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Regenerating Longleaf Pine Naturally

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Contents

Seeded under a moderate overstory in 1947 and released by a removal cut in 1954, this stand first alerted foresters at Brewton to possibilities for shelterwood management of longleaf pine. In 1974, 21 seasons after release, many dominants exceeded 8 inches in diameter. Escambia Experimental Forest, Escambia County, Alabama.

Regenerating Longleaf Pine Naturally

Thomas C. Croker, Jr., and William D. Boyer

Inherently the most valuable pine of the South, longleaf has been widely replaced by other species that reproduce more successfully. Research over the past two decades, however, provides guides for consistent natural regeneration by a shelterwood system. Key measures of the recommended system include hardwood control by fire and other means during the rotntion, timely preparatory and seed cuts, seed crop monitoring, seedbed preparation by fire or mechanical means, protection of established seedlings, prompt removal of parent trees when stocking of reproduction is adequate, and control oj competition and brown-spot disease after the removal cut.

Establishing the new crop primarily from the first 20 percent of seedlings emerging jrom the grass stage maximizes growth rates and tends to preserve inherited vigor and resistance to brown spot.

Additional keywords: *Pinus palustris,* shelterwood, prescribed burning, timber management systems.

Reduction of the longleaf pine (*Pinus palustris* Mill.) forests from an estimated 60 million acres in colonial times (Wahlenberg 1946) to less than 15 million acres today is in large part a reflection of regeneration failures. Old-growth longleaf provided the choicest timber of the southern pines. The second-growth is similarly straight, clear, and free from defect. Users, especially of poles and piling, generally prefer it to other pines. It is resistant to fire and most insects and diseases. Many foresters and landowners interested in a multi-product, multiple-use forest prefer longleaf pine.

Harvesters of old-growth timber appreciated the superior qualities of this tree but rarely attempted to reproduce it. Grass, or stands of hardwoods, loblolly pine *(P. taeda* L.), and slash pine *(P. elliottii* Engelm.) took over many sites after the longleaf was cut. On extensive areas and usually by accident, good second-growth stands did become established. Except for limited plantings and direct seedings of recent decades, these fortuitous reseedings provided today's commercial long-leaf pine forests.

Most of the second-growth longleaf will reach maturity and will need to be harvested and regenerated by the year 2000. Seeding or planting following mechanical site preparation can establish new stands, and is necessary where parent tree stocking is low or competition is excessive. Where feasible, however, natural regeneration offers substantial advantages.

Natural regeneration does not require purchase of seed, and costs less for manpower and for equipment operation. Less nonrenewable resources such as fossil fuels are needed. Large cash expenditures are unnecessary. During the regeneration period much high-grade wood can be grown on large, well-spaced trees retained as seed bearers. Retaining a partial stand while regeneration is being established is aesthetically and environmentally preferable to clearcutting and incurs less risk of soil erosion. Selection of high-quality seed bearers also preserves a diverse pool of desirable genotypes.

Desirable in theory, natural regeneration of longleaf pine proved difficult in practice. Biological and environmental factors, as well as genetic traits of the species, presented major obstacles. Until recently, therefore, deliberate natural regeneration was seldom attempted.

Beginning in the 1920's, research concentrated on planting grass-covered stumplands which then occupied millions of acres of former longleaf type. Two decades later studies were started which culminated in effective direct seeding.

Drawing in part on these studies, researchers at Brewton, Alabama, and elsewhere developed information on which to base a shelterwood system for obtaining natural regeneration consistently and economically. This paper presents essential background information and practical guides for applying the system.

ENVIRONMENT AND SILVICS

The most important single factor in longleaf silviculture is the species' unique adaptation to an environment where surface fires are frequent. Longleaf is native to most of the Gulf and Atlantic Coastal Plains from North Carolina to eastern Texas, with extensions into the Piedmont and Southern Appalachian regions. Its original range was probably similar to the present commercial range (fig. 1), but the acreage it occupies is greatly reduced.

Soils within the range are typically sandy, infertile, and acid. Though rainfall averages 40 to 60 inches annually, seedling losses to drought are frequent, especially on the coarse sands of western Florida and the sandhills of Georgia and the Carolinas. Topography is generally flat to rolling, with broad uplands broken occasionally by drainages wide enough to be barriers to fire. Originally, longleaf pine forests dominated the uplands, hardwoods the main river floodplains, and mixtures mainly of hardwoods and loblolly or slash pines the minor drainageways and other moist sites.

Fire Subclimax Type

Longleaf, like most other southern pines, is classified as a subclimax species, because in the absence of disturbance it eventually is replaced by more tolerant trees. Fire is one of the important disturbers and is almost requisite to perpetuation of longleaf under natural conditions. Without frequent fires, hardwoods would dominate understories or, with other pines, would outgrow longleaf seedlings (fig. 2). Ecologists have therefore interpreted the longleaf pine type as a "fire sub-climax" (Wells and Shunk 1931, Weaver and Clements 1938, Oosting 1956).

Longleaf pine's dependence on fire derives from differences in traits between it and its competitors. Hardwoods have higher photosynthetic rates in shade than pines (Kozlowski 1949, Kramer and Decker 1944). Eoth pine and hard-mood competitors grow continuously in height, while longleaf remains in a grass stage for several years. Over a rotation, prescribed burns are usually needed to control hardwood understories. During regeneration, fire and other measures are used at times when they reduce competition

