Chapter 9.

Reproduction Cutting Methods

for Naturally Regenerated Pine Stands in the South

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Abstract—*It is projected that plantations will make up 25 percent of the South's forest land area by the year 2040. Thus the remaining 75 percent of that area will consist of naturally regenerated pine, pine-hardwood, and hardwood stands. Naturally regenerated pines can be managed successfully by even-aged and uneven-aged silvicultural systems when the reproduction cutting method is properly planned and executed, and when there is timely application of site preparation, release, and intermediate treatments to ensure seedling establishment and development. Attention to residual basal area, seed production, preparation of suitable seedbeds, control of competing vegetation, and timely density control are important to the successful management of naturally regenerated stands.*

INTRODUCTION

In the last half of the 20th century, the practice of silviculture in southern pine (*Pinus* spp.) stands has focused on one silvicultural system—clearcutting and planting. This focus has been made possible by two great advances during that time: (1) the development of genetically improved planting stock and (2) the advent of herbicide technology for control of unwanted vegetation in planted stands. The silvicultural system of clearcutting, planting, and associated herbicide treatments has come to define intensive forest management. Forest industry, nonindustrial private forest (NIPF) landowners, and Government agencies have all employed variations of this prescription, and as a result the area in plantations in the South has gone from virtually none to roughly 12.5 million ha (31 million acres) in the last 50 years (fig. 9.1).

This silvicultural system has become popular because of the large total merchantable volume of wood and wood fiber that can be obtained. In 1995, plantations occupied 15 percent of the forest land in the South but provided 35 percent of the harvested volume (Wear and Greis 2002). By 2040, pine plantations will occupy approximately 20 million ha (50 million acres), or 25 percent of the southern forest area. This will represent roughly half of the projected pine-dominated forest area at that time (Wear and Greis 2002).

On the other hand, these data also imply that by 2040, 75 percent of the South's forest land will not be plantations, but rather in stands of naturally regenerated origin. Currently more than half of the area in the South's pine-dominated forest types is managed by methods other than intensive plantation culture. Some of this area will not be managed at all in a professional sense; it will simply be allowed to grow as it will and will be high-graded when an operable commercial harvest becomes feasible. But other areas are, and will continue to be, managed using classical silvicultural practices that establish and maintain

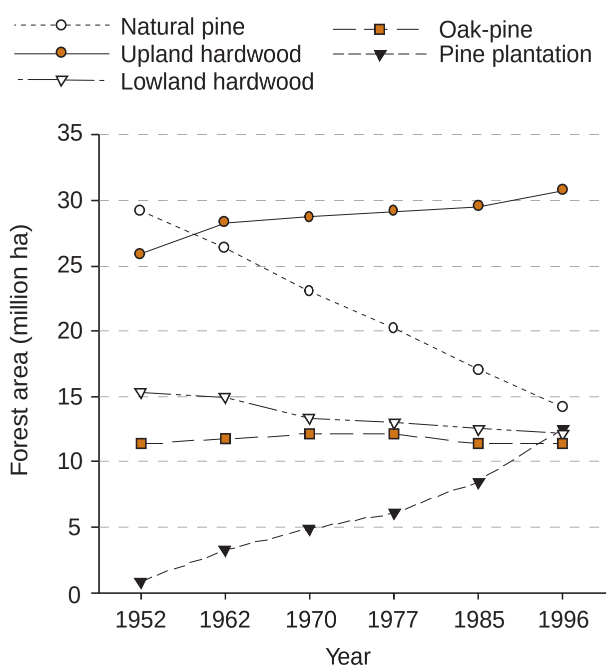

Figure 9.1—Trends in forest area occupied by forest type and year, 1952–96 (Sheffield and Dickson 1998).

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naturally regenerated pine stands. Specifically, these include even-aged reproduction cutting methods, such as the seed tree and shelterwood methods, and uneven-aged reproduction cutting methods, such as the group selection and single tree selection methods.

Management of naturally regenerated stands will have four prominent areas of application in the decades to come. The first of these is in management of the forest land owned by NIPF landowners. Many NIPF landowners choose not to employ clearcutting on their land, because clearcutting requires a large capital investment in stand establishment. Plantation establishment costs can quickly exceed \$500/ha (\$200 per acre), especially if intensive site preparation includes applications of chemicals and fertilizer (Dubois and others 2001). While such costs are easily borne by large companies, they are often difficult for NIPF owners of small properties to justify. Management prescriptions that rely on natural regeneration can be adapted to make stand establishment costs very low, although the tradeoff is that it takes longer to develop trees of merchantable size. However, many NIPF landowners find this acceptable, especially in light of the multiple management objectives they often seek, within which the aesthetic disadvantages associated with clearcutting do not fit.

