Chapter 7

Uneven-Aged Silviculture of Longleaf Pine

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Introduction

The use of uneven-aged silviculture has increased markedly in the past 20 years. This is especially true in the southern United States, where the use of clearcutting and planting is often viewed as a practice whose emphasis on fiber production results in unacceptable consequences for other values, such as those that benefit from maintenance of continuous forest cover over time. Public lands in general, and national forest lands in particular, have become the focal point for the replacement of clearcutting and planting with even-aged and uneven-aged reproduction cutting methods that rely on natural regeneration, and that can better achieve management goals that are defined by residual stand structure and condition rather than by harvested volume.

Land managers in the southern United States are keenly interested in a renaissance for longleaf pine (*Pinus palustris* Mill.) (Landers et al. 1995; Barnett 1999). Of the four southern pines, longleaf pine has experienced the greatest percentage loss in forest area, from 37 million hectares prior to European colonization to approximately 2.2% of that currently (Frost this volume). That scarcity has increased the ecological value of the stands that remain. The scattered tracts of remnant unmanaged longleaf pine stands have high emotional and physical appeal. Managed stands of longleaf pine, especially those in which prescribed fire has been regularly applied, provide exceptional values for endangered species such as the red-cockaded woodpecker (*Picoides borealis* Vieillot), game species such as bobwhite quail (*Colinus virginianus* L.), and fire-dependent species such as wiregrass (primarily *Aristida beyrichiana* Trin. & Rupr.). Then too, many foresters fondly recall the memory of the exceptional quality of lumber that mature stands of longleaf pine were, and are, capable of producing.

The perception exists that many of these values can be provided by management of longleaf pine especially through the use of uneven-aged silviculture. In public debates, this may be supported by little other than the layperson's view that uneven-aged silviculture is the opposite of clearcutting, and thus innately has something to recommend it. Foresters have been a bit more reluctant to wholly embrace the application of uneven-aged silviculture in longleaf pine, citing among other reasons the intolerance to shade of the

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species, the difficulty in obtaining natural regeneration, and the cost.

These factors may in part explain why the focus of discussion regarding uneven-aged silviculture in southern pines is especially prominent on public lands such as national and state forests, and private lands managed as game plantations. These ownership entities share a number of attributes, including a diversity of ownership objectives, and the capability, directly or indirectly, to subsidize timber production with other resource values. For example, the National Forests of Florida have made a commitment to manage longleaf pine using both even-aged and uneven-aged systems. While this is admirable from the perspective of using a diversity of reproduction cutting methods to meet a diversity of forest management objectives, the proposed scale of the practice may outstrip the research that supports widespread application.

There is no reason to suspect that the principles of uneven-aged silviculture cannot be successfully adapted to longleaf pine stands in the lower Atlantic and Gulf Coastal Plains. The method has been successfully applied over time in other southern pines—most notably, mixed loblolly (*P. taeda* L.)–shortleaf (*P. echinata* Mill.) pine stands in the upper West Gulf Coastal Plain (Baker et al. 1996). A review of that history of success and failure will be of value in providing perspective regarding the application of the method in longleaf pine.

Uneven-aged silviculture has been successful in different forest types (Guldin 1996). Success with the method depends on the ability to obtain regeneration of the desired species, and to have that regeneration develop into merchantable size classes. Conversely, failures with uneven-aged silviculture are typically associated with an inability to obtain desired regeneration (Guldin 1996; Guldin and Baker 1998). There is good reason to expect that the details of regeneration establishment and development under an uneven-aged system in longleaf pine stands will be difficult, if the experience associated with the development of the shelterwood method in longleaf pine (Croker and Boyer 1975) is any indication. There is anecdotal evidence to suggest that uneven-aged silvicultural prescriptions can be successful in longleaf pine stands (Farrar and Boyer 1991; Farrar 1996; Moser et al. 2002). There is also considerable debate about the implications of habitat quality for red-cockaded woodpeckers in uneven-aged longleaf pine stands (e.g., Engstrom et al. 1996; Rudolph and Conner 1996). In view of the current situation, the opportunity to develop and refine the application of uneven-aged silviculture in longleaf pine is timely.

This review of the selection method and of the principles that underlie its application for longleaf pine is based on another southern pine species in which experience has been successful over a long period of time—specifically, naturally regenerated stands of loblolly pine with a minor and varying proportion of shortleaf pine in the upper West Gulf Coastal Plain in southern Arkansas. Following that overview, thoughts about the application and modification of the method to longleaf pine will be discussed in detail.

Definitions and Concepts

The goal of any silvicultural system is to advantageously utilize the resources in a given stand for social benefit through the emulation of natural processes of succession and disturbance. Helms (1998) defines a silvicultural system as a planned series of treatments for tending, harvesting, and reestablishing a stand, and a regeneration method as a cutting procedure by which a new age class is created within the stand. Smith (1986) also makes this distinction, using the term "reproduction cutting method" instead of "regeneration method." These terms, "regeneration method" and "silvicultural system," are commonly misapplied in two ways. The first is that they are often mistakenly used interchangeably. The former refers to the short period of time during which a new age cohort of regeneration of the desired species is obtained, and the latter refers to the entire program of treatments for the life of the stand. The second is that they are often mistakenly applied to a forest rather than to the individual stand, which is their intended scope

(Smith 1986; Helms 1998). The confusion is in part because the treatment prescriptions in the silvicultural system are closely related to stand structure at any given point in time, and stand structure is established primarily using the reproduction cutting method at the point of stand or cohort establishment.

The choice of regeneration method determines the scale of disturbance that foresters can imitate (Brockway et al. this volume). Even-aged regeneration methods such as clearcutting, the seed tree method, or the shelterwood method are designed to emulate varying intensities of stand-replacing disturbance events, resulting in a new cohort of regeneration across the entire stand. Unevenaged regeneration methods such as the selection method are designed to emulate a small-scale within-stand disturbance event, resulting in a new age class only in that subset of the stand where the practice was imposed. In either even-aged or uneven-aged methods, the main indication of success in the execution of a regeneration method is whether a new stand of trees is successfully obtained to replace the trees that were removed during the harvest. Thus, the reproduction cutting method is the primary element of the silvicultural system in that the actions that comprise the silvicultural system depend upon the origin of the regeneration, its age distribution, and its spatial distribution over the stand.

The choice of regeneration method also has an inordinate influence on the overall course of silvicultural treatments and the way those treatments are imposed in the stand (Fig. 1). In an even-aged stand, the sequence of silvicultural practices depends upon stand age. The new stand is obtained using a regeneration method that results in a new cohort of regeneration across the entire stand. Subsequent treatments such as site preparation in advance of the new cohort, release of that cohort, and intermediate treatments such as thinning also occur across the entire stand. Each treatment is imposed in a manner that is correlated with the age of the new cohort of regeneration. Eventually, when the stand reaches maturity, a new reproduction cutting method is implemented at the rotation age r, which gives rise to a subsequent stand managed with a subsequent silvicultural system.

Conversely, in an uneven-aged stand, there is no rotation age r. Instead, treatments are based on a cutting cycle c, the basic interval of stand entry, which varies from 5 to 20 years. Cutting cycle harvests are imposed in each stand every c years. However, the trees

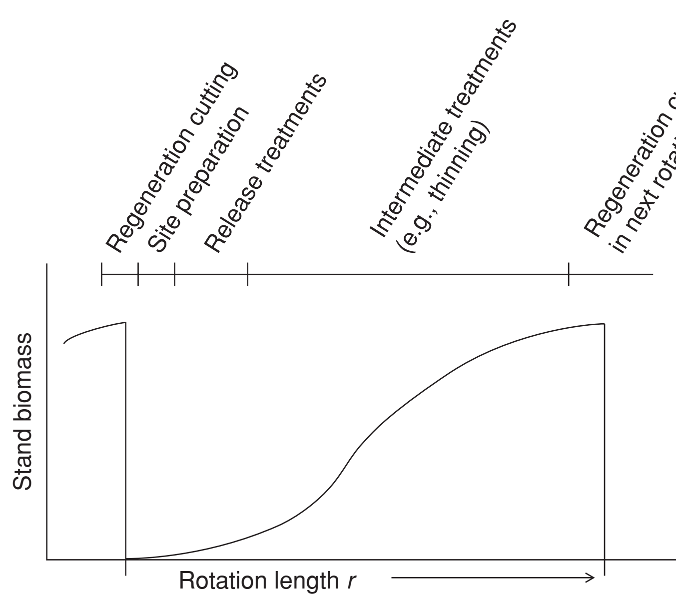

FIGURE 1. Chronosequential application of individual practices of a silvicultural system in even-aged stand. During the rotation age r, treatments are applied across the entire stand to meet silvicultural objectives that are related to tree age.

