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Uneven-Aged Management of Longleaf Pine Forests: A Scientist and Manager Dialogue

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Cover Photo

Uneven-aged longleaf pine forest in the sandhills of South Carolina, showing developing pines in an overstory canopy gap and suppressed seedlings beneath the crowns of nearby adult trees. Photo courtesy of William D. Boyer, Southern Research Station, USDA Forest Service.

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Abstract

Interest in appropriate management approaches for sustaining longleaf pine (*Pinus palustris* Mill.) forests has increased substantially during the recent decade. Although longleaf pine can be managed using even-aged techniques, interest in uneven-aged methods has grown significantly as a result of concern for sustaining the wide range of ecological values associated with maintaining continuous crown cover in these ecosystems. Indeed, land managers have recently sought to restore and sustain the many habitat attributes upon which numerous at-risk species depend, while simultaneously producing high-quality wood products from longleaf pine forest ecosystems. Although earlier research produced a substantial body of knowledge to guide even-aged management, less is known about application of uneven-aged management methods in longleaf pine forests. Much of this information is yet in the developmental stage. However, managers from the Florida Division of Forestry and Florida National Forests, having a keen interest in applying what is currently known, encouraged scientists of the U.S. Department of Agriculture Forest Service, Southern Research Station and faculty members from the School of Forest Resources and Conservation at the University of Florida to engage in a dialogue that focused on addressing 60 of their key questions concerning uneven-aged management of longleaf pine. This dialogue addresses issues related to (1) methods for converting even-aged to uneven-aged stands, (2) growth and yield, (3) selection harvest techniques, (4) optimum logging practices, (5) effects on red-cockaded woodpeckers (*Picoides borealis*), (6) prescribed burning approaches, (7) regeneration, (8) optimum stand structure, (9) competition tolerance and release of various seedling age classes, and (10) the viability of interplanting and underplanting.

Keywords: Artificial regeneration, group selection, growth and yield, natural regeneration, prescribed fire, red-cockaded woodpecker, single-tree selection, stand structure.

Prologue

At a meeting held in Tallahassee, FL, on February 7–9, 2001, U.S. Department of Agriculture Forest Service, Southern Research Station (SRS) scientists and University of Florida researchers met with managers from the Florida Division of Forestry and the Florida National Forests to discuss how to best apply uneven-aged management methods to longleaf pine (*Pinus palustris* Mill.) stands on State and Federal forests in Florida. In recent years, the public has expressed its desire to have public forests managed over longer rotations and with methods that mimic natural processes. They are interested in maintaining both the long-term sustainability and biological diversity of these ecosystems. Although uneven-aged management is one way to mimic the natural stand replacement dynamics that occur in longleaf pine forests, less information is available for ensuring that the goals of sustainability and biodiversity will be met. With few exceptions, forest managers and researchers alike have little experience in applying uneven-aged management to longleaf pine forests. Because these forests traditionally have been managed with even-aged practices, information related to the economics of uneven-aged management in longleaf pine forests is scarce.

The purpose of this report is to capture the individual responses of scientists to questions raised by forest land managers about the uneven-aged management of longleaf pine forests and make this information available to a broad range of interested parties. Two groups of research scientists participated, one group having expertise in the uneven-aged management of southern pines generally (but not longleaf pine specifically) and the other having expertise in longleaf pine ecology and management generally (but only limited exposure to uneven-aged management methods). The approach taken in this publication is that of a question and answer format, where practicing field foresters and natural resources managers who routinely face decisions about application of uneven-aged silviculture in longleaf pine stands were invited to ask questions of the scientists. The scientists then responded to any questions about which they could provide useful information, whether based on the findings from specific research studies and long-term demonstrations or, in many instances, based on their scientifically informed opinions (i.e., their "best guess"). As presented here, the resulting document more closely resembles a roundtable dialogue than a synthesis focused on providing a precise answer. Instances of disagreement were retained to underscore the currently developmental nature of this body of knowledge. These questions and answers have been organized into the following categories.

Part	Subject	Questions
A	Methods for converting even-aged stands to uneven-aged stands	1 – 7
B	Growth and yield	8 – 14
C	Selection harvest techniques	15 – 22
D	Optimum logging practices	23 – 24
E	Effects on red-cockaded woodpeckers (*Picoides borealis*)	25 – 29
F	Prescribed burning approaches	30 – 40
G	Regeneration	41 – 43
H	Optimum stand structure for management objectives	44 – 51
I	Competition tolerance and release potential of various age classes	52 – 56
J	Viability of interplanting and underplanting	57 – 60

Longleaf pine forests have been managed for many purposes and using several different techniques. Before deciding to implement one approach or another, managers should consider the following stand reproduction methods and management options and select the ones that best meet their goals:

- Longleaf pine forests can be sustainably managed with **even-aged management** methods. Uniform shelterwood and irregular shelterwood methods most closely mimic stand-replacing hurricane-type disturbances. Both shelterwood methods are easy to apply, and there is an extensive body of research to support their use in longleaf pine forests.
- Much research has been devoted to demonstrating the effectiveness of the **uniform shelterwood** method in regenerating longleaf pine stands. Even though the responses to the following questions focus on the application of uneven-aged management, we must recognize that even-aged management in the form of the uniform shelterwood method remains a viable alternative for application by many landowners on a variety of longleaf pine sites.
- The **irregular shelterwood** method is one way to begin shifting a stand toward uneven-aged management over time. Irregular shelterwood can be used to convert even-aged stands to a two-aged condition and eventually to an uneven-aged structure. The structure resulting from irregular shelterwood often results in excellent red-cockaded woodpecker habitat and retains large trees characteristic of old-growth forests. If desired, irregular shelterwood can be used indefinitely to sustain longleaf pine forests and the many ecological, economic, and social values associated with the longleaf pine ecosystem.
- **Patch clearcutting** is another method that can be used to successfully sustain longleaf pine forests. In application, it creates numerous dispersed small openings in the forest, and these should facilitate natural regeneration. Although technically considered an even-aged management method, it creates a mosaic of small even-aged patches within an uneven-aged forest matrix (much as group selection does where area regulation is employed). It may be considered a transitional method having the characteristics of an even-aged management method but producing results similar to those obtained by means of uneven-aged management. This method is easier to apply than either single-tree selection or group selection (with the volume regulation option). Most foresters can lay out an array of 0.25- to 2-acre patch clearcuts, thereby creating the initial gaps for longleaf pine regeneration. However, foresters would be wise to guard against creating unnaturally evenly spaced small clearcut patches across the landscape in a robotic fashion, since this would impose an artificially uniform pattern on forest structure that could degrade ecological values and aesthetic qualities. As field personnel acquire training and gain experience with application of the uneven-aged management volume regulation concepts of volume-guiding diameter limit (VGDL) or BDq (explained in the dialogue section below), a shift from small patch clearcutting to an uneven-aged management program is possible.
- We do not have enough long-term research on **uneven-aged management** in longleaf pine stands to state categorically that these methods will provide for the long-term sustainability of longleaf pine forests, but our long-term research on uneven-aged management in other southern pine forests suggests that it can be applied in this forest type as well. Public land managers must be committed to a system of monitoring these ecosystems over time to ensure that various measures of health in longleaf pine ecosystems are maintained over time. Studies and management experience from other forest types indicate that uneven-aged management is generally more expensive to implement and requires that

field personnel possess a higher level of expertise and training than is required to apply even-aged methods.

- Limited research suggests that **group selection** is the uneven-aged management method that most closely mimics the natural gap-phase stand replacement dynamics typical of longleaf pine ecosystems (e.g., small-scale disturbances such as lightning strikes, localized fires, insects, or pathogens causing gap formation). More research is needed on group selection to confirm these preliminary findings and further refine their application to longleaf pine forests.
- **Single-tree selection** has yet to be clearly demonstrated as an effective method for sustaining longleaf pine forests. Although single trees do die naturally in longleaf pine forests, there is little evidence to suggest that longleaf pine juveniles can regenerate in the very small space resulting from the death of a single longleaf pine tree. Most evidence indicates that several longleaf pine trees must fall from the canopy before sufficient space is available to allow longleaf pine juveniles to begin growing into the canopy. Group selection is more likely to provide the required minimum opening size (0.25 to 0.5 acre). Single-tree selection has never been comprehensively tested against all the other stand reproduction methods listed above. More research is needed before this method can be recommended for sustaining longleaf pine forest ecosystems.

It should be noted that longleaf pine forests grow on a wide range of site types (e.g., wet flatwoods, mesic uplands, xeric sandhills, and mountains), each characterized by a distinctly different ambient environment. Across its range, longleaf pine is often found growing in association with slash pine (*P. elliottii* Engelm.) on flatwoods sites, loblolly pine (*P. taeda* L.) and shortleaf pine (*P. echinata* Mill.) on upland sites, and various hardwood species on many site types. Therefore, no single management prescription is appropriate for sustaining longleaf pine forests everywhere. In pursuing their objectives, prudent managers will typically select a combination of approaches that is appropriate for the specific environment and that allows for the trajectory of forest development from current status to future desired conditions. Prior to implementing any of the above methods, it is desirable to restore the native plant community by an appropriate application of mechanical, chemical, and burning methods. In the absence of a restored ecosystem, forest management activities may simply increase competition from woody plants in the midstory and understory, thereby jeopardizing longleaf pine regeneration success.