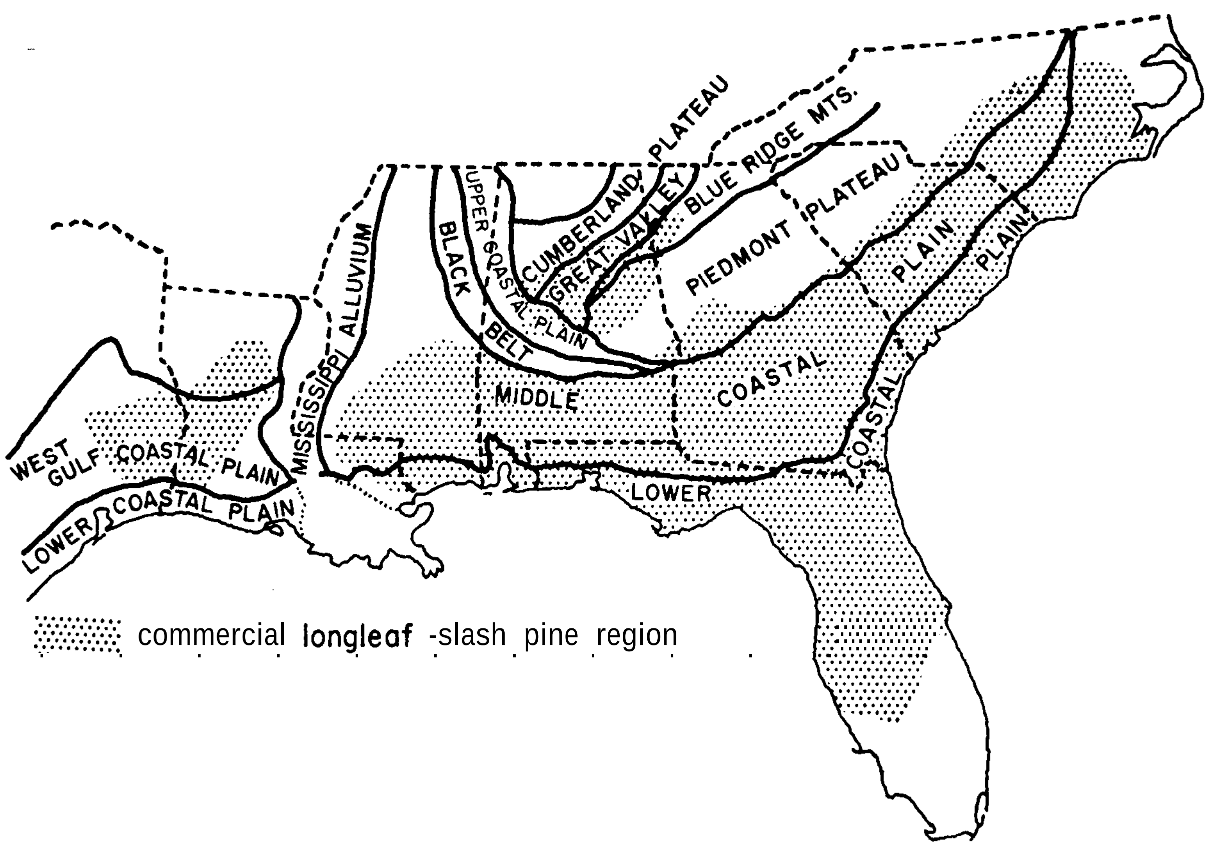

Figure 1.—*Commercial range of longleaf pine and major physiographic provinces.*

Figure 2.—*Without fires to control them, hardwoods may dominate regeneration areas and permanently suppress grass-stage seedlings.*

from grass and brush or control disease with minimal damage to the longleaf seedlings.

Seed Supply

A major regeneration problem is irregular seed production. Wahlenberg (1946) reported good seed crops at 5- to 7-year intervals, failures 1 year out of 5, but many exceptions to this periodicity. Maki (1952) noted that during a 20-year period after 1930 there were nine medium or better seed crops and 14 light or better crops in south Mississippi. Although these early records are observational, the "good" and "medium" estimates may approximate the frequency of crops adequate for regeneration.

On the Escambia Experimental Forest in south Alabama, seedfall has been measured by trapping since 1955. Results are shown in table 1. During a 19-year period, shelterwood stands produced five crops of 50,000 or more seeds per acre-an average of one every 4 years. Crops of this size usually provide a satisfactory stand of seedlings with no more site preparation than a burn.

Table 1.—*Longleaf pine seed crops per acre, Escambia Experimental Forest, 1955-1973*

Year	Shelterwood stands[1]	Seed-tree stands[2]
	M seeds	
1955	104	20
1956	Neglig.	Neglig.
1957	6	3
1958	27	24
1959	4	4
1960	33	21
1961	69	46
1962	4	4
1963	Neglig.	Neglig.
1964	23	4
1965	1	1
1966	Neglig.	Neglig.
1967	122	56
1968	34	5
1969	5	2
1970	1	1
1971	63	6
1972	2	Neglig.
1973	69	2
Mean	29.8	11.0

[1] Density of seed bearers per acre averaged about 30 square feet of basal area.

[2] Density of seed bearers per acre averaged about 10 square feet of basal area.

Under seed trees the count was much less. In the 19 years there was only one crop of 50,000 seeds or more.

Development of longleaf pine seeds is a hazardous process extending into 3 calendar years. Standard terminology for female strobilus stages, as proposed by Croker (1971a), is as follows:

Year and stage	*Usual start*	*Description*
Bud year		
Bud	July, second calendar year before seed year	Primordia visible under magnification
Flower year		
Flower	March	Bud sheaths break
Conelet, early	June	Flower scales closed
Conelet, late	October	Conelet losses taper off
Seed year		
Cone green	June	Specific gravity 1.0 +
Cone ripe	October, late September	Specific gravity .89
Cone open	Late October	Specific gravity .70

Matthews (1932) and others have described seed development in detail. The reproductive primordia are differentiated usually about the summer of the bud year, and the buds of male flowers begin to appear in December of that year. Female strobili usually appear in March of the flower year; the date ranges from mid-February to early April, depending on temperatures. Pollination follows immediately, but fertilization is delayed until early in the seed year, when the female strobili are still in the late conelet stage (fig. 3). After fertilization the strobili enter the green cone stage, and growth is rapid until early October when the cones are ripe.

Shoulders (1967) has shown that abundant rain in the spring and early summer of the bud year improves flower production. A severe freeze during the flower stage can do severe damage. On the Escambia Experimental Forest, entire flower crops have been destroyed by March frosts. Boyer (1974a) reported that cone production is strongly correlated with pollen density during the flowering period and that female strobili may abort if pollination is inadequate.

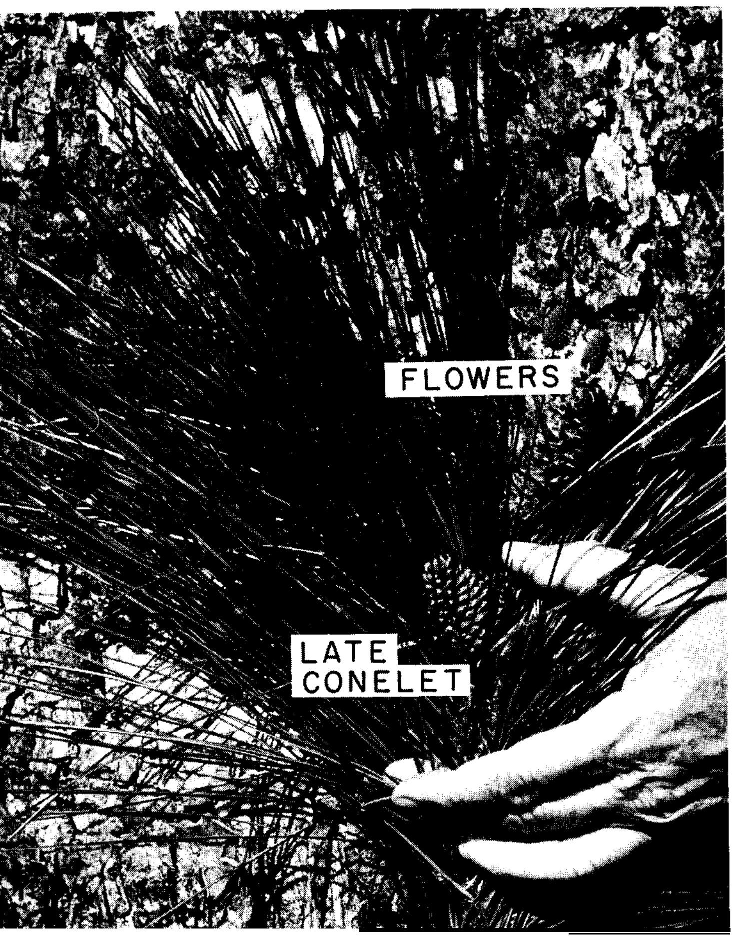

Figure 3.—*Pistillate flowers usually appear in February or March of the flower year; seeds are not mature until October of the seed year, 20 months later.*

The number of seeds per cone varies greatly. Croker (1973) found that the count averaged 50 in a good year, 35 in an average year, and 15 in a poor year.

Insects and disease can decimate promising seed crops; DeBarr (1967) noted that seed bugs (*Tetyra bipunctata* [H.-S.] and *Leptoglossus corculus* [Say]) cause much of this damage by feeding on the seed.

Dispersal starts in late October. Most seeds are down by the end of November, although a few may fall as late as the following February. The flight range is short. According to Boyer (1958, 1963b), the amount of sound seed deposited is halved with each additional ½-chain distance from a wall of timber. Effective seeding distance is usually not more than 100 feet. Viability also decreases sharply with distance, because empty seeds carry further.