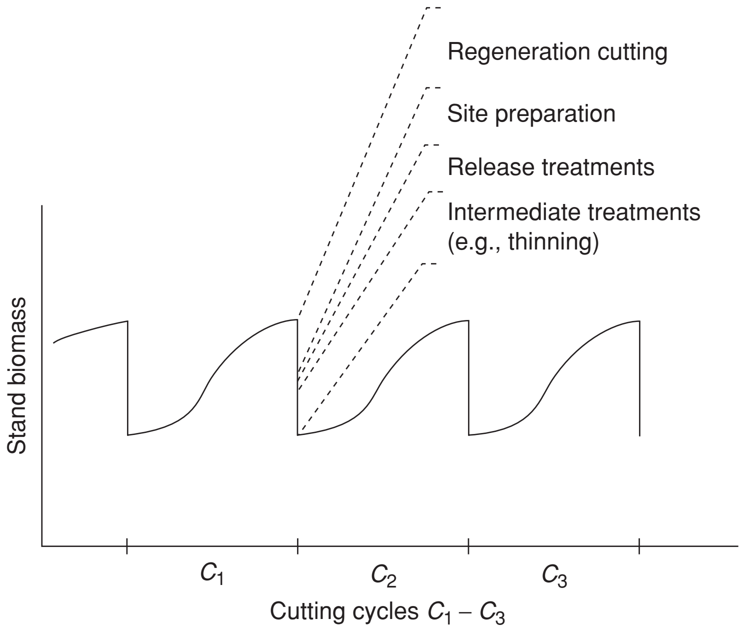

FIGURE 2. Concurrent application of individual practices of an uneven-aged silvicultural system during a cutting cycle harvest in a balanced uneven-aged stand. Treatments are applied to subunits of the stand depending on conditions within each subunit. Each cutting cycle harvest will support similar treatments.

removed during a cutting cycle harvest are taken for different reasons—regeneration cutting, release, or intermediate treatment such as thinning (Fig. 2). As a result, the different silvicultural practices that occur chronosequentially in an even-aged stand and that cover its entire area are conducted at the same time in an uneven-aged stand, but only over a portion of the stand area. This complicates the practical implementation of the method. Uneven-aged systems are often thought to be less intensive than even-aged systems, and that may be true in relation to, say, the degree of site exposure during regeneration cutting or the capital outlay required to establish a new stand. But uneven-aged systems require more attention on the part of the forester, and can be more inefficient to conduct in some ways because the scale of operation is at the scale of subunits within a stand rather than across the entire stand.

The Selection Method—An Overview

Uneven-aged silviculture is implemented using a reproduction cutting method called the selection method, used to regenerate and maintain a multiaged structure by removing trees either singly, or in small groups or strips (Helms 1998). By definition, an unevenaged stand has at least three age classes (Smith 1986; Helms 1998). In practice, age is not measured; stands are managed by controlling either the volume that is harvested, the diameter distribution in reference to a target distribution, or the area within the stand that is cut.

In an uneven-aged stand, growing space is subdivided among trees of all size classes, from regeneration through the largest overstory trees. A starting point to determine the appropriate basal area to maintain in an uneven-aged stand is to apply the basal area found in a mature even-aged stand of the same species that is marginally fully stocked or slightly understocked. A stand in that condition will have a slight amount of growing space available in the understory for the regeneration establishment but will be marginal for regeneration development. If that basal area is translated to an uneven-aged stand, the heterogeneous conditions that typify an uneven-aged stand will result in fully stocked clusters of overstory trees in some areas, and other areas that are sufficiently understocked such that regeneration development can occur. This concept gives rise to two generally accepted methods by which the selection method is implemented—one using very small openings and the other using larger openings.

Single-Tree Selection Method

Singletree selection imitates the smallest scale of disturbance, such as when a single tree falls or dies while standing in the woods. Possible causes of such a disturbance are insects, lightning, disease, windthrow, or some other agent. In unmanaged stands, this process results in gap-phase dynamics indicative of late-successional conditions (White 1979; Runkle 1982; Pickett and White 1985). When a large tree in an uneven-aged stand is removed, the growing space used by that tree is made available to adjacent trees, to smaller trees in the midstory, and to regeneration in the understory. In the smallest gaps, the gap may close before the regeneration can accede into the main canopy, and the regeneration may then persist without further growth or may even succumb to suppression. The occurrence of multiple gaps (where a nearby tree succumbs and creates a second nearby opening, either concurrently with or soon after the first), or expansion of existing gaps (where gap-bordering trees fall) can tip this ecological balance in favor of regeneration survival and development.

In the single-tree selection method, individual trees of all size classes are removed more or less uniformly across the stand (Smith 1986; Helms 1998). This is typically conducted by first identifying the trees that are to remain in the stand. The trees to remove then become obvious because their removal promotes the continued growth and development of the trees that are to remain. The diameter of the tree being removed is directly related both to the silvicultural objective for its removal, and to the retention of stocking levels by size class deemed desirable across the residual diameter distribution. Small-diameter trees, such as pulpwood or small sawlogs, are removed according to classical thinning rationale—to free an immature neighboring tree, presumably one with better form, condition, or other attribute, from the competition provided by the tree being removed. Removal of a large-diameter tree, such as one at or larger than the maximum diameter desired for retention, is intended to create a canopy opening within which regeneration is to become established and to develop.

Group Selection Method

In the group selection method, trees are removed and new age classes are established in small groups (Smith 1986; Helms 1998). Group selection imitates a small-scale natural disturbance that kills a small group or cluster of trees within a stand; examples include mortality of trees from a blowup of a surface fire or an infestation of pine beetles. In theory, the nature of the disturbance should promote a suitable and receptive seedbed for seedling establishment, and the size of the gap that is created by the disturbance is large enough to promote regeneration development. The seed source for that new cohort can be advance growth of regeneration in place prior to creation of the opening, seed from trees that border the gap or stored in the soil beneath the gap, or as seedfall disseminated from the trees being removed within the gap at the time of their removal. The size of the gap affects the species composition of that new cohort. Larger gaps favor species of greater intolerance to shade, while smaller gaps favor shade-tolerant species.

The group selection method is applied or suggested when there is a desire to use an unevenaged silvicultural system in a stand, yet still regenerate shade-intolerant species; hence the interest in the method relative to the southern pines. The maximum size for group openings depends on one's interpretation of ecological literature as modified by prevailing forest management guidelines. It is generally agreed that the upper ecological size limit for tolerant species within a circular group selection opening is one whose radius equals the height of the surrounding trees in the stand (Helms 1998). In trees with a height of 25 m, the ecological upper limit would be on the order of 0.2 ha. Larger openings would then be suggested for intolerant species such as longleaf pine. The suggested maximum group opening size on national forest lands within the Southern Region of the USDA Forest Service is 0.8 ha, which should allow for acceptable regeneration establishment and development of any of the southern pines. In practice, some trees are typically removed from the stand matrix between the groups as well, so as to promote stand health and acceptable basal area levels between group openings, and to prepare trees as seed producers in subsequent group openings.

The decision to locate a group opening within the stand is usually done to alleviate understocking, rectify excessive stem density, or take advantage of existing regeneration. If part of the stand is understocked, creating an opening gives the forester an opportunity to regenerate that group, and thus to restore that part of the stand back to full stocking. At the other extreme, if there is a place within the stand where the trees are all in a surplus size class on the marking tally, creating an opening harvests those trees and helps the forester more quickly achieve the desired residual stand density. Finally, if a species is difficult to regenerate naturally, one should not fail to create openings within the stand where advance regeneration is found.