In implementing the above methods, forest managers may consider using artificial regeneration to supplement seedling stocking when natural regeneration is inadequate. However, planting should not be viewed as an infallible remedy for improper application of these forest reproduction methods. Regardless of the stand reproduction method selected, managers should be mindful of the crucial importance of using prescribed fire to sustain longleaf pine forest ecosystems over the long term. Periodic fire is essential for maintaining longleaf pine forest composition, structure, and function, primarily by curtailing the proliferation of woody plants in the understory and midstory and creating seedbed conditions favorable for the regeneration and development of longleaf pine seedlings.

Part A. Methods for Converting Even-Aged Stands to Uneven-Aged Stands

Forest Manager: (1) *What are the best or most efficient methods for converting from even-aged management to uneven-aged management?*

Brockway: The quickest way for a land manager to convert an even-aged longleaf pine forest to an uneven-aged longleaf pine forest is through application of the irregular shelterwood stand reproduction method. Although shelterwood methods are generally thought to result in even-aged stand structures, the irregular shelterwood method allows rapid development of multiple age classes in a forest. As with application of the uniform shelterwood method, the seedcut will reduce stand basal area to 25 to 30 square feet per acre. However, the overwood is not removed once the regenerated seedlings have become established, as it is in the uniform shelterwood method. Rather, the overwood harvest is deferred, and it is retained onsite throughout the entire next rotation. As a bonus, the damage done to seedlings during harvest of the overwood is eliminated. Retaining wind-firm trees of this long-lived species presents little problem in implementing this method. Seed dispersed from overstory trees initially results in a two-storied forest structure. However, as additional seed trees mature and disperse seed across the site in ensuing decades, multiple waves of seedlings emerge, and an uneven-aged forest structure develops. Advantages of this method include (1) sustainable harvest of usable, often high-quality wood fiber; (2) continuous maintenance of a canopy of tree cover to achieve ecological and aesthetic objectives; and (3) easy implementation using existing machine technology and forest resource information. Once in an uneven-aged condition, the forest can be so maintained in a number of ways.

A somewhat slower but ecologically sound silvicultural method for converting from an even-aged to uneven-aged forest structure is through the group selection method. Creation of numerous 0.25- to 2-acre gaps in an even-aged forest encourages regeneration of varying ages to develop, much as in natural gap-phase regeneration, which is common in longleaf pine forests. The end product of this process is a series of small even-aged patches that constitute an uneven-aged forest across the landscape. This stand reproduction method probably comes closest to the manner in which natural longleaf pine forests have historically renewed and sustained themselves for thousands of years. Of course, periodic fire must be used to ensure that proper seedbed conditions are maintained for regeneration of longleaf pine seedlings and control of competing woody plants. Advantages of this method include (1) sustainable harvest of usable, often high-quality wood fiber and (2) continuous maintenance of a canopy of tree cover to achieve ecological and aesthetic objectives. This uneven-aged management method can be applied to a forest in perpetuity without degradation of resource values.

Boyer: The most rapid way to change from even-aged to uneven-aged stand structure, given a mature or maturing even-aged stand, is to create an irregular shelterwood, or two-aged stand. The typical reverse-J curve of size-class distribution is rapidly established. In one study on an average Coastal Plain site, the largest ingrowth was 14 inches in diameter at breast height (d.b.h.) at 40 years, only 2 inches less than the smallest of the residual trees. This occurred only in stands with a low density (10 square feet per acre) of residuals. Once a reverse-J curve is established, it can be maintained indefinitely through any of several strategies.

Guldin: Two stand reproduction cutting methods and one method that grades between intermediate treatments and reproduction cutting have been used successfully to convert from even-aged management to uneven-aged management in loblolly-shortleaf pine stands on the upper West Gulf Coastal Plain.

Group Selection or Single-Tree Selection

Regardless of whether you choose group selection or single-tree selection, one of two regulation methods is called for, BDq regulation or volume regulation. For BDq regulation, the forester must inventory the existing stand and generate a stand-and-stock table by 1-inch or 2-inch d.b.h. classes. Separately, a hypothetical uneven-aged target stand structure is created using the basal area (B), maximum d.b.h. (D), and age class distribution coefficient (q) parameters. The stand is then harvested to conform to this target. Many publications provide the detail necessary to properly implement the BDq method. Some of these studies and publications contain short-term research results. The VGDL method can also be adapted to conversion of even-aged stands, but since it is a sawtimber regulation method, separate attention must be paid to ensure adequate regeneration in smaller size classes. This is also true to a lesser extent with the BDq method.

The method of regulation is independent of whether single-tree or group selection is used. Regulating group selection with any other method (such as area regulation) is much less supported in the uneven-aged silviculture literature and comes uncomfortably close to patch clearcutting or some other form of patch-based even-aged management. Nor should it be assumed that the group selection method requires that an opening be cleared of all trees (as in patch clearcutting). Residual seed-producing trees can be left within group openings at the equivalent of seed-tree or shelterwood residual basal area levels (10 to 30 square feet per acre) if this is desired and more appropriate for the silvics of the species involved, and this might allow group openings to be made larger than 2 acres. Given the success that Tom Croker and his colleagues experienced in the 1960s and 1970s at the Escambia Experimental Forest (EEF) in southern Alabama, the group shelterwood with group openings varying from 2 to 5 acres might be a very effective means of managing longleaf pine using the selection method. (This does, however, deviate from current Forest Service Region 8 guidelines that specify a 2-acre maximum size for group selection).

Irregular Shelterwood

An irregular shelterwood approach can be used to establish three age classes. This approach would lead to an imbalanced uneven-aged structure with fewer age classes. Experimental use of the shelterwood method in longleaf pine at the EEF is well documented. Some modifications of the method would be needed to allow us to apply what we know about the silvical characteristics of longleaf pine. For example, longleaf pine's adaptation to advance growth could be used to compensate for its erratic seed production. A third age class could be obtained by retaining the first age class while conducting another shelterwood reproduction cut shortly after the second age class starts to produce cones. By this method the minimum of three age classes that defines uneven-aged condition would be obtained. A fourth iteration of shelterwood might also be possible. Prescribed fire would be needed to effectively manage these classes.

Rehabilitation Technique

Methods similar to those pioneered for rehabilitation of understocked loblolly-shortleaf pine stands at the Crossett Experimental Forest (CEF) could be used to move the stand toward an uneven-aged condition. The VGDL regulation method is one possibility. In its early stages, this prescription resembles classic improvement cutting, but as time goes on the practice graduates to the selection reproduction cutting method.

This combination of prescriptions evolved as follows. Stands at the CEF originated in about 1915 following pine high-grading to a 15-inch stump limit. Uncontrolled fire followed on an irregular interval. After 20 years, the Southern Forest Experiment Station established the CEF in 1934, and Station scientists began to control hardwood competition and encourage development of better pines by cutting the poorer ones using volume-control regulation methods. After 15 years of this management, pine stands were producing 400 board feet per acre (Doyle log rule) sawlog volume annually. Volume regulation (cutting-cycle harvests based on growth or a proportion thereof) has been used in these stands for the succeeding 50 years, and periodic yields in the vicinity of 400 board feet per acre have been maintained. There are good empirical and research data for this.

One might consider applying this sequence of techniques to the recently acquired longleaf stands in Florida and elsewhere. If those stands have a history of mismanagement that resembles high-grading but still have reasonable stocking levels of longleaf, they may be candidates for this rehabilitation prescription. Similarly, if stands have a history of being damaged by storms such as hurricanes, managing existing stands may be an easier proposition than starting over with new stands. Some simple research would be in order to establish the minimum acceptable stocking levels from which recovery can be expected.

Forest Manager: (2) *What cutting method is best for regenerating longleaf pine under an uneven-aged management system—single-tree selection, group selection, or another method?*

Guldin: During his tenure at the CEF, founding scientist Russ Reynolds explicitly refused to identify his VGDL method as single-tree or group selection. He simply called it selection. Sometimes this selection method would result in large openings in the forest; sometimes small ones would suffice. Following the guideline of cutting the worst and leaving the best, situations can be imagined where from one to many adjacent trees would be harvested. I'd propose that one approach for longleaf pine is probably a combination of group and single-tree selection after Reynolds's description of selection.

Both single-tree selection and group selection can be adapted for use in longleaf pine early in the process of converting stands to uneven-aged structure. Experimentation with cutting-cycle lengths, after-cut target stands, opening size, residual basal area, and so on will be needed, and in some cases data from existing studies of longleaf pine may be applicable. On drier sites such as the sandhills, group selection is probably more likely to produce desired results. Single-tree selection may be feasible on better sites, but more research is needed before we can recommend one method over the other for such sites.

