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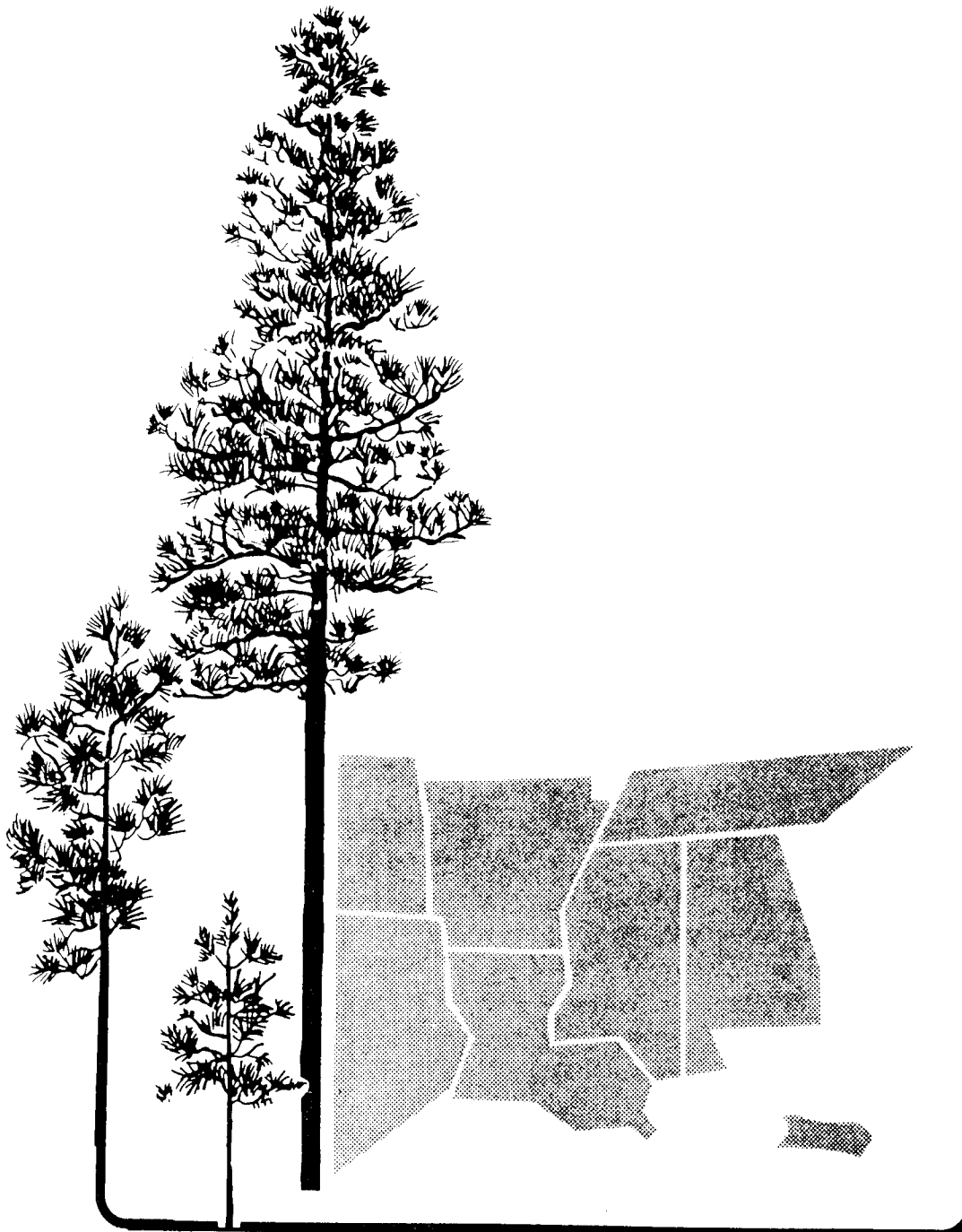
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NATURAL REGENERATION OF LONGLEAF PINE

William D. Boyer and John B. White¹

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

INTRODUCTION

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

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

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

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

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

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

ECOLOGY OF LONGLEAF PINE NATURAL REGENERATION

Seed Production

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

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

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

Cone production - Cone production by individual longleaf pine trees is affected by site quality, stand density, tree size, and genetic predisposition (Crocker and Boyer 1975). The best cone producers are dominant trees 15 inches or more in d.b.h., with large crowns and a history of past cone production, as evidenced by old cones under the tree. Tree size is an important factor in cone production. A tree 15 inches d.b.h. will produce, on the average, more than twice as many cones as a 12-inch tree, and a 19-inch tree more than twice as many cones as the 15-inch tree. Cone production per acre is affected by stand density and, on average sites, reaches a peak at stand basal areas between 30 and 40 ft² per acre and falls off rapidly above and below this range (Crocker and Boyer 1975). For a given stand density, per acre cone production is not greatly affected by increasing tree size above 15 inches d.b.h., as the increase in cone production per tree is largely offset by the reduction in trees per acre.

