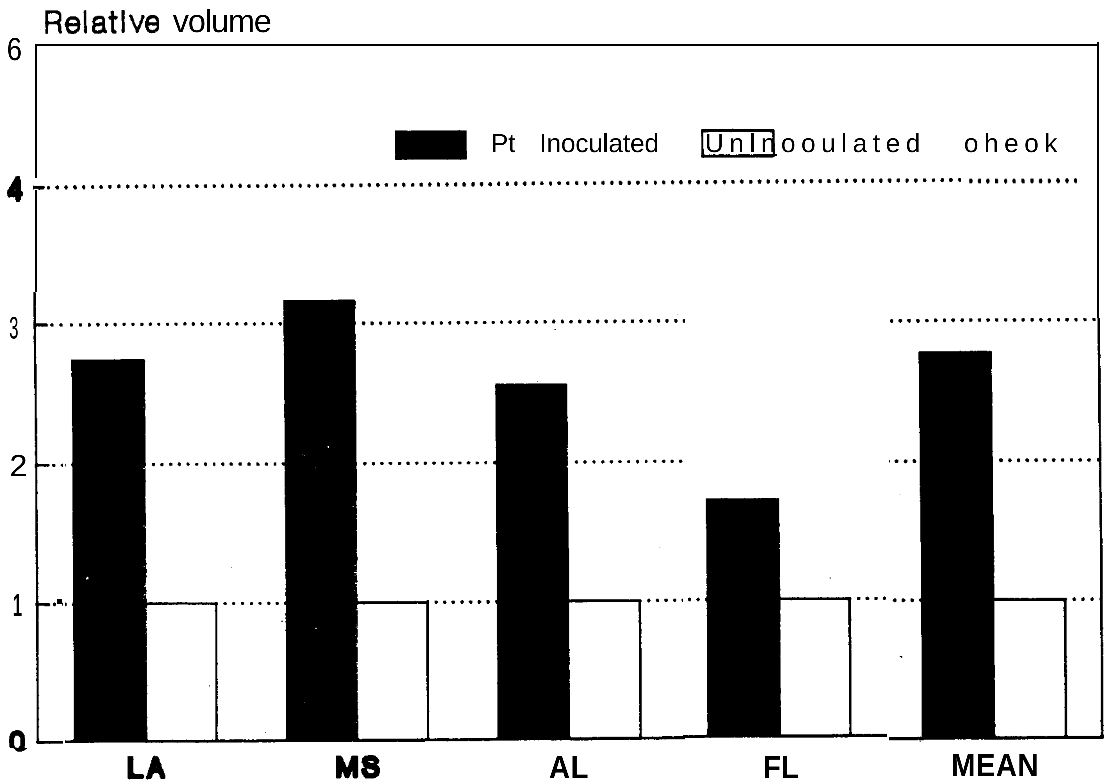


Figure 3. Effect of *Pisolithus tinctorius* (Pt) mycorrhizae on the volume of longleaf pines after 3 years in the field.

Bare-root nursery seedbeds can be inoculated by several different techniques using various types of commercial Pt inoculum. The most effective and consistent results are achieved when the inoculation dates are correlated with the soil and mulch fumigation dates. The types of commercial Pt inoculum that are currently available are vegetative inoculum from Mycorr Tech, Inc., Worthington, Pa.; and spore pellets, spore-encapsulated seeds, and bulk spores from either Mycorr Tech, International Tree Seed Co., Odenville, Ala., or South Pine, Inc., Birmingham, Ala. (Marx et al. 1989a, Marx et al. 1989b). A bare-root nursery seedbed applicator has been developed to apply Pt vegetative inoculum prior to sowing. It is commercially available from Whitfield Forestry Equipment Company, Mableton (Atlanta), Ga. This machine applies the inoculum in bands beneath seedling rows at desired depths for maximum inoculum effectiveness and efficiency (Cordell et al. 1989) (Figure 4).

Bulk spores can be sprayed, drenched, or dusted onto seedlings in bare-root nurseries. Spore pellets can either be incorporated into seedbed soil, or they can be broadcast on the soil surface or container medium and lightly covered. Spore pellets have been operationally applied at several bare-root nurseries. Spore-encapsulated seeds are sown by conventional methods. A major disadvantage of the Pt spore inoculum is the absence of a means of either determining or controlling spore viability. Consequently, Pt ectomycorrhizal development has generally been less consistent and effective with spore inoculum than with vegetative inoculum (Marx et al. 1989b). In 1988, 0.75 million longleaf pine seedlings were operationally inoculated with Pt vegetative inoculum at the Taylor State Nursery, S.C., for field forestation at the Savannah River Plant, Aiken, S.C. Evaluations made on Pt-inoculated 1-0 longleaf pine seedlings at this nursery in 1987 and 1988 revealed Pt indexes of 60+. Survival of these custom-grown seedlings exceeded 90 percent after 1 year in the field (unpublished data).

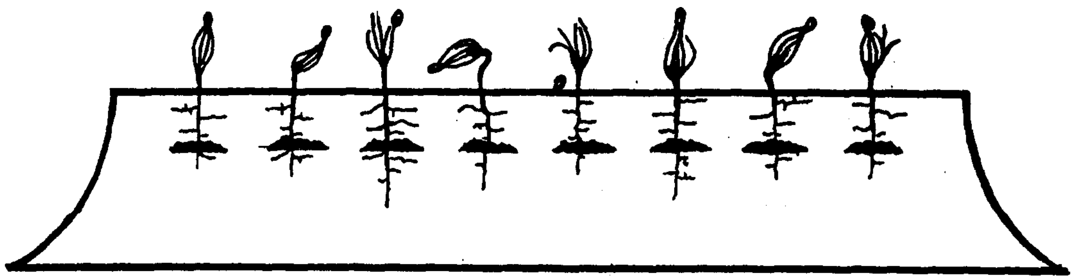


Figure 4. Dlagram of a bare-root nursery seedbed showing placement of the Pisolithus tinctorius (Pt) vegetative mycelium inoculum in 8 seed drill rows.

SOWING DATES

Generally, longleaf pine seedlings planted in the fall are larger by lifting date than are similarly treated spring sown seedlings (Hatchell and Marx 1986). Spring sown seedlings lose 2 to 4 weeks of optimum growing conditions during germination and may be subjected to high temperatures before becoming well established. Fall-sown seeds germinate in the fall, initiate rapid growth in early spring, and are large enough by late spring to withstand heat. The extended growing regime, in combination with other practices, provides additional time for growth of the root collar and roots. Custom longleaf pine seedling production during the past 2 years at a South Carolina state nursery (Marx and Cordell 1987) demonstrates that quality seedling production can be operationally obtained following spring fumigation, inoculation, and sowing dates. Spring seeding in late March resulted in the production of 90+ percent longleaf pine seedlings with root collar diameters of 10 mm (.4 in,) or larger (unpublished data). Also, as previously indicated, more recent results suggest the feasibility of inoculating fall-sown seedlings during the following spring. An advantage of this practice is that soil conditions during the fall are usually better for effective fumigation. A major disadvantage is that an abnormally cold winter can cause significant damage to fall plantings through frost heaving, winter "burn," and freezing,

SEEDBED DENSITY

Research studies have repeatedly shown that seedbed density affects diameter growth of longleaf pine seedlings in bare-root nurseries and subsequent survival and growth in field plantings (Table 1) (Derr 1955, Scarbrough and Allen 1954). Seedbed densities exceeding 160 seedlings/m^2 (15 seedlings/ft^2) reduce root-collar diameters and feeder root and ectomycorrhizae development, and increase shoot:root ratios. Field survival and growth of such seedlings are poor. Seedbed densities of 108 to 160 seedlings/m^2 (10 to 15 seedlings/ft^2), are considered best for longleaf pine seedling production in southern bare-root nurseries. Seedbed densities less than 108 seedlings/m^2 (10 seedlings/ft^2) do not efficiently utilize the seedbed and, consequently, are not cost effective. The demonstrated effect that density has upon longleaf pine seedlings is a result of plant competition for nutrients, water, air, and light, and obviously has a direct effect on seedling quality. Low seedbed densities (108 to 160 seedlings/m^2) coordinated with additional nursery cultural practices, such as row seeding, precision sowing, and lateral and horizontal root pruning, significantly improve longleaf pine seedling quality (Hatchell 1985b).

PRECISION SEED SOWING

Only recently have precision sowers become available to nursery managers in the United States. These machines operate by pulling a partial vacuum through specifically sized and spaced holes on a rotating drum or disk, which picks up, then drops individual seeds. Adjustments to tractor speed, drum or disk rotation speed, and vacuum pressure can provide a wide range of highly precise sowing rates. Very precise spacing is possible for small to medium seeds with high purity and germination (Lafleur 1986). Until 1988, longleaf pine seeds had never been sown with a precision sower. Characteristic low seed purity and germination capacity of most longleaf pine seedlots are major disadvantages in control of both density and spacing. However, with good quality seeds (greater than 95 percent purity and 70 percent germination), sowing rates can be adjusted to maintain desired density and fairly precise spacing. Maintaining sufficient spacing between individual seedlings in bare-root nurseries significantly affects seedling size and quality.

In addition to low purity and poor germination, the large irregular shape of the longleaf pine seed and its rigidly attached wing are primary limiting factors affecting precision sowing. The partially de-winged seeds bridge across each other in the seed hopper, and without some means of breaking this bridge, they do not maintain sufficient contact with the drum to be picked up by the vacuum holes. Skips in the seed spacing within rows result. Conversely, it is possible for more than one seed to be picked up by each vacuum hole when several bridged seeds are contacted. Recently, however, techniques have been developed for agitating seeds in the hoppers and "singulating" seeds on the vacuum holes (Cordell et al. 1989a). Potential benefits to longleaf pine nursery seedling management derived from improved control of seedbed density and spacing merit additional work to further improve the machine for the operational precision seed sowing of longleaf pine. A major disadvantage of all vacuum precision seed sowers is the slow rate of operation, as compared with other types of seed sowers. This negative factor merits additional effort to facilitate the large scale application of precision seed sowers in large Southern U.S. nurseries.

FERTILIZATION AND IRRIGATION

Nursery seedbed fertilization should be adequate and properly timed, but not excessive, for the production of quality longleaf pine seedlings. Fertilization rates and timing should be based on soil analyses. Inorganic fertilizers can be successfully applied as dry applications or through existing irrigation systems. Adjustment of soil fertility to an optimum level in southern pine nurseries depends basically on two factors: 1) system of seedling rotation and 2) soil type (May 1984b). Modifications in fertilizer amendments have been made to promote the growth, ectomycorrhizal development, and quality of custom-grown longleaf pine seedlings in a South Carolina nursery (Marx and Cordell 1987).

As with fertilization, irrigation should be adequate and properly timed, but not excessive, for longleaf pine seedling production (May 1984c). Excessive and/or improperly timed irrigation can increase the hazard of foliage and root diseases, and decrease ectomycorrhizae development (Cordell and Filer 1984). Conversely, inadequate irrigation can cause longleaf seedling stunting, yellowing, and overall poor quality. Proper irrigation is most critical during the seed germination period. Factors associated with the irrigation water quality are pH and the occurrence of toxic chemicals, fungus spores, and weed seeds. Irrigation water should have a pH between 5.0 and 6.0 to promote maximum soil nutrient availability, seedling growth and quality, and ectomycorrhizae development.

ROOT PRUNING

Lateral and horizontal (undercutting) root pruning significantly increases longleaf pine seedling quality (Shoulders 1965, Venator 1983) and subsequent field survival and early growth when properly applied. Recent studies (Table 1) clearly demonstrate the benefits of nursery root prunings to longleaf pine seedling quality, field survival, and growth at the Savannah River Forest Station, Aiken, S.C. (Hatchell 1985a, Hatchell 1985b). At the proper depth and distance from seedlings, root pruning stimulates formation of a compact lateral root system and increased ectomycorrhizal development. Injury of the root tips initiates greater carbon allocation to the root system, resulting in increased lateral root growth. Pruning increases the amount of feeder roots near the seedling taproot, effectively increasing the amount of ectomycorrhizae, feeder roots, and lateral roots that will be retained with the seedling during lifting and handling. With longleaf pine seedlings, it is particularly important to develop a compact root system with adequate lateral roots, feeder roots, and ectomycorrhizae. Recent guidelines for growing 1-0 longleaf seedlings in bare-root nurseries include two root pruning treatments (August and October) during the growing season (Marx and Cordell 1987, unpublished). After root pruning, seedlings should be sprayed with benomyl at 2.25 kg a.i./ha (2 lbs. a.i./acre) to reduce the root disease hazard. The fungicide treatment should be followed by irrigation to resettle the seedbed surface and avoid desiccation of the roots. Root-pruned seedlings have short lateral and taproots, and more compact root systems. They therefore are convenient to lift and pack in the nursery, ship to the field, and plant by machine (preferred) or by hand.

BENOMYL ROOT TREATMENT

Seedling root treatment with the systemic fungicide benomyl is recommended prior to packing at the nursery or planting at the forestation site for the control of brown-spot needle blight (Kais et al. 1986). A single fungicide root treatment has provided effective brown-spot disease control in longleaf pine plantations for 2 years (Kais et al. 1986) (Figure 5). Additional tree survival benefits have been obtained on benomyl-treated seedlings in field plantings (Kais et al. 1986, Barnett et al. 1988). Apparently, benomyl reduces the buildup of damaging pathogenic fungi in storage containers.

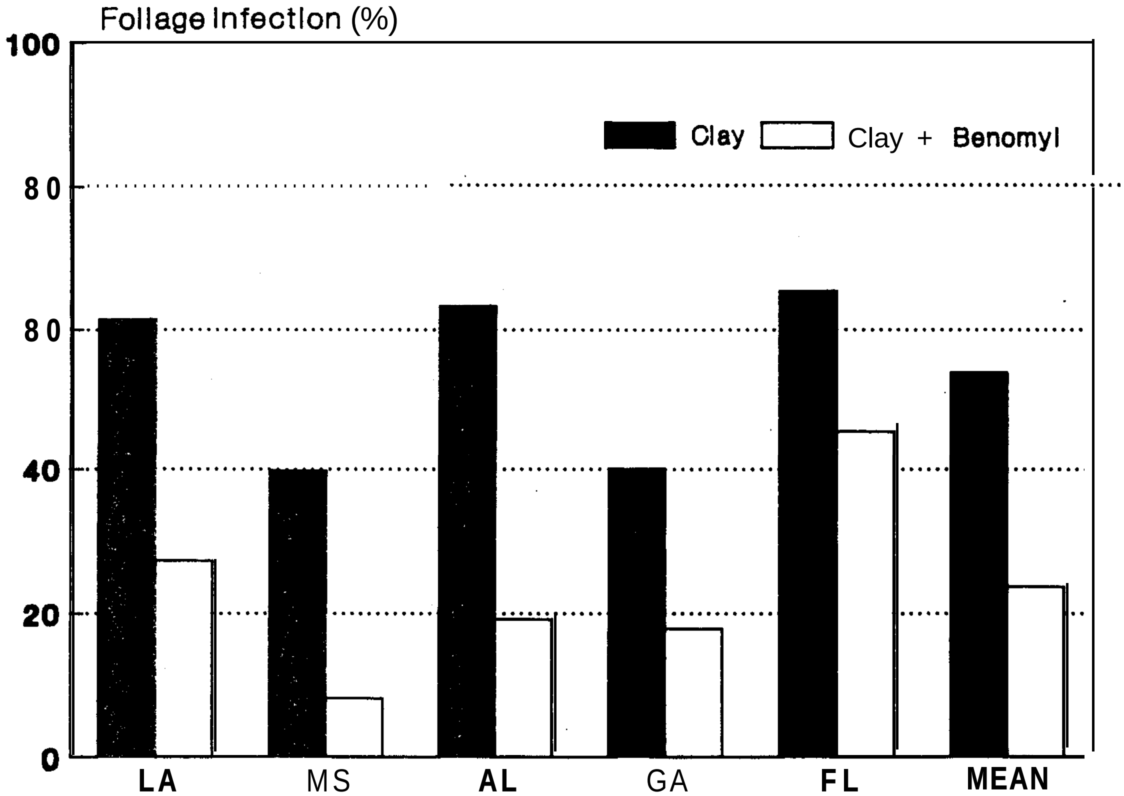


Figure 6. Effect of a Benomyl root treatment at planting on Brown-spot disease on longleaf pines after 2 year8 In the field.

Roots should be treated in a benomyl-kaolinite clay-water mixture consisting of either 0.45 kg (1 lb.) benomyl (Benlate - 50 WP) and 4.5 kg (9.5 lbs.) of dry kaolinite clay for brown-spot disease control (Kais et al. 1986), or 0.45 kg (1 lb.) benomyl (Benlate - 50 WP) and 10.8 kg (23.75 lbs.) of clay for control of fungus pathogens during seedling storage (Barnett et al. 1988). Enough water must be added to either mixture to form a semi-plastic clay slurry that will readily adhere to the moistened seedling roots. These fungicide-clay mixtures represent dosage rates of 5 and 2 percent, respectively, of the benomyl active ingredient (wt/wt). For consistent, effective results, the mixing tank should be continuously agitated, and the seedling roots should be sprayed with a relatively low pressure hydraulic type system rather than dipping the roots into the mixture. Both benomyl fungicide dosage rates and applications have been registered with the Environmental Protection Agency (EPA) for operational use on longleaf pine seedlings in the Southern U.S. One of these fungicide treatments (5% or 2%, depending on the target pests) has recently been adopted for operational use in the majority of southern nurseries producing longleaf pines. Treatment costs range from $1.50/1,000 seedlings for the 2 percent treatment, to $3.50/1,000 seedlings for the 5 percent treatment. These costs are minimal when considering the demonstrated treatment benefits. No surfactant or spreader-sticker is needed with this treatment. Do not apply the mixture to the seedling foliage. Avoid exposing the treated roots to abnormally high temperatures (i.e., above 32°C or 90°F), freezing temperatures, or excessive drying conditions. Use special care to avoid loss of the benomyl-kaolinite clay mixture from the treated roots during packaging, storage, transport, and field planting. The seedling roots cannot be watered or treated with additional pesticide solutions after the benomyl treatment. The kaolinite clay is presently the most effective carrier for the benomyl fungicide where extended brown-spot disease control is needed. Other seedling packing materials, such as peat and water gels, are being evaluated. To be effective in controlling brown spot, the fungicide must remain in contact with the seedling roots at a concentration lethal to the pathogen for an extended period (at least 2 years) (Kais et al. 1986).

SEEDLING HANDLING AND PROCESSING

Special care must be taken during all stages of seedling handling to maintain sufficient root systems and ectomycorrhizae. Feeder roots and ectomycorrhizae can be ripped off and left behind in seedling beds during lifting, desiccated in storage, or cut off prior to field planting. To preserve seedling quality, lifting and handling techniques must be modified to minimize damage. Stripping of roots has severe negative impacts on seedling field performance (Marx and Hatchell 1986). Custom seedling harvesters are more effective and efficient and less destructive than most conventional seedling harvesters in lifting longleaf pine seedlings with their longer tap and lateral roots and absence of stems. The condition of the root system should be monitored throughout the lifting process: even slight reductions in tractor speed can greatly reduce damage to the roots as seedlings are lifted. During transfer of seedlings from the field to the packing room and at all other times when seedlings are handled, avoid drying of the roots by exposure to wind or sun.

The procedure by which seedlings are packed influences their ability to endure storage and survive in field plantings. Longleaf pine seedlings deteriorate rapidly, significantly reducing field survival, if they are stored for more than 1 to 2 weeks (White 1981). Cold storage is vital to reduce seedling respiration. Studies have determined that seedling survival is significantly improved when peat moss, clay, or inert moisture absorbents are used rather than hydromulch (Cordell et al. 1984).

CONCLUSION

The effects of various nursery cultural, biological, and chemical practices on longleaf pine seedling quality have been repeatedly demonstrated. Three recent innovative and promising developments for bare-root nurseries are precision seed sowing to obtain optimum seedling density and spacing, Pt ectomycorrhizae application, and benomyl root treatments. These three practices should be utilized to produce longleaf seedlings of highest quality. Root pruning in bare-root nurseries also is recommended, Seedling quality must be maintained through careful lifting, handling, and planting. Seedling storage time should be minimized, and cold storage should be maintained throughout the shipping and planting phases.

Nursery personnel, field foresters, and tree planters should be aware of the characteristics of high-quality longleaf pine seedlings. They should also know that things can go wrong in nursery cultural management, seedling handling, storage, shipping, and tree planting. Successful longleaf pine planting requires close coordination and cooperation between nursery and planting specialists. Good communication and feedback can help to isolate and eliminate the cause for reductions in seedling quality.

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PRODUCING CONTAINER LONGLEAF PINE SEEDLINGS

John C. Brissette, Mark Elliott, and James P. Barnett

ABSTRACT. Container longleaf pine (Pinus palustris Mill.) seedlings are an alternative to planting bare-root stock, especially when short production times are required, the planting season is extended, or adverse sites are planted. Quality container seedlings are produced under various degrees of environmental control and in several container types. The quality of the planting stock depends on the quality of the seeds sown and proper use and timing of cultural practices. The most critical cultural practices include sowing methods and control of growing medium moisture and seedling nutrition. Seedling root and shoot morphology can be controlled in containers to produce stock of desired characteristics for outplanting under specified conditions. Handling and planting methods used with container longleaf pine will depend on the time of year and physiological condition of the seedlings.

INTRODUCTION

Longleaf pine (Pinus palustris Mill.) plantations are usually established by planting bare-root seedlings. Container seedlings offer foresters an artificial regeneration method for longleaf pine that is often more reliable than using bare-root stock, especially on adverse sites and for extending the planting season.

The production of container longleaf pine seedlings has increased in recent years. Current total production is about 10 million seedlings annually. However, many foresters are unfamiliar with how growing seedlings in containers differs from bare-root nursery operations. Also, they may not know how those differences affect the proper handling and planting of container stock. In this paper we present a brief outline of the methods of growing quality container longleaf pine seedlings and how they should be cared for and outplanted.

Relatively few plantations have been established with container stock. Therefore, knowledge and experience are lacking to determine what attributes are most important to ensure good survival and growth of planted container longleaf pines. When foresters are sincerely interested in the seedlings they plant and there is good communication between seedling procedures and silviculturists there will be continuous improvements in planting stock quality.

John C. Brissette and James P. Barnett are silviculturist and principal silviculturist, USDA--Forest Service, Southern Forest Experiment Station, Pineville, LA 71360; Mark Elliott is manager of the container seedling unit, International Forest Seed Company, Odenville, AL 35120.

FACILITIES FOR CONTAINER PRODUCTION

Site selection criteria for container nursery facilities are much less stringent than for a new bare-root nursery. Topography and soil constraints that can prohibit the development of a bare-root nursery do not influence construction of a container facility. Hahn (1982) provided some valuable insights into several aspects of site selection. Barnett and Brissette (1986) discussed aspects unique to the South.

Structures for growing container longleaf pine seedlings can vary from benches in the open to simple shadehouses to elaborate glass greenhouses. Most commercial nurseries now grow longleaf pine in the open on benches. The quality of longleaf pines grown outside with no shade during the growing season is superior to that of seedlings grown in greenhouses (Barnett 1989). However, overwinter production requires an enclosed, adequately heated structure.

CONTAINERS AND GROWING MEDIA

Container Type

The many container products available are divided into three general types: tubes, plugs, and blocks (Barnett and Brissette 1986). Each type has certain merits to consider in relation to the intended planting sites. Plugs, molded containers that have a cavity filled with a growing medium, are preferred for operational use. Unlike tubes or blocks, plug seedlings must be removed from the containers before outplanting. The rooted seedlings, along with the growing medium, are planted. Plugs provide an ideal biological setting for the seedlings because no root constraint occurs after planting, and roots readily elongate into the surrounding soil. However, the seedlings must be allowed to grow in the containers long enough for the roots to bind with and permit extraction of the medium. For longleaf pine the minimum growing time needed for most plug-type containers is 5 months. Several containers will produce excellent plug seedlings, including: Sytroblocks®, HIKO®, Todd Planter Flats®, Rootrainers®, and Ray Leach Single Cells®.

Container Size

Most containers in operational use have volumes of 40 to 165 cm^3 (2.5 to 10 in^3). A 10- to 12-cm (4- to 5-in) length is satisfactory for southern pines. Diameters of 2.5 to 3.0 cm (1.0 to 1.25 in) are minimal (Barnett 1974). However, container volume is less critical than seedling density (Barnett and Brissette 1986). Densities exceeding about 1,075 per square meter (100 per square ft) reduce initial development and later field performance of the southern pines. Longleaf pine is intolerant of shade and develops far better in large-volume containers (those >75 cm^3 [4.5 in^3]) and at densities of about 500 per m^2 (50 per ft^2) (Table 1).

Table 1.--Development of longleaf pine seedlings at 20 weeks after seeding as related to container size and seedling density

Container	Density of seedlings	Stem diameter	Top weight	Root weight
	no./m^2 (no./ft^2)	---mm---	--mg (ovendry)--	
Styroblock-4	807 (75)	2.9	975	135
Styroblock-8[1/]	441 (41)	4.8	2185	364

[1/] Seedling produced in styroblock 8 containers had 66% more stem diameter, 124% more top weight, and 169% more root weight than those in Styroblock 4 containers.

Growing Media

Several workers have tested combinations of soil mixes (Edgren 1973, Goodwin 1976, Hellum 1975, Pawuk 1981). The best combinations included sphagnum peat moss and vermiculite. Sphagnum moss provides good water holding and buffering capacities, low pH, and high cation exchange capacity. Vermiculite provides pore space that assures well-aerated roots. The ratio of peat to vermiculite most often used is 1:1.

Several commercial growing media are available for container seedling production. Most'are variations of the Cornell mixes, which'consist of various ratios of peat moss, vermiculite, perlite, and nutrients (Boodley and Sheldrake 1963). However, these mixes were developed for horticultural 'and vegetable use, 'and are unsuitable for conifers unless pH is reduced. Some manufacturers will custom blend and reduce the amount of limestone making the pH more satisfactory. Although nutrients in Cornell-type mixes are enough for the first several weeks, supplemental fertilizers must then be added.

SEEDLOT SELECTION AND TREATMENT

The high quality seeds essential for growing container seedlings result from well managed cone collections, seed processing, and handling. Seeds should be tested for viability: the results of these tests are an invaluable source of information. Seed buyers should specify complete removal'of unsound seed. When seedlots are small, it is often convenient for growers to process their own seeds with the small laboratory cleaners or aspirators available (Bonner 1977).

Fungi borne on southern pine seeds are not a major concern in bare-root nurseries because most observations show they are saprophytic and do not affect germination (Belcher and Waldrip

1972). However, with container culture seed-borne fungi can be an important cause of seedling mortality. Many seedlots contain infected seeds. For example, 8 to 20% of the seeds from five longleaf seedlots tested for Fusarium spp. were infected (Pawuk 1978). Furthermore, all five species of Fusarium recovered were pathogenic. Such infected seeds germinate poorly, and damping-off losses increase. Surface sterilizing or coating with fungicides will control microorganisms infecting pine seedcoats. Barnett and Brissette (1986) reviewed techniques for using seed sterilants and fungicides on southern pine seeds.

Bonner et al. (1974) discussed presowing treatments to speed pine germination in a chapter of "Seeds of Woody Plants in the United States." Although there is currently much interest in stratification of longleaf pine seeds, there is not enough evidence to recommend routine stratification of all longleaf seedlots. In fact, stratification for as short as 7 days may reduce the total germination of some seedlots by up to 10% compared to unstratified controls.

ENVIRONMENTAL CONTROLS

The degree of environmental control needed to produce longleaf pine seedlings depends on whether they are grown in or out of phase with the normal growing. season. For seedlings grown in phase, the only control required is to provide adequate moisture to the growing medium. However, if seedlings are grown out of phase, then the levels of light and temperature as well as moisture must be maintained within acceptable ranges. Detailed information about the facilities and equipment required to control light and temperature are in Tinus and McDonald (1979). The optimum environmental conditions for longleaf pine vary with the stage of seedling development. The two most critical stages when producing seedlings in containers are the germination and postgermination periods.

Germination Period

Light Southern pine seeds require light for germination (McLemore 1971, Nelson 1940, Toole et al. 1962). However, photoperiod is more critical than intensity (Jones 1961). The quality of light is also important. Red light (660 nm) promotes germination while far-red light (730 nm) inhibits germination (Toole et al. 1962, McLemore 1971, McLemore and Hansbrough 1970). The red wave lengths in artificial lighting are short enough so that germination is not adversely affected.

Moisture - During the germination period the moisture content of the potting medium should remain near field capacity. Any moisture stress greater than about -0.25 MPa (-2.5 bars) reduces germination of southern pines (Barnett 1969). Although containers require frequent watering during this period, the force of the irrigation water must not dislodge the seeds from direct contact with the moist medium. A mist watering system is best during germination.

Temperature - Under controlled conditions, longleaf pine seeds germinated well only at 18° and 24°C (65° and 75°F) (Barnett 1979). Germination decreased with alternating temperatures, which better represent actual conditions (Table 2) (Dunlap and Barnett 1982).

Table 2.--Germination of longleaf pine seeds at various temperature regimes

Temperature regime	Sample size	Germination
°C 1/	--number--	--percent--
24 (constant)	150	79a 2/
24 (for 18h) and 35 (for 6h)	150	61b
35 (constant)	150	12c

1/ 24°C = 75°C; 35°C = 95°F

2/ Means are all significantly different at the 0.05 level

Postgermination Period

Light - Photoperiod can either be lengthened or shortened, depending on the type of facilities available. Extending the photoperiod with low-intensity light at intermittent intervals produces larger seedlings during winter when natural photoperiods are relatively short. However, short days are important in developing cold hardiness, so growers must consider the season and expected site conditions at outplanting before extending the photoperiod to promote growth.

Shading will also control excessive temperatures, particularly in late spring and summer. By reducing incoming solar radiation, shadecloth can lower greenhouse temperatures 5°C (9°F) or more. However, recent research shows that shading affects seedling development in longleaf pine more than in loblolly pine (Barnett 1989). Seedlings grown at 30 and 50% shade were significantly smaller in stem diameter, top weight, and especially root weight (Figure 1). These results have major implications for producing longleaf pine in containers. Growing longleaf seedlings in full sun, or at the lowest level of shade possible, is highly desirable. The best way to apply this technology is to sow seeds in containers in late spring (May or early June), and grow them in the open throughout the summer. Seedlings with larger diameters and larger root systems are then available for planting in late summer or fall. Not only are seedlings of better quality, but outside production is less costly than greenhouse production.

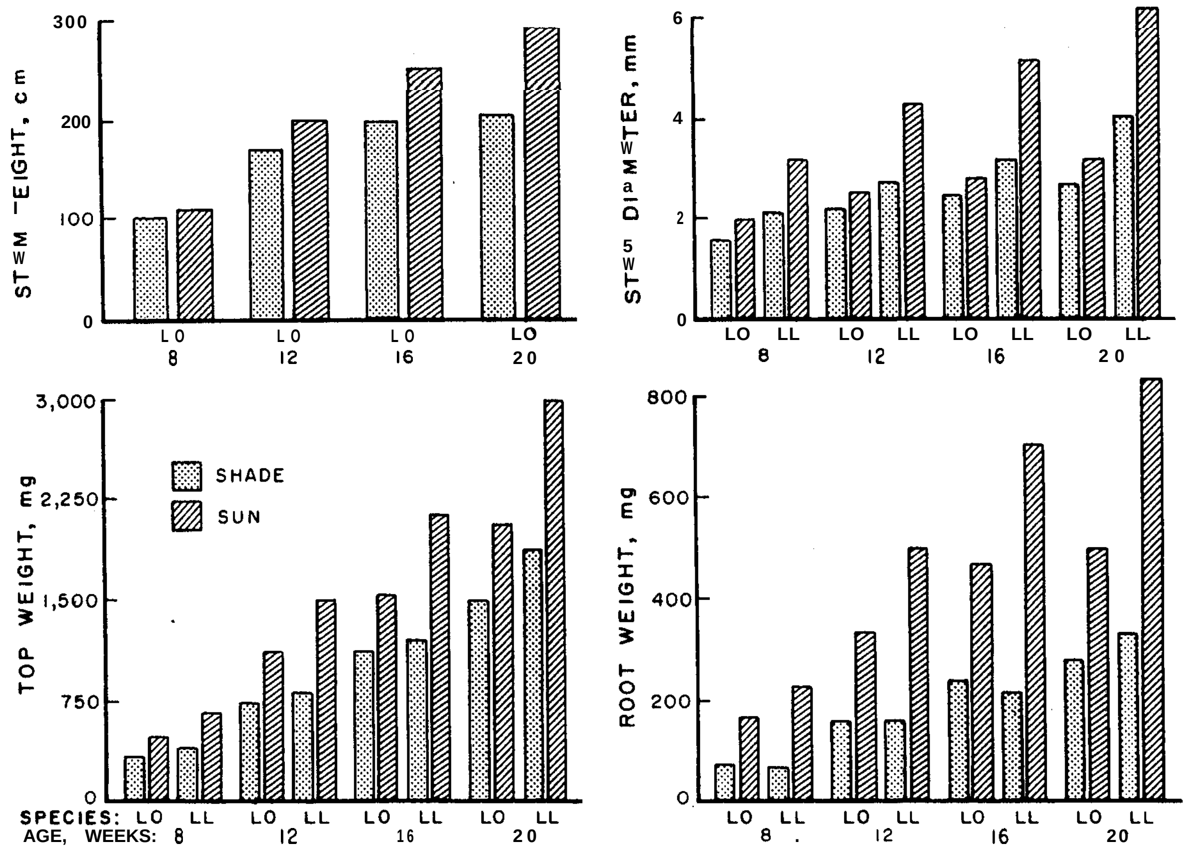

Figure 1.--Comparison of longleaf and loblolly pine seedling attributes at various weeks after seeding when grown under full sun or shaded conditions.

Moisture - Heavy, infrequent waterings should characterize the postgermination period. Such a regime allows the surface of the medium to dry between waterings and reduces the chance of damping-off fungi developing. Less frequent waterings also lower the water content of the medium, which increases aeration, absorption of nutrients, and root growth.

Temperature - Seedling production during the winter requires a heated greenhouse. To provide suitable growing temperatures during warm weather requires cooling. Tinus and McDonald (1979) gave a thorough discussion of various systems of greenhouse heating and cooling. However, although many workers have searched for specific optimum temperatures for growth, the complex relationship between temperature and growth makes determining the best temperatures difficult.

Growth is affected by day and night phases of a temperature regime and the differences between these phases. Bates (1976) concluded that the best day/night regime for container longleaf pine was $23^{\circ}/17^{\circ}C$ ($73^{\circ}/63^{\circ}F$). This combination increased seedling dry weight, a characteristic important for successful handling and planting. Warmer temperatures resulted in better top appearance, but produced weaker, finer roots. Although such strict temperature control is not possible under operational conditions, growers should be aware of the important effects diurnal temperature fluctuations have on seedling growth.

CULTURAL PRACTICES

The cultural techniques necessary to optimize growth and quality of container longleaf pine seedlings are not as well understood as they are for bare-root stock. The following brief description of cultural practices will provide the grower or forester with information about why certain techniques are used and how they affect seedling quality. Barnett and Brissette (1986) presented more detail about each of the practices outlined below.

Filling Containers

To produce a uniform crop, the containers must be filled uniformly. Each cavity should hold the same volume of growing medium settled to the same level. Slightly moist medium is easier to handle,' fills more uniformly, and will come to field capacity more readily than dry medium.

Containers are filled by hand or machine. Most commercial nurseries use machines to automatically fill containers with the correct amount of medium. The simplest hand method is to set blocks or trays on a paved surface and use a shovel to spread medium over the top. Water the containers before seeding to settle the medium below the container tops and to be sure that the medium is moist. Machines are available that can release a measured amount of medium into containers as they pass along a conveyor. These machines often vibrate the container to settle the medium.

Sowing Techniques

Number of seeds per container - Seedlots with low germination require multiple seeding to reduce the number of vacant cavities. On the other hand, containers with excess seedlings usually need thinning. To lessen these problems, Pepper and Barnett (1982) suggest a sowing scheme in which varying numbers of seeds are sown per cavity. For instance, 30% of the containers could receive three seeds, 20% two seeds, and the remaining 50% one seed. Mixed sowing schemes are more cost-efficient than the standard constant-number approach but still require some thinning to achieve one seedling per container.

Sowing Methods of seed sowing vary from hand seeding or use of simple templates to elaborate mechanical seeding machines. Many container operations use some type of vacuum seeder with holes drilled in the seeding head to match the container arrangement. Even the most efficient seeders occasionally leave blank containers, so growers should visually check the cavities.

Seed covering - The effect of covering southern pine seeds varies with the type of watering regime used (Waldron 1972). Germination is usually most complete and rapid when seeds remain uncovered and watered by a misting system (Barnett 1978). With less frequent watering, a seed covering, typically a 3-mm (l/8-in) layer of medium, helps germination through a mulching effect.

Mycorrhizal Inoculation

Development of some species of mycorrhizal fungi is limited on heavily fertilized seedlings (Marx and Barnett 1974, Marx et al. 1977). Less fertilization, about half of what is normally considered best, may be necessary for good mycorrhizal development. When container nurseries are located near forested areas where airborne mycorrhizal spores are abundant, natural inoculation may be enough. Barnett (1982a) found that airborne spores of *Thelephora terrestris* were sufficient to produce mycorrhizal fungi on seedling root systems in containers, and high fertility did not seem to inhibit its development. Evaluations of the field performance of longleaf seedlings showed that initial seedling size was more closely related to growth than the amount of mycorrhizae on roots (Barnett 1982a).

However, considerable evidence suggests that inoculation with mycorrhizae improves seedling performance on difficult sites such as droughty soils and reclamation areas (Barnett 1980, Barnett 1982a, Goodwin 1980, Marx and Artman 1979, Marx and Barnett 1974). Therefore, it is necessary to ensure that root systems of container seedlings destined for such sites have mycorrhizal development before outplanting. Marx and his coworkers (Marx and Bryan 1975) have developed techniques to produce mycelial inocula of *Pisolithus tinctorius* in a vermiculite culture. The International Forest Seed Company has developed techniques to inoculate seedlings with mycorrhizae spores. These techniques have made it possible to propagate and manipulate this fungal symbiont.

Inoculation of the container growing medium with mycorrhizal fungi requires some changes to normal culture. As previously stated, the grower must reduce the fertility level by about half. Pawuk et al. (1980) found that the development of *P. tinctorius* and *T. terrestris* mycorrhizae on roots of container-grown longleaf pine varied significantly with different fungicide drenches. Only seedlings drenched with products containing benomyl had greater mycorrhizal development than those not treated at all.

Transplanting and Thinning Germinants

Empty containers can represent a significant loss because they cost as much as a seedling to keep through a growing cycle. On the other hand, growing multiple seedlings per container often reduces seedling quality. Therefore, we recommend: (1) use only the best quality seeds available, (2) thin multiple seedlings to one per container, (3) transplant only vigorous germinants, and (4) do both thinning and transplanting as soon as possible after germination is complete.

Transplanting - Pawuk (1982a) studied the effect of transplanting on initial seedling growth and development. Transplanting longleaf pine germinants, regardless of their radicle length, is detrimental to later growth compared to undisturbed seedlings (Table 3). Total dry weight of longleaf pine seedlings at 15 weeks was directly and significantly related to radicle length at the time of transplanting. Undisturbed control seedlings were heaviest; their average weight was about twice that of transplants with short radicles and about 50% greater than transplants with long-radicles. Transplanting should be done as soon as an empty cavity becomes evident, usually about 10 to 14 days after sowing. Although growth after transplanting corresponds to radicle length, it is easier to transplant germinants without damage soon after sowing than waiting until later when seedlings would have longer radicles.

Table 3.--Effect of radicle length at transplanting on growth after 15 weeks[1/]

Radicle length	Root collar diameter	Total ovendry weight
--cm--	---mm---	----w----
1.5 - 2.0	1.12a[2/]	168a
3.0 - 3.5	1.20a	210b
4.5 - 5.0	1.28a	237c
Undisturbed (control)	1.48b	3426

[1/] 1 cm = 0.4 in: 1 mm = 0.04 in: 1 mg = 0.035 oz

[2/] Means in columns followed by the same letter are not significantly different at the 0.05 level

Thinning - If cavities contain several seedlings the grower must decide whether or not to thin. Multiple seeding affects longleaf pine seedlings more seriously than loblolly or slash pine seedlings (Barnett and Brissette 1986). After 14 weeks the average total dry weight of multiple-grown longleaf pine was only half that of single-grown seedlings. The smaller, multiple-grown seedlings also had poorer survival than single-grown trees after outplanting.

Growing Medium Moisture

For a 1:1 peat-vermiculite medium, longleaf pine seedlings grow best if the moisture content of the medium is about 400% on a dry-weight basis (Barnett and Brissette 1986). Growing medium moisture content can readily be measured with the container weighing method (McDonald and Running 1979), where the crop is watered when the weight of a filled container decreases to some predetermined percentage of its weight with the medium staturated. This percentage is often around 75 to 80% depending on the type of container, the composition of the medium, and the species being grown. The grower must periodically adjust the container weight for seedling growth.

Seedling Nutrition

Information about the nutritional needs of container longleaf pine seedlings is very limited. Fortunately, the range of nutrient concentrations that provides good growth is quite broad, and most coniferous tree species are similar in their requirements. Based on research with many species, Table 4 summarizes the current recommended concentrations of macronutrients and micronutrients for growing container longleaf pine.

Table 4.--Recommended nutrient concentrations for container-grown longleaf pine&/

Nutrient	Concentration
	-----ppm-----
Nitrogen	125 - 625
Phosphorous	25 - 38
Potassium	75 - 625
Calcium	300 - 600
Magnesium	15 - 73
Sulfur	20 - 150
Iron	0.93
Boron	0.17
Manganese	0.17
Zinc	0.02
Copper	0.02
Molybdenum	0.003

1/ Although these recommended nutrient concentrations should not be considered optimum, they can be used as a basis for fertilization until more complete information is available

Fertilizer formulations - Most seedling operations use commercial fertilizers dissolved in water and injected into the irrigation system. These fertilizers, produced by several manufacturers, are available in numerous formulations with different proportions of macronutrients and micronutrients. Growers can also mix their own nutrient solutions by adding various amounts of chemicals to water for the desired regime, depending on the medium and irrigation water composition. Tinus and McDonald (1979) developed a format for determining the chemical formulation best suited for an individual nursery situation.

Timinq'and initial application - Because nutrients are supplied initially by the seed, fertilization during germination is usually not recommended (Tinus and McDonald 1979). Also, adding nutrients early may increase losses due to damping-off fungi. Therefore, growers usually schedule fertilization to begin after cotyledons have shed their seedcoats. However, if the crop is on a short rotation--such as is typical with the southern pines--fertilization at the time of seeding may be desirable. Even if germinants cannot effectively use fertilizer early in development, nutrients applied at seeding are available as soon as needed and may hasten growth.

Pest Management

Diseases - Species of Fusarium are the fungi most commonly cultured from diseased seedlings and growing media (Pawuk 1982b). Fusarium spp. has been cultured from air and water samples in and around greenhouses, but always at low levels. However, it often produces abundant spores on infected seedlings: therefore, it probably spreads from infected seedlings during watering. Pawuk (1982b) observed Rhizoctonia spp. attacking seedlings in germination trays and the foliage of container longleaf pine. It develops when foliage is wet for extended periods and spreads from seedling to seedling, its mycelia clearly visible. Wet, poorly drained media favor Pythium spp. and Phytophthora spp., which cause damping-off of germinants and root rot of developing seedlings. As seedlings mature, they become more resistant to infection by these pathogens.

Foliage diseases and rusts have not been a problem on container southern pine seedlings. The main reasons are probably the short growing time required and because the foliage is seldom wet for prolonged periods. However, one should not overlook the possibility of infection, especially if seedlings are grown outside.

Some cultural practices can help prevent seedling loss due to diseases. The medium should be pathogen-free from the start. It should be well drained and not overwatered. Although several available fungicides will control damping-off and root rot if applied promptly and correctly, there is no one fungicide cure-all.

Weeds - When seedlings are grown in greenhouses, weeds are seldom a problem in the containers. Good sanitation practices and prompt hand weeding are usually enough to prevent a weed buildup. However, if seedlings are grown in containers outside--as we recommend for longleaf pine--then weed species dispersed by the wind can become a problem. No research has been done on weed control in containers. Because of the high organic matter content of the peat moss used in growing media, herbicide rates used in bare-root nurseries may be harmful to container seedlings.

Controlling Seedling Morphology

Shoot morphology - Even at low seedling density, the extensive needle development of longleaf pine can cause shading. Therefore, it may be helpful to clip the needles to allow all seedlings to have uniform exposure to light. Clipping also allows foliage to dry faster and thus reduces the chance of diseases spreading. However, clipping needles to a 10- to 20-cm length reduced root-collar diameter and root dry weight by about 10% and shoot dry weight by about 50% compared to unclipped seedlings (Barnett 1984). Such clipping did not significantly affect survival or growth during the first year after outplanting.

Root morphology - It is important to restrict root egress from the container during the growing period. Allowing roots to air-prune when they grow from the bottom of the container is the most efficient means of controlling root growth. The key to effective air pruning is to provide air access around the container drainage holes.

Root spiraling, the most serious problem imposed on longleaf pine by containers, can be prevented by proper container selection. Although a vertically oriented root system is common in plug-type containers, the rapid root growth from the lower portion of the plug does not seem to result in root deformity. In fact, it probably improves seedling survival and growth on adverse sites (Barnett 1982b).

Conditioning Seedlings

Most seedlings will cease height growth and set bud when exposed to moisture stress and short photoperiods. Reducing the nitrogen provided to seedlings also helps to slow growth. Although the ease of stopping growth depends on the season, it can be stopped any time of year. The length of time allowed for the hardening stage, when growth ceases, stems lignify, and buds set, depends on the environmental conditions expected at outplanting.

Moisture stress - As seedlings approach the desired size, reducing moisture content of the growing medium will begin the hardening process. Midday xylem water potential should be allowed to fall to between -1.2 and -1.5 MPa (-12 and -15 bars). The time required for water potential to drop to the desired level depends on moisture content of the growing medium and evaporative demand. Measuring xylem water potential and weighing containers to determine moisture content are means of evaluating water status. To avoid over-stressing the seedlings, frequent monitoring of moisture content or water potential is important.

Nutrition - When beginning moisture stress for conditioning, the nitrogen concentration and the frequency of fertilizer application should both be reduced. However, increased rates of phosphorus and potassium in the fertilizer solution may foster continued root and stem diameter growth (Tinus and McDonald 1979).

Cold hardening - Late fall or winter outplanting requires additional hardening beyond growth ceasation and stem lignification. The grower should gradually expose the seedlings to more severe conditions. Low temperatures will bring about the physiological changes that enable &he seedlings to tolerate the new conditions. Temperatures of 1 to 5°C (34° to 41°F) generate considerable cold hardiness. For container loblolly pine, Mexal et al. (1979) found that about 42 days of hardening in central Arkansas enabled seedlings to survive late fall and early winter outplanting.

HANDLING AND PLANTING

Handling and Storage

Extracted plug seedlings require considerably less shipping and storage volume than seedlings left in the containers. If extracted, roots as well as shoots can be graded, and there are no containers to return to the nursery. However, storage and handling can seriously impair stock quality if extracted seedlings are not completely dormant and cold hardy (Landis and McDonald 1982). If container seedlings are planted during an extended planting season, extraction before shipping should not be considered.

Extracted seedlings can be cold stored, and the recommended storage procedures are the same as for bare-root stock. These seedlings need little care other than making sure they are not severely water stressed or allowed to freeze.

Under natural conditions, seedling root systems are well insulated by the soil and do not attain the same level of cold hardiness as shoots. However, container seedlings kept outside, either at the nursery or at the planting site, can encounter low temperatures lethal to their roots. Moreover, because cold damage to roots is not as obvious as to shoots, root mortality is not seen until shoots begin to grow. In an Arkansas study, survival was 50% for container loblolly pine seedlings exposed to -10°C (14°F) in February, compared to 90% for seedlings moved inside before the low temperature (Mexal and Carlson 1982).

Because container seedlings have a relatively small volume of medium, they are very susceptible to desiccation and need protection from the drying influences of the sun and wind. One should handle extracted seedlings much like bare-root stock. Seedlings shipped in the container need a thorough watering before leaving the nursery and rewatering as necessary to maintain the medium at field capacity until planting.

Planting Container Seedlings

The ability to use container seedlings for extending the planting season is one of their major advantages over bare-root stock. However, soil moisture at the time of planting must be enough for seedling establishment. The soil water potential determines how much water is available to the plants. The predawn xylem water potential of established woody vegetation will provide an estimate of soil water potential. A planting site is a high risk if the predawn xylem water potential of established plants is less than about -0.8 MPa (-8 bars). An ideal water potential would be less than -0.5 MPa (-5 bars).

Container seedlings can be hand planted with conventional bare-root planting tools or with tools designed for specific container shapes. When container seedlings are properly hand planted, their roots should grow into the surrounding soil in a spatially uniform manner. Douglas-fir trees were dug up from 26 plantations on various soil types in Oregon and Washington 2 to 4 years after planting as plug seedlings. The root systems were classified longitudinally and radially into 13 zones. Roots egressed in an average of 11 of the available zones of the plug mass in the 325 seedlings excavated (Rischbieter 1978). In general, root egress was poor only where soils were compacted, aeration was poor, or seedling vigor was markedly reduced because of factors other than soil texture.

Most mechanical planters designed for bare-root seedlings are adaptable for container stock with only minor changes. Only the operator technique should need modification in continuous furrow machines. For mechanically fed machines, the seedling holding mechanisms might need changing.

As with bare-root stock, planting container seedlings to the proper depth is important to ensure good survival and growth after outplanting. Container seedlings should be planted deep enough so that the top of the root plug is covered with about 1 cm (0.4 in) of soil. This covering reduces drying of the root plug, which is caused by the "wicking effect" of moist growing medium exposed to the air. However, care is also required not to plant container seedlings so deep as to bury the shoot, especially during machine planting. Control of planting depth is more critical and can be more difficult with container than with bare-root longleaf pine seedlings (Robbins and Harris 1982).

SUMMARY AND RECOMMENDATIONS

Our intent in this paper has been to introduce foresters to container **longleaf** pine seedlings as a regeneration option with certain advantages and disadvantages when compared to other methods. We also hoped to promote an understanding between producers and users of container stock. Reforestation success can best be assured when the forester and the nursery manager both understand each other's needs and limitations.

The following recommendations should be considered when the use of container **longleaf** pine seedlings is contemplated:

* Use container seedlings under conditions where bare-root stock or natural or direct seeding will not do well.

* Take advantage of the flexibility of container production methods to tailor the growing period, container type, and cultural practices to provide the desired seedling attributes at the intended planting date.

* Specify the use of only high quality seeds in container production to avoid empty cells and minimize transplanting and thinning.

* Provide the least amount of environmental control necessary to produce the desired seedling attributes.

* Be aware that the relatively small volume of rooting medium in containers makes the timing and application of cultural practices, especially irrigation and fertilization, critical.

* Adjust handling and planting methods to the planting season and to the morphological and physiological condition of the seedling.

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Session II

April 4, 1989

Moderator:

L. Keville Larson
Larson & McGowin, Incorporated

Regenerating Longleaf Pine With Artificial Methods

James P. Barnett, Dwight K. Lauer,
and John C. Brissette

ABSTRACT. The artificial means for establishing stands of longleaf pine seedlings are reviewed. Relative merits of direct seeding and planting of bare-root and container seedlings are discussed, along with techniques that should help ensure successful stand establishment. Techniques that dramatically improve the reforestation success of longleaf pine include: (1) the use of high-quality seedlings (or seeds if direct seeding) from the proper seed source, (2) preparation of the site to control most competing vegetation, (3) careful lifting, storing, and transporting of seedlings and the inclusion of benomyl in the packing medium, (4) planting the seedlings carefully while controlling the planting depth, and (5) evaluation of the planting or seedling operation, including postplanting treatments if necessary to promote height growth.

INTRODUCTION

One of the primary reasons that the acreage of longleaf pine has declined so drastically over the last four or five. decades has been the lack of successful reforestation. Problems have been common in both natural and artificial regeneration. Poor seedling survival has been common in many planting efforts, partially due to inferior quality of seedlings, improper planting techniques, use of stock from nonadapted seed sources, and inadequate site preparation or control of competition. Not only has survival been a problem, but delayed initiation of height growth has resulted in poor stand establishment. Lack of prompt height development may reflect the effect of brown-spot needle blight disease or on-site plant competition, as well as poor seedling quality. Use of direct seeding has declined because reforestation sites are smaller, stocking control is lacking, and success is uncertain. However, in recent years a number of new techniques have evolved, and we now recognize interrelating factors that determine reforestation success of longleaf pine.

Successful regeneration of longleaf pine, both in terms of stocking and growth, is a result of a regeneration system rather than any individual option. Success involves the combination of proper site preparation, proper care and handling of seeds or seedlings, proper sowing of seeds or planting of seedlings, and proper postestablishment care.

Barnett and Brissette are principal silviculturist and silviculturist, respectively, USDA--Forest Service, Southern Forest Experiment Station, Pineville, LA 71360; Lauer is Research Forester, ITT Rayonier, Inc., Yulee, FL 32097.

ARTIFICIAL REGENERATION OPTIONS

Artificial regeneration options available to the forest manager normally include planting of bare-root or container-grown seedlings and direct seeding. Planting provides a higher assurance of success than direct seeding, but seeding may be the best or only option for some situations. Direct seeding, developed in the late 1950's, provided a quick, reliable method of regenerating vast areas of open cutover or burned land that existed in the South at that time; these areas are now in production. Typical reforestation areas--less than 250 acres--are usually more suited for planting than for direct seeding. However, direct seeding is still an ideal technique to quickly regenerate large areas following wildfires or where terrain is difficult to plant. Direct seeding also provides the small nonindustrial forest landowners with an economical option for regenerating their lands.

Compared to seeding, planting provides better control of stocking, efficiently utilizes expensive genetically improved seeds, simplifies thinning and harvesting, and usually prevents the need for precommercial thinning. The use of container-grown longleaf pine is relatively infrequent compared to that of bare-root seedlings because bare-root stock is easy to procure and less expensive. However, bare-root seedlings may not provide the desired results in some situations. Planting of container-grown seedlings is an option that has become available in recent years. Container seedlings can be used to: (1) improve survival and height growth, particularly on sites that are difficult to regenerate, (2) extend the planting season by allowing regeneration of dry sites in the fall, and (3) provide greater flexibility in seedling production to meet unexpected demands.

PROPER SITE PREPARATION

Longleaf pine is a very intolerant species and is difficult to regenerate without effectively controlling competing vegetation. Competition must be under control until an adequate number of seedlings are in height growth and at least on equal footing with the height and vigor of the competition. The nature and degree of site preparation vary somewhat with the regeneration technique being considered. For example, sites to be direct seeded usually require prescribed burning as a minimum. Although seeding on a light grass rough has been successful (Mann 1970), seeding on disked strips has been more reliable because it reduces competition to young seedlings. Mechanical site preparation boosts survival of planted bare-root stock appreciably. On open, grassy sites in Louisiana where survival has been only 33 percent, Shoulders' (1958) first-year survivals of bare-root seedlings were increased to 51 percent by scalping, 61 percent by disking, and 62 and 70 percent by shallow and deep furrowing, respectively.

Attachments can be mounted on the planting machine so that scalping and planting can be done in one operation with no increase in horsepower. Shallow furrowing can also be done in the same operation as planting, but it requires a larger tractor. Disking and deep furrowing, which are usually done in advance of planting, are relatively expensive (Mann 1969).

Field performance of container-grown longleaf pine seedlings is affected by the type of container, site quality, and nature of site preparation prior to outplanting (Barnett 1989b). Containers with lower seedling densities usually produce larger and better quality stock. Rapid establishment of roots in the soil improves initial seedling survival, particularly on droughty sites. Longleaf pine seedlings are very sensitive to competition, and overall performance is markedly improved by techniques that reduce herbaceous plant competition (Fig. 1).