The single best source for information on uneven-aged management is Bob Farrar's (1996) uneven-aged management guide, which is based on a combination of empirical experience and research. Farrar cites both the VGDL and BDq regulation methods as feasible in longleaf pine, but only under modified group selection and with cyclic prescribed burning. 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 700 to 800 trees per acre), a cutting-cycle harvest to remove the overstory trees will allow the 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. This varied approach should ensure that the method does not become patch clearcutting.

How can one tell whether a given cutting-cycle harvest more closely resembles group selection or patch clearcutting? Ideally a group selection harvest should have the following attributes: (a) openings are created in a random rather than geometric pattern, (b) the total area in groups is not obtained by using an area/rotation length calculation, and (c) there is variation in the size and shape of the openings created by harvesting.

Finally, the more experience one has with these methods, the more one will feel comfortable with following the marking rule "cut the worst trees and leave the best." This is difficult to do consistently over time under group selection. However, the greater one's experience with the selection method, the easier it will be to obtain regeneration in openings.

To better understand longleaf developmental dynamics, we need better data on the establishment and development of longleaf seedlings in openings of varying size and beneath residual basal areas that vary from 10 to 60 square feet per acre. Such data would help us understand the kinds of conditions under which longleaf regeneration can become established and, more important, develop in an acceptable manner.

Forest Manager: (3) ***At what age would a planted longleaf pine stand be capable of producing enough viable cones and seeds to reproduce itself through natural regeneration?***

Boyer: Longleaf tree size (dominant or codominant members of a stand) rather than age indicates the cone-bearing potential of a tree. Within shelterwood stands, a 9-inch d.b.h. tree produced an average of 4 cones annually, a 12-inch tree averaged 12 cones annually, a 15-inch tree averaged 32 cones annually, and an 18-inch tree averaged 58 cones annually. A shelterwood stand with 30 square feet per acre could have 68 trees of 9-inch d.b.h. or 24 trees of 15-inch d.b.h. Cones per acre, on average, will amount to 272 with the 9-inch trees and 768 with the 15-inch trees. The recent increase in size and frequency of longleaf cone crops, if continued, will likely increase the long-term averages noted here. At least 750 cones per acre are required for successful natural regeneration. The larger the seed trees, the more frequent the usable cone crops, but cone production per acre increases more slowly for trees with d.b.h. > 15 inches than for trees with d.b.h. from 9 to 15 inches.

Forest Manager: (4) ***What is the most effective regimen for accomplishing the conversion of even-aged stands to uneven-aged stands, beginning at various age or size classes and stocking levels? Also, we need to distinguish between a plantation and a natural stand.***

Boyer: For an explanation of the most effective way to convert even-aged stands to uneven-aged condition, see the replies to question 1 above. The stand should contain sufficient numbers of trees of seed-bearing size before you attempt to utilize natural regeneration, which is the most economical way to provide a stand with recruitment on a regular basis.

Guldin: The most effective way to convert an even-aged stand to an uneven-aged stand depends on the specific circumstances of the stand in question. Suggestions offered in my answer to question 1 might help the manager decide the direction for a particular stand. We could probably come up with some reasonable guesses (they might also be called guidelines) for various age classes and stocking levels and also for converting plantations. As a starting point, I would suggest the CEF standard for loblolly pine (see the following tabulation), perhaps reducing the residual basal area slightly to account for the greater intolerance of longleaf regeneration.

Variable	Value
B, residual basal area	60 square feet per acre
D, maximum diameter retained	18 to 20 inches
q, diminution quotient	1.2 for 1-inch classes or 1.44 for 2-inch classes
Cutting cycle	5 to 7 years, perhaps 7 to 10 years for longleaf pine
Volume	5,000 board feet per acre (Doyle log rule)

Residual stand parameters must be tailored to cutting-cycle harvest lengths so that residual stand conditions do not become dense enough to arrest regeneration development.

Practitioners should keep in mind that these parameters for applying the BDq method are a starting point. It is apparent from the CEF work and other work that the most important element of the target curve to achieve is B, the residual basal area. The maximum retained diameter, D, can be set at whatever d.b.h. class the landowner is willing to establish. A key factor in this decision is whether a landowner believes that the many ecological benefits provided by leaving large trees (under a large D) are worth the risk of financial loss that could result from the deaths of large residual trees, which may be lost to lightning and other mortality factors. Some have advocated tracking the target diameter distribution, but then allowing some trees to "escape" from the target BDq curve by simply retaining them as relict trees above the D. If this silvicultural tactic is employed, one key element is needed: the basal area of these larger relict trees must be accounted for in the retained B, the target residual basal area. For example, one cannot simply configure the target BDq curve using the target parameters of B, D, and q and then allow relict trees to exist outside the parameters of the target curve. The reason for that is that those relict trees carry significant basal area that must be accounted for in development of the target curve lest the residual basal area be too high for adequate regeneration development. If *x* square feet per acre of basal area are left in relict trees above the D, the BDq target curve at and below the D should have its B reduced by *x* as well, to retain the overall target basal area for all trees in the stand. Finally, attaining the proper q is of least importance, especially early in converting an even-aged stand to an uneven-aged structure. During conversion, it is more important to leave the best trees in the stand at the suggested residual basal area, and the best trees in a stand with an even-aged structure will generally not be distributed among all size classes. However, not leaving some trees in all size classes increases the likelihood of irregular product yields through time.

Forest Manager: (5) *How long does it take to establish a truly uneven-aged stand, beginning at various age or size classes and stocking levels?*

Guldin: The answer to this question depends on the definition of a "truly" uneven-aged stand, and on the age and stocking levels at the start of the conversion. Generally speaking, different age classes of trees (10-year groupings) are distinguishable by tree size in uneven-aged stands. This rule of thumb would suggest that the textbook requirement of three age classes to define an uneven-aged stand would require a minimum of 10 years to develop: the first age class would exist on the site at year 0 of management, the second would be obtained through reproduction cutting at year 0, and the third would be obtained after a cutting-cycle harvest at year 10.

More realistically, the length of time required to establish an uneven-aged stand depends on the number of size classes present in the initial stand after the first cut and the length of time to obtain two more seed crops from the longleaf pine overstory. This estimate assumes that seedlings could germinate and become established after each seed crop. As a practical matter, it is likely that from 10 to 30 years will be required to produce the minimal age class and structural attributes that define an uneven-aged stand, depending on initial stand condition and the time needed to obtain two new age classes of reproduction.

Forest Manager: (6) *How do different methods for converting even-aged stands to uneven-aged stands compare with respect to efficiency, growth and yield, prescribed fire, pine regeneration, and ground cover quality and diversity?*

Boyer: As can be seen below, the most rapid development of longleaf pine ingrowth occurred under lightest residual overstory (i.e., even-aged stands with initial stand basal area = 0).

Initial stand Basal area	Residual pine		Ingrowth pine		Total pine	
	Basal area	Volume	Basal area	Volume	Basal area	Volume
square feet per acre	*square feet per acre*	*cubic feet per acre*	*square feet per acre*	*cubic feet per acre*	*square feet per acre*	*cubic feet per acre*
Block A:						
0	0	0	79.1	1884.3	79.1	1884.3
0	0	0	73.9	1795.7	73.9	1795.7
9	9.6	265.7	50.9	1005.7	60.5	1271.4
18	31.7	885.7	29.6	430.0	61.3	1315.7
27	38.7	1067.1	10.0	88.6	48.7	1155.7
36	56.1	1565.7	3.5	62.9	59.6	1628.6
45	67.0	1811.4	0.9	15.7	67.9	1827.1
Block B:						
0	0	0	87.4	1998.6	87.4	1998.6
9	10.9	305.7	51.3	981.4	62.2	1287.1
18	27.4	767.1	20.0	251.4	47.4	1018.5
27	40.4	1125.7	7.8	74.3	48.2	1200.0
36	55.2	1527.1	1.7	21.4	56.9	1548.5
45	70.0	1940.0	0.4	2.9	70.4	1942.9

Growth rate was compared with that of even-aged stands at or near the same age as ingrowth in the two-aged stands (i.e., initial stand basal area > 0), at last remeasurement of 36 years in block A and 40 years in block B. Competition with the residual parent trees resulted in rapid establishment of the reverse-J diameter class distribution, with the largest number of stems in the small diameter classes, but also a fair number of sawlog size trees by age 40. The parent trees average about 90 years in age. This appears to be the most rapid way to obtain uneven-aged stand structure with a growth rate (in these tests) close to that of even-aged stands. For the last 5-year remeasurement interval, the two-aged stands have been growing at nearly 80 percent of the rate of even-aged stands, although total volume yield of the two-aged stand is still slightly under 50 percent of that of the even-aged stands. A note of caution is appropriate here. The stands used in tests of uneven-aged management on the EEF consist largely of mature trees, while the two-aged stands are largely young trees, mostly still below merchantable size classes. The next remeasurement of these stands will give us more information. See also my answer to question 28 for information on the effects of uneven-aged management with appropriate fire regimes on the diversity of natural communities.