Generally seed production is greatest on good sites (Croker 1973). Trees that have well formed crowns and are over 30 years old and at least 10 inches in d.b.h. usually are the most prolific. Production increases with diameter up to about 15 inches d.b.h. Some trees are inherently more fruitful than their neighbors (Allen 1953, Croker 1964, Shoulders 1967), regardless of morphological characteristics.

In studies of seven seed crops, Croker (1973) found that cone production declined with increasing stand basal area in excess of 30 square feet per acre. Other studies at the Escambia Experimental Forest have indicated that 30 square feet may be close to optimum, as decreases were observed at lower as well as higher densities (fig. 4). Cones per tree generally increased with declining basal areas, but the reduction in number of seed trees lessened the numbers of cones per acre.

When a stand is ready for regeneration, therefore, a seed cut should be made to reduce it to about 30 square feet per acre of seed bearers. This cut should be made well in advance, since cone crops will not benefit fully until at least three growing seasons after release. In the 1951 crop, for example, trees released during the bud year produced 61 cones apiece, those released

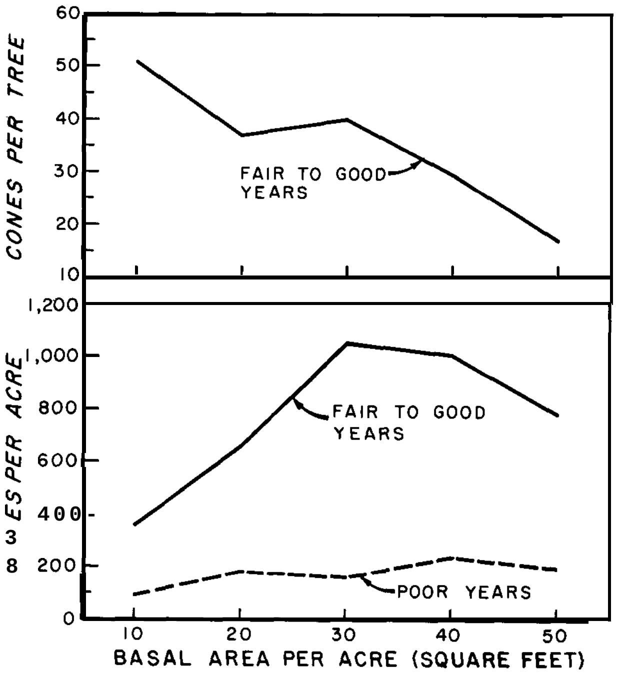

Figure 4.—*Longleaf pine cone production per tree* and *per acre,* as *affected by stand density (based on Escambia Experimental Forest records).*

during the flower year *28* cones, and those released during the seed year *16* cones (Croker *1952).*

Germination and Establishment

Unlike those of other southern pines, longleaf seeds germinate soon after dispersal in the fall. This habit reduces the period of vulnerability to predators like birds, mice, squirrels, and ants (Boyer 1964b; Stephenson, Goodrum, and Packard 1963). On the other hand, the cotyledonary seedlings are subject to freezing temperatures or frost heaving (Croker 1968) as well as to desiccation or high temperatures during droughts in late autumn. They are also exposed to destruction by grazing animals (Boyer 1967) and to clipping by rabbits (Campbell 1971).

The seeds require contact with mineral soil for germination and establishment, and they cannot tolerate flooding. Since the large wing prevents them from penetrating heavy grass or litter, burning or mechanical measures to remove such barriers are essential (Chapman 1946; Croker 1957, 1975; Morris and Mills 1948; Smith 1961a).

Tree percents (number of established seedlings per 100 seeds) are generally highest in good to excellent seed years (Gemmer, Maki, and Chapman 1940).

Survival and Growth

Survival and growth are closely related to longleaf's *two* unique silvical characteristics: its well-known grass stage and its high resistance to fire. The grass stage usually lasts for 4 or 5 years after the seedlings are released from the overstory but may range from 1 to 20 years; during it, the young trees make no height growth. If reproduction of competing species-hardwood or pine-is allowed to grow freely it will completely dominate the site while longleaf seedlings are in the grass. Once this has occurred, the longleaf stand can never regain dominance.

While in the grass stage, longleaf may be killed by hogs (Hopkins 1947, Peevy 1953) and damaged by heavy cattle grazing (Boyer 1967). It also is most vulnerable to its major disease, brown-spot blight, caused by *Scirrhia acicola* (Dearn.) Siggers. The infection prolongs the grass stage and kills many seedlings (Siggers 1944). Under certain conditions fire can be used for control (Croker 1967, Wakeley and Muntz 1947). A parent-tree overstory of medium or high density also tends to inhibit brown spot (Boyer 1963a, 1975).

Causes of the grass-stage habit are not completely known (Allen 1964, Brown 1964), but competition and site are important factors (Bruce 1951b, Croker 1959, Pessin 1944, Walker 1954).

Individual seedlings tend to express dominance early in life, even in the grass stage. This is a desirable trait, tending to prevent stagnation in dense stands. The seedling-to-seedling variation in growth may be genetically controlled. Derr (1963), for example, reports strains that are highly resistant to brown spot and make fast height growth (Snyder 1973). Studies by Boyer (1972) and Wakeley (1970) also suggest that wild populations include brown-spot resistant individuals that develop early dominance. Cultural practices should aim at selecting crop trees from this desirable and perhaps genetically superior portion of the local population.

Longleaf pine is adapted to withstand fire by thick bark on its lower stem and by its unusual habit of growth. Though vulnerable in their first year or two, seedlings soon develop a large, relatively insulated terminal bud. A groundline diameter of 0.3 inch can be taken as the size at which grass-stage seedlings become fire-resistant (Bruce 1951a, 1954). Immediately after height growth begins, the trees are again susceptible, especially those heavily diseased (Maple 1975). They usually gain height rapidly, however, and after they are 3 feet or taller a light fire does little harm.

Mortality of grass-stage seedlings from prescribed fires in Alabama tests is shown in figure 5. Mortality was higher among unreleased than among released seedlings of equal diameter, partly because the pine needles under the overstory supported hotter fires than did the grass on released areas. Brown spot, excessive competition, and any other factors that impede seedling growth may seriously prolong the period of initial vulnerability.

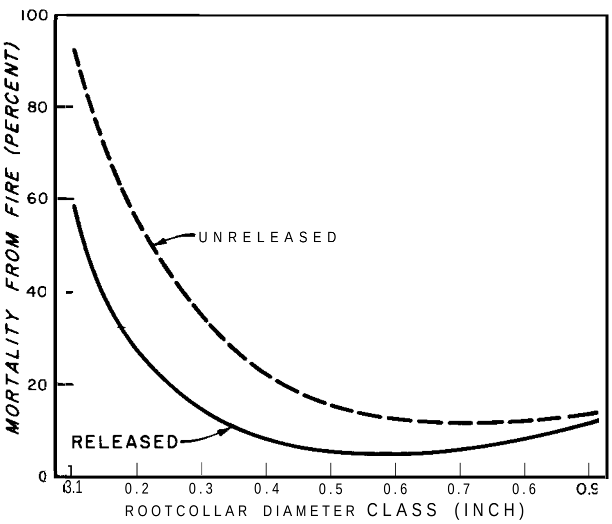

Figure 5.—*Fire kill in relation to size of released and unreleased longleaf pine seedlings. Mortality in the 0.9-inch class may reflect losses of seedlings beginning height growth, which are vulnerable while under 3 feet tall (based on Boyer 1974b).*

The seedlings are highly susceptible to root competition. Growth under full pine or hardwood overstories averages only about half that achieved in the open (Boyer 1963a, 1976). Suppression by parent trees extends well beyond the crowns, an indication that root competition has a greater impact on seedling growth than overstory shade.