Group selection has a number of administrative advantages over single-tree selection that contribute to its popularity. Most group openings serve as points of concentration for logging operations in the immediate area; logs are frequently decked in the openings, and haul roads typically run from one group to another. As a result, group openings are often heavily scarified. This is an advantage in promoting pine regeneration, which requires exposed mineral soil for optimal seed germination and establishment. Moreover, the group opening is the only part of the stand in which regeneration is expected. Site preparation or release treatments can thus be restricted to the groups, which is an advantage in that less area must be treated and the specifications for treatment can be made clearer than when a comparable treatment is prescribed in a single-tree selection stand. The advent of geographic positioning system technology adds to the ease of contracting treatments, since the precise location of each group can be specified.

Selective Cutting

The term "selective cutting" is often used to describe harvesting activity that resembles uneven-aged regeneration cutting in that trees remain on the site. But a strict definition of the term is "select some trees to cut and cut them"; it has no commonly accepted professional meaning except a derogatory one. The term does not refer to, and is not synonymous with, the practice of uneven-aged harvests using the selection method. All too often, stands harvested using selective cutting are high-graded—harvest is uncontrolled, the best trees are cut, and the poorest remain. Perhaps the most important silvicultural distinction between the selection method and selective cutting is that under the latter, no provision is made for establishment or development of desired species of regeneration. This is a trap into which improperly applied harvests under the selection method can fall.

Regulation of Uneven-Aged Stands

Regardless of whether single-tree selection or group selection is implemented, the methods for ensuring the regulation of growth and harvest are the same. Two methods of regulation have historically been associated with the selection method—regulation of the sawtimber volume in the stand through harvest of growth, and regulation of the structure of the stand through conformance with a target diameter distribution. With group selection, a third method enters the picture, in which regulation is based on proportion of harvested area during each cutting cycle.

These methods have varying degrees to which they conform to the origins of uneven-aged silviculture (Guldin 1996). The selection method, the most recently developed of the regeneration methods historically, traces its origins to the Dauerwald in Germany, which evolved as a counterpoint to area-based regulation methods. Under the Dauerwald, allowable cut was based on stand volume growth; a volume equal to roughly 15 times the annual growth was retained on the site (Troup 1928, 1952). Other European work at the turn of the century used a negative exponential algebraic relationship among the number of trees by diameter class to quantify the reverse J-shaped curve that approximates an uneven-aged stand (deLiocourt 1898), and that approach was further developed in North America in modern approaches to forest management (Meyer et al. 1961). Little historic evidence exists to support an area-based regulation method in the evolution of uneven-aged silvicultural systems. On the other hand, Smith (1986) points out that regulation method should be independent of silvicultural system; under such logic, any of the following systems might legitimately be applied to regulation of uneven-aged stands.

Regulation of Volume

The most successful application of the selection method in southern pines has been at the Crossett Experimental Forest (EF) in Ashley County, AR, in the mixed loblolly–shortleaf pine forest type of the upper West Gulf Coastal Plain. The Crossett EF, managed by the Southern Research Station of the USDA Forest Service, was established in 1934 and is still active. It supports several long-term research studies and demonstrations, notably the Good and Poor Farm Forestry Forty Demonstration Stands and the Methods of Cutting Study.

The uneven-aged stands of loblolly–shortleaf pine at the Crossett EF were regulated using the volume control-guiding diameter limit (VCGDL) method (Reynolds 1959, 1969; Baker et al. 1996; Guldin 1996, 2002). In this method, sawlog volume and volume growth are used to calculate harvests, and trees are marked based on whether their individual growth rates are sufficient to allow them to maintain acceptable sawlog volume growth.

Implementation of the VCGDL method has four broad steps. First, a current inventory of the stand is taken. That inventory is used to prepare a stand and stock table that quantifies the stem density and sawlog volume before harvest by diameter class per unit area. This requires application of an appropriate local sawlog volume table, so that the sawlog volume by diameter class can be included in the table.

Second, the compound growth rate of the stand must be determined. This is usually done by averaging the growth rate for a number of trees of varying size in the stand, using 10-year radial increment measured from increment cores, and calculated per tree using the formula

$$G = \exp\left[\frac{\left(V_0/V_{\mathrm{p}}\right)}{n}\right] - 1$$

where

G = growth rate (%)
V_{p} = previous tree volume
V_0 = present tree volume
n = growth interval (years)

Alternatively, experience shows that in managed stands, one can use an appropriate compound growth percentage for sawlog volume increment. Values between 6% and 8% are typical in unmanaged and managed loblolly–shortleaf pine stands, respectively, in south Arkansas. An appropriate range for longleaf pine would be based on local experience.

Either approach then requires the forester to determine an after-cut volume for the planned harvest. The after-cut volume is the cumulative volume to which the current stand must be reduced. That level is set by predicting the future cutting cycle length, by selecting the future stand volume sought at that time, and then by calculating the volume to which the current stand must be reduced so that it will grow to the intended future volume at the appropriate rate of growth.

Third, the allowable cut is calculated as the difference between the before-cut volume and the planned after-cut volume. This leads directly to the calculation of the guiding diameter limit (GDL), which is that diameter class that meets the allowable cut if all trees in larger diameter classes are cut. Usually, part of the

GDL class must also be cut to exactly match the allowable cut.

Finally, the field crews are given the GDL class and the percentage of the GDL class to cut. Markers are instructed to retain trees above the GDL if they are growing acceptably, and then to mark an equivalent volume to that retained in diameter classes smaller than the GDL. Marking crews can only do this efficiently by memorizing the appropriate local volume table. The crews then must keep a running tally, either mentally or on a notepad, of cumulative volume retained above the GDL and that removed below the GDL. At the end of the marking, the volume marked below the GDL should balance that retained above the GDL (Fig. 3).

The VCGDL method has a number of advantages. It requires the field crew to examine sawlog component of the stand from the perspective of trees that should be retained. As a result, crews can balance whether to cut and leave trees across a range of diameter classes. It also requires that large high-value trees above the GDL have a compelling record of growth to be retained.

However, there are several limitations of the VCGDL method. The approach does not provide any evidence to the forester about the growth of trees below the sawtimber size class. Foresters must judge in some other way whether regeneration is being established, and whether sub-sawtimber size classes are developing at an acceptable rate. That judgment is typically based on experience rather than objective standards, and that can be a limitation. Second, the method requires a high degree of experience on the part of the field crews who are marking the stand, especially in regard to estimation of the volume of trees above and below the GDL that are being retained and marked, respectively, such that the cumulative volume tally balances when the marking is completed. Finally, because decisions are made in the field about retaining trees above the GDL

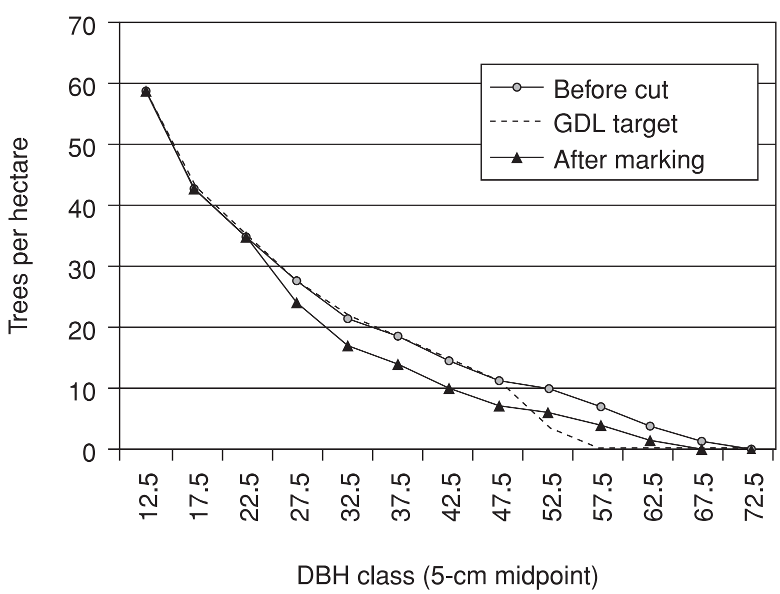

FIGURE 3. The volume control-guiding diameter limit (VCGDL) regulation approach conceptually applied in the 1978 before-cut inventory from the Good Farm Forestry Forty demonstration stand, an uneven-aged loblolly–shortleaf pine stand on the Crossett Experimental Forest in southern Arkansas. Before-cut, GDL target, and after-cut diameter distributions are drawn as curves rather than histograms. The GDL target reflects the allowable cut in sawtimber cubic volume based on 6% growth rate. The after-cut diameter distribution illustrates one possible outcome resulting from retaining trees above the guiding diameter limit, and removing trees below the limit such that the volume of the stand is retained at the guiding level.

and removing trees below the GDL, the use of computer models to predict stand development in advance of harvest is difficult.