Guldin: The effectiveness of different treatments in producing uneven-aged characteristics in longleaf pine stands can be discussed in terms of efficiency, growth and yield, prescribed fire, pine regeneration, and ground cover quality and diversity, as follows.

Efficiency

Most studies show that if one wants to convert an even-aged stand to an uneven-aged condition, it is more biologically and economically efficient to convert poorly stocked even-aged stands than fully stocked even-aged stands. Directly converting fully stocked even-aged stands to uneven-aged ones (especially those stands nearing maturity) is the most wasteful way to convert the stand. Group selection or the irregular shelterwood method might offer a compromise.

Growth and Yield

The same comments offered regarding efficiency apply here.

Prescribed Fire

I don't see any difference in the ability to maintain prescribed fires under any of these alternatives. The only exception would be that fire should be excluded when using the irregular shelterwood approach between the period of emergence from the grass stage and the point after crown closure when foliage of the pines is above the normal flame length of the fire, to minimize sapling mortality.

Pine Regeneration

The success of the shelterwood approach in achieving regeneration is well documented for longleaf pine. I see no reason that a third age class couldn't be established in such a stand. The same comment applies to group selection, an example being Farrar's modified approach. Few data are available on the success of single-tree selection or whether one would obtain longleaf pine seedlings when converting understocked even-aged stands of longleaf pine to an uneven-aged structure.

Ground Cover Quality and Diversity

Those methods that create the greatest diversity of microhabitats should result in the greatest diversity of ground cover. Modified group selection is such a method. A more important question would be, how much ground layer diversity is desired?

Forest Manager: (7) ***What criteria should be used to determine when to convert which even-aged stands to uneven-aged stands?***

Guldin: Landscape attributes and management implications are important factors in these determinations.

At the stand level, though, several structural attributes can be used to identify those stands more likely to be quickly converted to an uneven-aged condition. First, stands with more than one size class of trees are easier to convert since the second age class is already present. Second, stands that were high-graded or overcut in the past may be good candidates for converting to uneven-aged condition. If these stands are understocked but have sufficient volume to rehabilitate, they can be quickly converted to productive uneven-aged stands. Third, experience in a number of forest types suggests that uneven-aged silviculture is more easily done on sites of poor quality (i.e., those with site indices ranging from 50 to 70) rather than on good-quality sites (i.e., those with site indices of 80 or more), because competing vegetation is more vigorous on good sites. Supplemental release treatments to enhance seedling development are less likely to be needed on poor sites, and thus chances of success are higher there. Finally, stands with a great deal of within-stand heterogeneity in density, pockets where few trees exist, and other pockets where an excess of the most common age class exists would be better candidates for conversion than fully stocked even-aged stands.

Part B. Growth and Yield

Forest Manager: (8) ***What volume growth rates can be expected from longleaf pine seedlings established on a variety of common soil types and vegetation communities?***

Boyer: The nature and degree of competition largely determines the early growth rate of longleaf pine seedlings. The form of height-over-age curves of young longleaf pine is affected by competition level (both seedling density and site quality). Plantation site index curves differ among old fields, prepared sites, and unprepared cutover sites (Boyer 1983). All plantation site index curves differ from those for natural stands. Natural stands, while lagging greatly in growth during early years, tend to catch up with planted cousins in later years. Also, natural longleaf pine stands released early in their development get a substantial growth jump on same-aged seedling stands that are not released until later, but both types of stands reach small pole size (age 30) with no difference in tree size or volume yield per acre. This result was replicated on both poor and average Coastal Plain sites (Boyer 1985).

Forest Manager: (9) ***What volume growth rates can be expected from merchantable longleaf pine stands consisting of at least three age classes on a variety of common soil types and vegetation communities at various densities?***

Boyer: The oldest stand for which we have data on this issue, the EEF Farm Forty, had a mean annual increment of 36 cubic feet per acre per year over 50 years. Now this stand appears to have reached a steady state in terms of growth. Growth is 42 percent of that expected for an even-aged stand on the same site, maintained at the same average density, over an 80-year rotation. The gap between growth in these two types of stands would be smaller if the rotation of the even-aged stand were extended to 120 years, although information on average yield up to 120 years is not yet available. Permanent plots of a longleaf pine growth-and-yield study will soon supply these data.

Guldin: Here are some rules of thumb that are based on our Arkansas work with loblolly-shortleaf pine and other citations from the literature.

When properly configured, well-balanced uneven-aged stands can be managed by cutting growth. The growth to be expected depends on the conditions associated with determining balance. Annual growth expectations for sawtimber (Doyle log rule), using simple interest rate projections, at different rates and cutting-cycle lengths, assuming an initial volume of 5,000 board feet per acre, are shown below.

Length of cutting cycle	Interest rate (percent)		
	4	6	8
years	*board feet per acre per year*		
5	217	338	469
7	226	360	510
10	240	395	579

Our experience with yields from loblolly-shortleaf pine stands in Arkansas suggests that sawtimber volume production over 36 years of uneven-aged management parallels that expected from natural even-aged stand management. These stands showed slightly lower yields, but with higher log quality than that expected from plantations managed for similar lengths of time. Uneven-aged stands produce from 50 to 75 percent of the total merchantable cubic volume expected from plantations. Uneven-aged silviculture does not compare with plantations as a prolific producer of pulpwood, but it produces large volumes of high-quality sawtimber.

Forest Manager: (10) ***How can we create growth-and-yield tables for balanced, uneven-aged longleaf pine stands on various sites?***

Guldin: Individual tree growth-and-yield models will be required. Our research work unit in Arkansas (SRS-4106) is just completing a 15-year study to provide data to develop a model such as this for loblolly-shortleaf pine stands. Bob Farrar initiated a growth-and-yield study in even-aged longleaf pine stands that is being maintained by Ralph Meldahl at Auburn University. While neither of these can be used directly to estimate growth and yield of uneven-aged longleaf pine stands, they provide a starting place. Bill Boyer tells me that scientists in the Auburn research unit (SRS-4105) are currently tracking growth and yield for several uneven-aged longleaf pine stands on the EEF (different compartments managed with different techniques). These compartments should provide data that could be used to create a growth-and-yield table for uneven-aged longleaf pine stands sometime in the future.

Forest Manager: (11) ***How can we create growth-and-yield tables for various combinations of unbalanced, uneven-aged stands on various sites?***

Guldin: Individual tree growth-and-yield models will be required (refer to my answer to question 10).

Forest Manager: (12) ***What are the growth rates of trees of different diameter classes under the canopy of an uneven-aged stand?***

Boyer: Rates of volume growth of different diameter classes depend on crown class, stand density, and site quality. Rates for intermediate or suppressed trees are very slow. Rates of 20 to 25 years per inch d.b.h. have been observed. Growth of young trees depends on the proximity of older, dominant trees. Longleaf pine is the most intolerant of the southern pines and does best when free from all competition.

Guldin: Data that could be applied to this question should be available once the ongoing longleaf pine growth-and-yield studies noted in the responses to question 10 are completed.

Forest Manager: (13) ***Can we develop an uneven-aged extension for the Forest Vegetation Simulator (FVS) for longleaf pine and slash pine?***

Nowak: I have been in touch with the Forest Service staff at the Forest Management Service Center in Fort Collins, CO, who developed the existing FVS. I have not heard back from them yet, but would be interested in cooperation on this question if anyone else is interested in working on this. FVS is an age-independent model, and the recently developed Southern Variant of FVS includes models for longleaf pine and slash pine that would handle growth projections in uneven-aged stands. A near-term need is accuracy testing of the current models for longleaf pine and slash pine.

Forest Manager: (14) ***What are the growth rates of individual diameter classes under uneven-aged management?***

Boyer: We currently have studies on the EEF in uneven-aged longleaf pine stands that may help answer this and other questions (10, 11, and 12) concerning growth and yield for uneven-aged longleaf pine. These data do not yet provide enough information to answer these questions, but stay tuned.

Part C. Selection Harvest Techniques

Forest Manager: (15) ***Can methods be developed to mark uneven-aged timber sales in one pass?***

Guldin: Yes, but not according to regulation approaches that stand the test of time. Both the BDq and the VGDL techniques require inventories in advance of harvest. (But then again, so would ideally prescribed even-aged thinnings and reproduction cuttings.)

Scientists at research work unit SRS-4106 have discussed one possibility but have not tested it in the field. The theory is that one could mark an uneven-aged stand in a single pass if one intended to apply the uneven-aged marking rule of cutting the worst trees and leaving the best. The key would be to take the unusual step of marking trees to leave. This would require keeping a tally of every tree marked, then periodically checking the tally of marked residual trees against the cumulative area of the stand that had been covered by the marking crew. To do this, it would be necessary to keep electronic marking tallies such that cumulative tallies could be instantly generated in the woods; be able to subdivide the stand into subdivisions of known stand area, and be able to recognize the subunit boundaries in the field; and cut the worst trees and leave the best trees, regardless of spacing.