Most seedlings can survive under pines or hardwoods for 7 to 10 years (Boyer 1963a, Smith 1961b) and respond well when the overstory is removed (Boyer 1976). Poor timing of fires rather than competition causes excessive mortality of grass-stage seedlings under an overstory. In the absence of fire, Boyer (197413) found that mortality under pines or hardwoods differed little from that for seedlings released from all overstory competition.

Logging damage to be expected during removal of parent-tree overstories must be considered when evaluating the adequacy of stocking. Grass-stage seedlings are more resistant to damage than those making height growth (Boyer 1964a, Croker 1956a). Logging-related mortality is least when the overstory is removed at seedling age 1 or 2 (Boyer 1974c).

REGENERATION METHODS

A method for natural regeneration of longleaf pine should afford at least four essentials: (1) sufficient desirable parent trees, so distributed that they provide an adequate supply of seed throughout the regeneration area, (2) midstory and seedbed conditions favorable for the establishment, survival, and growth of seedlings, (3) protection from hogs, wildfire, brown spot, and other hazards, and (4) complete release from overstory and brush competition after adequate stocking has been secured. In addition, it is highly desirable to maintain a well-stocked overstory until seedlings are firmly established. The overstory provides seed in case more should be needed, and it also suppresses brush and grows substantial quantities of quality timber during the regeneration period.

Of the five American methods of natural regeneration, only three-clearcutting, seed tree, and shelterwood-need be considered for longleaf pine. Longleaf does not sprout satisfactorily for coppice. Because standwise regeneration measures are essential, selection systems are impractical.

Clearcutting has critical limitations (fig. 6). Advance reproduction is usually scarce and would be destroyed in a heavy cut. Seed must then come from the side, as it is not stored in the duff and has a short disnersal range. Four requirements for success with this method are: (1) all the regeneration area must be within about 100 feet of a seed source, (2) there must be a good seed crop on the adjacent timber, (3) seedbed conditions must be favorable, and (4) predator pressure must be low. In good years, clearcutting in a groupwise manner or as progressive strips may meet these requirements. In poorer seed Years, success is doubtful; brush will invade

Figure 6.—*The clearcutting method is of limited use in natural regeneration of longleaf pine. Advance reproduction, if present, is destroyed by logging or smothered by the heavy debris. Seeding from adjacent stands is effective for only about 100 feet.*

rapidly and corrective measures will be expensive.

Clearcutting followed by planting or direct seeding is being practiced, but is beyond the scope of this publication.

The seed-tree method removes from an area in one cut all the mature timber "save for a small number of seed bearers left singly or in small groups" (Ford-Robertson [ed.] 1971). Seed trees usually number three to five and rarely more than 10 per acre. In a 19-year test on the Escambia Experimental Forest (table 1), intervals between usable seed crops were longer than for shelterwood stands because the source was inadequate. Despite prescribed burns, cutting areas also reverted more rapidly to brush, since overstory competition was slight (fig. 7). Growth per acre on the reserve stand was much less than in shelterwood cutting (Croker 195613). Occasionally, good stands have been established by this method, but the risks are high.

Because of longleaf's presumed intolerance of overhead competition, few foresters prior to 1950 considered the shelterwood method suitable. Early studies (Croker 1956b) on the Escambia Experimental Forest, however, revealed that

Figure 7.—*Over 19* years, *seed-tree stands on the Escambia Experimental Forest rarely produced enough seed for adequate regeneration. Meanwhile, sites were occupied by brushy hardwoods released from competition by the cutting.*

seedlings established under moderately heavy overstories survived a removal cut, responded promptly, and grew well (fig. 8). This finding was supported by observations elsewhere. For example, Paul Garrison, former chief forester for Gaylord Container Corporation, reported development in Louisiana of several thousand acres of good second-growth from advance reproduction under old-growth stands fortuitously clearcut and protected from fire (personal correspondence, January 1955).

Following these leads, our research since the mid-1950's has sought basic silvical knowledge and techniques needed to apply a shelterwood approach.

We have learned that good seed crops are more frequent in shelterwood than in seed-tree stands; that the overstory reduces brush encroachment primarily by increasing the effectiveness of prescribed fire; that reproduction, if protected from wildfire and grazing, can be held for 7 or more years under the shelterwood; that advance reproduction grows satisfactorily after release; that the shelterwood tends to inhibit brown spot; and that 150 to 200 board feet per acre per year of high-quality wood can be grown while the stand is being regenerated. We have also developed guides for applying treatments to utilize these potentials economically, and have demonstrated their successful application on more than 15 representative areas.

On the average, about 3.5 years have been required to establish satisfactory reproduction, with a range of 1 to 6 years. Costs are well below those of artificial regeneration.

While shelterwood accommodates the basic biological requirements of longleaf pine better than the other methods and also fits the needs of most landowners, it is not a panacea. Where heavy hardwood undergrowth cannot be controlled without excessive damage to the pine overstory, it is necessary to clearcut. If the clear-

Figure 8.—**Left:** Area in *1954 after removal of longleaf pine stand to release seedlings established under a shelterwood overstory after the 1947 seed crop.* Right: *View from same camera, station in 1961. See frontispiece for 1974 view in this stand,*

cutting is done in narrow strips, natural reproduction may be obtained. The alternative is to plant or direct-seed. In many unmanaged second-growth stands the pine overstory is inadequate; shelterwood regeneration requires a minimum of 20 square feet of basal area per acre in suitable seed trees-less than this risks inadequate seeding. The method also requires close monitoring of seed crops, seedling establishment, and growth, so that cultural treatments can be properly timed.

USING A SHELTERWOOD SYSTEM

Management Before Regeneration

The shelterwood method works best if applied after steps have been taken to prepare for regeneration. Favorable understory conditions can be obtained most efficiently by frequent use of fire, especially toward the end of the rotation (fig. 9). In most well-stocked stands, periodic winter fires will kill back hardwood brush and keep it small. Exceptions are the more fertile sites and special

Figure 9.—*Well-managed longleaf. Frequent fire during the rotation has developed a clean understory, favorable to regeneration.*

areas such as palmetto understories in the Lower Coastal Plain, where summer fires or mechanical control may be needed. Where burning has controlled hardwoods and brush and has limited the accumulation of litter, there is little difficulty in providing adequate seedbeds. Cattle can also help condition the understory but must be excluded or carefully controlled after seeds germinate.

Cutting practices during intermediate management are important. Because longleaf pines prune themselves readily, most dominants and codominants contain wood of good quality. They can be favored by thinning from below. Such thinning develops the large crowns essential to abundant seed production. After stands reach seedbearing age, trees that produce abundant cones should be retained when feasible.

In all intermediate cuttings, care should be exercised to avoid creating openings that will invite hardwood encroachment. Even if they have been carefully managed, however, most stands that need regeneration today have some openings from lightning strikes, beetle kills, windfalls, or initial understocking. To rehabilitate such areas requires special mechanical, chemical, or fire treatments, or a combination of treatments.

Making the Preparatory and Seed Cuts

The shelterwood method is most efficient when cutting areas comprise complete burning blocks. Such blocks may vary from 25 to 100 acres, and should be bounded by natural or artificial breaks. Larger units increase the difficulty of fire control.

