Pine and Pine-Hardwood Regeneration

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EFFECTS OF FIRE ON SHORTLEAF AND LOBLOLLY PINE REPRODUCTION AND ITS POTENTIAL USE IN SHORTLEAF/OAK/HICKORY ECOSYSTEM RESTORATION

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Abstract—The shortleaf pine/oak-hickory (*Pinus echinata* Mill, *Quercus* spp., *Carya* spp.) forest, once the dominant forest community across north Louisiana, has slowly disappeared from the landscape, and is being replaced by loblolly pine (*P. taeda* L.), mixed hardwood/loblolly, and loblolly/shortleaf forests. One of the reasons for the demise of this fire-dependent ecosystem has been effective fire suppression programs. A study was established in three stands of the Kisatchie National Forest in north Louisiana, comprising a loblolly/shortleaf pine overstory, that were prescribed burned. A regeneration survey two growing seasons following fire revealed that 52 percent to 86 percent of the post-fire pine regeneration was from sprouts, and that 92 percent to 100 percent of these sprouts were shortleaf pine. Loblolly pine accounted for 55 percent to 100 percent of the new seedling germinants after fire. Sprout size averaged 11.2 inches in total height and 0.116 inches in groundline diameter, compared to 4.8 inches total height and 0.060 inches groundline diameter for post-fire seedling germinants. No significant difference was found in sprout size between shortleaf and loblolly pines. Loblolly pine seedlings produced an average of 1.7 sprouts per seedling compared to 2.1 sprouts for shortleaf. The role of fire in the shortleaf pine/oak-hickory forest ecosystem and its potential use in ecosystem restoration is discussed.

INTRODUCTION

It has been estimated that during the early 1800's the shortleaf pine/oak-hickory (*Pinus echinata* Mill./*Quercus* spp., *Carya* spp.) forest occupied some 4 to 5 million acres in Louisiana west of the Mississippi River (Smith 1992). The most recent (1991) forest inventory by the USDA Forest Service indicated that the shortleaf pine and shortleaf pine-oak forest types (FIA types) now occupy just a little over 300,000 acres in the west gulf coastal plain of Louisiana. It is apparent from these figures alone that this forest type—once dominant in the central and north Louisiana uplands—has suffered dramatic declines in acreage.

This dramatic decline has caused concern among conservation biologists and ecosystem managers alike; but perhaps of greater concern are the changes that have occurred in the structure and composition of the shortleaf pine system. It is likely that any examples of the system that are present today are very dissimilar to the historic conditions. As a result of the regeneration dynamics, the historic disturbance patterns of fire and windstorms, and variability in soil/substrate conditions, the density levels were probably quite variable from dense to open stands. Accordingly, this variability permitted a wide diversity of vertical stratification to exist in these forests across the landscape. Also, the species composition, i.e., the abundance of shortleaf versus the abundance of hardwoods [and loblolly pine (*P. taeda* L.)], varied from stand to stand due to differences in substrate and landscape position (ridge, midslope, lower slope, flats, etc.).

There is no doubt that fire was one of the major influences in defining the structure and composition of shortleaf pine systems. In these historic systems, fires are believed to have burned in a cycle of 5 to 15 years—most likely occurring during the growing season (Williams and Smith 1995). The historic fire disturbance regime has been altered significantly many decades ago by a variety of land management practices. Fire frequency in most cases has been significantly reduced from its original rates. In cases where forests are prescribed burned, the rates may be equal or even greater than the original rates, but are performed during dormant seasons. These alterations of the fire regime, combined with past land clearings, widespread timbering, and commercial reforestation with other species, particularly loblolly pine, have caused dramatic changes in the shortleaf system.

If future objectives for some of these lands that once supported shortleaf systems include the restoration of these systems, a better understanding of their regeneration and stand dynamics will be of critical value, notably the fire disturbance regime. It was the objective of this study to collect some baseline data concerning the response of shortleaf and loblolly pine reproduction to fire, to add to present knowledge about fire-impact dynamics, provide data for comparison, and provide direction for future studies in the use of fire to restore the shortleaf pine/oak-hickory system.

BACKGROUND

To provide background on the role of fire in the shortleaf pine/oak-hickory system and the magnitude of change that has taken place in this forest cover in Louisiana as a result of fire regime alteration, a brief description is offered. The most recent forest cover maps produced by the USDA Forest Service indicate that the shortleaf pine and shortleaf pine-oak forest types presently occupy just a little over 300,000 acres in the west gulf coastal plain of Louisiana. The typical designations of this cover include loblolly-shortleaf pine and oak-pine.

However, the latest forest cover map that actually depicts the occurrence of the shortleaf pine/oak-hickory forests in north Louisiana was produced by Brown (1945) (fig. 1). This map departs from the earliest known cover map produced of Louisiana in 1881 by Sargent (1884). This and

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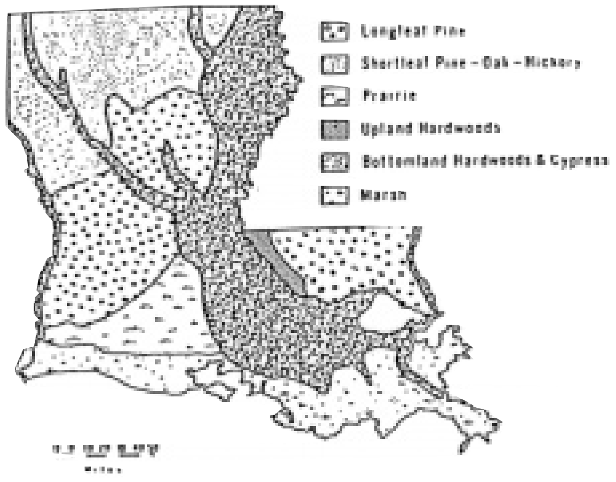

Figure 1—A vegetative cover map depicting forest cover types in Louisiana in 1945 (from Brown 1945).

other cover maps prior to 1945 indicate that shortleaf pine was the dominant pine species across north Louisiana. What is noticeably lacking on these early maps is the presence of loblolly pine.

The historical dominance of a shortleaf pine/oak-hickory forest across the uplands of north Louisiana, as documented by Lockett (1874), Hilgard (1873, 1884), and Mohr (1897) was undeniably a result not only of geology and soil conditions, but also of the dramatic influences of fire. It is axiomatic that plant species respond differently to fire; some are fire tolerant while others are fire sensitive, the degree of tolerance or sensitivity varying by species. It is well known that many pines and a number of hardwoods are tolerant of a certain amount of fire. In fact, it seems plausible that many of these species may actually require some level of fire for their perpetuation in particular settings. For example, without fire, fire-sensitive species may eventually come to dominate an upland site by out-competing fire-tolerant but less competitive species.

Shortleaf pine and its natural upland hardwood associates, principally dry-site oaks and hickories, are adapted to and were perpetuated as a forest type by a particular fire regime. It is unclear what that exact regime entailed, but Martin and Smith (1993) have estimated a fire return interval of 5 to 15 years would perpetuate a mixed shortleaf pine/oak-hickory forest type as described in historical accounts. Chapman (1944) stated that shortleaf pine could tolerate fires more frequent than once every 10 years because of its resprouting ability.

The pure shortleaf pine forests and pure hardwood forests reportedly present to some degree in presettlement uplands of north Louisiana (e.g., Lockett 1874, Hilgard 1873, Foster 1912) probably were a result, at least partially, of extremes in fire periodicity for the region, with the former maintained by frequent fire, and the latter by an essential absence of fire and other major disturbances. There is some difficulty, however, in postulating the origin of pure shortleaf forests based strictly on fire influences. While frequent fire (i.e., a fire every 5 years or less) would preclude the establishment and growth of dry-site hardwoods, such as post oak, blackjack oak, southern red oak, and black hickory (*Q. stellata* Wangenh., *Q. marilandica* Muenchh., *Q. falcata* Michx., and *Carya texana* Buckl.), it would do the same to shortleaf, all being roughly equivalent in their tolerance of fire.

It is possible that certain ridgetops of the region possessed particular “extreme” edaphic conditions (possibly very dry, very nutrient-poor, or with a near-surface consolidated and impervious layer, or other factors) that permitted, at least occasionally, the growth of shortleaf to forest-resistant sizes before fire return, but restrained hardwood growth to the extent that it could not attain (even through resprouting) fire-immune size before fire revisited the site. It is also possible that certain circumstances (involving life history characteristics of component species, fire dynamics, etc.) conspired to foster the establishment of an essentially pure shortleaf forest on dry ridgetops, perhaps after severe, forest-leveling windstorms. Regardless, the conspiracy of natural processes that would totally preclude hardwoods from the forest is difficult to specify.

Fires in the presettlement landscape originated from lightning strikes and the actions of aboriginal inhabitants. Lightning fires have been a primary factor in shaping the vegetational communities of the southeast for untold millennia (Komarek 1964), well before the arrival of aboriginal man. Observations of present-day climatic conditions indicate that the great majority of lightning firesin north Louisiana would have occurred between April and September, though also rarely at other times of the year. Spring and summer are characterized by a relatively large number of electrical storms, generated either through active frontal passage in the spring, or through summer heating and convection. Because vegetative litter such as oak leaves, pine needles, and dead grasses resists rapid decay (due to sclerophylly), litter produced in the previous season(s) remains available for fuel throughout the growing season and will readily burn if not too moist.

When compared to the catastrophic fires of the Western United States, presettlement lightning fires in north Louisiana and throughout most of the Southeast (with few exceptions) were relatively frequent but low-intensity surface or ground-level fires. Because of climate, vegetative structure, and fuel characteristics, catastrophic crown fires were essentially nonexistent in the upland pine, pine-hardwood, and hardwood forests of the South.

Prior to settlement by Europeans in north Louisiana, this area was inhabited by tribal American Indians whose main occupations were sedentary hunting, farming, and fishing (Fisk 1938). North Louisiana was inhabited by Caddo Indians before the earliest permanent settlements by immigrants to the Louisiana Territory in 1803 (Soil Conservation Service 1989). Delcourt (1976) describes the writings of early authors who indicated that the cultivation practice of slash-and-burn was common in upland areas of the Southeast by Indians. In fact, Delcourt quotes Dunbar (1804) in his writings that while traveling up the Ouachita River in Louisiana, a smokey appearance in the atmosphere was noted, and attributed the “smokey or misty appearance of the atmosphere which in our Country is common in the months of november and december...to a common practise [sic] of the Indians and Hunters, of firing the woods, planes [sic], or savannahs; the flames often extending themselves some hundreds of miles, before the fire is extinguished...”

The impact native Indians had upon the early forest communities in north Louisiana is not fully known. There is reason to believe that setting fire to the woods was performed; however, the extent and frequency is not known. If it is assumed that the landscape of north Louisiana burned regularly, both by lightning and aboriginal American fires, then the forest communities that existed during the presettlement era and some of the changes in forest communities that have taken place since then can be better understood.

Noticeably absent in presettlement upland forests, when compared to present-day forests, is loblolly pine. Early descriptions of early forest communities in this region display a clear picture of upland forests dominated by shortleaf pine and hardwoods, particularly on the drier sites. Loblolly pine is relegated to the wetter sites and bottoms in many of these descriptions, and often depicted as occurring in sparing groves or scattered throughout the bottomland hardwoods. In fact, many of the early forest-cover-type maps do not include loblolly pine in their type designations. This lack of loblolly pine in presettlement upland forests of north Louisiana relative to its overwhelming dominance today may be partly explained by the fire ecology of the species.

Loblolly pine is typically more sensitive to fire than shortleaf pine, both in seedling and more mature stages (Chapman 1944). However, fires of high intensity can easily kill both species. Fires of lower intensity probably favor shortleaf pine over loblolly pine. In addition, shortleaf pine saplings display better ability than loblolly pine to respond to top kill by producing sprouts. These sprouts exhibit faster initial growth rates over loblolly pine seedlings that may have established after fire, giving these shortleaf seedlings a competitive advantage over loblolly seedlings. Fire-free intervals of a few years allows these shortleaf seedlings to grow more rapidly to more fire-resistant sizes before the loblolly seedlings. Hence, areas where fire has been a major feature of the landscape tends to favor shortleaf pine over loblolly pine. Of the southern pines, longleaf and shortleaf pines are best adapted to fire, whereas loblolly and slash pines are less so. Thus, when fires were a dominant feature across the shortleaf pine region, loblolly pine was generally restricted to those moist or wet sites subjected to infrequent or no fire.

METHODS

Three stands that contained a shortleaf pine/loblolly pine/hardwood mixture that were prescribed burned during the early spring of 1995 were selected for this pine regeneration survey. These stands were located within the Caney Ranger District of the Kisatchie National Forest. They are even-aged, old-field stands approximately 65 years of age that had been placed under typical sawtimber management in the past, including a thinning regime. Within each of these stands, two 0.25r-acre plots were randomly located, from which the overstory measurements were taken. The diameter at breast height and species was recorded for each overstory tree.

The overstory plots were divided into quadrants to help facilitate the locating and measurement of all pine reproduction on the plot. Each quadrant was scanned painstakingly, and each reproductive stem was located, marked, and mapped for future measurement. The groundline diameter and total height of each stem, seedling and sprout, were recorded by species. If the seedling stem that had been killed by the fire and had produced the sprouts was located, it likewise was measured. It was assumed in this study that seedlings were of post-fire origin, and the size of all seedlings found would indicate that this was a correct assumption.

RESULTS

The overstory component of all three stands contained a shortleaf/loblolly pine mix to varying degrees (table 1). The majority of species composition based on basal area was loblolly pine for stands 1 and 2. The third stand was composed mostly of shortleaf pine. Hardwoods were a minor component in the overstory of all three stands,

Table 1—Summary of overstory attributes for stands used in this study

Stand	Species	Trees per acre	Average diameter at breast height	Basal area per acre
			- - -*Inches*- - -	*Square ft*
1	Loblolly	46	15.3	46.6
	Shortleaf	12	12.7	12.2
	Hardwoods[a]	10	8.7	10.1
	Total	68		68.9
2	Loblolly	50	15.4	54.7
	Shortleaf	26	12.1	26.3
	Total	76		81.0
3	Loblolly	14	15.4	14.2
	Shortleaf	42	13.6	46.6
	Hardwoods[b]	10	5.5	16.2
	Total	66		77.0

[a] *Fraxinus americana* L., *Liquidambar styraciflua* L., *Nyssa sylvatica* Marsh.
[b] *Liquidambar styraciflua* L.

especially in stand 2 which had no hardwoods. The total basal area did not vary much, ranging from about 70 to 80 square feet per acre.

Table 2 displays the pine regeneration summary for these sites. Shortleaf pine dominated the regeneration strata in each stand in terms of number of stems per acre, even though the overstory in stands 1 and 2 were dominated by loblolly pine. The reason for the domination by shortleaf is the superior sprouting ability displayed by shortleaf, which accounted for from 52 to 86 percent of all pine regeneration (seedlings and sprouts), and 92 to 100 percent of these sprouts were shortleaf pine. In fact, if it were not for sprout production by shortleaf pine in stand 1, shortleaf would not exist in the regeneration strata of this stand. Loblolly pine sprouts, on the other hand, accounted for 0 to 7 percent of all pine regeneration. In comparing seedlings, loblolly pine produced the largest number of post-fire seedlings, accounting for 55 to 100 percent of the new seedling germinants after fire.