A second possibility would be to mark a stand and to frequently check one's marking using a prism. Using this approach, one would make an ocular estimate of or a very cursory prism cruise to provide a rough estimate of basal area. One would then mark and tally to a residual basal area using the "cut the worst trees and leave the best" approach such that the desired residual basal area would be attained. This process would resemble a low thinning that would leave an understocked stand having a residual basal area of 50 to 60 square feet per acre. One would expect regeneration to develop in those portions of the stand where residual basal area is less than the average. To execute this marking, one would use the prism frequently to confirm that marking has retained the target residual stand basal area and cut the worst trees and leave the best trees, regardless of spacing.

There are two compromises associated with these approaches. Firstly, they violate all of the rules thought to be important to encourage development of structure through adherence to guiding curves or attention to sub-sawtimber diameter classes. Thus, these techniques suffer from the same limitation as the VGDL technique in requiring implementation by highly skilled crews. Secondly, there is no way other than by experience to tell whether an operable cut will be obtained.

The "mark to leave" procedure has been applied by Bureau of Indian Affairs foresters in uneven-aged ponderosa pine stands in the Rocky Mountains and Intermountain West. Field tests have been limited in the Southern Region by the need to mark trees being cut for timber sale contract administration purposes.

Forest Manager: (16) *Can a group selection technique be developed that is simple to implement and that guarantees adequate regeneration and residual old growth?*

Boyer: Yes, provided that volume yield is not a consideration. I suggest you read the paper by Farrar and Boyer (1991), which describes in detail the VGDL method. This method was developed by Russ Reynolds and applied to loblolly-shortleaf pine stands on the CEF. Under this method, diameter class distribution is not a concern and is not monitored as in the BDq method. This saves a lot of time. Board-foot volume is used to regulate the stand under the VGDL method, so the actual harvest tends to occur only in trees 9.6 inches and larger, with much of the cut based on trees of larger diameter. The manager has wide latitude for exercising his or her own judgment. In this regard, it is similar to the Stoddard-Neal variant of single-tree selection uneven-aged management. Compared to the EEF Farm Forty, the VGDL method has had lower total volume increment so far but higher sawtimber increment.

Brockway: Authorities typically recommend that silviculturists who implement the group selection reproduction method use one of the principal volume regulation techniques, VGDL or BDq. While these approaches may be modified to reduce the administrative workload and somewhat simplify their application, implementation of uneven-aged procedures requires greater information, more planning, and increased skill levels for field crew members than does even-aged management. Area regulation may be an alternative to volume regulation in applying the group selection method.

Implementation of group selection with area regulation is not very different from implementing small patch clearcuts. At the appropriate time, field staff mark the boundary of each small unit (0.25 to 2 acres) on the ground, and some or all mature trees within the defined unit can be harvested. Although tracking progress on a large land base for numerous 2-acre units is a complex task, currently available computer hardware and software (including geographic information system and global positioning system technology) should render this work manageable. The forest land base would thus be divided into a large number of small units, and forest regulation could proceed based on these units. Under area regulation, managers establish a rotation of field visits to individual units on a regular periodic basis. For example, each unit will be inspected in the field and its management status and needs assessed once every 10 years (or another time interval if that were more suitable). At the time of inspection, a harvest or no-harvest decision will be made based on the current condition in relation to a desired condition. Each year a certain proportion of your units can be scheduled for harvest. For example, the number of units to be harvested each year would not exceed 0.5 percent of the total number of land units if you had a goal of maintaining the age range of trees on the forest between 0 and 200 years old. On a forest with 400,000 acres (and 200,000 units) under such management, 1,000 units, or 2,000 acres, might be regenerated each year on the average. Of course there would be opportunity to deviate from such a schedule, should a natural or man-made disturbance necessitate intervention for restoration purposes. Note that the above scenario assumes a fully regulated forest condition. One key to making such a system work successfully would be the proper dispersion of units to be harvested during any single year. It is important not to cluster the harvest units too closely or the saturation effect could greatly degrade resource values in that area in the short term. Harvesting in adjacent units should be avoided during the same year or during any time frame that results in a large opening in the forest canopy. Obvious exceptions could be made for natural disturbance events that resulted in the mortality of trees over large areas. The great peril in this approach is that it essentially functions like small patch clearcutting and brings with it the potential for abuse previously associated with large block clearcutting. Therefore, managers should resist the temptation to expand individual unit sizes over time unnecessarily, to cut trees in regularly dispersed geometric patterns that appear aesthetically unnatural, to use area regulation as a cover for cutting the best trees and leaving the worst trees (i.e., high-grading), and to strictly limit the maximum tree age to an arbitrarily chosen "rotation age." Since longleaf pine is long-lived, it is entirely appropriate to plan for growth of individual trees and development of some stands to reach advanced ages (200 to 400 years) in parts of the forest.

Group selection, as a stand reproduction method, has been used in Europe to restore and sustain forests for hundreds of years. The methodology is well documented and taught in the forestry curricula at major academic institutions around the world. It is, however, a method that has been less applied operationally in the United States. A land manager is most fortunate to find longleaf pine regeneration already established before creating 0.25- to 2-acre gaps in the forest. However, if advanced regeneration is not present, this should not prevent the manager from harvesting timber and creating the gaps, generally cutting the worst trees and leaving the best trees. As long as periodic fire is applied to the forest, gaps unoccupied by longleaf pine seedlings can be maintained brush-free (or at least brush invasion will be discouraged) until longleaf pine can seed into the area. Gaps may be occupied by grasses and forbs (and a few shrubs) until a favorable seed year arrives. Alternatively, forest gaps created by this method need not have all adult trees removed at once. Residual seed trees may be retained within gaps to aid in regeneration and then removed during a future stand entry.

Old-growth forests in many environments renew and sustain themselves through the death of individual trees and groups of trees. Longleaf pine is generally too intolerant of competition to benefit from the death of individual trees (too small a gap is created). However, when a group of trees dies and creates a sufficiently large gap in the canopy and root zone, longleaf pine seedlings decades old are known to be responsive to release. Therefore, group selection is the forest reproduction method that most closely corresponds to the natural gap-phase regeneration dynamics that have been common in longleaf pine ecosystems for thousands of years. While old growth is technically forest that has never been harvested by humans, group selection is the single reproduction method that most closely resembles the structure and regeneration dynamics of old-growth longleaf pine forests. Thus, it is a method that will likely be increasingly used in the future to provide old-growth like stand conditions and to sustain over the long term the numerous ecological, economic, and social values of longleaf pine forest ecosystems.

Guldin: Farrar's (1996) modified group selection approach comes closest to having the characteristics you seek. His uneven-aged marking guidelines contain a description of how it would be implemented for longleaf pine.

In the BDq method, the standard marking rule for uneven-aged stands is to cut the worst trees and leave the best in diameter classes at or below D, the maximum retained diameter, and to cut all trees above D. No active research specifically tests whether trees larger than D can be retained. In the volume-control method, the diameter limit is a guide, and 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.

In either method, any tree whose retention is desired by the forester can be retained. But provision must be made to account for it. In the BDq method, the basal area of retained trees must be included in the calculations of stand structure. For example, a 24-inch tree has a basal area of 3.1 square feet. If two 24-inch trees per acre are retained for whatever reason in the stand, that 6.2 square feet of basal area must be accounted for in the development of the marking tally, since retaining them reduces the amount of growing space that can be used by trees of other sizes. For example, if the target BDq structure is 60-20-1.2, any trees above the maximum diameter must be added to the BDq target curve. Otherwise, too much basal area will be retained, and seedling development will be suppressed. Similarly, under the VGDL method, the volume and the volume growth of those big trees must be averaged into the calculation used to determine the guiding diameter limit.

In my opinion, area regulation should not be used. It becomes difficult to state unequivocally that one is conducting group selection rather than patch clearcutting under the area regulation approach.

Forest Manager: (17) ***When, what, and how do you thin within each of the following groups: regeneration (saplings), intermediate, mature, and old trees?***

Guldin: Reynolds had a simple marking rule: Cut the worst trees and leave the best trees across all diameter classes. This is done as described in Marquis (1978) by generating a stand inventory that counts the number of trees in each diameter class, developing the marking tally by diameter class, and calculating a percentage of each class to be marked. Then when marking, the marker's duty is to mark the poorest given percentage of trees in each diameter class. If dense stands of pulpwood-and-smaller longleaf pine don't stagnate (like slash pine does), little deliberate thinning has to be done in the pulpwood-or-smaller size classes. Nature will thin these over time. In commercial harvests, there's no need to precisely control stem density in the submerchantable component. However, if too much regeneration exists, the practical methods that have been applied in even-aged natural regeneration methods (i.e., fell mature trees into overly dense patches of regeneration or skid through them) can be applied to uneven-aged stands as well. Under the VGDL method, all thinning below the guiding diameter limit must be done using field experience and thus is difficult to quantify for marking crews.