The VCGDL regulation approach evolved as a means to regulate single-tree selection stands. However, modifying the approach to regulate a stand being managed using group selection is relatively straightforward. All trees within the group would be marked, and added to the marking tally. Trees smaller than the GDL within a group would have their volume added to the below-GDL cumulative volume tally. That would lead to retaining an equivalent volume of trees at or above the GDL in the matrix between groups.

Regulation of Stand Structure

The regulation of stand structure is based on the notion that the diameter distribution of a balanced uneven-aged stand has an ideal theoretical relationship, which can be compared with the actual stand structure for generating an after-cut residual stand (and indirectly, a marking tally) that carries the existing stand closer to the theoretical ideal. Several approaches can be developed to quantify this ideal theoretical stand, such as use of stand density index (Long 1998) or leaf area index (O'Hara 1996). But the most common in southern pines is based on the assumption of a constant ratio q in the number of trees in adjacent size classes, according to the simple formula

$$q = \frac{t_n}{t_{(n+i)}}$$

where

$q = q$ ratio
$t_n =$ number of trees per unit area in the nth diameter class
$t_{(n+i)} =$ number of trees per unit area in the next larger class of class width i

Thus, q is dependent on diameter class width, and the use of a given q ratio must include reference to the class width i. If the maximum diameter class D of trees to retain in the stand is known, one can use q to construct a negative exponential relationship that can be fit to any desired residual basal area B per unit area in the stand. Specification of B, D, and q thus constitutes a unique solution of diameter distribution. This approach, called the BDq approach, is used to generate the target balanced diameter distribution against which the existing stand structure is compared. The method was developed by Leak (1964), and its practical implementation was described in detail by Marquis (1978). Modifications for uneven-aged stands of loblolly–shortleaf pines in the West Gulf region were described in Baker et al. (1996), and for southern pines generally by Farrar (1996).

Simply stated, selection of the target BDq parameters allows the forester to calculate a unique hypothetical target diameter distribution. This is typically prepared on a unit area (per-hectare) basis. The diameter distribution of the before-cut stand, prepared from a preharvest inventory, is then compared to that target. In an ideal case, the before-cut stand will contain a surplus of trees in every diameter class compared with the target; that surplus then becomes the marking tally. However, far more common is the situation in which some diameter classes in the preharvest stand will contain a surplus of trees compared to the target, and others will contain a deficit of trees. Here, the basal area of those deficits must be calculated, and that basal area deficit must be accounted for by retaining more trees than called for in those diameter classes that have a surplus relative to the target stand (Fig. 4). Ultimately, deficits in a given diameter class will be corrected through ingrowth from smaller diameter classes over time.

When the final tally of trees to cut is determined for each diameter class, the proportion of trees to cut by diameter class is calculated. That information—number of trees to cut, and percentage, by diameter class—is given to the field crews, who use that information as they mark the stand. Field crews will find it easier to base their marking on the proportion rather than the absolute number, since it is easier to think about removing a set percentage of a given diameter class rather than an absolute number of trees in a given diameter class per unit area. That also allows the reinforcement

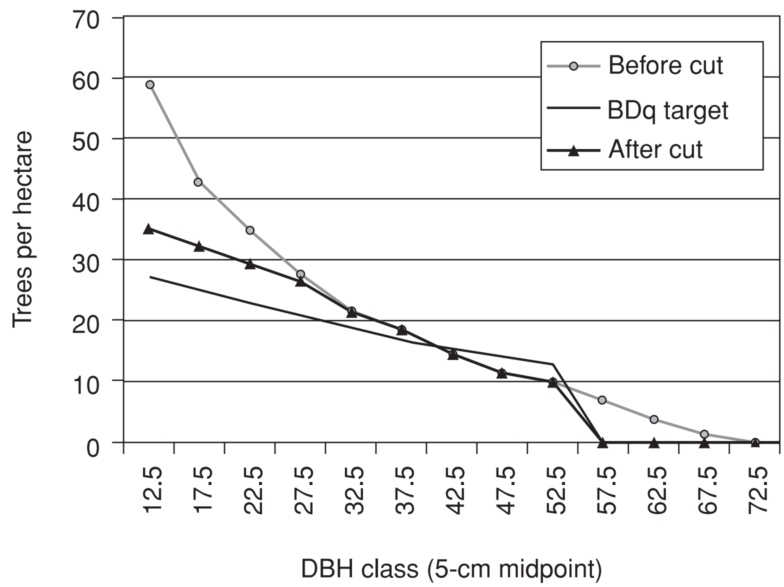

FIGURE 4. Regulation of stand structure using the basal area–diameter–q ratio (BDq) method conceptually applied in the 1978 before-cut inventory from the Good Farm Forestry Forty demonstration stand, an uneven-aged loblolly–shortleaf pine stand on the Crossett Experimental Forest in southern Arkansas. Before-cut, BDq target, and after-cut diameter distributions are drawn as curves rather than histograms. The BDq target reflects a $B = 14\ \mathrm{m}^2\ \mathrm{ha}^{-1}$, $D = 57.5$ cm, and q (5-cm classes) of 1.44. The after-cut diameter distribution illustrates the compensation by basal area according to the q ratio; the basal area in deficit diameter classes is retained in surplus diameter classes such that the target basal area is retained.

to be given that the poorest percentage of trees in the diameter class should be marked for harvest, and the best trees retained. The number of size classes the field crews must work with can be reduced if broader product classes are used. For instance, a fivefold product classification that includes small pulpwood, large pulpwood, small sawtimber, medium sawtimber, and large sawtimber would be very convenient for field crews to apply.

If some method other than the BDq approach is used to generate the target structure, the process for implementation still is most efficient if conducted as described above. Suppose a target diameter distribution is generated using a power function, for example, rather than the negative-exponential BDq approach. Once the target diameter distribution is obtained, there is still need to compare the existing stand to that target, generate a marking guide, and to compensate for diameter class deficits between the preharvest stand and the target, so as not to overcut the preharvest stand, and finally to determine if the projected harvest is operable.

Structural regulation has the advantage of objectivity. When generating a target diameter distribution, target diameter class data can be calculated for submerchantable diameter classes as well, which can provide guidance about whether cutting-cycle harvests are providing acceptable regeneration establishment and development through the submerchantable component and acceptable recruitment into the merchantable component of the stand. This depends on the assumption that the mathematical relationship used to characterize the stand structure is biologically meaningful at the smallest size classes, and this may not be the case for the negative exponential relationship upon which q is based (Baker et al. 1996).

The main disadvantage is that the process for calculating the marking tally is cumbersome, especially in cases in which deficit diameter classes are adjusted according to the mathematical relationship used in the initial target calculation. Spreadsheet programs are available to assist this calculation (Baker et al. 1996). A second disadvantage is that the appropriate *B, D,* and *q* parameters for application to longleaf pine have yet to be identified through research or practice.

Area-Based Regulation

Regulation of stands managed by group selection has been advocated using the area-based regulation concept borrowed from even-aged forest management (e.g., McConnell 2002). Under this simple device, the initial decision is to establish a rotation age, r, for the trees in the uneven-aged stand, essentially the age at which trees for the species under management are typically harvested in a comparable even-aged context. The area a of the stand is then divided by the rotation age r, and the quotient represents the proportion of the stand area a to be cut annually. That is converted to a, an area to be cut in a given cutting cycle harvest by multiplying the annual percentage of area to cut times the length of the cutting cycle, according to the simple formula

$$A_c = (a/r)c$$

where

A_c = area to be cut in a cutting-cycle harvest
a = stand area
r = rotation age and
c = planned length of the cutting cycle (years)

The problem in using area-based regulation with group selection is more theoretical than practical. It is difficult to distinguish between group selection and patch clearcutting, the small-opening even-aged variant of the clearcutting method that is also regulated using this approach. The best way to draw a distinction between the area-based regulation of the group selection method versus patch clearcutting is through applications that increase the within-stand heterogeneity of structure. Examples include varying the area cut in any one cutting cycle, varying group size and shape, or placing openings in a pattern that is not geometric or predictable. Use of group opening sizes less than two tree heights in radius, such that the entire group opening is under the ecological influence of the gap-bordering trees, would also provide ecological distinctions with patch clearcutting.