The second prominent area of application is in management of large-diameter pine trees and the higher unit value that sawtimber brings relative to pulpwood when trees are harvested. For example, during the past 10 years in Louisiana, prices of softwood sawtimber averaged from 3.2 to 5.4 times those of pine pulpwood on an equivalent weight basis (Louisiana Department of Agriculture and Forestry 2002a, 2002b). In multiple-use settings, management of stands to large tree size can produce aesthetic, wildlife, and other benefits sought by a landowner. Finally, a part of the South's forest industry will continue to concentrate on the manufacture of high-quality dimension lumber, the best source of which is high-quality trees of sawtimber size.

The third area of application is within streamside management zones (SMZs), often among the most productive sites in a forested ownership. Clearcutting is generally avoided in SMZs, because it has adverse effects on water quality and aquatic systems. High-grading or selective cutting is often used to capture standing volume of desired species found in SMZs, but experience shows that such practices are neither sustainable nor grounded in sound silvicultural practice. One sensible approach to the management of SMZs is to employ management prescriptions that naturally regenerate desired species while maintaining forest cover within the SMZs.

Finally managers of public forest land in the South, especially those who manage national forest lands, are increasingly seeking alternatives to clearcutting (Guldin and Loewenstein 1999). This trend has its origins in the fact that the public does not like the appearance of clearcutting on public lands. But it also is seen in modern approaches to management of Government lands by means of silvicultural prescriptions designed to retain or restore forest stand conditions that benefit underrepresented plant and animal communities, such as the pine-bluestem habitat restoration in the western Ouachita Mountains (Stanturf and others 2004).

Research and practical experience suggest that both even-aged and uneven-aged reproduction cutting methods can be used in southern forest stands, depending on forest type, prevailing economic and ecological conditions, and ownership (Burns 1983). It is likely that the range of potential applications will grow wider rather than narrower as a wider variety of practitioners employ a wider variety of these methods on a wider variety of ownerships.

THE ECOLOGICAL BASIS OF NATURALLY REGENERATED PINE STANDS

Reproduction cutting methods that rely on natural regeneration emulate a continuum of intensity of natural disturbance. Clearcutting, with its total removal of all overstory vegetation, approximates the most severe stand-replacement disturbances, such as the main path of a tornado or the flare-up of a canopy-destroying wildfire. But few ecological conditions in nature are so severe that all living trees are removed. More commonly, some trees remain following disturbance, and they provide seed to reforest the disturbed area. Reproduction cutting methods that rely on natural regeneration imitate this dynamic directly.

The even-aged seed tree and shelterwood methods approximate disturbance events sufficiently severe that a new regeneration cohort is established across the entire stand. They differ in the number of residual trees remaining on the site and in the provision of shelter by residual trees. In the seed tree method, few overstory trees remain, and microecological conditions for seedlings are essentially the same as if the area were clearcut. In the shelterwood method, more overstory trees remain, and their presence slightly ameliorates the microecological condition for developing seedlings.

The uneven-aged methods approximate disturbance events that open up only part of a stand. Thus the new regeneration cohort will be found only in those portions of the stand within which the openings are found, rather than across the entire stand. The group selection method emulates disturbance events such as beetle spots or locally heavy windstorms that remove small groups of overstory trees within a stand; regeneration then occurs in that group opening. The single tree selection method imitates the smallest scale of disturbance, that of the mortality of one or two mature trees. This creates a small opening marginally sufficient for development of a very small cohort of regeneration, provided that the species being managed is sufficiently tolerant of shade to develop. Thus the entire gradient of natural disturbance events, from severe events that give rise to continuous regeneration cohorts across the stand to localized events that give rise to discontinuous regeneration cohorts within the stand, are reflected in the reproduction cutting methods used to naturally regenerate managed stands.

EVEN-AGED REPRODUCTION CUTTING METHODS

Clearcutting Method

The clearcutting method can be applied in a manner that relies on natural regeneration rather than on planted seedlings to reforest the clearcut site (Langdon 1981, Smith 1986a). However the circumstances under which the practice will succeed are highly specialized. One common approach is to configure the clearcut opening so that trees from adjacent stands can naturally seed all parts of the harvested site (fig. 9.2). The more risky practice in southern pines, clearcutting using seed-in-place (Smith 1986a), relies on the harvest of trees at the point in the growing season when cones are mature but not yet opened. Harvest will disperse those cones across the site, and the warm temperature regimes that result from clearcutting promote cone scale reflexion and seed dispersal (Shelton and Cain 2001). This method can succeed only if many conditions are concurrently met. Cones must be present and contain viable seed, harvest must occur within a 1-month window prior to the autumnal seed fall, seedbed conditions must be adequate within the slash resulting from the harvest, seed must remain present and viable

Figure 9.2—The strip clearcutting method demonstrated in a loblolly-shortleaf pine stand, Crossett Experimental Forest, near Crossett, AR. Photo courtesy of James M. Guldin 2003.

until germination occurs, and seedlings must become established and must develop properly. The major difficulty is that there is no room for accident or error, since there is no residual seed source in the event that the initial cohort does not become established.