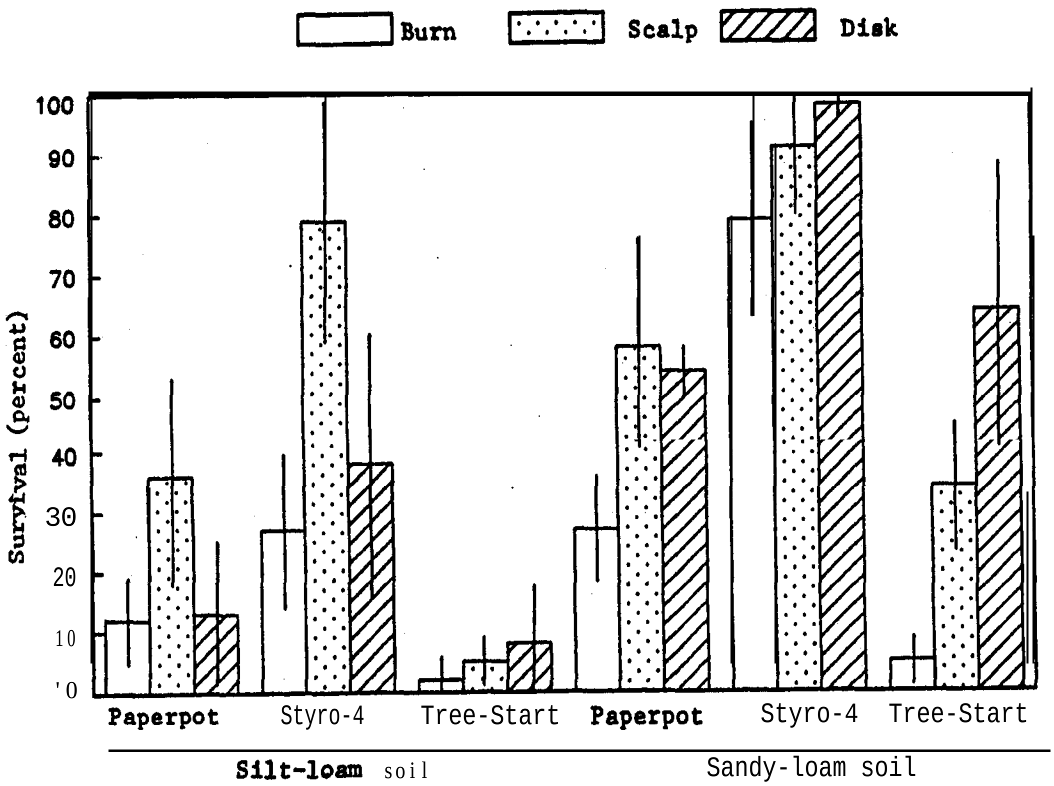

Figure 1.--Survival of longleaf pine seedlings by container type, site preparation treatment, and soil type, measured 2 1/2 years after outplanting.

Alternatives to prescribed burning and mechanical treatments are, of course, chemical treatments. These are versatile tools that expose no mineral soil, but they can be effective in retarding competing vegetation. Chemical site preparation consists of single stem treatments or broadcast applications. Selecting the optimal chemical treatment from the many chemicals available may be difficult since many factors influence the effectiveness of the herbicides. Weather conditions before, during, and after treatment: soil moisture levels: season of the year; texture and structure of the soil; type and vigor of the treated vegetation; formulation of the herbicide; and the quality of the application job all exert an influence on the chosen herbicide. Not all of these factors are controllable. However, the landowner should have reasonable success by following the instructions on the herbicide label. Guidelines are usually available from the USDA Cooperative Extension Service, which has many local agents available throughout the state. Herbicides are used most effectively in conjunction with either mechanical treatment or prescribed burning.

Recently, a system of chemical site preparation followed by a fall v-blade planting of container stock has been used by industrial landowners. Sites selected by industry for longleaf generally consist of well-drained to excessively drained sandy soils with abundent oak competition, although there is a trend to plant sites that consist of moderately well-drained soils. This trend is very dependent on the success rate for longleaf regeneration and the control of regeneration costs.

Chemical site preparation has the advantage over several mechanical methods in that:

(1) Already scarce nutrients are not moved into piles and windrows, but are left in place,

(2) Hardwood competition is more completely controlled, and

, (3) There is generally a low level of herbaceous weed cover on these sites in the spring after planting.

Fall planting of container seedlings allows the seedling to develop a good root system before the first spring drought. The additional cost of container stock is justified by higher stocking and the smaller chance that the area will have to be replanted. However, bare-root seedlings can also be used following chemical site preparation.

DIRECT SEEDING

Direct seeding of longleaf pine is effective, rapid, and inexpensive, but, like other regeneration methods, it is not fail-safe. Most of the recorded failures have been due to either inadequate site preparation or improper application techniques such as seeding on unsuitable sites, seeding out of season, using poor quality seed, and sowing too few or untreated seeds. Also, poor stand appraisal techniques have incorrectly classified some successful seedings as failures. Many such failures can be easily avoided by following some simple guidelines, seed as:

Condition of the seedbed

Each site must be judged on its individual merits before a prescription can be prepared. Generally, sites that can be planted can be seeded. Conditions that should be avoided are:

(1) Sites subject to heavy grazing, unless grazing can be

controlled the first 2 or 3 years until seedlings are at least 3 feet tall.

(2) Low, poorly drained sites that are likely to be covered with standing water for a week or more during February, March, and April.

(3) Deep, upland sands that dry out rapidly after a rain. (Not only is soil moisture usually too low to sustain germination, but a sandy surface often forms crusts and prevents penetration of the radicle even if the seeds do germinate.)

(4) Highly erodible soil and steep slopes where seeds are likely to be displaced by water movement.

There is one basic ground rule for direct seeding: seeds must be in contact with mineral soil. Seeds lodged in surface litter, grass sod, or on any other material besides mineral soil will not become established (Campbell 1982).

Seed handling and protection

An important prerequisite for direct seeding success is the use of good quality seeds from the correct source (Lantz and Kraus 1987) that have been properly collected, stored, and treated with bird and rodent repellents. Minimum specifications for longleaf pine seedlots are 95 percent purity and 75 percent germination. This standard is somewhat less than that for other southern pine species, but longleaf pine seeds usually have lower viability than the other species.

Longleaf pine seeds must be handled with extreme care, otherwise the quality will deteriorate. Few forest managers are equipped to collect the cones and then properly extract, store, and treat the seeds with repellents. When seeds are purchased, always use a reputable seed dealer and be sure that the seeds are ready for sowing. Arrangements for the purchase of seeds and a sowing contractor (if needed) should be made well in advance of the seeding operation, but delay the actual delivery of the seeds until time for sowing. Longleaf pine seeds do not normally require stratification, but because of their sensitivity they should be stored under refrigeration, preferably at subfreezing temperatures, until ready for use.

Bird and rodent repellents must be used if the seeding is to be successful, even with high-quality seeds (Derr and Mann 1971). Dense populations of these predators can consume up to 10 pounds per acre of untreated seeds during the germination period. Seeds should be coated with chemicals such as thiram and endrin; rates of chemical use and application techniques for these repellants are clearly provided by Derr and Mann (1971). Both the recommended chemicals are labeled for this use and are environmentally safe if guidelines are followed (Barnett et al. 1980). Seed handlers should always wear rubber gloves and an approved toxic-dust mask. After handling treated seeds, workers should wash their hands and face thoroughly before eating, drinking, or smoking. If proper precautions are not followed, treated seeds can be very dangerous. Endrin is no longer manufactured; supplies of this repellant are rapidly declining. Other effective rodent repellents are being evaluated.

Seeding methods

Broadcast seeding.--Small acreages are usually seeded by hand. One person using'a cyclone seeder on easy-walking terrain can cover up to 12 acres per day. Following carefully flagged lines will result in a uniform distribution of seeds. The seeder should be carefully calibrated for the sowing rate in use. On farm woodlands, seeds may be scattered by hand in a relatively uniform pattern.

Larger acreages are best seeded by aircraft, but equipment must be well calibrated for the sowing rate in use. On a calm day when everything goes well, a helicopter can seed up to 3,000 acres per day.

The major advantages of broadcast seeding are its speed and low cost. Major disadvantages are the lack of spacing and stand density control and a lengthy grass stage before height growth begins.

Row seeding.--Row seeding may be preferred over broadcast sowing when the landowner desires better control over spacing and density, or wants the trees in rows for mechanical harvesting. On a well-prepared site the seeds can be dropped by hand as one walks a furrow, row, or line. Seeds should be spaced 1 or 2 feet apart within the row. A common recommendation for spacing between rows is 10 feet; this reduces the number of trips across an area.

Spot seeding.--Spot seeding is just what the name implies: dropping a predetermined number of seeds on a small spot. It offers the same spacing control as planted nursery seedlings, but is the slowest and most labor-intensive of the three sowing methods. However, spot seeding is the best method for the small landowner who must minimize costs and can do the work in whatever spare time is available with a minimum of tools and equipment.

When the site has been properly prepared and mineral soil is exposed, three to five seeds should be dropped in a cluster. If surface litter or grass sod still occupies the site, a spot should be cleared with the foot, a hoe, firerake, or other means to bare mineral soil. The seeds are dropped and covered lightly with the foot. On drier sites or sloping terrain it may be benefical to cover the seeds with a layer of soil, but the soil cover should not exceed 1/4 inch in depth.

Sowing three to five seeds per spot is recommended to ensure stocking on most all spots. However, two or more seeds will germinate on many spots and result in a cluster of seedlings. Such multiple-stocked spots should be thinned back to a single seedling after 2 or 3 years. Clustered seedlings on a spot cause a significant reduction in height and diameter growth (Campbell 1983).

Time and rate of sowing

Longleaf pine seeds can be sown in the fall or late winter, except in a few unusual situations. Sowing in late winter may be most preferable on many sites, but the decision must rest on careful appraisal of several factors.

Sites with heavy soils and sparse vegetative cover are often subject to frost heaving and should be sown in late winter. Areas subject to early droughts should be sown in the fall, to give seedlings time to develop good root systems before severe dry weather occurs. However, when seeds are sown in the fall, newly germinated seedlings are susceptible to damage by small animals, primarily rabbits, that clip the tender seedlings near the groundline when other green vegetation is scarce. Losses due to clipping, which average about 25 percent during the winter, have exceeded 75 percent in some situations (Mann 1970). Consequently, February sowing is preferred if clipping has been a problem in the past or if the rabbit population is high.

Optimum sowing rates vary by method of sowing, soil condition, cover, site preparation, predator populations, stocking objectives, climate, and brown-spot needle blight hazard. However, most landowners employ a single rate for each method of sowing. In the West Gulf region, recommended rates per acre are 3 pounds for broadcast sowing, 2 pounds for disk seeding, and 1 1/2 pounds for furrow seeding. These weights are for dry seeds that have not been coated with repellents. The rates can be reduced about 35 percent on moist sites in the Southeast, where initial establishment and first-year survival are generally higher. Viability is assumed to be at least 75 percent; the rates will need to increased proportionally if germination is lower.

Recommended uses of direct seeding

Although direct seeding is not now widely used to regenerate longleaf pine, it does meet several reforestation objectives. Seeding is an excellent technique for landowners to inexpensively regenerate small acreages. Seeding has also been used to quickly reforest large acreages ruined by wildfires. Clearly, direct seeding will continue to be used to meet these special needs. However, general interest in direct seeding has decreased due to the lack of control of tree spacing and failures under unfavorable climatic conditions. Furthermore, direct seeding does not efficiently utilize genetically improved seeds because several seeds are needed to establish one seedling.

PLANTING SEEDLINGS

Relative merits of container and bare-root stock

The relative merits of container and bare-root seedlings have been discussed by various authors (Stein et al. 1975, Stein and Owston 1975, Barnett and Brissette 1986). Some of the advantages and disadvantages of container stock are listed in Table 1.

Table 1.--Advantages and disadvantages of container-grown longleaf pine seedlings.

Advantages	Disadvantages
Production is fast	Require more attention while growing
Planting season is extended	May cost more
Performance is improved	Are bulky to handle
Performance on adverse sites is relatively good	May require more intense site preparation
Uniform seedlings are produced	Are often of smaller size
Planting rates are fast	Field data are insufficient to reliably identify the characteristics of high-quality seedlings

Container-grown longleaf pine seedlings for planting can be produced in 16 to 20 weeks. If needed, seedlings can be produced and fall-planted in years when spring survival checks indicate replanting will be necessary. Progeny tests can be produced and outplanted the spring after fall seed collection. In both cases a year is saved compared to bare-root methods. Flexibility in production is also possible because container seedlings can be planted throughout an extended planting season, provided that soil moisture and climatic conditions are favorable for growth. Container-grown seedlings perform better on adverse sites than bare-root seedlings, and because growing conditions can be better controlled, container planting offers the potential for increasing seed efficiency, such as a higher plantable-seedlings-to-filled-seeds ratio. This is especially important for valuable or limited seed sources, such as clonal seed orchard lots.

There are, however, some disadvantages to the production and use of container seedlings (Barnett 1978, Stein and Owston 1975). The conditions that hasten container seedling development are also conducive to disease, nutritional imbalances, and other problems. Trees produced in containers are likely to cost more than bare-root stock from existing, depreciated nurseries, but not necessarily more than seedlings from a new bare-root nursery (Guldin 1983). Container seedlings are bulkier to transport and must be handled differently from bare-root seedlings. On sites with severe herbaceous competition, more complete site preparation may be necessary for success with container seedlings because seedlings may be smaller than bare-root seedlings (Ruehle et al. 1981).

Although there are biological and production advantages to be realized from growing seedlings in containers, success ultimately depends on field performance (Fig. 1). Survival of container-grown seedlings has generally exceeded that of bare-root stock, and growth comparisons are good (Barnett 1980, Boyer 1985, Goodwin 1976, Guldin 1982, South and Barnett 1986, Wood and Lauer 1985). Goodwin (1976) reports that container stock clearly outperforms bare-root stock when age-from-seed is considered. Comparisons of longleaf container and bare-root seedlings that are outplanted at the same time indicate that container seedlings can perform as well as or better than bare-root seedlings when high-quality stock is used (Boyer 1985). Goodwin (1980) found that after five growing seasons, container longleaf pine seedlings survived better and 'grew faster than 1+0 bare-root stock when planted on sandhill sites. He noted that container stock could be used to extend the normal planting season and also to replace bare-root seedling failures in the same growing season where there was sufficient soil moisture.

Amidon et al. (1982) reported that under droughty conditions container longleaf pine seedlings survived and grew better than bare-root stock when the container seedlings were outplanted in the late summer before the normal bare-root planting season. Even under severe moisture stress, container seedlings outperformed bare-root seedlings when outplanted at the same time in early spring.

The use of container longleaf pine seedlings has increased significantly in the Southeastern United States. This is due to superior field performance by container stock, particularly on severe sites.

Relating seedling quality to field performance

Need for quality seedlings.--In recent years planting stock quality has become important. Workshops have emphasized the technology to produce high-quality stock (Duryea 1985). The level of interest in this topic reflects the biological, economical, and managerial importance of getting plantations off to a good start.

To foresters, the ultimate measure of seedling quality is field performance. In terms of field performance, stock quality is a function of the seedlings' potential to survive and grow, after outplanting. Seedling quality represents a complex integration of physiological and morphological characteristics and therefore cannot be measured easily. Also, stock quality must be defined for a specific point in time, because subsequent handling, storage, or planting techniques can have a major impact on ultimate field performance.

High-quality longleaf pine seedlings can be grown as either bare-root or container stock. For either type of stock, morphological characteristics are used to define seedling quality. The most widely accepted standards for describing southern pine bare-root stock are Wakeley's (1954) morphological grades. These grades emphasize root collar diameter and classify as cull any longleaf pine seedling with a ground line diameter of less than 3/16 inch (Table 2). Similar standards have not been developed for container stock, although experience indicates that they should be similar.

Table 2.--Specifications for morphological grades[1/] of uninjured l-year-old longleaf pine seedlings (Wakeley 1954).

Grade	Usual[2/] heights	Thickness of stem at ground	Needles	Winter buds
	Inches	Inches		
1	12 to 16	1/4 to 1/2 or larger.	Abundant. Almost all in 3's or 2's.	Usually presen with scales.
2	8 to 15; 6 to 8 if stem and buds are good	3/16 part in 3's or 2's.	Moderately abundant; at least lacking.	Buds with scales usually
3	Less than 8 3/16	Less than short: often none in 3's	Scanty; or 2's.	Not present.

[1/] Grades 1 and 2 usually considered plantable; Grade 3 is culled.
[2/] Needle lengths of longleaf pine seedlings.

Wakeley's morphological grades were developed after years of observing the various morphological characteristics of each planted seedling and relating these characteristics to later survival and growth. Generally, the distinction between plantable and cull seedlings can easily be substantiated by outplanting. However, because of a number of exceptions, Wakeley (1949) recommended using physiological grades that might better reflect survival and growth potential. Since Wakeley's time, progress has been made in the physiological evaluation of planting stock, with root growth potential receiving the most attention (Stone 1955, Stone and Jenkinson 1971, Burdett 1979, Ritchie 1985, Carlson 1985, DeWald and Feret 1988). 'None of this important work has been done with longleaf pine, although work is now underway to evaluate performance attributes as a means of relating nursery cultural techniques to field performance.

Although morphological grades have limitations, they have provided an easily used method to predict seedling growth and survival after outplanting. The most significant modification that has been suggested since Wakeley's original classification, which was developed more than 35 years ago, is in the minimum root collar diameter requirement. White (1981) reported that seedlings with root collar diameters of less than 4/10 inch did not survive well after storage. Lauer's (1987) data indicated that for seedlings not undergoing a period of storage, permissable root collar diameters were between 3/16 and 13/16 inch. However, seedlings whose root collar diameters exceeded 7/16 inch resulted in planted seedlings with improved height, increased survival after the grass stage, and improved brown-spot resistance (Table 3). The only differences in the studies of White (1981) and Lauer (1987) seem related to the storage of seedlings---small seedlings may survive if planted promptly and not stored. This reinforces the commonly accepted conclusion that longleaf pine seedling performance decreases rapidly with storage (Kais and Barnett 1984).

Table 3.--Average survival and growth of longleaf pine seedlings by seedling size class after 3 years in the field (Lauer 1987).

Seedling size class	Height[1/]	Trees out of grass stage	Survival
---Inches---	--Feet--	---------Percent---------	
3/16 to 5/16	0.9 a	55 a	82 a
6/16 to 7/16	1.5 ab	71 ab	87 a
8/16 to 9/16	2.2 b	87 b	88 a
10/16 to 11/16	3.2 c	98 c	92 a
12/16 to 13/16	4.0 c	98 c	90 a
>13/16	5.1 d	96 c	83 a

[1/] Column means followed by the same letter do not differ significantly at the 0.05 level of probability. Comparisons of percentages used the arcsine transformation, but actual percentages are reported.

These data show that high-quality seedlings, based on morphology just prior to outplanting, are essential for acceptable field performance. Based on past research and years of observing planting results by field foresters, a longleaf pine seedling ideotype--or target seedling--can be described. The concept of a target seedling should include the acceptable range for each attribute, consequently reflecting the current state of knowledge. As more evidence is accumulated, the target specifications should change or be confirmed. It should be emphasized that different target seedlings may be appropriate for different geographic locations or site characteristics. The value of a target seedling is that it provides a goal for the nursery manager and a standard of comparison for the forester. Longleaf pine target seedlings should generally have a root collar diameter of at least 4/10 inch, a well-developed terminal bud, many largely fascicled needles free from brown-spot disease, a mycorrhizal root system with numerous 6- to 8-inch lateral roots; and a stout taproot 6 to 8 inches long (Dennington and Farrar 1983).

Producing seedlings of desired quality.--The goal of the nursery manager is to grow the greatest percentage of a crop to target seedling specifications. The more uniform the crop, the easier it is to produce the greatest number of seedlings of the desired quality. Crop uniformity requires sowing highly viable seed lots. Seed quality can be markedly reduced by poor seed extraction, processing, or storage practices. Longleaf pine seeds are the most sensitive of southern pine seeds and require unusual care through the collecting, processing, and storing processes.

Cones should be collected when fully mature and should be processed promptly (Barnett 1976, McLemore 1960). Temperature and duration of kiln drying are critical for longleaf pine. Rietz (1941) found that temperatures of 115° F or more reduced viability. After kilning, the seeds must be dewinged, cleaned, and dried. Longleaf pine seed wings are not completely removed in the dewinging process; they are merely reduced to stubs. Wet dewinging does not work with longleaf. In fact, longleaf seeds must have low moisture contents if dewinging is to be effective. Injury due to the dewinging process is common in longleaf pine, and mechanical dewingers must be carefully regulated to prevent injury. Wing removal that does not damage seedcoats will have no effect on seed quality (Barnett 1969, Belcher and King 1968). Although storing longleaf pine seeds requires greater care than other southern pines, the seeds can be kept highly viable for at least 10 years at a temperature of 0° F and moisture contents of 10 percent or less (Fig. 2).

Recently there has been interest in stratification of longleaf pine seeds to improve germination. This is a questionable practice, since stratification is not usually considered necessary for longleaf (Nelson 1940, Wakeley 1954). Both early research (Nelson 1940) and more recent evaluations (Barnett, unpublished data) show that stratification usually has a deleterious effect on germination. Also, stratified longleaf seeds are very susceptible to germination during storage and subsequent injury due to handling. Stratification cannot be considered an alternative when improper collecting, processing, and storing procedures have been used.

Producing a crop of seedlings to target specifications requires a thorough knowledge of how the seedlings will grow and respond to cultural manipulation. In a bare-root nursery, the first considerations are sowing date and seedbed density. Longleaf pine can be sown either in the fall or spring. Fall sowing dates are usually between October 15 and November 30 (May 1985). Fall-sown longleaf seeds germinate immediately after sowing,' allowing the plants to establish a deep taproot and produce larger seedlings. Shipman (1958) found that fall-sown stock survived better than spring-grown seedlings when planted on abandoned fields and sandy sites. Longleaf pine seeds germinate better at temperatures lower than those required for the other southern pines. So if the seeds are spring-sown, they should be sown earlier than the other species, which should also lessen the likelihood of the seedling being attacked by pathagens.

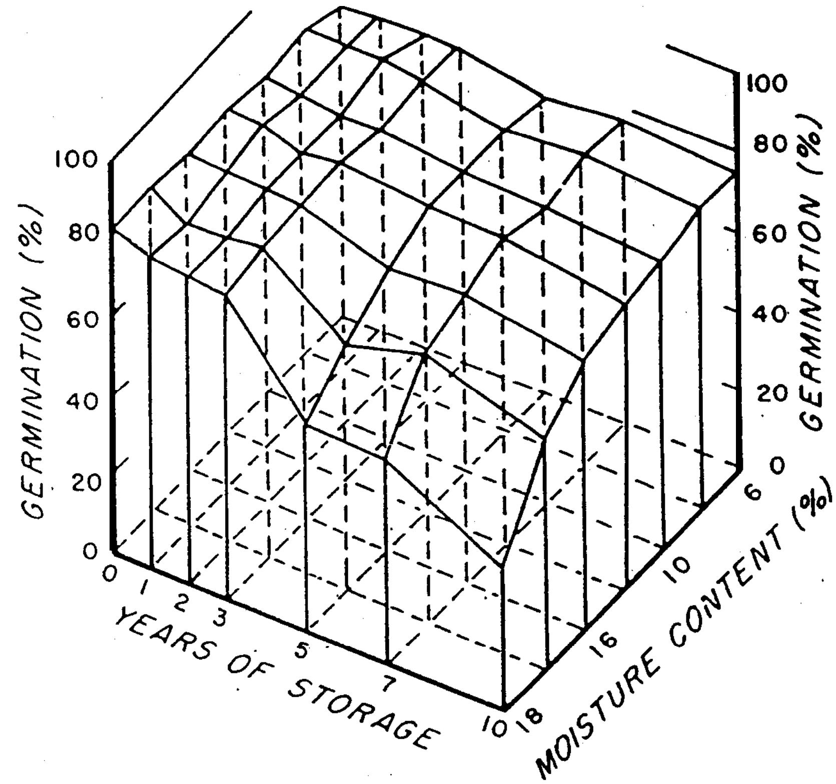

Figure 2.--Germination of longleaf pine seeds as influenced by moisture content and years of storage at 0° F.

Seedbed density has a tremendous impact on bare-root seedling morphology, especially root-collar diameter and root mass. Many of the early survival problems with planted longleaf seedlings resulted from growing seedlings at densities that were too high. Scarbrough and Allen (1954) showed that seedlings grown at 12 per square foot of bed averaged 25 percent higher survival at 1 year than those grown at 36 per square foot. At the end of the second year, 73 percent of the survivors from the low-density beds were starting height growth, as compared to 22 percent for seedlings from high-density beds. Derr's (1955) work comfirmed these findings: survival of seedlings grown at 10 per square foot was 33 percent better than those grown at 30 per square foot. These and later studies indicate that longleaf pine bare-root seedlings should be grown at about 10 to 12 per square foot, certainly no more than 15 per square foot.

For high-quality container stock, longleaf pine seedlings should be grown at 50 or less per square foot and should be grown outside in full sunlight during the summer months. If the seeds are sown in May or early June, high-quality stock will be ready for planting by late summer or early fall. The root-collar diameter of these seedlings might not average 0.4 inch, but they should be between 0.3 and 0.4 inch. Container longleaf pine seedlings of this size will perform well in the field because of the intact root system. Outplanting of container stock between October and early December is particularly desirable for droughty sites if soil moisture is adequate because the root systems become well established during the winter months before spring droughts occur. The fall planting period is usually drier than the spring, so particular care should be given to soil moisture availability. **Longleaf** pine is shade intolerant, and growing in full sun increases seedling and root system development markedly (Barnett 1989a).

As seedlings become established in the nursery, they enter a rapid growth phase. In this stage the nursery manager should promote growth by maintaining adequate levels of soil moisture, by fertilizing, and by controlling weeds and diseases. As seedlings approach target size, cultural treatments are used to limit growth and improve performance after lifting. At this stage, the nursery manager may induce stress by withholding water and applying undercutting. Shoulders (1963) reported that root pruning between 6 and 8 weeks prior to lifting improved seedling survival up to 39 percentage points on a good site and up to 42 points on a poor site. It is important to do any root pruning in the nursery bed rather than after lifting. Root pruning done in the field prior to planting can reduce survival by 12 percent and lower the proportion of live trees that initiate height growth by 9 percent (Lauer 1983).

Needle clipping, a routine practice in most nurseries to prevent needle lodging and control shading, seems to improve seedling performance on droughty sites (Allen 1955, Derr 1963). Early and severe needle clipping of **longleaf** container stock markedly slowed seedling development, whereas clipping shortly before outplanting improved survival when seedlings were exposed to significant moisture stress following planting (Barnett 1984).

Care and handling of seedlings

High-quality bare-root seedlings require careful lifting and handling to ensure good survival and growth after outplanting. Since **longleaf** pine seedlings do not store as well as other southern pines, lifting schedules need to be coordinated with planting needs to minimize storage time.

Standard timing guidelines for lifting of **longleaf** pine seedlings have not been developed. Brissette et al. (1989) have indicated that the optimum "lifting window" and length of storage may vary by seed source, but detailed recommendations are not yet available. The best lifting times for **longleaf** pine seedlings are considered to be in January and early February.

After lifting, seedlings are prepared for shipment to the planting site. This preparation may include passing the seedlings over a grading table. Although seedlings are seldom graded, broken, diseased, and excessively small or large seedlings are usually culled prior to packing. Seedlings grown at recommended **seedbed** densities (10 to 15 per square foot) may be lifted and field packed without grading because at these densities about 90 percent will be plantable. Regardless of timing or method of lifting, attention must be directed to: **(1)** retaining the maximum number of fiberous roots, (2) avoiding damage to roots and tops, and (3) preventing seedling roots from drying or becoming hot.

Ideally, seedlings should be planted as soon as possible after lifting. Often, however, seedlings must be stored for various periods to accommodate planting schedules. Since longleaf pine seedlings are extremely perishable, planting should be scheduled within 1 week of lifting. Consequently, seedlings are treated 'with clay-water slurries and synthetic superabsorbents to prevent the root systems from drying (Dierauf and Marler 1967). Some workers report that clay slurries are more effective than superabsorbents (Goodwin 1982, Windsor et al. 1982), but others have found that seedlings packed in superabsorbents perform better (Venator and Brissette 1983). There seems to be no clear advantage in the selection of one type of product over the other--reasons for preferring one system over the other include ease in application and handling.

Recent studies have shown that longleaf pine seedling establishment can be improved dramatically by the incorporation of a fungicide such as benomyl into the seedling packing medium at the time of lifting (Barnett et al. 1988, Kais et al. 1986). Benomyl is useful in controlling brown-spot disease for a year or more after planting and in improving the survival of seedlings following any period of storage (Fig. 3). Since the response to the use of benomyl is so impressive, it is recommended for all longleaf bare-root stock. It will markedly improve survival and early height growth, as well as eliminate the need for prescribed burns for brown-spot control.

Seedlings should be stored and transported under refrigerated conditions (34° to 38°F), both at the nursery and at field sites. Lengths of storage should be minimized (White 1981).

Proper Planting Procedures

Longleaf pine seedlings have little stem elongation in the nursery, therefore careful control of planting depth is critical. Smith's (1954) study of planting depth indicated shallow planting resulted in reduced survival, even poorer than deep planting. With the exception of trees planted 1/2 inch deep, the greater the deviation from a correct depth, the poorer the survival. Thus, the seedling bud should be planted between ground level and 1/2 inch below ground level. Machine planting is considered more effective than hand planting because seedlings with large root systems typically are difficult to hand plant. Planting machines should be adjusted to produce a clean hole 10 to 11 inches deep, insuring that the hole is closed firmly from top to bottom and that there is minimal surface soil disturbance. The speed of the tractor pulling the planter should be slow enough to allow careful and accurate placement of seedlings. The large root systems and critical bud placement of longleaf seedlings may require a slower speed than what would be required for either loblolly or slash pine seedlings.

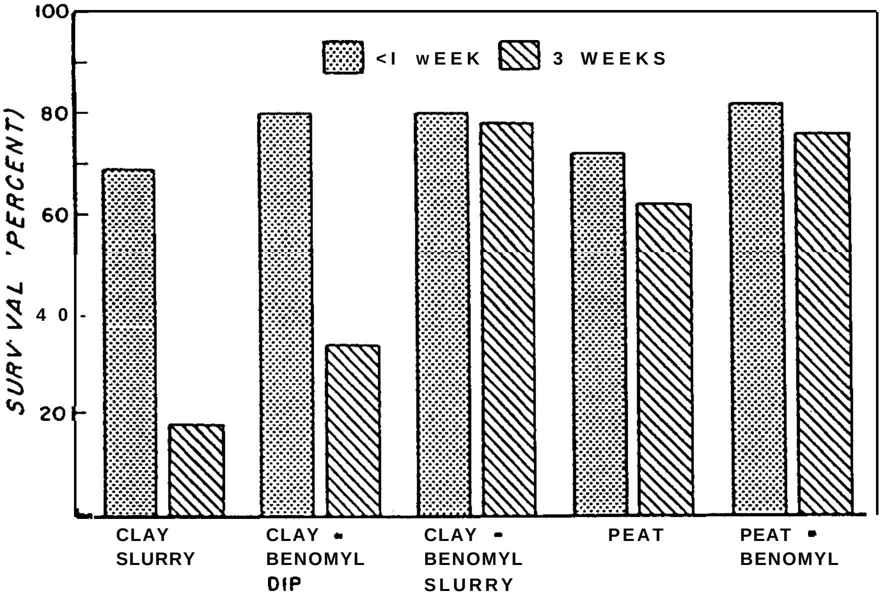

Figure 3.--Survival of longleaf pine seedlings stored for less than 1 week and for 3 weeks with various nursery packing materials, measured after 2 years in the field.

EVALUATION OF REGENERATION SUCCESS

An important consideration in the regeneration of longleaf pine is the evaluation of planting or direct seeding success. A walk through the area is not an adequate evaluation technique because longleaf seedlings in the grass stage are very difficult to locate unless the surrounding vegetation is brown. The most reliable means of evaluation is to intensively survey randomly selected areas after planting is completed. Terry (1983) suggests establishing twenty 1/100-acre plots on a grid on large tracts in March or April following planting. The center of each plot should be marked with a stake, the plot located on a map, and each planted seedling flagged. In the fall after the grass has died, the surviving seedlings should be located and counted.

If at least 300 healthy, well-distributed seedlings survive per acre, replanting would probably not be economical. When first-year stocking is unsatisfactory (<300 seedlings per acre) it is often best to burn the area and replant. If the shortfall is determined early enough, high-quality longleaf pine container stock can be used for interplanting the following summer or fall (Goodwin 1980).

Campbell (1982) provides a detailed description of how to make inventories of direct-seeded stands. A thorough evaluation is necessary. Many direct seedings have been judged as failures simply because the evaluators did not locate small seedlings in a grass rough.

POSTPLANTING CARE

Because of the grass-stage phenomenon of longleaf pine, special care is required after planting to assure reforestation success. During the evaluations of survival, problems common to longleaf pine should be identified. These normally will be either the development of significant levels of brown-spot disease on the needles or competition that limits the initiation of height growth. Plantations that survive the first year may be lost later if some type of corrective action is not taken. Generally, there are two approaches for overcoming these problems. One approach uses prescribed burning to reduce the amount of competing vegetation and the brown-spot inoculum present on the seedlings (Wahlenburg 1946). Another approach is to use appropriate herbicides to reduce vegetation that competes for light and moisture. Herbicides selected for grasses are very effective for longleaf pine and markedly speed height initiation (Boyer 1985, Hill 1985).

Although both site preparation and postplanting care are important in obtaining adequate seedling survival, another important consideration is the rapidity of initial height growth. If site preparation is initially adequate and quality planting stock is used, there may be little need for postplanting care. However, many typical longleaf siteswill often benefit from extra efforts to control competition. Shoulders and Wilson (1962) found significant improvements in longleaf pine height growth with furrowing and disking of the site prior to planting. At age 5, seedlings on furrowed and disked plots averaged 4.8 feet tall, twice that of an unburned grass rough. Boyer (1985) found postplanting treatments to control competition significantly increased initial height growth.

CONCLUSIONS

Longleaf pine can be successfully regenerated if the task is approached systematically. Survival and growth should attain levels similar to those of other southern pines. If fact, large-scale applications using the techniques described in this paper now are being routinely made (Sirmon and Dennington 1989, Wood 1985). The key elements for consistent success are: (1) the use of high-quality seedlings (or seeds if direct seeding) from the proper seed source, (2) preparation of the site to control most competing vegetation, choosing a method that prevents soil erosion or loss by nutrients, (3) careful lifting, storing, and transporting of seedlings and the inclusion of benomyl in the packing medium, (4) planting the seedlings carefully while controlling the planting depth, and (5) evaluation of the planting or seedling operation, applying postplanting treatments if necessary to promote early height growth.

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NATURAL REGEMERATIQN OF LONGLEAF PINE

William D. Boyer and John B. White[1]

Abstract. Longleaf pine natural regeneration is a practical and inexpensive option fcr most existing longleaf pine forests, provided there is an adequate seed source and competition in the stand is controlled. The shelterwood system appears best suited to the requirements of the species. The final harvest takes place after the new stand is established, so the land is not out of production during the wait for a good seed crop. The shelterwood stand maximizes per-acre seed production, and produces sufficient needle litter to fuel fires hot enough to limit hardwood encroachment. Careful advance planning, annual monitoring of cone crops, annual regeneration surveys, and proper timing and execution of cultural treatments, including regeneration cuttings, are essential to success.

INTRODUCTION

Longleaf pine (Pinus palustris Mill.) was once the premier timber species in the southeastern United States. It comprised an estimated 200 billion board feet, and occupied perhaps as much as 60 million acres in presettlement times (Wahlenberg 1946). The longleaf forest has been intensively exploited, beginning with the earliest settlers, for a wide variety of products and uses (Croker 1987). Logging of the original old-growth forest reached a peak in the first two decades of the twentieth century as lumbermen progressed from east to west, cutting merchantable trees with little or no thought for regeneration of this once vast resource. By the middle 1930s, according to an early forest survey, the resource was down to an estimated 19 to 22 billion board feet or about 10 percent of the estimate for the original forest (Wahlenberg 1946). Since then, forest surveys indicate that the longleaf timber type continues to decline, from an estimated 12-13 million acres in 1955 to less than 4 million acres by 1985.

The natural range of longleaf pine extends along the Atlantic and Gulf Coastal Plains from southeast Virginia south to central Florida and west to east Texas, with extensions into the Piedmont and Mountain Provinces of Alabama and northwest Georgia. The original longleaf pine forests occurred on a wide range of site conditions, from poorly drained flaiwoods near the coast to dry, rocky mountain ridges at elevations up to 2,000 feet.

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1 Research Forester, Southern Forest Experiment Station, USDA Forest Service, Auburn University, AL 36849, and Forester, Mississippi National Forests, USDA Forest Service, McHenry, MS' 39561

Longleaf pine has many desirable attributes. It is a high-quality timber tree suited to a wide range of products: logs, poles, piling, posts, pulpwood, and naval stores. Both its stumps and straw are also useful products. The tree is straight and prunes itself well. It almost always has a higher average specific gravity than other southern pines and thus produces more dry weight per unit of volume (Zobel et al. 1972). On average sites, depending on age and density, 30 to 80 percent of a longleaf stand will usually make poles. In addition to its commercial quality and versatility, longleaf is a comparatively low-risk species to manage, once established. It is considered a fire subclimax forest type that has maintained itself over the millennia in conjunction with periodic surface fires (Boyer and Peterson 1983). It is generally resistant to fire, as well as the more serious disease and insect pests that afflict other southern pines.

Longleaf pine has maintained itself in nature and, following logging of the old-growth, second-growth stands fortuitously sprang up on many millions of acres. These stands are now mature, and comprise a large fraction of the residual longleaf pine acreage. Nature regenerated these stands with little help from man. However, due largely to regeneration problems, most second-growth longleaf forests, upon harvest, have been replaced by other species.

Regeneration of longleaf pine, either naturally or artificially, has been inhibited by several problems associated with this species. First, it is a poor seed producer, and good seed crops are few and far between. Second, relatively few longleaf seeds survive to become established seedlings, due in part to the large number of predators that seek out and devour these large, nutritious seeds. Third, the slow early growth of longleaf seedlings means that they may spend years in the stemless "grass stage" before initiating height growth. Yet, these serious problems can be largely overcome. Although planning and care are required, longleaf pine can be regenerated naturally (Croker and Boyer 1975) by direct seeding (Mann 1970) and by planting (Mann 1969).

Selection of the appropriate regeneration option depends on several considerations, including site and stand conditions, management goals, financial resources, and planned rotation length. Natural regeneration is the lowest cost option, but is applicable only where there is an adequate number and distribution of seed-bearing trees. With the knowledge now available, foresters should be able to regenerate most existing longleaf forests naturally.

ECOLOGY OF LONGLEAF PINE NATURAL REGENERATION

Seed Production

Flowering - Longleaf pine is monoecious, as are all pines. Both the male and female flowers (strobili) are initiated during the growing season before flowers appear, the male flowers normally in July and the female flowers during a short period in August, as the overwintering bud is set. Weather conditions during the year of initiation appear to influence flower production. A wet spring and early summer followed by a dry late summer promote production of female flowers (Shoulders 1967), while wet weather through the entire growing season favors production of male flowers. As a result, large crops of female and male flowers do not necessarily coincide (Boyer 1981).

The development rate of both male and female flowers is almost entirely temperature dependent, and cumulative daily heat sums from December 31 can be used to anticipate peak flowering date (Boyer 1978, 1981). The emerging buds of male flowers can usually be seen by late November, but remain dormant for about a month before development resumes. Female flower buds emerge in January or February. Female flowers occur most frequently in the upper crown and male flowers in the lower crown (Schopmeyer 1974).

Peak flowering of longleaf pine usually occurs in March, but may be as early as late February or delayed into the month of April. Flowering of both male and female flowers on the same tree reaches a peak at about the same time. Individual trees, however, may vary considerably in date of peak flowering. Some are consistently early, others late (Boyer 1981).

Cone production - Cone production by individual longleaf pine trees is affected by site quality, stand density, tree size, and genetic predisposition (Croker and Boyer 1975). The best cone producers are dominant trees 15 inches or more in d.b.h., with large crowns and a history of past cone production, as evidenced by old cones under the tree. Tree size is an important factor in cone production. A tree 15 inches d.b.h. will produce, on the average, more than twice as many cones as a 12-inch tree, and a 19-inch tree more'than twice as many cones as the 15-inch tree. Cone production per acre is affected by stand, density and, on average sites, reaches a peak at stand basal areas between 30 and 40 ft^2 per acre and falls off rapidly above and below this range (Croker and Boyer 1975). For a given stand density, per acre cone production is not greatly affected by increasing tree size above 15 inches d.b.h., as the increase in cone production per tree is largely offset by the reduction in trees per acre.

Longleaf pine cone production varies considerably from year-to-year and from place-to-place. Given the optimum number and quality of seed-bearing trees, the region-wide frequency of cone crops adequate for regeneration approaches one year in three. Among observed locations, the frequency of acceptable cone crops ranged from 3 years out of 4 to zero over a period of 19 years (Boyer 1987). The frequency of good cone crops appears to be lower nearer the Gulf Coast than farther inland. Since flower production is less variable among geographic locations than cone production, differences in the frequency of good cone crops appear to be due more to flower and cone losses rather than a failure to flower.

Seed Dispersal

The large, winged seeds of longleaf pine are dispersed by the wind. Seedfall begins in late October and continues through November. Most seeds fall during a period of two to three weeks. Dispersal range is limited, with 71 percent of sound seeds falling within 66 feet of the parent tree (Boyer and Peterson 1983).

Seedlins Establishment

Longleaf pine seeds require contact with mineral soil for satisfactory germination and establishment. The seeds, with their large wings, cannot easily penetrate a heavy ground cover of vegetation and litter, so this material must first be removed, either mechanically or by fire. Usually, a burn within a year of seedfall will provide an adequate seedbed (Croker and Boyer 1975).

Longleaf pine seeds germinate promptly after they are dispersed, often within a week if weather conditions are favorable. This reduces the period of exposure to the many seed predators. Newly germinated seedlings have no hypocotyl, and the cotyledons are close to the ground. Primary needles appear soon after germination is complete, and secondary (fascicled) needles appear about two months later. Newly established seedlings are vulnerable to a number of hazards, including insects and other animals, diseases, fire, and unfavorable weather such as drought, flooding, excessive heat or cold, and frost-heaving on heavy soils. The risk of seedling mortality is highest during their first year and much lower thereafter. For this reason, regeneration success is based only on seedlings one year old or older.

Seedlins Survival and Growth

Unlike most other pines, epicotyl or stem growth in longleaf pine is slow to develop. The stemless condition of the seedling is characteristic of longleaf and is referred to as the grass stage, which may last from two to many years, depending on site, competition, disease, and weather conditions. While in the grass stage, longleaf seedlings develop extensive root systems. Development can be followed by observing the increase in root-collar diameter. Rapid height growth normally begins as seedling root-collar diameter reaches about one inch.

Longleaf seedlings are highly sensitive to competition from any *source* and are also susceptible to the brown-spot needle blight (Scirrhia acicola (Dearn.)Siggers), either of which can prolong the grass stage. The disease may eventually destroy the seedling.

Grass-stage longleaf seedlings in the open become relatively resistant to fire damage when they reach a root-collar diameter of 0.3-inch and remain resistant until they initiate height growth. Longleaf seedlings of this size owe part of their fire resistance to their ability to sprout from the root collar if top-killed by a fire hotter than expected, although sprouting ability declines rapidly after seedlings begin height growth (Farrar 1975). The large, succulent foliage of longleaf also helps protect the bud and stem from heat injury in surface fires.

Given longleaf pine seedling stands of the same size (root collar diameter), fire mortality of seedlings under a pine overstory will be about double that of similar seedlings in the open (Croker and Boyer 1975). Within forest stands, healthy grass-stage seedlings that have reached 0.4-inch or more in root-collar diameter are relatively safe from mortality in carefully prescribed and executed winter fires (foyer 1974a), even under parent overstories ranging up to 60 ft basal area per acre (Maple 1969). Some fire-resistance is lost during the early stages of height growth, up to a height of 2 to 3 feet, after which the seedlings again become less vulnerable to fire kill (Maple 1975).

Longleaf seedlings can survive under a parent pine overstory for at least 8 years and probably longer if they are not burned before reaching a fire-resistant size. Seedling growth, however, is very slow, and it can take a long time for seedlings to reach a fire-resistant size, depending on density of the overstory and amount of understory competition. Once the overstory is removed, seedlings will respond with increased growth.

Seedlings heavily infected with brown spot are at greater risk as the foliage, instead of protecting the seedling from fire, adds to the fuel load. However, brown spot is unlikely to reach serious levels in seedling stands retained under a pine overstory (Boyer and Peterson 1983), even at overstory densities as low as 9 ft^2 basal area per acre (Boyer 1975).

Growth rates vary widely among seedlings in a stand of the same age, and vigorous, brown-spot resistant individuals express early dominance. About 10 to 20 percent of a natural seedling stand will normally exhibit resistance to brown spot (Boyer 1972). The rapid breakup of a seedling stand into a range of size classes reduces the risk of stagnation and usually eliminates any need for precommercial thinning.

NATURALLY REGENERATING THE LONGLEAF FOREST

Reseneration Methods

Natural regeneration methods suited to longleaf pine are limited. Longleaf, like many other pines, is an intolerant pioneer species that normally establishes and maintains itself in even-aged stands. Even-age management can most effectively and efficiently capitalize on the natural habits and characteristics of the species. Neither the clearcutting nor the seed tree method of natural regeneration is effective for longleaf (Croker and Boyer 1975). Clearcutting a mature stand will destroy most advanced reproduction, if present, and the short seed dispersal range limits seeding from adjacent stands. Clearcutting, except in the case of a low- to medium-density stand with abundant advanced reproduction, must be followed by some form of artificial regeneration. A seed-tree method, leaving 5 to 10 residual trees per acre after harvest, is a high-risk regeneration method for longleaf, unless the cutting coincides with a heavy seed crop. A seed-tree stand produces only a fraction of the seed produced by a shelterwood stand, so the frequency of usable seed crops is much lower. During the wait for a good seed crop, growing space is rapidly occupied by hardwoods and brush, requiring rather costly seedbed preparation.

The shelterwood method seems to resemble most closely examples of successful regeneration in nature, and led to the hypothesis that this method is the most appropriate for longleaf pine (Croker 1956). This has since proven to be the case. The shelterwood method is highly flexible and can be adapted to a wide variety of site conditions and management objectives. The higher density shelter-wood stand retards the growth of hardwood brush and also produces enough needle litter to fuel surface fires hot enough to kill back invading hardwoods and'maintain good seedbed conditions.

Biological Requirements for Regeneration

Adeo-uate seed supply - An adequate seed source must be present in the regeneration area. The size, number and distribution of seed-bearing trees must be such that a minimum of 750, preferably 1,000 or more, cones per acre will be provided within the time span allotted for regeneration. Since average cone production varies with location, the expected frequency of usable cone crops must be based on local experience.

Pre-establishment comnetition control - Competition in the regeneration area, especially hardwood trees and brush, must be controlled before seedling establishment. Longleaf pine, especially in the seedling stage, is very intolerant of competition from all sources. Competition on the ground may also constitute a barrier between dispersed seeds and the soil surface.

Well-prepared seedbed - Longleaf pine seeds need to contact mineral soil for successful germination and establishment. A well-prepared seedbed will take optimum advantage of a limited supply of seeds, which is usually the case with this species.

Adequate establishment and survival - The criteria for successful regeneration can vary, depending on the landowner's requirements and management objectives. An accepted goal is a minimum of 500 well-distributed crop seedlings per acre at a height (> 3 feet) that is relatively safe from damage by a fire (Croker and Boyer 1975). This goal requires a far larger number of newly established seedlings due to variable, but often high, first-year mortality, the losses that accompany logging of the overstory, losses of vulnerable seedlings in periodic fires, plus normal attrition from insects, diseases, and other common hazards.

Post-establishment comnetition control - Elimination of all competition in a regeneration area is not practical, but an established seedling stand should be free from most overtopping competition. With the woody midstory and understory vegetation largely eliminated before seedling establishment, only the pine overstory and herbaceous vegetation on the forest floor remain as major competitors with a newly established seedling stand. Mature pines will retard seedling growth up to a distance of at least 55 feet, although degree of suppression diminishes with distance (Boyer 1963). Seedling growth will be slow until the parent trees are removed.

Control of brown-spot needle bliaht - This disease is the worst afflicting grass-stage longleaf pine seedlings, and is likely to intensify rapidly in a seedling stand following removal of the parent overstory. Fire is the cultural treatment used to control this disease in natural seedling stands, and may be prescribed for this purpose, depending on results of disease status surveys of dominant seedlings in the stand.

Protection of the seedling stand - The established seedling stand must be protected from untimely fire, which can be very destructive. Fire risk is highest for suppressed seedlings under a pine overstory and remains so for nearly two years after overstory removal. Seedlings should be protected from livestock, especially hogs that can rapidly destroy a grass-stage seedling stand. Grazing can remove the fuel needed to carry a fire for control of the brown-spot disease.

Management Requirements for Regeneration

Successful natural regeneration requires not only the necessary know-how but also commitment, time, manpower, and close attention to detail through the entire regeneration process. Careful advance planning is a must. The regeneration area must be closely and regularly monitored for competition intensity, prospective seed crops, establishment of regeneration, severity of brown spot, and presence of other hazards. Necessary cultural treatments must be properly prescribed, timed, and executed based on an intimate knowledge of conditions in the regeneration area.

The number of areas, or acreage, scheduled for regeneration within a selected time span should not exceed the capabilities and resources available within the responsible organization to meet effectively the requirements listed above.

Applying the Shelterwood System

The two principal variants of the shelterwood system applied to longleaf pine are the three-cut and the two-cut methods. They are identical, except that the three-cut method has a preparatory cut that precedes the seed cut. A well-managed longleaf pine stand periodically thinned to medium densities will not need a preparatory cut, so the regeneration process can begin with the seed cut. Planned regeneration of an unmanaged stand, or a stand with overstory pine densities in excess of 80 ft^2 basal area per acre, may need to begin with a preparatory cut. Guidelines for application of the shelterwood system of longleaf pine natural regeneration have been reported (Croker and Boyer 1975, Boyer 1979a).

Assuming that the three-cut shelterwood method is selected, it is typically applied as follows:

The Preparatory cut - This cut is made ten or more years before the planned harvest date of the stand at rotation end, and at least five years ahead of the seed cut. Stand density is reduced to a maximum of 60- to 70-ft^2 basal area per acre of dominant and codominant longleaf pines, depending on site quality. If there are gaps in the stand, the overall average density of the residuals will be somewhat less. This cut will promote crown development and thus cone production. At this time, hardwoods too large for control by fire should be harvested, if merchantable, or deadened. The regular use of prescribed fire during the rotation should have resulted in an understory essentially free of hardwoods and brush. If a large number of small woody stems are present, a series of annual or biennial growing season burns may be necessary to control this component of the understory. This control must be completed before the seed cut, while needle litter accumulation is sufficient to fuel relatively hot surface fires and a seedling stand has not yet been established.

The seed cut - This cut is made five years before the planned harvest. Residual parent trees in the regeneration area are marked to leave a density not exceeding 30 ft^2 of basal area per acre (the goal is not an average of 30 ft^2, as this might result in leaving, for example, 60 ft^2 in one location to compensate for a hole in another) of high-quality dominant trees with well-developed crowns, favoring those with some evidence of past cone production. Although cone production per acre peaks in the 30- to 40-ft^2 basal area per acre range, the lower end of the range is preferred, as logging-related seedling losses increase with increasing density of the overstory removed (Maple 1977b).

The dominant trees in the shelterwood stand will capture some of the released growing space, so even when stand density has been halved by the seed cut, merchantable volume growth is reduced only about 30 percent (Farrar 1985). The sacrifice in volume growth over a five-year regeneration period is not great and, when considering the value increment on high-quality residuals, the economic loss is likely to be less than the growth reduction alone would suggest.

A shelterwood stand still produces enough needle litter to enable continued prescribed burning with surface fires hot enough to check hardwood encroachment. The stand is also dense enough to retard growth of understory hardwoods, preventing them from reaching a fire-resistant size during a 2- to 4-year interval between burns.

Mortality among overstory pines remains about the same, per acre, after the seed cut as it was before. Long-term observations indicated an average annual mortality of one tree per 2.5 acres, although half of observed stands averaged less than one tree per 5 acres (Boyer 1979b). Much of this mortality in shelterwood stands can be salvaged in the final removal cut.

Monitor cone crops - Every effort must be made to utilize any good seed crop that occurs following the seed cut. This means that estimates of cone crop size must be made in advance. Such estimates are obtained by annual springtime binocular counts of both flowers and year-old conelets on selected sample trees within the regeneration area. These counts permit anticipation of cone crops potentially large enough to regenerate the stand so that cultural treatments for seedbed preparation can be carried out before cones open in the fall.

In practice, a total of 50 sample trees well-distributed throughout the regeneration area are selected and marked for annual springtime counts of flowers, conelets and, when desirable, open cones from the recent cone crop. This number should provide an estimate within about one-third of the actual value of average cones per tree. Binocular counts are made when both flowers (next year's cone crop) and year-old conelets (this year's cone crop) are most visible (Croker 1971). This is a relatively short period of time (2- to 3-weeks) in April or May before the flowers are obscured by developing foliage but after the enlarging conelets are easily seen in last year's foliage. When counts are completed, they are used to estimate cone crop size for the next two years. Flower counts are unreliable predictors of cone crop size because of the highly variable losses during the first year. Flower counts do, however, reliably predict cone crop failures. The conelet counts are fairly good predictors of cone crop size for the coming fall, and if they indicate an adequate cone crop (>750 cones/acre) is coming, action can be taken to prepare a seedbed. Cones per acre are roughly estimated by doubling the average conelet count per tree and multiplying by trees per acre, while average flower count per tree alone is multiplied by trees per acre (Croker and Boyer 1975). Local experience data on ratios between counts and actual cones produced can be gained by including counts of mature cones (on the ground and in the tree) produced by each sample tree.

Seedbed preparation - Assuming that most woody vegetation has been controlled, a prescribed burn within a year of seedfall should be all that is needed to remove accumulated litter and expose sufficient mineral soil for seedling establishment. If a winter seedbed burn is desired, it will be based on predictions from the more unreliable flower counts. A seedbed burn based on springtime conelet counts can be done as soon as scheduling and conditions permit. A late spring burn will be more effective in controlling any residual woody stems. A late summer or fall burn before seedfall will provide an adequate seedbed for two successive cone crops, if these are in prospect. However, a burn at this time of year is more likely to damage or destroy any longleaf seedlings already present in the regeneration area, and often results in increased.predation of longleaf seeds due to lack of a light, protective ground cover, and destruction of alternative foods.

If, for some reason, a prescribed fire cannot be used to prepare a seedbed, then some mechanical treatment (e.g. chop or disk) to expose mineral soil must be used. The combination of fire with a mechanical treatment may improve seedling establishment, but the increased cost may not be justified except in the case of a marginal cone crop, or if additional control of woody vegetation is required.

Regeneration survey - Regeneration surveys are initiated before the seed cut to determine the status of longleaf pine reproduction already on the site. If some regeneration is already present, another survey is taken a year after the seed cut. This will give logging slash some time to decay and allow damaged seedlings to recover or die. Status of regeneration is then monitored through annual regeneration surveys.

The regeneration area may be comprised of differing forest cover types, or a diversity of overstory and understory conditions. If so, it may be advisable to stratify the area into relatively homogeneous units, with a separate survey conducted in each. A common separation is that between longleaf pine upland and hardwood or pine-hardwood creek bottoms. The latter would not be included in the regeneration area. The upland itself may be stratified into units based on overstory or understory conditions that are expected to affect cone production or seedling establishment significantly. In practice, regeneration areas are usually small enough (less than 100 acres) that stratification of the longleaf upland is not necessary.

Regeneration surveys are made in the dormant season when the green grass-stage seedlings are easy to see. Grass and other herbaceous vegetation will obscure small longleaf seedlings during the growing season, making them very hard to find.

Nested, circular sample plots are easy to use and can provide all needed information on the number and distribution of longleaf seedlings in the regeneration area. A minimum of 100 nested 1/4-, 1-, and 2-milacre sample plots should be distributed throughout the regeneration area (at random, if sample confidence limits are desired). At each sample point a pin is stuck into the ground to serve as center of nested circular plots. If the smallest (1/4-milacre) plot is stocked with one or more seedlings, it is recorded as stocked, as are each of the two larger plots. If the smallest plot is not stocked, the next largest (milacre) plot is checked, and if it is stocked, then it and the largest (2-milacre) plot are both recorded as stocked. If the milacre plot is not stocked, then the largest plot is checked for stocking. During the survey, data on the condition of the best seedling in each stocked plot can be taken, depending on the kind of information needed for management purposes. Information that might be obtained includes:

(1) Size of the best seedling in each stocked milacre/2-milacre plot, namely root-collar diameter and height, if any, to base of terminal bud.

(2) Severity of brown-spot infection on the best seedling in each stocked milacre/2-milacre plot.

The above will provide information on the survivability of these seedlings, especially if the area must be burned for seedbed preparation or competition control.