Where smaller shelterwood areas are desired, prescribed burning of individual cutting areas may not be feasible. In such irregular situations, stands of various shapes and ages may be included in one burning block. Burning must then be restricted to the dormant season, and the prescription be adjusted to best meet the needs of all the stands, with particular attention to those most vulnerable to fire. Mechanical seedbed preparation may be required when fire cannot be used.

The shelterwood method usually employs two or three cuts. In the three-cut method, a preparatory cut is made and then is followed in about 5 years by a seed cut that removes all trees not needed for seed production. The third cut removes the overstory after the seedling stand is well established. The two-cut method is similar except that the preparatory and seed cuts are combined.

Objectives of the preparatory cut are to take out trees that are not suitable as a seed source, and to develop large crowns on the trees left. Optimum residual density ranges from 60 square feet of basal area per acre on the poorer sites to 70 square feet on the better (fig. 10). The preparatory cut is essentially a thinning, mostly from below, leaving the largest trees of good quality. Where the stand has been under management through the entire rotation, the last thinning before the regeneration period may constitute the preparatory cut. Some advance reproduction occasionally develops after the preparatory cut, but adequate amounts are not expected until after the seed cut.

The seed cut is designed to maximize seed production and develop a well-stocked stand of reproduction. By reducing the density of the overstory, the cut minimizes logging damage to seedlings during the removal cut. It is highly important that the trees to be left are carefully selected. They should be more than 30 years old, 10 inches or more in d.b.h., and preferably above average in height, form class, and volume. In addition, they should be above average in fruitfulness as evidenced by abundance of open cones under them. Ideally, they should also have branches of small diameter and flat branch angles, and should be free of crook, spiral, excessive knot stubs, or forks.

Hardwood control, if needed, should be completed before the seed cut or promptly after. Where labor is available, hardwoods can be deadened by injection of concentrated 2,4-D. Moyer (1967) used l-milliliter injections at 3-inch spacings to control hickory and dogwood in summer, and at 5-inch spacings to control oaks in all seasons. Other chemical applications may also be effective. The treatments may need to be followed by burns to control resprouting. Full-tree chipping, where feasible, provides an excellent means of removing unwanted hardwoods and pines from a shelterwood understory. Heavy brush cutters may also be used if damage to overstory trees and their roots can be avoided. Chipping and brush cutting usually can be most easily accomplished in conjunction with the seed cut.

Several years may elapse between the seed cut and establishment of adequate regeneration. Reduced stand density permits vigorous growth of

Figure 10.—*Cooperative shelterwood experimental urea, after preparatory cut reduced the basal area to 70 square feet per acre. Seed cut will be delayed 5 years to allow crowns to enlarge prior to reduction of the stand to 30* square *feet per acre of seed bearers.* (Photo by Eglin Air Force Base.)

hardwoods, which must be kept under control by timely burning. On some sites, especially the better ones, burns may have to be made during the growing season. Brush control is needed especially when restocking is delayed 5 years or more.

Seed production is maximized at a density of about 30 square feet of basal area per acre. This amount of overstory holds brush in partial check. Where available, trees totaling this density should be left in the seed cut (fig. 11). They should be spaced out individually and not left in

Figure 11.-Two-cut *shelterwood test area,* Bladen *Lakes State Forest. The seed cut, bringing the stand to* 30 *square feet of basal area per acre, has just been completed. Decay of logging debris will greatly reduce surface fuel before burns are made to control brush or prepare a seedbed.* (Photo by North Carolina Forest Service.)

groups. In many stands seed bearers are scarce; then no preparatory cut is made, but the best available trees, up to 30 square feet per acre, are left.

Loggers must avoid skinning trees at the base, since such damage invites black turpentine beetles (*Dendroctonus terebrnns* [Oliv.]). Barring a hurricane or similar disaster, mortality of unscarred seed bearers should be nominal. Over a 15-year period, losses on the Escambia Experimental Forest averaged less than one tree per 5 acres per year. Most losses were from lightning.

Monitoring the Seed Crop

After the seed cut, annual forecasts of seed crops should be made for the purpose of timing seedbed preparation. No completely satisfactory appraisal method has been devised, but counting conelets in the spring with binoculars will give good estimates for the current year's crop. Estimates based on flower counts may vary considerably from actual production, because losses of flowers are variable and sometimes heavy.

Binocular counts must be made in the spring "naked season" (Croker 1971b). At this time the flowers for the seed crop 18 months hence are visible at the end of the new shoots, which have not yet developed needles; the conelets of the current year's crop are easily seen among the foliage of the previous year's growth. The "naked period" usually occurs in April but sometimes is delayed until May.

For each regeneration area where a prediction is needed, 50 or more sample trees should be selected in an unbiased manner. To make the counts the observer should stand at a distance of about one tree height from the sample tree, and with the sun at his back. With 7-power binoculars he should then count all flowers he can observe without moving. Counts should proceed systematically throughout the crown. After flowers have been counted, conelets should be tallied by the same procedure.

To estimate seed production per acre, separate computations are needed for conelet and flower counts:

> To compute seed per acre in the current year, double the average number of conelets per tree, then multiply by trees per acre, and multiply the result by estimated number of seeds per cone.
>
> To estimate seeds per acre in the following year, multiply the average flower count per tree by number of trees per acre and multiply the result by expected seeds per cone.

Estimates based on conelet counts should be reasonably accurate about 90 percent of the time Flower counts are not nearly so reliable, but nevertheless are still useful. At minimum, they indicate when a crop failure may be expected, and thereby enable the forester to avoid untimely seedbed preparation.

The amount of seed necessary to insure a new stand depends on the condition of the seedbed, predator pressure, the soil, understory conditions, and existing seedling stocking. Table 2, which summarizes data from a 5-year study in Alabama, indicates numbers of seeds and newly established seedlings that provided 500 fast-growing, brown-spot resistant trees per acre at age 6 years. Survivors at this age totaled many more than 500 per acre, but only about 20 percent were thrifty and in height growth. Table 2 should not be regarded as a prescription, for conditions vary widely from one locality to another. Land managers should determine requirements from their own experience.

Fortunately, shelterwood regeneration has a number of safety factors. Ability to predict each seed crop at two times, one a year before the other, affords opportunity to adjust for early miscalculations. Mechanical scarifying, supplemental seeding, or both, can boost a marginal crop to a safe level. If a seed crop is inadequate, the land remains in a reasonably productive condition while awaiting fill-in reproduction.

preparing the Seedbed

Seedbed preparation must be carefully timed. It is usually ineffective if done more than 1 year in advance, because litter or grass will accumulate and reduce germination. If hardwood control has been adequate, the ground cover before preparation should consist largely of grasses, forbs, and brush under 4½ feet high. Any areas of palmetto or larger hardwoods should be treated as previously described.

Table 2.-*Amount of seed and number of established seedlings per acre in spring after seedfall, to provide 500 thrifty, well-distributed seedlings in height growth at age 6 years*

Seedbed treatment	Brushy site, good soil		Grassy site, poor soil	
	M seeds	*Seedlings*	*M seeds*	*Seedlings*
Fall burn[2], mechanical	30	6,500	56	10,000
Fall burn	51	10,500	71	12,000
Winter burn[3], mechanical	38	8,000	43	8,200
Winter burn	63	13,200	92	16,800
No burn, mechanical	64	12,000	233	35,800
No burn, no other	. . . Impractical			

[1] After Croker, 1975 (in press).
[2] One to three months prior to seedfall.
[3] *Six* to ten months prior to seedfall.