Seed Tree Method

In the seed tree method, a small number of trees are retained on the site after harvest as a source of seed for the harvested area. Seed trees should be distributed uniformly across the site in such a way that the entire area of the harvested stand is within an acceptable dispersal distance of one or more of the residual seed trees. A reasonable estimate for the number of seed trees depends on tree size, but it is not unusual to reserve 10 to 25 pine seed trees/ha (4 to 10 trees per acre), with a corresponding residual basal area from 1 to 3 m^2/ha (5 to 15 square feet per acre). The harvest that takes all but the seed trees is called the seed cut, and the subsequent harvest that removes the seed trees is called the removal cut (Smith 1986a).

Professional application of the seed tree method bears little resemblance to retention of seed trees under the old seed tree laws. Those laws, which mandated retention of a few trees/ha after harvest, had the effect of leaving the poorest phenotypes of marginal size to reforest the site. Many attributes of interest to foresters, such as cone production, straightness, and branchiness, are highly inherited traits, and trees that display such attributes are likely to pass them along. Thus proper application of the seed tree method dictates the retention of trees with good form, acceptable branch characteristics, and evidence of past seed production. These attributes are easier to determine in some species than others. For example, in shortleaf pine (*P. echinata* Mill.), cones tend to persist for a number of years after seeds are shed (Lawson 1990), whereas loblolly pine (*P. taeda* L.) tends to drop its cones after seed fall (Baker and Langdon 1990). In shortleaf pine stands, marking crews can use this information about cone persistence to help determine which trees to retain.

The biggest limitation on the effective use of the seed tree method is the production of seed by the parent tree. Of the four major southern pines, the seed tree method works best in application to loblolly pine, especially in the west gulf region where abundant seeds are produced with great regularity (Cain and Shelton 2001). Adequate seed production translates to adequate seed fall and the likelihood of effective catch of seed by the site. Unfortunately, seed production in longleaf pine (*P. palustris* Mill.) is highly periodic, and use of the seed tree method is rarely successful with this species. One way to compensate for erratic cone production is to plan to retain seed trees for a long period of time, in the hope of continued recruitment into the regeneration cohort. Empirical evidence suggests that the seed tree method can also be made to work in shortleaf pine, which falls between loblolly and longleaf in periodicity of seed fall (Guldin and Loewenstein 1999).

As seed fall from seed trees becomes marginal, the need for effective site preparation increases. One main element of site preparation is the creation of a suitable seedbed. This, for southern pines, generally means the scarification of the forest floor to expose mineral soil. Typically, the logging activity associated with a seed tree harvest provides sufficient scarification for acceptable establishment of seedlings during bumper seed crops (Baker and others 1996). If seed crops are marginal, supplemental scarification may be required. However, no amount of supplemental scarification will help if seed crops are a failure. As a result, early detection of impending seed crops is important to help schedule the amount of site preparation necessary to ensure acceptable seedling establishment. Since pine cones take 2 years to develop, one can get an early estimate of cone production expected for given autumn by inspecting tree crowns for conelets in the spring of the previous year. While this approach offers only a rough prediction of adequate to bumper crops, one can easily see when a cone failure is imminent. That information can then be used to schedule or defer site preparation treatments in the summer or autumn immediately prior to seed fall.

When properly applied, the seed tree method has a number of advantages. Enough residual trees should be retained to allow an operable harvest of the parent trees 5 to 10 years after the seed cut. That operable harvest can also provide a desirable precommercial thinning in the regeneration cohort, by felling the seed trees amidst the regeneration and by the passage of the equipment used to harvest and skid the felled logs to the logging deck.

An outstanding example of the seed tree method in application to southern pines exists in the loblolly-shortleaf pine type in the upper west Gulf Coastal Plain (Zeide and Sharer 2000) (fig. 9.3). No southern pine is easier to regenerate

Figure 9.3—The seed tree reproduction cutting method applied operationally in a loblolly-shortleaf pine stand managed by forest industry, Ashley County, AR. Photo courtesy of James M. Guldin 1984.

naturally than loblolly pine, which dominates this forest type; seed crops that are adequate or better occur 15 years in 20 in mature loblolly-shortleaf pine stands (Cain and Shelton 2001). For a number of decades, the silvicultural guidelines for a major industrial forestry landowner in the region called for use of the seed tree method, leaving 2.3 to 4.5 m^2/ha (10 to 20 square feet per acre) of basal area of trees with good form and with diameter at breast height of 40 to 50 cm (16 to 20 inches).[2] The seed trees were usually taken in a removal cut 3 to 5 years later, which produced an operable harvest of from 2.9 to 8.8 m^3/ha (500 to 1,500 board feet per acre) of saw logs. Removal of the seed trees also thinned the excessive pine regeneration that was common in this forest type. The first commercial thinning occurred between the ages of 17 and 20 years, leaving about 16 m^2/ha (70 square feet per acre). The next thinning, at age 25, included some small saw logs, and subsequent thinnings on a 5-year cycle averaged 11.7 m^3/ha (2,000 board feet per acre) in each thinning. The final seed cut produced between 29.2 and 40.8 m^3/ha (5,000 to 7,000 board feet per acre). Thus growth for the rotation averaged > 1.75 m^3/ha (300 board feet per acre) annually. Late-rotation thinning also released the crowns of the seed trees, which increased cone and seed production. Regularly scheduled prescribed fires on a 3- to 5-year cycle, coupled with hardwood control on a 5- to 10-year cycle, promoted visibility within the stand that enhanced subsequent thinning treatments, and if carried through the end of the rotation, reduced the need for intensive site preparation in the subsequent rotation.