Two-milacre stocking data provide information on the distribution and condition of the best 500 trees per acre, the most likely crop trees in the new stand. Milacre stocking provides data on the condition and distribution of the best 1,000 trees per acre, a better evaluation for young seedling stands. Milacre stocking of 75 percent or more is the normal criterion for successful regeneration after the removal cut, as this indicates at least 750 well-distributed seedlings per acre. Quarter-milacre stocking is used to estimate the number of seedlings per acre, as there is a close relationship between stocking percent and seedlings per acre (Boyer 1977). Seedlings per acre (Y) = $[(\text{Log}(1-X)/\text{Log}(0.53)]*4000$; when (X) is the proportion of quarter-milacre sample plots stocked with one or more seedlings.

The regeneration goal is 6,000 or more seedlings per acre at least one year old before removal of the parent overstory (Boyer 1979a). This number allows for logging losses of up to 50 percent of the seedling stand and still leaves enough surviving seedlings that the superior, fast-growing, brown-spot resistant fraction of the stand will provide 300 to 600 potential crop trees per acre. Quarter-milacre stocking of 62 percent indicates a seedling stand of about 6,000 per acre.

The goal of 6,000 seedlings per acre, while optimum, is not inflexible and may have to be adjusted downward due to local conditions. Some locations have a low frequency of good seed crops, so the chance of reaching the 6,000 seedling goal within a reasonable regeneration period is poor. The number, size and distribution of seed trees may also limit chances of reaching the goal. Failure to reach the goal within the time prescribed for regeneration leads to the option of harvest followed by artificial regeneration. However, the regeneration goal can be reduced by at least half and still retain a high probability of obtaining 500 well-distributed crop trees per acre, particularly if logging mortality is minimized through careful supervision. The manager may decide to accept an established seedling stand of as low as 2,000 per acre, especially if final harvest is due and no seed crops are in prospect, based on most recent flower and conelet counts in the regeneration area. If an inadequate seedling stand survives logging over all or part of the regeneration area, the artificial regeneration option is still available.

Small longleaf pine seedlings (<0.4-inch root-collar diameter) need protection from fire, so regular burning in the regeneration area should be discontinued following establishment of a good seedling stand. Seedlings established under a shelterwood overstory remain vulnerable to fire damage for some time due both to their slow growth and the presence of accumulated needle litter fuel, particularly under the crowns of parent trees. Under these conditions, any fire should be prescribed only for a necessary objective (seedbed preparation, competition control), with due regard for expected seedling mortality.

<u>The removal cut</u> - Once a satisfactory seedling stand is present, the parent overstory can be removed. If all has gone according to plan, the final harvest cut can be made on schedule, five years after the seed cut. However, the final removal cut can be delayed, if necessary, due to management needs or market conditions. Seedlings can survive seven or more years under a parent overstory with no effect on survival, provided the stand is not burned. However, seedling growth will be slow. When compared to a seedling stand released from overstory competition at age one, a shelterwood overstory of 30 ft^2 basal area per acre will account for 70 percent of the growth loss observed under overstory densities of 90 ft^2 basal area per acre (Boyer 1963).

The best time to remove the parent overstory, in terms of minimizing seedling mortality; is at seedling age 1 or 2. Mortality at this time has averaged 35 to 40 percent (Boyer 1974b). By ages 3 to 5, mortality has increased to 50 to 55 percent with overstory removal. Logging related seedling mortality also increases with increasing density of the parent overstory (Maple 1977b), from 42 percent with removal of 20 ft^2, to 54 percent with 40 ft^2, and 69 percent with 60 ft^2 basal area per acre. If density of the shelterwood overstory is 40 ft^2 or more in basal area per acre, it may be best to remove the overstory in two cuts rather than one. This reduces the load of logging slash on the ground at any one time, and can also result in additional seedling establishment between cuts. Logging damage becomes more serious once seedling height growth begins. Stemless grass-stage seedlings are less likely to suffer serious damage, and, even when they do, are more likely to sprout.

Seedling'mortality in removal cuts can be reduced with careful logging and close supervision. Log landings should be located outside the regeneration area if possible, and, if not, kept to an absolute minimum in size. Traffic should be confined to a minimum number of designated skid trails. Trees should be directionally felled, with butt toward a skid trail, and topped and delimbed where they fall. Logging slash should be dispersed as much as possible, as piles insure loss of seedlings buried underneath.

Post-harvest treatments - Following overstory removal, the principal factors affecting seedling development are competition intensity and the brown-spot needle blight. Prescribed fire is the most common cultural treatment used both to control brown spot and slow the development of competing woody vegetation. Timing of the burns is critical, as mis-timed fires can do more harm than good. The need for a burn must be carefully evaluated in advance, considering both the potential benefits and possible damage to the seedling stand.

Regeneration areas should not be burned until at least two years after the removal cut because of the excessive fuel load and the vulnerability of small, suppressed seedlings to fire. Two years allows enough time for both logging slash and accumulated pine needle litter to decay and the seedlings to respond to release.

The need for a brown-spot burn must be determined from a survey that carefully evaluates seedling condition and the distribution and severity of the disease. Status of the disease must be based on the best, or "crop," seedlings rather than the average seedling in the stand (Croker 1967).

Brown-spot surveys are normally conducted during the dormant season as part of the regeneration survey, as described earlier. The minimum of 100 sample plots in the regeneration area, for which brown-spot data are taken, may be one, two, or four milacres in size, depending on the manager's goal for crop seedlings: one milacre for the best 1,000, two-milacre for the best 500, and four-milacre for the best 250 well-distributed seedlings per acre. The crop seedling on each stocked sample plot is identified based on size, vigor, and freedom from brown spot. Root-collar diameter, height, and the amount of the current year's foliage destroyed by brown spot (estimated to nearest 10 percent) are recorded. Nature and condition of fuels in the regeneration area are also noted. The decision to burn can be derived from this information and depends on severity of the disease and expected mortality among crop seedlings from a cool winter fire. If average brown-spot infection on sample crop seedlings exceeds 20 percent, then a burn is needed to control the disease, provided it can be done without excessive mortality. The burn can be made in the spring or winter following the survey. Seedlings in the early stages of height growth are most susceptible to fire kill, especially if heavily infected with brown spot. Mortality risk for individual longleaf pine seedlings subjected to a winter fire can be estimated based on seedling height and percent of foliage killed by brown spot (Maple 1976). Since 10 percent or more of the stand should be resistant to brown spot, most of the crop seedlings may remain relatively free of the disease. In this case a fire need not be prescribed for brown-spot control.

Release of a longleaf seedling stand from competing vegetation will accelerate the early development of the stand, which has two major benefits. It will shorten the period of time that a seedling stand will be vulnerable to mortality from periodic prescribed fires and severe brown-spot infection. On the average, it may take three years after overstory removal for brown spot to reach a growth-retarding intensity in a seedling stand (Boyer 1975). If crop seedlings reach a disease-resistant size by this time, a serious brown-spot problem can be avoided.

Understory hardwood encroachment can be controlled with periodic prescribed burns. Burns in the spring (May) are not only more effective in controlling woody competition, but also actually seem to accelerate initiation of height growth by longleaf seedlings compared to similar seedlings burned in the winter or not burned at all (Grelen 1978, Maple 1977a).

If, after the final removal cut, a large number of fire-resistant woody stems are still present in the regeneration area, and are overtopping and suppressing pine seedlings, then a release treatment may be necessary, using a herbicide registered for this purpose. The cost of such a treatment will be high, but can be justified if required to insure survival and eventual dominance of the pines. This situation highlights the importance of controlling woody competition in the regeneration area <u>before</u> the seedling stand is established. Prescribed fire at two- to four-year intervals during the rotation is the most cost-effective way to attain this goal. The last opportunity to control woody competition efficiently and effectively is before the seed cut.

Modifications of the Shelterwood System

The shelter-wood method of longleaf pine natural regeneration, as described above, can be applied in three different ways, although there are gradations in between. These are:

<u>Block</u> - Blocks are associated with the establishment and management of even-age longleaf pine stands. The block is most likely to be a forest stand approaching rotation age that has been identified as a management unit. Block size can vary considerably. Most will fall between 10 and 100 acres in size, although some may be considerably larger. The area is normally enclosed, to the extent possible, within natural and artificial boundaries such as roads and creek or river bottoms. This will minimize the amount of artificial firebreaks that must be constructed and maintained, as the block will also comprise a burning unit.

Prosressive strip - The strip shelterwood, as applied here, aims to produce and maintain a range of age classes, from seedling to mature stand, within the larger management unit. Thus, completion of the cutting cycle will cover a rotation rather than a short span of years that results in a relatively even-aged stand over the unit. Strips are long and narrow, not exceeding 200 feet in width, so that all or most of the strip will be within seeding range of adjacent timber. Strip edges need not be straight, but can meander to fit the terrain. Strips should progress against the prevailing winds to facilitate seed dispersal into recently cleared strips. As the seed cut is made on the first strip, the preparatory cut is made on the next. At the next entry, assuming that a seedling stand has been established on the first strip, the overstory is removed. At the same time a seed cut is made on the second strip and preparatory cut on the third. Any gaps or holes in the first strip resulting from logging damage can be seeded in from trees on the second strip. Strips progress across the larger managementunit in this manner. When the removal cut is made on the last strip, it is time to make the seed cut on the first strip, completing a rotation. If needed thinnings are made throughout the unit at each entry, the two-cut method would be applicable, and the preparatory cut omitted.

Group - Group or "patch" shelterwood is descriptive of regeneration areas too small to be considered blocks. The break point in size between block and patch is rather broad and open to interpretation. The principal difference is that the block is a large management unit containing one age class, with much of the boundary based on natural or physical features or property lines. Patches begin as small regeneration areas within a larger area that is considered the management unit. As in the strip shelterwood, patches are created and regenerated over time in order to eventually obtain a full range of age classes within the larger unit. The shelterwood method is applied to patches in the same manner as in strips or blocks. At each entry new patches can be created, old ones enlarged, or both. In practice, patches initially are likely to range from 1/2 to 5 acres in size. If patches are enlarged by successive cuttings, they may come to resemble irregular strip cuttings.

The group or "patch" shelterwood method of regeneration described here is a technique appplicable to either even-aged management or uneven-aged management by the group-selection method. If the former, the even-aged stands created in the patches are identified and mapped on the ground and followed through time. If the latter, the entire management unit is treated as a whole, with no formal consideration given to the various age or size classes within the unit. Cutting is regulated by volume or stand structure (diameter distribution) control. The difficulty and cost of prescribing and applying cultural treatments and cuttings to, and maintaining records on, a large number of widely scattered small patches of varying ages strongly favors the uneven-age management option.

Manaaement considerations - A block comprising an entire, easily identifiable management unit within which an even-aged stand is created and maintained is the easiest and most efficient management method for longleaf pine, so this approach has been almost universally applied to the species. Examples of strip or patch shelterwood are rare. Strip or patch cutting in longleaf pine would be most applicable to small holdings where the owner wishes to have equal representation of all age classes on his property and, as a result, a fairly even flow of income and expenses. The patch shelterwood method of regeneration would also apply to those who wish to keep the size of clearings small, or to develop the group-selection method of uneven-age management for their forest.

The principal disadvantage of patch shelterwood for longleaf pine is the exposure of seedlings and saplings of this intolerant, pioneer species to prolonged suppression from adjacent older stands. Competition from a wall of mature timber extends 55 to 70 feet into an opening and can affect all or most of the seedlings in a clearing, depending on its size. Assuming a competition zone of 60 feet, 76 percent of a circular l-acre opening is exposed to competition from the side, as is 40 percent of a similar 5-acre opening. Some experience suggests that this type of management could result in mean annual volume increments substantially less than that expected of uniform even-aged stands under similar conditions of site, stand density and rotation length (Boyer and Farrar 1981, Farrar 1985). However, if the landowner's management objectives include creation and maintenance of the uneven-aged condition for his forest, the change in structure and appearance generated by patch cuttings may compensate for reductions in volume growth.

Another difficulty with both the strip and patch shelterwood is the use of prescribed fire, the principal cultural treatment in longleaf management. Needs will differ with stand age. While a shelterwood stand may need a seedbed burn, a seedling stand just beginning height growth may need protection from fire. Confining a burn to a single strip will be costly, due to the small area in a single age class. With patch cutting, burning (or omitting from a burn) just a single age class will be impossible as each age class occupies a number of small areas widely dispersed throughout the management unit. The manager can only adjust the timing and execution of periodic prescribed fires to accomplish priority objectives with minimum impact on the more fire-susceptible age classes. The general resistance of longleaf pine to fire damage throughout most of its life cycle and the breakup of a single age class into a range of size classes should result in minimal damage from careful prescribed fires.

CONCLUSIONS

Natural regeneration of **longleaf** pine is a low-cost regeneration alternative wherever there is an existing **longleaf** stand with a sufficient number of good seed-producing trees. The shelterwood method of regeneration seems best-suited to the habits and requirements of this species, and assures that an adequate seedling stand is established before the final harvest of the parent stand. The approach can be adapted to meet a variety of management objectives, and is especially applicable to the landowner who does not wish to make the heavy capital investment required for intensive site preparation and planting following clearcutting of the mature stand. Successful natural regeneration requires careful advance planning, regular monitoring of conditions in the regeneration area, and proper timing and execution of all necessary cultural treatments.

The shelterwood system of natural regeneration has been successfully applied to **longleaf** pine for over 30 years, covering a range of geographic locations and site conditions. If, for lack of an adequate seed crop or other reasons, natural regeneration cannot be obtained within prescribed time limits, the planting option is always available.

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Genetics and Tree Improvement of Longleaf Pine

R.C. Schmidtling and T. L. White[1]

INTRODUCTION

Longleaf pine (*Pinus nalustris* Mill) has been a tremendously important species economically as well as biologically in the southeastern United States. This past importance is not reflected in the amount of resources dedicated to perpetuating it's existence. A recent survey of forest-tree nurseries showed that less than one percent of the bare-root pine planting stock raised in southern nurseries was longleaf pine (Boyer and South 1984). A compilation of seed orchard acreage in 1981 showed Only 443 acres of longleaf pine seed orchards compared to 5,482 acres for loblolly and 3,151 acres for slash pines (USDA 1982).

Unlike related species, young longleaf pines typically remain in a stemless grass stage for several growing seasons. This growth pattern, possibly an adaption for fire resistance, has complicated artificial regeneration. Once past the grass stage, however, longleaf grows similarly to other southern pines and offers desirable characteristics that make it suitable for high value products.

Recent advances in artificial regeneration techniques detailed elsewhere in these proceedings have made tree improvement much more attractive for longleaf pine. The species is quite variable and therefore well suited for genetic manipulation. Significant genetic gains can be achieved by practical tree improvement programs (Goddard, et al 1984). This report reviews current knowledge on the genetics of longleaf pine and suggests improvement procedures.

FACTORS IN GENETIC VARIABILITY

Geographic Variation

Longleaf pine is largely concentrated in the Atlantic and Gulf Coastal Plains but also extends into the Piedmont and Appalachian foothills (fig. 1) (Little 1971). Elevations vary from sea level to 2,000 feet in northern Alabama. The frost-free period varies from 300 days in the south to 200 days in the north. Annual precipitation exceeds 50 inches over much of the range, and seldom is less than 40 inches. Rainfall is distributed rather uniformly throughout the year, but spring and summer droughts are common, especially in the western part of the range. Soils vary from deep, dry sands or low, wet sands near the coast to upland clays (Wahlenberg 1964). This diversity of environments would be expected to encourage a great deal of variation among populations, or seed sources.

The best long-term documentation of geographic variation in longleaf Pine is provided by the Southwide Southern Pine Seed Source Study (SSPSSS).

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[1]The authors are principal Geneticists, USDA-Forest Service, Gulfport, Mississippi, and Associate Professor, University of Florida, Gainesville, respectively.

Tenth-year measurements of this study led Wells and Wakeley (1970) to conclude that planters may find it desirable to move seed of central Gulf Coast origin slightly north, to take advantage of increased growth rate. The pattern of geographic variation was similar to that found for loblolly pine (Wells and Wakeley 1966); that is, southern seed sources are somewhat faster growing than local seed sources if the planting location is in a climate slightly colder than the origin of the seed. The 25-year data from the SSPSSS shows this trend in a general way, but the advantage of using non-local seed sources is much less well-defined.[2]

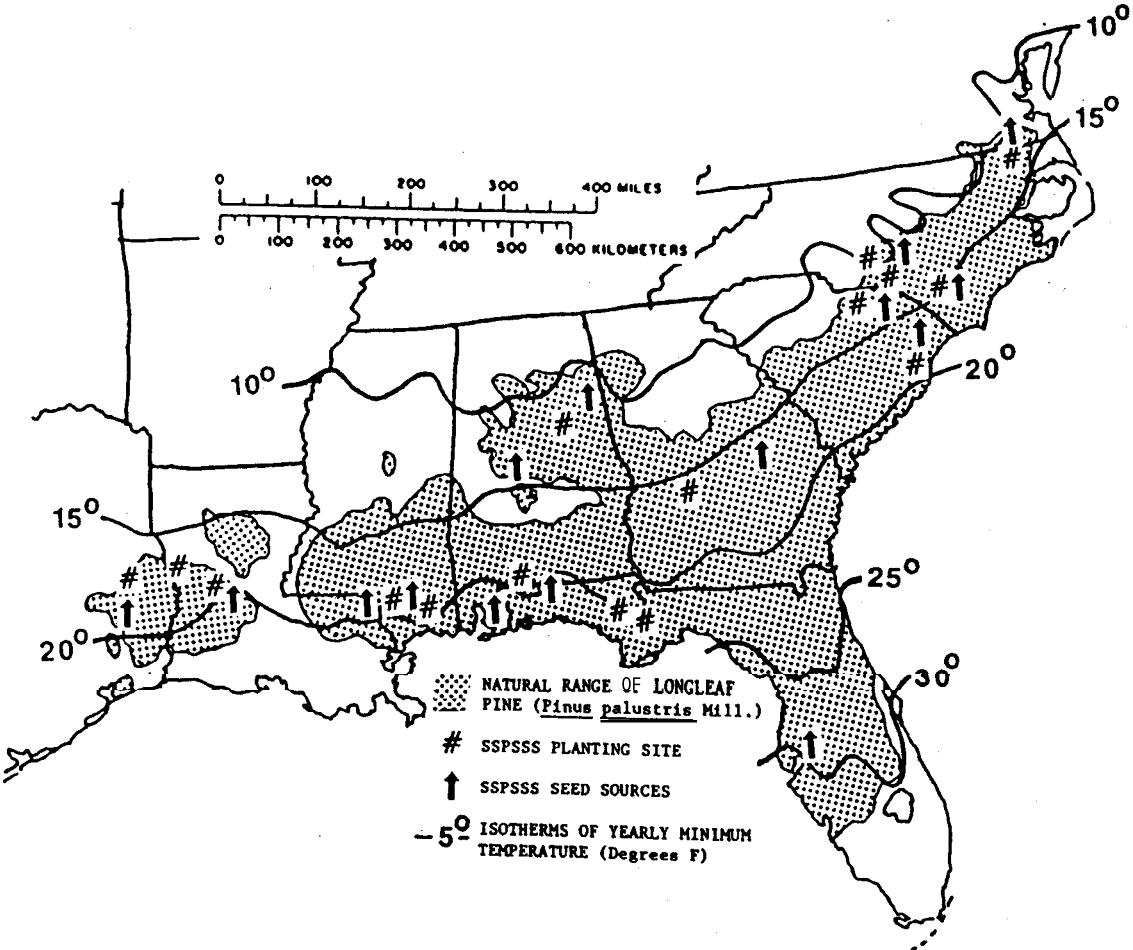

Figure 1 -- Map of the southeastern United States showing natural distribution of longleaf pine (after Little 1971) with isotherms of average yearly minimum temperature (adapted from Little 1971). Also shown are the locations of SSPSSS longleaf plantings surviving to 25 years of age, and seed source locations.

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[2]Based on unpublished 25 year data from the southwide Southern Pine Seed Source Study, Longleaf phase, on file at the Gulfport, MS laboratory of the USDA-Forest Service. Complete establishment details and 10th-year data can be found in Wells and Wakeley (1970).

The longleaf phase of the SSPSSS is large and complex, 15 different seed sources and six different series of plantings, established in 1953 and 1957 (fig. 1 and table 1). The plantings can be divided into two groups: those south of the isotherm of 15° F minimum yearly temperature (warm-climate plantings), and those north of this isotherm (cool-climate plantings) (fig. 1). Approximate comparisons can be made among all 15 seed sources -- even though'they do not all occur in all plantings'-- if height is expressed as a percent of the planting mean.

Table 1.--Seed sources used in the Southwide Southern Pine Seed Source Study.

State	County	ID in Fig. 2
Alabama	Auburn	N Al
	Perry	C Al
Florida	Okaloosa	W Fl
	Hillsborough	S Fl
Georgia	Treutlen	GA
Louisiana	Washington	E LA
	Rapides	C LA
Mississippi	Harrison	MS
North Carolina	Richmond	C NC
	Bladen	S NC
South Carolina	Florence	E SC
	Chesterfield	N SC
Texas	Polk	TX
Virginia	Nansemond	VA

In the warm-climate plantings, a plot of height versus minimum yearly temperature at the source shows that, in general, warm-climate sources grow the best (fig. 2a). The top three sources are from the central Gulf Coast: west Florida, south Mississippi, and south Alabama. The south Florida source, although the most southern, is about average in height, and appears to deviate strongly from the relationship with minimum temperature of the source.

Survival of the south Florida source in the warm-climate plantings was poor (fig. 2b). The south Florida source seems poorly adapted even in the warm-climate plantings. These plantings are located in a climate more than 10° F colder in minimum temperature than the south Florida source; thus, the poor Performance of the source should not be unexpected. Survival of the fast-growing Gulf Coast sources was about average, and there was no clear relationship between survival and minimum temperature at the source (fig. 2b).

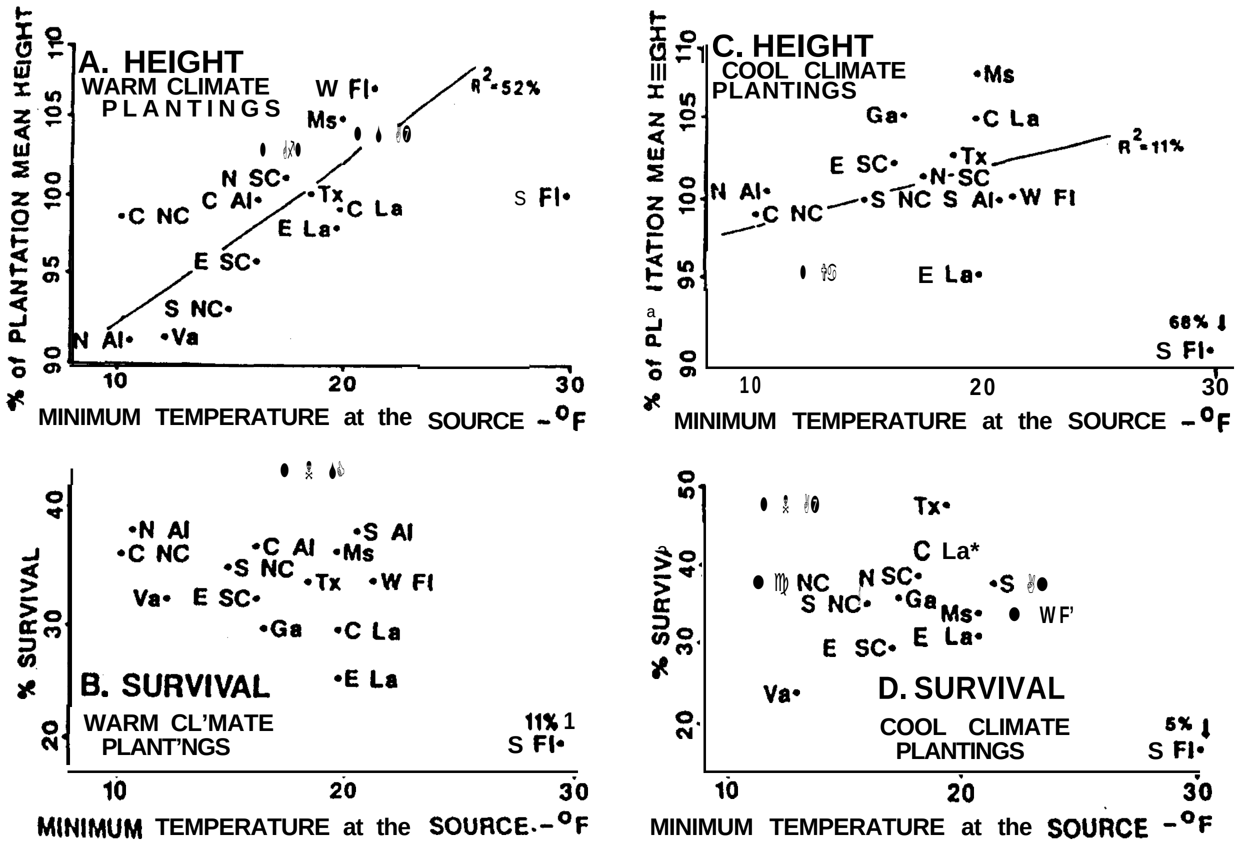

Figure 2.--Relationship between minimum temperature at the seed source (fig. 1) and height and survival after 25 years of the SSPSSS longleaf (unpublished data). The R^2 values were computed after excluding the south Florida source.

In the five cool-climate plantings there was no clear relationship between minimum temperature and growth of the 15 sources (fig. 2c). The best growing source was a Gulf Coast source, south Mississippi. The other two Gulf Coast sources were average in growth. The south Florida source did very poorly in the cool-climate plantings: 25-year height was only 68% of the planting means and survival was only 6% compared with 38% for the average of the other sources (fig. 2d).

The performance of the cool-climate seed sources in the cool-climate plantings was mixed. The north Alabama source survived well (fig. 2d) but was about average in growth (fig. 2c). The eastern North Carolina source was average in growth and survival:

the Virginia source was below average in both growth and survival--not only overall, but also in the planting in northern North Carolina, a few miles from the seed origin (fig. 1).

At the western edge of the natural range, the use of east Texas seed sources has been recommended (Van Buijtenen 1965, Wells and Wakeley 1970). There is some support for this recommendation in the SSPSSS. In the east Texas planting, the Texas source was the tallest, averaging 63.6 feet tall after 25 years versus 60.9 feet for the average of all sources. The Texas source also survived the best with 46% of trees alive after 25 years versus 40% for the planting average. Neither of these differences were statistically significant. In a planting in western Louisiana, about 50 miles east of the Texas planting, the Texas source was about average in survival and growth. In spite of the lack of really convincing evidence, however, it would seem prudent to use local seed sources at the western and northern limits of the species' range.

A great deal of geographic variation is not clinal, however, so making generalizations about seed sources will always be accompanied.by a certain amount of error. Compare, for instance, the south Mississippi source and the east Louisiana source (fig. 2). The areas where these sources were collected are separated by only 50 miles, east-to-west (fig. 1) and differences in climate and soils are negligible, but the two sources represent opposite extremes in height growth in the cold climate plantings (fig. 2c) and vary widely from each other in height in the warm climate plantings (fig. 2a). Utilizing geographic variation for improvement programs may be more risky in longleaf pine than in loblolly pine.

Nethertheless, the recommendation made after 10 years of growth (Wells and Wakeley 1970) is still appropriate after reviewing the 25-year data from the SSPSSS: a considerable amount of genetic gain can be realized by planting central Gulf sources over a large part of the central portion of the natural range. These sources also happen to be more resistant to brown-spot needle blight (see Snow et al, 1989).

Ecotypic Variation

Although longleaf pine occurs on a great variety of sites, there seems to be only scant evidence for ecotypic variation. Snyder and Allen (1968) found that longleaf pine collected from cove (good) sites performed somewhat better on good sites than those collected from ridge (poor) sites. One of the SSPSSS series was designed to test adaptability and growth of sand-hill sources versus coastal plain sources. In four sand-hill plantings and two coastal plain plantings in the Carolinas, sand hill sources grew only slightly taller than coastal plain sources: 43.6 feet versus 42.9 feet after 25 years. Similarly, in three sand-hill plantings and one coastal plain planting near the central Gulf Coast, sand hill sources grew slightly taller than coastal plain sources: 42.1 feet versus 40.1 feet after 25 years. These differences were not apparent in earlier measurements (Wells and Wakeley 1970): There was no seed source x planting site interaction--i.e., there was no tendency for the coastal plain sources to grow better on the coastal plain sites than the sand hill sources.

One would also expect that sand hill sources would survive better, for they would be well adapted to moisture stress inherent in sites with deep sand. In these same SSPSSS plantings, the sand hill sources did survive better than the coastal plains sources in the Carolinas plantings: 34.5% versus 29.5%. The opposite was true in the Gulf Coast plantings, where the coastal plains sources survived better that the sand hills sources: 41.6% versus 34.1%, after 25 years. Once again, there was no seed source x planting site interaction in either group of plantings. The differences in the Gulf Coast plantings parallel each other, and are probably a result of difference in height initiation at 10 years (Wells and Wakeley 1970). Most of the seedlings that did not initiate height growth by age 10 did not survive to age 25. These differences, however, may be due to individual stand variation, as only one source each was included from the sand hill and coastal plain province in the Gulf Coast plantings.

Thus, there is some evidence for ecotypic variation in longleaf pine, but the magnitude and uncertainty 'of this variation makes it of doubtful importance. There may'be some utility in using selections from deep-sand sites, especially on the east coast. These areas certainly should be included in any kind of improvement program.

Individual Tree Variation

Substantial variation in traits affecting survival, growth, and disease resistance also occurs among individual trees. Wells and Snyder (1976) concluded that individual family within-area variation was much more important than the geographic effect, even though the geographic effect was substantial.

Similarly, Byram and Lowe (1985) found that family within seed source effects were much larger than seed source effects in juvenile traits. Considerable genetic variation exists in the susceptibility of longleaf to two important diseases, brown-spot needle blight and fusiform rust (see Snow et al, 1989). Fusiform rust is usually not a problem over most of the natural range of longleaf pine, but can cause losses in areas of high hazard, such as central Georgia. There appears to be enough genetic resistance to this disease to allow sufficient gain in one generation of selection for 'use in problem areas (Sluder 1986, Snyder and Namkoong 1978). Considerable genetic resistance to brown-spot needle blight also exists (Snyder and Derr 1972). Breeding for this trait has become much less important with the development of systemic fungicide for its control (see Snow et al, 1989).

Survival in longleaf pine is influenced by numerous environmental factors as well as disease and is difficult to measure with precision (Snyder 1973). Heritability estimates typically are low (Snyder et al. 1977), but indirect selection appears promising. In an open-pollinated progeny test, Snyder (1973) achieved a 43-percent improvement in plot volume at age 15 years by selecting the tallest 10 percent of the families at 8 years. Increased productivity, however, was not so much a result of greater growth as of improved survival. Hence, selection for rapid early height growth indirectly improves survival. Similar

th were obtained in a 13-tree diallel crossing experiment
- 3 Namkoong 1979).
ee species have as much phenotypic variation in early ch as longleaf pine. Trees several years younger but s taller than their associates are common (Pessin 1938). (1954) noted that numerous trees in an 18-year-old cation had not begun height growth, but others were 38 feet ll. Such variability is diminished somewhat by intensive cultural practices (Schmidtling 1973). In addition, improved artificial regeneration and disease control techniques (Snow et al 1989, Barnett et al 1989) greatly reduce variability in early survival. Exactly how this will affect genetic variation in early growth is not clear.

Using the benylate root-dip to control disease may actually increase genetic variation in areas of high infection[3]. In Snyder and Derr's (1972) progeny test, brown-spot control resulted in an increase in 3-year height from 6 inches to 24 inches. Genetic variation, however, was essentially the same ($h^2=0.52$ without disease control, $h^2=0.48$ with control). Although several families performed well under both regimes, family rankings differed greatly, depending on whether disease was controlled or not. This illustrates a hazard of using phenotypic selection in longleaf pine: The disease history of the area from which the trees are selected (which is probably unknown) becomes very important. Susceptibility to brown-spot disease is heritable (Snyder and Derr 1972, Byram and Lowe 1985) and trees selected from areas where brown-spot disease was very severe may not be superior in areas where disease is not a problem, or where the benylate root-dip is used.

Gains can be made through phenotypic selection, but this is probably not the most efficient approach. In a large open-pollinated test of random parent trees, Snyder (1969) found that overall average height at age 8 years was 6 feet, but averages for the best 20 families ranged from 7 to 10 feet and the poorest family averaged only 1 foot. The best 25 % of the families as judged on the basis of parental phenotypes were 12% taller than the plantation average. Selection of a similar proportion on the basis of progeny test results, however, yielded a 35% increase--a 23% advantage over phenotypic selection. Snyder concluded that progeny testing appears to be almost three times more effective than phenotypic selection-- an outcome expected in view of the early growth pattern of longleaf pine. He also found that the most exceptional parents would probably have gone undetected in the absence of progeny testing, as they were not phenotypically exceptional.

Snyder (1973) also found that the advantages of early progeny testing persisted through age 15 years. In spite of decreased variation in height, the families that grew fastest at early ages produced the most wood per unit area in later years. Improved diameter growth and especially improved survival accounted for their superiority. Early evaluation of progeny tests for longleaf

[3]Snow, G.A. Stop #4, field trip notes for this symposium.

pine may be even more feasible than for other southern pines.

Thus, the most important source of genetic variation in longleaf pine is in individual trees, and progeny testing is the most efficient way of capturing this variation.

Seed Production

The success of any tree improvement program relies on seed production, usually from seed orchards. Traditionally, seed orchards of southern pines have been established by grafting scions from mature selected trees to seedling rootstocks. Longleaf pine can also be grafted successfully (Smith and Smith 1969), but results in the field have been quite sporadic. Other methods of vegetative propagation suffer from the same limitations as with other southern pines: they seem to work well only on immature trees (Snyder et al. 1977). This has caused many tree improvement programs to shift their emphasis toward seedling seed orchards (SSO) (table 2).

Relatively little research has been done on flowering and seed production in longleaf pine compared to loblolly. Like slash pine, longleaf does not flower as well or as early as loblolly pine. However, the same techniques useful for loblolly pine will probably work for longleaf pine. Fertilizers, for instance, enhance cone production in longleaf pine (Shoulders 1967) as they do in other species. Optimum levels of fertilizers may be lower for longleaf than for loblolly (Schmidtling 1973). The 200 lbs N/acre/year recommended for loblolly pine[4] probably should be reduced to 100 lbs/acre for longleaf pine. Phosphorous and potassium should be applied according to foliar analysis, standards that are currently being developed.

Other guidelines for seed orchard establishment and management such as those outlined by Jett (1987) for loblolly will apply in general to longleaf. Seed orchard sites should not necessarily be "good" sites, but should be well-drained to excessively well-drained, with irrigation supplied during early establishment and during severe droughts in later years. Soil fertility can always be manipulated artificially.

One problem peculiar to longleaf is conelet abortion (White et al. 1977). Whereas conelet abortion in other southern pines is often insect-related, in longleaf pine the cause appears to be physiological. In some experimental trials, spraying trees with plant hormones with cytokinin activity has increased conelet retention (Hare 1983), but this has not been tried on an operational scale. This is one problem that warrants further research.

TREE IMPROVEMENT PROGRAMS

Because of its relatively low importance as a commercial species for pine plantation establishment, longleaf pine tree improvement programs have received far less emphasis than those for loblolly and slash pine. Improvement programs have also been

[4]Schmidtling, R.C. 1988 Unpublished data from a fertilizer rate study at the USDA Forest Service Erambert Seed Orchard.

Table 2.-- Summary of current status of longleaf pine tree improvement programs in the southern United States.

Program Attributes	CFGRP[1]	NCSU[2]	USFS[3]	WGFTIP[4]
Selections				
Number made	961	179	400	470
Years made	1970-73	1963-70	Late 1960s	Early 1980s
Selection Intensity	Low	High	High	Low
Progeny Tests				
Tests/selection	5	0-l	4	7-9
Dates established	1979-87	1980-date	1987-89	1983-87
Type	Short-term: convert to sso	Orchard pollinated	Control pollinated long term	Short term and long term
Seed Orchards				
Type	OP Seedling	Grafted, clonal	Grafted, clonal	OP Seedling
Dates established	1979-87	1965-89	1065-70	1985-89
Acres established	180	140	175	<50

[1] Cooperative Forest Genetics Research Program (12 members); Data do not include early. program of intensive selection and grafted seed orchard. Source: White et al 1986

[2] North Carolina State University (6 members): Source: S.B. Jett, NCSU, Raleigh NC 27695

[3] USDA-Forest Service, Southern Region (single organization) data do not include recent plans to make more selections for seedling seed orchards. Source: Jim McConnel USDA-Forest Service, Atlanta, GA 30309.

[4] Western Gulf Forest Tree Improvement Program (6 members): Source: Tom Byram, Texas Forest Service, College Station, TX, 77843

hampered by some biological characteristics of longleaf compared with loblolly and slash. In general, it is more difficult to breed, graft, and establish in progeny tests. Also, flowering and seed production are more sporadic, generally occurring only on older material, and are often reduced by conelet abortion. As a result of these problems, longleaf pine tree improvement has not been easy.

Nevertheless, first-generation tree improvement programs in progress for longleaf pine in the southeastern U.S. have achieved considerable success (table 2). These programs, which were begun at various times over the past 25 years, have collectively made over 2000 superior tree selections and established nearly 550 acres of first-generation seed orchards.

These genetic resources easily meet the current demand for improved longleaf seed in the region and provide adequate orchard acreages even if demand should increase substantially. In addition, the selections provide a basis for continued improvement of longleaf pine. One possibility that holds some promise is the development of longleaf hybrids. For example, most longleaf x slash hybrid seedlings do not exhibit grass stage. When vegetative propagation techniques become operational, longleaf'hybrids could conceivably combine some of the best attributes of longleaf (perhaps rust resistance, wood characteristics, good form, good growth in later years, suitability for certain planting sites) with good characteristics of other species.

Brief descriptions of four tree improvement programs describe the nature of genetic resources being developed for longleaf pine.

Cooperative Forest Genetics Research Program

The Cooperative Forest Genetics Research Program (CFGRP) consists of 15 cooperating organizations and the Co-op staff at the University of Florida, Gainseville. Longleaf pine is considered a minor species whereas slash pine improvement has been the major thrust of the CFGRP for over 30 years. Longleaf improvement in the CFGRP began in 1963 with a program that closely paralleled that for slash pine: intensively graded selections were grafted into clonal seed orchards. However, in the early 1970's, program strategy was changed to a seedling seed orchard (SSO) approach and concentrated on several factors of concern in the improvement of longleaf pine: 1) longleaf improvement is lower in priority than slash mandating a less intensive program, 2) grafting longleaf pine is generally more difficult, 3) juvenile traits such as survival, emergence from grass stage, and early height growth are of relatively higher importance in longleaf to ensure stand establishment, and 4) most longleaf trees flower sporadically, making it difficult to. collect seed for testing.

In the SSO approach, open-pollinated progeny testing and orchard production activities are combined into a single planting. Open-pollinated offspring from 100-300 mother trees are planted in a statistically-valid field design that is managed for the first few years as a progeny test to obtain performance information on juvenile traits. Between years 5 to 10, the planting is converted into a seed orchard leaving only the best individuals from the best families. From then on, the planting is managed for maximum cone production and is of little or no use as a progeny test. The important juvenile characteristics in longleaf pine have moderate heritabilities and substantial gain is possible from the seedling seed orchard approach (Goddard and Rockwood 1981, Goddard et al 1984, Rockwood and Kok 1977, and White et al. 1986).

The CFGRP took advantage of good cone crops between 1970 and 1973 and an excellent cone crop in 1977 to identify 407 longleaf pine selections to begin the SSO program. These dominant trees were selected less intensively than previous slash and longleaf trees and each tree had to have a sufficient cone crop for inclusion into the program. Seed from these and 62 of the previous, intensive selections were used to establish the first seedling seed orchards in 1979. In 1979 and 1983 an additional 492 selections were made with emphasis on the Mid-Gulf coast portion of the longleaf range as being the best source for making selections. To date, nearly 190 acres of longleaf SSO have been established which include 96110ngleaf selections. Most selections are in approximately five test plantings (i.e. five SSO).

The selection and test establishment phases of the longleaf program have been completed as originally planned. The 961 selections are well-distributed across the longleaf range in the CFGRP operating area and provide a broad genetic base. Further, the SSO's are being measured and managed as progeny tests according to a strict schedule up to age 8. All cooperators follow the same format to maximize the effectiveness of the data collected.

At age 8, the orchards are managed for seed production by rogueing all but the best families and leaving only good individuals in each family. Since each parent is in approximately five different tests, the best families are chosen on the basis of overall performance across all tests. Preliminary analyses indicate that considerable genetic gains can be made in survival, emergence from the grass stage and early height growth by this family and within-family selection scheme.

Using current estimates that 1 acre of orchard produces enough improved seed to reforest 100 acres annually, the 188 acres of longleaf orchards will meet an annual regeneration load of 18,800 acres. This approximates the current collective reforestation needs of CFGRP members for longleaf pine.

NCSU-Industry Tree Improvement Program

Six of the cooperators in the North Carolina State University tree improvement program have participated in longleaf pine tree improvement. These organizations collectively made 179 longleaf pine selections from 1963 to 1970. These selections were made using the comparison-tree method, which involves measuring each candidate tree and several other nearby comparison trees for a variety of traits. The candidate tree's overall "grade" must surpass that of the comparison trees by a specified amount. This intensive method of selection was the same as that used in the NCSU loblolly pine program in the late 1960's (Zobel et al 1972).

Also, as with the loblolly pine program, these selections were immediately grafted into clonal orchards with plans to progeny-test the selections when the orchards flowered. Because flowering occurs on older material in longleaf (compared with loblolly), progeny-test establishment did not begin until 1980. Progeny tests have been established with open-pollinated seed from the orchards. However, because of test failures, not all selections have been tested.

The approximately 70 acres of grafted orchards established in the 1960s are currently producing commercial quantities of longleaf seed and the NC Division of Forestry has just added a sizable (50+acre) expansion to their longleaf pine orchard acreage.

USDA Forest Service

Region 8 of the USDA Forest Service (USFS) has had an active longleaf pine program since the late 1960s when 50 selections were made in each of the eight longleaf pine breeding units. These breeding units (Texas, Louisiana, S. Alabama, N. Alabama, Mississippi, Florida, North Carolina, and South Carolina) span the geographic range of longleaf pine (Wells and McConnell 1983). Each of the 400 selections was made using an intensive comparison-tree method similar to that described for the NCSU program.

The 50 selections in each breeding unit were immediately grafted into a clonal seed orchard in each unit. These range in size from 7 to 8 acres for the Texas and south Alabama units to 35 to 40 acres for the Mississippi, north Alabama and Florida units. A total of 175 acres of clonal orchards were established and these 15-20-year-old orchards now meet the USFS need for improved longleaf seed.

Because of the common problems with "time-to-flowering" and breeding, the 400 selections have, in general, not been progeny tested and the USFS plan now is to adopt SSO approach similar to that described for the CFGRP. Current plans call for 100-300 more selections to be made in each of the eight breeding units. These would be made much less intensively, with the proviso that all selections must have seed on them so that they can be progeny-tested immediately. The open-pollinated seed will be established into an SSO, for each unit. The SSO will be managed as a progeny test in the early years and then converted to a seed orchard by rougueing out poor families and poor individuals within good families.

Western Gulf Forest Tree Improvement Program

Six of the cooperators in the Western Gulf Forest Tree Improvement Program (WGFTIP) have been involved in longleaf pine tree improvement. The WGFTIP longleaf program has emphasized identification of superior longleaf pine genotypes for use in future orchard and breeding programs if the need should arise. These organizations began making selections in the early 1980's in the Western Gulf region (southeastern Texas! southwestern Louisiana, southern Mississippi, and northern Louisiana) (Byram and Lowe 1985). The 470 selections were made non-intensively: selected trees had to be dominant trees and have cones.

The open-pollinated seed from the selections was collected and a portion of the seed was used to establish the short-term stage of a two-stage progeny testing program. The remaining seed was stored for later use in establishing the long-term stage of testing. In the short-term tests (established between 1983 and 1987), the open-pollinated seedlings were planted in randomized complete block designs and each selection was well tested in seven to nine different field tests. These short-term tests are planted at close spacings (2' x 8') and, are measured for only 3 years (after which they are abandoned) for survival, emergence from grass stage, brown-spot incidence, and early height growth.

Once the data from the short-term tests are evaluated,, the best 30% of the selections are included in long-term progeny tests planted at conventional spacings. The first series of long-term tests was established in 1988 after the evaluation of results of the short-term tests planted in 1983. These, will continue to be established into the early 1990s until 140 parents (the top 30% of the 470 original selections) are included in long-term field tests.

Seed orchard establishment has not been a major priority of the WGFTIP longleaf pine program. The Mississippi Forestry Commission and Louisiana Office of Forestry have established or plan to establish SSO, but no private cooperators have plans to do so.

RECOMMENDATIONS

Longleaf pine is well-suited for tree improvement programs, but the more traditional use of intensive phenotypic selection and grafted seed orchards is not efficient for longleaf pine. Mass selection with progeny testing, perhaps with open-pollinated seed, should produce better results in the long-term. Using combined progeny tests-seedling seed orchards will bypass many of the problems of seed orchard establishment.

Breeding for resistance to fusiform rust may be necessary for areas where rust hazard is high, but generally this trait is not very important. Since systemic fungicides are verv effective, breeding for brown-spot resistance should probably be de-emphasized, with emphasis re-directed toward early height'growth. Previously identified resistant selections should not be discarded, however, for the future course of pathogenic variability and pesticide registration rules are uncertain.

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PEST MANAGEMENT IN LONGLEAF PINE STANDS

G. A. Snow, W. H. Hoffard, C. E. Cordell, and A. G. Kais

ABSTRACT. Longleaf pine (*Pinus palustris* Mill.) is resistant to many insects and diseases, and judicious use of the species should solve many of the present-day pest problems in southern forests. Extensive planting of longleaf pine, however, will likely increase the risks of future pest problems with this species. Forest management practices to reduce these risks are: use of natural regeneration practices; following guidelines in moving seeds; planting resistant genotypes in areas where fusiform rust and pitch canker are known to be a hazard; matching species to site; maintaining nursery stocks free from pests; treating bare-rooted longleaf seedlings with benomyl; avoiding overstocking, mechanical damage, and overmaturity; and monitoring stands for potential insect and disease problems.

As a species, longleaf pine (*Pinus palustris* Mill.) is resistant to, or at least tolerant of, all insects and diseases that are of major importance to other southern pines, It has been largely spared from the epidemics of fusiform rust and southern pine beetle that have ravaged southern forests for over 50 years. Longleaf pines are attacked by *Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme* and *Dendroctonus frontalis* Zimmermann when the disease and insect pressures are extremely high, but the degree of damage is usually much less than that sustained by loblolly (*P.taeda* L.) and slash (*P.elliottii* Engelm. var. *elliottii*) pines under the same conditions. Recent field survey results obtained from six comparable longleaf and loblolly pine plantations at the Savannah River Forest Station near Aiken, SC, showed longleaf plantings to be considerably less susceptible to fusiform rust than loblolly plantings in the same age group (<1% vs. 23% infection, Cordell et al., unpublished). These observations are consistent with those of Powers (1975), made approximately 10 years previously, also in South Carolina. Similar degrees of resistance in longleaf pine are documented for an array of other pests, e.g., annosus root rot (Hodges 1974), pitch canker (Blakeslee 1987), needlecast diseases (Czabator et al. 1971), tip moth, Ips, black turpentine beetle, and pine weevils (USDA 1985).

The inherent pest resistance qualities of longleaf pine make a strong argument for promoting increased use of the species in southern forestry operations. Judicious planting of longleaf will undoubtedly solve many of our current forest pest problems. However, the species is by no means immune to all pests. It is highly susceptible to *Mycosphaerella dearnessii* Barr (*Scirrhia acicola* [Dearn.] Siggers), which causes brown-spot needle blight (Siggers 1944) and to *Rhizoctonia solani* Kühn, which results in a serious nursery disease (Davis 1941). Therefore effective pest management is and will continue to be an important part of forest practices even in longleaf pine stands.

The authors are, respectively, Principal Plant Pathologist, USDA Forest Service, Southern Forest Experiment Station, Gulfport, MS; Entomologist and Pathologist, USDA Forest Service, Asheville, NC; and Principal Plant Pathologist (retired), USDA Forest Service, Southern Forest Experiment Station, Gulfport, MS.

Increased use of longleaf pine may lead to a corresponding increase in the number of pests associated with this species. Most insect and disease problems in southern pine forests currently occur in even-aged stands of a single tree species. These forests are typically managed to promote fast growth and uniformity of products. This results in a large food base that is ideal for the growth of pest populations and for the subsequent occurrence and recurrence of epidemics. Certain things can be done, however, to reduce the risks of epidemics in pine plantations.

Our purpose in this paper is to: (1) outline methods currently in use for the control of brown-spot needle blight in pine plantings and Rhizoctonia blight in pine tree nurseries, (2) discuss mechanisms of pest resistance in longleaf pine, with an emphasis on fusiform rust and the southern pine beetle, and (3) describe steps that foresters can take to avoid pest problems in longleaf pine forests.

Brown-spot needle blight

Mycosphaerella dearnessii infects the needles of longleaf pine seedlings causing irregular shaped, tan-to-brown colored spots. The spots merge and the affected needle turns brown, curls, and dies. This reduces the overall photosynthetic surface of the seedling, and the vigor of the plant is reduced. Loss of vigor prolongs the grass stage, which may eventually result in the death of the plant. The disease has been a serious obstacle in regenerating longleaf since the 1920's, and at least part of the early planting failures of longleaf pine were due to this disease. All present methods of successful regeneration of the species must include measures to either control or avoid brown-spot needle blight.

Infection by *M. dearnessii* is easily prevented with topical fungicides such as Bordeaux mixture, captan, and chlorthalonil. These materials should be used in nurseries so that disease-free trees are produced--otherwise there will be a rapid buildup of the pathogen when infected trees are planted in the field. Because application costs prohibit the use of contact fungicides to protect field plantings, the development of methods to use the systemic fungicide benomyl has given the forester a very effective tool for brown-spot control on planted longleaf seedlings. When the seedlings are lifted from the nursery beds, their roots are sprayed with a 5-percent (a.i.) slurry of benomyl in kaolinite clay. This single treatment controls the disease for at least 2 years. Under most conditions, this is sufficient time for the trees to begin height growth and reach a stage of growth at which they are no longer subject to severe infection (Kais et al. 1986). In addition, the benomyl root treatment increases survival by inhibiting pathogens that develop when the trees are in storage (Barnett et al. 1988) and stimulates the beneficial effects of ectomycorrhizae (Kais et al. 1981).

All site preparation practices that promote growth of the seedlings are beneficial because they reduce the time that the seedlings are in the grass stage and more susceptible to brown-spot infection. The fungus should be eradicated from any established seedlings growing on the planting site; this eradication is an important part of site preparation when longleaf pine is to be planted. Mechanical treatments or prescribed fire may be used. Prescribed burns should be made when there is sufficient fuel to support a hot fire.

Properly timed prescribed burns are part of the protocol for shelterwood regeneration systems (Croker and Boyer 1975). Burning before seed fall exposes the soil to allow seedling establishment, and the fire eradicates the inoculum on established seedlings. If the disease becomes extremely severe after the overstory is removed, another burn may be necessary. Such burns should be carried out during the dormant season and during weather conditions that will minimize fire damage to seedlings that have started height growth. The first seedlings that begin height growth may be superior genotypes, and care should be taken not to destroy them.

Rhizoctonia blight

Rhizoctonia blight has been recognized for many years in association with both pre- and post-emergence "damping-off" in nursery seedbeds of both conifers and hardwoods throughout the Southern United States (Boyce 1961). Davis (1941) described a disease of longleaf pine, occasionally referred to as "sand splash" or "sand-silt drift," that he attributed to infection by *R. solani* in forest tree nurseries in Mississippi, North Carolina, and South Carolina. In recent years, this problem has become more widespread and severe in southern nurseries producing longleaf pine (Barnard 1979). Although Rhizoctonia blight has usually been associated with bare-root nursery seedling production, it can also cause significant damage in young plantations of either planted or naturally regenerated longleaf pines while they are still in the grass stage.

Rhizoctonia blight symptoms include chlorotic, discolored, and/or water-soaked needles that eventually rot. The rot may also occur on stem and bud tissues at or near the soil surface, roots in the upper layers of soil, and even on distal needle parts as a result of needles touching the soil surface. Diseased seedlings become completely discolored (straw-colored or brown) and die. Affected nursery seedbeds are frequently characterized by circular to irregular patches of dead and dying seedlings (Barnard 1979). Infection, disease spread, and subsequent tree damage are enhanced by warm temperatures, neutral to somewhat alkaline soils, and high relative humidity (Davis 1941). The disease has been observed to be more severe on longleaf seedlings in sandy soils where the sand, washed by rain and irrigation, has a tendency to accumulate at the base of seedlings (Barnard 1979). This condition creates a microenvironment of reduced aeration and increased relative humidity that is highly beneficial to the fungus.

Several measures can be taken to control Rhizoctonia blight. Nurseries should not be established in deep sandy soils or where Rhizoctonia blight has been a problem. Seedbeds and mulch materials should be fumigated. Fall sowing of freshly collected seed is advised, with supplemental spring mulching to reduce the soil buildup around the base of young seedlings. Selective use of fungicides may be needed if the disease occurs during the growing season.

Resistance to insects and diseases

Longleaf pines appear to have many inherent traits that render them resistant to insects' and diseases. Their susceptibility to fusiform rust is limited by both morphological and physiological mechanisms. Terminal and lateral shoots are tightly encased in scale leaves (cataphylls), giving new shoots the appearance of a white candle. These cataphylls serve as a mechanical barrier that prevents the germ tubes of rust basidiospores from reaching the stem tissues. Rust infection is not thought to occur via the needles because the fast and long growth of longleaf needles prevents the rust mycelia from reaching the stem, even though the needle may be infected. This mechanical barrier concept is supported by the observation that rust galls on longleaf pine usually occur at 4 feet or more above the ground. When the growing shoots are at this approximate height, they expand rapidly and expose stem tissues for infection. Physiological mechanisms of resistance are best demonstrated by inoculation experiments in which seedlings of the same age and form show differences in susceptibility to fusiform rust (Anderson and Walkinshaw 1986) and to brown-spot needle blight (Kais and Griggs 1986).

Genetic resistance to *M. dearnessii* is well documented for longleaf pine (Snyder et al. 1977). A program to develop brown-spot resistant trees has been in progress via cooperative work between researchers at Gulfport, MS, and Region 8, USDA Forest Service, Atlanta, GA, for several years. This program is being continued, but the emphasis has been changed to combining resistance with improved growth. This change was brought about by the development of the benomyl root treatment, which has solved this disease problem on bare-rooted stock.

Resistance to fusiform rust is a highly heritable trait in longleaf pine (Snyder et al. 1977). Snyder and Namkoong (1978) reported 12 of 13 randomly sampled trees in Mississippi produced seedlings with moderate to high resistance. The frequency of resistant genotypes is high in Texas, Louisiana, and Mississippi, but decreases in more eastern seed sources (Wells and Wakeley 1970). Kraus (1985) found that trees grown from Georgia seed sources varied in resistance but were much more susceptible than south Florida sources. All these studies indicate that selection for rust resistance is possible and may amount to no more than rouging of current seed orchards.

Foresters have long recognized longleaf pine's resistance to several insect pests--most notably the southern pine beetle and tip moth. In Louisiana, for example, Hedden and Lorio (1985) noted that mixed longleaf and slash pine stands were 50% less likely to be attacked by southern pine beetles than mixed loblolly and shortleaf stands. Tree physiologists cite physical and toxicological properties of the oleoresin system as a principal factor in this resistance. Relative to other North American pines, longleaf and slash resin is significantly more viscous, crystallizes more slowly, and continues to flow longer after wounding. This apparently enables the species to "pitch out" bark beetles and drown or exhaust them in the copious, gooey exudate (Hodges et al. 1977).

Interestingly, longleaf's immunity to tip moth attack may reflect an evolutionary adaptation. With only one terminal bud in the grass stage, tip moth attacks could have caused extinction of the species through growth retardation at this highly susceptible growth stage. Thus, the tree's immunity is likely the result of intensive natural selection (R. L. Hedden, personal communications).

In studying longleaf pine's resistance to bark beetle attack, one should look beyond the direct interaction of tree and beetle. While the southern pine beetle is generally acknowledged to be the primary insect pest of southern pine, the beetles prefer to attack weakened or diseased trees (Belanger et al. 1986). Therefore, longleaf's resistance to diseases apparently plays an important secondary role in resisting southern pine beetle attack.