The forester has two options for seedbed preparation-the winter before seedfall or the following autumn just before the cones open. A fall burn may provide a bed for two seed crops-the current year's and the next. The relative efficiency of the two seasons is indicated in table 2. Survival is better on fall burns. Growth is also improved over that on a winter burn made 9 or 10 months before seedfall. But a winter fire will do less damage to advance reproduction, and when predators are numerous there may be fewer seed losses in a l-year rough than on a fresh burn. If many tracts are ready for seedbed preparation, dividing the total job between two seasons allows efficient use of men and equipment.

It is the experience of many people, including ourselves, that burning is essential if mechanical treatment is not done. Burning is an art acquired by experience. A keen knowledge of how fuels, weather, and topography affect the behavior and impact of fire is necessary. The aim is to get a clean burn without damaging the seed bearers. Where fuels are largely grasses and forbs, flank or head fires can be used when weather is suitable and where topography is level or moderately sloping (fig. 12). Normally, burning should be

Figure *12.-Strip-firing a seedbed burn in a two-cut shelterwood test* area, *Escambia Experimental Forest. The seed cut has left selected trees with average basal area of 30 square feet per* acre.

done within 2 or 3 days after a soaking rain, at air temperatures of 80” F or less, and when relative humidity is above 40 percent. Winds should be a steady 5 to 8 miles per hour at ground level to dissipate the heat and prevent damage to the tree crowns. Special prescriptions are needed for steep terrain and heavy fuels.

Combining a low-cost mechanical treatment with burning should increase establishment, survival, and growth of seedlings, especially on good sites where brush and small hardwoods are common. Mechanical treatment is absolutely essential if burning is not done. The various implements include disks, choppers, and rototillers. A low-cost treatment that has proven very effective in local tests near Brewton, Alabama, is scaribedding, accomplished with an implement similar to the one in figure 13.

Protecting Reproduction

Once seedlings germinate under the shelterwood overstory, they need protection. Rabbits may be troublesome during the first winter. Until the trees reach sapling size, hogs and sheep must be completely excluded and cattle grazing, if permitted at all, should be at low rates of stocking.

Fires should, if possible, be kept out until reproduction is released in the removal cut. When necessary to burn through partially stocked seedling stands for seedbed preparation or brush control, it is best to delay until logging slash has rotted for 2 years and then to use only a cool winter fire.

Making the Removal Cuts

The removal cut is not made until established reproduction is adequate in amount and distribution. Inventories should be taken annually, and full allowances made for probable mortality.

Stocking must be determined; it can be easily apparised with a mechanical sample of circular plots. Common plot sizes are ¼ milacre (radius 1.86 feet) and 1 milacre (radius 3.72 feet). Num-

Figure ***13.-This scaribedder, combining a chopper with a fire plow, stretches short seed crops by providing lanes of exposed mineral soil. The machine, on which bedding disks may be substituted, supplements prescribed fire.***

ber of plots required varies in relation to stocking, as indicated in table 3; a preliminary estimate of stocking is therefore necessary. The sampling procedure is discussed by Freese (1962, p. 20 ff.). In winter, green seedlings contrast with dead grass and are easy to see, but costs can be reduced by combining the seedling count with the strobilus counts in spring.

Table 3.—***Number of sample plots required fo provide stocking estimates within indicated confidence limits at 95-percent probability level***[1]

Percent of quadrats stocked (or nonstocked)	Confidence interval (percent)		
	±4	±5	±6
50	625	400	278
60	600	385	267
70	525	336	233
80	400	256	178
90	225	144	100
95	119	76	53

[1] Derived from Freese's (1962) table 3.

A widely accepted criterion of success is at least 500 well-distributed crop seedlings per acre at heights (3 feet or more) that are relatively safe from fire. As was indicated in connection with table 2, this 500-tree objective requires many more seedlings at earlier stages of development. Table 4, which is based on table 2 and is thus subject to the same reservations as regards local conditions, provides estimates of safe stocking before the removal cut. It allows for average mortality from natural causes, necessary prescribed fires, and logging damage; there is also some provision for unforeseen mortality. It is assumed that the reproduction will be protected from wildfire, hogs, and other livestock. Heavy initial stocking has the advantage of attaining desired stocking from the 20 percent or so of seedlings with above-average vigor and brown-spot resistance.

Once regeneration is adequate, the overstory should be removed. Within limits, the removal cut can be timed to fit harvesting programs or other management considerations, but usually removal at seedling age 1 or 2 years is best. If fire is kept out the seedlings will survive for a long time under an overstory, but they will not grow well.

An overstory of 30 square feet of basal area per acre can be removed in one cut. Heavier overstories should be harvested in two stages to avoid excessive damage by smothering from logging slash. No other special precautions will be needed if skidding under extremely wet conditions is avoided and log landings are carefully located. Some losses to pales weevil may occur after logging but will usually be within the margin of safety provided in table 4.

Post-Harvest Treatments

Once the overstory has been removed, height growth is the major concern of the forester. By reference to table 5, the percentage of seedlings in active height growth can be estimated on the basis of age at release and time since release. Values in the table are, of course, broad averages and may be affected by site and other factors. Rootcollar diameter is a good indicator of the time height growth begins. Usually the starting point is 1 inch.

Brown spot may slow the initiation of height growth. The only practical control in natural stands is prescribed fire. If logging slash is abun-

Table 4.—*Safe stocking levels at the time of removal cut, in relation to site and seedbed treatment*[1]

Seedbed treatment	Brushy site-good soil			Grassy site-poor soil		
	¼-milacre stocking	Milacre stocking	Trees per acre	¼-milacre stocking	Milacr stocking	Trees per acre
	- - - Percent - - -		No.	- - - - Percent - - -		No.
Fall burn, mechanical	45	90	4,200	60	97	6,100
Fall burn	65	98	6,900	65	98	6,700
Winter burn, mechanical	40	87	3,800	45	90	4,000
Winter burn	60	97	6,600	60	97	6,000
No burn, mechanical	60	97	6,000	90	100	15,000
No burn	...	...	...	...	...	...

[1] Based on 4-year survival after removal cut, as reported by Croker (1975, in press). Values for ¼-milacre and l-milacre stocking are estimated from unpublished data deriving stocking percents from number of seedlings per acre.

Table 5.-*Percentage of longleaf pine seedlings in active height growth, by seedling age and time since overstory removal*[1]

Seedling age at release (years)	Years after release								
	0	1	2	3	4	5	6	7	8
0	0	0	0	0	2	7	16	28	41
1	0	0	0	1	4	10	21	34	48
2	0	0	0	2	6	15	28	41	54
3	0	0	1	4	10	21	34	47	60
4	0	0	2	6	15	27	41	54	65
5	0	1	4	10	21	34	47	59	70
6	0	2	6	15	27	40	53	65	74
7	1	3	10	20	33	47	59	69	78
8	2	6	15	27	40	53	64	74	81

[1] Data from Coastal Plain and Mountain provinces of Alabama (Boyer 1976). Stepped line denotes age beyond which 20 percent of seedlings are in active height growth.

dant, fires should be avoided during the first 2 years after the removal cut, but brown spot does not usually become severe during this period.

Prescribed burning should be done very carefully. The degree of infection and possible damage to the stand should be determined from a survey. About 100 milacres are required to make a diagnosis for a stand. Examinations should be confined to the best or crop seedlings on each milacre.