Forest Manager: (18) ***How do selection harvest methods (single-tree and various sized, shaped, and spaced groups of trees) affect long-term overstory structure, pine regeneration, prescribed fire, ground cover, and red-cockaded woodpeckers?***

Guldin:

Long-Term Overstory Structure

The effect of different selection harvest methods varies and is locally determined. In an average fully stocked southern pine stand, the same after-cut diameter distribution on a per-acre basis can be obtained, but the stands can look entirely different depending on how the trees are distributed throughout the stand after harvest.

Pine Regeneration

After a group selection harvest that leaves openings, regeneration would be concentrated in openings. Regeneration would not be present in the matrix between openings because residual basal area would be too high. After a single-tree-selection harvest, in which residual basal area of the overstory is heterogeneously distributed across the stand and regeneration is presumably more uniformly distributed, there will be local pockets of increased density and other pockets of sparse regeneration.

Prescribed Fire

We only have empirical evidence about the effects of prescribed fire in stands that have been harvested by different methods. I've seen prescribed fires that burn through the matrix of an uneven-aged stand of ponderosa pine but that will not carry through the group opening. Bill Boyer tells me that he has seen this in longleaf pine stands as well. As brush becomes established in openings in the stand, there is less fuel to carry a fire (no grass or needle litter). Boyer recommends leaving a shelterwood overstory until a seedling stand is established in the targeted opening, when the remainder of the overstory can be removed. The shelterwood overstory will provide enough needle litter fuel to carry the fires needed to retard brush development.

Ground Cover

Different patterns of selection harvest (single-tree versus group) would result in different ground cover conditions and species composition. Ground cover species composition can probably be predicted by others more familiar with the longleaf forest type.

Red-Cockaded Woodpeckers

We have some interesting empirical data on the effects of different harvest techniques on red-cockaded woodpeckers. We have active colonies of red-cockaded woodpeckers in the Good Forty at the CEF. The Good Forty has been subject to uneven-aged silviculture since the late 1930s and has the classic multilayered characteristics of uneven-aged forest. I'm not convinced that generally accepted thoughts about what red-cockaded woodpeckers can tolerate are consistent with their use of habitat in the Good Forty.

Forest Manager: (19) ***How do various selection and marking techniques compare with respect to administrative efficiency?***

Guldin: The standard rule in working with uneven-aged methods is to assume that annual management costs per acre are double those for even-aged stands, with cited figures in the ballpark of $4 per acre per year.

Forest Manager: (20) ***What are statistically robust and administratively efficient sampling techniques for describing the structure of uneven-aged stands in order to determine management prescriptions?***

Guldin: Which sampling technique to use depends on the degree of heterogeneity of tree diameter in the initial stand and on the degree of variation in the sample with which the forester is comfortable. For example, Farrar recommends a 100-percent tally for stands < 100 acres in size. Under conditions where this is not possible, the sample design depends on the heterogeneity of the stand condition. Heterogeneous stands with trees of many sizes should be sampled using methods that sample trees of all sizes with equal probability, such as fixed-area plots or strips rather than a prism. Even though small trees may not be of value economically, they are important silviculturally in making marking decisions about uneven-aged stands. If the stand is an older and more homogeneous stand, such as an even-aged stand with a high proportion of sawlogs, a prism cruise can be used. Nevertheless, a 10-percent to 20-percent sample using strips, 0.1-acre or 0.2-acre fixed-radius plots, or a similar number of 10-BAF prism plots will give fairly reliable estimates of stand condition. Crew time can be saved with a minimum effect on marking efficiency if crews tally using 2-inch size classes.

Finally, some estimate of regeneration condition must be obtained as well. A systematic sample of 100 nested plots, using milacre plots (0.001 acre) to tally trees in the 0-inch class and 0.01-acre plots to tally trees in the 1-inch, 2-inch, and 3-inch classes, should give acceptable information about the adequacy of the submerchantable component of the stand in terms of both regeneration density and uniformity of distribution.

Forest Manager: (21) *What are the effects of heavy equipment on the ground cover within the openings created by uneven-aged management?*

Rummer: There are very few data on the direct effect of heavy logging equipment on ground cover plants. Most studies have documented the extent of soil disturbance after the logging operation is complete. Generally, after a ground-based clearcut logging operation, about 30 to 40 percent of the area will be undisturbed, 10 to 15 percent will be in trails, and about 50 percent will have been moderately disturbed, but without much mineral soil exposed.

Uneven-aged management will affect the amount of disturbed area. Residual trees will constrain traffic and limit the amount of disturbed area, but the severity of the disturbance that does occur may be increased. The amount of soil disturbance varies with the type of uneven-aged management practiced. In a study of uneven-aged management on the Ouachita National Forest, we found 42 percent, 17 percent, and 10 percent undisturbed area under single-tree, shelterwood, and clearcut prescriptions, respectively. The amount of area with mineral soil exposed did not differ significantly among the treatments, but the amount of area in moderately disturbed categories did so differ.

The amount of soil disturbance also varies with the type of harvesting system used. Ground skidding with clambunks, cable skidders, or grapple skidders creates the most soil disturbance due to the sweeping action of limbs and tops dragged along the trail. A forwarder, however, carries wood off the ground and minimizes soil exposure. Swing machines, which lift and rotate (feller bunchers or shovel loggers), also reduce soil exposure.

As mentioned above, these data represent the effects of heavy equipment on soil disturbance and not on ground cover. Does crushing of plants by wheeled traffic result in damage? This probably depends on other factors such as plant species, time of year, weather, etc. Tracked machines tend to minimize soil compaction but may have a greater impact on the herbaceous understory than rubber-tired machines. Cut-to-length systems minimize soil disturbance by creating a mat of limbs and tops to drive over. This mat may protect soil but may also affect herbaceous plants. We need to study whether heavy equipment may have residual impacts on the herbaceous layer that are not readily evident immediately after the logging operation. Disturbance to the soil may result in immediate reduction in herbaceous cover but could lead to increased amounts of herbaceous cover if regeneration is encouraged by exposure of mineral soil.

Available research information will indicate extent of soil disturbance, but additional research should be considered relating to the effect of traffic on herbaceous plant cover.

Outcalt: I am not aware of any research specifically looking at the effect of equipment on understory plants during uneven-aged harvests. However, I have conducted two research studies looking at the effect of clearcutting operations on understory plants in longleaf pine communities. Both studies were in Florida, one on the Ocala National Forest and the other on the Withlacoochee State Forest. In both cases, the only impact occurred on main skid trails. Even in these areas, however, the understory was recovering within a couple of years after harvest (Outcalt 2002). As shown by another study, where scalped strips were created through an existing longleaf pine understory, the understory plants are pretty resilient (Outcalt 1995). If the understory is healthy before a disturbance occurs, these plants will reinvade the areas in which they have been extirpated. Prescribed burning prior to a logging operation will improve the health and resilience of the understory, thereby speeding recovery from any damage that does result from selective harvesting.

Jose: I have great interest in exploring this issue further. I suspect that the wiregrass community would be very susceptible to any kind of disturbance. However, it would be important to examine how resilient the understory is and how long it would take to revert it back to the desired condition if we alter the composition.

Forest Manager: (22) *Is there soil compaction within the opening created by uneven-aged management?*

Guldin: Loggers tend to use group openings as places to concentrate operations. Group openings are commonly used to deck logs harvested in the opening and from the matrix surrounding the opening. That added physical impact associated with log decks would presumably increase compaction in the group opening. However, if amelioration treatments are applied, they need only be applied in the openings. Further, the degree of mineral soil exposure that results from intensive use of the opening often provides a good seedbed for natural regeneration. Group openings used in this manner often develop a very dense sapling cohort.

Rummer: This seemingly simple question is very complex. Soil compaction is a function of the machine size, number of passes, soil type, and moisture content. Not all even-aged management systems have the same combination of these factors, and thus any resulting compaction is highly variable. Generally, very dry soils or very wet soils will not significantly compact. Coarse-textured soils (sands) are not as susceptible to compaction. For example, a study of pine thinning in Florida found no compaction after the operation on a sandy soil. Additionally, the vertical and horizontal distribution of the compaction is important. Compaction varies with soil depth, with most compaction from forest operations occurring in the upper 4 to 6 inches, although the surface 2 inches is often loosened by traffic. A landing area becomes a heavily impacted continuous patch of compaction. The same amount of compacted area arranged as wheel tracks is significantly less detrimental. Thus, the traffic pattern associated with a particular type of uneven-aged management (group selection, single-tree selection) and logging system (skidders, forwarders, animals) is important in assessing impact. Soil compaction will also vary with time. Natural processes restore soil porosity over time. Depending on rotation length and the entry interval, compaction may or may not persist in the stand.