Shelterwood Method

The shelterwood method is similar to the seed tree method in that residual trees are retained to reforest the site after harvesting occurs, but more trees are retained. In his description of the shelterwood method, Smith (1986a) includes three specific elements: (1) the preparatory cut, (2) the seed cut, and (3) the removal cut.

The preparatory cut removes competitors of future seed trees, which then expand their crowns and root systems, thereby enhancing the potential for cone development. In southern pines, the late-rotation thinning commonly conducted in pine sawtimber stands generally fulfills the intent of the preparatory cut. During the seed cut, 35 to 75 pines/ha (15 to 30 trees per acre), having 4.5 to 9.0 m^2/ha (20 to 40 square feet per acre) of basal area, are selected for retention. Favorable traits for residual pines include stem form, windfirmness, and evidence of past seed production. The removal cut harvests the seed trees after the new stand has developed past the point of risk from seedling-related mortality.

One operational advantage of the shelterwood over the seed tree method in southern pines is that the volume of the residual trees in the shelterwood is greater than that of the seed tree method and is, thus, more likely to attract interest from loggers during the removal cut. Conversely, if carelessly done, logging during the removal cut can adversely affect stem density of the regeneration, especially at higher residual basal areas. Depending on management objectives, the final harvest may be deferred for half or more of the rotation length, resulting in a two-aged stand; this method is referred to as an irregular shelterwood (Helms 1998, Smith 1986a).

[2] Lovett, Ernest. 2003. Letter dated September 29 to James M. Guldin. On file with: Arkansas Forestry Sciences Laboratory, 114 Chamberlin Forestry Building, University of Arkansas at Monticello, Monticello, AR 71656.

Under traditional application of the shelterwood method, microclimatic ecological conditions are ameliorated relative to those found in fully open conditions; e.g., see Valigura and Messina 1993. Thus one reason to apply the shelterwood method is to moderate conditions that might be too harsh for seedlings to survive under a clearcut or a seed tree prescription. As a practical matter, the shelterwood method is popular for species in which seed production is erratic or unreliable; the added numbers of seed trees that remain in the shelterwood often make the difference between adequate stocking and less-than-adequate stocking.

Among the most prominent examples of the shelterwood method in southern pines is the experience with longleaf pine in southern Alabama (fig. 9.4). Longleaf pine has the deserved reputation of being the most difficult of the southern pines to regenerate naturally, but clever research has identified the practices needed to naturally regenerate the species using the shelterwood method (Boyer 1979, Croker and Boyer 1975). First, seed production in longleaf is optimal when the seed cut retains 6.9 to 9.2 m^2/ha (30 to 40 square feet per acre) of basal area (Maple 1977). Fewer trees result in fewer cones per unit area, and more trees do not enhance cone production. Second, prescribed fires are essential to control brown-spot needle blight (*Mycosphaerella dearnessii* Barr.) and, thereby, to release seedlings from the grass stage (Boyer 1979). Third, seedling mortality is highest beneath the crowns of residual trees, because the buildup of pine straw promotes prescribed fires sufficiently intense to kill them. All of these factors have led scientists to conclude that the need for available growing space, the need for frequent prescribed fire, the optimal development of cones in the canopy, and the ability to store seedlings in a seedling bank beneath the overstory of longleaf pine could be achieved using the shelterwood method.

Figure 9.4—The shelterwood reproduction cutting method applied in a research study on the Escambia Experimental Forest, near Brewton, AL. Photo courtesy of James M. Guldin 1982.

UNEVEN-AGED REPRODUCTION CUTTING METHODS

Prevailing wisdom suggests that uneven-aged reproduction cutting methods, especially the single tree selection method, are best for shade-tolerant species (Smith 1986a). As a result, the use of uneven-aged silviculture to manage shade-intolerant species such as the southern pines is often criticized. But historical experience suggests that the method can work with pines, subject to certain considerations. The Dauerwald, among the first applications of uneven-aged silviculture, was imposed in plantations of Scots pine (*P. sylvestris* L.) on poor sites in Germany (Troup 1952); some of its attributes still apply to current uneven-aged methods (Guldin 1996). Pearson (1950) applied a selection method to ponderosa pine (*P. ponderosa* Laws.) stands on the Fort Valley Experimental Forest in Arizona, thus laying the groundwork for contemporary application of that method in the American West (Becker and Corse 1997).