The reader is cautioned not to confuse longleaf pine's resistance to the southern pine beetle with immunity to attack. Longleaf is definitely subject to successful southern pine beetle attack. Generally, such losses are precipitated by explosive outbreaks of beetle populations in nearby loblolly stands, or some stress factors (e.g., drought) that predisposes trees to attack through a reduction in oleoresin exudation pressure.

Four direct methods are used for the control of southern pine beetles: salvage, cut-and-leave, pile-and-burn, and insecticidal (Swain and Remion 1981). Of these, salvage is the most popular because some return is obtained to help offset the cost of the control effort.

The cut-and-leave method is used from May to October, when relatively small spots are expanding rather than proliferating. By felling infested trees and trees in an adjoining buffer area, the attraction of more beetles to the area by pheromone production is disrupted, and the infestation stops. Cut-and-leave should not be used in cooler months when beetles are more likely to abandon felled trees and attack other standing trees, initiating a new infestation.

Although used far less than in years past, insecticidal control may be appropriate in small, especially valuable stands (e.g., those in recreation areas). Chlorpyrifos and lindane are currently registered chemicals. cost and environmental concerns account for the demise of pesticides as a popular control in forest stands. Pile-and-burn is also a rarely used method to control the southern pine beetle, and is practiced mostly in unmerchantable or inaccessible stands.

Direct controls are just one component of an integrated southern pine beetle management program.' At least equal emphasis should be placed on preventive controls, such as density control to maintain vigor (e.g., initial tree planting density and precommercial and commercial thinnings), careful site selection, and avoidance of damage to the residual and adjacent stands during logging. In the future, this integrated pest management approach is certain to take on increased significance,

Recommendations for avoiding future nest nroblems

As longleaf pine is used more extensively for regeneration in the southern pine region, the risks for pest problems in this species will increase. These risks can be minimized by observing one or more of the following practices:

(1) Use natural regeneration practices, i.e. shelter-wood or other natural seeding systems, whenever possible. These methods maintain the heterogenity of the species and create a diverse forest in time and space.

(2) Follow guidelines for selecting longleaf seeds, and do not plant the species north of its range. Most plants are best adapted to the area in which they have evolved, and this includes their ability to coexist with pests.

(3) In areas that are presently known to be highly hazardous in terms of fusiform rust and pitch canker, only plant longleaf genotypes with proven resistance.

(4) Match the species to the site and strive for a diversity of forest species, including hardwoods.

(5) Don't transfer nursery problems to the field. Maintain nursery stocks that are as free as possible from all pests.

(6) On planting sites where brown-spot disease is likely to be a problem, longleaf seedlings should be routinely treated with the benomyl root solution prior to planting.

(7) Develop management plans to avoid overstocking, mechanical damage to trees (particularly from logging operations), and over maturity.

(8) Monitor stands for insect and disease problems. When pest problems arise, take immediate steps for control or initiate research to develop controls.

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A Holistic Approach To Managing Longleaf Pine Communities

J. Larry Landers; Nathan A. Byrd, and Roy Komarek

Abstract: As the core tree of a vanishing keystone community, longleaf pine has attracted the conservation focus in the southeastern Coastal Plain. The future of countless wild species depends upon how diligently managers will work to restore aspects of a true forest. The complete longleaf forest will disappear unless managers maintain open small-scale mosaics with treeless areas among pine groups of various ages, extend the rotation beyond economic maturity, maintain native ground cover, and shorten fire intervals. Aesthetics can be compatible with uneven-aged forestry and game production, and conservative grazing can accommodate some other resource aspects; major trade-offs, however, are involved in trying to blend resources together. This paper contrasts some production approaches with one in which community integrity is the sole objective. Although their goals may differ, resource and ecological disciplines must work together if longleaf forests are to recover as a viable part of southern landscapes.

Introduction

Longleaf pine (*Pinus palustris*) has played a major ecological role in the southeastern Coastal Plain for the last several thousand years. As the climate shifted toward greater rainfall and lightning frequency, pronounced flammability of this tree and its grassland associates apparently contributed to great reduction of scrub habitats. This transformation not only rearranged a myriad of plants and animals but also created vegetation patterns favorable to man. Pine-grassland habitats formed the setting where the Indian-wild ungulate association eventually was replaced by European settlers with their cattle. Pine products later became the mainstay of rural economy as well as the nation's primary export sources. Development of private game preserves throughout the longleaf belt also had great economic importance.

J. Larry Landers, Director, Tall Timbers Research Station, Route 1, Box 678, Tallahassee, FL 32312.

Nathan A. Byrd, retired, U.S. Forest Service.

Roy Komarek, President, Tall Timbers Research, Inc., Route 1, Box 678, Tallahassee, FL 32312.

After an era of destructive lumbering, regeneration of longleaf became the focus of a national controversy -- total fire suppression vs. control burning. The outcomes of this political battle include better resource management and understanding of community fire processes to which countless organisms have adapted. Probably, no other single tree species in any region has so influenced cultural and natural ecology or advancement of the conservation sciences.

It should be no wonder the demise of this splendid tree has raised concern by so many different interest groups. We believe it will take multidisciplinary action for the longleaf ecosystem to continue significantly in southern landscapes; it cannot persist in isolated bits and pieces. In that vein we include in this report many subjects beyond the resources which can be rendered useful in some way. Here we will preface some management comments by a brief description of original forests and human influences, followed by a sketch of the ecosystem, because these topics bear heavily upon the management tasks at hand. Our primary objective is to contrast two management approaches, one covering several resource production goals, the other emphasizing natural community integrity. We hope these ideas will help elevate the ecological and scenic aspects relative to economic values of longleaf forests.

Original Forests

The Coastal Plain pine belt once stretched from southern Virginia to eastern Texas and southward through central Florida. Longleaf dominated some 78 million ac (Betts 1954) of what was probably the greatest area of "climax" consisting primarily of one tree species in the U.S. (Chapman 1932). The repeated occurrence of ground fires has long been recognized as an ingrained process which allowed longleaf communities to expand across such an immense region. Most investigators estimate a natural regime of rather uniform, mild fires which spread widely every 2-4 years prior to man's influence (see Landers 1989 for review).

Early European travelers had mixed aesthetic viewpoints concerning the almost interminable pines. Terms like "deserts" were applied by many writers. Among the many bewildering accounts that were summarized by Utley and Hemperley (1975) was this description by Fanny Kemble (1838-39), an English actress who moved to a Georgia plantation: -- "wilderness more oppressive a thousand times to the senses and imagination than any extent of monotonous prairie, barren steppe, or boundless desert can be." Some who sensed a degree of desolation such as Captain Hall (1828), a British naval officer and Sir Charles Lye11 (1840s), a geologist associated with Darwin, also found the forests graceful and interesting (Utley and Hemperley 1975); Lye11 is often credited for first describing the dependence of longleaf pine upon frequent fires. Naturalist William Bartram (1791) depicted one expansive area as "a level, open, airy pine forest, the stately trees scatteringly planted by nature, arising strait and erect from the green carpet, embellished with various grasses and flowering plants." Favorable perceptions generally increased when many people came to regard longleaf barrens as healthful because of the pine-scented air.

Although clashing aesthetic viewpoints are evident in the old narratives, all leave the impression that park-like vistas were the most common scenes. William Bartram's comments about forest birds not being numerous in the pine barrens are in agreement with other observations by people interested in wildlife. For example, during a trip in South Carolina John Davis (about 1800) stated he heard no sound but that of a woodpecker (Cheney 1910). Similarly, Buckingham (1828) stated he occasionally saw a mockingbird and that the turtle dove was the only bird seen in any numbers during his Georgia travels (Lane 1973) (scientific name of animals and plants are appendicized). Concentrations of forest birds apparently were suite uncommon, even though a lengthy bird list has been amassed for the habitat type. Similarly, little mention was made of terrestrial herp species other than poisonous snakes. In contrast, there were numerous. records of big game probably because of their size and utility as food sources. Bison, white-tailed deer, black bears and wild turkeys were commonly noted in early reports; also mentioned were eik, panthers, wolves and foxes (see Rostlund 1960).

Some records indicate the larger wildlife species were most abundant in the more diverse portions of the longleaf belt. Oaks and clearings were mentioned in most references to wild turkey habitat (Wright 1915). Great abundance of deer is documented by records of hides which were the region's number one export item from the late 1600s through mid 1700s (Johnson 1987). Although open, wet glades were visited by deer (Utley and Hemperley 1975) the apparent location of major foods (*e.g.* shrubby shoots, acorns) suggests that they used edges or interiors of mesic hardwood habitats more' than pine uplands. Bartram noted abundant waterfowl and wading birds in open wetlands of the Coastal Plain. Practically all southern records of the historic and prehistoric bison are within the longleaf pine range. Catesby (1731) noted droves of bison loafing in shady canebreaks during midday but foraging out into savannahs in the mornings and afternoons. Rostlund (1960) considered the Creek Indians' "beloved bear ground" in southern Alabama as one of several hundred preserves maintained by Indians in the Southeast; descriptions together with known seasonal requirements of bears suggest the presence of berry-producing shrub and hardwood mast species in bear preserves.

The habitat uniformity depicted in cursory descriptions has been taken literally by many who influence wildland management. Over-generalizations probably occur in interpretations of old records because the writers rarely included site-moisture descriptions in there accounts of vegetation. However, there is considerable evidence of diversity both in vegetative structure and composition. Some of the oldest eyewitness accounts of longleaf forests are the narratives of Spanish expeditions in the early 1500s. In addition to open forest and treeless land the Spanish chroniclers also passed through dense forests, open areas fringed by thickets, country with almost impassable undergrowth, and leagues of difficult woods (Rostlund 1957). Such habitat variants are probably under-represented in notes because travelers likely chose the clearest routes across upland terrain. In 1765-66 John Bartram recorded brush-filled borders of wet areas, dense ponds, upland thickets of brush, and sandhills with stunted mature pines and oaks over shrubs and a sparse herb layer (Harper 1942). Major xeric sandhills once comprised at least 8 million ac (Brendemuehl 1981) while many smaller riverside sand ridges were laced through the region (see Bozeman 19711. Even in open country the pine-grasslands were diversified here and there with shrub clumps, venerable oaks, and sloping hammocks on the better soils (Williams 1827; see also Utley and Hemperley 1975). Shallow rivulets with canebreaks stretched for many miles in some places (Catesby 1731); in fact, canebreaks totaled millions of ac in the Coastal Plain prior to intensive livestock grazing (see Hughes 1966). There were also numerous referrals to diverse wet meadows in the old accounts.

The natural history of certain indigenous plants also indicates that structural diversity must have been common in many places. Shade-intolerant shrubs (e.g. some myrtle, titi and holly species) and deciduous scrub oaks cannot survive long in association with the larger hardwoods; they become established and reproduce in open pine forests where fire is followed by several disturbance-free years. Relative to the inferred fire regime previously noted, either less frequent or more patchy fires were, in the natural state, essential for some woody plants which live only in certain pine forest zones. The variability of fires probably accounts for the existence of many plant and animal species which diversified this community type.

Eras of Man's Influence

The impact of American Indians became especially pronounced in the Southeast about 5,000 years ago. Historic records show widespread use of fire for routing game and opening forests for various reasons. Although Indians did not totally shift fire regimes from the lightning-fire season, it is clear that they conducted winter burns almost annually in many parts of the longleaf belt (Catesby 1731,'Bartram 1791). Slash-burn techniques became widely employed when agriculture gained importance mostly within the last 1500 years. Indians likely cultivated the better soils -- floodplains and clayey uplands -- rather than wet flatwoods or dry sandy lands, but frequently relocated their fields as the soil became depleted. Indians no doubt had an indelible impact long before any Europeans entered the Southeast.

Although early settlers gradually extended farming to nearly all arable lands in the region, the longleaf belt was one of the last provinces to be effected as large-scale agriculture swept through most of the South in the early 1800s. Cattle usage was of paramount importance to rural residents for approximately 300 years. As wild game became scarce, most local inhabitants depended even more heavily on livestock which ranged primarily on the lands of absentee landowners; by the 1850s nearly 6 million head of cattle, sheep, horses and mules were supported almost entirely on burned "open" range in South Carolina, Georgia, Florida, Alabama and Mississippi (Rostlund 1960). Long-term claims to grazing rights were made without legal basis. Much of the virgin longleaf pine forest was cut over to some extent by the mid 19th century.

An era of massive lumbering was spurred by economic changes following the Civil War together with expanded railroad systems. Just as the boll weevil was bringing an end to the cotton era the Deep South became the nation's primary wood basket, which led to removal of the remaining virgin forests from 1880 to 1920. Cattle production was expanded to take advantage of greater forage availability resulting from removal of the overstow. Several important developments occurred during that period: absentee landowners were wanting to start regenerating pines; timber companies were expanding their land bases; our young forestry profession was gaining influence in the region; and a national conservation movement was under way. Deeply seated in European tradition and reinforced by rampant wildfires in the western and northern states, the misguided conservation movement began a no-burn campaign which culminated in the South. What followed was a long, embittered battle primarily between U.S. Forest Service administrators and those who believed in using fire to manage lands (Schiff 19621. The' longleaf type became the focal point. Open-range grazing was sharply curtailed by the no-burn campaign coupled with laws to protect landowner rights and to keep cattle away from highways. In desperation the landless cattlemen began to set damaging fires rather than the mild burns typically used in range maintenance. Logging debris set the stage for many unnaturally catastrophic fires. Several researchers began to work independently to document the benefits of fire, including R. M. Harper in botany, H. H. Chapman in longleaf silviculture, Frank Heyward in soils, S. W. Green in range and H. L. Stoddard in wildlife management (Schiff 19621. It took nearly half a century for research and the reality of wildfires (via man and lightning) to reinstate the age-old practice of control burning to any appreciable degree. Even today the logic behind appropriate burning is still one of the best kept secrets from the general public; the total extent of fire in the Southeast has decreased about 95% in the last 50 years (Simard and Main 1987).

Seed-tree removal together with fire protection led to complete loss of two-thirds of this forest type by the 1940s (Wahlenberg 19461. Wild hogs were an added factor which prevented longleaf regeneration in many areas. Forest change subsequently was accelerated by increased utilization of smaller trees, improved pulping processes, and row-crop forestry best suited for pine species other than longleaf. Between 1955 and 1965 the longleaf forest was reduced from 13 million to 7 million ac (Croker 19871. Today, less than 4 million ac (about 5%) of the original type remains as second-growth stands of which only 1-2% of the original is publicly held. That on private lands is disappearing most rapidly. Essentially all remaining areas have severely altered pine population structure, pronounced invasion of other species of pines and hardwoods, and ground cover in great disrepair. There are only a handful of small tracts with essentially intact original-growth components together with native ground cover. The suggestion that the longleaf community is "endangered" (Means and Grow 1985) thus has a logical basis. Fortunately, however there are numerous longleaf tracts with fairly intact ground cover in which diverse forests could be restored.

Ecosystem Description

The ecosystem concept entails a community and its environment functioning as an ecological unit. Fire is a driving force in the longleaf pine ecosystem. There appears to be an evolutionary link between frequent lightning and developed traits of longleaf and its primary grass associates that promote fire in this humid region. In the completely natural state, nutrient balances were likely sustained by frequent growing-season fires which neither tended to increase nor reduce soil fertility. Natural fires driven by shifting winds certainly molded habitats that were much more structurally diverse than those managed today with repeated line-fires set under predictable weather conditions. Longleaf forests were none-the-less stable in composition rather than being successional or transitional. Several ecologists have applied the term "climax" to the longleaf type; if climax is determined by climate, of which lightning is a major component, then the forest permanence geared to lightning-set fires should indeed establish longleaf forest as a regional climax.

Fires originating within the community also extend into virtually every ancillary habitat type. Inferred fire regimes (see Cypert 1973, Wharton 1978, Rebertus 1980, Clewell 1981, Trowel1 1987, Landers 1989) suggest decreasing frequency/increasing intensity away from typical longleaf expanses toward both the xeric and hydric extremes (Table 1). Although no one can determine what percentage of burns in intense-fire habitats originated in longleaf, few will disagree that its regional dominance greatly increased fire frequency in neighboring habitats. The character of all such communities would change dramatically without this process. Therefore, what appears to be a community type with distinct boundaries is actually the hub of a landscape complex (mosaic of ecosystems) laced throughout the Coastal Plain. It is crucial for managers to understand that their practices impact intricate lifelines from this keystone community type to numerous other plant - animal assemblages which may appear disassociated.

Table 1. Sane examples of habitat types influenced by fires originating in longleaf pine forests.

Habitat Type	Soil Type	Drainage	Topographic Exposure	Inferred Fire Freq. (No./Century)
Coastal Backdune	Sandy	Rapid	Very Low	Uncommon-Variable
Sand Pine-Scrub	"	"	"	1-5
Coastal Woodland	"	"	Low	5-10
Sandhill	"	"	Moderate	10-33
Longleaf-Rolling Savannah	Loamy-Sandy	Moderate	High	25-50
Longleaf-Flatwoods	Sandy	Slow	"	25-50
Slash Pine Flatwoods	"	"	Moderate	10-20
Canebreak	"	"	"	14-20
Slope Pine-Hardwood	Loamy-Clayey-Sandy	Moderate	"	8-12
Dry Prairie	Sandy-Peaty	Slow	"	Periodic
Herb Bog	"	"	"	"
Wet Prairie	"	very Slow	"	"
Freshwater Marsh	"	"	"	"
Baygall	"	"	Low	6-8
Shrub-Pond Pine Bog	"	"	"	5-10
Swamp Forest	"	"	Very Low	3-4

High stand densities are not characteristic of longleaf forests in the natural state. Most descriptions of virgin conditions suggest mosaics of mature trees irregularly spaced apart: young intermingling cohorts ranging from clumps of grass-stage seedlings to gangly saplings to pole-sized trees approaching the almost random pattern of adults: and narrow openings that remain so for extended periods. The uneven-aged, small-scale mosaic character, apparent from descriptions of old growth (Schwartz 1907, Wahlenberg 1946, Engstrom 1980, Clewell 1981, Platt *et al*. 1988b), is in large part, the basis of community stability.

The open character of longleaf forests is attributable in part to point lightning strikes of one to several trees (the probability of which increases with tree size/age), and partly to intolerance of shade. At many locations there are large treeless areas, some of which apparently stay open because of alternating fires and months-long flooding or nearly continuous seepage. Some other natural openings result from blowdowns. Heavy masting just before blowdown sometimes creates large even-aged parcels; massive wind damage in stands with few juvenile pines (and subsequently reduced needle fuel deposition) could account for some of the well-developed shrub thickets reported in virgin forests. In either case the vegetation likely persists for decades before the diverse pine pattern redevelops.

Each portion of the longleaf belt seems to be unique in some way. Composition varies locally with the influence of western prairie, subtropical, and/or northern floras. Added to those variables are topographic, soil and moisture differences which influence species distribution and abundance. In many areas literaliy hundreds of low plants (grasses, forbs, shrubs) are present. Of these, the very flammable bunch grasses (e.g. wiregrass, dropseed grasses) play a major role in dominating the ground cover and root zone while detering invasion by hardwoods. However, clumps of tall shrubs (e.g. saw palmetto, gallberry, wax myrtle) and a few hardwoods seem characteristic of flatwoods, while patches of shrubs (e.g. blueberries), deciduous scrub oaks, and debris patches are notable natural features of the most xeric sandhills. Sandhill forests seem to be small-scales mosaics of contrary parts -- pyrogenic (pine-grass) and apyrogenic (deciduous scrub) -- between which narrow tension zones are threaded. Although each component likely varied in abundance over time, both apparently were maintained in natural balances by variable, periodic fires where deep-phase sands decreased the fuel accumulation rate; greatest abundance of scrub oaks probably occurred where wet boundary areas further reduced the fire return across sandhills.

Factors which increase diversity of surface vegetation include differential shading by thick-and -thin pine coverage together with disruptions by wind-thrown trees -- upturned roots, blockage of fire by downed boles, intense burning of crown debris. Frequent sprays of lightning insure continual production of standing and fallen dead wood. As an example, Schwartz (1907) estimated a snag density of about 6/ac in an old-growth forest.

Most wildlife species exist in moderate to low numbers in this community. Some specialized adaptations center around frequent fires, meager or variable nutrient bases, and use of retreats (cavities, burrows). Species like the red-cockaded woodpecker and fox squirrel utilize core areas from which they venture to eke out a living within large home ranges. Overmature, living longleaf trees with heart rot meet the red-cockaded's needs for cavities and certain insect foods. A similarly close relationship has been described between Sherman's fox squirrel and longleaf pine (Weigl et al. 1989). The squirrel's unusually large size enables it to travel far to locate food concentrations as well as handle and tear apart large longleaf cones; it is also a primary dispersal agent of the pine's michorrizal fungi. The burrowing gopher tortoise is an extremely habitual grazer; its exothermic system allows the slow building of fairly high population biomass (per unit area) on infertile sandhills which are severely limiting to grazing mammals. Among the dozens of burrow users associated with tortoises are the indigo snake, diamondback rattler, coachwhip.

pine snake and gopher frog. Pocket gophers make separate burrow complexes which also-are frequented by pine, snakes. Here it is notable that the 9 previously mentioned wildlife species exhibit adaptive strategies of relatively long life potential, large size, and/or emphasis on survival of a few rather than numerous young (even the red-cockaded is relatively "large" considering that the clan rears only a few young). Similar adaptive schemes are evident in plant constituents including longleaf pine, wiregrass, and several dozen other herbaceous and woody plants that slowly reproduce primarily by vegetative means (see Clewell 1981). This assemblage of plants and animals exemplifies the most stable or persistent sector of the community, very much in contrast to colonizers geared to population expansion into settings that suddenly become open, then diminish via succession. In-place stability in many life forms seems to be consistent with the fire-stabilized community type having reached its limits long ago.

Other community members may be considered ephemeral at any given location because resources upon which they depend vary greatly in time and space. Some are (were) fire followers such as bison, bobwhite, mourning dove, Bachman's sparrow, etc. which depend on fresh herbs or herb seeds which peak within a year or two of a burn; many grasses and forbs are fire followers as well. Soil churning by harvester ants, pocket gophers, tortoises and (formerly) bison add to treefalls in opening small patches of ground. Microsites with very sparse vegetation enhance burrowing of tortoises (especially hatchlings) and pocket gophers. Bare spaces are primary sites of fugitive plants like certain composites and grasses with air-borne seeds, and possibly some woody plants whose seeds are dispersed by animals (e.g. gopher apple, dwarfed wax myrtle, runner oak). Cavity users like the brown-headed nuthatch and red-headed woodpecker follow the occurrence of lightning-killed pines, which stand for limited periods, then fall and are used for some time as refuge by small vertebrates. Varying post-fire phases of vegetation together with opening and closure of treeless areas likely influence the kestrel (another cavity user), loggerhead shrike, mockingbird, meadowlark, etc. Boundary dynamics in the vicinity of certain wet places comprise the diverse habitat of the pine barrens tree frog as well as some bird species. In fact, the integrity of several communities depends upon overlapping disturbances by fire and flooding (e.g. wet flatwoods, bogs, wet prairies, some bay-swamp habitats).

A third wildlife group includes species which are not actually characteristic of expansive longleaf pine habitat but sometimes occur there as transients or occasional residents. Included in this category are opportunistic species which primarily inhabit edges with or interiors of hardwood forests. Examples include gray and flying squirrels, tufted titmouse, Carolina chicadea, blue-gray gnatcatcher and red-eyed vireo, just to name a few. Substantial numbers of these and associated plants (mesic shrubs and hardwoods) are signs of community degradation when they occur well within typical longleaf forests.

When this happens more aggressive predators (snakes, raptors, raccoon, opossum) and cavity users also increase activity in the pine forest interior; gradual decline of pine community species may result. Under natural conditions frequent fires probably kept pine-grasslands and mesic hardwoods so widely separated that competition between the respective wildlife groups was minimal.

Wildlife populations in longleaf forests differ in several other ways from those of richer, more structurally complex habitats. A comparison of Tall Timbers' Wade Preserve and Woodyard Hammock will serve to illustrate. The longleaf type supports more bird species but far fewer total individuals per unit area than the hardwood hammock (Table 2). A substantial drop in overall bird abundance occurs during winter when about 60% of the summer-resident species tend to migrate out or expand activities in mesic forests, while in hammocks a dramatic increase occurs with the influx of numerous migrants and local generalists. However, seasonal shifts from the pine type probably were far less common when tens of millions of ac existed in various post-fire stases, including vegetation phases with abundant soft mast and acorns of runner oak, dwarf live oak, etc.

Seventy-one bird species have been recorded thus far on the Wade Preserve, of which 50 appear to be much more closely tied to the longleaf type than to hammock. Among the species recorded during surveys of the two habitats, some are found almost solely in (17) or exclusively in (24) longleaf. The two dozen core species are especially characteristic of this forest type; nearly two-thirds of them (15) have been documented as declining in the wild within at least part of their ranges: Bachman's sparrow, common yellowthroat. red-cockaded woodpecker, red-headed woodpecker, eastern meadowlark, brown-headed nuthatch, northern flicker, eastern bluebird, loggerhead shrike, eastern kingbird, red-winged blackbird, northern mockingbird, hairy woodpecker, common ground dove, common nighthawk, field **sparrow, gray** kingbird, and American kestrel (listed from greatest to lowest average abundance on the tract).

Compared to hammock, the longleaf forest bird **assemblage** includes more species which nest in cavities **or** in low strata (ground to low shrub) and proportionately fewer in tree crowns. Longleaf residents tend to feed omnivorously while those of hammocks specialize **more** on small prey. Most feeding modes in longleaf entail gleaning from ground to low shrub level, aerial hawking or pouncing to the ground for prey, and tree probing rather than foliar gleaning on trees or tall shrub-vine clumps.

The wildlife component of the longleaf pine community changes with plant composition reflected by the soil/moisture regime. The Wade Preserve has a well-drained clayey-sandy substrate except on small parcels with sand caps or titi drains. All of the 300 plant species on the tract are probably important as food or cover to one or more animal species. In addition to the 71 kinds of birds, at least 20 mammal and 54 herp species inhabit the area. The management plan for the St. Marks NWR points out that dry sandhills and flatwoods share many kinds of wildlife, but that species show marked preferences for one type or the other (Table 3). The whole complement of wildlife and plants spans a considerable moisture gradient. The majority of precarious species tend to specialize at the xeric or hydric extremes.

Table 2. Numbers of bird species in old-growth longleaf pine forest (Wade Preserve) and low hammock forest (Woodyard Hammock), vicinity of Tall Timbers Research Station, North Florida-Southwestern Georgia.

	Lonaleaf Forest			Low Hammock		
	Spring	Winter	Combined	Spring	Winter	Combined
Number of Species						
Resident	46	43	63	37	37	56
Total	55	47	71	41	45	66
No. of Individuals/km^2	478	353	--	698	1,645	--

Table 3. Number of wildlife species utilizing subcommunities of the longleaf pine type as primary habitat at St. Marks National Wildlife Refuge (from the Refuge's Management Plan, 1980).

Wildlife Group	Preferred Habitat Type: Flatwoods	Preferred Habitat Type: Sandhills	Total
Birds			
Cavity Nesters	8	0	8
Non-cavity Nesters	28	7	35
Wintering Species	8	3	11
(Subtotal)	(44)	(10)	(54)
Herps	27	17	44
Mammals	16	4	20
TOTAL	87	31	118

Multiple Resource Management

Managers of public forests have pursued the multiple-use objective in several ways, but usually with the viewpoint that "other" resources somehow must be worked in as accessories to productive forestry. The typical approach on industrial lands is to modify tree farm systems; recommendations often include low-intensity site preparation, conservative stand sizes, well-distributed stand age classes, judicious tree thinning and prescribed burning, irregular edge development, leave-strips along roads, and protection'of selected hardwoods. Some companies have a policy of leaving streamside hardwood zones and/or upland pine corridors to link high-value wildlife areas. Public land stewards often combine those same steps with measures to retain special sites for endangered species. Either pine plantations or seed catches (via seed tree or shelter-wood cuts) are typically used to develop even-aged stands.

Here, an outline will be made of suggested ways to retain many of the appealing aspects of a true forest while producing timber, wildlife, and/or cattle. In this as in any other multiple resource approach, compromises must be made during field inspections and carried out to whatever extent the landowner desires. Trade-offs are inevitable in favoring one type of resource or in trying to blend two or more types together. These recommendations are not presented in a schedule fashion because they involve the needs of numerous free-living species and aspects of scenic vistas that are unquantifiable. We hope they will encourage better management of this vanishing type by private landowners as well as stewards of those public lands where timber production must be a prominent goal.

Aesthetics

A steadily increasing standard of living during recent decades has resulted in a sharp increase in the mobility of the public. Where national forests were once largely the domain of the local hunter, fisherman and rugged hiker, the great outdoors has now become the arena of diverse national recreation. And from the highways, the waterways and from the air, what was viewed often gave a discerning public grave concern. The natural landscape was scarred, not by natural upheaval but by those in whom the care of our natural resources was entrusted.

Political pressures moved discussions in the direction of multiple use (which is not a recent concept), and preservation of natural beauty in forest or other landscapes. Fortunately, in the management of the longleaf pine forest their are possibilities in meeting those demands but not without trade-, offs. This community possesses structurally simple, but appealing aspects not generally found in other southern forest types. The open character seems to be increasing in aesthetic value as unobstructed vistas become less common and the public becomes more aware of ecological factors.

One of the primary goals in providing scenic beauty is to insure that visitors never perceive that they are going through a young forest, because regeneration significantly obstructs the view. This factor is important in quail shooting as well. At the same time, visual diversity should be maintained in subtle ways by creating a degree of structural variety. A striking variation in tree size is important. From a single observation point, one'should be able to see several distinct size/age classes sparingly meshing together or overlapping but slightly. Of great importance is isolation of individual, flat-topped trees, occasionally in well-drained areas and commonly in wet savannahs or sandhills. Sharply contrasting edges should be avoided, especially straight lines such as often occur along fire breaks. On most longleaf sites the most obvious contrasts should be small clusters of mature (but different sized) pines next to patches of juveniles and/or narrow open spaces -- all with irregular shapes. A similar approach can be taken in managing xeric sandhills except for wider pine spacing plus the addition of scattered scrub domes of various sizes, fingering between swards and shrubby clumps.

There are a number of small details a manager can take care of that would add much appeal to the overstory, especially in high-use areas, such as favoring a few woody plants with attractive spring flowers (e.g. dogwood, redbud, plum, buckeye) or colorful fall leaves (e.g. blackgum, maple, hickory, grapevines). The addition of a few large shade trees makes visitors more comfortable during the hotter months. And small enclaves of practically all attractive broad-leaved plants also tend to localize flocking bird5 which certainly add to a quality recreational experience. For the most part, however the scenery should have abundant sunlight filtering through characteristic tree species, striking the forest floor in most places, but with great variation in light intensity.

Attractiveness of a longleaf forest depends to a great extent on how the surface vegetation has been treated. Plant5 with aspect dominance vary from one site drainage class to another, but often include various bunch grasses, composites, legumes and sedges; several dozen other plant families are typically represented by one to several species. A few showy plants sometimes occur densely in impressive numbers within longleaf forests; pitcher plants, blazing stars, native azaleas, legumes, and sunflowers are some examples. Striking floral displays in longleaf forests, however do not generally hinge upon mass of a plant taxon, as might occur in western prairies, but rather the contrast of points of bright colors and unusual shapes against a matrix of greens and browns (by grass and low shrub leaves). The tremendous plant diversity usually prevents large concentrations of any single flowering species.

Although showy wildflowers occasionally occur incidental to land management, they are sustained in the long run only through proper habitat treatments. Most herbaceous plants require ample sunlight, so judicious tree thinning and brush burning are important (see latter sections for general recommendation5 on these practices). Uniform treatments regularly repeated over, long time periods may tend to maximize plant diversity (per unit area) but also tend to dilute floral displays comprised of one or a few closely associated plants. In contrast, variation in land treatment5 tend to diversify scenic beauty. For example, on St. Marks NWR, plot burning conducted at different times of the year shows remarkable differences in plant response (see Platt et al. 1988a); whereas regular winter burning spreads and dilutes flowering of the numerous plant species, growing-season fires tend to shift and synchronize flowering time and abundance (e.g. late-spring burning proliferates the purple flower5 of blazing stars, carphephorus, and most other fall-flowering composites, among plumes of wiregrass heads). Combination of fire and patchy soil disturbance also favors some colorful plants. A few observation5 will illustrate this point. Turned-up soil mounds just prior to March-April burning increase the yellow bloom5 of wild sunflowers in areas where these plants are generally established; light disking prior to winter burning increases purple flowers of several blazing star species if the combined treatment is applied where bulbs are already established; and it has been noted that a mechanical operation to push out woody thickets from a certain boggy stringer, followed by annual winter burning, has maintained plant diversity including 12 orchid species for at least 30 years (see Komarek 1986). Floral concentrations of some plants attract nectar feeders (bees, butterflies, ruby-throated hummingbirds) which add variety in life forms plus moving colors to the scenery. Thus, the key to maintaining aesthetic diversity lies in varying the time and extent of disturbances, taking advantage5 of plant5 occurring locally, and monitoring specific areas to insure the continuance of desirable species. Detailed attention must be given to individual kinds of plants, including expansive types such as insectivorous species, if they are to remain in southern landscapes. Even small populations should be viewed as critical 'pieces of a once larger puzzle; the continuance of numerous species depends absolutely on the manager'5 willingness to locally enhance the pieces. Much experimental research is needed to insure survival of many types of germplasms on the remaining wildlands.

Management specifically for interesting and attractive plants offer5 unique educational experiences to observers, whether they be private landowners or citizens visiting government-held forests. The recreational experience is heightened by knowledge of species adaptations to fire and water regime5 as well as specialized life forms such as animals which dwell in cavities or burrows. For this purpose, walking trails can be planned to extend from a place where different habitat5 come together out into the longleaf forest interior.

Trade-offs arise when the land management Program must encompass objectives other than aesthetics and very conservative timber production. Game management can be compatible, particularly quality deer programs in which the herd density is held suite low. Several challenges arise with management for huntable numbers of game birds. Measures to increase wild turkeys often include development of hardwoods, particularly oaks, in sizable blocks or strands through pine woodlands; brushy nesting cover and plantings of chufas, bahia, and other cultivars are typically incorporated. Similarly, sustained production of bobwhites in woodland portions of hunting areas depends on interspersion of fairly low nesting cover (shrub-grass mixes) together with occasional tangles for escape cover; both cover types are generally planned to accommodate bobwhite use of woodland food patches or field borders. Habitat management for game birds can be done conservatively to keep from diminishing the character of longleaf forests. Longleaf areas can provide turkey brood habitat and breeding sites but should not become dissected over large areas with arboreal hardwoods. Food plots for either turkeys or bobwhites can be restricted to sites formerly cleared of native ground cover. Special attention must be given to thickets which follow food plot cultivation or are provided specifically for cover. Rather than allowing thickets to develop into hardwoods, the manager can rotate patches -- flattening old ones while developing new ones nearby -- as if pockets of shrubbery are moved over time back and forth in the woods. Coverts can be positioned so as not to subtract from the appearance of longleaf forests.

More serious conflicts can occur with livestock grazing. Much natural diversity was lost during the open range era of the South. Cattle grazing, especially during dry times, removes many legumes, composites, and some other forbs and grasses: soil erosion often occurs with grazing on rolling to hilly sites. Intensive grazing operations in pine forests are not very compatible with the aesthetic viewpoint previously described, nor with aesthetic game habitat production.

Livestock Considerations

Whether plans include natural or artificial regeneration methods, several questions need to be answered by the land manager who intends to utilize pine production areas for grazing cattle. What type of site preparation will get a stand of longleaf established with minimal cost and be most favorable to forage production and cattle using the area? The major forages -- wiregrass, bluestems, panic grasses and paspalums -- will produce best if disturbed the least by site preparation. Prescribed burning would be most desirable while complete disruption of the ground cover would be the least desirable. If cattle depend on forage for the winter season, then a late-winter burn would be best. To aid in site preparation, rather heavy grazing prior to seeding or planting of longleaf can be considered to help reduce shade and competition for young seedlings as well as prepare sites for seed germination (on sandy soils especially). Plans should be made to remove or greatly reduce livestock use during seedling establishment especially during the winter months. Good seed crops can be detected early enough in the year to adjust cattle use. A period of abundant masting is an ideal time to plan to supplement native forage with new improved pastures which can be in the form of wide firebreaks, roadsides, or various odd areas that would fit in with other management objectives.

The location and shape of pastures can be planned to improve wildlife habitat as well. For example, superior reproductive areas for wild turkeys and many songbirds are provided by rough pastures positioned between pine uplands and lowland hardwoods. Light to moderate grazing in woodlands can benefit certain wildlife species, especially in the palmetto-gallberry type. The open habitat conditions and trails created by livestock can increase access to terrestrial species such as mammals and the wild turkey, while cropping of grasses between shrubs sets the stage for territories of several hawking-type insectivorous birds. Some seed-eaters (sparrows, meadowlarks) are often abundant on grazed open land. Burning-grazing operations in wet savannahs are fairly compatible with the habitat needs of some large wetland birds. It is important to recognize that cattle can be competitive with wildlife species which feed on seeds or foliage of legumes, other forbs and large-seeded grasses. This competition can be reduced somewhat by rotating cattle among compartments at the critical time of flowering and seeding of key food plants, or by using fresh burns to guide cattle activity. The land manager can adjust cattle stocking rates to accommodate other objectives to some extent. However, there are important trade-offs in maintaining a cattle program that must be considered.

Due to the difficulty of establishing longleaf, every precaution must be taken to protect newly established seedlings. Cattle use generally should be curtailed during the first two years of seedling growth. Cattle should not be grazed in the winter months while seedlings are still in the grass stage. If cattle are grazed, the area should be monitored closely for seedling damage. Although longleaf has been successfully established without changing existing use of livestock in some cases, new stands often'have been badly damaged before the manager became aware of the problem. Under certain circumstances, cattle grazing can be beneficial during the critical first year after seed germination. Light grazing can reduce the number of excess seedlings and help control competing vegetation. However, this type management requires skills which may not be readily available to the landowner. The ability and diligence to detect damage before it becomes serious is frequently lacking. Under no circumstances should free-ranging hogs be permitted in longleaf pine regeneration areas; for this reason, swine should probably be banned altogether from longleaf forests. The uprooting of seedlings can occur quickly and unexpectedly. The authors are aware of an incidence in which a group of 24 hogs completely rooted out a 1000-ac stand of Z-year old longleaf during late February and March. Damage is not always obvious until it is too late to prevent destruction of the stand. When seedlings are about 3 feet tall, cattle use under managed conditions may be resumed. The one exception is winter grazing. Cattle often damage longleaf seedlings when fed certain supplemental foods;- they should be kept out during winter until seedlings are at least 6 feet tall. Thereafter, grazing intensity should be based on forage carrying capacity minus allowances for wildlife considerations.

Sparse tree density enhances forage production. A density of 500 to 550 well-spaced seedlings/ac is suitable for heightened production of both forage and pine timber, but much lower densities are required for a full spectrum of objectives. As tree density is increased, forage production will decrease, especially with increasing stand age. Longleaf pine's fire resistance makes it ideal for forage and livestock management objectives. Prescribed burning increases production as well as quality of forage for most grasses found in the longleaf pine type. As a minimum, managers should plan to burn grazed areas every third year. Timing of burns should complement forage yields (late winter1 as well as wildlife and other objectives.

The relatively sparse foliage of longleaf allows abundant sunlight to reach the forest floor. This aspect along with frequent prescribed burns to clear needles, dead grasses and other debris, makes longleaf stands ideal for forage production. Stands should be thinned as early as possible to the minimum basal area acceptable for silviculture in order to increase forage; the sparser the tree cover, the better the forage production. Plans should be carried out to prescribe burn debris soon after thinning. As stands increase in size, opportunities for sustained forage production will decrease. Cattle stocking should be reduced accordingly to protect the forage and wildlife resources. Periodic range analyses should be conducted to determine the degree and intensity of allowable grazing. Managing the forest for cattle along with other resources is more challenging than single objective management. Several complexities must be considered.

Logging, hunter access and other uses of the area create opportunities for fence damage, gates left open and (potentially1 livestock loss. Through careful planning and management these risks can be minimized. If possible, cattle should be removed during the hunting peak. Loggers should know specifically what is expected of them when fences are damaged and gates are opened. Timber sales contracts should specify requirements for protection of each resource. If cattle are managed by people other than the landowner or land manager, they should be told of all permitted activities on the area. Their contracts should specify measures to protect the other resources as well as their own interests.

Practices such as prescribed burning, fertilization for timber production, timber thinning, wildlife openings, improved pastures, and site preparation frequently offer opportunities for increased production or improved quality of other resources. Because it is unusual for one manager to possess expertise needed to manage several resources properly, pools of expertise are frequently needed to do the best job. Forest forage management expertise is not available in many areas of the South. However, several practical publications are available (see S.R.M. 1974, Grelan 1975, Pearson 1979, Byrd et al. 1984). Some grasses such as wiregrass are palatable for only 2 to 3 months in the spring following fire, while most others are nutritious and palatable throughout the growing season. The quality of the forage will determine the supplementation needed for a healthy herd. All of these factors and many more must be considered when managing forage for livestock production. Basic to forage management is an inventory and analysis of the forage resource.

Activities such as hunting or other recreation, livestock management, berry picking or other uses add to the manager's challenge. Liability, safety, wildfire prevention, and certainly an economic return are among the factors which must be foremost in the manager's mind.

When the time arrives for pine harvesting the time is also ripe for several forage management decisions. Would it be in the best interest of all concerned to temporarily remove livestock from the harvest site? What measures can be taken to assure that downed fences are repaired immediately or that gates are kept closed? When the overstory is removed and prescribed burning is done, how can the increased forage production be best utilized? (It will likely more than double on the harvested areas.) Can livestock grazing be employed to help prepare the site for a new longleaf stand? This is a time of opportunity for meeting many resource management objectives. All other resource objectives should be considered prior to initiating tree harvest.

There are many factors involved in cattle management that are beyond the scope of this paper. Selection of cattle, breeding seasons, supplemental feeding, animal care, placement of salt and other nutrients, water availability and quality, cattle sales, road systems, and a multitude of other factors are involved in the cattle and forage side of resource management. Some of these such as fertilization of pastures (supplemental feeding) and road placement affect management of the timber, forage and wildlife resources. Here it is recommended that grazing be considered among other land uses to determine if it can contribute to an integrated plan to make the most of land management expenditures.

Vertebrate Wildlife

It is no simple task to manage for the full spectrum of community wildlife, because such a variety of species is involved. To illustrate, some habitat components required by a dozen animals are listed in Table 4. Substantial numbers of veteran pines and standing and fallen snags are needed, as are surface conditions ranging from bare ground to various stages of low vegetation. Tree densities must range from clumpy to Savannah-like settings that are broken at least in some places by open spaces of various sizes, Plus, oak pockets and feathered boundaries with wetter areas are needed to sustain some species. Quantified recommendations do not exist for sustaining viable populations of most wildlife. On large properties, the best a manager can do is to create component variety to the extent his funds and manpower will allow, while guarding against vegetation conditions that attract invading-colonizing species. An objective of maximizing wildlife diversity, by greatly mixing vegetation stages per unit area, leads to demise of open pineland species which are in need of special attention. A more viable objective is to maintain species which are characteristic of each natural setting within longleaf forests.

For habitat management purposes, a distinction should be made between wet flatwoods, rising or rolling moderate sites with loamy or clayey sands, and hills with the deep sand phase. The goal should be to maintain an appropriate mosaic pattern that is guided by a mental picture of appropriate settings and tailored by adjusting the fire regime.

Flatwoods habitats in general have deteriorated with proliferation of mostly evergreen plants such as various bay trees or tall shrubs like gallberry, titi, wax myrtle and saw palmetto, among others. A concerted effort should be made to reduce such species to well-spaced clumps except in places which likely supported natural thickets (e.g. drains, swamp borders). In certain cases, late-summer burns may be the best initial control measure. After woody vegetation is brought under control, the fire regime should be adjusted to insure ample fruit production by bay trees and shrubs, both of which provide important wildlife food. A special effort should be made to maintain, through patchy-periodic burning, the oak thickets that exist on sandy rises in some flatwoods.

On moderate sites, bay species should generally be minimized and the taller shrubs confined to crevices or folds in the terrain. However, because brushy patches are essential to many wildlife species, managers often protect places where there is a starting of brush at a location generally devoid of woody cover. This practice is central to quail management programs. To keep them from eventually converting to hardwood trees, it is advisable to level established patches after a few years of growth while planning ahead to develop others nearby. Individual or small groves of moderate-site oaks should be maintained sparingly and positioned away from lowland habitats. The population size of several wildlife species depends on the occurrence of small pockets of dissimilar habitats within pine forests.

Sandhills pose a great management challenge. The appropriate extent of midstory scrub oaks is a much debated point. Obviously, deciduous scrub species like turkey and bluejack oaks are indigenous trees since they exist only in the sandhill complex; because they are not extremely long-lived, sexual reproduction most likely was important in the natural state and thus existence at acorn-bearing size was common. Acorn supplies are beneficial to game species. Oak mast, patches of leaf litter, bare sand and shrub clumps are important resources of some nongame wildlife (Table 4). Because of their contribution to wildlife habitat it is recommended that extensive sandhills contain 10-20% coverage by clumps of mature scrub oaks with full crowns; a slightly greater percentage should be retained on management areas where very narrow sand ridges provide the major acorn potential, but in all cases the scrub component should be confined to small groves (e.g. 1/4-1 ac) surrounded fully by pine-grasslands and be held less that 30% total coverage. Sandhills with overabundant oaks can be improved with a series of frequent winter burns of moderate intensity; in some cases selective herbicide use and longleaf planting may be necessary to increase fuel (pine needles, grasses) before a viable burning program can begin. Thereafter, a desired balance of mature scrub oaks can be maintained by switching from sweeping line fires to spot fires set on ridges within grassy zones. Fuel moisture conditions can be selected to attain the desired habitat condition with fire. Growing-season burns are necessary, at least on occasion, to prevent encroachment of woody plants into herbaceous zones. If errors are made in management it is best to err on the side of burning, because the scrub component can be revived, but the ground cover may never return once it has been shaded out.

Table 4. Some habitat components needed by selected wildlife species of the longleaf pine community.

Wildlife Species	Old Pines Live	Old Pines Dead	Ground Cover[a] 1	Ground Cover[a] 2	Ground Cover[a] 3	Treeless Space	Large Oaks Mast	Large Oaks Litter	Bare Sand	Downed Wood	Wetland Gum Mast	Wetland Open Water
Red-Cockaded Woodpecker	X	X	X									
Brown-headed Nuthatch	X	X		X								
E. Ground Dove			X		X				X			
Prairie Warbler				X								
N. Mockingbird			X		X[b]	X[d]						
Loggerhead Shrike			X		X[b]	X[e]						
Yellow-breasted Chat					X[c]	X[d]						
E. Meadowlark			X			X[e]						
Southeastern Shrew			X					X		X		
S. Fox Squirrel	X		X	X			X				X	
Flatwoods Salamander			X							X		X
Gopher Tortoise			X	X		X			X	X		

[a] Post-fire stages 1=fresh burn to green herb; 2=herb-shrub; 3=tall shrub.
[b] Scattered clumps.
[c] Sizable thickets.
[d] Small openings within pine stands.
[e] Fairly large expanses.

Silviculture

A managed forest will be most productive for a variety of resources if numerous pine ages are maintained. Compared to plantations, uneven-aged forests are structurally heterogeneous, more stable and less susceptible to catastrophe; they also provide more wildlife niches and varied microsites with greater plant variety. To achieve diverse conditions the primary silvicultural goal must be based on sustained production as measured in terms of wood products rather than dollars; further, the multi-aged concept must take precedence over the concepts of stands and rotation ages and thus constitutes a trade-off in timber inventory, mapping, and planning silvicultural operations. However, natural regeneration and wood production can be combined in artistic ways to produce regular income from tracts ranging from woodlots (Boyer and Farrar 1981) to many thousands of ac (Komarek 1986). This objective requires a flexible management schedule. For example, close attention must be paid to mast events for regeneration. Seedlings can be accumulated by taking advantage of light to moderate cone crops, or started in great pulses during years of peak mast which cycle within a 5-10 year range, depending on the location. Patch regeneration can be accomplished in small irregular openings that are no farther away than about 1.5 times the height of primary seed trees. Regeneration occurs in openings as small as 1/4 ac if the surrounding stands are quite open; it is recommended that seedling areas range from that size up to l-2 ac. To take full advantage of a mast event the manager usually has to break the burning routine. Successful seedling establishment occurs in thin vegetation not more than one year post fire. Good results may be achieved by late-summer burning well before seeds begin to fall in October; this burning time allows enough plant regrowth to reduce seed predation, soil erosion, and pine seedling defoliation which can be great where there is little green vegetation upon which herbivores feed. Because it maintains a diverse mosaic pattern, patch regeneration is much superior to the less ecologically sound approaches of seed tree or shelterwood cuts, but random tree spacing by any method is better than row plantings. Where seedlings must be planted it is recommended that burn-only site preparation, minimal ground cover disturbance, and irregular patterns be used. To achieve the latter, some managers have planted trees in coil patterns, the end result being no apparent row effects when the planted area is viewed outside from any direction.

Tree density must be held much lower than in forests where pine production is the sole objective. A single-tree selection system, as encouraged here, is essentially a thinning operation for production of sawlogs, poles and pilings sustained for the long term so that clearcutting is never conducted. Consistent selection of "the right tree" for thinning takes into account all habitat and scenic aspects. Individual trees may have biological importance that outweighs their immediate dollar value. For instance, certain mature pines which frequently produce cones should be left indefinitely for wildlife food and regeneration sources. It is advisable for pines to be retained where their needle cast provides essential fuel for brush control, especially along drains and within upland thickets. Some large pines should be spared because they contribute to core areas of rare species. Other leave trees may have an interesting character or have cavitieswhere animals may nest or store food. The point here is that several values should be considered before marking any tree for harvest. Other important aspects include thinning for irregular spacing, retaining some old flat-topped pines, and protecting snags and a number of weak, soon-to-be snags. A single-tree selection program can be designed to'move the forest into a mosaic pattern in which an array of tree dominance categories are represented; retention of some co-dominant and semi-suppressed pines would be important for future development of trees preferred by certain wildlife. The process of aesthetic thinning can be combined with preparing open spaces for regeneration, but care should be taken to gradually thin dense stands to guard against shock mortality or windthrow. In these activities it is important to insure that paint marks, logging decks, etc. are hidden from the view along roads or trails. Short-stumping and flat-lopping of downed tree tops help reduce unsightly harvesting effects. Precaution also should be taken to minimize equipment crossings of drains.

Standard basal area (BA) or board-feet volume targets have little applicability in multiple resource management because greatly variable tree density is a paramount goal. Even on a small area the miniplot BA might range from about 85-0 ft^2/ac. The periodic cut should be kept below growth until the balance is achieved between standing timber and degree of openness desired to meet other objectives; thereafter, the cutting goal can be set to approximate the increment. Different local tree densities are required on different sites and for different wildlife species. For example, for adequate bobwhite production on moderate sites the BA (ft^2/ac) should be about 60 or less, ideally only 35-45. In this case, averages toward the upper end of this range would require proportionately more food plots or supplemental feeding to maintain huntable numbers of bobwhites. Slightly heavier BA (e.g. 70 ft^2/ac) might best serve the needs of red-cockaded woodpeckers in the flatwoods. but very xeric sandhills should not carry much more than half that amount of wood.

The degree of diversity depends to a great extent on the distribution of trees among age/size classes. Estimates based upon old-growth conditions should provide usable guidelines., Data from several sources (Schwartz 1907, Wahlenberg 1946, Engstrom 1980, Clewell 1981) suggest that these general ranges would be suitable for moderate sites: 30-80% crown coverage (note 20-70% unshaded area) by trees numbering about 30-170/ac constituting a BA within tree clumps of about 65-150 ft^2/ac. Platt et al. (1988b) presented information on part of the aforementioned Wade Preserve: a per ac density of about 70 trees ($\geq$ 1 in. dbh) distributed among age class ranges of (1) up to 25 years -- 45%; (2) 26-50 years -- 25%; (3) 51-150 years -- 20%; and (4) older -- 10%. Although somewhat lower densities might be targeted for subcommunities such as xeric sandhills and very wet flatwoods (e.g. 25-50 trees/ac), a similar population structure should be maintained on all sites. Of utmost importance is the retention of large, old trees (80-90 years or older) which are preferred nesting and feeding sites of the red-cockaded woodpecker and associated birds and are the more consistent seed producers (see Hooper and Lennartz 1981, Horvis 1982, Platt et al. 1988b). A target of 4-8 snags/ac would likely enhance populations of those wildlife species requiring dead wood.

Prescribed Burning

A vigorous burning program is essential not only for maintaining nontimber aspects, but for each silvicultural phase from regeneration to reducing the costs of harvest and site preparation. The traditional burning program outlined by Stoddard (1962) is suitable for maintaining diversity in the longleaf-wiregrass type. However, before pursuing any burning program, any person unfamiliar with the art of prescribed burning should first work with a skilled practitioner to gain knowledge of the proper equipment, permits, and smoke management techniques. The continued use of fire as a tool will depend on how carefully we control our burns in regards to the rights of other people.

For mixed objectives considered in this report, the best typical burn frequency would be every other year, with adjacent compartments treated alternately. However, judgement is required in timing, severity and type of fire to properly mold forests. Bobwhite management, for example, usually entails burning most acreage each year. Basic maintenance can be achieved by setting headfire which will hardly back or flank if set in 2-3 year rough that is quite damp towards ground level. The best burns are begun in the afternoon within a few hours after a heavy rain and under clear skies with steady, cold wind at 10-15 mph: as this wind speed exceeds the potential rate of fire spread, flames are held close to the ground. Unsightly bark scorch is minimized with this technique. Headfire under these conditions can be set along parallel strips or spots between which bands of vegetation are intentionally missed (about 1/3 of the'area would be left unburned). Priorities should be set to reserve the ideal burning periods for igniting parcels which usually burn too cleanly. Wherever feasible, night burning should be tried to add habitat, diversity or to spare pine regeneration areas. On still nights with heavy dew, fires often die out as they approach openings of 1/4 ac or larger due to the lack of pine needle litter.

Fire intensity can be adjusted to achieve the desired level of vegetation control. Under conditions when flames will only head, the intensity can be adjusted by expanding or contracting the distance between strip fires. Flank fires are sometimes used to achieve moderate burn effects. General maintenance is usually achieved by igniting fuels as soon after rain as they will burn satisfactorily. In variable terrain this entails setting longleaf-wiregrass ridges first, then heading fire as far downslope as possible. Lower slope types may be reignited after a few days of drying. This general ploy of burning from high to low combustibility also has application in other fuel types. Very light burning can be used to maintain wildlife and scenic values in special habitats (e.g. flats with mature dogwood, blackgum, maple) or features like red-cockaded colonies, old house places, or historic sites.

It is important to recognize that problem areas frequently develop under a conservative land management program. Where too many large hardwoods have developed, a series of dwelling backfires may be used; intense headfire under dry conditions is often necessary to reclaim areas with large thickets or dense drains after perimeter vegetation has been carefully burned. A combination of bush cutting along with fire provides long-term vegetation control in many cases.

One of the greatest challenges is to prevent damage of neighboring habitats while controlling vegetation in pinelands. Plowed firebreaks should be avoided whenever possible; when their use is absolutely necessary they should be kept shallow, placed on contours well away from wetlands, and be smoothed after use. Soil erosion has irreparably damaged many wetlands (e.g. insectivorous plant bogs, seepages which support pine barrens tree frogs); in numerous cases, plowed firebreaks have caused lowland vegetation to thicken and expand upslope. The maintenance of such habitats depends on intact drainage patterns together with occasional sweeping fires. Wildlife diversity hinges on feathered ecotones created by variable fires much more than abrupt edges between habitats. Thus, alternatives to plowing should be used wherever possible, such as a combination of band mowing and "wetlines" (spray saturation) or burned-out "blacklines". Plowing can be avoided in many cases by choosing damp conditions and taking advantages of the tendency for fire intensity to be low at the point of ignition and to die-out in a direction downslope and/or towards wet conditions. Even under moderate burning conditions fire can be passively withheld from the less flammable vegetation types by torching along the edge. A detailed knowledge of fuel types and terrain are required for a manager to take advantage of natural fire breaks.

In a multiple resource management regime, all large-scale burning should be completed in longleaf forests before the white buds show much growth and certainly before candles expand beyond the cloak of green needles. Initiation of apical growth varies with the first warming trend of the year. This and other precautions should be taken to guard against severe scorching which reduces pine growth and possibly seed production. The completion of burning before April is also recommended for maintaining high populations of many wildlife species, particularly those which nest at or near the ground. However, options should be held open to shift burning time to late spring or summer to achieve greater control of hardwoods and brush in problem areas, then to shift back to winter-early spring burning.