It is also important to understand why compaction may be a concern to the resource manager. Compaction can (1) reduce infiltration and thus increase runoff and erosion, (2) impede subsurface flow and thus alter water table depth, (3) reduce porosity and thus affect soil biological processes, and (4) damage roots directly by shearing. Forest Service long-term site productivity studies have attempted to evaluate the long-term effects of soil compaction on forest productivity for different forest sites in the United States. Thus, more specific information may be available for Florida.

Part D. Optimum Logging Practices

Forest Manager: (23) ***What logging techniques are most efficient and provide minimum damage to residual trees when harvesting is conducted in uneven-aged stands?***

Guldin: Points to remember regarding logging techniques:

- Efficiency increases with average log size, and average log size is high in uneven-aged harvests.
- Skidding of logs that are 16 to 32 feet in length is preferable to tree-length skidding, because shorter logs can be more easily maneuvered through the residual stand by careful operators.
- Use small mobile harvesting equipment (e.g., small three-wheeled harvester, grapple skidders).
- Careful contract administration can keep damage to the residual stand at a minimum. Careless administration can result in problems.

Forest Manager: (24) ***How do different methods of logging affect prescribed fire and ground cover quality and diversity?***

Rummer: Fire behavior would be affected by the volume, size distribution, and spatial arrangement of residual fuels. Logging systems vary in how they affect these parameters. Whole-tree logging, in which the stem is felled by a feller buncher and then skidded to a roadside for processing, tends to leave very little volume in the stand. Gate delimbing removes the limbs and tops at some point near the landing. Pull-through delimbers and whole-tree processors concentrate all the limbs and tops at the landing. Often whole-tree systems are so effective at removing material that logging specifications require that slash be carried back into the stand and scattered. The amount of this material can be specified and controlled by fire specialists to obtain any desired fuel conditions. Cut-to-length (CTL) logging systems process trees "at the stump." This type of logging leaves the entire volume of limbs and tops distributed across the stand. Some CTL systems concentrate the processing along the trails, driving over the residual material. This results in a slash mat that can be a fire risk (creates hot spots during prescribed fire) as well as impacting regeneration and ground cover. Use of any logging system can be followed by applications of fuel treatment prescriptions. Mulching machines drive through the stand and reduce material to smaller fuel classes in order to promote decomposition and minimize smoke. Hand lopping and scattering operations can be used to cut submerchantable material and arrange it appropriately for burning. The most efficient approach is to have a clear stand-specific prescription that considers desired post treatment fuel conditions prior to logging.

See my answer to question 21 for a discussion of the effects of logging operations on ground cover.

Rudolph: In longleaf pine communities, the herbaceous ground cover is dominated by perennials. A large portion of the diversity is contributed by perennial species, many of which may be quite rare. Soil disturbance may temporarily eliminate species that may then require extended periods to re-establish. Logging procedures that minimize damage to the soil surface would be preferable.

Brockway: The understory plants of longleaf pine ecosystems have been reported to be vulnerable to mechanical damage. Actions such as double-chopping with a roller-chopper have been shown to significantly reduce the cover of wiregrass. Wiregrass and other understory plants may also be reduced (at least for several years if not permanently) by machines that scrape away topsoil. Therefore, it is reasonable to conclude that mechanical disturbance of the soil either by the direct action of a machine or by dragging logs across the soil surface could be deleterious to understory plants. Adverse changes in the understory plant community not only lead to declines in the total biological diversity in the forest, but also would very likely decrease the effectiveness with which prescribed fire can maintain the ecosystem. Reduction of the understory plant community diminishes one of the principal carriers of fire. Burning stands in which this has occurred may be more difficult and give very spotty results. Fortunately, most of the impact of logging machines is normally confined to skid trails, decks, and roads, all of which normally constitute only a portion of any particular site. Ideally, to minimize ecological damage to any longleaf pine forest, harvesting should be performed with equipment that produces the least practical amount of surface soil disturbance. This may require the use of smaller machines that have a lighter "footprint" and can transport logs from the site without causing excessive soil damage. Log suspension is preferred to dragging, wherever possible.

Part E. Effects on Red-Cockaded Woodpeckers

Forest Manager: (25) ***How do we implement uneven-aged management of longleaf pine while leaving adequate recruitment trees and foraging substrate for red-cockaded woodpeckers? Will this require alteration of harvest guidelines, stand tables, and desired outcome?***

Rudolph: The recovery plan for red-cockaded woodpeckers has been completed and contains some general guidelines (U.S. Fish and Wildlife Service 2003). However, some additional comments are necessary. Most existing stands do not contain adequate potential cavity trees; the stands are too young. The goal is to grow and retain sufficient numbers of old trees. Single-tree selection with a diameter-limit approach requires careful attention to tree ages. With new silvicultural regimes, the growth rates may change with time, so monitoring is necessary, and adjustment of the diameter limit may be required. The goal is to produce sufficient numbers of trees at least 120 years of age to provide potential cavity trees. Minimal data are available to predict the response of red-cockaded woodpeckers to forests with older trees. Consequently, it will also be necessary to monitor cavity excavation dynamics as older trees become available to ensure that 120-year-old trees, for example, are sufficient. A possible alternative would be to allow some of the older trees to escape the diameter limit and be retained in the stands in perpetuity. It is also important to set silvicultural parameters (entry intervals, q) so that the stands contain relatively little midstory, including pine midstory. This is possibly the most significant deviation required from management based solely on timber objectives. Similar considerations apply to group selection approaches. In both of these approaches, attention must be given to basal areas and group sizes to ensure adequate regeneration.

Although not strictly an uneven-aged technique, irregular shelterwood offers many of the advantages of uneven-aged management. In irregular shelterwood, most or all of the leave trees are retained throughout the succeeding rotation. With a 120-year rotation, the leave trees would reach 240 years of age at the next harvest. Any survivors could then be retained as leave trees for the next rotation, with the deficit made up with 120-year-old trees. Substantial numbers of potential cavity trees would then be possible. This approach has the advantage of minimal suppression of the regeneration, few harvest entries to disturb the herbaceous flora, known age of residual pines, and simplicity.

Regardless of the approach used, fire is critical. Very frequent fire maintains many other ecosystem functions, controls midstory vegetation, enhances foraging habitat (recent data suggest that prey abundance is tied to a well-developed herbaceous layer), and reduces risks associated with severe wildfire (or prescribed fire).

Clearly, implementation of these methods to produce suitable red-cockaded woodpecker habitat will require alteration of silvicultural guidelines. Most important, it will require adjustment of maximum tree ages, reduction in the number of midstory trees (including pines), and modification of guidelines for basal area.

Forest Manager: (26) ***What is the maximum height and stocking of premerchantable trees within a cluster or foraging zone before the cluster is no longer suitable for red-cockaded woodpeckers?***

Rudolph: Maximum height is not an issue for red-cockaded woodpeckers. However, midstory density (stocking) is an issue. The U.S. Fish and Wildlife Service recovery plan (2003) should be consulted. There is not necessarily a hard threshold for midstory density. Midstories typically need to be sparse enough to provide a generally open midstory and a healthy herbaceous layer. Low levels of midstory, including hardwoods, that are consistent with a fire-maintained pine ecosystem are not detrimental to red-cockaded woodpeckers and provide many other ecosystem benefits. See the reference section for papers that relate to management of red-cockaded woodpeckers.

Forest Manager: (27) ***How do uneven-aged stand conditions affect red-cockaded woodpecker reproductive output, foraging behavior, nesting behavior, and demography?***

Rudolph: Uneven-aged stand conditions do not necessarily differ from even-aged stand conditions in relation to red-cockaded woodpecker biology. However, factors such as midstory development, tree ages, and herbaceous understory should be within the acceptable levels. Again, the U.S. Fish and Wildlife Service recovery plan covers these issues in some detail. Demographic integrity of red-cockaded woodpecker populations and landscape fragmentation are also considerations. This issue is more easily addressed under uneven-aged management because the silvicultural treatments involved do not contribute to fragmentation.

Forest Manager: (28) ***What are the effects of uneven-aged management of longleaf pine and slash pine on the biodiversity of natural communities?***

Boyer: Given appropriate fire regimes, group selection should have minimal impact on natural communities. This uneven-aged stand reproduction method mimics natural processes in place for thousands of years (natural attrition in mature trees through lightning strikes and insect outbreaks, fire-related mortality, and limited blowdown).

Rudolph: The biodiversity of natural communities should be enhanced by uneven-aged silviculture, since it more nearly approximates natural disturbance regimes. A possible exception would be early successional species that require openings of substantial size (e.g., certain avian species).

A two-aged shelterwood (irregular shelterwood) mimics uneven-aged management to some extent because residual trees are held until the next regeneration cut or even longer. If residual longleaf pines are left beyond the second rotation, this can produce a three-aged stand with substantial numbers of quite old trees, a limited pine midstory, and new pine regeneration. The resulting two-aged or three-aged stand structure can result in good red-cockaded woodpecker habitat throughout the next rotation. By contrast, in loblolly pine and shortleaf pine stands, reproduction after a shelterwood cut can be abundant and result in a dense pine midstory until the regeneration grows into the canopy. Prescribed fire to reduce the density of regeneration (thermal thinning) or mechanical thinning can substantially reduce the midstory problem. At worst, this is a problem for only a fraction of the rotation cycle. The pine midstory is generally less dense in longleaf pine stands than in stands of loblolly or shortleaf pines, but the midstory in longleaf pine stands should be reduced if and when it becomes too dense for red-cockaded woodpecker habitat requirements.