Adaptive Experience in Southern Pines

The long-term studies and demonstrations at the Crossett EF in south Arkansas provide keys to the successful implementation of the method in mixed loblolly–shortleaf pine stands. That background is the best source of experience with the method in the South and serves as a point of departure for considering the application to other forest types.

Regeneration

At the stand level, the first indicator of long-term forest sustainability is whether adequate regeneration is obtained when a regeneration cutting is made in a stand. This is especially true with the selection method, which requires a delicate balance between the stocking and development of the merchantable component of the residual stand versus the stocking and development of seedlings and saplings. It applies also in situations where conversion from even-aged condition to uneven-aged condition is imposed. It is critical to obtain regeneration after a cutting cycle harvest in any conversion, transition, or initial steps in implementation of either the single-tree or group selection method.

Abundant seed crops are an excellent attribute on which to rely when prescribing a reproduction cutting method that depends on natural regeneration. Long-term data on seedfall in loblolly–shortleaf pine stands on the Crossett EF show that, on average, natural regeneration is adequate or better four years in five, and rarely do seed failures occur in two consecutive years (Cain and Shelton 2001). This prolific seedfall is one of the reasons underlying the successful application of either even-aged or uneven-aged reproduction cutting methods that rely on natural regeneration in this forest type and region (Baker and Murphy 1982; Zeide and Sharer 2000; Cain and Shelton 2001).

Conversely, irregular seed crops can reduce the probability of success in obtaining natural regeneration under the selection method. This is important both for initial period of conversion to uneven-aged structure, and in maintenance of that structure. Experience at the Crossett EF suggests that failure to secure a new age class following a given cutting cycle harvest was not in itself an impediment to maintaining desirable uneven-aged structure, but missing two age classes in consecutive cutting cycle harvests is to be avoided (Reynolds 1969). If a given cutting cycle harvest fails to secure a new age cohort of regeneration, supplemental site preparation efforts should be conducted at the next cutting cycle harvest to ensure that regeneration is obtained (Guldin and Baker 1998).

Rehabilitation of Understocked Conditions

The stands on the Crossett EF originated as cutover understocked stands, and were managed in a manner by which stocking was built over time. The stands had been harvested by the Crossett Lumber Company in 1915 to a 38-cm stump limit, roughly equivalent to a 30-cm diameter limit. No management occurred on the area until it was leased to the Forest Service in 1934 (Guldin 2002). These stands were not fully stocked, homogeneous, and even-aged; rather, the stands showed considerable within-stand heterogeneity at the start. The research and demonstration work that began at that point successfully restored understocked and marginally stocked stands back to full stocking through harvest of a portion of growth. Two elements of this work were especially important.

The first was the reaction of these pines to removal of competition. In the upper West Gulf Coastal Plain, both loblolly and shortleaf pine respond to release at advanced age. Data from studies at the Crossett EF (Baker et al. 1996) suggest that pine stems in the 10- to 15-cm diameter class will respond to release if their live crown is greater than 20% and if the stem diameter at the base of the live crown exceeds 5 cm (Fig. 5).

FIGURE 5. A loblolly pine sapling on the Crossett EF that meets the minimal size criteria for response to release—a 20% live crown ratio, and diameter outside bark at the base of the live crown of 5 cm. A similar rule of thumb for response to release would be helpful to have in applying the selection method to longleaf pine. (James M. Guldin)

The second was the use of herbicides to control hardwoods that were competing with the pines. Effective hardwood control was critical both as site preparation for the establishment and development of new seedlings and also as a release treatment and liberation cutting (Smith 1986) to free established pine saplings and small merchantable stems. Thus, the ability to use herbicides effectively to control hardwoods competing with pines, and to then have the pines respond quickly to the growing space made available, lies at the root of success in using the selection method to manage loblolly–shortleaf pine stands in the West Gulf region.

Developmental Dynamics

Uneven-aged stands exist in a delicate balance between understocking and growth. Baker et al. (1996) describe this balance in the context of shade management. That balance is controlled by three factors: the distribution of basal area retained in the residual stand immediately after a cutting cycle harvest, the length of the cutting cycle, and the operability of the future cutting cycle harvest.

After a cutting cycle harvest, the residual overstory trees grow and some degree of ingrowth into the overstory also occurs. As a result, stocking levels increase in the overstory over time. But this increased stocking serves to increasingly inhibit the development of regeneration. Subsequent cutting cycle harvests will be needed to reduce overstory stocking sufficiently to allow the continued development of the initial regeneration cohort, and to obtain a new cohort. On the other hand, if a given cutting-cycle harvest removes too much basal area, the stand will not grow rapidly enough to allow an operable cutting cycle harvest in the subsequent cutting cycle.

One simple metric for the upper limit of acceptable basal area to carry in an uneven-aged stand is to quantify the residual basal area in a classic low thinning at which accidental regeneration just begins to be suppressed. This point approximates the highest acceptable before-cut basal area in uneven-aged stands. For example, pine regeneration can become established in even-aged Coastal Plain loblolly stands thinned to 16 m^2 ha^{-1}, but will cease to make acceptable height growth if basal area exceeds 17–18 m^2 ha^{-1}. Because overstory tree distribution in uneven-aged stands is more heterogeneous, these basal area levels represent an upper limit to the acceptable basal area range for successful uneven-aged prescriptions.

The lower limit is defined by maintaining acceptable overstory growth over the expected duration of the cutting cycle. In uneven-aged loblolly–shortleaf pine stands at the Crossett EF, the target residual basal area after a cutting cycle harvest is roughly 14 m^2 ha^{-1}, and the stands grow approximately 0.55–0.7 m^2 ha^{-1} in basal area annually. After 5 years, the stands will have grown in basal area to about 17 m^2 ha^{-1}, and the subsequent cutting cycle harvest can then be imposed.

Because basal area can also be related to stand volume, operational feasibility of harvests can be tested. In south Arkansas, loblolly–shortleaf pine stands support after-cut volumes of roughly 26–27 m^3 ha^{-1} of sawlog volume, and the stands grow on the order of 2.2–2.4 m^3 ha^{-1} of sawlog volume annually. After 5 years, the stands will support roughly 37–40 m^3 ha^{-1} of sawlog volume. Operable harvests in the vicinity are about 9 m^3 ha^{-1} of sawlog volume. Thus, sawlog volume growth of the stand can be cut on roughly a 5-year interval with operational harvests, which also maintains regeneration development. Metrics such as these are needed for longleaf pine stands.

Another clue about the appropriate upper limit of basal area is whether acceptable rates of height growth can be maintained in the regeneration component. In loblolly and shortleaf pine stands, height growth of regeneration is a useful indication of maintaining the ability to recover full growth potential. Minimum acceptable annual height growth in these species is 0.15 m. If seedlings or saplings less than 1.3 m in height are not growing at this rate, they will probably not survive.

Finally, the Crossett EF experience suggests a final visual clue for determination of acceptable balance between overstory and understory—the presence of foliage of the desired species at all levels of the canopy profile in the stand. If regeneration is successfully established and making acceptable height growth, and if repeated cutting-cycle harvests are successful in obtaining regeneration, seedlings and saplings will be visible in the stand. The longer the period of successful silviculture under the selection method, the more prominently will foliage of the desired species be found at all levels of the canopy profile (Fig. 6).