If crop seedlings have less than 20 percent infection, and especially if they are in a stage susceptible to damage, burning should be postponed. But if the average rate of infection on crop seedlings is over 20 percent and expected fire damage is light, a prescribed burn should be made in the dormant season. Headfires will do a good job in proper weather-temperature '70" F or less, relative humidity 40 percent or more, and a good steady wind of 5 to 10 miles per hour at seedling level.

After removal cuts, stands may need burning for control of brush; the fire may also successfully thin overdense seedlings.

A final evaluation of regeneration success should be made when the crop seedlings are in height growth. The stocking goal is 500 well-distributed crop seedlings per acre-the equivalent of loo-percent stocking of 2-milacre plots (radius 5.3 feet if the plots are circular).

For various reasons, small areas sometimes remain unstocked. Perhaps the best practice is to plant them with nursery-grown seedlings after the overstory has been removed.

After a well-stocked stand is established and released, precommercial thinning usually will be unnecessary, since longleaf expresses dominance better than the other pines. If needed, it should be completed before seedlings are 4½ feet high.

SOME TEST RESULTS

Large-scale pilot testing of the shelterwood approach has been in progress over the past 20 years. Some of the early stands have been carried through to pole size, and good seedling catches have also been obtained in the more recent trials.

On the Escambia Experimental Forest a 55-acre compartment was reproduced from the 1955 seed crop by a two-cut method (fig. 14). On the same forest, reproduction has been obtained in both strip and group shelterwood in 13 forty-acre compartments (fig. 15). Two areas in the Mountain and Piedmont provinces of Alabama were reproduced with two-cut shelterwoods from the 1961 seed crop.

Beginning in 1966 a regional test of two-cut and three-cut shelterwoods was installed over a 5-year period. Cooperators include three State forest services, four national forests, a pulp company, an investment owner, and a military base. Test areas have been established in seven States: Louisiana, Mississippi, Alabama, Florida, Georgia, North and South Carolina. Units range from 12 to 40 acres in area. Seed cuts have been completed on 13 tracts, including 10 two-cut shelterwoods and 3 three-cut shelterwoods (table 6). Adequate regeneration is established on all of the three-cut areas and on seven of the two-cut areas. Two of the three remaining two-cut areas are partially stocked and awaiting fill-in from an additional seed crop. The third is in a greatly overstocked stand in Okaloosa County, Florida, on a difficult flatwoods site heavily infested with palmetto. In addition, on five of the seven three-cut areas where the seed cut it pending, considerable advance reproduction has come in as a result of the preparatory cuts. One of the two with little regeneration is also in Okaloosa County.

Removal cuts are yet to be made in most of the satisfactorily regenerated areas, but their stocking is adequate to insure acceptable stands after logging. The 10 adequately regenerated

Figure 14.—*Longleaf sapling stand 6 years after removal cut. It is part of a 55-acre compartment regenerated by the two-cut shelterwood method from the good seed crop of 1955. Escambia Experimental Forest.*

Figure 15.—*Two successful shelterwood areas on the Escambia Experimental Forest. The saplings in the foreground are from the 1958 seed crop; the pole stand in the background is from the crop of 1947.*

Table 6.-*Progress in regional longleaf pine shelterwood tests*

Location by county and State	Method	Year of seed cut	1974 stocking: Milacre percent	1974 stocking: Thousand trees per acre	Status
Perry, Alabama	Three-cut	1970	98	126	Ready for removal cut
	Two-cut	1967	99	101	Ready for removal cut
Coosa, Alabama	'Three-cut	1969	100	52	Removal cut made
	Two-cut	1966	93	19	Removal cut made
Leon, Florida	Three-cut	Pending	99	21	Seed cut scheduled
	Two-cut	1967	100	21	Ready for removal cut
Santa Rosa, Florida	Three-cut	Pending	95	2	Seed cut scheduled
	Two-cut	1968	84	3	Needs fill-in reproduction
Perry, Mississippi	Three-cut	1971	100	24	Ready for removal cut
	Two-cut	1967	97	30	Removal cut made
Grant, Louisiana	Three-cut	Pending	92	24	Seed cut scheduled
	Two-cut	1968	97	91	Ready for removal cut
Decatur, Georgia	Three-cut	Pending	7	1	Seed cut scheduled
	Two-cut	1968	40	3	Needs fill-in reproduction
Okaloosa, Florida	Three-cut	Pending	1	0	Seed cut scheduled
	Two-cut	1969	0	0	Needs fill-in reproduction
Bladen, North Carolina	Three-cut	Pending	75	4	Seed cut scheduled
	Two-cut	1969	96	11	Ready for removal cut
Chesterfield, South Carolina	Three-cut	Pending	84	7	Seed cut scheduled
	Two-cut	1970	92	8	Ready for removal cut

areas required an average of 3.5 years to achieve a new stand, the range being from 1 to 6 years. Prospects are that all test areas except possibly those in Okaloosa County will regenerate with the next good seed crop.

Although the studies are not yet complete, these results are convincing evidence of the effectiveness of the shelterwood method for regenerating longleaf pine naturally.

LITERATURE CITED

Allen, R. M.
1953. Release and fertilization stimulate longleaf pine cone crop. J. For. 51: 827.

Allen, R. M.
1964. Contributions of roots, stems, and leaves to height growth of longleaf pine. For. Sci. 10: 14-16.

Boyer, W. D.
1958. Longleaf pine seed dispersal in south Alabama. J. For. 56: 265-268.

Boyer, W. D.
1963a. Development of longleaf pine seedlings under parent trees. USDA For. Serv. Res. Pap. SO-4, 5 p. South. For. Exp. Stn., New Orleans, La.

Boyer, W. D.
1963b. Longleaf pine seed dispersal. USDA For. Serv. Res. Note SO-3, 2 p. South. For. Exp. Stn., New Orleans, La.

Boyer, W. D.
1964a. Logging damage to longleaf seedlings. J. For. 62: 338-339.

Boyer, W. D.
1964b. Longleaf pine seed predators in southwest Alabama. J. For. 62: 481-484.

Boyer, W. D.
1967. Grazing hampers development of longleaf pine seedlings in southwest Alabama. J. For. 65: 336-338.

Boyer, W. D.
1972. Brown-spot resistance in natural stands of longleaf pine seedlings. USDA For. Serv. Res. Note SO-142, 4 p. South. For. Exp. Stn., New Orleans, La.

Boyer, W. D.
1974a. Longleaf pine cone production related to pollen density. *In* Seed Yield from Southern Pine Seed Orchards, p. 8-14. Proc. Colloq. Ga. For. Cent., Macon.

Boyer, W. D.
1974b. Impact of prescribed fires on mortality of released and unreleased longleaf pine seedlings. USDA For. Serv. Res. Note SO-182, 6 p. South. For. Exp. Stn., New Orleans, La.

Boyer, W. D.
1974c. Longleaf pine seedling mortality related to year of overstory removal. USDA For. Serv. Res. Note SO-181, 3 p. South. For. Exp. Stn., New Orleans, La.

Boyer, W. D.
1975. Development of brown-spot infection in longleaf pine seedling stands. USDA For. Serv. Res. Pap. SO-108 (In Press). South. For. Exp. Stn., New Orleans, La.

Boyer, W. D.
1976. Timing shelterwood removal in longleaf pine. J. For. (In press).

Brown, C. L.
1964. The seedling habit of longleaf pine. Ga. For. Res. Counc. Rep. 10, 68 p.

Bruce, D.
1951a. Fire resistance of longleaf pine seedlings. J. For. 49: 739-740.

Bruce, D.
1951b. Fire, site, and longleaf height growth. J. For. 49: 25-28.