A system of occasional growing-season burns, rotated over time among compartments, would favor certain natural elements of the community. A carefully planned late-spring burn may also induce early height growth of grass-stage longleaf seedlings. All managers of longleaf forests should stay abreast of the developing knowledge about the role growing-season fire plays in forest stability, as implications for future management (see Community Integrity section).

Thinning of dense young longleaf on moderate to dry sites can be accomplished with light or patchy burning after seedlings are about 1 year old. To encourage sparse seedlings, fire can be delayed for 2-3 years if surface vegetation is not very dense. Winter fires may tend to reduce density of very young seedlings more than growing season fires, but the fuel load bears heavily on this effect. Site quality is also important, and slow-developing seedlings, such as often occur in wet flatwoods, may require 3 years of growth before a significant number will survive fire. Managers must weigh such factors against the accumulation rate of competing vegetation to determine the best burning scheme. Trial burns and on-the-ground judgement are thus required. After adjustment to desired initial density, competition in regeneration patches combined with normal maintenance burning will adjust the stocking as trees enlarge. Protection of regeneration parcels with plowed fire breaks is not necessary if burning is timed to prepare the seed bed ahead of a substantial masting, and the next burn is delayed for an appropriate period. Soil disturbance in general should be minimized to maintain as much natural ground cover as possible.

Community Integrity

There is much interest in restoring native communities on many public lands and private preserves. The purely natural approach contrasts sharply with propagation-oriented management in that wildness becomes the valued "resource" and emphasis is placed on natural processes to arrange species within a dynamic equilibrium. The basic concept is to return vegetation to presettlement conditions, based upon early descriptions together with clues from research into how natural processes likely operated. Background information of any type is scanty for longleaf forests. While we know that open, park-like vistas were quite common, we can only guess how landscapes would have looked had Indians not been impacting the region throughout the millennia as this forest type burgeoned. If Indians were to be considered a natural factor, management toward presettlement conditions certainly would have to include much winter burning plus some extent of land clearing, low-key farming, exaggerating habitat components favorable to game, hunting, etc. Decision makers who consider such influences unnatural attempt to factor them out altogether; in this scenario the sole intervention in longleaf forests often becomes ignitions during the plant growing season to substitute for widely-spreading lightning fires, a process that has long been severed by forest fragmentation and fire suppression.

Much hinges on the long-term impact of management decisions. Perhaps the most serious community change brought about during the no-burn era was widespread invasion by noncharacteristic hardwoods and shrubs. Fire exclusion is known to proliferate broad-leaved woody plants which eventually displace the entire community. Reinstatement of late-winter burning is largely responsible for the surviving longleaf forests; this practice stunts broad-leaved plants down into surface vegetation where they may survive as long a3 the management regime continues. Winter fires repeated for many year3 may increase the abundance of undesirable vegetation (e.g. bracken, woody sprouts) which can spread laterally and very gradually overtake grasses. For example, in a pine forest in the Coastal Plain of S. C., Waldrop et al. (1987) compared vegetation responses in control plots and plots receiving different burn treatments. After 30 years the plots receiving annual winter fires contained by far the greatest density of small (<1 in. dbh) hardwoods, primarily sweetgum and oaks; plots with this treatment averaged about 2.5 times as many small hardwoods and about 25% more shrubs as occurred'in plots burned biennially during summer. Conversely, the biennial summer plots contained the greatest coverage of total herbs, especially grasses, which averaged nearly twice that in annual winter plots. Recurring fires from late spring-early summer increase the relative dominance of grasses over woody plants; burning at this time also triggers the early exit of young longleaf from the "grass" stage plus seed production of wiregrass and enhanced flowering by many other plant associates. These factors form the basis of recommendation3 to shift burning time to the growing season. Moreover, burning primarily in the growing season may be crucial to community maintenance, especially on an extensive scale, if it is the practical way to keep scrubby growth from displacing bunch grasses, because the grassy turf comprises an essential part of the fuel complex.

Arranging key plants into a preconceived pattern with appropriate burns may not insure that community members will all fall into place. Other disturbance agents should be considered as well. For example, the now extinct megafauna certainly exerted disturbances on Coastal Plain habitats; theorists generally hold the aboriginese largely responsible for that massive extinction plus the subsequent 1033 of some smaller animal3 dependent upon habitat disturbances by the megafauna. Some also believe that bison populations were held low by Indians in this region but expanded when Indians began to declined (Rostlund 19601. An important question is whether some plants and animals became dependent on man's influence that otherwise would have been perpetuated through influences of large animals now removed from the scene. For some reason there are numerous species in the Coastal Plain that benefit from soil disturbance: some uncommon ones depend largely upon it for their continuance.

Several habitat disturbance and population control agents have been greatly diminished in the longleaf community. Completely gone or greatly diminished from most areas are the wildlife that physically damaged vegetation while exposing bare soil (bison, elk, bear); top predators like panthers, wolves and large raptors which exerted pressure on medium-sized mammals (raccoon, opossum) and snakes which prey on eggs or young animals: and burrowers (gopher tortoise, pocket gopher) upon which dozens of vertebrate and invertebrate species depend. The point here is that intervention beyond warm-season burning may be necessary to perpetuate some members of the community.

Essentially all areas,, even those with much original ground cover, have far too many trees of hardwood species not indigenous to the community type, plus prodigious woody plants dwarfed into the ground cover. In most cases the vegetation to be burned is not a natural fuel complex and the over-story is not a multi-aged mosaic. Nor does typical torch burning duplicate the vagaries of natural fires. A sudden switch to growing season fire could reduce portions of the longleaf over-story to the point that brush proliferates: moreover, it could wipe out native species that have dwindled to very small populations, even though they were formerly adjusted to lightning-set fires. Therefore, the first reclamation step for many longleaf areas should be a series fuel-reduction burns (winter) to phase into a series of spring-summer burns on a 2-year rotation. Initial warm-season fires should coincide with high-humidity conditions. After reconditioning, the fire intensity can be adjusted to achieve the desired habitat changes. An intense fire may reduce hardwood trees into sprouting brush that may escape the next or subsequent burns. There is some indication that complete mortality of sizable hardwoods results from fire intense enough to damage but not reduce them completely to brush, followed by frequent low-intensity fires that repeatedly deplete tree reserves. Additional experimentation is needed to guide forest restoration projects involving fire.

The real challenge of maintaining community integrity comes as the pine-grassland balance is being restored. Many indigenous wildlife species will severely decline if habitat uniformity is taken too far, such as if shrub clumps and hardwoods become quite rare. Even if enclaves of broadleaf woody plants were originally sparse it is important to recognize that well over 100,000 square miles of habitat formerly existed. It is necessary to tighten the scale at which some components occurred now that only a tiny fraction of the type remains in disjunct parcels. This becomes more important as the size of the preserve decreases. Another concern is that over one-third of the precarious wildlife species reproduce at or near ground level during the season of lightning-simulated burns (another factor of no consequence back when variable fires moved intermittently through immense habitats). Presently there are no definitive publications on wildlife impacts by warm-season fires in the longleaf type. Until that knowledge gap is closed we recommend conservative measures to maintain structural and temporal diversity in the habitat scheme.

This can be accomplished without diminishing either relative dominance of grasses or sensitive wildlife in need of open expanses.

Many troubled species require individual or clumps of tall shrubs emerging from a diverse ground cover. These can be provided either by withholding fire from a specified area for several years or by burning during moist periods to produce a mosaic. The first ploy would more likely reduce the essential bunch grasses, but even grass-shrub mosaics must soon be wiped clean to guard against hardwood expansion. For this reason we recommend a system of sizable compartments, each burned in a different year, and each treated within a 2 - 4 year burn cycle in which mosaic burns and uniform burns are alternated. A 3-10 year frequency range might be more appropriate for sandhills after the scrub-pine balance is restored. Variability can be added by selecting a season for each burn weighted by probability of lightning ignition (see Komarek 1964) -- about 57% May-June, . 36% July-August, 7% dormant season. It is important to note, however, that estimates exist for frequency of ignitions per month but not for resulting extents of natural fire coverage. Ground fuels (pine needles plus grasses) were'formerly almost continuous across huge areas, and widely spreading lightning fires have been noted even during rains (Chapman 1950). Stewards of preserves should consider these questions: Did late-summer fires in the natural state commonly burn on into or reignite during the dormant seasons? Did lightning fires starting in the dryer dormant seasons cover much greater extents than the ignition frequency might imply? Did natural history aspects of some native species become attuned to burning at times other than at peak lightning ignition (May-June)? Because of limited baseline information we recommend flexibility in burn regime (season, intensity, frequency, extent) and more emphasis on response by community elements than strict adherence to schedules.

Timber harvesting operations are fundamentally counter to community integrity. While some timber production can be accomplished without greatly disrupting wildlife which depends on the overstory, the cumulative impacts of both site-preparation and thinning operations irreputably damage the ground cover, alter fire behavior, and favor hardwood invasion over time. Careful thinning, however, may be necessary in some preserves to guide the overstory towards a multi-aged pattern. Very dense tree stands will not open through natural mortality fast enough for young pine cohorts to accumulate or for certain ground cover plants to thrive. In the absence of large old pines, which attract lightning, the preserve steward may need to create mini-openings to approximate those once created by lightning strikes or windthrows. It is recommended that thinning operations, where necessary, be completed in one pass in order to avoid repeated disruption of surface vegetation.

Very light grazing might help maintain natural diversity. Some wildlife species are favored as grazers closely crop grasses and churn soil between patches of unpalatable shrubs (saw palmetto, wax myrtle, hawthorn, etc.); this condition is not generally created by white-tailed deer (primarily a browser) which is now the only extant ungulate. Certain animals (e.g. ground doves, pocket gophers) and plants (e.g. some blazing stars, orchids) would likely respond positively to spotty soil disturbance by hooves gouging the ground between grass tussocks. Recognition of the importance of grazing led the Florida Park Service to restock bison into Paynes Prairie in 1975. Limited cattle grazing may be a viable alternative in some areas. Experimentation with low-intensity mechanical methods is also needed to determine if certain rare plants actually require areas recently opened by light soil disturbance for successful regeneration. Methods to approximate several kinds of natural disturbances are needed to maintain species diversity on small preserves.

Now that top predators have been extirpated, intervention is needed to control certain smaller predators. Special attention should be given to cropping mid-sized mammals whose unchecked populations, especially where locally spurred by agriculture or other active land management, can bring unnaturally severe pressure on ground-nesting species of wildlife. For the same reason, free-ranging dogs and house cats should be eliminated from wildlands. Also, rigid control of deer herds is necessary to maintain a variety of herbaceous plants including some rare species.

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APPENDIX

Scientific names of plants and animals mentioned in the text.

Am. Kestrel (Falco sparverius)
Azalea (Rhododendron spp.)
Bachman's sparrow (Aimophila aestivalis)
Bahia (Paspalum notatum)
Bison (Bison bison)
Black bear (Ursus americanus)
Blackgum (Nvssa sylvatica)
Blazing star (Liatris spp.)
Blue-gray gnatcatcher (Polioptila caerulea)
Blueberry (Vaccinium spp.)
Bluejack oak (Q. incana)
Bluestem (Andropogon/Schizachyrium spp.)
Bobwhite (Colinus virginianus)
Boll weevil (Anthonomus grandis)
Bracken (Pteridum aquilinum)
Brown-headed nuthatch (Sitta pusila)
Buckeye (Aesculus spp.)
Cane (Arundinaria spp.)
Carolina chickadee (Parus carolinensis)
Carphephorus (Carphephorus spp.)
Chufa (Cyperus esculentus)
Coachwhip (Masticophis flagellum)
C. ground dove (Columbina passerina)
C. nighthawk (Chordeiles minor)
C. yellowthroat (Geothlypis trichas)
Composite (Asteraceae)
Dogwood (Corms florida)
Drop-seed grass (Sporobolus spp.)
Dwarf live oak (Q. minima)
Dwarf wax myrtle (M. pumila)
E. bluebird (Sialia sialis)
E. diamondback rattler (Crotalus adamanteus)
E. flying squirrel (Glaucomys volans)
E. kingbird (Tyrannus tyrannus)
E. meadowlark (Sturnella magna)
Elk (Cervis canadensis)
Field sparrow (Spizella pusilla)
Flatwoods salamanader (Ambystoma cingulatum)
Florida Panther (Felis concolor coryi)
Fox (Urocyon cinereoargenteus/Vulpes fulva)
Fax squirrel (Sciurus niger)
Gallberry (Ilex glabra)
Gopher apple (Licania michauxii)
Gopher frog (Rana areolata)
Gopher tortoise (polyphemus)
Grape (Vitis spp.)
Grass (Poaceae)
Gray kingbird (Tyrannus dominicensis)
Gray squirrel (S. carolinensis)
Hairy woodpecker (Picoides villosa)
Harvester ant (Pogonomyrmex spp.)
Hawthorn (Crataegus spp.)
Hickory (Carya spp.)
Holly (Ilex spp.)
Indigo snake (Drymarchon corais)
Legume (Fabaceae)
Loggerhead shrike (Lanius ludovicianus)
Longleaf pine (P. palustris)
Maple (Acer spp.)
Mourning dove (Zenaida macroura)
N. flicker (Colaptes auratus)
N. mockingbird (Mimus polyglottos)
oak (Quercus spp.)
Orchid (Orchidaceae)
Panic grass (Panicum spp.)
Paspalum (Paspalum spp.)
Pine (Pinus spp.)
Pine barrens tree frog (Hyla andersonii)
Pine snake (Pituophis melanoleucus)
Pitcher plant (Sarracenia spp.)
Plum (Prunus spp.)
Pocket gopher (Geomys pinetis)
Pond pine (P. serotina)
Prairie warbler (Dendroica discolor)
Raccoon (Procyon lotor)
Redbud (Cercis canadensis)
Red-cockaded woodpecker (Picoides borealis)
Red-eyed Vireo (Vireo olivaceus)
Red-headed woodpecker (Melanerpes erythrocephalus)
Red-winged blackbird (Agelaius phoeniceus)
Ruby-throated hummingbird (Archilochus colubris)
Runner oak (Q. pumila)
Sand pine (P. clausa)
Saw palmetto (Serenoa repens)
Sedge (Cyperaceae)
Shennan's fox squirrel (S. n. shermani)
Slash pine (P. elliottii)
SE shrew (Sorex longirostris)
Sunflower (Helianthus spp.)
Sweetgum (Liquidambar stvracif lua)
Titi (Cyrilla racemif lora)
Tufted titmouse (Parus bicolor)
Turkey oak (Q. laevis)
Turtle dove (mourning dove)
Va. Opossum (Didelphis virginiana)
Wax myrtle (Myrica cerifera)
White-tailed deer (Odocoileus virginianus)
Wild turkey (Meleagris gallopavo)
Wiregrass (Aristida stricta)
Wolf (Canis rufus, C. lupus)
Yellow-breasted chat (Icteria virens)

Session III

April 6, 1989

Moderator:

Douglas P. Richards
Mississippi State University

Predictions of Volume and Volume Growth in Naturally-Regenerated Longleaf Pine Stands

Robert M. Farrar, Jr.

ABSTRACT. The history, development, and application of growth and yield predictors for naturally regenerated stands of even-aged longleaf pine (*Pinus palustris* Mill.) are reviewed in this paper. Although the current prediction systems for thinned stands of longleaf are useful, they do have limitations. Ongoing efforts that continue to improve the predictors are discussed along with future information needs and plans to secure that information.

INTRODUCTION

Longleaf pine (*Pinus palustris* Mill.) once covered some 50 to 60 million acres in the Southern United States in a broad arc, mostly on the sandy Coastal Plain from southern Virginia to east Texas, and has been considered "one of the finest timber trees the world has known" (Wahlenberg 1946). Due to a number of factors, including forest land clearing for agriculture, urbanization, and purposeful or accidental conversion of longleaf stands to other pine species, the area occupied has decreased until at present only some 4 million acres of longleaf stands remain according to data furnished by the USDA Forest Service Forest Inventory and Analysis groups located in Asheville, NC, and Starkville, MS. This is unfortunate because the species has a number of inherent advantages from a forest management standpoint. The major advantages are:

1. At most stages in the development from seedling to mature trees, longleaf is notably resistant to damage by fire, insect attack, and most diseases-- notably fusiform rust ***(Cronartium quercuum*** [Berk.] Miyabe ex Shirai f. sp. *fusiforme)* --which often can be severely damaging to other southern pines at certain stages and under certain patterns of development.

Robert M. Farrar, Jr. is principal silviculturist, USDA Forest Service, Southern Forest Experiment Station, Mississippi State, Mississippi 39762, in cooperation with the School of Forest Resources and Agricultural'& Forestry Experiment Station, Mississippi State University.

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2. Longleaf is generally straight-stemmed, with good form and good natural pruning, which makes it a preferred species for utility poles and high-quality sawtimber that command premium stumpage prices.

3. The wood has a high-density, giving it good strength properties and making it desirable for both construction lumber and wood pulp.

Longleaf also has some disadvantages relative to other southern pines that have made it unpopular for management by some landowners. The major disadvantages are:

1. Good seed crops are infrequent, and longleaf is exacting in its seedbed requirements for good seed germination and seedling establishment, survival, and growth.

2. Longleaf has a grass stage in which seedlings are very intolerant of competition, and this in turn often delays stand height growth and development into merchantable sizes.

3. While in the grass stage, longleaf is susceptible to brown-spot needle blight (*Scirrhia acicola* [Dearn.] Siggers), which reduces seedling vigor and growth, may prolong the grass-stage period, and may result in death in severe cases.

However, these disadvantages can be minimized if not completely overcome. A shelterwood method for natural regeneration has been developed that capitalizes on moderate or better seed crops to obtain adequate reproduction, minimizes the impact of brown-spot, and promotes rapid development of the seedlings once they are released from the parent stand (Croker and Boyer 1975). The grass stage can be minimized in natural systems by proper control of competing vegetation during the rotation (and especially just before the regeneration period), securing adequate numbers of seedlings under a shelterwood, prompt removal of the parent stand, and proper use of prescribed fire.

Consequently, due to its advantages and the difficulties with disease losses, wildfire damage, and poor growth experienced with plantations of other southern pines on some former longleaf sites, many landowners would like to retain or reinstate longleaf on their lands. In particular, certain industries and public agencies, such as the T. R. Miller Mill Company and the National Forest System (Sirmon and Dennington 1989), are committed to maintaining or re-establishing longleaf on sites in land bases currently or formerly occupied by the species. A number of nonindustrial private concerns are also interested in maintaining longleaf forests for both timber production and recreational uses.

Successful longleaf timber management demands accurate predictions of the growth and yield that will result from various management alternatives so each can be evaluated quantitatively and economically. A review of the development and usefulness of current stand growth prediction systems and a discussion of future information needs and research plans are presented in this paper.

BACKGROUND

Since the advent of normal yield tables in the 1930's (USDA FS 1976), researchers have continued their efforts to refine predictions of the growth and yield responses of pure even-aged stands to natural or man-modified environments. The main independent variables used to predict growth and yield have been stand age, site quality (usually expressed as site index), stand density (trees or basal area per acre) and seedbed or planting site situation (such as old-field, site-prepared, and cutover). A classification of stand growth and yield prediction systems, with longleaf examples when available, is given in table 1. The utility and versatility of the systems increase as one reads down through the table.

Normal Yield Tables

Normal yield tables assess the effects of varying age and site index (SI) on yields from unmanaged "fully stocked" or "normal" stands. The tables are based on temporary plots taken in stands judged to be producing cubic-foot volume at the fullest capacity. It is assumed that these normal stands portrayed for a given site by ages represent a real-growth series over time, when in fact they very well may not. Also, little provision is made to predict for non-normal stands that occur naturally or as a result of thinning. These tables have had little practical usefulness as growth predictors, except as indicators or benchmarks for comparisons, because the normal stand is rarely found and is probably even more rarely chosen as a management option.

Well-stocked Yield Tables

"Well-stocked" or "stocking-norm" yield tables (e.g., Schumacher and Coile 1960) followed normal yield tables in an evolutionary sequence and generally suffer from the same deficiencies. Their main advantage is that stand densities lower than normal were chosen as the norm or well-stocked condition and thus they are more likely to resemble stands commonly encountered in the field. Yet, with few exceptions, provision was not made to address the effects of varying stand density such as that imposed by thinnings. However, the normal and well-stocked yield tables often remain useful sources of SI curves and tree-volume tables.

Table 1.--*A classification of growth and yield predictors for natural stands, with a typical example for longleaf pine, when available*

Predictors	Example
Normal yield tables (unthinned)	Forest Service 1976
Stocking-norm yield tables (unthinned [1])	Schumacher & Coile 1960
Point studies (usually thinned)	
'compartment studies	Boyer & Farrar 1981
plot studies	Farrar 1968
Variable-density predictors (thinned and unthinned)	
Multiple Regression Predictors	
Yield	none
P.A.I.	none
Stand Volume and Growth Predictors	
Stand-level (deterministic)	
Lump-sum (simultaneous models)	Farrar 1985b
Stand-and-stock table (dia.-distr. models)	Farrar 1985a
Tree-level (deterministic and stochastic; tree growth and inter-tree competition models)	
Distance-independent	none[2]
Distance-dependent	none

1 Some allow estimation of the effect of thinnings.

2 A distance-independent'tree-level predictor is under development.

Point Studies

Most studies of stand growth and yield before the 1960's were mainly point (compartment or plot) studies. In compartment studies, large areas of 5 to 40 acres were used to test management alternatives and intensity. Few such studies were replicated due to their size and some, such as the longleaf "Farm Forties" discussed in 'Croker (1966) and Boyer and Farrar (1981), were intended to test long-term management regimes or silvicultural systems. Most of these studies were primarily demonstrations rather than experiments. Their results were not highly useful for prediction, but they effectively demonstrated the importance of management. Although most such studies had been discontinued by the mid-1960's, their data still have some usefulness in developing stand-level models, diameter-distribution prediction methods, and studying the effects of varying age, site quality, and density within a stand. Plot studies employed groups of small plots (usually 1/10 to 1/4 acre each) to compare treatments such as thinning levels or initial spacings. They were usually installed in pure stands and replicated, but individual studies were small and considered only a few ages, sites, and treatments. An example is the Loxley longleaf thinning study (Gaines 1951, Farrar 1968). Many of these studies are still maintained and continue to contribute data. Each point study is unique in its objectives, analysis, results, and, possibly, interpretation. collectively, the results do not provide a basis for predicting growth over a wide range of conditions, but the data can often be pooled to develop more comprehensive predictions.

Variable-densitv Predictors

In almost all subsequent growth and yield investigations, the effects of spacing and thinning have been actively studied because stand density is an easily altered variable usually second only to stand age in its influence on stand volume and growth. For naturally regenerated stands, we have progressed from studies that used regression analysis and observations on varying stand age, SI, and density to predict the yield of unthinned stands (e.g., MacKinney and Chaiken 1939) or the periodic annual increment (p.a.i.) in thinned stands (e.g., Nelson et al. 1961) up through the simultaneous stand volume and volume growth predictors developed by Sullivan and Clutter (1972), improved by Murphy (1983), and employed by Farrar (1979, 1985b) for thinned natural longleaf stands. The latter four have been valuable additions to our information base, but such lump-sum predictors are limited in prediction of product volumes by merchantability classes. Although we can now predict volume and growth for the merchantable and sawtimber components in simultaneous-type predictors, we still lack a comprehensive d.b.h.-distribution or individual-tree system for thinned natural stands of longleaf. Only one limited d.b.h.-distribution predictor has been developed for natural stands of longleaf, and it is for young unthinned stands (Farrar 1985a). However, a comprehensive d.b.h.-distribution prediction system for thinned natural longleaf stands is nearing completion. Individual-tree based prediction systems, such as "STEMS" (USDA FS 1979), are the most versatile, and although we currently have no such system for natural longleaf stands, one that is distance-independent is under construction. Table 2 shows the growth and yield prediction systems currently available for natural stands of longleaf.

REGIONAL LONGLEAF GROWTH STUDY

All the current prediction systems and those under construction for natural longleaf stands draw on the Regional Longleaf Growth Study (RLGS) initiated by the Southern Forest Experiment Station and maintained with cooperation from industrial and nonindustrial private owners, Region 8 of the Forest Service and other public owners, and universities in the mid-South. This ongoing study was started in the mid-1960's and now comprises some 265 permanent plots installed on cooperator lands in a broad array of stand ages, site qualities, and residual densities and is maintained by periodic low thinning. The study is inventoried on a 5-year cycle, and the plots are rethinned at each inventory', as needed, to maintain the assigned density level. The fifth 5-year inventory will start in the early fall of 1989, and the field work will be conducted cooperatively by Auburn University, Auburn, Alabama.

Studv Details

The objective of the RLGS is to monitor the development of thinned even-aged stands over time so the output in product volumes can be predicted at various ages for virtually any stand occurring on a given site and maintained under a certain density regime. This is the only way such information can be obtained--it cannot be "simulated." The best information ultimately comes from young stands managed to rotation age, but rather than go through a rotation to obtain the estimates, plots were selected to fit into the array of cells formed by all possible combinations of four 20-year age classes, five lo-foot SI classes, and five 30-square-foot basal area classes, with three replications of each combination. This design allows responses to be quickly estimated after a few years, and leads to a study structure that will afford better and better estimates as time passes.

In the array of plot cells, the age classes range from 20 to 80 years, SI classes vary from 50 to 90 feet at age 50, and residual basal area ranges from 30 to 150 square feet per acre (table 3). In addition to the initial set of 20-year-old plots installed in the mid-1960's, a second set of 20-year-old plots

Table 2.--*Preprogrammed natural* ***longleaf*** *pine stand* ***growth and*** *yield systems available in spreadsheet* ***templates*** *and BASIC programs*

System and source	**Input**[1]	**Output**[2]
Stand-level		
Farrar **1979b**	Al, A2, **BT1,** Q	BT2, **T1,** T2, Ml, M2, Cl, c2, 11, 12
Farrar 1985b	Al, A2, **BT1, BS1,** Q	BT2, BS2, **T1, T2,** Ml, M2, Cl, c2, 11, 12
Dbh-distribution		
Farrar **1985a**[3]	Al, A2, **TSO(A1),** Q	Stand-and-stock tables at Al **&** A2 showing trees, basal area, and volumes per l-inch d.b.h. class **&** stand totals

[1] Al = initial age; A2 = final age: **BT1** = initial total basal area (BA); **BS1** = initial sawtimber BA; Q = site index (index **age** = 50); TSO(A1) = total number of surviving trees at age Al.

[2] BT3 = final total BA; BS2 = f'nal sawt. BA; **T1** = initial total ft^3 vol.: T2 = final total ft^3 vol.; Ml = initial merch. ft^3 vol.: M2 = final merch. **ft^3 vol.;** Cl = initial sawtimber **ft^3** vol.: c2 = final sawtimber ft^3 vol.; 11 = initial Int. **1/4-**inch fbm; 12 = final Int. l/l-inch fbm.

[3] BASIC program only (no spreadsheet template available).

Table 3.--*Expected plots per age, site index, and basal area cell at the beginning of the 2-year inventory of the regional longleaf growth study*[1]

Age	Site index	Residual basal area ft² per acre 30	60	90	120	150
yrs	*ft*	*number of plots*				
20	40	1	(1)[2]	(1)	(1)	
	50	3	3	(3)	(3)	(3)
	60	4	2+(1)	(3)	(4)	(4)
	70	5	3+(2)	(5)	(5)	(4)
	80	1	1+(1)	1+(1)	(2)	(3)
	90	-[3]				
40	50	-				
	60	2	2	2+(1)	1+(1)	2
	70	5	3	5	3+(2)	(4)
	80	7	9	7	7+(1)	3+(3)
	90	2	-			1
60	50	1	2	2	1	
	60	1	-	1	2	1+(1)
	70	3	3	1		(3)
	80	3	4	6	2+(1)	2
	90	-		1		1

Table 3.(cont.)--*Expected plots per age, site index, and basal area cell at the beginning of the 25-year inventory of the regional longleaf growth study*

Age	Site index	Residual basal area ft^2 per acre 30	60	90	120	150
yrs	*ft*	*number of plots*				
80	50	2	1	1		-
	60	2	1	2	1	4
	70	2	4	1+(1)	2	-
	80	5	3	3	3	2+(1)
	90		3	2	2+(1)	-
100	50	1	1	2	1	-
	60	1	2	1	1	-
	70	5	4	3+(1)	3	4
	80				-	-
	90	-	-	-	-	-

1 This study was initiated by the Southern Forest Experiment Station in 1964; a cell refers to a combination of age, site index, and basal area.

2 Parentheses denote plots assigned to cells even though the required basal area was not present at the 20-year inventory.

3 A dash indicates no plots exist for this cell.

was installed in the mid-1970's and a third set in the mid-1980's, each with a similar complement of site and density combinations. Plans are to carry each set to a rotation age of 80 or more years. Beside affording the best information on stand development over time, these sets of plots will allow detection of any changes in growth rate that may occur with time. Additionally, because of increasing interest in the performance of stands older than what would be a normal rotation, the oldest plots are being maintained to an age of 120'years.

Predictors

The RLGS study has afforded a number of predictors related to development, volume, and volume growth of thinned natural longleaf stands. The first comprehensive stand-level prediction system utilized the data from the first 5-year growth period (Farrar 1979). It permitted estimates of total, merchantable, and sawtimber cubic-foot volumes and International 1/4-inch board-foot volumes and volume growth for a great variety of stand conditions and, by simulated manipulation of the initial density at the start of a growth period, permitted estimates of the results of simulated thinning: If desired, it could also provide estimates of the dry weight of wood in the merchantable and the sawtimber stand; However, only total basal area manipulation could be simulated, and the effects of thinning on the sawtimber component of a stand could not be directly estimated. An updated and improved system was developed using data from the 5- and lo-year inventories (Farrar 1985b). This is the main system currently suggested for use, and it provides all the features of the earlier system plus it allows simulated manipulation of both the total and the sawtimber basal area, within limits, in a stand and thereby permits direct estimates of the effect of thinning on the total, merchantable, and sawtimber components of a stand.

The main prediction system (Farrar 1985b) normally starts at age 20 and uses basal area as the density measure. However, a prediction can be started at a much earlier age, say about age 10, when the stands are composed of seedlings and saplings and number of trees has more utility than basal area as a density measure. To develop a procedure for making this density translation from trees per acre to basal area over time, the data from a spacing experiment in young natural longleaf stands on medium sites was used to develop a companion prediction system (Farrar 1985a) for the main system. Development of density expressed as both trees per acre and basal area per acre was monitored from age 10 to age 20, enabling prediction of basal area at age 20, when basal area can be used in the main prediction system.

There have also been publications on tree-volume definition (Farrar 1981a, 1984, 1987) and SI estimation (Farrar 1981b) that draw directly from RLGS data and other publications dealing with the use of information provided by the stand volume and volume growth predictors (e.g., Boyer and Farrar 1981, Dennington and Farrar 1983, and Farrar et al. 1985).

In the following section, current prediction systems for natural stands of longleaf pine are examined in more detail to see what they predict and discuss their uses and limitations.

CURRENT PREDICTORS

Predictor Usefulness

There are two related stand volume and volume growth prediction systems currently available for managed stands of natural longleaf. One is the comprehensive main stand-level system (Farrar 1985b) which can normally be entered at age 20 and which has the most versatility. The other is a limited supplemental d.b.h.-distribution system (Farrar 1985a) for young stands, which permits estimates to start as early as age 10 on medium sites. Other improved systems are being developed, but they will be discussed later. Basically, these predictors can first estimate the current volume of a stand given its current age, SI, and current density and then project the stand for a period of years to obtain future estimates of stand density and volume. This can be done for one period or a sequence of periods comprising a planning horizon or rotation. In the main system, at the start of each period, stand density reductions can be simulated to imitate and estimate the effects of thinning. The earlier stand-level system (Farrar 1979) can still be used, but this is not recommended because the current main system is more versatile and based on a larger database.

There are several ways in which one can use these predictors, depending on the computing facilities available. If no programmable computer is available, one can simply use the tables given in Farrar (1985b) (fig. 1) but this is time-consuming, generally requires some interpolations that may result in loss of precision, and may require considerable interpolation if the conditions one wishes to evaluate are not given in the tables. Evaluation of the systems becomes much easier if a microcomputer is available because both BASIC programs and electronic spreadsheet templates (Farrar et al. 1985) are available for the main stand-level system, and a BASIC program is available for the supplemental d.b.h.-distribution system for young stands. The BASIC program for the main system allows one to predict certain current wood volumes, dry weights, and future densities, volumes, and weights and to calculate the estimated growth for a given stand (fig. 2). Obviously, all predictors in the system are not included in this small program, but the program is easily modified to include any desired predictor. If one wishes to evaluate a thinning regime over several growth periods, "Lotus 1-2-3" and "SuperCalc" spreadsheet templates are available for this purpose (fig. 3). These

Table 35.--Current and projected merchantable cubic foot volumes,i.b.,(VIM) and projected total basal area (BT2) for natural even-aged stands of longleaf pine in the East Gulf,initial basal area (BTi) = 80 square feet.

Initial age (Years)	Final age	Site index so	60	70	80	90	Projected basal area (sq. ft.)
A1	A2	VIM (cubic feet,i.b.,/acre)					BT2
20	20	312	624	908	1168	1431	80
	2s	788	129s	1709	2099	2509	108
	30	1360	1985	2495	2999	3548	130
	3s	1927	2615	3200	3804	4476	147
	40	2440	3162	3810	4500	5280	160
	4s	2885	3629	4331	5096	5968	169
	so	3266	4027	4776	5606	6557	177
2s	2s	599	972	1276	1564	1869	80
	30	1101	is90	1992	2391	2828	103
	3s	1626	2191	2676	3179	3739	122
	40	2123	2738	3295	3890	4563	138
	4s	2568	3221	3841	4518	5291	150
	so	2960	3643	4317	S067	5926	160
	55	3300	4008	4732	5544	6479	168
30	30	877	1250	1559	1868	2208	80
	3s	1350	1803	2196	2606	3064	100
	40	1818	2332	2801	330s	3876	116
	45	2253	2816	3354	3944	4617	130
	so	2647	3250	3849	4516	5281	142
	55	2997	3634	4288	S023	5870	is2
	60	330s	3974	4676	5472	6391	160
35	3s	1108	1464	1777	2107	2476	80
	40	1538	1959	2349	2770	3247	97
	45	1954	2431	2891	3399	3978	112
	so	2341	2866	3392	3978	4651	125
	55	2694	3261	3845	4503	5262	136
	60	3011	3615	4253	4976	5811	145
	65	3295	3933	4617	5398	6302	153
40'	40	1290	1630	1950	2297	2692	80
	4s	1679	2078	2468	2899	3393	9s
	so	2052	2503	2960	3470	4057	108
	ss	2401	2899	3417	4001	4674	120
	60	2721	3262	3835	4486	S239	130
	65	3013	3591	4215	4928	5752	139
	70	3277	3889	4559	5327	6217	147

Figure 1. --*Volume and growth predictions as seen in table 35 of the appendix* given in Farrar *(1985b)*.

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E-A LONGLEAF STAND PROJECTION - EAST GULF AREA -

-------------- per acre --------------

SITE INDEX 75

	CURRENT VALUE	PROJECTED 5 YEARS	5 YEARS GROWTH
STAND AGE	40	45	5
TOTAL BA	80	95	15
SAWTIMBER BA	16	31	15
MERCH. C.F. VOL.(i.b.)	2119	2677	558
SAWT. C.F. VOL.(i.b.)	381	795	415
INT.-1/4 B.F. VOL.	2311	4914	2603
MERCH. WOOD DRY WT.(lbs)	70071	88528	18456
SAWT. WOOD DRY WT.(lbs)	12832	26804	13973

****

Figure 2.--*Example of output from a BASIC program using portions of the prediction system given in Farrar (1985b).*

LlpGYITw.CAL Stand: Example Strategy: Lv. 80 RBT & Cut >1500 fbm

SI(50)	AGE	STATUS	BT	TotCF	MerCF	8s	SawCF	Int.1/4	TotCF	MerCF	SawCF	Int.1/4
			STAND VALUES (per acre)						P.A.I. / M.A.I.			
75	20	b-c	75.0	1173	976	.0	0	0	58.7	48.8	.0	0
		a-c	75.0	1173	976	.0	0	0	58.7	48.8	.0	0
		cut	.0	0	0	.0	0	0				
75	25	b-c	103.3	1996	1818	1.0	15	87	164.6	168.3	3.1	17
		a-c	80.0	1556	1420	1.0	15	87	79.9	72.7	.6	3
		cut	23.3	441	3%	.0	0	0				
75	30	b-c	103.2	2308	2188	4.1	76	445	150.4	153.8	12.2	72
		a-c	80.0	1800	1711	4.1	76	445	91.6	86.2	2.5	15
		cut	23.2	508	477	.0	0	0				
75	35	b-c	99.6	2475	2396	12.0	258	1552	134.9	137.0	36.4	221
		a-c	80.0	1998	1938	12.0	256	1552	97.8	93.5	7.4	44
		cut	19.6	477	458	.0	0	0				
75	40	b-c	97.0	2607	2554	26.6	632	3896	121.9	123.1	74.9	467
		a-c	80.0	2161	2119	16.0	381	2311	100.8	97.2	15.8	97
		cut	17.0	447	435	10.6	252	1575				
75,	45	b-c	95.0	2715	2677	30.9	795	4914	110.9	111.6	82.9	521
		a-c	80.0	2296	2266	21.0	542	3315	101.9	·98.8	23.3	144
		cut	15.0	419	411	9.9	254	1599				
75'	50	b-c	93.4	2804	2776	36.2	993	6170	101.5	102.0	90.4	571
		a-c	60.0	1820	1806	27.0	743	4579	101.9	99.1	30.0	187
		cut	33.4	984	970	9.2	251	1591				
75	55	b-c	71.4	2245	2231	40.9	1184	7363	85.0	85.0	88.2	561
		a-c	30.0	962	960	30.0	870	5385	100.4	97.8	35.3	221
		cut	41.4	1283	1271	10.9	314	1998				
75	60	b-c	37.5	1238	1234	37.5	1136	7079	55.0	54.9	53.3	339
		a-c	.0	0	0	.0	0	0	96.6	94.2	36.8	231
		cut	37.5	1238	1234	37.5	1136	7079				
Yield =			210.3	5795	5655	78.0	2206	13842				
M.A.I. =			3.5	97	94	1.3	37	231				

Figure 3.--*Example of output from a SuperCalc template using portions of the prediction system given in Farrar (1985b).*

templates are available from Forest Resources Systems Institute in Florence, Alabama. The BASIC programs mentioned above are currently available only from the author.

The BASIC program for the supplemental young stand system (Farrar 1985a) will allow predictions for one set of stand conditions or an array of stand conditions. By itself, this prediction system is limited regarding the ages and sites for which it can predict and is probably best used to provide input for use by the main system. In this capacity, the system will allow predictions to start as early as age 10 whereas the main system essentially starts at age 20. Figure 4 shows typical output from this program.

Both systems provide estimates of total and merchantable cubic-foot volumes, both inside- and outside-bark, and the main system further provides estimates of sawtimber volumes and permits simulation of thinnings in both the merchantable and sawtimber stand components. The main system also allows estimates of wood production in dry weight, if desired (fig. 2). This means that a wide variety of stand management scenarios can be investigated regarding the effect on volumes of age, SI, and varying stand densities through time. This can vary from looking at predictions for one short growth period for a known stand to viewing the predictions for an array of hypothetical thinning regimes on different sites for different rotation lengths. Spreadsheet output for one thinning regime, SI, and rotation are given in figure 3 in which the volume predictors are the same as in figure 2. This scenario shows thinning from below to leave a total basal area of 80 square feet every 5 years for a 60-year rotation with regeneration cutting starting at age 50. A further condition imposed is that sawtimber cuts of at least 1,500 fbm will be.made each 5 years, starting as early as practical.

Precautions in Predictor Use

The main and supplemental prediction systems provide the means for simulating a wide variety of thinning schedules and rotation lengths both for existing and hypothetical stand conditions. Their versatility is great but not without limit. Therefore, certain limitations, conditions, and precautions must be observed so that the systems are not misused.

The limits on initial and final ages, SI, and initial densities given in the publications for the main (Farrar 1985b) and supplemental (Farrar 1985a) systems should not be exceeded. The minimum initial age can actually be as low as 15 years in the main system, but 20 years is preferable because SI estimates are more precise at older ages. Also, ingrowth above merchantablility thresholds may have a sudden and highly variable effect at young ages and-can severely reduce predictability. It is possible to start predictions as early as age 10 on medium

```
YIELDS GIVEN TSO (# OF TREES PER ACRE AT DESIRED INITIAL AGE) WITH TYPICAL
SURVIVAL--

                                              CU. FT. VOL. ABOVE 0.2 FT. STUMP
                                           ALL  TREES   * 4-INCH CLASS AND GREATER
          AV.   STEMS                      ********FOR O.B.  TOPS OF----********
JSO SI AGE D+C DBH PER BASAL CR AV.       0 INCHES  *   2 INCHES  *    3 INCHES
          HT.   ACRE  AREA        HT.   o.b.    i.b.*o.b.   i.b.   *o.b.   i.b.
------------------------------------------------------------------------------
900 80 10 10.4
                 1 273   1.5  58.2   6.1  11.1     5.1
                 2 164   3.6  69.5  11.9  32.4    18.0
                 3  10   0.5  72.6  14.9,  4.9     3.0
                 ----  -we-             ------  ------  ------  ------  ------  ------
                   447   5.6              48.4    26.2

ARITH. MEAN DBH =1.41       QUADR. MEAN DBH = 1.51
WEIBULL PARAM: A-0.55       B=0.98      C=1.93
SURVIVAL =100.0        MEAN CROWN RATIO = 62.5

------------------------------------------------------------------------------
900 80 15 28.4
                 1 112   0.6  33.0   5.6    4.3     2.0
                 2 284   6.2 '63.3  15.8   71.6    40.9
                 3 268  13.2  70.0  22.3  189.5   119.5
                 4 150  13.1  72.8  26.5  210.2   140.3   198.8   132.1   164.0   107.3
                 5  54   7.4  74.4  29.3  125.9    87.3   122.2    84.6   110.4    75.9
                 6  13   2.6  75.4  31.4   45.4    32.4    44.6    31.8    42.0    29.8
                 7   2   0.5  76.1  33.0    9.8     7.1     9.7     7.0     9.3     6.8
                 ----  ----             ------  ------  ------  ------  ------  ------
                   883  43.5             656.7   429.6   375.3   255.5   325.7   219.8

ARITH. MEAN DBH =2.77       QUADR. MEAN DBH =3.00
WEIBULL PARAM: A=0.55  B=2.51      C=2.05
SURVIVAL = 99.9        MEAN CROWN RATIO = 64 .0

------------------------------------------------------------------------------
900 80 20 41.6
                 1  49   0.3  11.7   8.6    2.5     1.2
                 2 167   3.6  38.7  22.9   58.5    34.6
                 3 230  11.3  45.7  31.7  224.6   145.6
                 4 209  18.2  48.9  37.3  402.7   275.5   387.9   264.6   340.7   230.2
                 5 137  18.7  50.7  41.2  437.9   310.6   429.4   304.1   401.5   283.0
                 6  67  13.2  51.9  43.9  320.3   233.2   316.5   230.3   304.4   220.9
                 7  25   6.7  52.8  46.0  166.9   124:0   165.6   123.0   161.5   119.8
                 8   7   2.4  53.4  47.7   62.1    46.9    61.8    46.7    60.8    45.9
                 9   1   0.4  53.8  49.0   11.4     8.7    11.3     8.7    11.2     8.6
                 ----  ----             ------  ------  ------  ------  ------  ------
                   892  74.8            1686.9  1180.3  1372.5   977.4  1280.1   908.4

ARITH. MEAN DBH -3.63       QUADR. MEAN DBH =3.93
WEIBULL PARAM: A=0.55       B=3.48      C=2.22
SURVIVAL = 99.2        MEAN CROWN RATIO = 44.8
```

Figure 4.--*Example of output from a BASIC program using the prediction sysfem given in Farrar (1985a).*

sites by using information on trees per acre at this age in the supplemental system. But again, such a procedure carries considerable risk of imprecision for the same reasons already given. The main system assumes an SI from a function developed from RLGS data (Farrar 1981b), but the supplemental system assumes an SI from curves given in Forest Service publication MP50 (USDA FS 1976). This is no real problem because a site-index function fitted to MP50 data for longleaf (Farrar 1975) can be solved for dominant height if stand age is given and these data can be input into the RLGS site-index function (Farrar 1985b) to obtain an SI value usable by the main system. The main system also requires that any initial value for sawtimber basal area be greater than zero. If zero is input a program error will result.

The set of prediction equations involved in the main system is based on stands essentially thinned from below for one or two 5-year growth periods. Equations for the supplemental system are based on young stands initially given a precommercial thinning and observed for 10 years. Therefore, it is prudent to restrict projections to short periods--preferably 5 to 10 years but probably no more than 30 years at the most. Single long-term projections are not as reliable as short-term projections and also exclude long-term mortality effects. Forecasting production to age 80 from a thinning regime starting at age 30 and employing 5- or lo-year cutting intervals is preferable to forecasting from age 30 the production of an unthinned stand to age 80.

The fit statistics for the main system (Farrar 1985b) indicate that sawtimber volume predictions are about as reliable as those for total and merchantable cubic.feet, but a qualification is necessary. The system predicts a unique set of volumes for any given combination of age, SI, and total or sawtimber basal areas, regardless of the way a stand may have reached that condition. For stand total and merchantable cubic-foot volumes, in general, this is reasonable because such volumes are largely a function of age, SI, and total basal area of the stand without regard to the size distribution of the stems. But the nature of the diameter distribution of the stand above the sawtimber threshold is very important in detgermining stand sawtimber cubic-foot and board-foot volumes, especially for a highly diameter-dependent log rule such as Doyle. Additionally, the diameter distribution above the sawtimber threshold is highly dependent on the timing of the first thinning, the residual density level maintained, and the frequency of thinning.

Many of the stands in the RLGS contributing data to the current main system have grown under their prescribed densities for only 5 to 10 years, not for all or even most of their lives. Consequently, diameter distributions and predicted sawtimber responses probably do not yet completely reflect the density treatments imposed, particularly in what were the older age classes at the start of the study. The International 1/4-inch rule is used as the measure of board feet because, similar to stand total or merchantable cubic-foot volumes, it should be less sensitive to these circumstances than, say, the Doyle rule. The International rule most accurately reflects the board-foot content of a tree recoverable by an efficient bandsaw mill and does not penalize small or large trees as do the Doyle and Scribner rules, respectively, but the sawtimber diameter distribution remains the key factor determining the stand board-foot volume.

Since the sawtimber predictions are likely to reflect to some degree the unknown stand histories that occurred before the stands were included in the study, they should be used with caution. Additional inventories and analyses should provide ever-improving sawtimber volume estimates because, as time passes, more of the stands will have been managed for longer periods under their prescribed density levels. A true picture of treatment-induced diameter distributions and sawtimber-sized material will emerge when the original sets of 20-year age-class plots have been managed under the imposed density levels by periodical thinning over rotations of 60 to 80 years or perhaps longer.

One further precaution should be mentioned. Users should recognize that these predictors are best used in relative comparisons among stand management options for prescriptive purposes on an average basis. They are not to be considered absolute predictors of the volumes one would actually obtain from a specific stand or stands over a growth period or rotation. The supporting data come from very homogenous small plots regarding age, site, and density and include only the effects of suppression-related mortality. Therefore, the results are probably the optimum that one could expect and will probably overestimate the results from operable stands in the field, which are much more variable regarding age, SI, density, and mortality impacts. Also, these are regression-based predictors that predict very well for the mean situation but possibly very poorly for an individual situation, depending upon how near the individual is to the mean and how variable the conditions are in the individual situation. For these reasons, the predictors are best used to choose among alternative treatments or management regimes on a relative basis rather than an absolute basis. For example, they can be used to choose among, say, alternative residual basal area levels for a specific stand but not to precisely predict the actual growth that would result from leaving any given basal area;

ONGOING RESEARCH

Several activities are underway in data analysis and inventory in the RLGS to improve the natural longleaf pine growth and yield prediction systems. A combination stand-level and d.b.h.-distribution prediction system enabling prediction of multiple-product volumes for thinned stands is nearing completion. This cooperative work with Mississippi State University, Starkville, MS, involves data from the 5- through 20-year inventories and will employ a stem-profile function (Farrar 1987) to predict,an assortment of tree product volumes both as stand-and-stock tables and/or as stand-level sums. This work is near completion and the results should be available for use within a year.

Individual-tree based prediction systems are the most versatile and provide the most detail on responses to simulated treatments. However, they can also be very data-demanding and time-consuming to construct, require large computer programs, and be relatively expensive to exercise, particularly if multiple species and intertree distances are involved. If they invlove only a single or a very few species and do not involve tree spatial location, they can be kept relatively small and efficient. In order to best accomodate the wide range of real-world stand and treatment situations and provide good response estimates for them, such predictors will undoubtedly be required in the future. Consequently, a deterministic distance-independent system is now under construction cooperatively with Auburn University using the 5- through 20-year inventory data from the RLGS. Results should be available within 2 years.

The 25-year inventory of the RLGS will be conducted during the next three dormant seasons, starting in the early fall of 1989. The work will be conducted cooperatively by the Southern Forest Experiment Station (Starkville, MS) and cooperators, with Auburn University handling the field measurements. During this inventory, in addition'to the full agenda of regular measurements, the utility pole class and length of the qualifying trees on the plots will be assessed. The desirability of production information on these valuable products has long been acknowledged but, due to lack of personnel, funds, and expertise, data have not been gathered. Even though extra funds are not available for this work, and the available time during a dormant season will be limited by the agenda of usual measurements, a complete classification of all plot trees qualifying as poles will be attempted because some plot establishment tasks are not required during plot re-measurement. As a result, very useful information on pole production in thinned longleaf stands under varying conditions should be obtained.

RECOMMENDED RESEARCH

In addition to the current efforts in modeling and maintenance of the RLGS, several other efforts should be initiated to obtain information to guide future management.

Individual-tree-based prediction systems are likely to become and remain the most useful types of the future. In addition to the ongoing work with Auburn University to develop a first-stage distance-independent system, work has been initiated to facilitate improvements. Azimuth and distance from plot center to each plot tree was obtained during the 20-year inventory to make intertree distance data available for construction of a distance-dependent individual-tree prediction system. A study of tree stem and crown dimensions and d.b.h. growth rates of open-grown longleaf pine trees has been conducted (Kush et al. 1988), and now the upper limits of d.b.h. growth can be estimated to form upper boundaries for growth estimates in individual-tree systems.

The present systems can largely account for the effect of the main stand variables (age, SI, and density) on stand volume and net growth for essentially pure stands. The remaining sources of error now need to be accounted for to make any substantial improvements. Sources of error include:

1. Impact of admixtures of other woody species, including the effects of species mix, density, and vertical and lateral spatial arrangement of other species on growth of longleaf and the entire timber stand.

2. Impact of nonhomogeneous stands, including effects of variations in age, site (soils, etc.), and density within stands.

3. Environmental effects in the short- and long-term, including climatic variations in precipitation and temperature regimes; geographic, physiographic, pyric, and edaphic influences: and pollutants of air, soil, and water.

4. Impact of nonsuppression sources of mortality, including effects of lightning, windstorm, fire, disease, and insect epidemic on long-term production.

There is also a need for additional mensurational support work in the area of tree volume- and weight-defining functions for natural longleaf pines and probably for the major timber associates of longleaf. Comprehensive. predictors are needed for the volume, green weight, and dry weight of the wood, bark, and foliage in tree stems, crowns, and, perhaps, roots in terms of tree d.b.h., height, and form. Some information is available in this area but it needs to be supplemented and expanded. Work is also needed on the functioning of the forest ecosystem, including the forest floor, understory, midstory, and overstory components, regarding energy accumulation and losses, nutrient cycling, and wildlife habitat aspects.

CONCLUSION

The RLGS has existed for some 25 years and continues to provide improved information on the growth of thinned natural longleaf pine stands with each 5-year inventory. The study, plots, and data become increasingly important and valuable with the passage of time and as the plot tenure under assigned densities increases. The study provides increasingly useful prediction systems as the database improves and accumulates, as new variables-are taken into account, and as improved techniques for analysis and prediction are developed. The study should be maintained as planned until the initial three sets of 20-year-old plots are carried through a rotation under their assigned densities. The permanent plots in this study can also be used for any number of additional or superimposed studies as long as they are nondamaging, do not endanger plot trees, and do not interfere with objectives of the main study. For example, the first two time replications in the 20-year-old stands have been used to investigate the possibility of a change in growth rate between the mid-1960's and mid-1970's, and this work will be extended to include the third time replication. The plots can also be used for more definitive investigations of the effects of climate, physiography, and soils on tree and stand growth and plans are being drafted for such work. So the usefulness of this long-term study is likely to remain high, and its protection and maintenance will remain first-priority activities in the future.

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A DIAMETER DISTRIBUTION MODEL FOR THINNED LONGLEAF PINE PLANTATIONS: A BEGINNING

Charles E. Thomas
and
Richard E. Lohrey

ABSTRACT Thinned plantation studies in Louisiana, Mississippi, and Texas are being analyzed, and growth and yield models assembled. A new method of obtaining Weibull parameters for the diameter distribution is employed to emphasize the larger trees in the fitting process. Compatible height and height growth equations are being tested to insure better estimates of plot total height. Schumacher volume equations were modified to incorporate age since planting to reveal trends in growth and yield for these thinned stands. The utility and direction of modelling strategies for longleaf can lead to more flexible systems of addressing new questions regarding growth of thinnedlongleaf pine plantations.

INTRODUCTION

The potential for growing longleaf pine (*Pinus nalustris* Mill.) in plantations continues to improve. After a long period of declining acreage and loss of favor that came with the infatuation foresters had with rapid early growth, longleaf acreage appears to be stabilizing at about 3.75 million acres (Kelley et al. 1989). On the National Forests the acreage may be increasing and plantation establishment is increasing(K. Stoneking, pers. comm.). This trend accompanies the recognition that a number of risk factors (rust, bark beetles, etc.) associated with more rapidly growing species are reduced for longleaf. Good progress has been made on the establishment of longleaf, and prescriptions for hastening the passage through the 'grass' stage have been developed; regeneration techniques are well documented (Mann 1969; Croker and Boyer 1975).

Several management regimes are possible with longleaf. A growing body of literature on natural stand and thinned natural stand information is available (Farrar 1979; Farrar 1985). Unthinned plantation results are available (Lohrey and Bailey 1977). We are in the early-to-middle stages of developing a distribution dependent thinned-stand model that will permit better prediction of growth patterns for longleaf pine. We will report progress on several parts of our analyses.

Charles E. Thomas is research forester, Institute for Quantitative Studies, New Orleans, and Richard E. Lohrey is research forester, Timber Management Research, Alexandria, Southern Forest Experiment Station, USDA Forest Service.

First, we have been investigating the Weibull probability density function (pdf) as a potential diameter-distribution model. This model has been widely applied, and its properties relating to stand diameter distributions have been studied exhaustively. A new method for obtaining the parameters of the Weibull distribution is in the final stages of development at the U S D A Forest Service, Institute for Quantitative Studies. The techniquehas been specifically developed to emphasize the larger trees in the fitting process. The program we have employed attempts to fit the three-parameter Weibull, and failing that, the two-parameter is fit. We have fit both pre-thinning (pretreatment) and post-treatment diameter distributions in l-inch classes.

Second, given diameter data, it is necessary to have good estimates of total tree height to make estimates of tree volume and biomass. We have begun an analysis of total height-height growth curves that give good estimates of total heights on each.plot.

Third, we have producedvolume andbiomass equations for felled-tree sample data. For this first assessment we use a modified Schumacher volume equation, using age since planting (Ap) as a co-variable. Introduction of this co-variable significantly reduces root mean squared error and implies an improvement in bole form typical of longleaf that is also correlated with Ap.

Finally, we would like to look into the future needs as we continue the development of longleaf thinned-stand models. What light can we bring to bear on current concerns for the growth of the South's pine forests in a rapidly changing human-influenced environment? Can our choice of modelling strategy incorporate degrade from rust, losses from southern pine beetle, responses to increased air pollution, and possible changes in climate of the region?