FIGURE 6. A view of conditions in an uneven-aged stand of loblolly–shortleaf pine within the Poor Farm Forestry Forty Demonstration Area on the Crossett EF immediately following the cutting cycle harvest in the spring of 2003. Note the presence of foliage of the desired pines at all heights in the canopy profile, a simple visual clue that denotes sustainable regeneration cutting over time in uneven-aged stands. (James M. Guldin)

Marking Rules

During his tenure at Crossett, CEF founding scientist Russ Reynolds explicitly refused to identify his volume-control method as "single-tree" or "group" selection; he called it "selection." Occasionally large openings would occur, occasionally small ones would suffice. Reynolds's key decision was whether the tree being examined while marking was of acceptable form, size, and quality to retain. Reynolds captured this concept in the simple phrase, "cut the worst and leave the best" (Reynolds 1959, 1969). Attention to this simple marking rule ensured that stem quality was gradually improved over time. As practiced on the Crossett EF, the selection method has a reputation as one that produces sawtimber of high quality (Guldin and Fitzpatrick 1991); the long-term application of a marking rule such as this contributes to that reputation.

This rule raises distinctions between regulation by volume under the VCGDL and regulation by structure under the BDq method. It is easier to leave the best trees under the volume control regulation method versus the BDq, because the marking tally in the BDq is specific to a given diameter class whereas the marking tally of the volume control method cuts across diameter classes. Under VCGDL, a residual tree is judged to be part of the population of "best" trees regardless of diameter class. Conversely, in the BDq method, a tree that is retained is judged relative to other trees in that diameter class only, and the proportion to cut changes from one diameter class to another.

For example, suppose that a BDq marking tally requires removal of 1 in 10 trees in the 45-cm class, but half of the trees in the 30-cm class. Field crews will invariably come across a tree in the 20th percentile of quality in the 45-cm class immediately adjacent to a smaller tree of better absolute form and with better developmental potential in the 40th-50th percentile of quality in the 30-cm class, and will complain about marking the better tree and leaving the poorer one. The answer for the field crews in that event is to use common sense, and to mark the poorer tree. Carrying that logic to its conclusion leads to a critical point relative to the BDq method. Of the *B*, *D*, and *q* variables, residual basal area is most important to retain, followed by maximum diameter; *q* is least important. Some thought has been given to modifications of the BDq method as a BD method (Baker et al. 1996); this would result in essentially a basal area control method implemented in a manner similar to regulation by volume, but in which the basis for compensation among trees being retained is by equivalence of basal area rather than volume.

Reynolds's marking rule also raises distinctions between group selection and single-tree selection. A rule that guides the forester to "cut the worst and leave the best" can be more strictly followed in single-tree selection than in group selection. In most instances, the localized area of the stand within which a group opening is planned will contain trees that under an individualistic evaluation would qualify for retention. That might allow one to further refine the logic for placement of group openings—locate the opening in those parts of the stand where a disproportionate number of the trees within the planned group are of poorer condition than those in other parts of the stand. Such manipulation in the location of group openings is possible if the group selection method is being implemented using regulation by volume or structure. However, improvement in residual stand condition as a result of this marking rule is by definition unlikely to occur under area regulation of group selection, especially if imposed using strict geometric patterns.

The Selection Method in Longleaf Pine

Interest in implementing the selection method in the longleaf pine forest type is driven by a number of considerations. Foremost among them is to develop habitat conditions in longleaf stands that favor the species that inhabit these stands, such as bobwhite quail (Moser et al. 2002) and the red-cockaded woodpecker (McConnell 2002). To a certain extent, arguments about habitat condition that can be developed in uneven-aged stands of longleaf pine are premature without a careful examination of what a sustainable application of the selection method would look like in longleaf pine, using the subjective metrics developed from our understanding of the method in the loblolly–shortleaf pine forest type.

The state-of-the-art treatise on the selection method in longleaf pine (Farrar 1996) is a primary source for managers to consider as the selection method is operationally applied in longleaf pine. Equally important in application to the selection system in longleaf pine is research on longleaf pine autecology that culminated three decades ago on the Escambia EF near Brewton, AL (Croker and Boyer 1975), where detailed studies of the reproductive biology and silvics of longleaf pine were fundamental to the development of the even-aged shelterwood method (Fig. 7). A subjective interpretation of these sources suggests that a successful prescription for the selection method in longleaf pine will require attention to regeneration establishment, the pattern of implementation, the approach to regulation, and developmental dynamics. Among the largest challenges will be the integration of prescribed fire as a standard element of the method.

FIGURE 7. A view of the shelterwood method in application to longleaf pine in 1982 on the Escambia Experimental Forest, Brewton, AL. The residual basal area in the overstory was 7 m^2 ha^{-1}, and seedlings have emerged from the grass stage several years following the seed cut. (James M. Guldin)

Regeneration

The application of natural regeneration in a selection method for longleaf pine will be difficult. Seed production is much less reliable in longleaf pine, where adequate seed crops only occur between 10 and 20% of the time (Wahlenberg 1946), than in loblolly pine. The degree of silvicultural attention required to make a successful prescription involving natural regeneration will be greater for longleaf pine than for loblolly pine, if for no other reason than the greater infrequency of adequate seed crops. This can be especially problematic in mixed-species southern pine stands that include longleaf pine as part of the mix, because the other pines will be more prolific seed producers.

Careful attention to silvicultural detail is needed to ensure practical success with natural regeneration in longleaf pine. For example, the key to the development of the shelterwood method in longleaf pine was the detailed work by Croker (1973). He reported that over a 7-year period, cone production in a longleaf pine stand reached an optimum when the stand basal area of longleaf pine was 6.88 $m^2\ ha^{-1}$ and declined as basal area decreased or increased from that level. Greater overstory basal area resulted in less seedfall and reduced numbers of seedlings. A uniform residual overstory of 10.33 $m^2\ ha^{-1}$ resulted in virtually no surviving saplings over time (Boyer 1993). Fieldcraft such as that described in the development of the shelterwood method (Croker and Boyer 1975) would improve natural seedfall in any selection method applied in longleaf pine stands. Because cone production is a highly inherited trait genetically (Croker 1964), marking crews should include an evaluation of past cone production as a decision element in whether to retain a tree during cutting cycle harvests (Fig. 8).

On national forest lands in the South, another practical approach for management of longleaf pine using the selection method is to plan for natural regeneration, but to use planting as a fallback position to prevent excessive delays in reforestation. There will be two opportunities for successfully obtaining natural regeneration prior to planting. The first chance is that associated with the initial harvest. Foresters with the USDA Forest Service generally allow a logger a multiyear window within which to complete a cutting cycle harvest. Hopefully, the period when the stand is actually cut would occur in conjunction with an adequate seed year. However, the administration of sales on National Forest lands precludes the ability to guarantee harvest in conjunction with seed crops and receptive seedbeds. Logging contractors are typically given several years to harvest a timber sale, and cultural work to improve seedbed condition must be programmed a year in advance.

FIGURE 8. Longleaf pine seed after seedfall in fall 1982, a good seed year in a managed even-aged longleaf pine stand in central Louisiana. A prescribed fire had been used that year to prepare the seedbed for the anticipated seed crop. (James M. Guldin)

The second chance is to catch the first good seed crop after the sale closes. Site preparation should be conducted to prepare a receptive seedbed when that seed crop occurs. This, too, is constrained by administrative procedures. Site preparation on National Forest lands is funded using proceeds from timber sales under the Knutsen–Vandenberg Act of 1933, which limits expenditures to a 5-year period following sale closure. If longleaf pine produces one good seed crop in 5 years, the chances are that site preparation can be timed to that expected seedfall. However, site preparation dollars must be requested in the fiscal year in advance of that in which they would be spent—and the ability to predict a good seed year is limited to 6 months in advance of seedfall (Croker and Boyer 1975).

Practically, then, a forester with the USDA Forest Service has 4 years after the cutting cycle harvest is concluded to obtain natural regeneration; the fifth year must be devoted to spending the available funds to prepare the site and plant seedlings. Standards should be developed that provide guidance to silviculturists about when natural regeneration difficulties are likely to be profound (such as poor seed producers left on the site, an absence of advance growth, or the lack of adjacent stands that could contribute seed to a cutover area from adjacent mature trees). That information could help foresters identify stands that might be good candidates to plant initially under residual overstories, rather than to tackle the chain of efforts to synchronize site preparation to seedfall.