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

Seed Dispersal

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

Seedling Establishment

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

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

Seedling Survival and Growth

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

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

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

Given longleaf pine seedling stands of the same size (root collar diameter), fire mortality of seedlings under a pine overstory will be about double that of similar seedlings in the open (Crocker and Boyer 1975). Within forest stands, healthy grass-stage seedlings that have reached 0.4-inch or more in root-collar diameter are relatively safe from mortality in carefully prescribed and executed winter fires (Boyer 1974a), even under parent overstories ranging up to 60 ft² basal area per acre (Maple 1969). Some fire-resistance is lost during the early stages of height growth, up to a height of 2 to 3 feet, after which the seedlings again become less vulnerable to fire kill (Maple 1975).

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

Seedlings heavily infected with brown spot are at greater risk as the foliage, instead of protecting the seedling from fire, adds to the fuel load. However, brown spot is unlikely to reach serious levels in seedling stands retained under a pine overstory (Boyer and Peterson 1983), even at overstory densities as low as 9 ft² basal area per acre (Boyer 1975).

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

NATURALLY REGENERATING THE LONGLEAF FOREST

Regeneration Methods

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

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

Biological Requirements for Regeneration

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

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

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

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

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

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

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

Management Requirements for Regeneration

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

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

Applying the Shelterwood System

The two principal variants of the shelterwood system applied to longleaf pine are the three-cut and the two-cut methods. They are identical, except that the three-cut method has a preparatory cut that precedes the seed cut. A well-managed longleaf pine stand periodically thinned to medium densities will not need a preparatory cut, so the regeneration process can begin with the seed cut. Planned regeneration of an unmanaged stand, or a stand with overstory pine densities in excess of 80 ft² basal area per acre, may need to begin with a preparatory cut. Guidelines for application of the shelterwood system of longleaf pine natural regeneration have been reported (Croker and Boyer 1975, Boyer 1979a).

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

The preparatory cut - This cut is made ten or more years before the planned harvest date of the stand at rotation end, and at least five years ahead of the seed cut. Stand density is reduced to a maximum of 60- to 70-ft² basal area per acre of dominant and codominant longleaf pines, depending on site quality. If there are gaps in the stand, the overall average density of the residuals will be somewhat less. This cut will promote crown development and thus cone production. At this time, hardwoods too large for control by fire should be harvested, if merchantable, or deadened. The regular use of prescribed fire

during the rotation should have resulted in an understory essentially free of hardwoods and brush. If a large number of small woody stems are present, a series of annual or biennial growing season burns may be necessary to control this component of the understory. This control must be completed before the seed cut, while needle litter accumulation is sufficient to fuel relatively hot surface fires and a seedling stand has not yet been established.

The seed cut - This cut is made five years before the planned harvest. Residual parent trees in the regeneration area are marked to leave a density not exceeding 30 ft² of basal area per acre (the goal is not an average of 30 ft², as this might result in leaving, for example, 60 ft² in one location to compensate for a hole in another) of high-quality dominant trees with well-developed crowns, favoring those with some evidence of past cone production. Although cone production per acre peaks in the 30- to 40-ft² basal area per acre range, the lower end of the range is preferred, as logging-related seedling losses increase with increasing density of the overstory removed (Maple 1977b).

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The removal cut - Once a satisfactory seedling stand is present, the parent overstory can be removed. If all has gone according to plan, the final harvest cut can be made on schedule, five years after the seed cut. However, the final removal cut can be delayed, if necessary, due to management needs or market conditions. Seedlings can survive seven or more years under a parent overstory with no effect on survival, provided the stand is not burned. However, seedling growth will be slow. When compared to a seedling stand released from overstory competition at age one, a shelterwood overstory of 30 ft² basal area per acre will account for 70 percent of the growth loss observed under overstory densities of 90 ft² basal area per acre (Boyer 1963).

The best time to remove the parent overstory, in terms of minimizing seedling mortality, is at seedling age 1 or 2. Mortality at this time has averaged 35 to 40 percent (Boyer 1974b). By ages 3 to 5, mortality has increased to 50 to 55 percent with overstory removal. Logging related seedling mortality also increases with increasing density of the parent overstory (Maple 1977b), from 42 percent with removal of 20 ft², to 54 percent with 40 ft², and 69 percent with 60 ft² basal area per acre. If density of the shelterwood overstory is 40 ft² or more in basal area per acre, it may be best to remove the overstory in two cuts rather than one. This reduces the load of logging slash on the ground at any one time, and can also result in additional seedling establishment between cuts. Logging damage becomes more serious once seedling height growth begins. Stemless grass-stage seedlings are less likely to suffer serious damage, and, even when they do, are more likely to sprout.

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

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

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

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

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

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

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

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

Modifications of the Shelterwood System

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

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

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

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

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

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

The principal disadvantage of patch shelterwood for longleaf pine is the exposure of seedlings and saplings of this intolerant, pioneer species to prolonged suppression from adjacent older stands. Competition from a wall of mature timber extends 55 to 70 feet into an opening and can affect all or most of the seedlings in a clearing, depending on its size. Assuming a competition zone of 60 feet, 76 percent of a circular 1-acre opening is exposed to competition from the side, as is 40 percent of a similar 5-acre opening. Some experience suggests that this type of management could result in mean annual volume increments substantially less than that expected of uniform even-aged stands under similar conditions of site, stand density and rotation length (Boyer and Farrar 1981, Farrar 1985). However, if the landowner's management objectives include creation and maintenance of the uneven-aged condition for his forest, the change in structure and appearance generated by patch cuttings may compensate for reductions in volume growth.

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

CONCLUSIONS

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

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

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