In the South, the best long-term uneven-aged dataset comes from the Good and Poor Farm Forestry Forties of the Crossett Experimental Forest (CEF) in southern Arkansas. Established in mixed loblolly-shortleaf pine stands on the west Gulf Coastal Plain in 1937, the Good and Poor Farm Forestry Forties have yielded data that were summarized after four decades (Baker 1986, Reynolds and others 1984). Other long-term examples are the quarter-century summary from the Farm Forestry Forties at Mississippi State University (Farrar and others 1989) and the 33-

year record from the University of Arkansas's Hope Farm Woodland at Hope, AR (Farrar and others 1984). Empirical evidence suggests that the selection method can be made to work with longleaf pine in the lower Coastal Plain of Florida and Alabama (Farrar 1996), and with shortleaf pine in the Interior Highlands of Arkansas and Oklahoma (Guldin and Loewenstein 1999, Lawson 1986). In short, the selection method can be adapted to southern pines if attention is paid to marking, regeneration, and stand structure (Guldin and Baker 1998).

Figure 9.5—The group selection method in application to longleaf pine in a Farm Forestry Forty demonstration on the Escambia Experimental Forest, near Brewton, AL. Photo courtesy of James M. Guldin 1982.

The general experience with uneven-aged silviculture in intolerant pines would lead one to suspect that group selection, with its larger openings (fig. 9.5), would be more effective than single tree selection, with its minimal canopy opening. Certainly some evidence suggests that in longleaf pine, group selection may be an effective reproduction cutting method (Brockway and Outcalt 1998, Farrar 1996, Farrar and Boyer 1991). On the other hand, Russ Reynolds, the scientist who pioneered the research at CEF, did not distinguish specifically between single tree selection and group selection; he spoke instead of using whatever size of openings was indicated by local stand conditions (fig. 9.6). Whether group selection or single tree selection is preferred, a number of considerations should receive special attention when selection methods are applied to southern pines: initial stand conditions, regeneration, developmental dynamics, application of marking rules, and residual stand structure.

Initial Stand Conditions

Circumstantial evidence suggests that early 20th century southern pine stands were largely even-aged before they were high-graded. Loblolly pine was known as old-field pine, and early photographs show that virgin upland pine-hardwood stands in the west gulf region had an open understory (Reynolds 1980).

Figure 9.6—Stand structure in a stand under management using the selection method, Good Farm Forestry Forty demonstration, Crossett Experimental Forest, near Crossett, AR. Photo courtesy of James M. Guldin 1984.

Similarly, virgin shortleaf pines in the Ouachita Mountains grew in open forest consisting of widely spaced overstory trees and little undergrowth (Smith 1986b).

Naturally occurring loblolly-shortleaf pine stands in the west gulf region originated after the first cutting of virgin forest in the early 1900s. In 1915, the Crossett Lumber Company, which owned the virgin forest land that would later become the CEF, harvested the area using a 38-cm (15-inch) stump limit cut, which was roughly equivalent to a 30-cm (12-inch) diameter limit cut. Between 1915 and 1934, no deliberate management was undertaken. The area supported occasional harvest of small hardwoods for chemical distillation and periodically was subject to arson fires. The company leased the 680-ha (1,680-acre) tract to the U.S. Department of Agriculture Forest Service (Forest Service) in 1934 for establishment of the CEF. While the company was interested in research information on management of second-growth forests, they also thought that Forest Service research staff could help prevent arson or control the resulting fires (Reynolds 1980).