DATA COLLECTION

Plots

Data for these analyses were collected in longleaf pine plantations in Mississippi, Louisiana, and Texas (Table 1). Several individual studies were involved. All were on cutover forest sites except one on an abandoned (old) field. Their current ages (Ap) range from about 35 years to 50 years old. Frequent fires, after the previous stands were clearcut, controlled woody competition and allowed the pines to be planted without mechanical or chemical site preparation. Some of the plots were established at the time of planting to test initial stand densities from 250 to 2500 trees per acre. Other plots were installed in existing plantations, 16 or more years old, that showed no evidence of severe insect or disease damage. Most, but not all, of these stands had been burned by prescription. The density of their hardwood and brush understories varied with the frequency and effectiveness of the fires:

We report results from a subset of the longleaf thinned plantation studies, eventually all studies will be included. All ages reported are growing seasons since field planting (Ap). The subset consists of two thinning studies and a control study with no thinning, for a total of 119 plots. The plots vary in size. The oldest thinned-stand plots were 0.25 acres in size more recent plots have been 0.1 acres. The unthinned control study consists of 59 plots ranging in size from 0.05 to 0.21 acres. Stand densities before thinning ranged from 120 to 720 trees per acre and 40 to 125 square feet of basal area per acre. Residual densities after thinning ranged from 40 to 140 square feet per acre. Plots that had not reached their assigned density were not cut until the next scheduled thinning five years later. Some plots were thinned at Ap = 20 years to a specified number of merchantable tree with no subsequent thinning. Seven

Table 1.-- Longleaf Pine Plantation Data

Study No.	Plots	Location/ origin	Treatments	Measurement age (Ap)	Planting density
				years	trees/acre
3.12	20	MS/Old field	Thinned	20 to 40	1200
3.13	42	TX/cut over	Thinned	25 to 45	1200
3.29	59	LA/cut over	Unthinned	16 to 38/ 31 to 53	250 to 2500
2.03 & 3.02		LA/cut over	Thinned	16 to 50	250 to 2500

unthinned plots collocated with the thinned plots were remeasured periodically and serve as local experimental control treatments.

Trees

The same tree measurement methods and procedures were used on all plots. The diameter at 4.5 feet (d.b.h.) of each tree 0.6 inch or larger was measured with a steel diameter tape to 0.1 inch. Tree diameters were remeasured at five year intervals just prior to thinning. The number of individual tree age-diameter remeasurements was over 30,000. Total height and height to live crown were measured to 1.0 foot on sample trees in all l-inch diameter classes; 9200 trees were measured for total height over the 25- to 30-year period of the study. The mean total height of dominants and codominants was computed and used with Ap determined from planting records to estimate the site index of each plot.

Measurements on 147 felled trees -- 125 from thinned (Table 2) and 22 from unthinned (Table 3) plots -- were used to compute equations for stem volume, green and dry weight, volume and weight ratios, and stem taper. These felled trees were selected from an array of stand conditions. Thinned stands had been repeatedly cut to residual basal areas of 40 to 80 square feet per acre for at least 15 years before the sample trees were felled. Only sound trees that did not fork were measured. Some had.been marked for cutting in regularly scheduled thinnings, but the sample also included some high-quality fast-growing trees that ordinarily would have been left to grow.

Table 2.-- Distribution of felled sample trees in thinned longleaf pine plantations by dbh and total height classes.

Dbh,** inches	Total height in feet* 40	50	60	70	80	90	Total
	----------------	----------------	Number	of	trees	----------------	----------------
4							
5	5	2					7
6	1	3	4	2			8
7			8	6			10
			1				7
8			3	5			8
9				7	2		9
10				3	4		7
11			1	5	2	1	·9
12				14	7		21
14				9	7		16
15				2	10	2	14
				1	4		5
16					1	1	2
17					1	1	2
Total	6	5	17	54	38	5	125

* 40 = 36 to 45, etc.

** 4 = 3.6 to 4.5, etc.

Table 3.-- Distribution of felled sample trees in unthinned longleaf pine plantations by dbh and total height classes.

Dbh,** inches	Total height in feet* 60	70	80	90	Total
	--------------	Number of	trees	--------------	
7	1				
8	3	1			4
		2			5
18	4	0	2	1	4
11		1	2	1	4
12			2		2
13			1	1	2
Total	8	4	7	3	22

* 60 = 56 to 65, etc.

** 7 = 6.6 to 7.5, etc.

Treatments

Residual density levels of 40 to 120 square feet per acre at 20 square foot intervals were established in stands. An additional 140 square foot level was included in study 3.13. Most stands were thinned shortly after plot establishment. Stands were repeatedly thinned to'maintain the target basal area assigned to them. A few that were assigned to, but had not reached; higher stand densities were allowed to grow until they surpassed the assigned'density at a five-year remeasurement occasion. Diseased and insect-infested trees, defective trees, and trees of poor form or vigor were removed first. A few rough, limby dominants were given second priority for cutting. Additional trees from the lower crown classes were then removed to achieve the assigned density. A second criterion used in the thinnings provided a uniform distribution of residual growing stock trees on the plot.

ANALYSIS

Diameter Distributions

For this presentation we have concentrated on fitting the diameter distribution data for the thinned plots to a Weibull probability density function. Because we are still in the process of analyzing data from the thinned longleaf studies, two thinned-stand studies have not been included in this paper (they are indicated in Table 1, below the dashed line).

The method we have used is based on Probability Weighted Moments (PWM). Special statistical moments based on the ordered observations are computed and the Weibull parameters are obtained directly from these moments. Emphasis can be placed on either the right or left tail of the distribution using probability weighted moments. Either the arithmetic mean diameter or the quadratic mean diameter can serve as a basis for computation of the moments. The distribution can include the case in which zero is the smallest observation, or it may be that some positive lower limit is defined. An intensive treatment of this flexible probability weighted moment parameter estimation is in manuscript (Dell et al. in prep; Grender et al. in prep; Reich et al. in prep). For brevity, we present only a restricted formulation for a right tail weighting (WR), for minimum diameter equal zero (the two-parameter case) and for the arithmetic mean.

The first step in obtaining parameters of a Weibull distribution for a stand is to compute the weighted moments from the data. The data needs to be sorted in ascending order and the order of the dbh (x) noted by subscript i. Then the right tail weighted (WR) moments (Mj) are calculated from:

$$\hat{M}_j = \frac{1}{n} \sum_{i=j+1}^{n} x_{(i)} \frac{\binom{i-1}{j}}{\binom{n}{j+1}} \qquad (1)$$

where n = number of trees,

i = the ith tree, and

j-the index of the moment to be computed.

Parentheses indicate standard combinatorial operations.

Favorable characteristics of PWMWR estimation include simple parameter equations, better estimation of the right side of the distribution, and an unbiased estimate of the moments. PWMWR has been developed for analyzing diameter distribution of trees so that the influence is on the right tail of the data where the larger and more valuable'trees are located.

The next step is simply to calculate the three Weibull parameters (a, b, and c) from moments. Again, for brevity, we present only the two parameter model solutions. The two-parameter density for the Weibull is given by:

$$p(x) = \frac{c}{b} \cdot \left(\frac{x}{b} \right)^{(c-1)} \cdot e^{-(x/b)^{(c)}} \tag{2}$$

where e = base of natural logarithms (2.718..).

The formulae for PWMWR estimates of b and c parameters follow:

Two parameter case (a-0).

Solve for the c parameter:

$$C = \frac{\ln(2)}{\ln\left[\frac{M_0}{2(M_0 - M_1)} \right]} \tag{3}$$

Solve for the b parameter:

$$b = \frac{M_0}{\Gamma \left\{ \frac{\ln\left[\frac{M_0}{M_0 - M_1} \right]}{\ln(2)} \right\}} \tag{4}$$

where ln = natural logarithms and
Γ = a real valued gamma function.

Formulae for the three-parameter model are also available and we actually fit either the two- or the three-parameter model as was appropriate. Younger stands include some small trees, and stands that have been thinned several times do not; hence, both forms are necessary. Example graphs selected from a large number of fitted distributions and their corresponding tree-frequency distributions are presented in figures 1 and 2. Figure 1 presents data from plot 2 study 3.12 before the initial thinning and the second thinning. Ages (Ap) of the plots were 20 and 25 years, two-parameter models were fit, because the "a" parameter was zero. Figure 2 represents (Ap) 30 and 35 for the same plot, however, they were already thinned for the third and fourth time. Examination of the figures indicate that the mode and the range of the Weibull probability distribution and the frequency distribution are similar.

Each plot-age combination (about 200 observations) was fitted. The hypothesis that the observations did not differ from a Weibull pdf was tested. Chi-square tests for goodness-of-fit on the pre-treatment stands resulted in rejection of the null hypothesis 45 percent of the cases. For the post-treatment

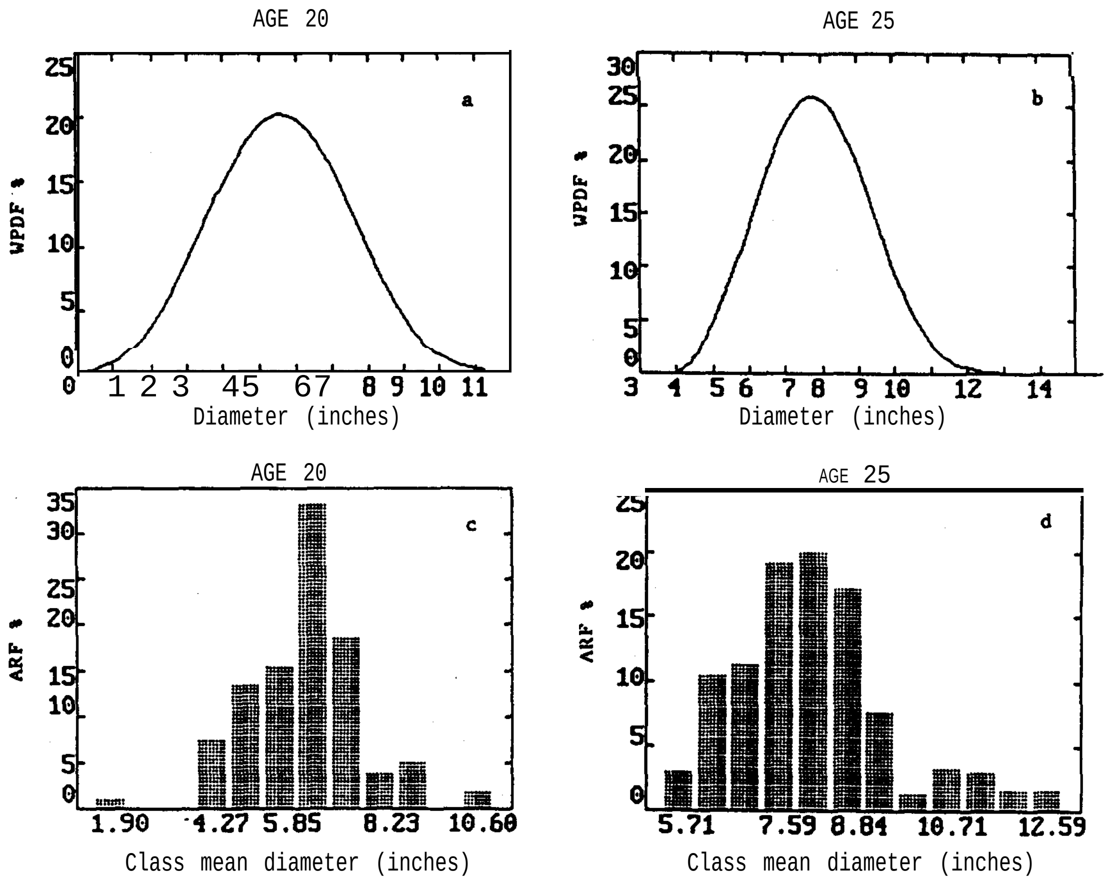

Figure 1a-d.-- Weibull probability density function (WPDF) and actual relative frequency (ARF) of tree diameters before thinning at two ages in a longleaf pine plantation.

stands only about 15 percent of the cases resulted in rejection. The former results do not support use of the Weibull density. The lack of fit may be the result of a few small trees entering the lower end of the diameter distribution, giving rise to a bimodal distribution. However, the latter results do support the use of the Weibull and are similar to results reported by Bailey et al. (1981) working in thinned slash pine.

Tree Heights

Once we have modelled stand diameter distribution transition, we need to estimate tree heights, given the diameter of trees, to compute volume estimates for individual trees and, ultimately, for the estimation of volume per acre in the study plots. Our data include a total of 9200 tree-height measurements. Several recentmodelling efforts have suggested that the total height of the tree

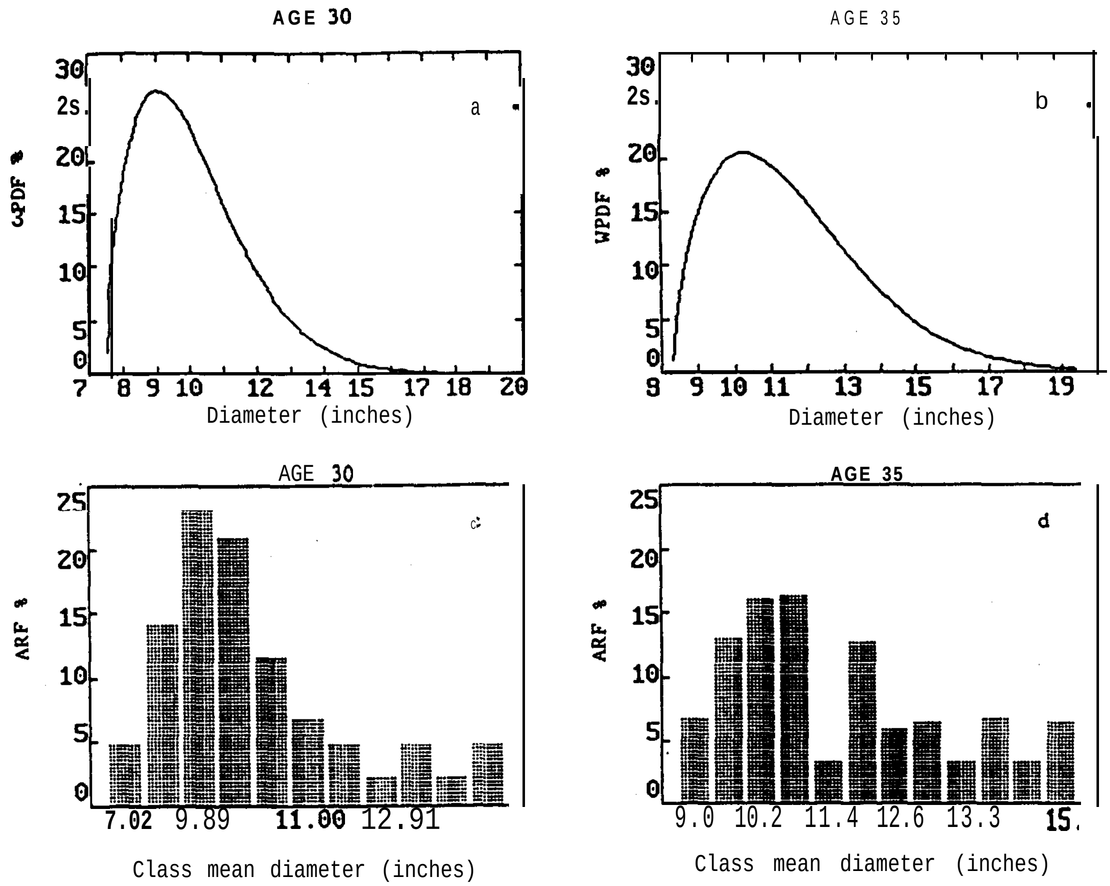

Figure 2a-d.-- Weibull probability density function (UPDF) and actual relative frequency (ARF) of tree diameters after thinning at two ages in a longleaf pine plantation.

and the first derivative of the height function should agree with one another (Murphy and Farrar 1988, Strub and Sprinz 1988). After examining these models and their hefty data requirements we chose to build on the work of Bayer (1983). We examined his height model for young longleaf trees growing in the east Gulf. Differentiation of the equation results in a height growth function. Figures 3a and 3b graph total height based on old-field and cut-over forest sites from Boyer. Figures 3c and 3d graph the growth (rate of change of height, the first derivative) from his model. The figures correspond well with the actual tree height growth for the period represented in our data. Building on the data from the younger plantations represented in Boyer's work, we have constructed a height-height growth model that incorporates both the diameter and Ap of the

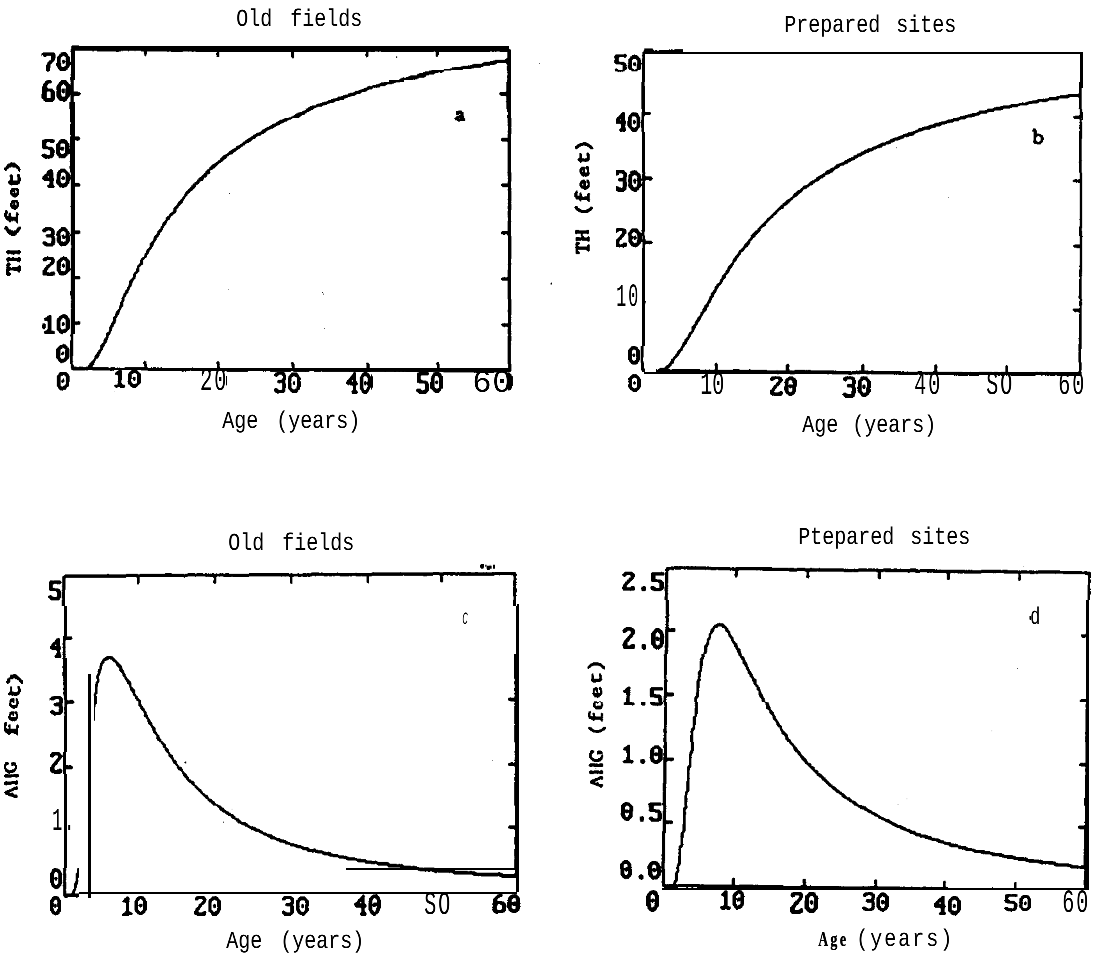

Figure **3a-d.--** Total height (TH) and annual height growth (AHG) curves derived from **Boyer's** (1983) data for **longleaf** plantation.

trees and an interaction term. 'Our model is :

$$Ht = e^{(b_0 + b_1/Ap + b_2/dbh + b_3/(Ap*dbh))} \qquad (5)$$

where Ht = individual-tree total height.
The rate of change in height with respect to age is obtained by taking first partial derivative with respect to Ap ($\frac{\partial Ht}{\partial Ap}$):

$$\frac{\partial Ht}{\partial Ap} = -Ht * (b_1/Ap^2 + b_3/(Ap^2*dbh)) \qquad (6)$$

where Ht = total height given above.

Figures 4a through 4d present an example of the height growth function for a fixed diameter at varying Ap. Maximum height growth occurs early in the life

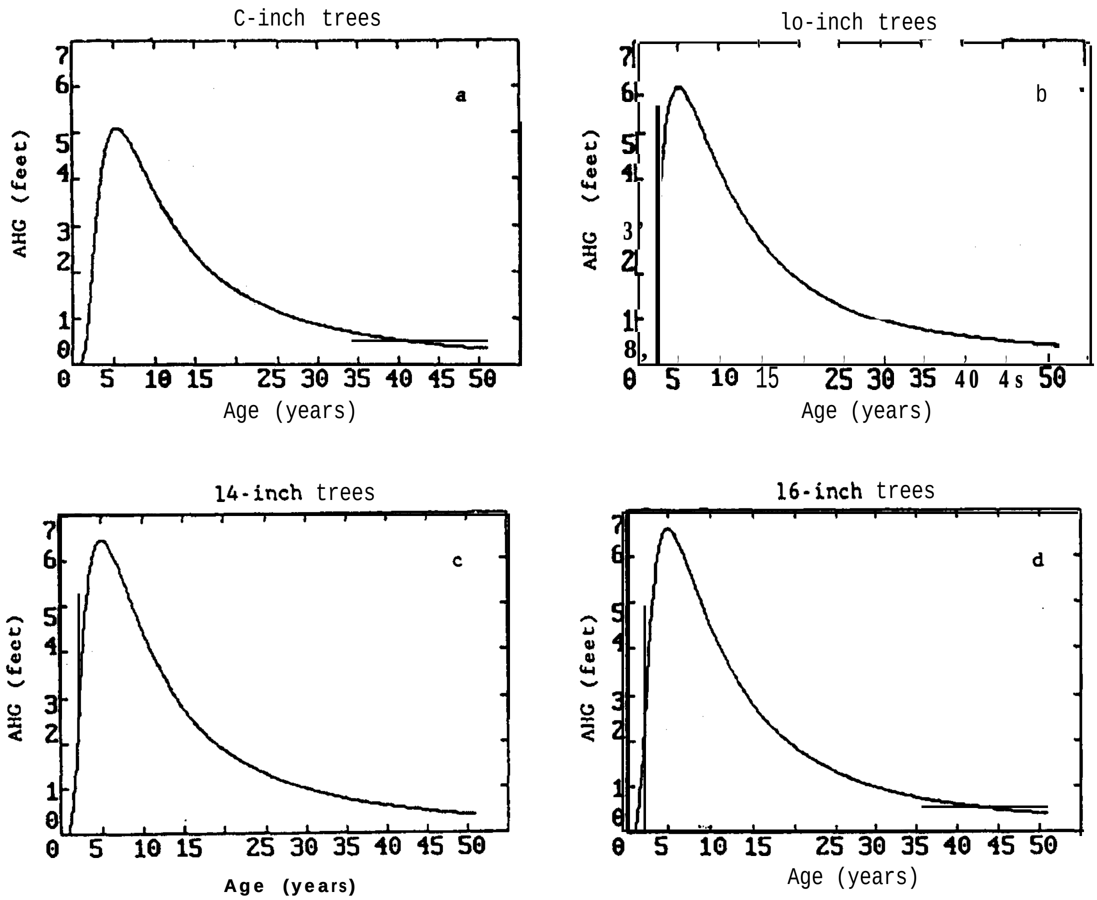

Figure 4a-d.-- Annual height growth (AHG) for trees from four diameter classes.

of the tree and these figures confirm that our model gives reasonable results when differentiated. Refinement of the equation will depend on having stem analysis data that detail heights prior to the plot establishment. For the present, the work of Boyer is reassuring if not absolute evidence that our model is reasonable. This equation certainly yields statistically valid results within the range of our data; extrapolation to younger and older plots is the greatest concern remaining.

The data allow fitting individual height curves for each plot. Therefore coefficients specific to each plot were used in developing the height for the entire study. Significance of all coefficients for each plot's regression was not entirely consistent. However, for the overall model (all plots combined), all coefficients were highly significant.

Tree Volume

To model volumes of individual trees, the coefficients from the tree height regressions were to be applied along with diameter of the tree. We began with a Schumacher volume model and again introduced a term for the Ap of the tree. The addition of Ap acts as a surrogate for the effect of form change over time and is not redundant for Ap introduced into the height equations. Our final model is:

$$V = b_0(Ap)^{b_1}(dbh)^{b_2}(Ht)^{b_3} \tag{7}$$

which is solved by transforming to natural logs as:

$$lnV = lnb_0 + b_1*ln(Ap) + b_2*ln(dbh) + b_3*ln(Ht) \tag{8}$$

where *In* indicates the natural logarithm.

The same equation form was used to fit inside and outside bark volumes. The results with index of fit for both inside and outside equations are presented in Table 4.

Table 4.-- Volume equation coefficient estimates for 147 felled longleaf pine (Schumacher model with ln(Ap)

	Coefficients				Statistics	
Equation	b_0	b_1	b_2	b_3	FI [1]	SEE [2]
Volume o/bark [3]	-6.345	0.1610	1.0826	0.0688	0.00	1.43
Volume i/bark [3]	-7.512	0.2068	1.8720	1.1530	0.00	1.42

[1] Fit Index: the expression of coefficient of determination in original units.

[2] Standard error of estimate in the original units. Coefficientsof variation about the mean volume (24 cubic feet) were about 6 percent.

[3] Volume expressed in cubic feet.

YIELDS

The ultimate interest of growth and yield modelling is to understand the relationships between density and management regimes in the productivity and distribution of wood: in what range of densities is it possible to obtain utilizable wood volume of a given quality from a given acre of forest land under a thinning regime? We have made a brief effort at examining the volume per acre produced and removed from the two thinned-stand studies using the tree volume equations. We have also examined the relationship between basal area yield and the thinning levels. These represent a visual analysis of plotted data only.

The results are presented in figures 5 through 8. First, data from study 3.12 were plotted for **40-** to **100-square-foot** basal area levels. Few plots had densities above 100 square feet per acre when the plots were established and first thinned at Ap 20 years. Figure **5** shows the sum of present basal area plus that removed in thinnings at S-year intervals. Data for plots in the **120-square-**foot and unthinned treatment levels were not graphed, but both of these levels were lower in basal area yield than the **80-** and **100-square-foot** level., Volume yields continued to accumulate at a rapid rate at all densities (fig.. 6). If the rate of volume growth has been reduced, it is only in the more drastic thinning levels --e.g., **40-** and **60-square-feet** per acre.

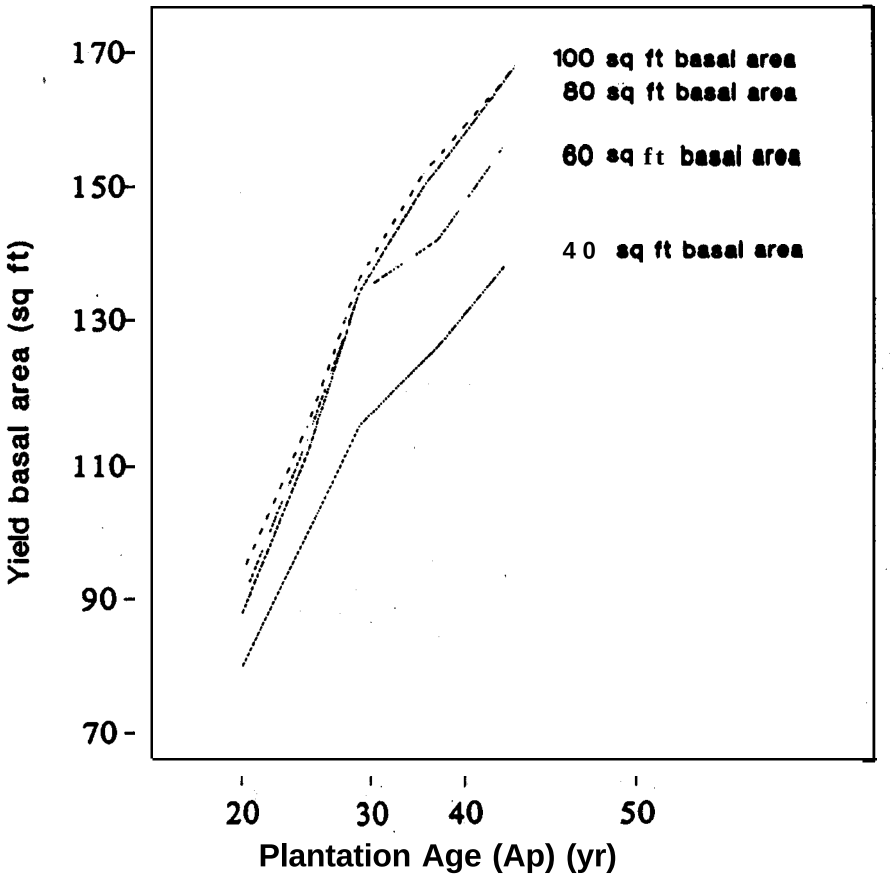

Figure 5.-- Basal area yield curves (residual + thinnings) Study 3.12

A graph of the basal area yield for study 3.13 (fig. 7) includes the **120-**square-foot basal area; however, it is the lowest **yield** of the three **higher** basal yield curves, though only slightly lower. Volume yield for study 3.13 (fig. 8) shows a slightly different trend from study 3.12,; volumes continue to increase up to **at least** 120 square feet per acre. If board-foot volume yields had been graphed instead of cubic-foot yields the results would have looked much different. Early board-foot yields are usually highest at low stand densities where diameter growth is faster and trees reach sawtimber size at an earlier age than in more crowded stands.

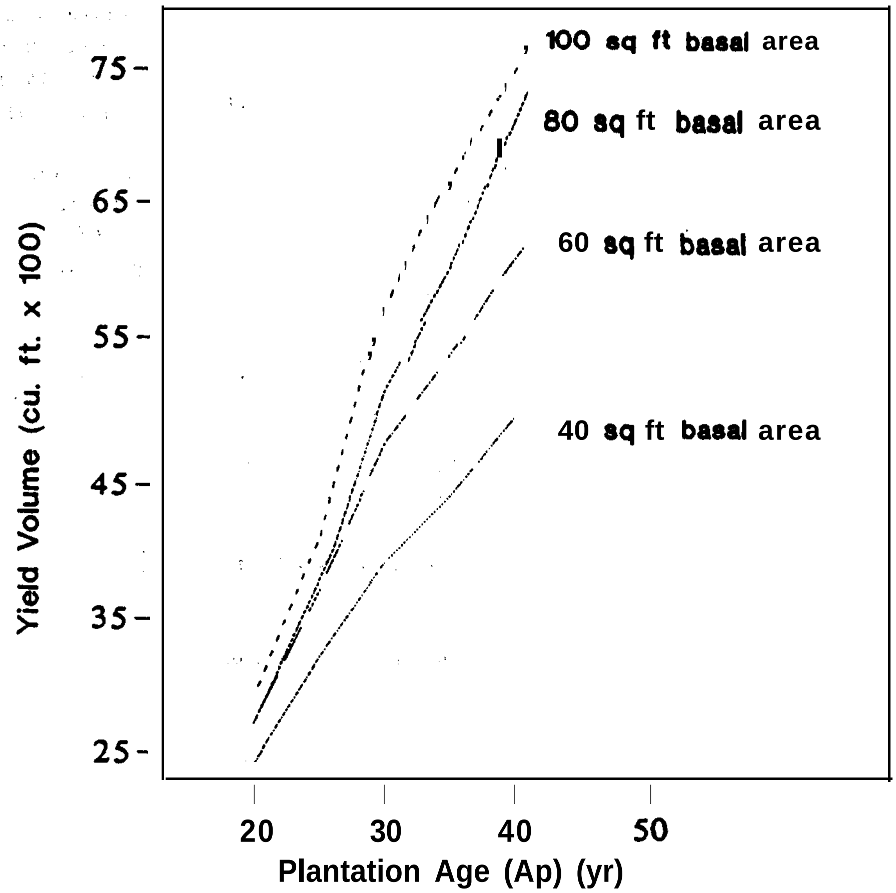

Figure 6.-- Volume yield curves (residual + thinnings) Study 3.12

DISCUSSION

We have reported progress in the development of components of a rather traditional growth and yield model for thinned-plantation longleaf. We are confident that the data will be useful to managers of today's longleaf plantations, though some modifications may be necessary. Early growth of these stands is not well documented, we hope to approach this problem by using stem analysis of volume sample trees to extrapolate backward. It appears to be possible that even this may not serve current conditions as well as might be wished. For one item it appears that emergence form the grass stage and early growth of current planting stock may be considerably more rapid than in the'past.

Modelling growth and yield of southern pines has served strictly pragmatic purposes. Efficiency and ease of application have served us well in the past. However, modelling philosophy is in the midst of a revolution. The questions we have to ask in growth and yieid models are considerably more complex and the responses must be considerably more detailed. Concerns we currently face include: 1) Are the southern pine forests in a growth decline? If so, how dan we identify the culprits? Weather, and perhaps climate; patterns are thought to be drier in the decade of the '80s than in any other decade this century. The increase of industrialization and urbanization in the South has been spectacular during the past 20 years, and costs come with progress. The increases in air pollution sources over the period are undeniable. Is there a connection between the current hypothesized tree-growth decline and atmospheric

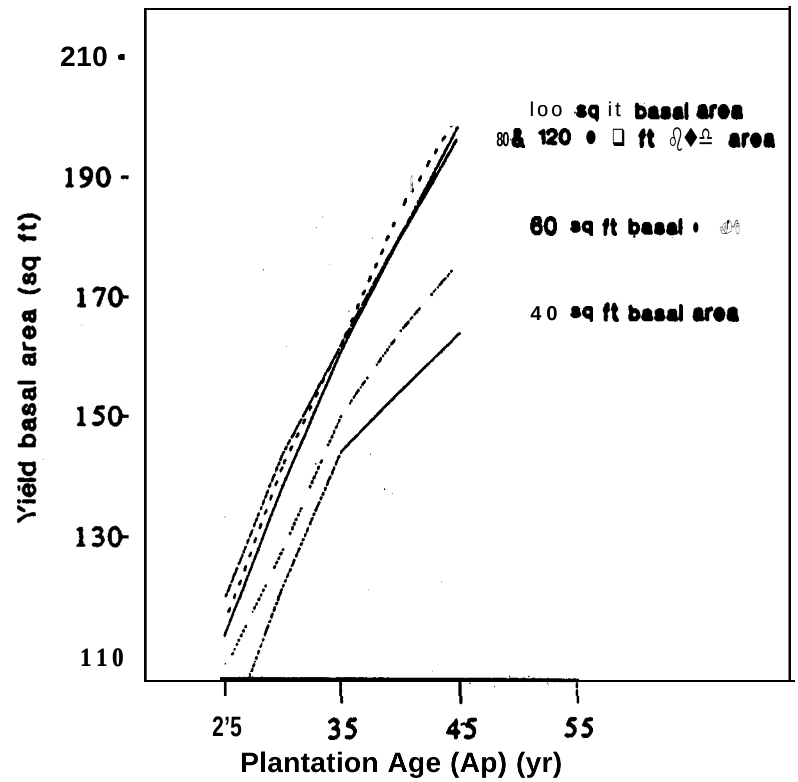

Figure 7.-- Basal area yield curves (residual + thinninga) Study 3.13

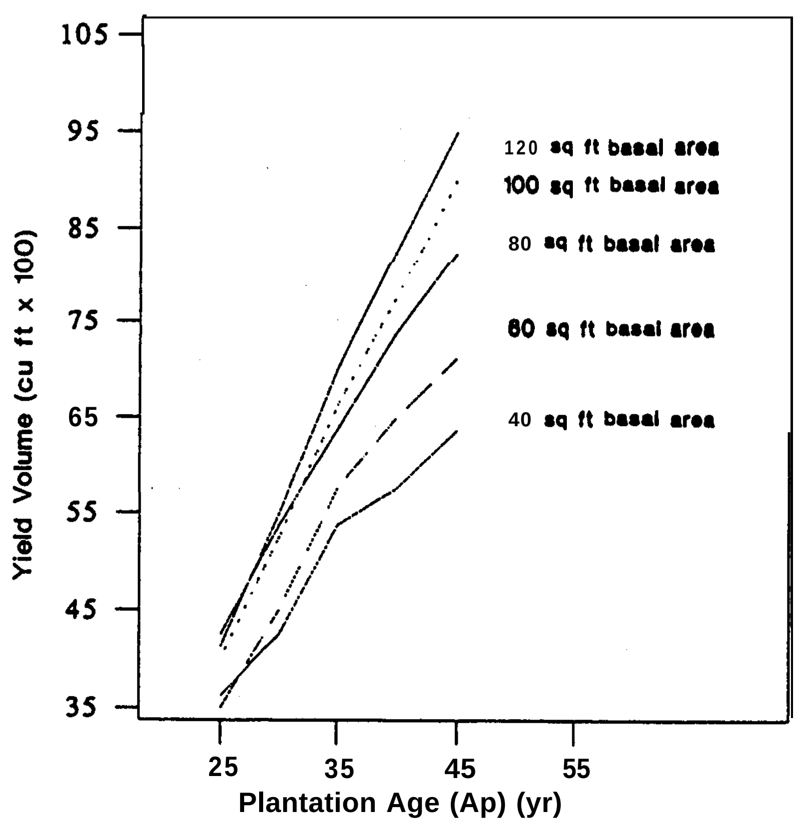

Figure 8.-- Volume yield curves (residual + thinnings) Study 3.13

pollution? Acid rain and ozone have received the majority of media attention, but what about locally specific pollutants? 2)Long term risks for rapid growth species need to be considered **in the** selection for reforestation. What are the mortality risks -- the possible loss of growth from fusiform rust infections and other forest pests? Current models are not amenable to introducing these factors. We can reconstruct regression equations, but we can not incorporate the knowledge directly in a biologically sound fashion.

We are in the process of examining a number of new modelling strategies that could provide the traditional forest products information and at the same time allow for addressing the more complex questions: will the climate shift accompanying increased CO_2 in the atmosphere cause us to shift to growing slash and Honduras pine? Is the initial slower growth of **longleaf** actually insurance against the rust, fire, and beetle risks that face loblolly and slash?

We have presented a progress report on the development of a traditional, integrated, diameter distribution growth and yield model for thinned plantation **longleaf** pine. We plan to continue analyses of the diameter distribution, looking at alternative weighting schemes, expanding our test procedures, and, most importantly, modelling trend in the parameters or moments. We hope to conclude this modelling effort in the near future and that the data can also be used in developing a model that is more flexible, adaptable and will provide answers to the new questions foresters face in growing of **longleaf** pine in plantations.

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Managing and Harvesting Longleaf Pine for Specialty Products

Hamlin L. Williston, John G. Guthrie, Claude A. Hood

ABSTRACT. Managing longleaf pine for poles and piling requires some modification from those techniques employed in managing for sawtimber and pulpwood. It is very important to make pole growing an objective early in the rotation. The production of pine straw from longleaf pine can be a lucrative biennial practice where" markets are available. But the naval stores industry is fast fading from the scene.

W. G. Wahlenberg in his monograph Longleaf Pine (1946) stated that "Lumber and pulpwood from the harvested tree, and naval stores from living trees, are the principal products of longleaf pine." There was little mention made of poles and piling except in the Appendix where it was stated that "some trees are worth more as piles or poles than as sawlogs or pulpwood" and tables were given for the standard dimensions.

NAVAL STORES

Longleaf pine has been used for naval stores production since the landing of the earliest colonists' in Virginia. Tar and pitch for caulking wooden ships were among the very earliest exports from this country. Naval stores generally yielded more profits than agricultural crops. By 1895, 2.5 million acres of forest were being turpentined and nearly 1 million additional acres.were invaded each year. Inventories made in the 1930's categorized the southern pines as "turpentine pine" and "other pines." Longleaf pine stumps became a major source of naval stores.

While the virgin timber lasted, nearly all United States gum naval stores came from longleaf pine. Since then much of it has come from slash pine. Today there are only 165 producers supplying gum to one plant, that in Baxley, Georgia. Because of

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Hamlin L. Williston, Consulting Forester, Oxford, MS
John G. Guthrie, Consulting Forester, Wiggins, MS
Claude A.' Hood, Forest Supervisor, Bladen Lake State Forest, North Carolina Department of Natural Resources and Community Development

foreign production, high labor costs and the development of similar products from paper mill liquor the naval stores industry is fast disappearing from the scene.

POLES AND PILING

'The market for poles expanded greatly with the advent of the Rural Electrification Authority and continues. The senior author was involved in establishing three studies in the period 1949 to 1956 in which the development of poles in loblolly and' shortleaf pine stands was followed. These studies led to the publication of the Pole Grower's Guide and Managing for Poles and Piling (1957, 1978). Much of what was true then can be repeated today. If the timber grower wants to obtain maximum returns per acre:' from his longleaf pine stands, he should manage for a product mix, including poles.

In 1965 L. N. Dantzler Lumber Company, of Perkinston; Mississippi, remeasured its CFI plots on 107,400 acres of land in Stone, George, Harrison and Jackson Counties, Mississippi. James Bryan, in a personal communication, has provided the information in Table 1 from these plots which stresses the importance of longleaf pine for pole production compared with other pine species.

Table 1. Percent of trees of quality to make Class 9-20 and better poles

Species	Pulpwood Sized (4.6" - 8.5" DBH)		Sawtimber Sized (8.6" & up DBH)	
Longleaf	(1,989,781 trees)	8% poles	(1,326,862 trees)	63% poles
Slash	(3,300,275 trees)	2% poles	(835,811 trees)	25% poles
Loblolly	(1,008,702 trees)	0 poles	(373,404 trees)	3% poles
Shortleaf	(100,256 trees)	1% poles	(26,599 trees)	2% poles
Spruce	(55,243 trees)	0 poles	(70,589 trees)	0 poles

Poles are best grown in even-aged well stocked stands with a site index of 75 (base age 50) or better. Dense stands will produce more lineal feet of poles than sparsely stocked stands, not only because there are more trees per acre but because more trees in dense stands will meet taper requirements. The increase in number of long poles produced will more than compensate for slower diameter growth.

Natural regeneration of longleaf pine often results in overly dense stands of 1500 to 2000 stems per acre. Where a market exists such stands should be first thinned for posts. Most large landowners now control spacing by planting rather than relying on direct seeding or natural regeneration.

Two thinnings or sanitation cuts should put the average stand in shape for growing poles. Concentrate on removing defective, crooked, and broken-topped trees. Spacing is of secondary importance. Timber markers concentrating on spacing have removed many straight co-dominants whose only fault was that they were growing next to a good dominant. Remember too, that many trees will outgrow early sweep as they put on diameter growth.

To qualify for the next larger merchantable length, a tree with a 20-foot pole in it must, on the average, grow 0.9 inch in diameter per five feet of growth. The diameter increase needed per five feet of height growth becomes progressively less for the longer pole classes. For example, the needed diameter increase is 0.5 inch for a 50-foot pole tree to become a 55-foot pole tree and 0.4 inch for an 80-foot to become an 85-footer.

The boles of trees on lightly stocked plots (55 square feet of basal area per acre, for example) may enlarge too rapidly for optimum pole development. Continual excessive diameter growth in relation to height growth leads to excessive taper. In addition as taper increases, the stumpage price per thousand board feet decreases because additional volume is given for the same price. Rapid diameter growth shortens the time required to produce long poles but widely spaced trees must be inspected every two or three years so that they can be harvested before they grow too large for poles.

The Mississippi National Forest has a leave basal area target of 65 and 70 square feet per acre after the first thinning in longleaf pine stands. In the second thinning when the trees are 8 to lo-inches in d.b.h. their leave target is 75 to 80 square feet per acre. Many pole growers believe that economics dictate concentrating on the production of 30', 35', 40' and 45'-poles because it takes too many years to grow the large, high-valued poles. Others believe that the larger poles are so much more valuable that waiting a few more years before harvesting them is worthwhile

The rate of growth and number of knots greater than a half-inch in diameter must be taken into consideration in management. Trees up to 37.5 inches in circumference (11 inches in diameter) at 6 feet from the butt must have more than six rings per inch in the outer two inches. For larger trees the same rule applies but in the outer three inches. (Except that poles with four or five rings per inch are acceptable if 50 percent or more summer wood is present.) The diameter of any single knot and the sum of knot diameters must not exceed the limits set forth in the specifications. For example, the sum of diameters of all knots greater than 0.5 inch in any l-foot section cannot exceed 8 inches in poles 45 feet and shorter.

Even on the best sites only a few 25-foot or 30-foot utility poles can be produced on each acre under a 25-year rotation. It takes an 80-foot tree to produce a utility pole 45 to 50 feet long. In one mid-South survey, 48 percent of the poles marketed came from the 14-inch-plus diameter class. The T. R. Miller Company has prepared a table showing the percentages of longleaf pine yields 'as poles by age and site index. See Table 2. For example if you grow longleaf pine on a 60-year rotation on site 80, 80 percent of the trees will make poles. T. R. Miller thins their longleaf pine stands back to 70-80 square feet of basal area per acre every 10 years and expects them to grow to 100 to 115 square feet before the next cut. Their objective is to grow 15 and 16-inch trees on a 60 year rotation. Planting genetically superior stock on thoroughly prepared sites should lead to a shorter rotation.

Table 2. Percentages of longleaf pine yields as poles, by age and site index

Age	Site Index 50	60	70	80	90
(Years)	(Percent)	(Percent)	(Percent)	(Percent)	(Percent)
30	0	0	10	20	20
35	5	10	30	45	45
40	15	20	50	70	70
45	'20	25	55	75	75
50	25	35	65	80	80
55	25	35	70	80	80
60	30	35	75	80	80
65	20	35	55	65	65
70	10	35	35	50	50
75	10	25	30	40	40
80	10	20	30	30	30

Source: T. R. Miller Mill Co., Brewton, Alabama

Timber growers should insist on selling their poles on a marked-woods run basis. If given a free hand, pole producers will remove too many of the best trees at one time. Five utility poles per acre is an acceptable cut; 8-10 a good cut. Long poles are so scarce that one 80-foot pole per acre is well worth cutting.

Loggers generally equip themselves to handle the worst logging situations with which they may be confronted. Since pole and piling longleaf stands generally grow on the better logging sites the logger may actually be over-equipped. In the younger dense stands poles can be removed with small feller bunchers. In older ,-larger dense pole stands trees can be felled with chain saws and snaked out with a cable. In more open timber directional felling machines equipped with saws can be used in conjunctions with grapple skidders. Loggers have been using shears to fell pole trees but there is some feeling that this damages the butts. Tops and limbs should be removed before skidding. Damage to the residual stems must be kept to a minimum. The attitude and efforts of the boss logger control the quality of the logging job.

Most of the better longleaf pine sites are dry and sandy and can be logged with little damage to the soil. Skidding should be spread over many trails on sandy sites. Skidding should avoid changing natural drainage and should be toward uphill landings to form a fan-shaped runoff-dispersing pattern.

Piling specifications from the grower's standpoint are much the same as pole specifications. Pole plants provide many of the piling orders directly out of their pole stock. Pole growers can sell straight, short, thick boled trees for piling which would have no market as poles. Grow them straight and relatively clean-boled, and they will sell for a premium.

PINE STRAW

One of the most valuable products of longleaf pine is its straw or needles. Valued as a source of weed seed-free mulch it is used by farmers, nurseries, and landscapers. Raked, piled, and baled it offers the forest landowner a biennial source of income. On the Bladen Lake State Forest in North Carolina a fully stocked acre - basal area 90 square feet or more - will yield an average of 65 bales (3900 pounds) annually. Harvested every other year for efficiency, this volume is doubled..

Currently the State Forest pays a contractor to produce and deliver baled straw while providing the baling wire and maintenance on the baler. Total costs are $1.70 per bale and the net profit $1.55. Sold on the ground straw "stumpage" prices currently range from 25 cents to $1.00 per bale depending upon the amount of foreign debris present in the litter.

When establishing a longleaf plantation for straw production prepare the site as flat as possible using a V-blade or fire plow for light scalping or a single cut bush and bog disc. Keep the rows straight with a 7-to-8-foot minimum distance between the rows. Chemically or mechanically eliminate any wire grass, honeysuckle or other vine type vegetation prior to planting. Longleaf plantations should be ready for harvesting between 15 and 25 years of age, depending upon the site quality.

To prepare an existing plantation or natural stand for straw production chemically eliminate as much of the hardwood understory as possible. In plantations remove every fourth row to provide easy access and thin the remaining 3 rows, leaving a residual basal area of 90+ square feet per acre. In natural stands cut straight access corridors at half chain intervals and thin to 90+ square feet per acre. As soon as the herbicide has had maximum effect and the debris from thinning has dried, prescribe burn the area or hand pile the debris and remove with a grapple skidder.

Maintenance of an established straw production stand is a matter of controlling hardwood invasion, suppressing insect attack and, if the landowner desires, increasing straw production and annual increment by fertilization. The application of 200 pounds of diammonium phosphate per acre produces an increase of 10 to 15 percent per year of straw by weight over a three year period. Biennial removal of pine straw from a longleaf pine stand will ultimately result in some form of site deterioration.

CONCLUSION

Naval stores are no longer an important by-producrt. Pole growing is compatible with management for sawtimber butt one product must be primary and the other secondary. Wheree there are good markets returns can be maximized by managing for poles as the primary product. Harvesting longleaf pine straw caan increase the total return per acre whether the primary objectivat of management is poles or sawtimber.

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THE ECONOMICS OF MANAGING LONGLEAF PINE

by

Fred Cubbage and Don Hodges

ABSTRACT. Sample management regimes for longleaf pine were developed to analyze the economic returns of alternative approaches. Based on existing growth and yield models and representative input costs and product prices, the analysis indicated that longer rotations in both artificially and naturally regenerated stands provided the largest economic returns. Regimes of both management types provided substantial returns, with the 50-year plantation rotation exhibiting the largest net present value; followed by the 40-year plantation and the natural regeneration, 80-year rotation regimes. Comparing the regimes on the basis of internal rate of return reduced the differences among the returns, though the relative rankings remained similar. As only five regimes were examined, the results are not, meant to be conclusive, but instead illustrate a simple framework for evaluating management alternatives on specific sites.

INTRODUCTION

Interest in longleaf pine silviculture and management has increased in recent years. It has been estimated that when the first colonists came to America, longleaf pine stands covered almost 50 million acres in the South. At present, only abut 4 million acres of longleaf pine type remain. This drastic reduction in area suggests-that land use patterns changed substantially after white settlers supplanted native indians. Additionally, it suggests that the longleaf pine ecosystem is not very robust, and must obviously depend on a rather narrow range of natural or managed conditions for survival. Additionally, management decisions in recent decades have favored other pine species.

Fred Cubbage is an Associate Professor, University of Georgia School of Forest Resources, Athens. Donald Hodges is a Post-Doctoral Research Forester, Southern Forest Experiment Station, Forest Resource Law and Economics Work Unit, New Orleans.

This paper discusses the economics of longleaf pine timber management. We will present a framework for analyzing the costs and returns from longleaf pine management and use this framework to estimate the economic returns of various longleaf management alternatives. We analyzed a number of selected management scenarios for longleaf based on the existing silvicultural and growth and yield literature. All of these scenarios assume that the management regimes used can indeed be effectively put in place on the ground, i.e. that plantations and natural regeneration methods will be successful. In fact, this may well be a substantial problem, one which has caused much of the great decline in the longleaf pine area, but without some basis for estimating growth and yield, one can perform few meaningful economic analyses. Accordingly, we will use deterministic methods to estimate growth, harvest, and returns for longleaf pine management. The question of risk--the probability of successful regeneration--will be discussed only in subjective terms.

ECONOMIC ANALYSES

Discounted cash flow analyses are the principal means that most forest economists, public agencies, and private firms use to analyze the costs and returns of forestry investments. These methods require several steps in order to estimate the returns for an individual investment or to compare investments. Basic information on the management alternatives must be obtained. This includes identifying likely management regimes, procuring of information on growth and yield of stands in each management regime, estimating costs of stand establishment and management, and projecting prices for the probable product mixes. This basic information is then used to estimate the costs and returns for each management regime on a yearly basis. Once yearly cash flows are determined, various discounted cash flow criteria can be used to measure investment returns.

We developed representative longleaf pine management scenarios from the literature and then applied discounted cash flow techniques to arrive at comparative returns. In selecting the management scenarios and estimating costs and returns, we tried to use data that were as representative as possible. However, conditions for management, input costs, yields, and product prices vary widely by region, ownership, site, and other factors. As such, this paper's principal contribution should be viewed as outlining a means of making economic analyses of longleaf pine for conditions unique to each potential investor, rather than making definitive conclusions about the returns to longleaf management investments. Based on local conditions, analysts can use the methods presented here to perform their own, more specific financial analyses.

Manaaement Reaimes

The first step in analyzing a forestry investment is determining likely silvicultural regimes. Many authors have discussed longleaf pine management. We chose likely management regimes based on general discussions by Croker and Boyer (1975), the USDA Forest Service (1983); and Boyer and Farrar (1981). These ranged from relatively short rotation plantation management regimes to relatively long planned natural regeneration regimes. Plantation regimes are believed to have advantages in terms of ease of establishment and management compared to natural stand regeneration. Additionally, the shorter rotations usually used in plantation management are also believed to offer economic advantages in discounted cash flow analyses. Longer natural rotations are believed to offer very good yields, especially for longleaf pine, which grows slowly in early years and more rapidly in later years than other southern pines. Longer natural stand rotations are also believed to offer more ecological diversity than plantations, particularly for important threatened or endangered plant and animal species. The drastic declines in longleaf pine area suggests, however, that successful regeneration of natural stands has proven difficult.

Plantation management of longleaf pine is straightforward, but somewhat more difficult than for other southern pines. Site preparation must be more thorough, so that longleaf seedlings are not suppressed in the grass stage. Seedling stock must be larger than for other southern pines. And vegetation control must be very good in the first years of the plantation, again to prevent suppression and brown-spot needle blight. Based on these silvicultural characteristics, the analyses here used i-ntensive site preparation methods of shear, chop, disk, and burn.

Natural stand management of longleaf pine is more complex. Successful planned regeneration requires well prepared seedbeds. This may entail at least controlled burning, and probably chemical applications to control herbaceous vegetations tit well. Stand management also may require periodic thinnings in order to open the stand before a shelterwood cut. Most authors recommend that stand basal area should be less than 100 square feet, at least, or even as low as 50 to 70 square feet, before a shelterwood or seed tree cut is made. Thus thinnings are essential for successful natural regeneration, as is periodic burning to control competition. Additionally, natural regeneration methods are likely to take about five years in order to establish a viable new stand. These practices were used for the management regimes analyzed here.

Growth and Yield

Growth and yield of longleaf stands also had to be determined for the management regimes selected. A variety of yield functions for longleaf pine are available. Since most management regimes seemed likely to require some commercial thinnings, we relied on yield function sources that allowed calculation of growth and yield data from intermediate and final harvests. Growth and yield predictions for thinned stands of even-aged natural longleaf pine were taken form Farrar (1979); for thinned plantation stands from Lohrey (1979).

The management regimes selected for analysis here and the growth, yield, and harvest volume estimates are summarized in Table 1. The ages of the intermediate thinnings were selected based on the basal area and total volume present in the stand at each age. Stands were required to have at least 80 square feet of basal area per acre before thinnings could occur, and at least 6 cords per acre had to be removed in order to make a sale attractive to a logger. Thinnings reduced residual basal area to about 50 to 60 square feet, depending on stand age and volume. The shelterwood cuts were assumed to thin the residual stand to a basal area of 20 square feet per acre.

The yield tables were used to calculate basal area and volume at each class. Both authors provided formulas to calculate future basal area based on initial basal area, initial stand age, future stand age, and site index. Site index was assumed to be 45 feet on a 25 year basis; 70 on a 50 year basis. The basal area figures were then used in volume formulas to predict either cubic foot or board foot volume, as relevant. Removals of thinnings were made in proportion to the basal area removed. For example, a reduction in basal area from 80 square feet to 50 square feet would remove 37.5% of the stand volume at that time. Growth from that point on would be calculated based on the new initial basal area of 50, projected into the future as dictated by the management regime.

Product breakdowns of the stands were based on conversations with people familiar with longleaf pine management and yields. The first thinning was always considered to produce only pulpwood. Subsequent thinnings and final harvests were assumed to produce predominantly sawtimber and some pole timber. The pole timber proportion increased slightly as age of harvest increased. The shelterwood harvest left only sawtimber-quality trees, so no poles would be lost to blow-down or disease. Table 2 summarizes these breakdowns by stand type and harvest age.