In the past decade, a focus of regeneration research in longleaf pine has been to examine longleaf seedling establishment, survival, and growth in openings of various size and condition. Results are generally of the opinion that a clumped residual overstory condition, suggestive of the group selection approach, promotes early seedling development when compared with homogeneous overstory conditions. Seedlings initiate height growth primarily in the center of gaps, but height growth is reduced along the borders of gaps or adjacent to residual trees. This border effect is on the order of 12–20 m. The major reasons for this seedling growth pattern are related to increased light intensity in gaps (Grace and Platt 1995; Palik et al. 1997; McGuire et al. 2001; Battaglia et al. 2002; Gagnon et al. 2003) and decreased levels of intraspecific competition for soil resources in gaps (Brockway and Outcalt 1998).

More than any of the other southern pines, longleaf pine will benefit from some applications that involve planting as the source of regeneration. However, research experience with that is limited. Probably a minimum number of seedlings is rationally feasible to plant. If natural regeneration is inadequate, and planting is needed, one should plant enough seedlings to ensure a fully stocked stand of planted seedlings. The number to plant will vary depending on seedling stock and the level of understory competition. For example, 1000–1200 seedlings per hectare may be sufficient using containerized planting stock and a preplant herbicide treatment in a group selection opening. Without these refinements, more seedlings will be needed.

Planting should be done in association with an effective site preparation prescription that promotes survival and height growth of the planted seedlings. Genetic improvement of planting stock has produced seedlings that make rapid early height growth under open conditions with intensive site preparation. Although families selected for rapid growth in the open would probably be successful if planted beneath a residual overstory or within a group opening that is under the ecological influence of the overstory trees that surround the group, there are opportunities to explore the best families to plant in conditions that are subject to partial shade or neighbor influence. However, there is little basis for this at present.

Pattern of Implementation

Because the presence of overstory trees affects longleaf pine seedling establishment and development, most recent research has concentrated on the possibilities associated with use of the group selection method in longleaf pine. Farrar (1996, 1998) suggests that a "modified group selection" approach be used in which groups are not removed until regeneration is established beneath the group. He further suggests that this be integrated with cyclic prescribed burning (Fig. 9). Either the VCGDL or the BDq regulation approaches would be feasible (Farrar and Boyer 1991). Under the BDq, Farrar's suggested target structure for longleaf

FIGURE 9. Longleaf pine seedlings and saplings of natural origin in a group selection opening on the Escambia Experimental Forest in Brewton, AL, during the 1982 growing season. (James M. Guldin)

pine includes a residual basal area target B of 14 m^2 ha^{-1}, maximum retained diameter D of 50 cm, and a q ratio for 5-cm diameter classes of 1.44, and a suggested cutting cycle length of 10 years (Farrar 1996). His uneven-aged marking guidelines contain a description of how to implement either method for longleaf pine. The burning program is required to keep competing hardwoods in check and to keep seedbeds prepared for any seedfall that might occur. When seedlings become established at acceptable densities within an area (local distributions equivalent to 1800–2000 trees ha^{-1}), cutting cycle harvest to remove the overstory trees will allow seedlings to initiate height growth. Subsequent cutting cycle harvests can be used to expand existing groups or to establish new groups, and as a free thinning in the matrix of the stand between the group openings.

Given the success in regenerating longleaf pine naturally using the shelterwood method, another possibility, or perhaps a variant of Farrar's modified group approach, is to adapt the shelterwood prescription for longleaf pine (Croker and Boyer 1975) in the context of a group selection regeneration method, where the groups are treated as small shelterwood openings. Smith (1986) noted that although group selection is usually imposed by removing all trees within the group, groups could certainly be created that retained overstory trees within them as silviculturally appropriate. This method would resemble a group selection with reserves (cf. Helms 1998) except that the reserves are explicitly retained for the silvicultural purpose of obtaining natural regeneration.

A shelterwood-based group selection approach in longleaf pine would use groups within which longleaf pine seed trees are retained at shelterwood (6–7 m^2 ha^{-1}) residual basal area levels. During one cutting cycle harvest, groups would be marked to resemble the seed cut of a shelterwood residual basal area (Smith 1986), using the same decision variables for seed tree retention as described in Croker and Boyer (1975). During the intervening cutting cycle, prescribed fires would be imposed as an element of the prescription, so as to prepare the site for seedfall, and Farrar (1998) offers suggestions to accomplish that. The seed trees in the group openings would eventually maximize their ability to produce cones, seedfall would be optimized 3 to 5 years after the cutting cycle harvest, and at the next adequate seed year seedlings would become established in the shelterwood group opening. The residual seed trees within the group would then be removed in the subsequent cutting cycle harvest to release established seedlings. If the removal cut of the shelterwood residuals within the group opening is not timely, seedling survival would be compromised.

Alternatively, if groups are initially created without residual trees, an area adjacent to the group opening could be retained at shelterwood basal areas such that group expansion would occur in the subsequent cutting cycle harvest, resulting in an expanded group coalescence. The same suggestions regarding marking, use of prescribed fire, seedling development, overstory removal, and so on would apply in this modification of the practice.

It might be that stands larger than 15 ha could be managed this way, and also that the method would be amenable to group openings larger than the 0.81-ha maximum for group selection suggested by the USDA Forest Service. Research would be needed to determine an effective range of group opening size such that longleaf seedlings can initiate height growth in a short period of time. It is likely that the size would be larger rather than smaller. This approach could be regulated using any of the usual regulation methods that apply to uneven-aged stands.

Approach to Stand Regulation

More than in other southern pines, managers in longleaf pine are looking for ways to retain larger trees, in some cases much larger, above the diameter limits that have been established in other uneven-aged experience. This would be done to meet resource attributes, values, or needs for associated species within the longleaf forest ecosystem, such as legacy trees or for nest construction by species such as the red-cockaded woodpecker. There is little theory available in the uneven-aged literature to account for the influence of large trees retained above the maximum diameter or in addition to the desired target residual stand. But even if only a few large trees are retained, their presence can adversely affect the development of the stand, because retaining them prevents growing space from being used by trees of other sizes. The regulation method and marking guides must account for any trees that are retained for special purposes, simply because large trees usurp considerable growing space that if unaccounted for could disrupt stand development.

For example, the BDq method calls for harvest of the worst trees and retention of the best in diameter classes at or below the maximum retained diameter *D*, but calls for all trees above the *D* to be cut. There are no active research studies on the Crossett EF that test whether trees larger than *D* can be retained. As a starting point, the basal area of retained trees should be included in the calculations of stand structure, simply because they create a very large influence in basal area calculations. An 80-cm tree has a basal area of 0.5 m^2, or roughly 4% of the residual basal area target of 13 m^2 ha^{-1} after a typical cutting-cycle harvest. If three trees above *D* per hectare were retained for special purposes and the stand below *D* was managed for the after-cut residual basal area target of 13 m^2 ha^{-1}, the actual basal area in the stand would be 14.5 m^2 ha^{-1}, more than 10% higher than the target. Over time that would adversely affect stand development. Similarly, under volume control, the volume and the volume growth of those big trees must be averaged into the calculation used to determine the allowable cut and the guiding diameter limit. Trees above the limit can be retained at the discretion of the marker, provided that an equivalent volume is then marked below the guiding diameter limit.

Growth and Yield

Empirical data on growth and yield of uneven-aged stands of longleaf pine are difficult to find because uneven-aged stands managed for a sufficient length of time are relatively rare (Kush et al. this volume). One of the few papers to cite data on growth and yield directly under the selection system is that of Farrar and Boyer (1991), who describe the growth of two uneven-aged stands on the Escambia EF over a 10-year period in comparison to that of a demonstration stand being managed using the shelterwood method. In all three stands, sawtimber volume growth was comparable at roughly 2 m^3 ha^{-1}, or roughly two-thirds the rate expected in the study. At these rates of volume growth, cutting cycles of 10 years or longer will be required to generate operable harvests.

Farrar and Boyer (1991) also speculated that over time, volume yield from selection stands will likely be less than that produced from a forest of large even-aged stands, because the zone of competition between large and small trees is minimized with large blocks found in even-aged stands (Farrar and Boyer 1991). The use of group selection, which would also have less area within the stand in this zone of competition relative to single-tree selection, might partly compensate for that hypothesized volume shortfall.