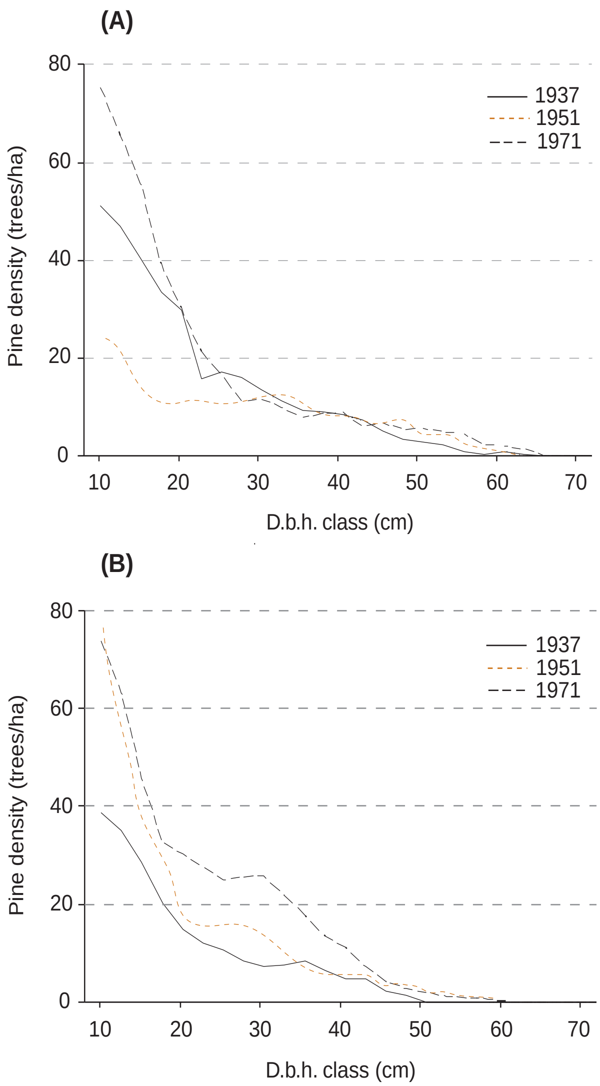

Figure 9.7—Diameter distributions of the Good Forty and the Poor Forty on the Crossett Experimental Forest in the first 35 years of the demonstration—(A) Good Forty in 1937, 1951, and 1971; (B) Poor Forty in 1937, 1951, and 1971.

Thus the use of uneven-aged silviculture in southern pines originated as a result of selective cutting. In 1937, the CEF Forties were stocked with scattered residual overstory trees that had survived the 30-cm (12-inch) diameter limit cutting in 1915, and the second-growth seedlings, saplings, and poles that seeded in after the cut and grew until 1937. On average, the stands were about 40 percent stocked by then (Reynolds 1969). The diameter distribution of the pine component in the CEF Good and Poor Forties in 1937 showed the reverse J-shaped curve typical of uneven-aged structure (fig. 9.7). This description of selective cutting and its effects on stand conditions at CEF was typical of that in the region; the stands in the Farm Forestry Forties and Hope Farm Woodland demonstrations had a similar history and initial condition. Because the stands in these demonstrations were relatively understocked when the selection method was initially applied to them, their rapid recovery to fully stocked conditions under the selection method shows that uneven-aged silviculture is a powerful tool for bringing understocked or cutover stands to full stocking within a short time (Baker and Bishop 1986; Farrar and others 1984, 1989).

Additional research illustrates not only the speed of the recovery, but also the degree of understocking from which recovery can occur. Baker and Shelton (1998a, 1998c) reported that stands with 20- to 30-percent stocking could develop acceptable stocking and basal area within 15 years, provided that competing vegetation is controlled with herbicide application. These threshold levels are lower than previously thought, and lower than threshold levels in the long-term demonstrations.

This suggests a strategy for implementing uneven-aged silviculture in southern pines across a forested ownership in the public or private sector. If the ownership supports both fully stocked even-aged stands and stands that for one reason or another are understocked, the best approach would be to convert the understocked stands rather than the fully stocked even-aged stands.

Regeneration

The importance of regeneration in these demonstrations is poorly documented for two reasons. First, there is no record of regeneration development in the 20- to 40-year period between the initial high-grading and demonstration establishment. Second, because regeneration was so abundant, the scientists who established the demonstrations paid little attention to it.

Reynolds (1959, 1969) reported that pine regeneration was established as a result of removal of poorer hardwoods of large and medium size, continuing fire protection, and control of small hardwood stems. He also noted that pine seedlings, saplings, and poles typically are found in small openings and often directly under high-crowned larger stems. This is apparent in the diameter distributions of the Good and Poor Forties during the first 20 years of management (fig. 9.7). The continued ingrowth into the 10-cm (4-inch) class during this period resulted from recruitment of saplings from the smaller diameter classes.

Thus obtaining regeneration and promoting its development through the seedling and sapling classes are critical for successful uneven-aged management (Shelton and Cain 2000). The initial cohort of reproduction should be established or released at the first cutting-cycle harvest in order to meet two goals: (1) the need for reproduction cutting to result in regeneration, and (2) the need to establish three or more distinct age classes in the uneven-aged stand (Helms 1998). If the establishment of the initial regeneration cohort is delayed, the conversion period will be correspondingly lengthened.

Residual Basal Area

In southern pines, regeneration establishment and development are strongly related to the basal area of the merchantable component of the stand. Data from the CEF and elsewhere suggest that uneven-aged stands can be managed successfully within a range of residual basal area from 10 to 17 m^2/ha (45 to 75 square feet per acre) (Baker and others 1996; Farrar 1996; Farrar and others 1984, 1989). At residual basal area levels < 10 m^2/ha (45 square feet per acre), the overstory is understocked and growth will not be optimal (although such stands can be rehabilitated to optimal production easily, as discussed earlier). At residual basal areas > 17 m^2/ha (75 square feet per acre) at the end of the cutting cycle, regeneration development is adversely affected.

The residual basal area target immediately after harvest must be established in conjunction with the expected length of the cutting cycle, the expected growth of the residual stand, and the upper basal area limit for the species. For example, basal area growth of uneven-aged loblolly-shortleaf pine stands at CEF is 0.5 to 0.7 m^2/ha (2 to 3 square feet per acre) annually. If a 5-year cutting cycle is planned, the target residual basal area immediately after the cutting cycle harvest must, therefore, be 14 to 15 m^2/ha (60 to 65 square feet per acre), so that stand basal area does not exceed 17 m^2/ha (75 square feet per acre) at the end of the cutting cycle. Longer cutting cycles require lower residual basal area levels.