Input Costs and Product Prices

The product prices and total revenues form each harvest are summarized in Table 2. Pulpwood prices were assumed to be $18 per cord; sawtimber prices $160 per thousand board feet; and pole timber prices $220 per thousand board feet. Hunting lease revenues of $4 per acre per year for natural stands and $3 per acre per year for planted stands were the only other direct benefit included in the analyses. Some.tax benefits may also be obtained by some landowners under the reforestation investment credit; these too were included in an after-tax calculation. These consist of a federal income tax credit for planting trees,

Table 1. Example Longleaf Pine Management Regimes and Yields Per Acre

	Planned Natural Regeneration			
	45 year rotation		80 year rotation	
Harvest Type	B.A. & Age	Volume	B.A. & Age	Volume
Initial Basal Area	15 ft^2 a 15	----	15 ft^2 @ 15	----
First Thiming				
Initial	80 ft2 a 30	1,442 ft^3	80 ft2 @ 30	1,442 ft^3
cut	30 ft^2	6.4 cds	30 ft^2	6.4 cds
Residual	50 ft^2	845 ft^3	50 ft^2	845 ft^3
Second Thinning				
Initial	----	----	102 ft^2 a 45	5,990 bd.ft.
cut	----	mm--	42 ft^2	2,466 bd.ft.
Residual	----	----	60 ft^2	3,524 bd.ft.
Third Thinning				
Initial	----	----	98 ft^2 @ 60	14,000 bd.ft.
cut	----	----	48 ft2	7,000 bd.ft.
Residual	----	----	50 ft^2	7,000 bd.ft.
Shelteruood Cut				
Initial	102 ft^2 a 45	5,990 bd.ft.	a6 ft2 @ 80	16,880 bd.ft.
cut	a2 ft2	4,815 bd.ft.	66 ft^2	12,930 bd.ft.
Residual	20 ft^2	1,175 bd.ft.	20 ft^2	3,950 bd.ft.
Residual Tree Cut	30 ft^2 @ 50	1,390 bd.ft	25 ft^2 @ 85	4,000 bd.ft.
Clearcut	----	we--	---v	----

Yield Equation Sources: natural longleaf • Ferrer (1979); planted longleaf • Lohrey (1978).

Site Index: 70 @ 50 years; 45 @ 25 years.

Table 1. Continued.

	Site Preparation and Planting					
	40 year rotation		40 year rotation		50 year rotation	
Harvest Type	B.A. & Age	Volume	B.A. 8 Age	Volume	B.A. & Age	Volume
Initial Basal Area	20 ft^2 @ 15	----	20 ft^2 @ 15	----	20 ft^2 @ 15	----
First Thinning						
Initial	76 ft^2 @ 28	1,971 ft^3	----	----	76 ft^2 @ 28	1,971 ft^3
cut	26 ft^2	7.4 cds	----	----	26 ft^2	7.4 cds
Residual	50 ft^2	1,304 ft^3	----	----	50 ft^2	1,304 ft^3
Second Thinning						
Initial	----	----	----	----	90 ft^2 @ 40	9,030 bd.ft.
cut		----		----	30 ft^2	2,987 bd.ft.
Residual		----		----	60 ft^2	6,043 bd.ft.
Third Thinning						
Initial	----			----	----	----
cut		----	----	----	----	----
Residual		----	----	----	----	----
Shelterwood Cut						
Initial	----	----	----	----	----	----
cut	----	----	----	----	----	----
Residual	----	----	----	----	----	----
Residual Tree Cut	----	----	----	----	----	----
Clearcut	90 ft^2 @ 40	9,030 bd.ft.	120 ft^2	14,538 bd.ft.	85 ft^2 @ 50	17,726 bd.ft.

Table 2. Example **Longleaf** Pine Regime Product Mixes and Revenues Per Acre

Regeneration/ Harvest Type	Year of Harvest	Product Mix	Total Revenue ($1988)
Natural Regeneration/ First Thinning	30	100% Pulpwood	115
Natural Regeneration/ Shelterwood Cut	45	90% sawtimber 10% poles	799
Natural Regeneration/ Second Thinning	45	90% sawtimber 10% poles	409
Natural Regeneration/ Reeidual Tree Cut	50	80% sawtimber 20% poles	239
Natural Regeneration/ Third Thinning	60	70% sawtimber 30% poles	1246
Natural Regeneration/ Shelterwood Cut	80	60% sawtimber 40% poles	2379
Natural Regeneration/ Residual Tree Cut	85	100% sawtimber	640
Plantation #1,			
First Thinning	28	100% pulpwood	133
Clearcut	40	90% sawtimber 10% poles	1499
Plantation #2, **Clearcut**	40	90% sawtimber 10% poles	2413
Plantation #3,			
Second Thinning	40	90% sawtimber 10% poles	496
Clearcut	50	80% sawtimber 20% poles	3049

1988 Product prices: Pulpwood $18 per cord; sawtimber $160 per thousand board feet (MBF); pole timber $220 per MBF.

as well as a deduction for 8 years thereafter. Details of financial analysis of this income tax treatment are contained in Cubbage et al. (1989).

The management inputs and costs used are summarized in Table 3. Property tax and administration **equalled** $5 per acre per year. Costs for the regeneration and stand management practices employed were taken from Watson et al. (1987) and inflated to 1988 price levels. Timber marking charges for each'thinning were assumed to equal 10% of the harvest value--a fairly common percentage charged by consulting foresters. Public agencies or private firms are also likely to incur sale administration costs, perhaps of this magnitude. For the after-tax analyses performed, marginal tax rates were assumed to equal 28% for federal income taxes and 2% for state taxes, for a total of 30% of gross timber sale revenues.

Discounted Cash Flow **Analyses**

The preceding information on management regimes, product prices, and input costs provided the basis for developing yearly summaries of costs and returns and for performing discounted cash flow analyses of investment returns. Financial analysts and forest economists use a variety of economic criteria to determine the merits of an investment. Being economists, they do not always agree on which economic criteria are best; an issue which we will cover only briefly here. Foresters seeking more information should examine Brealey and Myers **(1984),** Gunter and Haney **(1984),** Bullard et al., **(1986),** or Cubbage et al. (1989).

Net present value (NPV) measures the amount of capital that an investment returns at a given discount rate. For example, if the discount rate is 4% and the net present value **equalled** $10'0, this would mean that the net returns on the capital invested would yield 4% per year for all the costs incurred, plus $100. A negative present value at 4% would imply that the discounted value of the benefits earned less than discounted value of the costs at the 4% per year hurdle rate. Financial theory dictates that for individual accept/reject decisions, one should accept investments with a positive net present value at the given discount rate. For capital budgeting decisions (choice among many projects), one should chose the alternative with the highest net present value. Land expectation value (LEV) is similar to net present value, only calculated for an infinite series of identical rotations. Its use is similar; positive **LEVs** indicate acceptability; greater **LEVs** superiority. LEV provides a means of comparing the returns of two or more rotations of different lengths. Equivalent annual income is another NPV variant, only measuring returns on an annual basis. Last, benefit:cost analysis measures the ratio of discounted benefits to discounted costs. Ratios greater than 1.0 indicate acceptability; higher ratios preferred investments.

Table 3. Example Longleaf Pine Management Regime Costs Per Acre

	Planned Natural Regeneration		Site Preparation & Planting	
	45 Year Rotation	80 Year Rotation	40 Year Rotation	50 Year Rotation
Costs	------------------------ $1988/acre	(years	incurred)	------------------------
Property tax	3.00 (O-45)	3.00 (O-80)	3.00 (O-40)	3.00 (O-50)
Administration	2.00 (O-45)	2.00 (O-80)	2.00 (O-40)	2.00 (O-50)
Prescribed burns				
Before regeneration	7.72 (0)	7.72 (0)	7.72 (0)	7.72 (0)
During rotation	3.55 (6, 9,...,45)	3.55 (6, 9,...,80)	3.55 (6...60)	3.55 (6...50)
Shear, chop, disk	-----	-----	184.00 (0)	184.00 (0)
Herbicide application	83.47 (0)	83.47 (0)	-----	-a---
Seedlings (1200/ac)	-----	-----	30.00 (0)	30.00 (0)
Machine planting	--a--	-----	58.32 (0)	58.32 (0)
Timber marking	10% of all but final harvest	10% of all but final harvest	10% of thinning	10% of thinning
Income taxes	30% of all cuts	30% of all cuts	30% of all cuts	30% of all cuts

Internal rate of return (IRR) is a means of measuring the average annual rate of return of an investment. It is the discount rate that when used will equate the discounted costs with the discounted returns from the yearly cash flows. The internal rate of return can be compared with the rate of return of another investment, such as a savings account or a certificate of deposit. It can also be used by an owner to be compared with a personal, corporate, or public hurdle rate. Internal rates of return greater than the hurdle (interest) rate would indicate investment acceptability; less than the hurdle rate unacceptability. Similarly, IRRs can be used to rank a group of investments in order of desirability.

We used a microcomputer software package named CASH (Belli et al. 1985) to calculate these measures of return for the various management regimes. We calculated all costs and returns using a real discount rate of 4 percent. This means that inflation was not included in the analysis; costs and returns were kept in constant 1988 dollars. Accordingly, when making comparisons of these investment returns with other assets, such as savings accounts or stocks, one should add in the inflation rate to the timber returns or subtract it from other asset returns. Inflation has been about 3% to 4% in recent years. The analysis did assume that sawtimber and pole timber prices increased at a rate 1% greater than the inflation rate. The appropriate discount rate for public and for private organizations is also subject to debate. Row et al. (1981) found that the long-term before-tax real rate of return on corporate stocks and bonds was about 4%, and recommended its use for Forest Service analyses. It also provides the basis for our calculations.

RESULTS

The results of the discounted cash flow analyses of the longleaf pine management regimes are very interesting (Table 4). In some instances, they confirm conventional wisdom about managing longleaf, but in other cases they do not.

Of the five longleaf pine management regimes analyzed for this paper, three seemed clearly superior by any economic criterion used. The artificial regeneration, 50-year rotation regime that had no thinning had the third highest NPV and the second highest LEV. The 80-year rotation natural stand regime also had excellent returns, with the second highest NPV and the third highest LEV. The shorter natural stand and plantation regimes that included just one thinning were uniformly less desirable. Both had before-tax net present values of less than $170 per acre, and LEVs of less than $210 per acre.

If one compares these management regimes on the basis of internal rate of return, the differences seem less significant, but the comparative rankings still are similar. In this case, the 80-year natural rotation had the greatest IRR (6.8%),

Table 4. Example Longleaf Pine Economic Returns Per Acre

Investment Criterion	Management Regime						
	Planned Natural Regeneration			Artificial Regeneration			
	45-Year Rotation Before-Tax	45-Year Rotation After-Tax	80-Year Rotation Before-Tax	40-Year w/Thinning Before-Tax	40-Year w/Thinning After-Tax	IO-Year No Thinning Before-Tax	50-Year Rotation Before-Tax
Net Present Value ($1988 per acre)	146	86	443	165	102	408	538
Land Expectation Value ($1988 per acre)	170	100	460	208	130	516	626
Equivalent Annual Income ($1988 per acre)	7	4	18	8	5	21	25
Real Internal Rate of Return (%)	6.0	5.7	6.8	5.2	5.0	6.2	6.3
Benefit:Cost Ratio	1.6	1.3	2.5	1.4	1.2	2.0	2.2

Note: real discount rate = 4 percent.

followed by the 50-year plantation (6.3%) and the 40-year non-thinned plantation (6.2%). The remaining rotations with only one thinning looked better using IRR, at 5.2% (plantation) and 6.0% (natural) before-tax.

The effect of taxes was as expected--they reduced the present values, by about $60 in each case where they were examined. The internal rate of return, however, dropped only 0.2 to 0.3 of a percent on an after-tax basis, because the tax credits and deductions reduced the initial investment in early years. The results also confirm the commonly held belief that longleaf performs better with long rotations. This was true whether the stands were regenerated naturally or artificially. The reason for this is simply that only small volumes were grown at ages up to abut year 40, but volumes increased rapidly after that. In fact, the plantation stands may have performed even better financially at rotations beyond 50 years, but the yield equations did not predict accurately beyond that age. The much greater yields at later stand ages more than offset the effect of discounting those future yields at the relatively low real discount rate of 4 percent. Higher discount rates would penalize returns from longer rotations more.

The results also illustrate why economists do not always agree about the most appropriate criterion to use in selecting among several mutually exclusive investments. No one management regime was superior using all the economic criteria. At the assumed real discount rate of 4% the 50-year plantation was clearly the best in terms of both NPV and LEV. However, the 80-year natural rotation had the second largest NPV and the 40-year plantation without thinning had the second largest LEV. The 40-year plantation actually was the better of the two regimes. The reason for this is that the 80-year rotation had twice as many years to generate returns, so might be expected to have a higher NPV than an investment lasting only 40 years. If one compared two 40-year plantations with one 80-year natural stand, the plantation investment would have a greater NPV. This illustrates why LEV is useful for foresters--it facilitates comparisons of management regimes with unequal rotation lengths.

On the basis of internal rate of return and the benefit:cost ratio, however, the 80-year natural regeneration management regime had the greatest economic returns. In fact, for any discount rate greater than 6.3%, this would be the only investment that yielded a positive NPV or LEV. Most forest landowners would probably deem a 6.8% return better than a 6.3% return. This inconsistency is one reason many financial theorists recommend the use of NPV or LEV, although one must know the appropriate discount rate to use these criteria. In any case, the closeness of the rankings for these three management regimes using all economic criteria indicate that all might be viable depending on the site, yields, prices, and other factors relevant in any individual. investment decision.

The CASH program also automatically performed sensitivity analyses for each management regime. These results indicated that the comparative rankings would not be affected much by a change in assumptions. The factors that could affect rankings the most were the yields or prices or final harvests. But yield reductions of 40% to 80% would be required to make the NPV negative at the 4% discount rate. Site preparation costs could also affect returns for artificial regeneration slightly, but it would take cost increases of over 50% before it would create a negative NPV at 4 percent. Most other costs and returns could be off by over 100% without affecting the NPV accept/reject decision. These sensitivity analyses indicate that one can be fairly confident in the relative economic merits of the regimes analyzed.

CONCLUSIONS

This analysis of longleaf pine economics provides several insights about longleaf management and about economic analyses as well. In a brief paper, one cannot examine many management regimes or scenarios. Therefore, we selected some that seem reasonable based on the current literature, and analyzed their costs and returns. More importantly, this paper presents a framework that can be used to analyze costs and returns of any longleaf pine investment, or indeed any forestry investment.

The basic methodology for analyzing forestry investments involves identifying management regimes, determining input costs and product prices, using this information to compute yearly cash flows, and then calculating various economic measures of investment performance. These steps quantify the most likely physical input-output relationships and investment costs and returns. These quantifiable analyses can then be used with qualitative investment considerations to determine the desirability of any particular management alternative.

The quantitative framework presented here should not be the only basis for making an investment decision nor the substitute for informed professional judgment. This fact is particularly important in the case of longleaf pine management decisions. For example, our deterministic analyses indicated that natural pine management offered investment returns comparable to those of plantation management. However, we assumed that natural longleaf pine regeneration would always be successful using the hypothetical management regime. Assuming successful natural regeneration with such a difficult species is undoubtedly much easier to do on paper than to accomplish on the ground. If natural regeneration failed, the returns would obviously be dismal. The substantial risks of regeneration failure must be considered in making a management decision, and indeed suggest one likely reason that foresters have preferred plantation management to natural stand management, especially for longleaf pine ecosystems. Future research could quantify these economic risk/return relationships.

Our analyses do suggest some interesting conclusions regarding longleaf pine management. Longer rotations seem to be preferable to shorter ones. Plantation rotations of up to 50 years, and perhaps even longer, seem reasonable based on economic criteria. If plantations are managed on shorter rotations, thinning seems to detract from investment returns, so should be avoided. Natural stand management and regeneration seem to offer the best returns at quite long rotations, up to 80 years in length. In fact, the 80-year rotation analyzed here actually had the greatest internal rate of return. Its rate of return was greater than that of the plantations because it had reasonable harvest yields and revenues, but less than one-half the initial investment costs of the plantations. Thus its rate of return on the smaller amount of invested capital was higher. The lower investments required for natural stand might recommend their use to nonindustrial private forest landowners, or to public agencies with limited budgets. At the 4% real discount rate, the 50-year plantation investment actually had a higher net present value, however. This indicates that one would receive more discounted benefits for the money invested in an acre of longleaf plantations at the discount rate, even though a greater amount of initial capital would be required.

The five management regimes presented here represent only a few of the infinite number of possible alternatives. As such, our conclusions should not be applied indiscriminately to all longleaf investments. Instead, the methods we presented here should be used to analyze specific investment alternatives based on individual sites, management regimes, timber yields, input costs and product prices, risk, owner objectives, and other qualitative criteria. Our analyses do suggest, however, that both natural and plantation management regimes can be economically viable; that relatively long rotations are desirable; and that one must use and interpret economic criteria with care. Determination of the discount rate for present value calculations or use of the hurdle rate for internal rate of return calculations can affect quantitative decision-making. Managers interested in evaluating longleaf pine can use the approach and rationale explained here to analyze their own unique investment and management opportunities.

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IV Session

April 6, 1989

Moderator:

Roger W. Dennington
USDA, Forest Service, Southern Region

ESTABLISHMENT OF LONGLEAF PINE AT GULF STATES PAPER CORPORATION

For those of you, not familiar with our Company, Gulf States Paper Corporation is a family owned forest products business with operations in Alabama, North Carolina, Kentucky, Texas and Missouri. Founded in 1884 in the mid-west, moving to the South about 1900, and locating in Tuscaloosa, Alabama in 1929, Gulf States owns or manages approximately 400M acres of timberland in West Central Alabama, We were invited to this conference to tell you about our efforts to establish Longleaf on a portion, of this ownership.

On pine sites Gulf States Forest Management objective is to produce high quality pine sawtimber and poles. Longleaf is the most desirable species on about 15% of the pine land.

During the 1970s efforts to establish Longleaf with bareroot seedlings was only marginally successful, due in part to seedling quality, planting technique, and a lack of herbaceous control. For several years, we stopped trying. In the early 1980s, after a Container Seedling Conference in Savannah, we established a small container production facility and began to produce and plant Longleaf seedlings. After a great deal of trial and error, but learning from our mistakes, we have progressed to a point today, where we are optimistic about the opportunities for success with this program.

Our presentation will consist of a brief overview of seedling production and a look at our establishment strategy.

Our container operation is designed to produce quality Longleaf and Loblolly pine seedlings to be planted on Company owned lands. We have tried to keep the operation as cost effective as possible. Along the way we have certainly proven that you can't grow Longleaf seedlings as cheaply as Loblolly, and cost control is a major concern. Most of the operation is our own design, with initial input provided by North Carolina Division of Forestry,'Jim Barnett, and others.

We obtain our seed from commercial suppliers and industry seed orchards. We are interested in the best quality seed, both genetically and physically, that is available.

Our seeding operation begins in mid-April for Longleaf and mid-June for the Loblolly. The Longleaf is grown about 18 weeks and the Loblolly about 14 weeks before outplanting in the field.

We use a pre-mixed peat moss (3 parts) and vermiculite (1 part), with no additives, from a commercial supplier. Water is added to the media utilizing a ribbon blender. The containers are filled by hand and then seeded with a vacuum seeder. The Longleaf is double seeded and the Loblolly is single seeded. The containers are then placed on the tables by hand.

Initial fertilization and fungicide applications are made at 21 days. At this time we also transplant excess Longleaf seedlings into empty cells ideally before the radicle grows . over 1½ inches long. We are seeking methods to minimize or eliminate the transplanting because it is labor intensive and very expensive. We also suspect some development problems with transplanted seedlings. After a 28 day germination period the crop is thinned. We remove the shade as soon as the Longleaf is established, usually about 6 to 7 weeks. We have found that the trees develop much better in full sunlight. Fertilizer and fungicides are applied through the irrigation system utilizing an injector system. After 18-20 weeks, root collar diameter usually averages about one-quarter inch.

Site preparation is accomplished by herbicide application in the spring and burned in July or August. On Longleaf sites, generally Hexazinone is aerially applied in liquid or granular form, or by hand with a spotgun. We prefer a broadcast method for more effective herbaceous control. Hand application is predominantly used where we have a local ban on aerial application of herbicides. Burning is usually done with the aid of a helicopter.

For us, container planting season is mid-September to mid-November, and the earlier we can finish the better., Starting time will vary due to soil moisture conditions, A three day supply of trees is delivered to the district office from the nursery. The day prior to a shipment, the seedlings will be fertilized and well watered. Logistics has been a real challenge. Initially we sought to pull seedlings and transport to the field in some type of container for direct planting. Our primary motivation being to conserve. the life of the Styrofoam container, as it is a major investment. When these first efforts failed, we designed and constructed a trailer for transporting the Styrofoam containers, and provided aluminum trays in which to carry the containers. These worked reasonably well, but the problem, was to keep the planterman supplied with sufficient trees. This year we are returning to lifting and packing at the nursery, which solves most logistics and planting production problems. We take to the field, only, what will be planted for that day. This enables us to keep the trees on the nursery tables in their containers, where it is much easier to maintain them, or at the office where they can be protected and watered as necessary. My crew and I prefer planting from the boxes rather than the containers. Each box has approximately 250 seedlings and we plant directly from the box. The Styrofoam containers might contain 120 seedlings.

All our container seedling planting is done by hand with our company crew and contract labor. The average number planted per man day is about the same as bare root planting.

Hand planting seems to work best for us due to the terrain, and planting longleaf and loblolly on same tract based on most desirable site. We use a cone shaped plugger, dibble, or a hoedad. Our crew size will vary from 8-12 men with one man carrying trees from the truck to plantermen. Planting depth is critical as the peat plug must be completely covered to prevent wicking, and the bud position exposed. We have tried spring planting and found that early spring is okay, but fall is overall, preferable. Needless to say, we've had our failures. While past spacing has been 7' X 10', with survival potential of 95+%, we are considering some reduction in trees planted per acre.

Herbaceous vegetation control is used on every longleaf tract in the spring following planting. Herbicide combinations used to date include 3 oz. Oust with 1 quart of Velpar in 5 gallons total aerially applied mix, or 3 oz. Oust and 16-20 oz. Roundup in ten gallons total mix. Hand application has also been successfully employed with the Roundup/Oust mixture by backpack sprayer. While it uses much less herbicide and a lot more labor, it is not preferable to a broadcast method. Especially on spotgun treated tracts, it is difficult to find all the seedlings due to heavy herbaceous growth. We only apply herbaceous control one time and seem to get most of our trees out of the grass stage in the second growing season.

Authors: Phillips Sasnett
Dale Larson
John W. Foster, Jr.

LONG TERM MANAGEMENT ON LONGLEAF PINE - T. R. MILLER MILL COMPANY

Introduction

I would like to introduce my company to you by reviewing some of our history,

Cur original sawmill began operations in 1848, located 3½ miles northeast of Brewton on Cedar Creek. This was a water driven sawmill. In 1872, Cedar Creek Mill was sold to the ancestors of T. R. Miller's present owners. The mill and 1200 acres of land sold for $740.

In 1892, the sawmill was moved to Brewton at our present location adjoining Murder Creek and the C.S.X. railroad. A steam mill was constructed at this site.

In the late 60's, a "modern" bandmill and chip'n saw head rig replaced our steam mill. This is the sawmill operated today along with a box and treating plant located in Brewton and a sawmill producing green lumber only in Castleberry, Alabama.,

In 1899, our landownership was 19,000 acres; in 1912, it was 83,000 acres; in 1948, forest ownership had grown to 172,000 acres; and today, 202,000 acres are owned in Alabama and Florida with 95% of this acreage located within a 25 mile radius of Brewton.

For those of you who do not know where Brewton is, it is 50 miles north of Pensacola, 100 miles southwest of Montgomery, and 85 miles northeast of Mobile.

General

Cur forest is comprised of longleaf, loblolly, slash, shortleaf and spruce pine along with all the typical southern hardwoods. We estimate that we have 80,000 acres of longleaf type.

(Slide 1) We are told that this depicts a typical conditionexisting withinthevirginlongleaf forestonour company's land around the turn of the century.

In the early 1900's, (Slide 2) logging camps were strategically located in the forest for harvesting the virgin timber.

The virgin timber was completely cutout on our company's lands by the 1920's.

During the period 1930 through 1936, growth studies were made by Dr. Austin Carey to assist the Company's Management in decisions to be used in establishing cutting practices to be followed on the longleaf forest. Through thinnings that followed, (Slide 3) a mixed age timber stand resulted in longleaf types similar to this picture that was made in 1965.

Our oldest identifiable longleaf plantation is 100 acres in size and is 50 years old (Slide 4). Our sample measurement in this stand indicates a volume of 14 MBF/acre with 73% of this volume making poles. An average of 95 trees/acre that were 13" dbh (ranging 10" - 18") and 81' total height with 92 square feet of basal area were measured. Current board footage growth rate is 2%. This stand has had three previous thinnings.

The oldest plantation that we have is a 57 year old slash planting (Slide 5).

Our first longleaf pine direct seeding attempt was made in 1931when Brooks Lambert, the Woodlands Superintendent, collected enough cones to fill the trunk of his 1929 Chevrolet Coupe. This tnmkservedas a kiln for drying the cones and the shaker for seed extraction. Seed were collected from the automobile trunk and sown. This project was unsuccessful; however, in the mid 50's, more direct seeding was accomplished with a greater degree of success by sowing longleaf seed on log landing sites behind logging operations.

In the mid 60's, CCA purchased 49% of the T. R. Miller stock. Cur family stockholders borrowed money to purchase enough of the stock for sale so as to retain controlling interest.

Selected timber tracts of high volume and value were clearcut for cash generation to amortize this debt. Two D-8's and one D-6 tractor were purchased at this time to be used in site preparation for reforesting these clearcut areas. (Slide 6). One D-8 equipped with "V" blade is used for shearing, (Slide 7) one D-8 equipped with root rake is used to windrow or pile the sheared material, (Slide 8) and the D-6 is used to pull a disc harrow to disc the cleared land. (Slide 9) All planting is accomplished by machine with farm tractors and homemade planting machines except on extremely wet sites which are hand planted.

Reforesting the clearcuts began in the 68/69 planting season. Availability of longleaf seedlings was limited at this time. Also, an acceptable level of longleaf planting success on a large scale basis had not been attained at this stage within our area of operations. Consequently, loblolly and slash pine were planted "off site" in these site prepared areas where longleaf was previously growing, We have just begun pulpwood thinnings in these plantings.

The planting season of 72/73 was the first large scale planting of longleaf pine on T. R. Miller lands. 980 acres were planted.

In the early 70's an oil and gas discovery (Slide 10) on company lands relieved the cash flow pressure that had been placed on the forest.

We use 16 years as the age of pine plantations attaining merchantability. When these plantations reach this age, we cruise them and add these volumes into our forest inventory. The next slides follow the development of longleaf plantings on similiar sites from one (1) year to 16 years of age:

(Slides)

Slide 11 - 1 yr., 12" height
Slide 12 - 2 yr., 12" height
Slide 13 - 3 yr.,
Slide 14 - 4 yr., 3' height
Slide 15 - 5 yr., 5' avg. height

Slide 16 - 6 yr.,
Slide 17 - 7 yr., 18' avg. height
Slide 18 - 8 yrs., 15' avg. height
Slide 19 - 9 yrs., 3.5" dbh, 30' height
Slide 20 - 10 yr., 29' avg. height
Slide 21 - 11 yrs., 38' avg. height
Slide 22 - 12 yrs., 37' avg. height
Slide 23 - 13 yrs., 40' avg. height
Slide 24 - 14 yrs., 41' avg. height
Slide 25 - 15 yr., 6.3" dbh, 45' height
Slide 26 - 16 yr., 5.3" dbh, 37' height

(Slide 27) Today,, we have a total of 42,000 acres of pine plantations. 8400 acres are planted in longleaf. This represents 20% of the total planted acreage,

Summary

Our pine species are being managed on a 60 year rotation. We are operating on a 10 year cutting cycle that is regulated by area control.

(Slide 28) Longleaf pine types are prescribe burned on a four year cycle. We attempt to regenerate all of our pine stands naturally with the shelterwood method used in longleaf and the seed tree or shelterwood method used in loblolly, shortleaf, and slash pine types.

In 1947, T. R. Miller made a 99 year lease agreement with the U. S. Forest Service on a 3,000 acre block of land located south of the Brewton Municipal Airport. This property is used as an experimental forest for research with longleaf pine. We have been very fortunate to have had intimate access to this research work. Tom Croker, better known as Mr. Longleaf, gained his reputation while serving as Project Leader of this research unit.

In my early years (1957) with Gulf States Paper, it became apparent to me how blessed we were to have the longleaf pine species to grow on the poorer, sandy soil sites of Alabama. (Slide 29) This recognition came to me after seeing the root development in a yearling seedling, after reaching 18 months of age from the time of seed germination. (Slide 30) This seedling was born from direct seeding of a deep, sandy soil in Autauga County, near Montgomery, Alabama.

In 1957, Bill Black, shown standing at top and Ted Hixon at lower level, were making an inspection of their direct seeding results and decided to check the depth of the seedling tap root. They proceeded to dig for almost two hours. The result shown on the graduated chart is a 6', 2" tap root.

Mr. Carl A. Muller, a former Alabama Forestry Commission nurseryman, was responsible for the planning, construction, and operation of the Hauss Nursery near Atmore, Alabama in the early 50's. Mr. Muller, after his retirement with the State was employed by Hammermill Paper to build a tree seedling nursery near Selma, Alabama. We received two off springs from Mr. Muller's efforts:

No. 1) Carl F. his son, (better known as "little Carl") who is an Auburn Forester thatgrewup as akidinthe shadows of the Hauss Nursery and was.hired by Ed Leigh McMillan to handle T. R. Miller's expanded reforestation plans.

No. 2) And from the Hauss Nursery, (Slide 31) the best longleaf seedlings produced in our seedling market area have come from there.

Some folks have given T. R. Miller credit for success in our longleaf plantings. If there is any merit to this opinion, Little Carl and Ed Leigh are responsible.

I will summarize some of the pertinent points that are important in longleaf plantings from observations made by Carl:

1) Good intensive site prep work is essential.
2) Good quality seedlings must be planted.,
3) Good seedling care after receiving them from the nursery must occur until time they're planted.
4) (Slide 32) Machine planting is more successful than hand planting due to the length of the lateral roots found on longleaf seedlings. (Slide 33) This is Carl's designed, homemade planting machine.
5) (Slide 34) Deep planting of seedlings has been successful when planted (Slide 35) to the depth of the base of the bud.
6) Adequate rainfall, of course, is always the prime factor in any reforestation success.(Slide 36)

Thank you so much for the opportunity to introduce you to our company and to express some opinions regarding longleaf pine.

Frank E. Jones
T. R. Miller Mill Company, Inc.
April 6, 1989

Prescriptions for Successful Longleaf Management in, South Georgia

by Frank Vande Linde and James Hodges

Our work with longleaf pine has concentrated on techniques needed to establish plantations. For the past twenty-five years we have grown and planted several hundred thousand longleaf seedlings each year. This longterm approach has allowed us to experiment with numerous nursery and field techniques. We have planted longleaf pine on a wide variety of sites and site preparation conditions during this time. Growth information for side by side plantations of longleaf and slash by soil type are given in Table 1.

Table 1. Compargtive growth and yield of slash and longleaf

SOIL-DRN(l)	EST(2)	SPECIES/	TPA (3)	DBH 1978	DBH 1983	HEIGHT 1978	HEIGHT 1983	CORDS/ACRE 1978	CORDS/ACRE 1983
GOLDSBORO-MW	1966	L	357	5.8	7.3	36	51	12.8	26.6
		S		5.3	6.7	37	48	15.3	27.1
LYNCHBURG-SP	1966	L	418	5.5	7.1	39	57	11.9	30.5
		S		6.8	7.8	47	62	33.5	42.9
NORFOLK -W	1965	L	364	5.9	7.1	39	53	16.7	28.0
		S			7.8		57	--	35.8
CHIPLEY -W	1965	L	308	4.8	5.9	31	41	7.2	12.8
		S		5.0	6.2	32	44	8.4	16.9
MANDARIN-SP	1963	L	356	5.4	6.6	39	49	14.0	24.7
		S		6.0	6.7	44	54	23.3	35.3
FORT MEADE-MW	1963	L	253	5.9	7.3	37	50	11.4	23.1
		S		6.3	7.7	46	56	25.6	38.0
BLADEN -VP	1963	L	331	5.5	6.4	30	43	8.4	16.7
		S		6.3	7.4	45	55	26.6	37.7
LEEFIELD -SP	1962	L	324	5.4	6.8	35	52	12.1	21.8
		S		6.4	7.6	49	62	28.7	41.0
SAPELO -P	1962	L	337	5.6	7.0	38	54	13.8	25.1
		S		6.1	7.2	44	56	23.0	36.9

1: Drainage W=well MW=moderately well P=poor SP=somewhat poor VP=very poor 2: year established, 3: TPA= trees/acre 1978
L=longleaf S=slash

Only on one site is longleaf equal in volume growth to slash. On this Goldsboro site longleaf has grown faster during the five year measurement period. The longleaf trees are now taller but the difference in volume is due to the lower stocking in the longleaf stand. The trees per acre data was not available for the slash, but on most of the sites density was substantially higher because of first year survival differences. On the Goldsboro site the slash had 52% fusiform rust infection in 1978 and the longleaf only 13%. The slash stand has suffered substantial rust associated mortality since the last measurement, Today the longleaf stand on the Goldsboro site is visually much superior.

It is difficult to judge from this data what the comparisons of slash and longleaf are on the various sites because of the differences in survival. The differences in growth in these young plantations was affected by other factors. Where survival was marginal emergence from the grass stage of the surviving trees may have also been slower, All of these plantations 'were measured at ages 12-16 and then five years later. In six of the plantations height differences between the two species is getting smaller. This may indicate that the differences in yield between the two species may be less over longer rotations. On sites where fusiform rust is a problem this is certainly true.

After reviewing our past plantings successes and failures we have developed several necessary steps for longleaf. You must pay close attention to several key items to be successful with longleaf. They are listed below.

1. Quality planting material
2. Proper handling and planting of seedlings
3. Good site preparation and control of competition
4. Matching species to appropriate site and disease conditions
5. Fertilization on appropriate sites

Most difficulties in longleaf plantation management occur during the first three years. A successful regeneration programs with longleaf pine must begin with quality planting material. Undersize, poorly handled bareroot seedlings will not survive and develop quickly in the field. It is best to grow seedlings at low bed densities of seven to twelve per square foot. Grade seedlings and cull any trees with root collar diameters less than three-eighth inch. Lift trees as close to planting as possible to minimize storage time. Plant during December or January if weather conditions are favorable. Avoid long periods of storage and late season planting. Machine planting is a requirement when using large bareroot stock. Specify in planting contracts or with company personnel that reduced speed and estra care are. required to get a quality job.

We have tried containerized longleaf, seedlings for several years with excellent results. Either planting by hand or with machines worked well. Proper size, vigor, and handling are just as important with containerized trees. Our best results have been with an 8 cubic inch container with a depth of 6 inches. This container produces a large tree that is easily planted. In one trial of smaller container grown trees we obtained better survival, but at the end of two years in the field most were still in the grass stage. There were more seedlings emerged from the grass stage in our larger bareroot trees.

Proper site preparation is critical to insure good survival and early growth. Intensity of site preparation is --highly correlated with successful longleaf plantings. Longleaf seedlings are very susceptible to the negative effects of early herbaceous and woody competition. Longleaf must develop strong root systems and tops before height growth will begin.

Longleaf should be used in regeneration situations where the benefits are obvious. Don't get caught up in the enthusiasm for planting longleaf and try to plant longleaf pine everywhere. Many of the biases against longleaf today are because of the long held notion that longleaf should be planted on the poorest driest sites available. This thinking has led to many unsuccessful and poor stands of longleaf. Utilize longleaf as a part of your normal regeneration program.

It is helpful to develop a decision model for your management situation. The model we developed is illustrated in Table 2. A number of criterion were used to develop this model. Soil type, drainage, and competing vegetation were considered. Broad soil classifications developed by the University of Florida Fertilizer Cooperative are shown in the model. Within these general groups like soil group A, are listed more specific soil series and their Coile codes. Fertilization prescriptions were included for the different soil groups.

Our model was developed with a particular forest management strategy in mind. The land base was used to support a large pulpmill and several sawmills. Fiber was the major product and a rotation of 25 years was used. Product need determined our management strategy. . Under different circumstances treatments and species selection could change.

We had the option of planting four different pine species in south Georgia. These species were loblolly, slash, sand, and longleaf pines. We planted each species on sites to maximize our fiber production using our forest management system. Species selection was based on soil properties, drainage, site preparation, fertilization schedule, and fusiform rust infection hazard.

In Georgia fusiform rust is a serious disease of slash and loblolly pines, Rust hazard is not shown in our model because of the large variablity of infection within specific soil groups. An example of this is soil group A. Our plantation survey data showed and average rust infection of 40-50% with a range of 0-90% in 17 year old plantations. Information on rust infection was collected on each stand or plantation. This previous stand information was combined with tract averages and broader region averages to access the current rust hazard. Longleaf was used on sites with heavy rust hazards as an alternative to both slash and loblolly. In our model we specified longleaf for several soil types within the D and E soil groups. Rust hazard on these sites is usually high and longleaf growth rates are comparable to slash or loblolly,

Table 2. Prescribed activities by soil

SOIL GROUP/ TYPE	COILE CODE	SITE PREP	SPECIES	FERTILIZATION TYPE	LBS/A	AGE
A, BLADEN	d5c2F	KC,BED	LOBLOLLY	TSP	250	l-3
COXVILLE	d4b4F					
B. PELHAM	d4a5E	KG,BED	LOBLOLLY	DAP	250	3-5*
LEEFIELD	d3a6E					
LYNCHBURG	d3b4E					
PLUMMER	d4a8E		'SLASH			
OCILLA	d4a5C					
MASCOTTE	d3a5E/h					
SAPELO	d4a7E/h					
C. LEON	d3a4B/h	CHOP,BURN,BED	SLASH	UREA	300	10-16**
MANDARIN	d3a6A/h+h					
CENTENARY	d3a8/h					
D. CHIPLEY	d2a7A	CHOP,BURN,BED	SLASH	NONE		
GOLDSBORO	d2b5D		LOB,LL	DAP	250	3-5
FUQUAY	d2b7D					
FT. MEADE	d2b7B		LONGLEAF			
E. ALAGA	d1b7B	CHOP,BURN, &	LONGLEAF	DAP	250	3-5
ORSINO	d1a5A/h	STRIP-HARROW	SLASH	NONE		
F. LAKELAND	dxa8A	CHOP,BURN, & STRIP-HARROW	SAND	NONE		

* To be refertilized with 225-250 lbs/a of UREA at age 10-16

** If fertilized at age 13 or earlier, may be refertilized with 250 lbs/a of UREA at age 16

We do not exclude longleaf from soil groups A and B, but would specify them only where rust hazard is considered high, If we planted longleaf on these soil groups we would fertilize as with slash or loblolly. Longleaf has responded well to phosphorus and nitrogen fertilization on appropriate sites. Foliage samples taken on the Bladen soil in Table 1 indicated phosphorus levels below standard critical levels. This longleaf stand was growing very poorly at that time. *On* fertilized sites longleaf is *growing* extremely well on the same soil type.

We do not generally specify longleaf on C soils. Rust hazard is low and slash does best on these soils.

Our recent work with longleaf has been on using containerized trees, herbicides, and fertilization to improve early survival and emergence from the grass stage. Proper size longleaf container seedlings have increased our average survival rate. When first year herbaceous weed control in added our results are extremely good. Second year results from herbicide and fertilzation are shown in Table 3.

Table 3. Survival, height growth and percent out of the grass stage of two year old bareroot planted longleaf

Treatment	Height(ft)	Survival	Percent out of Grass Age 1	Percent out of Grass Age 2
Control	.28 c *	79 ab	18	48
Fertilizer (1)	.40 b	70 b	17	58
Herbicide (2)	.90 a	77 ab	41	85
Fert t Herb	.78 a	84 a	41	76

* Numbers with different letters are significantly different at the 95% level

(1) Fertilized with 250 lbs/a of DAP first year

(2) Sprayed with Velpar t Oust first year

Herbicide gave significant improvement in height growth and emergence from the grass stage at this location. Fertilizer alone increased growth slightly but tended to reduce survival.* This happened because of the increased growth of competing vegetation on the fertilizer alone plots. Fertilizer plus herbicide was not significantly better than the herbicide alone plots. Our most recent studies with container planted trees shows better fertilizer herbicide responses when fertilizer is delayed until the second year if the fertilizer contains nitrogen.

Our current scenario for planting longleaf would be to plant containerized seedlings, use herbaceous weed control the first year, and fertilize if appropriate the second growing season. We have been successful in 1988 with chemical site preparation and planting containerized seedlings. We used **pronone** on upland sites with large numbers of oaks. No additional weed control was needed during year one and survival of the seedlings was good.

Our use of **longleaf** was based on specific management objectives and environmental conditions. Each organization must match their objectives and conditions to the species they have available. **Longleaf** definitely deserves consideration in regeneration programs through out the deep south.

A PRESCRIPTION FOR SUCCESSFUL MANAGEMENT OF LONGLEAF PINE

I appreciate the opportunity to discuss with you some of the things we have accomplished in longleaf management during the last 15 years, and some of the rationale behind the decision to get totally involved in an aggressive longleaf program. For those of you who may not know, approximately 98% of the longleaf sites on the National Forests in Mississippi are here on the DeSoto. There are about 5000 acres on the Bienville National Forest.

The commitment to a more intensive longleaf program was initiated in the mid 1970's for several reasons: (1.) We were concerned about the acreage of longleaf sites that had already been and continued to be regenerated to other southern pines, primarily slash. At that time, of the 4000 or so acres being regenerated annually, on the 500,000 acre DeSoto Forest, no more than 300 - 400 acres were to longleaf: (2.) Because our rotations tend to be longer than most others, in order to accommodate the needs of other resources such as wildlife and visual quality, we felt that longleaf would be better suited than slash or loblolly because it tends to culminate in growth at an older age: (3.) Strong local poles markets traditionally pays premium prices for sales with a high percentage of poles and longleaf is the preferred specie for poles; (4.) Red-cockaded woodpeckers, a threatened and endangered specie inhabits the National Forest and prefers longleaf over slash: (5.) The need to develop and maintain a diversity of species and age classes throughout the Forest and; (6.) The resistance of the species to insect and disease, tolerance to fire, resistance to windthrow which is a major considerationin the hurricane prone

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Presented at the 1989 Longleaf Pine Management Symposium, Long Beach, Mississippi, April 4-6,1989, by Gene A. Sirmon, Staff Officer, Timber Soils & Watershed, USDA Forest Service, 100 W. Capitol St., Suite 1141, Jackson, MS 39269

coastal areas. At that time we had just begun our soils survey program on the National Forests and we had enough information to'know that at least one-half of the DeSoto would grow excellent longleaf, so we established a "rule of thumb" to regenerate at least one-half of the DeSoto to longleaf. Going in we knew there would be some problems in gaining total commitment to the project from all of the key players, i.e., silvicultural technicians, foresters and older key technicians who were keenly aware of past failures of longleaf plantings and seeding and also of the demonstrated ease of getting perfectly good slash stands of almost as high quality timber on some sites.

The initial effort consisted of an indepth analysis of possible causes of past plantation failures. Operational procedures examined were: (1) Nursery practices,(2) Seedling care and handling, (3)Site prep and; '(4) Planting techniques from which a number of possible problems were identified. Among the possible nursery practices identified were bed densities, sowing dates, soil fertility, lifting dates, lifting and packing techniques, packing systems, refrigeration and transportation. Possible field problems identified, included the lack of refrigeration facilities on most Districts, excessive storage time, excessive root exposure time prior to planting, site preparation, competition from grasses and woody vegetation, planting techniques and systems and supervision. After a careful study of all of these factors, it was concluded that probably no particular one or two things was the culprit but probably a combination of several factors which had resulted in many years of frustration in trying to successfully regenerate longleaf pine. We were doing some things right some of the time, rather than all things right all of the time which is necessary for a successful program.

NURSERY PRACTICES

Probably no greater potential for plantation failure exists than those resulting from improper nursery practices. Seedlings for the National Forest in Mississippi are grown at Ashe Nursery, located at Brooklyn, Mississippi. Ashe was established in 1935 and has been in constant use since then. After careful study of research findings and personal experiences of such notable experts as Croker, Mann, Boyer, Barnett, Kias, South, et.al., a number of operational changes were made at the Nursery. In 1978 a technical committee consisting of the above individuals, as well as others, to provide technical guidance at Ashe.

Soil Management

Because of over 40 years of continuous production, many without the benefit of rotation and cover cropping, the fertility of the soils at Ashe had probably reached an all time low. Organic content in many parts of the nursery was alarmingly low and consisted primarily of the mulch material added at the time of spring sowing. Although annual soils test were conducted, these were primarily for determining macro and trace element deficiencies and did not pinpoint such problems or poor infiltration and high sodium levels. A thorough study of the soils at the Nursery reveals 3 pressing needs: (1) A proper rotation of cover crops with seedling crops, (2) Reduction in erosion at the Nursery, (3) Preparation of a Soils Management Plan for use of Nursery personnel.

To correct the rotation and erosion problem, 60 additional acres of bed space was added to the present site which now allows a 2-2 rotation. In addition to the expansion area, the remainder of the nursery was leveled and a new above ground irrigation system installed. These measures have resulted in a more fertile nursery and the soils management plan is a tool through which nursery personnel can do a better job of maintaining soil fertality.

Bed Densities

One of the surest ways to improve seedling quality is by growing stock at low bed densities. Contrary to earlier beliefs, root collar diameter is extremely critical in longleaf survival and growth. Seedlings grown at high bed densities must compete for water and nutrients which result in less energy being stored in reserve, thereby, reducing seedling vigor and chances of survival when outplanted in a hostile environment. Also, when lifting seedlings grown at high densities there is a greater danger of root damage by destroying lateral roots, thereby, removing the Ectomycorrhizae that attaches itself to the roots.

The objective at Ashe is to grow longleaf seedlings to a minimum of 0.5 inch root collar caliper. To reach this size, seeds are sown at rates which will allow 10-15 seedlings per square foot. If germination is such that the density is over 20 seedlings per square foot, the beds are thinned back to 10-15 per square foot. The objective in thinning is to space seedling about 1.5 inches apart. Hopefully, we have reached the'point in technology development, with precision seeding, that thinning will not be necessary in the future.

It is not always an easy task to grow longleaf to the optimum size because of uncontrollable environmental factors. However, by controlling bed densities, timely fertilization and watering and delaying lifting until after January 1, we feel confident that ninety percent of the crop can be grown to at least 0.4 inch diameter most years. As an aid in controlling growth, a comprehensive growth monitoring system which features sophisticated infield atmospheric data collection, was initiated six years ago. The information is very helpful in making decisions relative to fertilizing and watering throughout the growing season.

Relationship of Seedling Size and Height Growth

Not only do larger seedlings survive better, but the grass stage time is reduced. Height growth of longleaf seedlings normally does not begin until seedlings reach about 1" root collar diameter. This could vary one or two tenths depending upon the vigor of the individual. An examination of 18 plantations in the fall of 1985 revealed that 91% of the seedlings in 4 year old plantations were in height growth while 82% of those in 3 year old plantations had initiated height growth.

FIELD PRACTICES

Seedling Handling

Extreme caution must be taken in the storage and handling of longleaf seedlings. Studies have shown that a definite correlation exists between survival, length of storage and seedling size. White (1980) found that seedlings 0.4 inch root collar diameter stored 20 days had a 62% survival rate while seedlings 0.5 inch root collar stored 10 days had an 85% survival rate. This study also showed that seedlings 0.6 inch diameter and larger could be stored up to 30 days without detrimental effects on survival. In order to minimize the likelihood of seedling damage, the following measures are taken: (1) Cold storage facilities were purchased for all Districts. (2) Seedlings are shipped to units in refrigerated vans. (3) Seedlings are kept in cold storage at the receiving unit until outplanted. (4) Seedling are held no longer than 10 days. Any seedling over 10 days old are discarded at the receiving unit. (5) During planting operations, no more seedlings are removed from the cooler than will be planted in one day. (6) Seedling are transported to the job site in Styrofoam lined storage boxes. (7) Planting crews are encouraged never remove the seedlings from the bag before planting, but instead place the seedling bag in the machine tray and remove seedlings directly from the bag during planting. (8) No seedlings are left unplanted overnight or during breaks, etc.

Lifting

Longleaf seedlings are much more fragile than other southern pines, and mortality is more likely to occur from mechanical damage than other southern pines. Damage to the tap root, as well as stripping of lateral roots is a common occurrence in nurseries where mechanical lifters are used, especially,if ground condition are too wet or too dry at time of lifting. Stripping of lateral roots not only causes root damage but removes the ectomycorrhizae fungi which is critical to the survival and growth of longleaf.

To reduce the occurrence of mechanical damage, all longleaf at Ashe Nursery are now hand lifted. To reduce potential damage by overexposure, the objective is to allow no more than one minute exposure time between the time the seedlings ae lifted until they are bagged. Time test conducted on this phase of lifting shows that the time actually required is between 30 and 40 seconds. As a further precaution, seedlings are promptly transferred to the cooler within 30 minutes.

Packing System

Traditionally all seedlings grown at Ashe Nursery were packed in round bales using spaghanim moss as a packing medium. Adequacy in the care of seedling among receiving units were suspect. Some units watered to frequent, some watered too infrequent, some stored in unheated or uncooled buildings which probably resulted in overheating or freezing while others insisted in healing the seedlings out. This, plus the fact that moss was not only expensive but also suspect in causing sporotrichosis, a rash like skin infection, prompted the installation of a slurry treatment system which features treating seedlings roots with a koalin clay solution and packing in polyethylene lined bags which are sewn closed and strapped with plastic straps. This method also requires storing in refrigeration units and shipping in refrigerated trucks. This system has a number of built in safety factors which tend to eliminate many of the human errors associated with packing and handling of seedlings.

Site' Preparation

Longleaf pine seedlings are more sensitive to competition than other southern pine, therefore, a successful job depends to some degree upon good site preparation. A number of site preparation techniques are used on the DeSoto National Forest. These range from very intensive mechanical 'work such as shearing and piling to less intensive prescribe burning. All, however, have the same common objective, and that is removal of the woody vegetation and reducing the herbaceous vegetation. The most common technique used is shearing and piling. Double chopping and burning is' also effective on sites when the remaining stems on the site can be pushed over by the tractor pulling the chopper. A new technique which has promise, especially on sites 'on which logging debris and other material permits tractor operation, is band spraying with velpor L (Hexazone) at the rate of 1 quart per acre in 20 gallons of water. Also, a mixture of glyphosate (round-up) and oust has possibilities, although not yet labeled for this use.

Planting

All of our longleaf is planted with machines. We prefer the heavy duty Lowther-Reynolds machines' with double coulters. This type machine normallydoes a better fob of packing seedling in than single coulter machines which rely mainly on the puckering wheels for packing.

We have also intensified our supervision of planting operations. Practically all of our planting is done under contract by the lowest bidder, so we must train a new crew each year. We are now getting into multi-year contracting which should alleviate some of this problem. We have found that it is best to keep an inspector on the job at all times. Several years ago we would let a contract go by every other day or so and check the job. With the quality of contractors we sometimes get, we believe that full time inspectors will more than pay their salaries through better survival.

Several years ago, in order to insure a successful plantation, we would plant as many as 1000 seedlings per acre. With the current survival rates, we have reduced our rates to no more than 550 to 600 seedlings per acre. I feel confident that we can reduce our planting rates even -more.

Implementation of the above procedures is resulting in a much improved program. During the last 13 years 612 longleaf plantations totalling 19559 acres have been planted on the DeSoto Forest. Of this total,'18337 acres have been successful for a 94% success ratio. In addition, 5,824 of shelterwood regeneration was attempted. Of this amount, 5,228 acres is currently stocked with at least 300 seedlings free to grow. The remaining 600 acres representing 21 stands failed and have been planted. Some of these failures can be directly attributed to hurricane Frederick in 1979. More importantly, the longleaf ecosystem is being reinstituted and we feel good about the fact we are no longer contributing to the decline of the longleaf type.

LONGLEAF PLANTATION ESTABLISHMENT RECORD

DESOTO NATIONAL FOREST

1985 - 1987

District		85 Ac	85 % Sur.	86 Ac	86 % Sur.	87 Ac	87 % Sur.	Ave. Survi By Month (
Biloxi	1 1/	96	79.7	375	80.8	370	82.8	81.1
	2	292	79.2	193	82.1	332	78.4	79.9
	3	176	81.7	20	92.5	50	78.5	84.2
		564	80.2	588	85.1	752	79.9	

District		85 Ac	85 % Sur.	86 Ac	86 % Sur.	87 Ac	87 % Sur.	Ave. Survi By Month (?
Black Creek	1	161	90.8	752	69.0	406	80.6	80.1
	2	526	84.2	387	77.4	684	85.4	82.3
	3	106	80.9	-	-	206	83.5	82.2
		793	85.3	1139	73.2	1296	83.17	

District	85 Ac	85 Sur.	86 Ac	86 Sur.	87 Ac	87 % Sur.	Ave. Survival by Month(%)
Chickasawhay 1	254	80.8	179	84.7	403	89.0	84.8
2	191	**77.9**	283	70.6	205	**98.9**	82.5
3	158	65.8	25	69.4	28	94.2	76.4
	603	74.8	487	**74.9**	636	**94.0**	

_/ Month planted, i.e. 1. January 2. February 3. March

Total by Years	1960	80.1	2214	77.7	1517	85.7

Year	No. Plantations	No. Acres Planted	No. Acres Successful	Acres Shelterwood
73-84	434	13868	12646(91%)	5315
	49	1960	1960(100%)	105
	61	2214	2214(100%)	201
	68	1517	1517(100%)	203
	612	19559	18337	5824

Longleaf Pine's Place in the South's Fourth Forest

J. Lamar Beasley

ABSTRACT. Longleaf pine has a place in the South's Fourth Forest, but professional foresters must be careful not to prescribe longleaf in situations where success is doubtful.

INTRODUCTION

I am pleased to be here today, pleased and honored to be invited to wrap up this highly productive session on the management of longleaf pines. My years as a forester have taught me to value the longleaf, both as a symbol of our past and as a vehicle for realizing some important opportunities in southern forestry.

These opportunities have long been recognized, but I think they have been documented more thoroughly in the recent study of the South's Fourth Forest (USDA 1988).

There was never any doubt in my mind that the South is a leader in forestry, and that southern forestry has the potential to be even stronger in the future. True, the Pacific Northwest has much to offer and will continue to be an important supplier of forest products. But controversial issues in the West prevent significant increases in timber outputs. With much of the Pacific Northwest in public ownership, it is easy to understand how the various segments of that public can disagree so vigorously over appropriate management. This is not to say that there isn't and that there will not be more debate around forestry in the South.

The South's advantage is in the ownership of forest land. Very little is in public ownership--the amount varies somewhat from area to area but the overall average is around 10%. Somewhat more acreage is in the hands of the forest industry (22%), but the bulk (68%) belongs to a diverse group of non-forestry landowners classified as NIPF or Nonindustrial Private Forest. The NIPF class of owners consists of corporations (10%), farmers (23%), and other individuals (34%).

J. Lamar Beasley is Director of the Southeastern Forest Experiment Station, USDA Forest Service,, Asheville, North Carolina 28804.

This diversity of owners has sometimes worked against forest productivity in the South, resulting in poor forestry practices and, in particular, the reduction of the longleaf forests of the coastal plain States. Managers of public and industrial lands, for various reasons, did not place much emphasis on regenerating longleaf pine sites to longleaf. It was not until the research base was developed, and its technology transferred to land managers, that the value of longleaf was again accepted. And problems with slash and loblolly pine growth could have furthered this acceptance.

Diversity of forest ownership has also resulted in a somewhat unplanned approach to forest management for the region as a whole, as well as a scattered response when challenges and opportunities present themselves.

"The South's Fourth Forest" presented many such challenges and opportunities. The study's major conclusion--that softwood growth is declining--was simple, but the reasons for that decline were perplexing. The study listed a combination of four contributing factors:

* Since the 1960's, landowners in the NIPF class have not adequately regenerated their stands after harvesting, opening the way for encroachment by hardwoods. This has caused a 30 to 50% reduction of pine saplings in stands held by NIPF owners.

* Also since the 1960's, timberland in the South has declined from 197 to 182 million acres, an 8% reduction that stems from conversion of timberland to farming, grazing, and urban development.

* In the last decade, losses to insects and diseases have doubled, with mortality now causing a 15% reduction in gross annual pine growth.

* The last factor, a 20 to 30% reduction in radial growth on natural stands, is not as easily understood. Some suspect that atmospheric deposition is contributing to this reduction, but no one knows for sure. The Southeastern Station is now immersed in studying the impact of acid rain, ozone, and other airborne chemicals on individual seedlings and saplings, and on overall patterns of forest growth.

Given these trends and the demographics of forest ownership, it was not surprising that the study group viewed the NIPF class as the best opportunity for increasing forest productivity in the South. Nor was it surprising when they predicted that new and innovative approaches would be needed to reach this diverse group of landowners.