The number of pine seedlings that were top-killed by fire and produced sprouts are displayed in table 3. There were significantly more shortleaf stems producing sprouts on all three sites than loblolly. Shortleaf overall displayed an average ratio of number of sprouts produced per sprouting stem of 2.10 compared to 1.65 for loblolly pine. It is evident that when loblolly seedlings were able to produce sprouts, they were not able to produce as many as shortleaf pine.

The sizes of the sprouts produced by shortleaf and loblolly pine were not significantly different at the p=0.05 level, with an average sprout size of 11.2 inches total height and 0.116 inches groundline diameter. Likewise, there was not a significant difference in seedling size at the p=0.05 level between the two species, with an average size of 4.8 inches total height and 0.060 inches groundline diameter. However, there was a significant difference in the sizes of sprouts and seedlings. Therefore, shortleaf in this case displayed a distinct advantage over loblolly pine by producing more sprouts per stem and more sprouts per acre; and sprouts have a distinct size advantage over seedlings, making them the dominant source of post-fire regeneration for loblolly pine.

RESTORATION APPLICATIONS

It is evident from this case study survey that under certain conditions, shortleaf pine displays an advantage over loblolly pine within a fire disturbance regime. It is not the fact that fire is required to regenerate shortleaf on the site, as it is with other species, but that it is required to maintain it on a site in the presence of other species, notably loblolly pine. Young shortleaf pines grow slower and subsequently take longer to dominate a site than loblolly pine or many of its associated hardwood competitors (Burns and Honkala 1990). It is the sprouting feature of this species—that trees up to age 8 or 10 years (Harlow and others 1991) or diameters of 6 to 8 inches (Burns and Honkala 1990) will sprout if the crown or main stem is killed or badly damaged by fire or cutting—that enables it to be maintained and eventually dominate a site. Loblolly pine seedlings, on the other hand, may sprout from buds in axils of primary needles only up to age 3 years if the tops are killed by fire or cutting (Burns and Honkala 1990).

Hence, a prescribed burn through a stand where the pine regeneration layer is within the 3- to 10-year age range, or diameters at least less than 6 to 8 inches, should discriminate against loblolly pine in favor of shortleaf pine. Prescribed burns of a frequency estimated for the pre-European settlement era of 5 to 15 years should maintain the shortleaf dominance within the regeneration strata.

Even though existence of pure stands of shortleaf pine was documented in the 1800's, most stands contained a mixture of various upland oaks and hickories. Most hardwood species of this mixture will likewise respond to such a fire regime, and develop with the shortleaf pine. Under these circumstances, shortleaf will endure the hardwood competition longer than loblolly pine, and eventually maintain dominance once it overtops its competition (Burns and Honkala 1990). The fast-growing sprouts produced by shortleaf pine will help the species attain a dominant position in the regeneration layer.

On sites where restoring this system is desirous and appropriate, but an adequate seed source is lacking, it may be necessary to plant shortleaf pine seedlings to provide the catalyst for future development. Since the densities of these original forests were quite variable, and the clustering of trees occurred, the planting does not need to be of equal

Table 2—Regenerating stems per acre 2 years after fire

	Sprouts		Seedlings		
Stand	Shortleaf	Loblolly	Shortleaf	Loblolly	Total
1	87	0	0	14	101
2	126	6	12	99	243
3	405	37	37	46	525

Table 3—The number of top-killed seedling stems producing sprouts 2 years after fire

	Shortleaf			Loblolly		
Stand	No. of stems	No. of sprouts	Sprout-to-stem ratio	No. of stems	No. of sprouts	Sprout-to-stem ratio
1	59	87	1.5	0	0	—
2	51	126	2.5	4	6	1.5
3	166	405	2.4	21	37	1.8
Average ratio			2.10			1.65

spacing and density. Once the seedlings have been established, then a burning regime as previously described may be employed.

Finally, in any restoration attempts there are three other considerations that must be contemplated and studied. First, most natural fires in the shortleaf pine/oak-hickory system occurred during the growing season. Few studies, if any, have examined the effects of growing season fires upon shortleaf and loblolly pine regeneration. Results reported in this study surveyed the effects following a late-winter prescribed burn. More studies of growing season fires will be necessary to determine if different results are attained.

Second, Native Americans burned the north Louisiana landscape at various intervals, sometimes encompassing extremely large areas. The extent to which this influenced the presence and composition of the shortleaf pine/oak-hickory forest is unknown. However, it is conceivable that the occurrence of some of these forests was a result of this burning.

Third, all that has been addressed here in the context of the restoration of this system has been the forest tree species composition. Whether the methods described here will likewise restore the associated flora and fauna of the shortleaf pine/oak-hickory system is still left to conjecture. However, when these methods are employed, continuous studies will be necessary to document the subsequent changes in flora and fauna, and compare them to what is known about the composition of historic systems.

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OLEORESIN CAPSICUM HAS POTENTIAL AS A RODENT REPELLENT IN DIRECT SEEDING LONGLEAF PINE

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Abstract—Direct seeding of southern pines has been a versatile and inexpensive alternative to planting on many reforestation sites across the South. Successful direct seeding has required that seeds be coated with thiram to repel birds, and with endrin to repel rodents. Endrin, which is extremely toxic, is no longer produced in the United States. Therefore, a substitute is needed. Oleoresin capsicum, a natural substance derived from pepper plants, has potential as a repellent. It occurs in an extremely concentrated form, and its repellency is caused by the heat of the capsicum. Preliminary tests have shown that at low rates oleoresin capsicum had little effect on the germination of longleaf pine (*Pinus palustris* Mill.) seeds, and significantly reduced losses from predation.

INTRODUCTION

Direct seeding is an affordable alternative to planting on many sites needing reforestation of the southern pines. It is also an appropriate supplement to natural regeneration where seedfall is inadequate. Techniques were thoroughly researched during the 1950's and 1960's by Derr and Mann (1971) and the 1970's by Campbell (1981a, 1981b). Studies show that success depends on protection of seeds from birds and rodents (Derr and Mann 1971; Campbell 1981a, 1981b). The recommended formulation of thiram and endrin protects against all important species of seed-eating birds, and deters small mammals common to most southern pine sites. Many field studies, tests with caged animals, and operational seedings have confirmed the repellent properties of these chemicals (Campbell 1981c).

Thiram, a fungicide currently marketed as Gustafson 42-S[R2], is safe, effective, and easy to use. Anthraquinone is almost as effective, but is more difficult to apply because it is a powder. It is, however, a good alternative as a bird repellent.

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

In a series of tests evaluating potential repellents, Barnett (1995) and Campbell (1981c) could not find an effective replacement. Recently, the substance oleoresin capsicum (OC) has shown promise. For example, it is added to the paint used for hulls of ships to deter barnacles. Oleoresin capsicum, a rust- to red-colored liquid obtained from dried cayenne peppers (*Capsicum frutescens* L.), is standardized with olive oil. The chemical in capsicums that can produce a burning sensation in the mouth is capsaicin. Its strength is measured in parts per million (ppm). These ppm are converted into Scoville Units (SV), the industry standard for measuring the heat of peppers (American Spice Trade Association 1960, Hoffman and Lego 1983). One ppm is equivalent to 15 SV. The material used in this study has an SV of 500,000. Although oleoresin capsicum is a natural and nontoxic chemical derived from pepper plants and is used in many foodstuffs to increase their pungency, it is an irritant to the skin or eyes. Protective gloves and eyewear are recommended when handling this product. The repellancy of capsicum is attributed to its heat. This paper describes initial evaluations of oleoresin capsicum as a rodent repellent for direct seeding.

METHODS

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

Lab Tests for Germination

Longleaf pine seeds were chosen for the evaluations because they are the most sensitive of the southern pines to such treatments. Germination was tested under standard laboratory conditions for 28 days (Association of Official Seed Analysts 1980). Results were recorded three times weekly during the periods of peak germination. Three replications of 100-seed samples from each treatment replication were tested. The seed treatments used were: an untreated control; thiram- and clay-slurry treatments with and without latex; and 1x, 2x, 4x, 8x, and 16x dilutions with capsicum and with thiram- or clay-latex slurry. The 1x capsicum treatment (500,000 SV, American Mercantile, P.O. Box 240654, Memphis, TN 38124) was applied at a rate of 1 tablespoon per 25 pounds of seed. The rates of application per pound (454 grams) of seed were: 76 mililiter of thiram, 3 mililiter of latex, 0.6 mililiter of capsium (1x), and 45 grams of kaolin clay in 100 mililiter of water. The latex was added to the mixture to improve binding of the materials to the seeds. The same proportion of materials was used for each treatment. The laboratory tests were conducted in the Alexandria Forestry Center Seed Testing Laboratory.

Field Tests

Longleaf pine seeds, selected from a single lot of Louisiana seed orchard origin, were selected for field evaluations.

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Empty seeds were removed from the lot by pentane flotation (Barnett 1971). Random samples were drawn for treatments. Repellent treatments were applied and the seeds were air-dried overnight.

It is logical to evaluate candidate rodent repellents in caged animal trials before testing in the field. However, the Alexandria Forestry Center no longer has the facilities to conduct such tests. We, therefore, skipped the intermediate step and moved directly to field tests conducted on the Palustris Experimental Forest in central Louisiana.

Five of the seed treatments were evaluated in the field: (1) an untreated control, (2) 1x capsicum plus thiram (0.6 mililiter capsicum, 76 mililiter thiram, and 3 mililiter latex per pound of seed), (3) 2x capsicum plus thiram (1.2 mililiter capsicum, 76 mililiter thiram, and 3 mililiter latex), (4) 1x capsicum plus kaolin clay (0.6 mililiter capsicum, 45 grams clay in 100 mililiter water, and 3 mililiter latex), and (5) 2x capsicum plus kaolin clay (1.2 mililiter capsicum, 45 grams clay in 100 mililiter water, and 3 mililiter latex). Treatment plots consisted of five 12-inch circular spots arranged around a central stake. Each spot was sown with 100 seeds. Plots were randomly selected for a particular treatment and marked with a flagging pin. Twenty replications, separated by at least 50 feet, were established April 1, 1996, on a previously cleared site. Plots were randomly arranged. Seed losses were determined by counting seeds remaining on the spots at 2- to 3-day intervals. Heavy rains washed the seeds from the spots 12 days after initiation of the test.

Because the plots in this study were small and subject to overwhelming predation, we evaluated them frequently to determine predation patterns for each of the five treatments.

RESULTS AND DISCUSSION

The laboratory germination test results show that capsicum with thiram or clay reduced germination when applied at rates greater than 2x (table 1). However, the 1x and 2x rates did not reduce laboratory germination more than the thiram- or clay-latex controls. Thiram alone reduces germination in the laboratory (Campbell 1981c), but the reduction in these tests was more than expected. Previous studies have shown that thiram has less impact on germination in the field (Barnett and others 1980, Campbell 1981c). The key to success for a repellent is field performance, so field evaluations of capsicum were initiated.

Results from the field evaluations indicate that the seeds were subjected to heavy predation. After 11 days, 78 percent of the seeds in the control treatment were lost due to predation (table 2). Because rapid losses were anticipated from the small seed spots, seed counts were started 4 days after sowing and continued at 2- to 3-day intervals until heavy rains washed seeds from the spots. Though there were heavy losses in the control and in the clay-capsicum treatments, the thiram-capsicum treatments protected the seeds well through 11 days of the test, with average losses of less than 1 percent. Because this study did not evaluate endrin and capsicum alone, their effectiveness could not be compared. Caged animal and additional field tests will be required to make these comparisons. Losses in the capsicum-clay slurry treatment were less than in the control, but were significant. If these losses were caused by partial predation from birds, treatment with the combination of thiram and capsicum is needed to assure protection.

The results from this study indicate that oleoresin capsicum has potential as a rodent repellent for southern pine seeds. The 1x rate is as effective as the higher 2x rate in these tests.

It is difficult to state with any certainty whether birds or rodents were the primary predators. An examination of remaining seedcoat fragments suggested that both birds and rodents were feeding on the longleaf seeds.

Despite the heavy predation on these small plots, the seed loss figures show that the repellents are effective. However,

Table 1—Effects of oleoresin capsicum with thiram or clay slurry on the germination of longleaf pine seeds

		Treatment combination	
Variables	None	Thiram	Clay slurry
		- - - - - - Percent - - - - - -	
Control	89	—	—
Without latex	—	45	85
With latex	—	46	69
1x capsicum	—	41	76
2x capsicum	—	47	68
4x capsicum	—	35	59
8x capsicum	—	34	46
16x capsicum	—	23	37

Table 2—Percentages of seeds removed or damaged on each plot 4, 7, 9, and 11 days after seeding on April 1, 1996, by treatment

	Seed losses at (days)			
Treatment	4	7	9	11
	- - - - - - - - - - -Percent- - - - - - - - - - -			
Control	2.2	26.4	58.9	78.5
Thiram + 1xOC	.6	.6	.6	.7
Thiram + 2xOC	.1	.2	.3	.4
Clay + 1xOC	1.1	3.7	22.0	53.6
Clay + 2xOC	.3	3.0	19.3	44.1

a larger-scale field evaluation should be conducted to gain additional information on the use of oleoresin capsicum as a rodent repellent for direct seeding. Seeding large acreages with thiram and capsicum treated seeds will be necessary to evaluate the effectiveness of the repellents when exposed to the environment and predators for a longer time period.

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EFFECTS OF STOCK TYPE AND FALL FERTILIZATION ON SURVIVAL OF LONGLEAF PINE SEEDLINGS PLANTED IN LIGNITE MINESPOIL

Mary Anne McGuire and Hans M. Williams[1]

Abstract—One-year-old longleaf pine (*Pinus palustris* Mill.) seedlings were hand-planted in January 1996 on an east Texas minespoil site. Effects of two seedling stock types and four levels of preplanting fall fertilization on seedling survival were evaluated. Fertilizer treatments consisting of a single application of ammonium nitrate (73 kilograms per hectare N), phosphorus (81 kilograms per hectare P), diammonium phosphate (73 kilograms per hectare N, 81 kilograms per hectare P), or control (no fertilizer) were applied to bare-root and container seedlings in November 1995. Root growth potential, the ability of a seedling to initiate and elongate new roots when placed into a favorable environment, was measured at time of planting. Field survival was surveyed monthly beginning in April 1996. Data were examined using analysis of variance. Container seedlings had significantly higher root growth potential and survival than bare-root. Fertilizer treatment effects, while not significant, tended to decrease both root growth potential and early survival for bare-root seedlings, and to increase root growth potential and decrease survival for container seedlings. Drought conditions during the 1996 growing season probably had a negative effect on survival of both bare-root and container seedlings. Only 2 percent of bare-root and 56 percent of container seedlings survived through the growing season, suggesting that only container stock should be used for reforestation of longleaf on minespoil sites. However, in years with normal precipitation, stock type effects on survival may not be significant and planting bare-root seedlings may be a viable option.