Thus managing for the proper residual basal area is an important element of uneven-aged silviculture. This is one reason why structural regulation using the basal area, maximum diameter, and q-ratio or the BDq method (Baker and others 1996, Farrar 1996, Marquis 1978) has become popular. The CEF experience and other work suggest that BDq is more than an alphabetical ranking; this order reflects the priority for implementation (Baker and others 1996, Farrar 1996). The importance of maintenance of stand structure is based on obtaining the appropriate basal area; retaining a specified maximum diameter class or a given q is much less important (Guldin and Baker 1998).

Developmental Dynamics

By definition, uneven-aged stands have three or more distinct regeneration cohorts; so, if one begins with an even-aged stand or an understocked stand, conversion to an uneven-aged structure is a long-term proposition. A minimum of two cutting-cycle harvests will be needed to recruit two additional cohorts of regeneration, and a third cutting-cycle harvest will be needed to avoid suppressing this new regeneration, especially with shade-intolerant southern pines. For the 5- to 7-year cutting cycles used for loblolly-shortleaf pine stands at CEF and elsewhere, it will be 20 to 30 years before even-aged or understocked stands are minimally reconfigured to uneven-aged structure. For species such as shortleaf pine in the Interior Highlands, where 7- to 10-year cutting cycles are common, the conversion period will be 30 to 40 years. These estimates are confirmed in data from the CEF Good and Poor Forties, where the time from high-grading harvests in 1915 to initial development of full stocking was 36 years.

Marking Rules

When conducting a cutting-cycle harvest in an uneven-aged southern pine stand, the guidance given to field crews can be summarized by a simple rule: cut the worst trees and leave the best (Baker and others 1996; Farrar 1996; Farrar and others 1984, 1989; Guldin 1996; Reynolds 1959, 1969). When stands have developed an uneven-aged structure through time, tree size generally becomes correlated with age across the diameter distribution (Baker and others 1996). Marking a percentage of the poorest trees in each diameter class improves the average tree quality within each class, and over time only the best trees of highest quality attain the largest size. As a result, one attribute of the selection method is that over time, it produces large sawtimber that has high quality.

In stands being converted from even-aged to uneven-aged structure, size is not correlated with age, because the smaller trees may be of the same age as the larger trees. This means that most trees in the left-hand tail of a normal bell-shaped diameter distribution may in fact be the worst trees in the stand. Strict adherence to the rule of cutting the worst and leaving the best may result in an effect similar to thinning from below, where most of the smaller trees are removed. This is preferable to retaining poorer trees in smaller size classes at the expense of better trees in larger classes simply to achieve a target structure. If the best trees are being retained below the maximum diameter and are retained in a manner that allows development of subordinate stems and newly established regeneration cohorts, a perfectly balanced stand structure is immaterial.

Marking crews need guidance in judging whether an intermediate tree in the pulpwood size class can respond to release if it is allowed to remain in the stand. Reynolds (1959) noted that loblolly pine in the west gulf region could respond to release, even at advanced age. Baker and Shelton (1998b) observed that if a loblolly pine had a 20-percent live crown ratio and good apical dominance, it should satisfactorily respond to release, even if it developed in the lower crown classes of fully stocked, uneven-aged stands for up to 40 years; anecdotal evidence for longleaf pine is similar. Different standards would probably apply for other southern pine species and for trees from lower crown classes in even-aged stands.

To a certain extent, the group selection approach to management of uneven-aged stands violates the rule of cutting the worst trees and leaving the best. Group selection usually prescribes cutting of all trees, best and worst, if they are within the group. The degree of conflict depends on how the groups are located. If groups are identified independently of density or stocking, for example, by systematically installing groups of similar size and shape according to a predetermined pattern, the opportunity to cut the worst and leave the best is seriously compromised. Conversely, if groups are established in understocked portions of the stand, without regard for size, shape, or pattern of group opening, the number of best trees that must be cut will be reduced. Group selection with reserves (Helms 1998) is probably the best, though least often prescribed, method to minimize conflicts with the "cut the worst and leave the best" axiom, provided that reserved trees within the group are the best trees and do not adversely affect regeneration establishment or development.

OTHER ELEMENTS

Additional silvicultural considerations are important in the management of naturally regenerated stands by even-aged or uneven-aged methods.

Seedbed preparation is critical. Southern pine seeds germinate best on exposed mineral soil. In southern pine types that produce prolific seed crops, such as the loblolly-shortleaf pine type in the west gulf region, the scarification associated with logging provides enough exposure of mineral soil to promote establishment of regeneration. For other species, such as longleaf pine, supplemental mineral soil scarification is often recommended. Prescribed burning can also be used to prepare seedbeds.