Bruce, D.
1954. Mortality of longleaf pine seedlings after a winter fire. J. For. 52: 442-443.

Campbell, T. E.
1971. Cottontail rabbits clip young longleaf pine seedlings. USDA For. Serv. Res. Note SO-130, 2 p. South. For. Exp. Stn., New Orleans, La.

Chapman, H. II.
1946. How to grow longleaf pine seedlings. Yale Univ. Sch. For., Rep. to Lockhart Lumber Co., Lockhart, Ala. 7 p.

Croker, T. C., Jr.
1952. Early release stimulates cone production. USDA For. Serv. South. For. Exp. Stn. South. For. Notes 79.

Croker, T. C., Jr.
1956a. Longleaf pine seedlings damaged when seed trees are tractor-logged. J. For. 54: 401.

Croker, T. C., Jr.
1956b. Can the shelterwood method success-

fully regenerate longleaf pine? J. For. 54: 258-260.

Croker, T. C., Jr.
1957. Scalping aids longleaf seedling catch. USDA For. Serv. South. For. Exp. Stn. South. For. Notes 112.

Croker, T. C., Jr.
1959. Scalping stimulates longleaf growth. USDA For. Serv. South, For. Exp. Stn. South. For. Notes 121.

Croker, T. C., Jr.
1964. Fruitfulness of longleaf trees more important than culture in cone yield. J. For. 62: 822-823.

Croker, T. C., Jr.
1967. Crop-seedling method for planning brown-spot burns in longleaf pine. J. For. 65: 488.

Croker, T. C., Jr.
1968. Longleaf pine regeneration in Mountain and Piedmont provinces of Alabama. USDA For. Serv. Res. Note SO-76, 3 p. South. For. Exp. Stn., New Orleans, La.

Croker, T. C., Jr.
1971a. Female strobilus stages of longleaf pine. J. For. 69: 98-99.

Croker, T. C., Jr.
1971b. Binocular counts of longleaf pine strobili. USDA For. Serv. Res. Note SO-127, 3 p. South. For. Exp. Stn., New Orleans, La.

Croker, T. C., Jr.
1973. Longleaf pine cone production in relation to site index, stand age, and stand density. USDA For. Serv. Res. Note SO-156, 3 p. South. For. Exp. Stn., New Orleans, La.

Croker, T. C., Jr.
1975. Improving natural regeneration of longleaf pine with seedbed preparation and supplemental seeding. USDA For. Serv. Res. Pap. (In press). South. For. Exp. Stn., New Orleans, La.

DeBarr, G. L.
1967. Two new sucking insect pests of seed in southern pine seed orchards. USDA For. Serv. Res. Note SE-78, 3 p. Southeast. For. Exp. Stn., Asheville, N. C.

Derr, H. J.
1963. Brown-spot resistance among F_1 progeny of a single, resistant longleaf parent. For. Genet. Workshop Proc. 1962, p. 16-17. South. For. Tree Improv. Comm. and Soc. Am. For. Tree Improv. Comm.

Freese, F.
1962. Elementary forest sampling. USDA Agric. Handb. 232, 91 p.

Ford-Robertson, F. C. [ed.]
1971. Terminology of forest science, technology, practice and products. Soc. Am. For. Wash., D. C. 349 p.

Gemmer, E. W., T. E. Maki, and R. A. Chapman.
1940. Ecological aspects of longleaf pine regeneration in south Mississippi. Ecology 21: 75-86.

Hopkins, W.
1947. Perhaps the hog is hungry. USDA For. Serv. South. For. Exp. Stn. South. For. Notes 50.

Kozlowski, T. T.
1949. Light and water in relation to growth and competition of Piedmont forest tree species. Ecol. Monogr. 19: 207-231.

Kramer, P. J., and J. P. Decker.
1944. Relation between light intensity and rate of photosynthesis of loblolly pine and certain hardwoods. Plant Physiol. 19: 350-358.

Maki, T. E.
1952. Local longleaf seed years. J. For. 50: 321-322.

Maple, W. R.
1975. Fire mortality of released longleaf pine seedlings following a winter brown-spot burn. USDA For. Serv. Res. Note SO-195, 3 p. South. For. Exp. Stn., New Orleans, La.

Mathews, A. C.
1932. The seed development in *Pinus palustris*. J. Elisha Mitchell Sci. Soc. 48: 101-118.

Morriss, D. J., and H. 0. Mills.
1948. The Conecuh longleaf pine seedbed burn. J. For. 46: 646-652.

Moyer, E. L., Jr.
1967. Controlling off-site hardwoods with 2,4-D amine concentrate. USDA For. Serv. Res. Note SE-77, 2 p. Southeast. For. Exp. Stn., Asheville, N. C.

Oosting, H. J.
1956. The study of plant communities: an introduction to plant ecology. Ed. 2, 440 p. W. H. Freeman & Co., San Francisco.

Peevy, F. A.
1953. Hogs still prefer longleaf. USDA For. Serv. South. For. Exp. Stn. South. For. Notes 87.

Pessin, L. J.
1944. Stimulating the early height growth of longleaf pine seedlings. J. For. 42: 95-98.

Shoulders, E.
1967. Fertilizer application, inherent fruitfulness, and rainfall affect flowering of longleaf pine. For. Sci. 13: 376-383.

Siggers, P. V.
1944. The brown spot needle blight of pine seedlings. USDA Tech. Bull. 870, 36 p.

Smith, L. F.
1961a. Tree percent on burned and unburned longleaf seedbeds. J. For. 59: 201-203.

Smith, L. F.
1961b. Growth of longleaf pine seedlings under large pines and oaks in Mississippi. USDA For. Serv. South. For. Exp. Stn. Occas. Pap. 189, 4 p.

Snyder, E. B.
1973. 15-year gains from parental and early family selection in longleaf pine. Proc. 12th South. For. Tree Improv. Conf., p. 46-49.

Stephenson, G. K., P. D. Goodrum, and R. L. Packard.
1963. Small rodents as consumers of pine seed in east Texas uplands. J. For. 61: 523-526.

Wahlenberg, W. G.
1946. Longleaf pine: its use, ecology, regeneration, protection, growth, and management. 429 p. Chas. Lathrop Pack For. Found. and USDA For. Serv., Wash., D. C.

Wakeley, P. C.
1970. Thirty-year effects of uncontrolled brown spot on planted longleaf pine. For. Sci. 16: 197-202.

Wakeley, P. C., and H. H. Muntz.
1947. Effect of prescribed burning on height growth of longleaf pine. J. For. 45: 503-508.

Walker, L. C.
1954. Early-scrub oak control helps longleaf pine seedlings. J. For. 52: 939–940.

Weaver, J. E., and F. E. Clements.
1938. Plant ecology. Ed. 2, 601 p. McGraw-Hill Co., New York.

Wells, B. W., and I. V. Shunk.
1931. The vegetation and habitat factors of the coarser sands of the North Carolina Coastal Plain: an ecological study. Ecol. Monogr. 1: 465-520.

Croker, Thomas C., Jr., and William D. Eoyer

1975. Regenerating longleaf pine naturally. South. For. Exp. Stn., New Orleans, La. 21 p. (USDA For. Serv. Res. Pap. SO-105)

Research has developed guides for consistent natural regeneration of longleaf pine by a shelterwood system. Key measures include hardwood control by fire and other means, timely preparatory and seed cuts, seed crop monitoring, seedbed preparation, protection of established seedlings, prompt removal of parent trees when reproduction is adequate, and control of competition and brown-spot disease after the removal cut.

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