INTRODUCTION

It is estimated that between 1 and 2 million acres of land will eventually be disturbed by surface mining of lignite coal in Texas. Much of this mining will occur in the pineywoods region of east Texas (Hossner and others 1980). The Federal Surface Mine Control and Reclamation Act of 1977 requires restoration of vegetation on these lands for the primary purposes of limiting erosion and controlling flow and quality of water. Establishment of vegetation may be difficult on these sites due to physical properties, chemical toxicities, and nutrient deficiencies of the spoil material.

Reclamation of spoil banks on surface lignite mines in Texas has traditionally been accomplished using pasture grasses, even though many of these sites were forested prior to mining. Pasture grasses are relatively easy to establish, and offer immediate erosion control. However, pastures require long-term maintenance, including weed control and fertilization. On the other hand, establishment of forests is more difficult, but may provide more long-term benefits. Once established, forests require less maintenance than pastures. Forests provide wildlife habitat and recreational and economic opportunities as well as excellent control of erosion and water quality.

Texas Utilities Mining Company (TUMCO) operates several surface coal mines in east Texas, including the Beckville Mine in Panola County, which supplies fuel for the Martin Lake generating plant. In the early 1980's, TUMCO reclamation managers recognized the potential economic and environmental benefits of establishing forests on mined lands, and commenced with a program of intensive tree planting. To date, about 7 million seedlings have been planted on the Beckville Mine, consisting of approximately 85 percent improved loblolly pine (*Pinus taeda* L.) and 15 percent various hardwood species. These seedlings have been planted on both established pastures and recently graded spoil material.

TUMCO is interested in using longleaf pine (*P. palustris* Mill.) in its reclamation program in east Texas because the Beckville Mine site lies within the historical range of longleaf pine (Landers and others 1995). However, establishment of longleaf pine seedlings is more difficult than other southern pines for several reasons. First, bare-root longleaf seedlings are sensitive to handling and do not tolerate long periods of cold storage (Dennington and Farrar 1983, Dougherty and Duryea 1991). When weather delays planting, storage limitations can result in severe seedling mortality. Also, planting depth is critical because longleaf seedlings have no stems. If seedlings are planted too deep, the apical bud is smothered; if planted too shallow, the root collar is exposed and desiccation occurs. Movement of soil onto or away from seedlings after planting can have the same effect as incorrect planting depth. Finally, longleaf seedlings are very intolerant of woody competition (Dennington and Farrar 1983).

Many planting problems may be overcome when using container seedlings. Handling stress and storage are minimized. Container seedlings also perform better than bare-root in droughty conditions, and have an extended planting season. However, container seedlings have disadvantages. Compared to bare-root seedlings, they require more attention while growing, are more expensive to produce, are bulky to handle and transport, and are often smaller (Barnett and others 1989).

Obtaining quality nursery stock is an important factor in planting success. According to Duryea (1985), a high-quality seedling is one that meets defined levels of survival and growth on a given planting site. Late fall nursery

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fertilization has been used to improve the nutrient reserves of seedlings with the intent of improving survival and growth after outplanting. Previous research has shown varying effects of late-season nursery application of fertilizer. Hinesley and Maki (1980) found that fall nursery fertilization increased longleaf seedling dry weight, root collar diameter, and root:shoot ratio over controls. Field survival was not significantly affected, but height growth commenced sooner in fertilized seedlings. Anderson and Gessel (1966) found that late-season nitrogen application in the nursery significantly increased survival and height growth of outplanted Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco]. However, Ursic (1956) found a detrimental effect on field survival when loblolly seedlings were fertilized with nitrogen and potassium in the nursery in January. Shoulders (1959) found that fall nitrogen fertilization improved field survival of longleaf, loblolly, and slash pine (*P. elliotii* Engelm.) from one nursery, while survival of longleaf and loblolly from another nursery was depressed by fertilization.

This study attempts to assess effects of stock type and fall nursery fertilization treatments on survival of longleaf pine seedlings planted at the Beckville Mine.

METHODS

Seedling Treatments

Stock type treatments consisted of bare-root and container seedlings. Bare-root seedlings were commercially grown at the Texas Forest Service nursery located at Alto, TX, using seed obtained from a wild collection in east Texas. Ammonium nitrate was applied to bare-root seedlings weekly from April to August for a total growing-season application of 180 kilograms per hectare of nitrogen. Container seedlings were grown outdoors at the Arthur Temple College of Forestry greenhouse facilities located on the campus of Stephen F. Austin State University in Nacogdoches, TX. Seeds from the same east Texas source were sown in April 1995 in a commercial peat-pinebark-vermiculite growing medium in 144 cubic cm plastic cone containers. Seedlings were fertilized weekly from April to October with a commercial 30-10-10 liquid formula for a total growing-season application of 840 kilograms per hectare of nitrogen.

Four levels of mineral fertilizer treatment were applied to bare-root and container seedlings in November 1995. Treatments consisted of a single application of ammonium nitrate (73 kilograms per hectare N), phosphorus (81 kilograms per hectare P), diammonium phosphate (73 kilograms per hectare N, 81 kilograms per hectare P), or control (no fertilizer). Commercial grade fertilizer was applied to bare-root seedlings using a tractor-drawn agricultural spreader. High-purity ACS grade minerals were applied in liquid form by measured dose to each container seedling.

Design of Experiment

The study was conducted using a randomized block split plot 2 by 4 factorial design with five replications. Stock types were the whole units and fertilizer treatments were the subunits. Data were examined by analysis of variance using Statistical Analysis System procedures (SAS Institute, Inc. 1989). Results are reported as significant at the 5 percent probability level.

Bare-root and container seedlings were hand planted at the Beckville Mine in January 1996. Bare-root seedlings were lifted 1 day before planting and placed in plastic bags. Roots were sprayed with Terrasorb super-absorbent gel, bags were sealed, and seedlings were stored at 3 ^{o}C overnight. Container seedlings were watered thoroughly the day before planting. A total of 600 seedlings (15 seedlings per treatment combination per replication) were planted on 3-meters by 3-meters spacing. Field survival counts were made monthly from April to October.

The planting site was located in an area scheduled for machine-planting of loblolly seedlings. Mining operations were completed, the site was graded, and hay mulch was applied for stabilization during the summer of 1995. Winter wheat was sown in September 1995 to further stabilize the site. Seedlings were planted in spoil consisting of mixed overburden material with a silty clay texture and average pH of 6.9. At the time of planting, soil moisture content averaged 30 percent (dry weight basis) and winter wheat was about 10 cm tall.

Root growth potential (RGP) was measured at planting time on a sample of four seedlings per treatment combination per replication, using a hydroponic method modified from Ritchie (1985). RGP is defined as the ability of a seedling to initiate and elongate new roots when placed into an environment favorable for root growth. A seedling with high RGP is expected to have high potential for survival and growth after outplanting (Ritchie 1985). The experiment was conducted in a growth chamber with photoperiod controlled at 16 hours, day temperature controlled at 26 ^{o}C and night temperature controlled at 20 ^{o}C. After 28 days in the growth chamber, seedlings were removed and root counts conducted. RGP was determined as the number of new roots initiated greater than 1 cm in length.

RESULTS AND DISCUSSION

Root Growth Potential

Stock type had a significant effect on RGP. Mean RGP was 39 for bare-root seedlings and 61 for container seedlings. Of 80 bare-root seedlings tested, 25 initiated no new roots and were dead at the end of the experiment. There was no mortality among container seedlings. We expected container seedlings to have higher RGP than bare-root seedlings. Container seedlings have a fibrous root system consisting of a taproot and many higher order laterals that provide many potential initiation points for new root growth. In comparison, bare-root seedlings have a root system consisting of a large taproot and a few primary and secondary laterals, providing fewer potential initiation points. Also, bare-root seedling root systems are damaged in the lifting process; many fibrous roots are removed and stress may be induced. However, we did not expect mortality among either stock type in the RGP experiment.

Fertilizer treatments did not have a significant effect on RGP (P>0.42). Interaction effect between stock type and fertilizer was also not significant (P>0.14), but tendencies were strong, as shown in figure 1. Fertilizer treatments tended to improve RGP for container seedlings and depress RGP for bare-root seedlings. Control (unfertilized) bare-root seedlings had a higher average of RGP (68) than control container seedlings (50), but fertilized bare-root seedlings performed worse than all other treatment combinations. Container seedlings are often subject to nutrient deficiencies because soil-less growing media provide few mineral ions, container volume is small, and frequent irrigation leaches nutrients (Landis 1989). Therefore, fall fertilization was expected to improve container seedling quality and performance. Fertilizer treatments were not expected to be detrimental to bare-root seedlings, and reasons for this effect are not apparent.

Field Survival

Stock type had a significant effect on survival for all monthly counts. RGP results indicated an expected initial mortality of at least 30 percent for bare-root seedlings. No mortality was noticed in a visual inspection in February, but bare-root seedlings appeared stressed and unhealthy. Precipitation in February was less than 25 percent of normal and soil moisture was low. Drought conditions persisted throughout the growing season. Cumulative precipitation and survival count results are depicted in figure 2. In April, 56 percent of bare-root seedlings were dead, while more than 99 percent of container seedlings remained alive. All living seedlings appeared stressed and competition from winter wheat and hairy vetch was intense. Herbicide was sprayed in a 1-meter radius around each living seedling in May to control competition. By June, 91 percent of bare-root seedlings were dead, but container survival was still high at 98 percent. New growth was visible on most living seedlings, but young needles were only 6 to 8 centimeters long. Herbaceous vegetation on the entire site was brown and dry, so effects of herbicide were not obvious. Container survival declined sharply to 75 percent in July, and only 3 percent of bare-root seedlings remained alive. By October, bare-root survival was 2 percent, and container survival had stabilized at 56 percent. Young needles on surviving seedlings had elongated to only 20 to 25 cm.

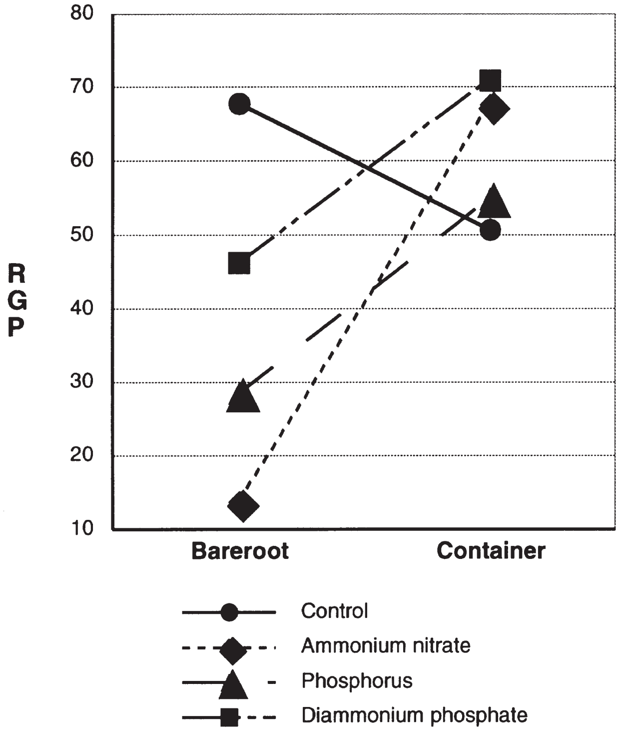

Figure 1—Interaction effect of stock type and fertilizer treatments on root growth potential of bare-root and container longleaf pine seedlings.

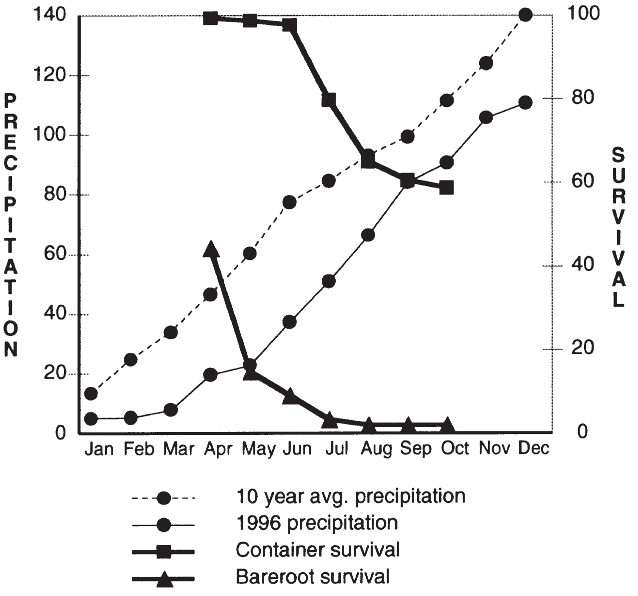

Figure 2—Cumulative 10-year average and 1996 precipitation in centimeters, and percent survival of bare-root and container longleaf pine seedlings planted on a lignite minespoil site in Panola County, TX.

Container seedlings were expected to survive and perform better than bare-root in this study, but effects of the drought probably intensified this phenomenon. Fibrous root systems of container seedlings have a larger absorptive surface than bare-root root systems and therefore have a greater ability to extract water from the surrounding soil and tolerate drought. However, we believe that both container and bare-root seedlings were negatively affected by the poor soil moisture conditions.

Fertilizer treatments had no significant effect on seedling survival. However, bare-root seedlings fertilized with ammonium nitrate tended to die sooner than those receiving other treatment combinations. Survival of container seedlings also tended to be lower for nitrogen fertilizer treatments for all monthly counts. Perhaps the effects of fertilizer treatments would have been greater if mortality had not been as rapid and severe.

Visual inspection of seedlings in March 1997 indicated no additional over-winter mortality, and new growth was noticeable on most seedlings. Effects of herbicide treatment were obvious; a patch of bare ground surrounded each seedling. Intense winter rainstorms had caused sheet erosion to remove up to 4 centimeters of soil from around the roots of some seedlings. Effects of this soil removal on seedling survival remain to be seen.

CONCLUSIONS

Container seedlings had significantly higher overall RGP and survival than bare-root seedlings. High mortality of bare-root seedlings suggests that only container seedlings should be used for longleaf reforestation on east Texas lignite minespoil sites. However, effects of stock type on survival may not be as noticeable when growing season precipitation is closer to normal. Results of this study indicate that fall fertilization may be detrimental to both RGP and survival of bare-root seedlings, although effects were not statistically significant. Fertilizer effects on container seedlings were also not significant. However, fall fertilization tended to improve RGP of container seedlings; in contrast, survival of container seedlings tended to be depressed by fertilizer treatments. Additional study of the effects of fall fertilization on both stock types is needed before recommendations can be made.

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GROWING SEASON EFFECTS ON 5-YEAR GROWTH OF LOBLOLLY PINE NEAR PARKERSBURG, WEST VIRGINIA

David W. McGill and Edmund T. Bridge[1]

Abstract—A study was established in 1990 to assess the effects of a reduced first growing season due to late planting near Parkersburg, WV. A randomized complete block factorial experiment was used to test the null hypothesis that a reduced first growing season does not significantly influence the long-term development of loblolly pine trees. Seedlings were planted at 2-week intervals from the middle of February until the end of May for five types of seedlings and in each of four blocks. Various seedling types were used in the study to separate the effects of storage method from those of a shortened growing season. Results suggest that following five growing seasons, the effects of a shortened first growing season are still present. This study considered the effects of a shortened growing season for the 1990 planting season only, and the results presented should be interpreted with this in mind.