The relative competitive abilities of pines and hardwoods after a harvest dictate that foresters must pay attention to relative growth rates and intervene if necessary. After a seed cut or cutting-cycle harvest, the intent is to allow pine seed to germinate on exposed mineral soil, become established, and be free to develop. However, hardwoods cut during harvest or subsequent site preparation will sprout and quickly outgrow seed-origin pines. Similarly, under certain circumstances grasses and other herbaceous plants may become sufficiently dense to impede pine seedling development, and control of grasses may also be necessary. Therefore site preparation or release treatments are often an integral part of effective silvicultural prescriptions for natural regeneration.

For example, competing hardwoods, as well as nonnatives such as privet (*Ligustrum vulgare* L.) and honeysuckle (*Lonicera japonica* Thunb.), commonly inhibit the development of pine regeneration (Shelton and Cain 2000). Given the slow rates of height growth of pine seedlings and the competition provided by hardwood sprouts and invasive nonnative plant species, herbicides are critically important in managing stands of naturally regenerated pines, and may be more important to the establishment and development of naturally regenerated pine seedlings than to the survival and development of planted pine seedlings. The use of herbicides has in fact been an element of every successful long-term demonstration of uneven-aged silviculture in southern pines, including the successful practical experience of which the author is aware. Periodic control of hardwoods by applying herbicides at roughly 10-year intervals was an element of uneven-aged silvicultural prescriptions at CEF (Baker 1986). Farrar and others (1984) noted that deficits in the smaller diameter classes in uneven-aged stands were due in part to the failure of recruitment from regeneration to pulpwood-size classes, which was attributable to hardwood competition and the presence of privet. Farrar and others (1989) reported that control of hardwoods by cutting, girdling, or herbicide treatments occurred in the past on the uneven-aged Mississippi State Farm Forestry Forties, and was recommended in the future for all hardwood stems > 1.0 cm (0.4 inch) in diameter. Prescribed fire and herbicides were used in much the same way in stands regenerated using the shelterwood method on the Escambia Experimental Forest (Croker and Boyer 1975). Their use has been recommended in industrial seed tree silvicultural guidelines for south Arkansas and north Louisiana (see footnote 2 and Zeide and Sharer 2000). Prescribed fire, which does not kill larger hardwoods, probably cannot completely eliminate the need for herbicides in naturally regenerated stands, especially in uneven-aged stands.

Finally control of regeneration density is fundamental to the successful application of natural regeneration in managed stands. Regeneration development in loblolly pine is improved by early precommercial thinnings to control stem density (Cain 1995). Nevertheless regeneration density will always be less uniformly distributed in naturally regenerated stands than in successfully established planted stands. Industry foresters in the west gulf region observed a long-term average rate of understocking of 7 percent of the stand area in managing naturally regenerated stands (see footnote 2). Invariably, one of the challenges in managing naturally regenerated stands is the likelihood of damage to regeneration when conducting removal cuts or subsequent cutting-cycle harvests. In situations where regeneration is far in excess of desired density, such logging-related precommercial thinning may actually be desirable. However, the situation is more critical when regeneration density is marginal prior to the removal cut or to subsequent cutting-cycle harvests. Careful supervision of logging operations is needed in such situations.

SUMMARY

Successful use of natural regeneration in managing southern pines depends on a number of factors. The establishment and development of pine regeneration is critical. Prescriptions must leave a sufficient number of seed trees to adequately regenerate the site during an average or better seed year. Sites must be properly prepared to be receptive to pine seed, and timing of harvests and site preparation must optimize the establishment and development of regeneration.

In even-aged stands, late-rotation thinnings or preparatory cutting is recommended to expand crowns of future seed trees and to promote cone production. The seed cut must create an appropriate balance of residual trees and seed production capacity per tree to ensure adequate seed fall, and site preparation must be timed to that seed crop. In uneven-aged stands, the first cutting-cycle harvest must be heavy enough not only to create conditions suitable for the establishment of regeneration, but also to prevent suppression of regeneration before the second cutting-cycle harvest occurs. Subsequent cutting-cycle harvests must continue this developmental pattern. Regardless of system, herbicides will almost certainly be needed to control competing vegetation and enable young pine cohorts to develop successfully.

Experience and research suggests that all four major southern pines can be managed using one or more of the even-aged or uneven-aged reproduction cutting methods that rely on natural regeneration. Certainly some forest types, such as the mixed loblolly-shortleaf pine type in the west gulf region, are amenable to any of the even-aged and uneven-aged prescriptions, whereas in other forest types, such as longleaf pine, the range of available options is perhaps narrower and requires greater care in application. Each of the systems must be implemented in a manner that takes into account the silvical characteristics of the species in question. Choosing which method to use in a particular forest type depends on proper application of available research and experience with the desired species in specific situations. Overall, these methods present feasible and economically viable alternatives to clearcutting and planting for public land managers, forest industry foresters, and NIPF landowners in the South.

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