In a study of longleaf pine regeneration development under varying residual overstory basal area levels, Boyer (1993) reported that even a few residual longleaf pine parent trees resulted in substantial growth reductions of the new age cohort. The growth of two-aged stands in this study was less than half the growth reported in the naturally regenerated even-aged stands released from overstory competition when young. This provides another estimate of the total merchantable volume growth that might be produced in uneven-aged stands—less than half that found in comparable released even-aged stands.

Given the shortage of long-term data on growth and yield from uneven-aged stands in the literature, among the first priorities for research is to better quantify the growth and yield that one can expect from application of the selection system in the longleaf pine forest type. At a minimum, one should expect reduced rates of volume growth, especially in total merchantable cubic volume, in the uneven-aged stands. This point has been observed elsewhere in application of the method in southern pines (Guldin and Baker 1998).

Developmental Dynamics

If uneven-aged silviculture is applied in longleaf pine stands similar to that in other forest types where the method has been successful, a number of attributes will be apparent. Longleaf pine trees in the sawtimber size class will constitute roughly two-thirds of the residual basal area, but only 25% of the number of stems 10 cm and larger in the stand (Farrar et al. 1984; Baker et al. 1996). Cutting cycle harvests will require two visits by field crews to the stand—one to obtain the before-cut stand inventory upon which regulation calculations are based and to determine operability of the proposed cutting cycle harvest, and a second to actually mark the stand using the marking guidelines that the regulation calculations produce. Marking will follow a pattern of cutting the worst longleaf pines, and leaving the best, during every cutting cycle. Some form of competition control that meets the multiple silvicultural objectives of site preparation, release, and liberation cutting will be required on the order of every other cutting cycle. In longleaf pine stands, that will probably take the form of prescribed fire, with perhaps occasional herbicide use or mechanical felling of competing hardwood species. Regeneration of longleaf pine must be monitored after each cutting cycle harvest. Some regeneration will be expected to become established and to initiate height growth after every cutting cycle harvest, and especially after the first cutting cycle harvests in stands recovering from understocked conditions or being converted from even-aged fully stocked conditions. After several decades of implementation using a 10-year cutting cycle, visual examination of stands will reveal foliage of longleaf pine present at all levels of the canopy profile from the ground up through the main canopy. It will require three or more 10-year cutting cycle harvests to approach an uneven-aged structure, and longer to develop a well-balanced stand structure. Fewer cutting cycles will be needed if the initial stand condition is understocked and if multiple age cohorts are already present; more will be needed if the stand under management

FIGURE 10. A within-stand view of a new regeneration cohort in a longleaf pine stand managed as a quail plantation in southern Georgia. (James M. Guldin)

was initially a well-stocked even-aged stand at midrotation or later.

This description is at odds with several existing and notable approaches to management of longleaf pine—that proposed for management of the red-cockaded woodpecker, and that reflected in the Stoddard–Neel approach for management of uneven-aged longleaf pine stands for quail habitat. Open understory conditions are sought for both red-cockaded woodpeckers and for bobwhite quail. An understory full of trees in the submerchantable and smallest merchantable size classes are sought in an uneven-aged stand. The question is whether uneven-aged practices can be, or have been, modified so as to simultaneously maintain an open understory condition, while concurrently maintaining the development of regeneration cohorts in sufficient number and distribution within the uneven-aged stand (Fig. 10).

Consider the Stoddard–Neel approach of uneven-aged silviculture, an excellent description of which was recently published by Moser et al. (2002) (see also boxes A and B). In this approach, single-tree selection is used to maintain low residual basal area at 15 m^2 ha^{-1} or less; open midstory conditions are maintained, removals are made from below, and regeneration occurs in patches. The purpose of this variant of the single-tree selection method is to provide habitat for northern bobwhite quail. Graphs of the diameter distributions for several quail plantations (Moser at al. 2002) differ from the reverse J-shaped curve typically associated with uneven-aged silviculture at the stand level, specifically in a lack of trees in the smallest diameter classes. For example, no 1-cm diameter class less than 10 cm in any of the plantations managed using the Stoddard–Neel approach has more than 5% of the total number of pines per hectare. Conversely, the 1995 preharvest inventory on the Good Farm Forestry Forty demonstration stand on the Crossett EF showed 4450 trees ha^{-1} in the submerchantable diameter classes (1.5–8.9 centimeters inclusive), corresponding to 92% of the total trees per hectare in the demonstration stand (Guldin unpublished data). This raises the question of whether regeneration is being recruited at a sufficient rate under the Stoddard–Neel approach to ensure the long-term sustainability of not only uneven-aged stand structure, but also the habitat values for which those stands are justifiably prized.

Similarly, debate is currently active in the literature about the habitat values provided by uneven-aged stands for the red-cockaded woodpecker (Engstrom et al. 1996; Rudolph and Conner 1996; Hedrick et al. 1998). This debate has its roots within the application of the Stoddard–Neel selection system as well, since it is largely upon that experience that habitat descriptions of uneven-aged longleaf pine stands are based. But the debate embraces other situations in which desired habitat for the red-cockaded woodpecker is inconsistent with information available from the literature about uneven-aged stand dynamics. It is not really a question of the conditions that are appropriate for the red-cockaded woodpecker, which are fairly well defined (Conner and Locke 1982; Hooper 1988; Hooper et al. 1991; Conner et al. 1994; Ross et al. 1997). Rather, the question is one in which a regeneration method that provides desired residual stand conditions is sustainable, according to the first rule of sustainability at the stand level—that an imposed regeneration method must result in the successful establishment and development of regeneration.

Summary

The successful practice of uneven–aged silviculture in mixed loblolly–shortleaf pine stands of the upper West Gulf Coastal Plain has been characterized by a number of attributes (Guldin and Baker 1998). Key factors are attention to stand-level regulation, use of appropriate residual basal area levels that approximate those found in slightly understocked mature even-aged stands, establishment and development of regeneration, and attention to a marking rule that cuts the poorest trees and leaves the best across a range of diameter classes.

Longleaf pine shares some silvical attributes with loblolly and shortleaf pines, but not all. The favorable elements will be useful in development or refinement of the selection method in longleaf pine. First, dominant or codominant longleaf pines respond to release, though suppressed trees do not (Boyer 1990). Thus, cutting cycle harvests in which codominant or better longleaf pines are released from competition of others will stimulate a growth response in the residual stand, which promotes continued stand development. This attribute has been a feature of the Stoddard–Neel variant of the selection method in longleaf pine as well (Moser et al. 2002). Second, it can be successfully managed using the shelterwood method (Croker and Boyer 1975), which has been observed in other forest types where the selection method has been applied (Guldin 1996).

Where longleaf differs most prominently from other southern pines is in the periodicity of seed crops and the difficulty in securing natural regeneration. This will require new interpretations of existing knowledge, and the development of new knowledge, to ensure that longleaf pine seedlings can become established and can develop properly following regeneration cutting under the selection method. With respect to natural regeneration, refinements of existing knowledge from the application of the shelterwood method might be promising as a variation under modifications of the group selection method (Farrar 1996). Conversely, should natural regeneration techniques fail or result in unacceptable delays in regeneration establishment or development, technology should be developed for application of planting as an alternative or a preferred method of obtaining establishment of regeneration at acceptable levels. More than any other southern pine, or for that matter any other species in which the selection method has been used, planting seedlings for reforestation of uneven-aged stands will have a prominent place in the successful application of the selection method for longleaf pine.

The biggest question that remains unresolved is the level at which regeneration development can be considered acceptable in the selection method. The Stoddard–Neel selection method points in one direction about this, and experience from the selection method as practiced in mixed loblolly-shortleaf pines, and in other forest types, points in another. The Stoddard–Neel approach differs from most other instances of successful application of uneven-aged silviculture due to the smaller number of stems in the submerchantable class. That difference leads to allied relationships in habitat condition that promotes open midstory conditions in one case, and midstory conditions occluded by development of seedlings and sapling in the submerchantable diameter classes in other conditions. Ultimately, the question relates to the degree to which deviations from the reverse J-shaped structure can be considered to be sustainable at the stand level. This is the most prominent research gap in our understanding of the regeneration dynamics of uneven-aged longleaf pine stands, and one that is critical in order to ultimately evaluate what constitutes sustainability of uneven-aged structure in longleaf pine stands in the long term.

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