INTRODUCTION

In the Parkersburg area of Westvaco's Appalachian Region, hardwood stands are converted to loblolly (*Pinus taeda* L.) or pitch × loblolly pine plantations to provide the company with pine fiber for its paper production lines. Most pines are planted in March. However, unfavorable weather or site conditions, and plantation logistics can hamper planting efforts so seedlings must be stored until conditions are favorable.

Prolonged storage can decrease the effective growing season for newly planted seedlings. Field performance may be negatively affected by this reduction in growing season. In the late 1950's and early 1960's, studies of loblolly pine plantations established in Mississippi showed that cold-stored seedlings had acceptable survival and growth when planted between February and early May (Ursic and others 1966). In plantings made after early May, survival remained satisfactory for plantings made into early June but height growth was reduced.

More recent studies show similar conclusions. In one of these, Hallgren and Tauer (1989) concluded that survival and height growth of shortleaf pine were always less for seedlings stored for 28 days than for unstored seedlings. Furthermore, a decreasing trend in 1-year total height growth for both stored and unstored seedlings occurred across the early December to mid-April planting dates and points to the negative impact of a shortened growing season.

Hallgren and others (1993) discussed the confounding effects of lifting date, cold storage, and planting date on field performance of shortleaf pine. For example, planting dates will differ for two groups of seedlings lifted on the same date, where one group is planted and one stored. Different planting dates will likely have different field conditions and thus field performance cannot be ascribed to the impact of storage alone.

Bridgen and Nelson (1989) designed and established a study using several storage methods and a single lifting date in an attempt to separate these potentially confounding effects. Working under the notion that seedlings stored in different ways might respond to storage and planting date differently, they proposed that containerized seedlings that are stored outside "should show no growth loss due to time of planting, as they would be able to fully use the normal growing conditions" and thereby maintain a more superior physiological condition. Under this assumption, if the length of the growing season was not important but storage effects were, then these outside-stored seedlings would have equal 5-year performance for seedlings planted at any planting date. Seedlings stored in coolers, on the other hand, should show decreased growth when planted at later and later planting dates because they do not have exposure to the ambient and hypothetically beneficial growing conditions.

Results following 2 years of growth of the loblolly pines were reported by Bridgen (1992). The report ended in the recommendation to monitor and report the study at age 5 since most past studies that examined growing season effects were short term, following growth for only the first year or two after planting. This report documents the impact of a shortened first growing season on the 5-year field performance of loblolly pine.

PROCEDURE

Experimental Design

A randomized complete block factorial experiment was used to analyze the data to test the influence of a shortened growing season on the long-term growth of loblolly pine near Parkersburg, WV (Bridgen and Nelson 1989). Seedling type and planting date were the two factors of interest. Seedling type was a combination of production method (nursery or containerized) and storage method (outside under mulch, lighted cooler, and dark cooler); it was treated as a single factor to represent several types of storage systems. The intended purpose of using multiple storage systems was to separate the effects of a shortened growing season from those of storage treatment (Bridgen 1992).

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The five seedling types used were:
(1) Nursery-grown, stored in cooler,
(2) Nursery-grown, stored outside (roots in moist sawdust and shoots exposed),
(3) Containerized, stored in cooler,
(4) Containerized, stored in cooler (under 400-watt lights for a 12-hour photoperiod), and
(5) Containerized, stored outside (roots in moist sawdust and shoots exposed).

The initial characteristics of these seedlings are shown in table 1.

The second factor, planting date, was selected to represent the length of growing season; the later a seedling is planted, the shorter is its growing season. Every 2 weeks, from February 14 through May 24, 1990, seedlings of each seedling type were planted in one 25-tree plot in each of four blocks in the Parkersburg area. Nine internal trees on each plot served as measurement trees.

Numerical Analysis

Analysis of variance for a randomized complete block, factorial experiment was performed using the ANOVA procedure in SAS to detect differences between plot-level mean treatment responses (SAS Institute 1988). Quantitative contrasts were written to evaluate trends in response parameters across planting dates. Response parameters of interest included: total height, diameter at breast height (d.b.h.), average tree volume, and survival. Cubic foot volume for the 5-year-old loblolly pines was estimated using volume equations from Owens (1969). Survival values were arcsine transformed prior to analysis. *Ad hoc* contrasts were written to test for differences between groups of seedling types using the SAS GLM procedure with CONTRAST and ESTIMATE statements. Significance levels for all tests were set at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Following 5 years, the resulting range in average tree size went from the smallest: containerized seedlings stored in the dark cooler (0.104 cubic feet) to the largest: nursery-grown seedlings stored in a dark cooler (0.132 cubic feet; table 2). Containerized seedlings stored outside had the lowest survival of 74 percent. Containerized seedlings stored in a lighted cooler had the highest average survival rate of 95 percent over all planting dates.

Averaging over all seedling types, 5-year growth characteristics decreased in the later planting dates (table 3). The seedlings planted on the last few planting dates showed less and less growth on later and later planting dates. Survival ranged from 82 to 92 percent. From this perspective, there were no apparent trends in survival through the planting period. However, planting date was treated as an ordinal variable, which permitted the exploration of potential linear, quadratic, and cubic trends across the range of planting dates.

Analysis of variance for survival showed a significant interaction between seedling type and planting date (table 4). Further, when the variation explained by this interaction

Table 1—Average initial size measurements of seedlings planted in spring of 1990 (adapted from Bridgen 1992)

Variable	Containerized			Nursery	
	Dark cooler	Light cooler	Outside	Cooler	Outside
Height (in)	6.65c[a]	6.85abc	7.05a	6.77bc	7.01ab
DGL (in)	0.11b	0.11b	0.11b	0.18a	0.17a
Number of branches	1.3 b	1.4 b	1.5 b	5.0 a	4.5 a

[a] Mean values followed by a common letter are not significantly different at alpha = 0.05 by Duncan's New Multiple Range Test.

Table 2—Average 5-year growth and survival of loblolly pine trees by seedling type

Seedling type	Height	D.b.h.	Volume per tree	Survival
	Feet	*Inches*	*Cubic feet*	*Percent*
Nursery, dark cooler	12.7	2.11	0.132	93
Nursery, outside	12.5	2.04	0.125	86
Containerized, dark cooler	11.6	1.85	0.104	86
Containerized, light cooler	12.3	2.03	0.126	95
Containerized, outside	11.9	1.91	0.113	74

Table 3—Average 5-year growth and survival of loblolly pine trees by planting date in 1990

Planting date (1990)	Height	D.b.h.	Volume	Survival
	Feet	*Inches*	*Cubic ft*	*Percent*
February 14	12.8	2.10	0.135	82
February 27	12.2	2.02	0.122	84
March 12	12.8	2.13	0.136	92
March 27	12.8	2.17	0.139	87
April 9	12.5	2.04	0.128	92
April 23	12.1	1.94	0.115	87
May 9	11.7	1.86	0.100	83
May 24	10.9	1.66	0.084	87

Table 4—Analysis of variance tables for transformed survival and average tree volume[a]

Source	p-value
Transformed survival:	
Blocks	0.05
Planting date (PD)	0.38
Linear	0.60
Quadratic	0.15
Cubic	0.09
Departure	0.66
Seedling Type (ST)	<0.01
PD X ST	<0.01
PDlinear x ST	<0.01
PDquadratic x ST	0.49
PDcubic x ST	0.78
Departure	0.58
Error	
Total	
Average tree volume:	
Blocks	<0.01
Planting date (PD)	<0.01
Linear	<0.01
Quadratic	<0.01
Cubic	0.63
Departure	0.64
Seedling Type (ST)	0.05
PD X ST	0.16
PDlinear x ST	0.27
PDquadratic x ST	0.35
PDcubic x ST	0.34
Departure	0.34
Error	
Total	

[a] Diameter and height paralleled the results for average volume. Variation due to planting date is partioned into linear, quadratic, cubic and higher order effects. Departure from a cubic model represents the additional sum of squares accounted for by a model fit through the means of each planting date (see Hicks 1984).

term was partitioned into linear, quadratic, cubic, and higher-order effects, the result showed a significant linear interaction. That is, there was evidence that one or more seedling types had linear trends in survival over the planting season.

Figure 1 shows an interaction plot for survival. Containerized seedlings, stored outside, showed a significant increasing trend in survival. High mortality was due to some kind of severe weather conditions. A maintenance log described the seedlings as “appearing frozen at the top.” This climate impact was not noticed until after a couple of planting dates had already passed, then care was taken to use only the more vigorous looking

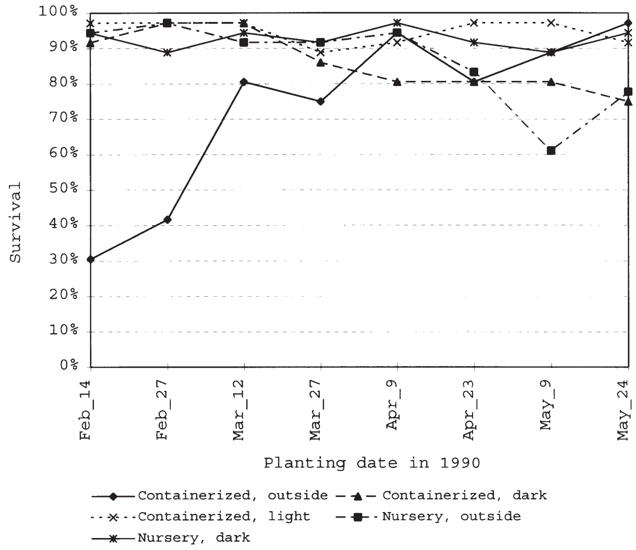

Figure 1—Five-year survival by seedling type and planting date. Value for a given planting date × seedling type combination is the average from nine seedlings in each of four blocks.

seedlings for planting at later dates. This change in procedure resulted in a significant increasing trend in survival, where the seedlings of this type had mostly over 80 percent survival for the rest of the planting dates.

There were also two significant decreasing trends in survival. Both containerized seedlings stored in the dark, and nursery-grown seedlings stored outside under mulch showed lower survival for seedlings planted at later planting dates.

For average tree volume, planting date and seedling type explained significant amounts of variation (table 4). Further, orthogonal contrasts pointed to significant quadratic trends in the data. Diameter at breast height, and total height responses paralleled the volume response. The estimated quadratic relationship between planting date and average tree volume is shown in figure 2. The quadratic function has a slight depression in the beginning of the planting season and a significant decreasing trend through the later planting dates.

Seedling type was also significant in explaining variation in 5-year growth in this study. Three important contrasts related to seedling type were performed:

(1) H_0: Stored outside = Stored in dark cooler.
(2) H_0: Nursery grown (bare-root) = Containerized.
(3) H_0: Stored in lighted cooler = Stored in dark cooler.

The first test evaluated whether outside-stored seedlings grew better than the dark cooler-stored seedlings. The results showed no evidence of any interactions or main effects in the comparison. As stated previously, the hypothesized results that would suggest negative storage effects would be no planting date effects for outside-stored seedlings and decreasing 5-year increment for cooler-stored

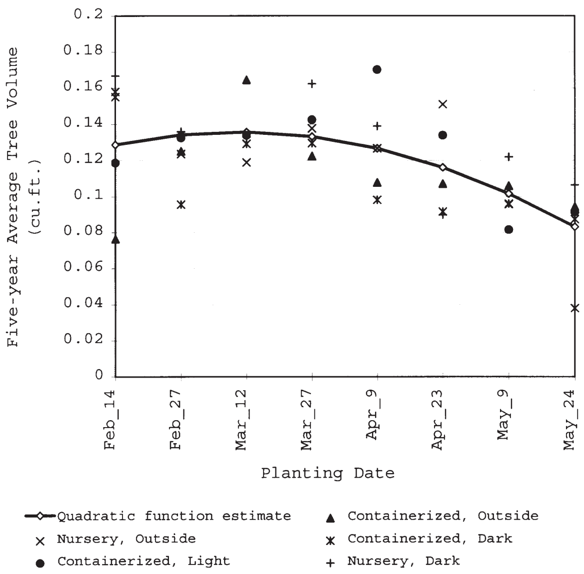

Figure 2—Estimate (line) of quadratic relationship between average tree volume and planting date.

seedlings (leading to a significant seedling type × planting date interaction in the analysis of variance). Thus, the effects of a shortened growing season far overshadow any suggestion that prolonged storage affected these seedlings.

When testing for differences between nursery-grown and containerized seedlings, the nursery-grown seedlings performed slightly better on average than the containerized seedlings. Nursery-grown seedling types were 0.86 feet taller ($p<0.01$), 0.19 inches d.b.h. larger ($p<0.01$), and 0.02 cubic feet greater ($p<0.01$) than containerized seedling types at the end of 5 years.

Containerized seedlings stored in the lighted coolers performed better than containerized seedlings stored in a dark cooler. Containerized seedlings were 0.75 feet taller ($p=0.02$), 0.18 inches d.b.h. larger ($p=0.02$), and 0.02 cubic feet greater ($p=0.03$) than containerized seedlings stored in a dark cooler. This suggests some improvement in the lighted storage conditions over dark storage.

Few studies have investigated the effects of photoperiod during cold storage (Rose 1985). However, in one study, lighted cooler storage of nursery-grown loblolly pine was shown to increase bud activity, accelerate budbreak, and increase first-year height growth (Johnson 1982). Loblolly pine photosynthesizes at temperatures as low as 8 °C. While the cooler temperatures were kept at 4 °C, leaf temperature may have been higher with the high intensity lights. If the lighted-cooler seedlings were actively photosynthesizing, depletion of stored carbohydrate may have been reduced and would have been at higher levels than dark-stored seedlings at the time of planting.[2] This study did not include a lighted, cold storage treatment for nursery-grown seedlings. If containerized seedlings require cold storage, their subsequent field performance may be improved by providing a simulated photo-period. However, prior to implementation, further studies should address this option.

This study assessed the impact of a shortened first growing season on subsequent 5-year tree growth for a single planting season. National Weather Service station data from Parkersburg showed higher than average minimum temperatures through March of 1990, but precipitation was well within the range of 10-year observations (except for May having high rainfall). Obviously, each planting season is different with changing patterns of temperature, rainfall, and soil conditions; however, 1990 did not seem to have unusually extreme climatic variation. Still, generalizations of these results should consider these important year-to-year variations in site conditions. Future research investigating plantation establishment would benefit by replicating the study for several years.

CONCLUSIONS

The effects of a shortened first-year growing season in 1990 were evident 5 years following planting. Five-year height, diameter, and volume showed a decreasing trend for plantings made after mid-April. This reduction in 5-year volume shows the importance of early rotation cultural treatment to long-term productivity.

Seedlings stored outside, theoretically having higher physiological activity, did not show consistently greater 5-year height, diameter, or volume growth than seedlings stored in unlighted coolers.

Containerized seedlings stored in lighted coolers in this study had improved 5-year growth over containerized seedlings stored in dark coolers. Lighted coolers may have lowered the depletion rate of these loblolly seedlings, thus improving their physiological condition over those stored in unlighted coolers.