Since publication of "The South's Fourth Forest", several major efforts have gotten underway to help NIPF owners increase and improve their forest holdings.. Planting and seeding are now at a record levels of a million acres a year, largely due to the Conservation Reserve Program, which reported nearly 1.5 million acres of highly erodible southern cropland enrolled for tree planting 'by the spring of 1988 (Robertson 1989).

Another successful effort has been the establishment of the Brender Demonstration Forest at the 5,000-acre Hitchiti Experimental Forest near Macon, Georgia. A cooperative venture involving the Georgia Forestry Commission, the Forest Service Southern Region, and the Southeastern Forest Experiment Station, the Brender serves as an outdoor classroom to showcase the latest research findings on managing and regenerating stands, genetically improving stock, controlling insects and diseases, and realizing non-timber benefits from forest resources. Although the staff's major focus is to work with owners of NIPF 'land on the Piedmont, they also arrange guided tours, field days, and workshops for forest managers and consultants, youth organizations, teachers, conservation groups, and historical societies.

These efforts have gone a long way towards increasing productivity of the South's Fourth Forest. But we have not succeeded yet. And until we do, we must keep our minds open to 'every resource and tool at our disposal.

Most professional foresters would agree that there are potential benefits from planting longleaf pine, whose ancestors once covered much of the southern landscape.

Once established, the longleaf pine offers many advantages. It is a hardy species that thrives on sandy sites where fires are common. Its wood is strong and durable. And it has a natural resistance to insects and diseases, a characteristic that is especially encouraging now that losses to these pests have doubled among other pine species.

These qualities make longleaf pine an excellent choice for landowners who cannot or will not invest heavily in the management of their forests.

But, as we have heard'over the past few days, longleaf pine stands are difficult to establish, so difficult that post-war foresters came very close to abandoning the species as commercially non-viable. During those years, entire longleaf forests were cleared to make room for slash and loblolly pines.

Because of problems with regeneration, sentiment was still strong against longleaf pines in the early 70's. I realized this myself during my assignment as forest supervisor of the Kisatchie National Forest. We decided that the potential benefits of establishing longleaf in this area outweighed the risks, but also that we would need help. We spent many hours identifying favorable sites and planning our strategies. We relied heavily on information from current research and even asked Tom Croker to conduct a longleaf seminar at the Forest.

Our efforts proved successful and the Kisatchie is now regenerating longleaf pine on longleaf sites. But without careful planning and execution, our efforts could just as easily have failed, and been used as one more justification for eliminating the species.

Since those days, much has been done to improve the survival rate of seedlings, and longleaf pine seems to be making a comeback. In an outstanding example of multidisciplinary research, three Forest Service organizations--State and Private Forestry, the Southern Station, and the Southeastern Station--have been working with the Department of Energy for the past eight years to develop protocols for nursery production and handling of seedlings. Now in the third year of production, the project is producing three-quarters of a million seedlings per year, and test plantings at the Savannah River Project have been highly successful.

The Savannah River experiments show that longleaf pine certainly has a role in efforts to increase southern forest productivity. Industry is beginning to place more emphasis on longleaf. And given the right incentives, there is every reason to believe that the NIPF ownership class would choose longleaf pines over other species, for both esthetic and practical reasons. The longer rotations and open, parklike floor are attractive. In addition, these kinds of forests provide much-needed habitat for many species of wildlife, and are essential for the survival of some, like the endangered red-cockaded woodpecker.

But we must not fall into the trap of assuming that longleaf is for everyone. In his excellent history, Tom Croker (Croker 1988) kindly refers to me as a devotee of longleaf and he is right...as a southern-born forester, I do have a special fondness for the beauty and historical significance of the species. But I am also a realist. And I understand the difficulties that can confront longleaf growers.

My challenge to you is to be realistic in evaluating the advantages and disadvantages of establishing longleaf. Use it where it has a good chance of survival, but do not prescribe it if proper management seems doubtful. The longleaf has had a pretty rocky history since the arrival of European settlers, but the pendulum is beginning to swing in the other direction. It would be irresponsible of us to jeopardize this comeback by overestimating longleaf's potential for success.

LITERATURE CITED

Croker, T. C. 1988. Longleaf pine: the history of man and a forest. USDA For. Serv. For. Rpt. R8-FR7, 37 p. Atlanta, GA.

Robertson, F. D. 1989. The South's fourth forest-we can increase the forest wealth of the South. For. Farm. Man. 48(5):72-73.

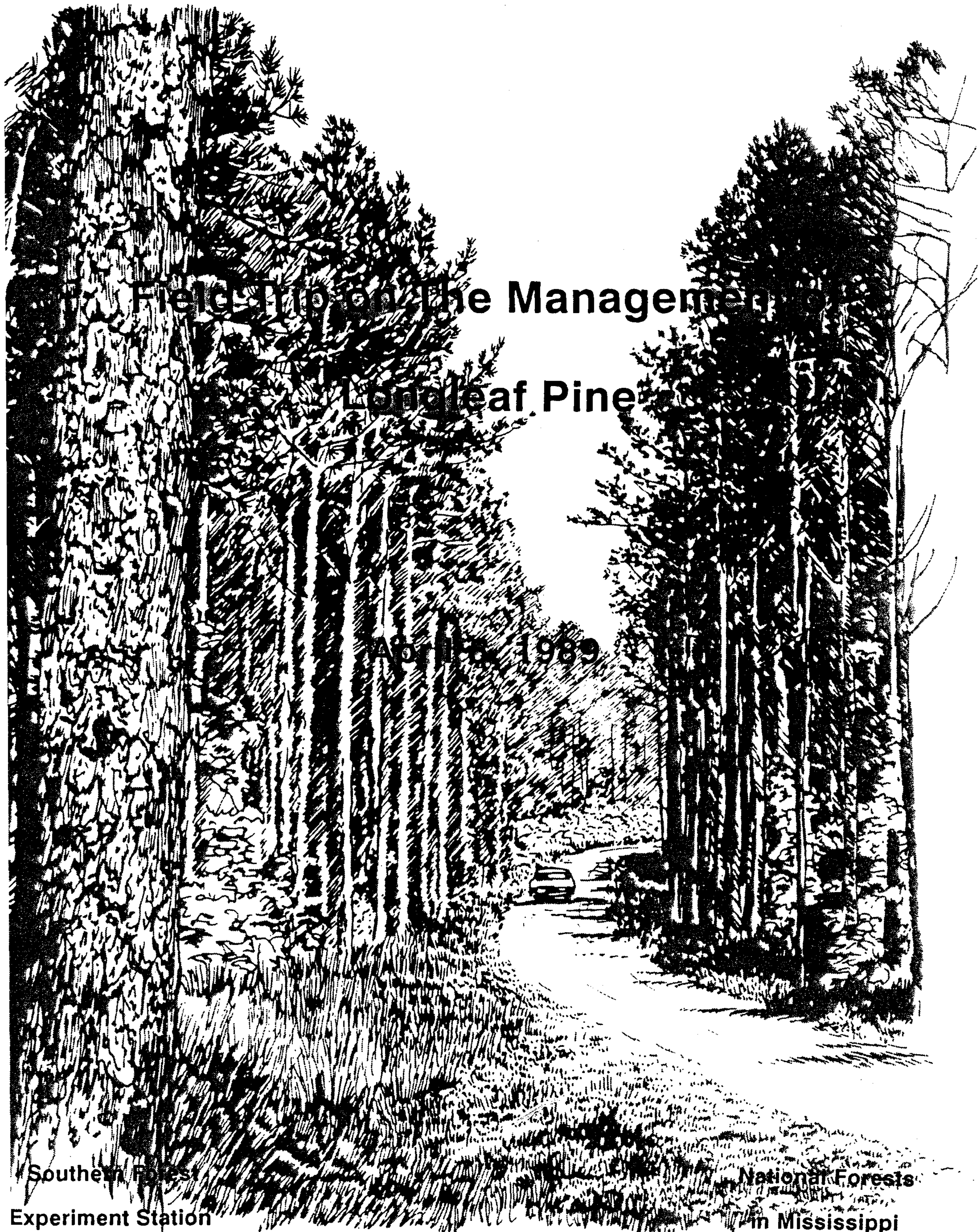
U.S. Department of Agriculture, Forest Service. 1988. The South's fourth forest: alternatives for the future. For. Resour. Rep. 24, 512 p. Washington, DC.

Field Trip

April 5, 1989

Moderator:

Albert G. Kais
Forestry Consultant


Field Trip on The Management of
Longleaf Pine
April 6, 1989
Southern Forest
Experiment Station
National Forests
in Mississippi

TOUR SCHEDULE

7:30 A.M. -----DEPART GULF PARK COLLEGE CAMPUS BY BUS

9:00 A.M. --------------ASHE NURSERY, BROOKLYN MS.

STOP 1 A) PROPER LONGLEAF SEEDLING PRODUCTION - CHUCK GRAMLING
STOP 1 B) ECTOMYCORRHIZAE APPLICATOR - ED CORDELL
STOP 1 C) PRECISION SEEDING - CHUCK GRAMLING & ED CORDELL
STOP 1 D) REFRESHMENT BREAK

10:00 A.M. -----DRIVE TO BILOXI DISTRICT - DESOTO N.F.- SAUCIER, MS.

11:00 A.M. -------------SHELTERWOOD SYSTEM FOR LONGLEAF REGENERATION

STOP 2 B) ESTABLISHMENT BY SHELTERWOOD SYSTEM - JOHN WHITE
STOP 2 A) 1989 BROWNSPOT DISEASE CONTROL BURN - JOHN WHITE

11:35 A.M. -----DRIVE TO HARRISON EXPERIMENTAL FOREST

11:45 A.M. -----STOP #3 - RESPONSES OF PLANTED PINES TO VARIOUS CULTURAL TREATMENTS - RON SCHMIDTLING

12:30 P.M. -----STOP #4 - LUNCH AT HARRISON EXPERIMENTAL FOREST HEADQUARTERS

1:15 P.M. -----STOP #5 - EFFECTS OF BENOMYL IN GENETICALLY IMPROVED LONGLEAF PINE - AL KAIS

2:00 P.M. -------------- MANAGEMENT OF LONGLEAF PINE STANDS

STOP 6A) GROWTH AND YIELD OF NATURAL STANDS - BOB FARRAR
STOP 6B) MANAGING FOR SPECIALTY PRODUCTS - BOB FARRAR

2:30 P.M. -----STOP #7 - CONTROL OF BROWN SPOT NEEDLE BLIGHT ON LONGLEAF PINE BY BENOMYL FUNGICIDE-DIP TREATMENT - AL KAIS

2:45 P.M. -----REFRESHMENTS

3:00 P.M. -----STOP #8 - COMBINED EFFECTS OF MYCORRHIZAE AND BENOMYL ON LONGLEAF PINE SURVIVAL AND GROWTH - GLEN SNOW

3:20 P.M. -----DRIVE TO BILOXI DISTRICT - DESOTO NATIONAL FOREST

3:30 P.M. -----STOP #9 - SUCCESSFUL PLANTING OF LONGLEAF PINE - JIM DURRWACHTER

4:00 P.M. -----RETURN TO GULF PARK COLLEGE CAMPUS

DESOTO NATIONAL FOREST

On August 30, 1933, the Leaf River, Biloxi, and Chickasawhay Purchase Units were established by approval of the National Forest Reservation Commission. In 1936 all three Units were merged into the DeSoto Purchase Unit. The DeSoto Natioal Forest was established by proclamation of President Franklin D. Roosevelt on June 17, 1936. Originally, the Forest was divided into three Districts named after the purchase units.

In 1950, the Black Creek District became the fourth Ranger District by combining portions of the Leaf River and Biloxi Districts. In 1969, the present Black Creek Ranger District was created by consolidating the entire Leaf River and Black Creek Districts into one District.

The DeSoto National Forest is the largest of the National Forests in Mississippi, lying adjacent to the expanding Gulf Coast Metropolitan Area. The soils are generally more sandy, less fertile, and erosion hazard ranges from slight to severe depending on slope. The area is known for its diversity of plant communities, such as Longleaf Pine, Pitcher Plant flats, Titi swamps. It is characterized by large man-established pine forests, interlaced with blackwater streams. It contains the State's only segment of a Wild and Scenic River, and two wilderness areas.

The National Forest ownership, on the DeSoto is 479,659 acres. Of this, 173,994 acres are in Longleaf Forest Type. The Longleaf type is increasing due to the fact that the problems associated with regenerating Longleaf Pine have been solved in the last 10 years, and we are now regenerating Longleaf Pine back on lands on which it originally grew.

SOUTHERN FOREST EXPERIMENT STATION

HARRISON EXPERIMENTAL FOREST

The Harrison Experimental Forest is located 25 miles north of Gulfport, Mississippi, on the Biloxi Ranger District of the DeSoto National Forest. It consists of 3,850 acres and was established in 1934. Much of the early development of the facility was made possible through labor and funds by the CWA, WPA, And CCC.

The area more or less typifies several million acres of forest land of the Longleaf Pine type with similar soils and topography in the South. Because of the importance of this vast forest area, the Harrison Experimental Forest has been developed into one of the principal experimental forests used by the Southern Station. It's primary use is a place to do forestry research by the three research units at Gulfport, Mississippi ---Genetics of Southern Pines, Pathology of Pine Diseases, and Control of Termites and Wood Destroying Beetles.

The combined workforce at the Experimental Forest and the Gulfport Laboratory is 56 people. Ten of these are scientist.

ASHE NURSERY

The Ashe Nursery on the DeSoto National Forest in Mississippi is the only Forest Service Nursery in the Southern United States. This gives Ashe the position of serving three vital areas that are extremely important to the National Forests in the South and the Forestry community of the southern region.

The three priorities of the Ashe Nursery are to:

1. Provide QUALITY seedlings for National Forests in the southern coastal plains.

2. Cooperate with Research to develop the best methods to produce quality seedlings.

3. Work with Cooperative Forestry in Demonstrations and Technology Transfer with all other forest nurseries.

The first priority at Ashe is to grow QUALITY seedlings. This means using the latest known practices that will produce seedlings that will survive and grow. This requires lower seed bed densities and strict attention to care and handling of seedlings.

Research by the Southern Station and others is an important part of the Mission for Ashe. Research performed here has been used to change nursery management and improve the quality of seedlings and efficiency of operations. Ashe will continue to serve as a testing facility for forest nursery research in the South.

Ashe Nursery demonstrates the latest practices in nursery ❑ snagement. Individuals and groups are welcome to visit and see nursery research and operational nursery practices.

The Forest Service established Ashe Nursery in 1936 during the Civilian Conservation Corps period. Since that time 1,148,101,000 seedlings have been produced.

TOUR STOP 1 - W.W. ASHE NURSERY

A. Longleaf Seedling Beds

B. Demonstration - Precision Sowing Longleaf Seed. (Cordell and Gramling)

C. Demonstration - Innoculation of Seedbeds with PT mycorrhizae (Cordell)

Longleaf Seedling Production At Ashe Nursery (Notes)

DISCUSSION

It must be pointed out that the successes we have had in the artificial regeneration of Longleaf Pine on the Desoto National Forest in Mississippi, and other National Forests in the South are a result of attention to some very important details in the day to day process. We have found that these details are non-negotiable, that is if any one is not adhered to, then all the other work and money spent to regenerate Longleaf Pine is totally wasted.

Many of these details are under the control of the nursery manager, and are his total responsibility. If the nursery manager does not follow these rules to the letter, and produce high quality seedlings, then the forest manager will have failures and not know why.

The.first rule involves seedling size. The forest manager should **NEVER** plant a Longleaf seedling that has a root collar diameter of less than 0.40 inches. Seedling survival is dependent to a great extent on the stored food supply of the seedling. We have found that seedlings having a root collar diameter of less than 0.40 inches simply are not big enough to have a stored food supply sufficient to see them through the process of re-establishing their root system, to begin taking up nutrients and water. They also are not big enough to have the water holding capacity to see them through'the usual spring dry spell that usually follows the winter planting season. Therefore, many Longleaf plantations fail. This is one of the rules that the Nursery Manager has to adhere to, by either growing the seedlings to plantable size (as we at Ashe Nursery have done) or he must grade the seedlings to this standard before he sends them out to the forest manager.

The second rule involves storage time for seedlings. The Forest Manager should **NEVER** plant a Longleaf seedling that has been lifted more than TEN days if it is less than .5 inches root collar diameter. Seedlings .5 inches and larger may be stored up to three weeks and still obtain 85% survival. No longleaf seedlings, regardless of size, should be stored more than thirty days. This literally means outside these time frames, after the seedlings have been lifted, they should be taken to the dump and disposed of. It is even better if the seedling can be planted within seven days. The reason for this rule being so "iron clad" is we have found that in Longleaf seedlings there is no such thing as dormancy. **Longleaf** seedlings may stop growing or respirating for a few days during the coldest weather of the winter, but they never go through the physiological process of becoming dormant. Therefore, anytime the temperature warms up, **Longleaf** seedlings begin to respirate and burn up their stored food supply. Depending upon seedling size, after a period of storage these seedlings have depleted their stored food supply to the point that when they are planted, survival will be difficult to impossible. If the seedlings are stored without refrigeration, this process happens even faster. Here again, the Nursery Manager has control of your success, He should lift **Longleaf** seedlings to order, that is, he should not lift any **Longleaf** seedling order until 24-48 hours prior to shipment, and of course, lifted seedlings MUST be stored under refrigeration until the day they are to be planted,

The third rule is to.use strict care in the lifting and handling process. At **Ashe** Nursery we have found that most mechanical lifters damage the succulent 'tap root if soil conditions are not ideal. **Longleaf** pine is much more susceptible to mechanical damage than other pines because it is very succulent. This damage will show up as grayish bruised spots in the root cortex and cambium several weeks after lifting, and will not be observable before the seedlings are outplanted. A vibrating undercutter and handlifting have been the only successful methods used to eliminate root damage during lifting. Also, the undercutting blade must be run at a depth so that the roots are not cut in the lifting process. Root exposure must also be minimized in packing. We allow no more than one minute to elapse from the time a seedling is lifted until it is packaged in a bag with its roots coated with a Benomyl slurry; in our field packing operation 20-40 seconds will typically elapse between lifting and packing. When seedlings are grown at low **seedbed** densities so that no grading is required, root exposure time may be decreased over an operation where seedlings must be graded. To further reduce root exposure **longleaf** quantites should be determined by bed inventories with no attention to placing a set number of seedlings in each bag. Seedlings are damaged and killed by root exposure in the process of maintaining exact numbers of trees per bag; this happens when seedlings are kept on weighing scales in the open air and whole bags of seedlings are exposed to the air for the purpose of counting them. Both the Nursery Manager and Forest Manager must be constantly aware that a barerooted pine in the open air is like a fish out of the water. A root that has been allowed to partially dry out will not function properly even when rewetted.

The fourth rule is of recent origin: a decision made within the last 3-4 years. That is we will not plant **Longleaf** seedlings that have not been treated with Benomyl at the time of lifting. As you will see later today, the results have been nothing short of amazing.

We realize that our rules will create a lot of controversy, and yes, there are always exceptions to the rules. However, over the last 8-10 years, we have proven these rules to provide consistent success, over millions of seedlings, **and** over thousands of acres. Therefore, if you want consistent success, **ADHERE TO THE RULES.**

TOUR STOP #2B

NATURAL REGENERATION BY A SHELTERWOOD SYSTEM

This site demonstrates the successful establishment of a stand of longleaf pine seedlings by using the shelterwood system.,

LOCATION: Compartment 551, Biloxi Ranger District of the DeSoto National Forest. Site is on FS 426 approximately 2.6 mi. south of FS 426 and Bethel Road intersection.

CONTACTS: U.S. Forest Service, Harrison Experimental Forest Headquarters, Highway 67, Saucier, MS (601) 832-2747.

Southern Forest Expt. Station, Project 4503, U.S. Forest Service, 1925 34th St., Gulfport, MS 39501 (601) 864-8256

Biloxi Ranger District, DeSoto National Forest, P.O. Box 248, Wiggins, MS 39577 (601) 928-5291

'PLANTATION SIZE: 72 acres

MANAGEMENT:
1. Seed cut FY81 to 20-30 basal area
2. Hand tool site preparation FY83
3. Brush control burn in FY84
4. Seedbed burn FY86
5. 5% miliacre stocking in FY85
6. 18% miliacre stocking in FY86
7. 63% miliacre stocking in FY87, 99% fire resistant
8. 94% cone production in spring 87
9. Seedbed burn Fall 87
10. 82% miliacre stocking in FY88

SUMMARY

Natural regeneration by the shelterwood system is a reliable, low-cost alternative for existing longleaf pine forests. It can be very practical for landowners wishing to retain a natural forest and avoid high costs of site preparation and subsequent planting.

Suggested references --- Numbers 2, 4, and 5.

TOUR STOP #2A

SHELTERWOOD SYSTEM FOR LONGLEAF REGENERATION

This site demonstrates the final stage of the shelter-wood system for the establishment of a longleaf pine plantation.

LOCATION: Compartment 554, Biloxi Ranger District of the DeSoto National Forest. Site is approximately 8.2 mi. from the Headquarters of the Harrison Experimental Forest (HEF), via Highway 67 (1.2 mi.) and Bethel Road (7.0 mi.)

CONTACTS: U.S. Forest Service, Harrison Experimental Forest Headquarters, Highway 67, Saucier,. MS (601) 832-2747.

Southern Forest Experiment Station, Project 4503, U.S. Forest Service, 1925 34th St., Gulfport, MS 39501 (601) 864-8256

Biloxi Ranger District, DeSoto National Forest, P.O. Box 248, Wiggins, MS 39577 (601) 928-5291

PLANTATION SIZE: 35 acres

MANAGEMENT:
1. Seed cut FY82 to 20-30 BA
2. Seedbed burn FY83
3. 80% miliacre stocking in FY84 90% fire susceptible
4. 73% miliacre stocking in FY85 43% fire susceptible
5. 82% miliacre stocking in FY86 21% fire susceptible
6. Removal cut and brown-spot burn in FY87 (62 MBF)
7. Brown-spot burn in FY89

SUMMARY

Utilization of the shelterwood system, if done properly, results in a successful regeneration of a longleaf pine plantation. Brown-spot infection survey and crop-seedling selection methods can be correlated with seedling height estimates to determine potential mortality of longleaf pine. Prescribed burns are suggested when the mean infection rate of crop seedlings reaches 20%. This assures minimal seedling loss from the burn.

Suggested references --- Numbers 2, 4, 5, and 15.

TOUR STOP #3

THE RESPONSE OF PLANTED PINES TO VARIOUS CULTURAL TREATMENTS

This study demonstrates the relative performance of longleaf, loblolly, and slash pine under various levels of intensive culture on a site in southern Mississippi.

LOCATION: Section 36 of Harrison Experimental Forest (HEF) near Saucier, MS. Approximately 2.7 mi. from Headquarters at the HEF via MS Highway 67, Bethel Road, and H-6 Road.

CONTACTS: U.S. Forest Service, Harrison Experimental Forest Headquarters, Highway 67, Saucier, MS (601) 832-2747

Southern Forest Expt. Station, Project 4503, U.S. Forest Service, 1925 34th St., Gulfport, MS 39501 (601) 864-8256

STUDY OBJECTIVES To determine the effects of cultivation and fertilization on the survival and height growth of longleaf, slash, and loblolly pines planted in sourthern Mississippi.

STUDY DESIGN: Split plot having four replications: Main plot was species, and completely randomized within each plot there were 10 subplots, five cultural treatments applied to high specific gravity populations and five to the average specific gravity populations. Each subplot consisted of 100 trees. Study consisted of 3 species X 5 cultural treatments X 2 specific gravity types X 4 blocks X 100 trees = 12,000 seedlings.

PLANTING: The l-year-old seedlings were bar-planted in February and March of 1960. Seedlings were planted at 10 X 10 ft. spacing and each subplot was surrounded by two rows of border trees. Plantation covered approximately 55 acres.

TREATMENTS

Species	Spec. gravity	Cultural treatments
1. Longleaf	1. High	1. No Cult.; no fert.. (-C-F)
2. Slash	2. Average	2. Cult.: no fert. (C-F)
3. Loblolly		3. Cult.; 1000 lb/A fert. (C+F1)
		4. Cult.; 2000 lb/A fert. (C+F2)
		5. Cult.; 3000 lb/A fert. (C+F3)

LABELED SUBPLOTS FOR OBSERVATION (See next page)

A= Loblolly, Cultivated, Fert. 1
B= Longleaf, Cultivated, Fert. 1
C= Slash, Cultivated, Fert. 1
D= Longleaf, Cultivated, Fert. 1
E= Slash, Cultivated, Fert. 1
F= Loblolly, Cultivated, Fert. 1
G= Longleaf, Uncultivated, no Fert.
H= Longleaf, Cultivated, no Fert.

RESULTS

Average height and DBH at 25 years (1985).

Species	#1 -C-F		#2 C-F		#3 C+F1		#4 C+F2		#5 C+F3	
	Height (ft); DBH (in)									
Longleaf	46.5*	6.1*[1]	51.9*	7.0	58.1	8.0	60.1	8.7	59.4*	8.6*
Loblolly	42.7	6.3	41.1	6.1	58.6	8.8	61.0	9.3	67.3	'9 .9
Slash	51.5	6.9	47.7	6.4	59.0	8.4	62.0	8.8	60.0	9.0

* Indicates that differences wihin a column were **significantly** different.

[1] First figure is height while second figure is DBH.

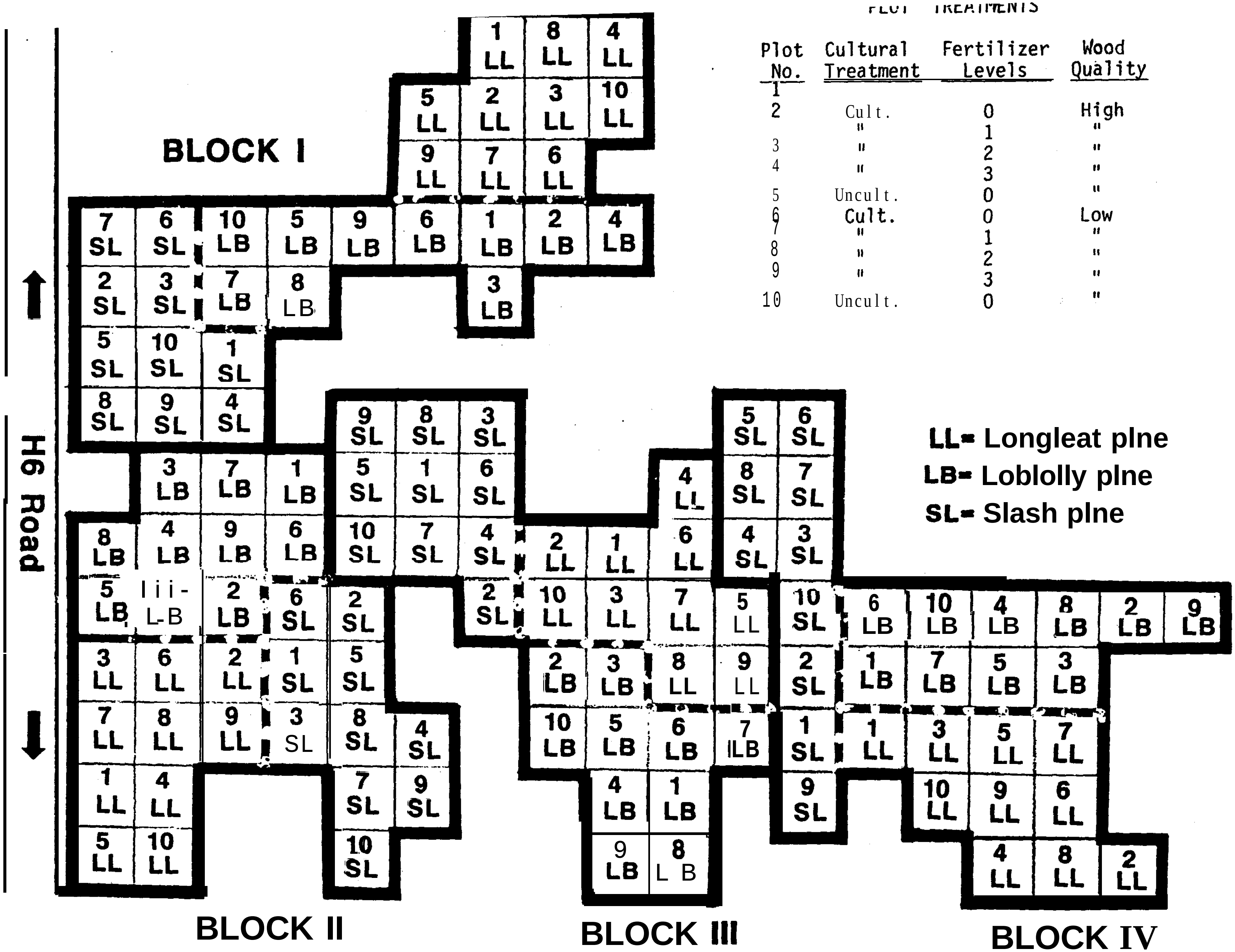
SUMMARY

Although longleaf pine benefitted from intensive culture, it lagged dramatically behind slash and loblolly in growth in all treatments after 9 years. However, after 25 years the overall growth of longleaf pine had increased to the point that it was as good as slash and loblolly under most conditions evaluated in the study.

Suggested references --- **Numbers 16 and 17.**

PLOT TREATMENTS

Plot No.	Cultural Treatment	Fertilizer Levels	Wood Quality
1			
2	Cult.	0	High
	"	1	"
3	"	2	"
4	"	3	"
5	Uncult.	0	"
6	Cult.	0	Low
7	"	1	"
8	"	2	"
9	"	3	"
10	Uncult.	0	"



TOUR STOP #5

THE EFFECTS OF BENOMYL ON GENETICALLY IMPROVED LONGLEAF PINE

This study demonstrates improved survival and growth rates across a wide range of longleaf pine genotypes as a result of benomyl root-dip treatment at the time of outplanting. Differences in growth of genotypes were best demonstrated by trees receiving the benomyl treatment. Differences in disease resistance was demonstrated by trees receiving the benomyl treatment.

LOCATION: Harrison Experimental Forest (HEF) at Saucier, MS. Site is 1.2 mi. from Headquarters building via H-l, H-5, and H-4 roads.

CONTACTS: U.S. Forest Service, Harrison Experimental Forest Headquarters, Highway 67, Saucier, MS (601) 832-2747.

Southern Forest Experiment Station, Project 4503, U.S. Forest Service, 1925 34th St., Gulfport, MS 39501 (601) 864-8256.

STUDY OBJECTIVES: Determine if benomyl root treatment is equally effective on selections of longleaf pine with varying levels of resistance to brown-spot needle blight.

STUDY DESIGN: Test consisted of 5 replicate blocks each containing 29 families in paired plots of 8 seedlings each.

TREATMENTS: The 8 seedlings of each paired plot of the 29 families were root-treated with either a clay dip or with a benomyl/clay mix (10% a.i. benomyl) at the time of planting. These paired treatments of each family were planted side by side in each of the 5 blocks.

PLANTING: Nursery grown seedlings were machine planted in January 1982. They were planted 3 ft. apart in rows spaced at 10-ft. intervals. Blocks were separated by a 10-ft. buffer zone.

ID OF SAMPLE PLOT

Field ID and Family	Root treatment: Left plot	Root treatment: Right plot	Benomyl and family performance
A= 27-168 X 22-216	no benomyl	benomyl	Good with; bad without
B= 14-346 X 27-168	benomyl	no benomyl	Good with: fair without
C= 8-25 X 12-13	no benomyl	benomyl	Worst with and without
D= 8-144 X 27-168	benomyl	no benomyl	Good with, poor without
E= 11-467 X 27-168	no benomyl	benomyl	Good with and without

RESULTS

Evaluation made after 5 years in the field (November 1986)

Treatment	Survival %	Infection %	Diameter cm.	Stem length cm.	Height growth %
Benomyl	83.7[1] (57-98)	26.2 (9-52)	5.4 (3-7)	180.8 (67-309)	97.2 (88-100)
Clay	56.4 (12-81)	65.6 (44-89)	2.7 (2-4)	53.8 (11-131)	54.7 (9-88)

[1] Mean and range of means of the 29 families

SUMMARY

Benomyl root treatment at planting time improved survival and growth of all 29 longleaf families. Differences in growth rate among families were much greater for trees treated with benomyl than for untreated trees. This study demonstrates a great potential for genetic improvement of longleaf pine.

The National Forest's Ashe Nursery currently treats longleaf pine seedlings with a benomyl-clay slurry prior to packing for storage. This procedure protects seedlings from brown-spot needle blight when they are outplanted. Excellent results have been achieved in many operational plantings in Mississippi.

Suggested references --- Numbers 10, 11, and 12.

TOUR STOP 6A

GROWTH AND YIELD OF NATURAL STANDS[1]

This plot represents one of some 265 permanent plots in a cooperative **Midsouth** study of managed natural **longleaf** pine growth and yield. The study covers a broad array of stand ages, site indices, and residual densities, maintained by periodic thinning. The study was started in the mid-1960s and has been remeasured every 5 years since. At each remeasurement, the stands are rethinned as needed, to maintain their assigned residual density levels and some new plots are added to replace those accidentally lost or to fill gaps in the distribution of plots. The intent is to maintain the study until 3 sets of the initially youngest plots have been managed for an entire rotation of perhaps 80 years or longer. Such a long term study is necessary to determine the quantity and quality of products produced over time under management, particularly **sawlogs,** veneer bolts, and poles.

This study has produced considerable useful information and the utility improves with time as more of the stands have been under management for longer periods. The information includes site-index curves, tree-volume functions, stand volume **and** growth predictors, and computer simulation programs for estimating growth and yield under management. (See number 6 and 7 in Suggested References)

In the fall of **1988,** this particular plot was 56 years old, had 'a site index of 82 feet, and contained **59** sq. ft. of total basal area, of which about 1 sq. ft. is sub-merchantable and 54 sq. ft. is in sawtimber. Assume that this plot represents a larger stand that we want to thin every 5 years from below to leave 60 sq. ft. of basal area, cut at least 1,200 bd. ft. Int. **1/4"** of sawtimber each time, and **want** estimates of the before-cut volume, the volume removed in thinning, and the after-cut volume at 5 year intervals for a period of 20 years. The tabulation on the following page shows this scenario and is generated from a micro-computer program that uses the stand volume and growth predictors developed from this study.

[1] Color code of plot:

Blue flags =	Poles within plot
White flags =	Outside boundary of plot
Red metal pole =	Center of plot

PLEASE DO NOT DISTURB **THE** PLOTS. THIS STUDY IS ACTIVE AND THESE PLOTS CONTINUE TO PRODUCE VALUABLE INFORMATION ON THE DEVELOPMENT OF MANAGED **LONGLEAF** PINE STANDS.

ge	Status	BT	TotCF	MerCd	BS	SawCd	Int. 1/4	TotCF	MerCd	SawCd	Int. 1/4
		Stand Values (per acre)[1]						P.A.I / M.A.I[1]			
5	b-c	59.3	2100	26.2	54.2	22.1	11376	37.5	0.47	0.39	203
	a-c	59.3	2100	26.2	54.2	22.1	11376	37.5	0.47	0.39	203
	cut	0.0	0	0.0	0.0	0.0	0				
1	b-c	69.5	2531	31.5	65.4	27.8	14395	86.2	1.08	1.14	604
	a-c	61.0	2229	27.8	60.0	25.5	13192	41.5	0.52	.46	236
	cut	a.5	302	3.8	5.4.	2.3	1203				
6	b-c	70.4	2636	32.9	69.6	30.7	15940	a1.4	1.02	1.04	550
	a-c	60.0	2254	28.1	60.0	26.5	13693	44.5	0.55	0.50	260
	cut	10.4	382	4.8	9.6	4.2	2248				
1	b-c	68.7	2633	32.9	68.7	31.2	16230	75.8	0.95	0.96	508
	a-c	60.0	2307	28.8	60.0	27.3	14138	46.7	0.58	0.53	277
	cut	a.7	326	4.1	a.7	3.9	2092				
6	b-c	68.1	2664	33.3	68.1	31.8	16538	71.3	0.89	0.90	480
								48.3	0.60	0.56	291

The legend for the tabulation is:

BT = Total basal area sq. ft., all trees ≥ 1" dbh.

TotCF = Total cubic-foot volume, i.b., all trees ≥ 1" dbh.

MerCd = Merchantable cords, trees ≥ 4" dbh to a 3" top dob.

BS = Sawtimber basal area, sq. ft., trees ≥10" dbh.

SawCd = Cords in sawtimber, trees ≥ 10" dbh.

Int. 1/4 = Bd-ft volume, International 1/4" rule, trees ≥ 10" dbh.

P.A.I. = Periodic annual increment.

b-c = before cut

a-c = after cut

We see in the tabulation that we initially had only about 59 sq. ft. of total basal area, which will not allow a cut to leave 60 sq. ft., so we do not simulate a cut initially at age 56 but wait 5 years to age 61. At age 61, we leave about 61 sq. ft. of total basal area and 60 sq.ft. of sawtimber because about 1 sq. ft. will probably still be sub-merchantable. The estimated cut is about 3.8 merchantable cords per acre of which about 2.3 cords or 1,203 bd. ft. are in sawtimber. The estimated residual stand contains about 27.8 merchantable cords, including about 25.5 cords or 13,200 bd. ft. in sawtimber. Note that the sawtimber basal area (BS) is psrt of the tots1 basal area (BT) and, likewise, the cords in sawtimber (SawCd) are part of the merchantable cords (MerCd) so the pulpwood left at age 61 would be 27.8 - 25.5 = 2.3 cords. Five years later, at age 66, we estimate that our residual stand will have grown to have nearly 32.9 merchantable cords containing 30.7 sawtimber cords or over 15,900 bd. ft. As shown, we can again thin from below to leave 60 sq. ft. and cut an estimated 4.8 merchantable cords containing about 4.2 sawtimber cords, or 2,250 bd. ft. We can simulate repeating this process again at age 71. cutting about 4 merchantable cords including about 2,100 bd. ft. At age 76, we have about 33 merchantable cords containing about 32 sawtimber cords or over 16,500 bd. ft.

At the right side of the tabulation, the periodic annual increments (P.A.I.) at each 5-year interval, from age 56 to 76 under this thinning scenario, are given at the top line followed by the mean annual increments (M.A.I.) immediately underneath. We see that the estimated P.A.I.s were about 1 cord/ac./year in the merchantable stand and 480 to over 600 bd. ft./ac./year in the sawtimber stand. Mean annual increments varied from about 240 to over 290 bd. ft./ac./year during this time span.

This is just one of many simulations that might be performed to help a forest manager decide what thinning scheme he might employ on various sites for various management objectives. The simulation could be extended to cover a rotation and various rotation lengths as well 8s other thinning schemes could be compared. The forest manager could then use this informstion to help decide which would likely be his best option.

Suggested references --- Numbers 6 and 7.

TOUR STOP 6B

MANAGING FOR SPECIALTY PRODUCTS

Utility poles are a group of highly valuable products in **longleaf** stands that are not accounted for in the previously presented growth and yield prediction. In this particular plot, there were 45 poles per acre (out of 55 candidates) in the following classes and lengths and having the following current values.

Class/Length:	4-40	6-40	3-45	4-45	5-45	3-50	4-55
	5	5	5	15	5	5	5
Value/Unit:	27.35	20.50	38.05	33.00	28.65	46.55	45.65
Stumpage:	136.75	102.50	190.25	495.00	143.25	232.75	228.25

Total = **$1,528.75**

plus about 370 board feet in non-poles **@ $110/Mbf** = 40.00

Grand total **$1,569.45**

If we price the sawtimber at **$110/Mbf stumpage, (Int. 1/4" rule)**, the stand value is **11.376 M** X $110 or about **$1,251. However,** if we price the stand as poles its value is about **$1,569** or $318 greater than the sawtimber value and obviously more attractive to a landowner. As a rule of thumb, pole values are usually about 20 to 30% higher than sawtimber values for the same trees.

Longleaf stands tend to have more poles than other pine species due to the inherent straightness, good form, and natural pruning of the species. This is the good news. The bad news is that with generally high pole values in **longleaf** stands, unless the landowner is careful to remove only those trees that need to be removed from a silvicultural and growth standpoint, a timber sale involving poles can easily degenerate into simply a high-grading operation in which all the qualifying poles are cut. Such mistreatment usually leaves the stand in very poor condition for future value production and natural regeneration. Many thousands of acres of **longleaf** have been mistreated in this fashion and - to add insult to injury - the remnant stands have been criticized because they did not perform well and were usually converted to other less desirable species. Such "mining" of **longleaf** stands for poles is not desirable silvicultural treatment and certainly cannot be condoned as good long-term natural-stand management. It is analogous to selling only the best animals from a cattle herd and keeping only the poorer ones for breeding stock.

Previous inventories and data analyses of this study have not included pole quantities. But, starting with the 25-year inventory in the fall of 1989, we intend to determine the poles on each study plot and at each subsequent inventory in the future. Future analyses will endeavor to predict pole production along with other product-volume amounts, such as veneer volume and board foot volume by various log rules, under different stand conditions.

Suggested references --- Numbers 6 and 7.

PLEASE DO NOT DISTUHB THE PLOTS. THIS STUDY IS ACTIVE AND THESE PLOTS CONTINUE TP PRODUCE VALUABLE INFORMATION ON THE DEVELOPMENT OF MANAGED LONGLEAF PINE STANDS.

TOUR STOP #7

CONTROL OF BROWN-SPOT NEEDLE BLIGHT ON LONGLEAF PINE SEEDLINGS BY BENOMYL FUNGICIDE-DIP TREATMENT

This study demonstrates the effects of benomyl root-dip treatment and Pt ectomycorrhizae on the survival, growth, and brown-spot infection of outplanted longleaf pine seedlings.

LOCATION: Harrison Experimental Forest (HEF), Saucier, MS. Site is approximately 0.8 mi. on H-2 road across from the HEF entrance on Mississippi Highway 67.

CONTACTS: U.S. Forest Service, Harrison Experimental Forest Headquarters, Highway 67, Saucier, MS (601) 832-2747

Southern Forest Expt. Station, Project 4503, U.S. Forest Service, 1925 34th St., Gulfport, MS 39501 (601) 864-8256.

STUDY **OBJECTIVE** To determine: (1) efficacy of benomyl root-dip treatment for brown-spot needle blight control over a wide geographic area, (2) optimal rate of benomyl, (3) duration of effective control, and (4) if longleaf pine survival and growth can be improved by utilization of *Pisolithus tinctorius* ectomycorrhizae.

STUDY **DESIGN** Test consisted of 8 treatments X 4 states X 5 blocks X 25 seedlings for a total of 4000 seedlings.

PLANTING: Seedlings were machine-planted in January 1982. They were planted 3-ft. apart in rows spaced at 10-ft. intervals. Blocks were separated by a 20-ft. buffer zone.

FIELD ID	TREATMENTS
A.	5 % benomyl dip of Pt seedlings
B.	10% benomyl dip of Pt seedlings
C.	20% benomyl dip of Pt seedlings
D	Clay dip of Pt seedlings (no benomyl control)
E	5% benomyl dip of Pt-free seedlings
F	10% benomyl dip of Pt-free seedlings
G	20% benomyl dip of Pt-free seedlings
H	clay dip of Pt-free seedlings'(no benomyl control)

RESULTS

Plant responses after **4 years** in the field (December 1985)

Field ID and Treatment	Survival %	Infection %	Stem Length **(cm)**	Stem Diam. **(mm)**	Height Growth %
Seedling + Pt					
A= 5% benomyl	77.4	49.6	59.2	33.1	71.7
B= 10% benomyl	76.2	44.3	556.0	34.4	74.2
c= 20% benomyl	75.7	44.9	65.0	36.2	84.4
D= no benomyl	63.3	81.9	15.5	21.3	29.3
Mean	73.2	55.2	48.9	31.3	64.9
Seedlings - Pt					
E= 5% benomyl	61.3	64.8	34.2	29.4	65.3
F= 10% benomyl	67.2	55.8	39.0	30.2	63.8
G= 20% benomyl	42.8	58.0	43.1	32.0	78.5
H= No benomyl	34.8	88.2	6.5	14.8	11.7
Mean	51.5	66.7	30.7	26.5	54.8

SUMMARY

A 5% benomyl-clay root-dip treatment proved to be optimal for disease control and for stimulation of growth of **longleaf** pine over a wide geographic area. Treatment effectively controlled disease for a 3-year period. **Longleaf** pine seedlings inoculated with Pt ectomycorrhizae generally had significantly higher rates of survival and greater growth than their noninoculated counterparts. These results were also noted at the sites in Louisiana, Alabama, and Florida.

Suggested references --- Numbers 10 and 13.

TOUR STOP #8

COMBINED EFFECTS OF MYCORRHIZAE AND BENOMYL ON LONGLEAF PINE SURVIVAL AND GROWTH

This study demonstrates that significant volume increases of lonaleaf nine can be achieved by the combined use of ectomycorrhizae and benomyl fungicide.

LOCATION: Harrison Experimental Forest (HEF) Saucier, MS. Site is just off H-2 Road, approximately 2.5 mi. from the HEF entrance on MS Highway 67.

CONTACTS: U.S. Forest Service, Harrison Experimental Forest Headquarters, Highway 67, Saucier MS (601) 832-2747.

Southern Forest Expt. Station, Project 4503, U.S. Forest Service, 1925 34th St., Gulfport, MS 39501 (601) 864-8256

STUDY OBJECTIVE: Determine if ectomycorrhizae reduce the effects of brown-spot needle blight on longleaf pine seedlings and determine if ectomycorrhizae are affected by the root dip treatment with benomyl.

STUDY DESIGN: Test consisted of 8 treatments X 2 sites X 8 blocks X 20 seedlings for a total of 2560 seedlings.

PLANTING: Nursery-lifted seedlings were hand planted in December 1976. Seedlings were planted 5-ft. apart in rows spaced at 10-ft. intervals. Blocks were separated by 20-ft. buffer zones.

TREATMENTS

Clay Dip (1)	Clay dip + Benomyl (2)
A= High (25%) Pt	E= High (25%) Pt
B= Medium (15%) Pt	F= Medium (15%) Pt
c= Low (5%) Pt	G= Low (5%) Pt
D= No Pt (Control)	H= No Pt (Control)

RESULTS - SITE 2

Survival and growth after 10 years in the field (1986)

Treatment ID		Survival (%)	DBH (in.)	Tree Height (ft.)	Volume (cu. ft.)
A		46.3	3.9	19.2	11.3
B		39.4	3.9	22.1	11.0
C		32.5	3.8	26.3	8.1
D		24.4	3.0	16.7	4.8
	Mean	35.7	3.7	19.6	8.8
E		70.6	3.8	22.7	19.0
F		72.5	3.7	21.4	18.0
G		58.3	3.8	21,.7	15.3
H		54.4	3.9	21.8	14.5
	Mean	64.1	3.8	21.9	16.7

SUMMARY

The combined treatments of benomyl and Pt ectomycorrhizae have resulted in a significant additive gain in both survival and growth over the first lo-year period of the test. Generally, survival and the various growth responses were negatively correlated to severity of brown-spot infection.

Suggested references --- Numbers 18 and 13.

TOUR STOP #9

SUCCESSFUL PLANTING OF LONGLEAF PINE

This site demonstrates the value of site preparation for the successful installation of a longleaf pine plantation. It also shows the benefits from utilizing benomyl-treated seedlings and controlling competition.

LOCATION: Stand 3, Compartment 584, Biloxi Ranger District, DeSoto National Forest. Site is reached from Headquarters of Harrison Experimental Forest by driving 4.1 mi. south on Highway 67 to Carson Road. Take Carson Road west approximately .8 mi. to tour sign.

CONTACTS: U.S. Forest Service, Harrison Experimental Forest Headquarters, Highway 67, Saucier, MS (601) 832-2747.

Southern Forest Experiment Station, Project 4503, U.S. Forest Service, 1925 34th Street, Gulfport, MS 39501 (601) 864-8256

Biloxi Ranger District, DeSoto National Forest, P.O. Box 248, Wiggins, MS 39577 (601) 928-5291

PLANTATION SIZE: 46 acres

SITE PREPARATION: Double chopped in August 1985

PLANTING: Benomyl-treated seedlings from Ashe Nursery were machine planted in February 1986, at the rate of 851 seedlings per acre.

MANAGEMENT:

1. Survival check January 1987= 88 percent: 749/TPA
2. Adjacent timber stands were burned in January 1987 to reduce grazing impacts by dispersing cattle pressure.

SUMMARY

Competition control by double chopping is effective in light understories such as adjacent to this pine stand. It serves to control competing vegetation and also eliminates sources of inoculum of the brown-spot needle blight disease. The high survival rate was probably due to the planting of large benomyl-treated seedlings and the elimination of disease inoculum and competing vegetation.

In this instance, grazing was beneficial due to low brown-spot incidence; a result of the rapid growth of the benomyl-treated seedling. However, grazing in most cases can prove to be detrimental.

Suggested references --- Numbers 5, 8, and 10.

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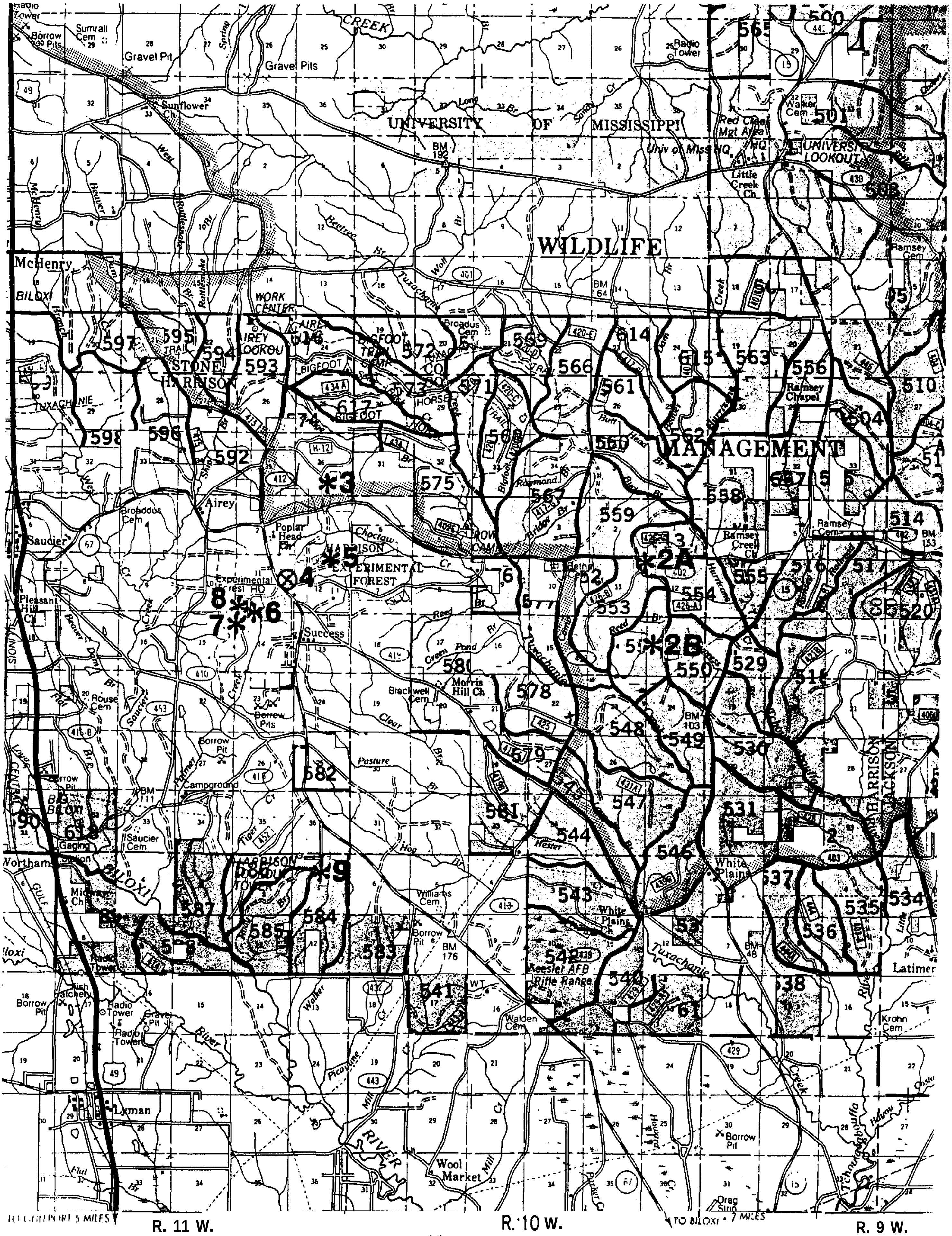

R. 11 W. R. 10 W. R. 9 W.

SPEAKERS AND MODERATORS

James P. Barnett, USDA-FS, Southern Forest Exp. Station, Pineville, LA
J. Lamar Beasley, USDA-FS, Southeastern Forest Exp. Station, Asheville, NC
William A. Bechtold, USDA-FS, Southeastern Forest Exp. Station, Asheville, NC
William D. Boyer, USDA-FS, Southern Forest Exp. Station, Auburn, AL
John C. Brissette, USDA-FS, Southern Forest Exp. Station, Pineville, LA
Nathan A. Byrd, USDA-FS, Southern Region - retired, Atlanta, GA
Stanley B. Carpenter, Louisiana State University, Baton Rouge, LA
C. Edward Cordell, USDA-FS, Southern Region, Asheville, NC
Thomas C. Croker, Jr., Forestry Consultant, Greeneville, TN
Frederick W. Cubbage, University of Georgia, Athens, GA
Roger W. Dennington, USDA-FS, Southern Region, Atlanta, GA
Mark Elliott, International Forest Seed Company, Odenville, AL
Thomas H. Ellis, USDA-FS, Southern Forest Exp. Station, New Orleans, LA
Robert M. Farrar, Jr., USDA-FS, Southern Forest Exp. Station, Mississippi State, MS
John W. Foster, Jr., Gulf States Paper Corporation, Tuscaloosa, AL
John G. Guthrie, Consulting Forester, Wiggins, MS
Glyndon E. Hatchell, USDA-FS, Southeastern Forest Exp. Station - retired, Athens, GA
Donald G. Hodges, USDA-FS, Southern Forest Exp. Station, New Orleans, LA
James Hodges, Champion International, Roanoke Rapids, NC
Willian H. Hoffard, USDA-FS, Southern Region, Asheville, NC
Claude A. Hood, North Carolina Division of Forestry, Bladen Lake State Forest, NC
Frank E. Jones, T. R. Miller Mill Company, Brewton, AL
Albert G. Kais, Forestry Consultant, Biloxi, MS
John F. Kelly, USDA-FS, Southern Forest Exp. Station, Starkville, MS
'Roy Komarek, Tall Timbers Research Station, Tallahassee, FL
J. Larry Landers, Tall Timbers Research Station, Tallahassee, FL
Dale R. Larson, Gulf States Paper Corporation, Tuscaloosa, AL
L. Keville Larson, Larson & McGowin, Inc., Mobile, AL
Dwight K. Lauer, ITT Rayonier, Inc., Yulee, FL
Richard E. Lohrey, USDA-FS, Southern Forest Exp. Station, Pineville, LA
Donald H. Marx, USDA-FS, Southeastern Forest Exp. Station, Athens, GA
Robert S. (Sid) Moss, Mississippi Forestry Commission, Jackson, MS
Douglas P. Richards, Mississippi State University, Mississippi State, MS
Phillips Sasnett, Gulf States Paper Corporation, Tuscaloosa, AL
Ronald C. Schmidtling, USDA-FS, Southern Forest Exp. Station, Gulfport, MS
Eugene Shoulders, USDA-FS, Southern Forest Exp. Station, Pineville, LA
Gene A. Sirmon, USDA-FS, Southern Region, Jackson, MS
Glenn A. Snow, USDA-FS, Southern Forest Exp. Station, Gulfport, MS
Charles E. Thomas, USDA-FS, Southern Forest Exp. Station, New Orleans, LA
Frank Vande Linde, Georgia-Pacific Corp., Brunswick, GA
John B. White, USDA-FS, Southern Region, McHenry, MS
Timothy L. White, University of Florida, Gainesville, FL
Hamlin L. Williston, Forestry Consultant, Oxford, MS

Farrar, Robert M., Jr., ed.
1990. Proceedings of the symposium on the management of longleaf pine; 1989 April 4-6; Long Beach, MS. Gen. Tech. Rep. SO-75. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 293 p.

Nineteen papers are presented in four sessions dealing with subjects including silvics, ecology, artificial and natural regeneration, genetic improvement, pest management, volume and volume growth prediction, managing specialty products, and economics of management. In addition, the printed material presented on an associated one-day field trip is appended.

☆U.S. Government Printing Office: 1990-766-847