Nursery-grown seedlings produced greater 5-year growth than containerized planting stock. The growth differences may have been due to the initial size, particularly the number of branches and caliper, of the nursery stock at the outset of the study.

The results of this study suggest that loblolly pine plantations in the mid-Ohio Valley near Parkersburg, WV, should be planted by mid-April. Planting before mid-April will avoid the reduced growth associated with a shortened first-year growing season.

ACKNOWLEDGMENT

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[2] P.M. Dougherty, personal communication.

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POTENTIAL PROBLEMS WHEN PARTIAL CUTTING IN OVERSTOCKED STANDS OF MATURE SHORTLEAF PINES TO ENHANCE NATURAL REGENERATION

Michael D. Cain[1]

Abstract—A single-tree selection reproduction cut was imposed in a mature, overstocked, natural even-aged stand of shortleaf pines (*Pinus echinata* Mill.) in southeastern Arkansas using basal area—maximum diameter—quotient (BDq) regulation to mold an uneven-aged structure. Hardwood control treatments were applied before and after the reproduction cut to facilitate natural pine regeneration. The effort was hampered by wet summer weather which coincided with the scheduled harvest, a below-average pine seed crop during the winter after harvest, a severe ice storm, and high mortality of residual pines. Recommendations are provided to assist forest managers in circumventing similar problems at the operational level.

INTRODUCTION

When naturally regenerating the southern pines, four reproduction cutting methods are generally recognized. These include the clearcutting method, the seed-tree method, the shelterwood method, and the selection method (Smith 1986). The first three methods result in even-aged stands, whereas the latter technique produces stands with uneven-aged structure. Because of public concerns about the ecological consequences of even-aged management, plans are underway to increase the acreage of uneven-aged stands on some national forests in the Southeastern United States (USDA FS 1990). Uneven-aged management may also serve private nonindustrial forest landowners as a low-investment silvicultural technique (Williston 1978). In the selection system, some trees are harvested regularly as individuals or in groups, with total volume cut at any one time being roughly equal to the growth that occurred since the last harvest (Reynolds and others 1984).

Because loblolly and shortleaf pines (*Pinus taeda* L. and *P. echinata* Mill.) are shade intolerant, certain guiding principles must be followed to secure adequate natural regeneration from these two species in uneven-aged silviculture. These principles involve maintenance of appropriate stocking, regulation of stand structure, and control of competing vegetation (Baker and others 1996). The purpose of this paper is to examine the problems that were encountered in a silvicultural study during conversion of a mature, overstocked, natural even-aged shortleaf pine stand to uneven-aged structure, and to offer suggestions for circumventing such problems. Results were part of a broader investigation to monitor the efficacy of hardwood control treatments for improving pine establishment from seed.

METHODS

Study Area

The study was located within a 36-acre compartment on the Crossett Experimental Forest in southeastern Arkansas. Bude silt loam (Glossaquic Fragiudalf) occurs on 75 percent of the area, and Providence silt loam (Typic Fragiudalf) occupies the other 25 percent (USDA 1979). Both soils have a site index of 85 to 90 feet at 50 years for shortleaf pine. Although the terrain is essentially flat, wetness can limit equipment use during tree harvesting because the soils have a fragipan at a depth of 18 to 24 inches that restricts internal drainage. At the time of study installation, pine and hardwood basal area averaged about 100 square feet per acre and 50 square feet per acre, respectively. There had been no harvests or hardwood control in over 20 years, and the pines averaged more than 50 years old.

Field Methods

The compartment was subdivided into six blocks containing 6 acres each. Three blocks were randomly assigned a preharvest prescribed winter burn, and three blocks were not burned. Within each burned and unburned block, four hardwood control treatments were randomly assigned along with an untreated check. Hardwood control treatments included chain-saw felling or herbicide injection, both before and after a single-tree selection harvest (Cain 1995). Hardwood control plots were 104.4 feet by 104.4 feet (0.25 acre) with 66-feet by 66-feet (0.1 acre) interior measurement subplots. Within each interior subplot, ten 1-milacre sample quadrants were systematically established and monumented for assessing ground coverage from herbaceous vegetation (forbs, grasses, semiwoody plants, and vines) and submerchantable-sized hardwoods (including shrubs). One year after hardwood control, ground cover was ocularly estimated to the nearest 10 percent by vertical projection of foliar cover to the ground.

The objective of the single-tree selection harvest was to mold the residual stand so that the diameter distribution resembled a reversed-J or uneven-aged structure. Merchantable-sized (>3.5 inches d.b.h.) shortleaf pines were tagged for retention on each plot according to the basal area—maximum diameter—quotient (BDq) technique (Farrar 1984). The BDq technique involves the following guidelines, in order of importance: (1) a specific basal area should be left in residual trees after harvest; (2) all trees larger than a maximum diameter should be removed unless some are needed to achieve the target basal area; and (3)

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the residual diameter distribution should approach a balanced uneven-aged structure, characterized by a constant ratio (q) between the number of trees in succeeding diameter classes. Guidelines for applying the BDq in this study were a basal area of 60 square feet per acre in pines >3.5 inches d.b.h., a maximum d.b.h. of 22 inches, and a q of 1.22 for 1-inch d.b.h. classes. Although pine basal area was prescribed at 60 square feet per acre within each 0.25-acre plot, an additional 6 square feet per acre (10 percent) was retained to account for postharvest mortality.

Merchantable-sized pines, reserved as crop trees, were measured to an accuracy of 0.1 inch before harvest and at 1 and 3 years after harvest. In June 1992, about 35 square feet per acre of pine basal area was removed from each plot during the single-tree selection harvest. Throughout the 36-acre compartment, the logging contractor harvested an average of 5,300 fbm per acre (Doyle scale) in pine saw logs.

During the three winters following harvest, shortleaf pine seedcrops were monitored on the area. One seed trap (Cain and Shelton 1993) was placed at the northeast corner of each hardwood control plot and these were visited monthly between October 1 and March 1 for seed collection. A less-intensive assessment was made of the preharvest shortleaf pine seedcrop by monitoring seed catch in five systematically spaced seed traps during the winter before harvest. Collected pine seeds were cut open to determine the number of potentially viable seeds per acre (PVSA). Because of a below-average shortleaf pine seedcrop during the first winter after harvest, study plots were direct seeded with repellent-treated shortleaf seeds at the rate of 0.5 pound per acre during February 1993. The germinative capacity of these seeds was 92 percent according to a 30-day indoor germination test on moist sand.

Data Analysis

Data were analyzed by analyses of variance for a split-plot design. The main effects were prescribed burning versus no burning, with each burning treatment replicated three times completely at random in the 36-acre compartment. Subeffects were four hardwood control treatments and an untreated check. Analyses of variance were used to compare (1) pine seedcrops among years, (2) ocular estimates of ground coverage from competing vegetation, and (3) development of merchantable-sized pines among hardwood control treatments. Ground coverage and crop pine survival were compared following arcsine, square-root proportion transformation of percentage values. Since there were no statistically significant effects (P>0.05) from the burn treatments and no burn by hardwood-control interaction in analyses of variance, only means from hardwood control treatments are presented here. A linear regression was fitted for mortality of crop pines relative to d.b.h. All analyses were carried out at the α=0.05 probability level (P).

RESULTS AND DISCUSSION

Shortleaf Pine Seedcrops

The potential size of a seedcrop is probably the most important criterion for ensuring the success or failure of any natural reproduction cutting method for loblolly and shortleaf pines (Cain 1991). According to Liming (1945), 1 pound of viable seeds per acre (about 50,000 PVSA) is required for successful natural regeneration of shortleaf pines. In the present study, shortleaf pines produced over 800,000 PVSA during the winter before harvest. The first seedcrop after harvest—the most critical for regeneration purposes—was below average at about 45,000 PVSA, which necessitated direct seeding of study plots. That number was greatly exceeded (P<0.01, Mean Square Error=9.347E09) during the second winter (about 1,500,000 PVSA) and third winter (over 500,000 PVSA) after harvest.

Trousdell (1954) proposed that seedbeds in Virginia would remain receptive for loblolly pine establishment 3 years after site disturbance. However, just one growing season after hardwood control in the present study, ground coverage averaged 26 percent from submerchantable-sized hardwoods and 85 percent from herbaceous vegetation (table 1), with no differences (P>0.05) among hardwood control treatments. This degree of competition diminished seedbed receptivity so greatly that no additional shortleaf pine seedlings could become established even when pine seedcrops were more than adequate during the next two winters after hardwood control.

Table 1—Ground cover from submerchantable-sized hardwoods and herbaceous vegetation one growing season after hardwood control

Hardwood control treatment	Ground cover[a]: Submerchantable hardwoods	Ground cover[a]: Herbaceous vegetation
	- - - - - - - - - - *Percent* - - - - - - - - - -	
Untreated check	22	79
Herbicide injection before harvest	23	91
Herbicide injection after harvest	30	85
Chain-saw felling before harvest	31	85
Chain-saw felling after harvest	25	84
Mean square error	0.0115	0.0233
P>F[b]	0.44	0.16

[a] Submerchantable hardwoods are woody, nonpine rootstocks less than 3.6 inches d.b.h., including woody shrubs. Herbaceous vegetation includes forbs, grasses, semi-woody plants, and vines.
[b] The probability of obtaining a larger F-ratio under the null hypothesis.

Merchantable Pine Basal Area

Optimum stocking of loblolly and shortleaf pines for maximum growth of both merchantable trees and pine regeneration is between 45 and 75 square feet of basal area per acre (Baker and others 1996). Therefore, basal area in residual pines of merchantable size was specified as 60 square feet per acre, with an extra 10 percent allowance for mortality at the time of initial harvest. Three years after the initial single-tree selection harvest, merchantable pine basal area averaged only 48 square feet per acre, with no differences (P>0.05) among treatment means (table 2) for reasons described below.

The initial harvest was conducted within a 4-week window in June 1992, so that hardwood control treatments could be applied while the trees were actively growing, both before and after harvest. Consequently, completion of harvest during this window was specified in the logging contract, regardless of the weather. Removal of cut trees was accomplished with articulated rubber-tired skidders. By happenstance, June 1992 had above-average rainfall (10 inches) when compared to the previous 65-year mean (4 inches) for that month. These wet conditions resulted in undesirable rutting of the soil and, no doubt, pine root damage from skidders, across the entire 36-acre compartment. Slick soil conditions contributed to poor traction, so the skidders often slid into some residual pines, scraping away patches of bark and exposing the tree's cambium. Even when inclement weather is not a consideration during a logging operation, some damage to residual trees should be expected when using a single-tree selection harvest in an initial basal area reduction cut to bring an even-aged stand to uneven-aged structure. For example, Kluender and Stokes (1994) reported that the use of rubber-tired skidders resulted in unspecified damage to 17 percent of residual trees during an initial single-tree selection harvest that removed 29 percent of merchantable-sized pines on a 52-acre tract in northwest Arkansas.

By spring 1993, there was an infestation of bark beetles (*Dendroctonus* spp. and *Ips* spp.) in residual pines. This infestation was attributed to the weakened condition of the trees as a result of thinning shock (Oliver and Larson 1990), root damage from wet-weather logging (Moehring and Rawls 1970), cambium exposure, or a combination of these factors. Subsequently, a salvage contract was written to remove these infested trees in an effort to control the insect activity. During the salvage in June 1993, 15,660 fbm (Doyle scale) were removed from the 36-acre compartment (440 fbm per acre in trees 10 to 25 inches d.b.h.).

In February 1994, an ice storm of historic significance (Halverson and Guldin 1995) resulted in collapse of some crop pines and limb breakage on others. This disturbance further exacerbated the bark beetle infestation. During summer 1994, another salvage contractor removed 29,560 fbm (Doyle scale) of dead and dying pines from the compartment (820 fbm per acre in trees 5 to 24 inches d.b.h.). Basal area loss in merchantable pines, that occurred after the June 1992 harvest and before an October 1995 inventory, averaged 18 square feet per acre, with no statistically significant differences (P=0.80) among hardwood control treatments (table 2). The change in basal area from one inventory to the next included both increases from growth and decreases from mortality. On good sites (site index >85 feet at 50 years for shortleaf pine), basal area growth in a well-regulated uneven-aged pine stand should average 3 square feet per acre per year (Baker and

Table 2—Status of crop pines 3 years after the initial harvest

Hardwood control treatment	Basal area: Residual trees	Basal area: 3-year loss	3-year survival	Annual d.b.h. growth
	- - - - - - Ft^2/acre	- - - - - -	*Percent*	*Inches*
Untreated check	53.6	12.8	70	0.069
Herbicide injection before harvest	50.8	16.7	64	0.086
Herbicide injection after harvest	45.8	18.7	63	0.076
Chain-saw felling before harvest	42.7	22.8	56	0.072
Chain-saw felling after harvest	45.1	19.5	58	0.061
Mean square error	203.8	196.0	0.067	0.00046
P>F[a]	0.68	0.80	0.71	0.41

[a] The probability of obtaining a larger F-ratio under the null hypothesis.

others 1996). Therefore, the projected loss in merchantable pine basal area in this study averaged about 27 square feet per acre between autumn 1992 and autumn 1995.

Chapman (1941) proposed that, in the absence of early thinning in pine stands, crowns of loblolly pines are often reduced to less than 40 percent of total height. According to Chapman, subsequent selection thinning of previously unthinned stands that are older than 50 years often results in heavy mortality of released trees. To test Chapman's hypothesis in the present study, total height and height to live crown were measured during February 1996 on 10 shortleaf pines that appeared healthy, and on 10 shortleaf pines with sparsely foliated crowns and an unhealthy appearance. The sample pines ranged from 12 to 22 inches d.b.h. Live-crown ratio averaged 37.4 percent for the healthy pines and 35.9 percent for the unhealthy pines. Although these data suggest that a low live-crown ratio was probably not responsible for the most recent decline of residual shortleaf crop pines in the present investigation, no crown data are available from pines that died or were salvaged before 1996.

In mid-January 1996, a visual inspection was made of 30 shortleaf pines in various stages of decline to determine whether annosus root rot [*Heterobasidion annosum* (Fr.) Bref., formerly *Fomes annosus* (Fr.) Karst.] might be causing pine mortality. This time of year was chosen because indicator conks are most common from December through March (USDA FS 1989). Litter was removed from around the base of these dead and dying pines, but there was no visual evidence of butt-rot conks. Moreover, finer textured soils, such as occur on the Crossett Experimental Forest, are classified as low hazard for annosus root rot. A more definitive assessment of root disease would require laboratory examination of pathogen cultures.

Bormann (1966) theorized that intraspecies root grafting can permit trees of low vigor to survive by using a food gradient from dominant trees. He noted that this energy transfer is probably important to the survival of low-vigor trees and may account for the observation that weak trees often die after removal of larger members of a stand. Because shortleaf pines dominate the present study area, their root systems may have naturally grafted through time. If so, heavy thinning in 1992 reduced the root-to-shoot ratio of residual pines to the point that the aboveground mass could no longer be sustained by a smaller root system. The greatest crop pine mortality occurred in the smallest d.b.h. classes (fig. 1) where pines were least thrifty due to years of suppression in the undisturbed stand. Similar trends were reported by Chaiken (1941) after partial cutting in a mature loblolly pine stand.

In autumn 1995, survival of crop pines on study plots averaged 62 percent, with no differences (P=0.71) among hardwood control treatments (table 2), suggesting uniform mortality across the compartment. Annual d.b.h. growth of these surviving pines averaged only 0.073 inch per year, also with no differences (P=0.41) among hardwood control plot means (table 2). Yet, on this site, healthy pines with

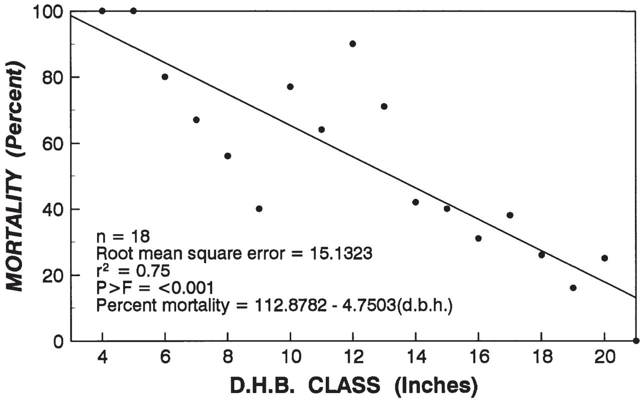

Figure 1—Mortality (percent of reserved pines) as related to d.b.h. during 3 years following partial cutting.

well-developed crowns and room to grow should average 0.3 inch of d.b.h. growth per year (Reynolds and others 1984).

SUMMARY AND RECOMMENDATIONS

Site treatments to ameliorate seedbed conditions for natural pine regeneration are most advantageous when applied just before a better-than-average seed year (Cain 1991). Had the hardwood control treatments and single-tree selection harvest been conducted 1 year previous-to or 1 year later-than what actually occurred in this investigation, good rather than marginal shortleaf pine seed crops would have been disseminated onto the study area. This is important because 1 year after hardwood control, receptive seedbed conditions disappeared on this good site due to invasion by herbaceous and woody nonpine vegetation.

Basal area of merchantable-sized pines was reduced to 66 square feet per acre in a single harvest that removed over 5,000 fbm per acre (Doyle scale). Basal-area reduction was accomplished in one operation so that the efficacy of hardwood control treatments could be assessed when applied before and after a single harvest within the same growing season. Operationally, however, and to avoid excessive mortality of residual pines from thinning shock, pine basal area should be reduced to an acceptable level for uneven-aged management by employing two harvests whenever initial stocking exceeds 90 square feet per acre (Baker and others 1996). The first cut should reduce basal area to about 80 square feet per acre, and 3 to 5 years later, a second cut should reduce basal area to 60 square feet per acre. Because pines were not thrifty in the smaller d.b.h. classes, retention of dominant and codominant pines as crop trees would have been more judicious in this investigation than trying to mold an uneven-aged structure by using BDq guidelines in the initial harvest.

To facilitate the application of hardwood control treatments during a single growing season, before and after harvest, June was chosen as the month of harvest. Based on 65 years of precipitation records, June is normally a dry month in southeastern Arkansas. However, June of 1992 was exceptionally wet, with precipitation that was 6 inches above normal. Use of articulated rubber-tired skidders to remove the high volume of cut pines during these wet conditions resulted in undesirable rutting of the soil and probably caused root damage to residual pines. Because of poor traction on these wet soils, skidders often slid into residual pines, resulting in bark removal near the butt section and exposure of the cambium to insect attack. Operationally, the harvest would have been postponed as soon as the soil could not support the logging equipment.

Because of reduced vigor in residual pines following the single-tree selection harvest, bark beetles infested the area and caused considerable mortality. A salvage cut in June 1993 removed an average of 440 fbm per acre (Doyle scale) in dead and dying pines to stop the infestations. However, a severe ice storm in February 1994 caused breakage of limbs on some remaining pines and complete collapse of other pines. This damage further weakened the residual pines and the bark beetle infestation continued. A second salvage cut was made in the summer of 1994, removing 820 fbm per acre of dead and dying trees to again slow the beetle activity.

The message from this 3-year investigation is quite clear. For a natural reproduction cutting method to be successful, forest managers must pay close attention to site, stand, and weather conditions and plan for unusual events. Lack of attention to detail may result in undesirable consequences that are not consistent with short-term management objectives.

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EFFECTS OF OPENING SIZE ON PINE AND HARDWOOD REGENERATION 3 YEARS AFTER GROUP SELECTION CUTTING IN SOUTHERN ARKANSAS

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Abstract—Openings of three sizes (0.25, 0.625, and 1.0 acres) were created in a pine-hardwood stand dominated by loblolly pine (*Pinus taeda* L.), shortleaf pine (*P. echinata* Mill.), and sweetgum (*Liquidambar styraciflua* L.). A randomized complete block design was used with three replicates, and about 16 percent of the total stand area was in openings. Pines in the residual stand were thinned to a merchantable basal area of 75 square feet per acre, but hardwoods, which averaged 30 square feet per acre, were not thinned. Monitoring included: (1) regeneration and competing vegetation before harvesting and after the first and third growing seasons, (2) seedbed conditions after harvesting, and (3) pine seed production through the third year. The 0.25-acre openings had more undisturbed litter and mineral soil but less logging debris than larger openings. The pine seed supply near the center of the 0.25-acre openings was nearly twice that of the 1.0-acre openings. Seedling densities did not significantly differ among openings after 3 years and averaged 3,833 and 920 seedlings per acre for pines and oaks, respectively. Although pine regeneration was significantly shorter in the 0.25-acre openings than in larger openings, more time will be needed to determine the optimum opening size.

INTRODUCTION

Group selection is an uneven-aged reproduction cutting method that is reputed to favor the more shade-intolerant species by creating larger openings than single-tree selection. However, less is known about group selection than about any of the other natural reproduction cutting methods (Murphy and others 1993). The goal of group selection is to create or maintain an uneven-aged stand by making a number of small openings during each cutting cycle, in addition to thinning the residual stand as needed. The regeneration effort is focused within the distinctive openings. If group selection is applied over several cutting cycles, a fragmented stand composed of small even-aged groups should result, but this has yet to be tested over a long time period in the Southern United States. The larger openings provided with group selection do not appear to be needed for pine regeneration when traditional stocking guidelines for single-tree selection are followed (Baker and others 1996). However, group selection seems to have merit when a significant hardwood component is desired because the larger openings provide the higher light intensities needed by the shade-intolerant pines and the intermediate-tolerant oaks.

The environmental requirements for regeneration of targeted species are critical to setting suitable opening sizes. Experience suggests that large openings will favor the establishment and development of the more shade-intolerant species, but large openings are also felt to have poor visual qualities by some forest users. Thus, the optimum opening size would be the smallest one that provides a favorable environment for regenerating targeted species. In 1992, a study was installed in southern Arkansas to provide information on applying the group selection system in pine-hardwood stands; results through the first 3 years are presented in this paper.

METHODS

Study Site

The study was installed in a 34-acre, second growth pine-hardwood stand located in the Crossett Experimental Forest in Ashley County, AR. Soils in the study area are mapped as the Bude series (Glossaquic Fragiudalfs). This soil occurs on broad upland flats and has a silty loam surface horizon and a clayey subsurface. Site index is 85 to 90 feet for loblolly pine (*Pinus taeda* L.) at 50 years.

Before harvesting, merchantable basal areas averaged 84 square feet per acre for loblolly and shortleaf (*P. echinata* Mill.) pines [trees with a diameter at breast height (d.b.h.) of 4.6 inches and larger] and 30 square feet per acre in hardwoods (trees with d.b.h. of 5.6 inches and larger). The hardwoods were mostly in midcanopy positions. Sweetgum (*Liquidambar styraciflua* L.) was the dominant hardwood, accounting for 64 percent of the merchantable hardwood basal area; mixed oaks (*Quercus* spp.) accounted for 29 percent. In addition, 17 square feet per acre in basal area was present in submerchantable hardwoods (trees from 0.6 to 5.5 inches d.b.h.). The most common submerchantable species was flowering dogwood (*Cornus florida* L.) (44 percent of the submerchantable basal area), followed by sweetgum (30 percent), blackgum (*Nyssa sylvatica* Marsh.) (12 percent), and mixed oaks (6 percent). There were no submerchantable pines. The stand was prescribed burned in February 1992, which was during the dormant season before harvest.

Study Design and Treatment Implementation

Treatments were circular openings with areas of 0.25, 0.625, and 1.00 acres. These openings had diameters that were about 1.1, 1.8, and 2.2 times the height of the dominant trees in the surrounding stand (about 105 feet). Each opening size was replicated three times in a randomized, complete block design. Adjacent openings were separated by at least 100 feet, and about 16 percent

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of the total stand area was in openings. Because stand conditions were uniform, openings were located systematically within the 34-acre stand. Boundaries were established for each opening, and all merchantable pines and hardwoods occurring within the area were marked for harvest. The stand between the openings was marked to leave 75 square feet per acre of pine basal area; marking was for an improvement cut focusing on the pine sawtimber. No hardwoods were marked outside the openings.

Harvesting was conducted during November and December 1992. The only restriction imposed on loggers was that no trees from one opening could be skidded through another opening; this prevented greater traffic from occurring in the openings near landings. The loggers removed the pine sawtimber first and then the pine and hardwood pulpwood. Pine sawtimber was skidded in 34-foot lengths using rubber-tired skidders. Pulpwood was cut in 5-foot lengths and hauled to landings by forwarders. The timber volume removed within openings averaged 3,416 cubic feet per acre, of which 10 percent was pine pulpwood, 23 percent hardwood pulpwood, and 67 percent pine sawtimber. The thinning in the residual stand averaged a total of 377 cubic feet per acre, of which 15 percent was pine pulpwood and 85 percent was pine sawtimber.

Removal of the submerchantable hardwoods within openings was delayed until October 1993 (after the first growing season) because few residual stems existed after harvesting. All submerchantable hardwoods with d.b.h. ≥ 1 inch were stem-injected with Tordon® 101R.

Measurements

Within each opening, permanent points were systematically located to monitor regeneration and seedbed conditions. There were 9, 13, and 17 points in each of the 0.25-, 0.625-, and 1.0-acre openings, respectively. The sample points were located so that each represented an equal area, which prevented any bias caused by bordering trees. One point was located at the opening center. The remaining points were located along eight radii, beginning at 0 degrees and repeated at 45-degree intervals.

Seedbed conditions were evaluated immediately after the completion of harvesting at 12 locations along a 24-foot line transect with the midpoint positioned at each permanent point. The seedbed at each location was classified as undisturbed litter, disturbed litter, exposed mineral soil, logging debris, or natural features (mainly coarse woody debris not associated with logging).

Regeneration inventories were conducted at the permanent points during September 1992 (before harvest), October 1993 (after the first growing season), and September 1995 (after the third growing season). Woody plants in the seedling size class (≤0.5 inches in d.b.h.) were counted by species or species group in a circular milacre plot (3.72 feet in radius) centered around each permanent point. Seedlings were recorded by the following size classes: ≤0.5, 0.6 to 2.5, and 2.6 to 4.5 feet in height, and ≥4.6 feet in height but ≤0.5 inch in d.b.h. Seedlings with multiple stems were tallied as one rootstock. Stems of woody plants in the sapling size class (0.6 to 3.5 inches in d.b.h.) were counted by 1-inch d.b.h. classes and by species or species group in a 0.01-acre plot (11.78 feet in radius) around each permanent point. Coverage of understory vegetation was ocularly estimated within each milacre plot to the nearest 10 percent for grasses, forbs, vines, shrubs, hardwoods, pines, and total vegetation.

During the 1995 inventory, the two tallest pines and the two tallest nonpine woody plants within each milacre plot (if present) were measured for groundline diameter (to 0.04 inch) and height (to 0.1 foot). These stems were also classified as being free to grow or overtopped by understory vegetation, and the species group of overtopping vegetation was recorded.

Pine seed production was monitored from October 1993 through February 1995 in three 0.9-square foot seed traps (Cain and Shelton 1993) per opening; traps were located 20 feet from the opening center in a triangular pattern. Seeds were collected during the middle and end of each October-to-February period. Seed viability was determined by splitting seeds and inspecting the contents (Bonner 1974). Seeds with full, firm, undamaged, and healthy tissue were judged to be potentially viable and were recorded as sound seeds.

Data Analysis

Mean values were calculated for the regeneration plots for each opening. Milacre plots were considered stocked by pine or hardwood regeneration if at least one seedling represented the species or species group. To facilitate presentation of regeneration results, species were grouped by genus for the pines and oaks. Other woody vegetation was grouped by potential stature and form as follows: (1) other canopy trees, principally ashes (*Fraxinus* spp.), blackgum, sweetgum, and hickory (*Carya* spp.); (2) midcanopy trees, principally dogwood, red maple (*Acer rubrum* L.), black cherry (*Prunus serotina* Ehrh.) and winged elm (*Ulmus alata* Michx.); and (3) shrubs, principally American beautyberry (*Callicarpa americana* L.), sumac (*Rhus* spp.), and huckleberries (*Vaccinium* spp.).

Analysis of variance for a randomized, complete block design was used to test for treatment differences, which were isolated by using the Ryan-Einot-Gabriel-Welsch Multiple Range Test at the 0.05 probability level (*P*). This procedure, which is one of the most powerful step-down, multiple-range tests available, controls the experiment-wise error rate (SAS Institute 1989). Changes in regeneration and understory coverage through time were analyzed as a split-plot in time (Steel and Torrie 1980).

RESULTS AND DISCUSSION

Seedbed Conditions

The harvesting operation modified the existing seedbed conditions by disturbing litter, exposing mineral soil, and creating logging debris. The 0.25-acre openings had significantly less logging debris and significantly more exposed mineral soil than the larger openings (table 1). Undisturbed litter in the 0.25-acre opening was nearly twice that in the larger openings, although this difference was not significant. The lower percentage of exposed mineral soil in the 0.625- and 1.0-acre openings probably reflected the covering of mineral soil by logging debris. The lower percentage of logging debris in the 0.25-acre openings appeared to be related to the small opening diameter (118 feet) and the great height of the dominant and codominant pines (over 100 feet)—the crowns of cut trees tended to fall outside the opening's boundary.

Pine Seed Supply

The seed supply was not monitored during the fall and winter of 1992-93 because the stand was being harvested. However, nearby stands that were similar to the one in this study produced about 80,000 sound seeds per acre, which was a below-average seed crop (Cain and Shelton 1996).

The 0.25-acre openings consistently had about twice as many seeds dispersed near their center as the 1.0-acre openings, but differences were significant only during 1994-95 and for sound and total seeds (table 2). This dispersal pattern reflected the distance from the seed traps to the bordering trees—39 feet in 0.25-acre openings, 73 feet in 0.625-acre openings, and 98 feet in 1.0-acre openings. Pomeroy (1949) described a similar dispersal pattern for pine seeds into clearcut strips. A bumper seed crop was produced during 1993-94 when more than 1,000,000 sound seeds per acre were dispersed into the 0.25-acre openings. This was followed by an above-average seed crop the next year, when about 250,000 sound seeds per acre occurred in the 0.25-acre openings. The dispersal of seeds within the 1.0-acre openings should not adversely affect regeneration when seed crops are average or better, but may limit regeneration during marginal years.

Table 1—Seedbed conditions after the initial harvest implementing group selection in a pine-hardwood stand in southern Arkansas

Condition	Opening area (acres)[a] 0.25	0.625	1.0	Mean square error	*P*
	- - - *Percent of area* - - -				
Undisturbed litter	21	10	10	33.5	0.12
Disturbed litter	32	30	28	49.2	0.78
Mineral soil	16a	8b	6b	12.1	0.05
Logging debris	27b	49a	50a	27.7	0.01
Natural feature[b]	4	3	6	5.9	0.46

[a] Row means followed by different letters are significantly different (*P*=0.05) by the Ryan-Einot-Gabriel-Welsch Multiple Range Test.
[b] Mainly coarse woody debris not associated with logging.

Table 2—Dispersal of pine seeds near the opening center after the initial harvest implementing group selection in a pine-hardwood stand in southern Arkansas

Seed condition and year	Opening area (acres)[a] 0.25	0.625	1.0	Mean square error	*P*
	- - - - *1,000 per area* - - - -				
Sound					
1993-94	1,300	820	560	154,000	0.19
1994-95	260a	90b	140b	3,090	0.04
Unsound					
1993-94	620	470	320	33,700	0.25
1994-95	250	170	150	2,120	0.12
Total					
1993-94	1,920	1,290	880	315,000	0.20
1994-95	510a	260b	290b	1,650	<0.01

[a] Row means followed by different letters are significantly different (*P*=0.05) by the Ryan-Einot-Gabriel-Welsch Multiple Range Test.

Regeneration Density and Stocking

An average of 1,387 pine seedlings per acre occurred before harvesting, and milacre stocking averaged 43 percent (table 3). Most of these seedlings were less than 0.5 feet tall and developed from the 1991-92 seed crop. The presence of pine seedlings before harvesting demonstrates that pine regeneration can periodically become established even beneath a closed canopy, but these seedlings will gradually die because of shading

Table 3—Density and stocking of pine seedlings before and after the initial harvest implementing group selection in a pine-hardwood stand in southern Arkansas

Property and growing season	Opening area (acres) 0.25	0.625	1.0	Mean square error	*P*
	- - - - *Stems per acre* - - - -				
Density					
Preharvest	960	1,800	1,400	1.02E6	0.60
First	960	2,400	1,900	4.37E5	0.12
Third	4,100	3,900	3,500	2.69E6	0.89
	- - - - - - - *Percent* - - - - - -				
Milacre stocking					
Preharvest	29	62	39	4.19E2	0.25
First	45	64	63	1.72E2	0.25
Third	52	72	61	4.75E2	0.57

(Cain and Shelton 1995). Some of the existing seedlings were destroyed during logging, but others survived. In addition, this base was supplemented by seedlings developing from the 1993-94 seed crop, resulting in an average of 1,750 seedlings per acre and 57 percent milacre stocking after the first growing season. Seedling density in the 0.25-acre openings averaged considerably lower than that in the larger openings, but differences were not significant. By the third growing season, however, the pine regeneration was very similar in all openings, averaging 3,833 seedlings per acre and 62 percent milacre stocking. These levels of regeneration are considered adequate by uneven-aged guidelines (Baker and others 1996). There were no pines in the sapling size class during any inventory.

Density of nonpine woody stems in the seedling size class was not significantly affected by opening size either before or after harvesting (table 4). Mean densities ranged from about 4,000 to about 10,000 rootstocks per acre and are typical of similar sites and stand conditions (Cain 1994, Cain and Shelton 1995).

Density of nonpine woody rootstocks in the sapling size class was very uniform before harvesting, ranging from 500 to 600 stems per acre (table 4). Many of these saplings were killed or damaged during logging, which reduced density to about 200 stems per acre in the 0.25-acre openings and to about 100 stems per acre in the larger openings. This difference was significant and reflected the greater logging disturbance in the larger openings, where high timber volumes were removed and where skidder maneuvering and traffic were less restricted by bordering trees than in the 0.25-acre openings. The saplings existing after the first growing season were stem-injected with herbicide shortly after they were inventoried. Thus, the saplings present after the third growing season (200 to 300 stems per acre) represented outgrowth from the seedling size class.

The species groups making up the nonpine seedlings and saplings are shown in table 5. Most of the seedlings were midcanopy species (33 percent) and shrubs (38 percent). However, there were also 920 rootstocks per acre for the oaks after the third growing season and 600 rootstocks per acre for the other canopy species group. Thus, there appears to be ample regeneration of desirable species to achieve the mixed pine-hardwood regeneration goal for the stand. The changes in seedling density through time reflected: (1) mortality of existing seedlings, chiefly from logging disturbance and self thinning; (2) sprouting of cut or damaged stems; (3) outgrowth of seedlings to the sapling size class; and (4) new seedlings developing from seed.

Table 4—Seedling and sapling density for all nonpine woody species before and after the initial harvest implementing group selection in a pine-hardwood stand in southern Arkansas

Size class and growing season	Opening area (acres)[a] 0.25	0.625	1.0	Mean square error	*P*
	- - -*Rootstocks per acre* - - -				
Seedlings					
Preharvest	4,150	9,540	8,660	8.28E6	0.16
First	9,970	8,640	9,340	4.02E6	0.72
Third	7,170	6,310	6,970	2.41E5	0.24
	- - - - *Stems per acre* - - -				
Saplings					
Preharvest	600	515	512	2.80E5	0.78
First[b]	211a	98b	95b	9.19E2	0.02
Third	300	220	200	2.87E3	0.15

[a] Row means followed by different letters are significantly different (*P*=0.05) by the Ryan-Einot-Gabriel-Welsch Multiple Range Test.
[b] These saplings were stem-injected with herbicide shortly after the inventory.

Table 5—Seedling and sapling density for hardwood and shrub species groups before and after the initial harvest implementing group selection in a pine-hardwood stand in southern Arkansas

Size class and species group	Growing season)[a] Preharvest	First	Third	Mean square error	*P*
	- - -*Rootstocks per acre* - - -				
Seedlings					
Oaks	750	600	920	1.62E2	0.40
Other canopy species	730	620	600	4.43E4	0.40
Midcanopy species	3,300a	2,200b	2,400b	6.88E5	0.05
Shrubs	2,800b	5,900a	2,900b	3.37E6	0.01
Total	7,450	9,320	6,820	4.18E6	0.06
	- - - - *Stems per acre* - - -				
Saplings					
Oaks	39	10	20	1.07E3	0.20
Other canopy species	93b	29c	180a	9.83E2	0.01
Midcanopy species	400a	92b	25b	8.82E3	<0.01
Shrubs	10	3	12	1.66E2	0.31
Total	542a	135c	237b	1.01E4	<0.01

[a] Row means followed by different letters are significantly different (*P*=0.05) by the Ryan-Einot-Gabriel-Welsch Multiple Range Test.

The saplings present before harvest were mostly midcanopy species, which accounted for 74 percent of the total (table 5). After the third growing season, however, 77 percent of the saplings were in the other canopy species group (mostly sweetgum), which reflects the rapid growth of sprouts and advance regeneration in this species group.

Regeneration Size

After the third growing season, dominant pine regeneration was considerably smaller than that of any other species group, by 2 to 10 times for groundline diameter and 4 to 10 times for height (table 6). Opening size significantly affected only the height of the pines, which were about twice as tall in the 1.0-acre openings as in the 0.25-acre openings. This difference reflects both the younger age of the pine seedlings in the 0.25-acre openings and probably the greater suppression by bordering trees. An average of 33 percent of the dominant pines were free to grow. Vines were the most frequent type of overtopping vegetation, accounting for 51 percent of the total. Dominant regeneration in the other canopy species group averaged 8.1 feet tall after the third growing season and was followed by shrubs (5.4 feet), oaks (5.0 feet), and midcanopy species (4.7 feet).

Table 6—Size of the dominant regeneration occurring three growing seasons after the initial harvest implementing group selection in a pine-hardwood stand in southern Arkansas

Property and species group	Opening area (acres)[a]			Mean square error	*P*
	0.25	0.625	1.0		
	- - - - - - *Inches* - - - - - -				
Groundline diameter					
Pines	0.12	0.17	0.21	0.001	0.07
Oaks	0.29	0.50	0.48	0.037	0.41
Other canopy species	1.17	0.61	0.71	0.091	0.22
Midcanopy species	0.31	0.47	0.46	0.009	0.17
Shrubs	0.36	0.40	0.43	0.011	0.72
	- - - - - - - *Feet* - - - - - - -				
Height					
Pines	1.1b	1.6ab	2.0a	0.08	0.05
Oaks	3.8	5.7	5.5	8.04	0.68
Other canopy species	10.6	6.0	7.7	6.98	0.33
Midcanopy species	3.7	4.9	5.4	0.60	0.14
Shrubs	5.4	5.9	5.0	1.05	0.57

[a] Row means followed by different letters are significantly different (P=0.05) by the Ryan-Einot-Gabriel-Welsch Multiple Range Test.

The results of this study differ from those obtained by Perry and Waldrop (1995), who reported that pines planted in small openings had overtopped competing hardwoods after 2 years. These conflicting results can be attributed to differences in site quality (loblolly pine site index was 85 to 90 feet at 50 years in this study and 70 feet at 50 years in Perry and Waldrop's study) and to differences in seedling origin (natural regeneration in this study compared to planted, genetically improved seedlings in Perry and Waldrop's study).

Vegetative Coverage

Horizontal coverage by understory vegetation changed dramatically through time but was not significantly affected by opening size during any of the inventories. Therefore, only changes through time are shown in table 7. Grasses and forbs displayed the greatest increase in coverage during the first growing season, when their coverage essentially doubled over preharvest levels. In contrast, vines and all woody groups increased dramatically only after the first growing season. Vines, shrubs, and hardwoods essentially doubled in coverage between the first and third growing seasons, while coverage of the pines increased from 0.0 to 0.7 percent. This developmental pattern shows that most of the early competition to the desired regeneration in this stand was from grasses and vines. Although the pines appear to be overwhelmed by the nonpine vegetation at this stage of development, experience has usually shown that an acceptable pine component will eventually develop under these stand conditions.

CONCLUSIONS

This study showed that opening size affects the level of logging disturbance within openings (the 0.25-acre openings had less disturbance than larger openings) and

Table 7—Horizontal coverage of understory vegetation before and after the initial harvest implementing group selection in a pine-hardwood stand in southern Arkansas

Vegetative group	Growing season)[a]			Mean square error	*P*
	Preharvest	First	Third		
	- - - - *Percent of area* - - -				
Grasses	15.1b	33.3a	35.9a	29.8	<0.01
Forbs	6.7b	14.3a	5.0b	40.2	0.02
Vines	21.7b	22.2b	48.1a	73.0	<0.01
Shrubs	6.2b	9.0b	17.7a	4.0	<0.01
Hardwoods	9.7b	8.7b	21.4a	28.4	<0.01
Pines	0.0b	0.0b	0.7a	0.1	<0.01
Total vegetation[b]	47.3c	75.9b	90.9a	156.4	<0.01

[a] Row means followed by different letters are significantly different (P=0.05) by the Ryan-Einot-Gabriel-Welsch Multiple Range Test.
[b] Total vegetation is less than the sum of the species groups because of overlapping.

the dispersal of pine seeds (the 0.25-acre openings had more pine seeds dispersed to their interior than larger openings). Since increases in both disturbance and seed supply tend to favor the establishment of pine regeneration, their opposing relationship with opening size essentially cancels out so that opening size has little net effect on the density and stocking of pine regeneration. However, opening size significantly affected the height growth of pine seedlings (seedlings were shorter in the 0.25-acre openings than in larger openings), and this may ultimately affect the success of regeneration. Early results suggest that ample regeneration of desirable hardwood species exists after harvesting to achieve the mixed pine-hardwood regeneration goal within openings. More time will be needed to make specific recommendations for the optimum opening size for natural regeneration of pine-hardwood stands using group selection.

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NATURAL REGENERATION IN CANOPY GAPS IN PINE, PINE-HARDWOOD, AND HARDWOOD FOREST STANDS IN THE UPPER COASTAL PLAIN

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Abstract—Canopy gaps are a common feature in temperate forests, and stem from a variety of natural and man-caused disturbances. A study was conducted in three forest cover types in the upper Coastal Plain of Virginia to assess the abundance and composition of natural regeneration found in small gaps. Across all three cover types, the number of seedlings of intolerant species was greater than the number of seedlings of tolerant species in gaps as compared to nongap areas. For example, in the pine cover type, intolerant seedlings in the gaps numbered 39,271 per hectares, whereas intolerant seedlings in the nongap areas numbered 8,125 per hectares. Loblolly pine (*Pinus taeda* L.) was the dominant species in the gaps in both the pine and pine-hardwood cover types. White oak (*Quercus alba* L.) was the dominant regeneration species in the canopy gaps of the hardwood cover type. Although intolerant seedlings were abundant in the canopy gaps, they are not expected to persist, since the gaps were small and canopy cover (overstory and understory combined) averaged over 90 percent.

INTRODUCTION

Small-scale disturbances, such as single tree deaths, are an integral part of the forest regeneration cycle (Whitmore 1989, Pickett and White 1985, Runkle 1985). In natural forests, small disturbances have an important function influencing species regeneration. In many natural forest types, like parks and preserves, small canopy openings, or gaps, are the primary recruitment areas where future forest canopy individuals develop (Cho and Boerner 1991, McClure and Lee 1993, Oliver and Larson 1990, Pickett and White 1985, Runkle 1981). Currently, these forests are undergoing successional change in the absence of fire (Cooper 1989). These forests may exhibit any number of features, including southern pine beetle (*Dendroctonus frontalis* Zimm.) patches, dense understories, invasive exotic species, heavy browsing, and, recently, recurrent droughts linked to increased mortality (Clinton and others 1993).

Canopy gaps may be characterized by many variables, such as frequency, size, and severity, all of which have impacts on the amount and type of regeneration (Pickett and White 1985). Generally, southeastern forests experience frequent small-to-medium natural disturbances resulting from recurring tornados and hurricanes.

Many studies have investigated forest regeneration in canopy openings in the temperate forests of the Northeastern United States and the Southern Appalachian Mountains. Few studies examine natural regeneration in single tree openings in southeastern forests. In addition, small disturbance studies seldom explore all the variables influencing regeneration, including light and soil conditions associated with the disturbance. The objectives of this study were to quantify seedling abundance and species composition in small canopy gaps and adjacent forested areas (nongaps) of pine, pine-hardwood, and hardwood forest cover types.

METHODS

Study Area

The study was conducted in the forests of the Petersburg National Battlefield (PNB) in Petersburg, VA, which is in the upper Coastal Plain physiographic province (Frye 1986). The underlying rock in the Petersburg area is a combination of Petersburg granite, which is mostly feldspar and quartz, and the late Pliocene Bacons Castle formation (Frye 1986). Developing from a combination of marine sediments and residual parent materials, the dominant soil series represented are the Emporia and Slagle in the Ultisol soil order, which are well-drained, sandy loams with a clay loam subsurface.

The PNB is one of many commemorative Civil War battlefields administered by the National Park Service, U.S. Department of the Interior. Historical use of the park land before the Civil War was half forest and half agriculture, with tobacco and cotton as principal crops (Wallace 1983). Currently the forests are in the late consolidated and subclimax successional sere, with loblolly pine (*Pinus taeda* L.), several oak species (*Quercus* spp.), sweetgum (*Liquidambar styraciflua* L.), and tulip poplar (*Liriodendron tulipifera* L.) as the dominant canopy species.

Within the PNB, forests were classified into the three following cover types:

Pine: Species composition consists of >75 percent pine basal area, including loblolly pine, Virginia pine (*P. virginiana* Miller), and shortleaf pine (*P. echinata* Miller).

Pine-hardwood: Species composition consists of 25 to 50 percent pine basal area, with the remaining composed of any mixture of oak, hickory (*Carya* spp.), tulip poplar, sweetgum, or red maple (*Acer rubrum* L.).

Hardwood: Species composition consists of >75 percent oak basal area, with the remaining composed of any

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mixture of pines, hickory, tulip poplar, sweetgum, or red maple.

For this study, four stands were randomly selected from each of the three cover types. Each stand was traversed to locate gaps, which were canopy openings where the stocking level was below 60 percent (Roach and Gingrich 1968, USDA 1986). In each stand, three paired plots (gap and adjacent nongap) were randomly established, for a total of 36 paired observations in the study.

Gap Measurements

To determine the size of each gap, the length and width of the gap were measured from the base of the surrounding border trees, consistent with the "expanded gap" definition used by Runkle (1981, 1982). Gap area was estimated using the formula for either a circle or an ellipse, depending upon gap shape (Runkle 1985). Gap age was approximated through examination of growth rings of two dominant trees bordering each gap and two dominant saplings within each gap.

Site and Vegetation Sampling

Site and vegetation sampling were conducted within each gap and its adjacent forest. In the center of each gap a fixed, circular, 0.04-hectare plot was established where canopy cover was determined at each plot center using a spherical densiometer (Lemon 1956). The same size plot was randomly established at least 25 meters inside the adjacent undisturbed forest, creating the gap and nongap pair. Woody stems over 5 meters tall were classified as part of the canopy and measured by species, diameter at breast height (d.b.h.), and crown class on each plot. Within each overstory plot, a circular 0.004-hectare subplot was located at about the plot center. In two random quadrants of the subplot, four 1-square meter plots were used to tally the seedlings (<1.37 meters tall) by species.

Data Analysis

Seedling importance value was calculated as the mean of relative density and frequency. Differences in vegetation variables between gap and nongap areas were determined using the paired-t test for sample means at the 0.05 alpha level.

RESULTS AND DISCUSSION

Gap Measurements

Gap size and age help explain the presence and abundance of regeneration within gaps (Clinton and others 1994). At PNB, the mean sizes of the canopy openings in each cover type were similar, ranging from 281 square meters in the pine-hardwood cover type to 317 square meters in the hardwood cover type (table 1).

Gap ages were estimated from interpretation of growth rings of border trees and saplings growing within the gaps. Three gap age classes were developed: young (<5 years), intermediate (6 to 9 years), and old (>10 years). The majority (58 percent) of the gaps were in the intermediate age class (table 2).

Table 1—Mean size (square meters) of gaps in pine, pine-hardwood, and hardwood forest cover types at Petersburg National Battlefield, VA

Cover type	Number	Area	Seedling density	Range
		- - - - - - - - - *Square meters*	- - - - - - - - -	
Pine	12	308	110	93-474
Pine-hardwood	12	281	115	138-665
Hardwood	12	317	122	152-597
Total	36	—	—	—

Table 2—Distribution and mean size (square meters) of gaps by age class in pine, pine-hardwood, and hardwood forest cover types at Petersburg National Battlefield, VA

	Young		Intermediate		Old	
Cover type	No.	Area	No.	Area	No.	Area
	- - - - - - - - - - - *Square meters* - - - - - - - - - - -					
Pine	2	298	9	319	1	303
Pine-hardwood	1	292	7	313	4	320
Hardwood	0	—	5	299	7	335
Total	3	—	21	—	12	—

Canopy Cover

The gaps in each forest cover type consistently had significantly less cover than their associated nongap counterparts (table 3). In general, the canopy cover was high in the gaps, none less than 90 percent. This is a result of most of the gaps being older, with lateral branches invading the gaps.

Vegetation Characteristics

Overstory composition—The pine cover type had the most diverse overstory, with 19 different species totaling 45 square meters of basal area per hectare and 310 trees per hectare (table 4). Loblolly pine, with 127 trees per hectare and 36 square meters per hectare basal area, clearly was the dominant species (table 4). Sweetgum was the most important species in the pine-hardwood cover type; however, loblolly pine composed 54 percent of the basal area and was also a major species. In the hardwood cover type, white oak (*Quercus alba* L.) and blackgum (*Nyssa sylvatica* Marsh.) composed over half of the total density, with a combined importance value of 46 percent (table 4). Blackgum was present as many small stems, compared to white oak which appeared as fewer and larger trees.

Table 3—Canopy cover (percent) for gap and nongap areas in pine, pine-hardwood, and hardwood forest cover types at Petersburg National Battlefield, VA (means within a row followed by a different letter are significantly different at the 0.10 level)

	Gap			Nongap		
Cover type	Mean	Seedling density	Range	Mean	Seedling density	Range
	Percent					
Pine	91a	5	78-97	98b	2	93-99
Pine-hardwood	95a	2	89-98	99b	1	98-100
Hardwood	92a	10	61-99	98b	1	96-100

Table 4—Overstory density, basal area, and importance values of gap and nongap areas in the pine, pine-hardwood, and hardwood cover types in the Petersburg National Battlefield, VA

Species	Mean	Standard deviation	Basal area	Importance value
	No./ha		----m^2/*ha*----	---*Percent*---
Pine				
Loblolly pine	127	57	36	31
Tulip poplar	56	105	2	13
Sweetgum	29	44	3	11
Red maple	23	48	<1	9
Misc.	71	—	3	36
Total	310	—	45	100
Pine-hardwood				
Sweetgum	77	54	4	22
Loblolly pine	52	43	18	19
Blackgum	31	66	<1	9
Red maple	29	52	<1	10
Misc.	92	—	11	40
Total	281	—	34	100
Hardwood				
White oak	60	57	20	24
Blackgum	50	70	1	22
Sweetgum	27	42	<1	13
Willow oak	21	46	10	9
Misc.	54	—	12	32
Total	212	–	43	100

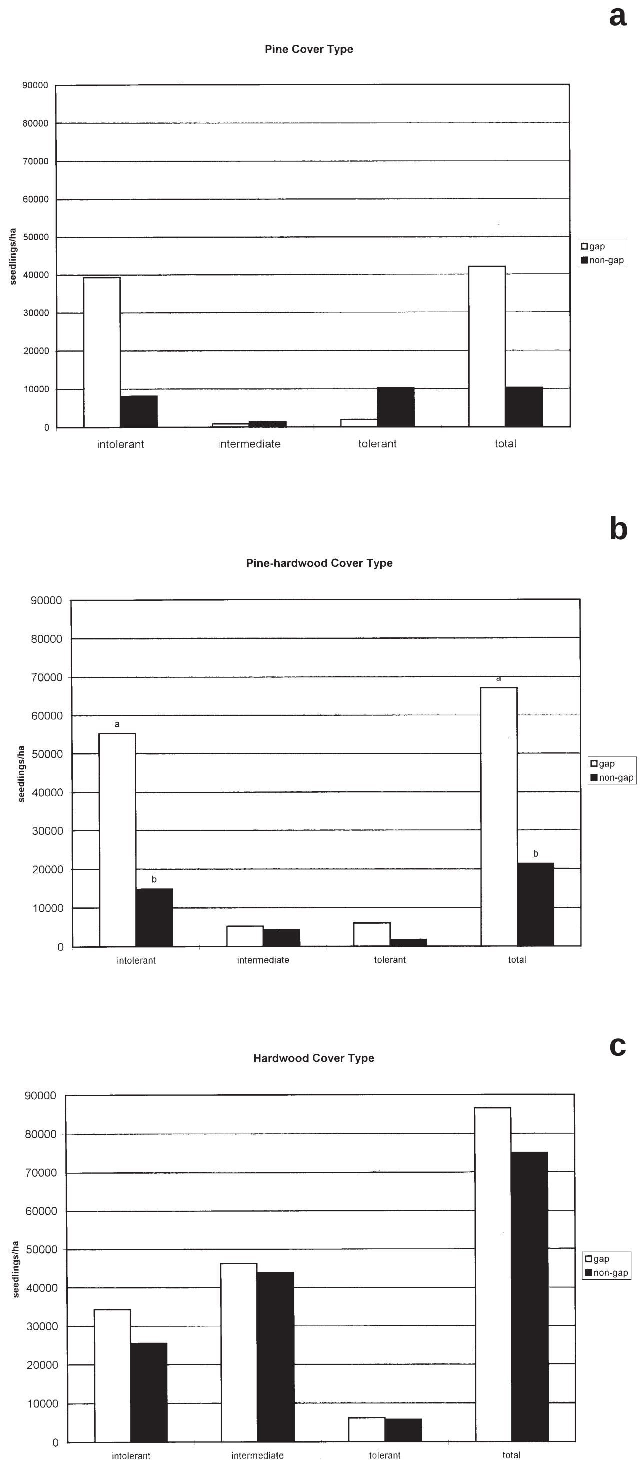

Figure 1—Seedling density for (A) pine, (B) pine-hardwood, and (C) hardwood cover types in total and for shade tolerance classes in gap and nongap areas in Petersburg National Battlefield, VA.

Regeneration composition—Total seedling density, which was composed primarily of shade-intolerant seedlings in the gaps of the pine cover type, was greater than in the nongap areas, although not significant (p = 0.15) (fig. 1). Loblolly pine, sweetgum, and tulip poplar were the most important species in the gaps as well as in the nongap areas (fig. 2). The miscellaneous group of 10 species contained over half of the importance value in the nongap areas, and includes the shade-tolerant species, which were more dense in the nongap areas than in the gaps. Gap size was large enough to allow for

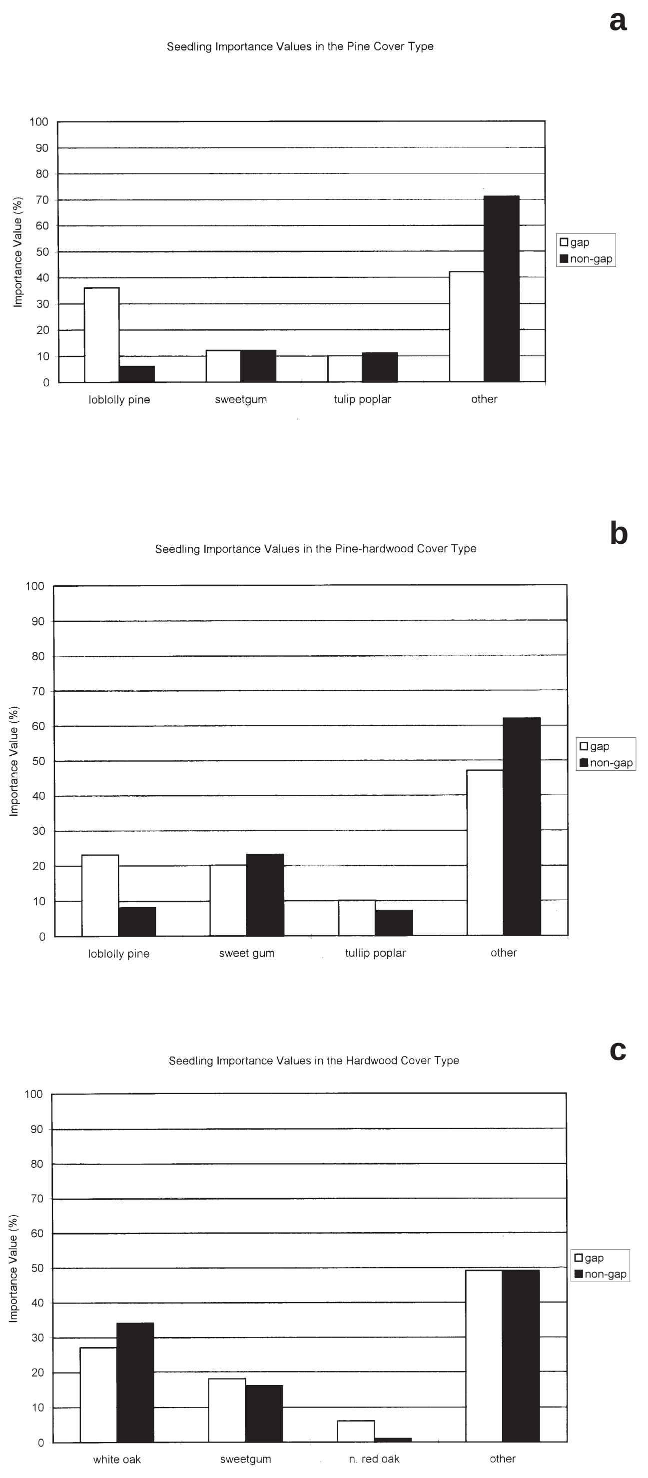

Figure 2—Seedling importance values by species for (A) pine, (B) pine-hardwood, and (C) hardwood cover types in gap and nongap areas in Petersburg National Battlefield, VA.

ample pine regeneration. However, it is not expected that many of the seedlings will survive into a canopy position because of crown closure, unless another disturbance occurs.

The gaps in the pine-hardwood cover type had a significantly greater number of shade-intolerant seedlings, mostly made up of loblolly pine, with an importance value of 23 percent, compared to the nongap areas (p = 0.01) (figs. 1 and 2). In fact, the gaps had greater seedling density in all of the shade-tolerant groups, and total seedling density was significantly greater than in the nongap areas (p = 0.01). Such a significant difference is interesting, given that mean gap size was the smallest and percent canopy density was the highest in the pine-hardwood cover type compared to the other cover types (tables 1, 2, and 3). Shade-intolerant species were also the three most important species in both gap and nongap areas. The miscellaneous group contained 14 species in the gaps, and 15 species in the nongap areas.

The hardwood cover type had prolific and diverse regeneration within the gaps, represented by 19 different species. Total seedling density was the highest in this cover type, approaching 87,000 seedlings per hectare (fig. 1). Generally, the regeneration within both areas was similar. There was no discrimination between gap and nongap densities. White oak was the most important species in both the gap and nongap areas, followed by sweetgum. The similarity in composition and density of the gap and nongap areas in this cover type is a function of the older age of the gaps, allowing equilibrium site conditions to develop (table 2).

CONCLUSIONS

Small canopy gaps create an environment for large influxes of natural regeneration to develop. Most of these seedlings will die as the gaps close and resources are recaptured, and there will be a small group of saplings remaining. Gradually, the individual sapling that outcompetes the others will develop into the canopy position.

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