A large literature exists specific to individual taxa. However, most is not specifically in reference to uneven-aged management. We need to explore the literature for information relevant to these taxa.

Forest Manager: (29) ***What uneven-aged stand conditions support both expanding and stable red-cockaded woodpecker populations?***

Rudolph: See my answer to question 25 above.

Part F. Prescribed Burning Approaches

Forest Manager: (30) ***What is the best indicator of potential tree mortality from prescribed fire during prolonged dry periods?***

Boyer: The best indicators of potential tree mortality from fire are tree size, fuel load, time since last burn, and fire intensity.

Nowak: I have tried to reach Todd Engstrom of The Nature Conservancy (formerly of Tall Timbers Research Station) about the possibility of working together on this question. I have not heard back from him yet. The people at Tall Timbers burn some tracts of longleaf pine every year and have tagged their trees. It would be ideal to do this research there, if they are interested.

Outcalt: The best indicator of potential tree mortality is a combination of the duff moisture level and the Keetch and Byram (1968) drought (or burn) index (KBDI). Prolonged periods of drought dry the duff layer sufficiently for it to ignite and burn completely via smoldering combustion following prescribed burning. The long residence time of this smoldering combustion will cause significant cambial and root damage, especially to larger trees. This leads to abnormally high mortality rates. Use of the KBDI alone can lead to problems, since rainfall sufficient to lower this index will not necessarily rewet the duff layer enough to prevent smoldering combustion. In summary, be very cautious during and following a prolonged period of drought. It is best to confine prescribed burning to areas that are fully restored with a grass-dominated understory and a minimal duff layer. Avoid any areas that have not yet adjusted to frequent prescribed burning.

Forest Manager: (31) ***What are the optimum techniques for ensuring the protection of regeneration during burning in uneven-aged stands?***

Boyer: Regeneration can survive and develop with a frequency of one fire every 2 or 3 years, with best results from periodic spring fires. Survival is best in stands of relatively low density, as young trees there reach fire-resistant size sooner, and needle litter serving as fuel is at a lower level. Data below show longleaf pine ingrowth in shelterwood stands of varying residual overwood densities that are unburned or subjected to biennial winter, spring, or summer fires.

Overstory density	Winter burn	Spring burn	Summer burn	No burn	Average
square feet per acre	*- - - - - - - - - - -*	*- - - - -*	*stems per acre*	*- - - - -*	*- - - - - - - - - - -*
	Longleaf pine ingrowth (d.b.h. > 1.5 inches)				
20	218	582	400	369	392
30	138	613	227	253	308
40	0	89	4	116	52
50	0	31	0	53	21
Average	89	329	158	198	193
	All hardwood trees (d.b.h. > 1.5 inches)				
20	116	9	31	716	218
30	4	0	0	436	110
40	18	0	31	333	96
50	27	0	67	342	109
Average	41	2	32	457	133

Principal findings were that (1) longleaf pine seedling development was better with spring burning than with summer or winter burning; (2) hardwood development was inhibited by burning and became virtually nonexistent with spring burning; (3) development of pine, and to some extent of hardwood, was inhibited by increasing overstory density; and (4) at low overstory densities, periodic spring burning results in the best combination of maximum development of pine regeneration with minimal hardwood encroachment. Also note that many longleaf pine grass-stage seedlings can sprout from the root collar if top-killed by fire.

Forest Manager: (32) ***What burning techniques best enhance diversity and maintain native ground cover and understory?***

Brockway: We know from research studies that dormant-season burning and growing-season fire affect the diversity and productivity of native understory plants quite differently. Dormant-season fires generally burn under cooler conditions and are less effective in stimulating seed production of native herbs and controlling encroachment by woody vegetation. Woody vegetation directly competes with herbaceous plant species and tends to depress native plant diversity. Thus dormant-season burning alone is generally thought to be less effective in maintaining native plant diversity in the understory of longleaf pine ecosystems. By contrast, growing-season fires stimulate herbaceous seed production and more effectively discourage the invasion of longleaf pine sites by woody plants. Burning during May is especially effective. Growing-season fires are generally more effective than dormant-season burns in enhancing and maintaining native diversity in the understories of longleaf pine forests.

However, the story is not quite so simple. The logistical problems involved in conducting all burns during the growing season make it necessary for managers to also consider dormant-season fires as a management option. In forests where the rough has accumulated to dangerously high levels, burning during the cooler dormant season is the only safe management alternative. Also, it is important to recognize that while most natural fires may have historically occurred during the growing season, natural fires did occur at all times of the year. Native ecosystems developed as a product of fire with a variable frequency, not a constant growing-season-only fire with a fixed return interval. Therefore, managers who wish to maximize native plant diversity in longleaf pine forests may want to consider burning mostly during the growing season, but also during the dormant season once in a while and at intervals that vary over time. This variable fire regime will most closely simulate the natural fire pattern and provide the best opportunity for the greatest number of native organisms to occupy the widest range of high-quality habitats.

Outcalt: I see this as two separate questions. The first question is, How can fire be used to maintain native ground cover in longleaf pine communities? Once you are at the maintenance phase (i.e., you have a healthy overstory of longleaf pine with a grass- and forb-dominated understory), you can pretty much use prescribed fire as best suits your particular situation to keep the ecosystem healthy and productive. Large areas can be burned with aerial ignition. Strip head fires from ground ignition can also be used and are more appropriate for smaller areas. Practitioners of prescribed burning pretty much already know how to burn these areas to minimize damage to overstory trees while controlling the growth of the woody understory species. The key is to burn often enough to maintain the dominance of the grasses and forbs and prevent a big increase in woody species. The more productive the site, the more frequently it must be burned. Thus, relatively infertile xeric sandhills only need one fire every 4 to 6 years, while mesic uplands may need one fire every 2 to 3 years to control woody species (Glitzenstein and others 2003). In all cases, there should be variability in both timing and frequency, to mimic what happened with natural ignitions. An emphasis should be placed on growing-season burns, but dormant-season burns are also acceptable every third or fourth burn.

The second question is, How should prescribed burning be used to enhance diversity? I am interpreting this to refer to the restoration of diversity in longleaf communities that have an understory that has been captured by woody species. If the soil has not been heavily disturbed by mechanical means, there should be a viable assortment of native grasses and forbs available either as remnant populations or in the soil seed bank. What is needed is a reduction in the woody understory species cover that will allow the grasses and forbs to increase and eventually become the dominant understory species groups. Prescribed fire is one tool that can be used to accomplish this transition. Research shows that growing-season burns are better than, or at least as good as, dormant-season burns for readjusting understory composition (Robbins and Myers 1992). Thus, they should be favored, but dormant-season fire may be necessary to reduce fuel loads before switching to growing-season burns. Thus, a dormant-season burn or two may be used to gradually reduce litter buildup before a growing-season burn is applied. In addition, it is usually best to conduct these burns at short intervals (i.e., within 2 years or less) to minimize fuel accumulations between burns. Expected results depend on the community type and your starting conditions. Sandhill sites where scrub oaks are the major problem tend to respond quite quickly, with noticeable oak top-kill after only a couple of growing-season burns (Rebertus and others 1989b). Flatwoods understories dominated by saw-palmetto [*Serenoa repens* (Bartr.) Small], gallberry [*Ilex glabra* (L.) Gray], and Lyonia [*Lyonia ferruginea* (Walt.) Nutt. are more resistant to burning. Research indicates that only repeated burns at short return intervals over a long period significantly reduce these woody species (Glitzenstein and others 2003). Thus, burning every 2 years for a period of 10 to 20 years may be required to readjust the understory composition on flatwoods sites. This may seem like a long time to wait for results. However, if it took more than 30 years of dormant-season burns at intervals of at least 4 to 6 years for the understory to reach its current composition, there is no reason to expect that this condition can be reversed with one burn or in a 5-year period. As long as the plant community is moving toward recovery, then worthwhile progress is being made. A similar scenario of frequent growing-season burns is needed for mesic uplands with better soils where the woody competition is often in the form of hardwoods, many of which are now of midstory size. Other tools like herbicides and mechanical reduction of woody species may be used to speed the process of readjusting understory species composition and dominance (Brockway and Outcalt 2000).

Walker: By choosing the fire season, the conditions under which to burn, and the firing techniques (including pattern and methods), the prescribed fire manager exercises considerable control over fire effects. Making the best choices depends on a solid understanding of the effects of fire on target species or communities. Understanding how vegetation is expected to respond to certain kinds of fire (e.g., fire at different seasons, intensities, and spatial patchiness) provides the basis for prescribing the best fire to achieve objectives. Note that a single fire will not enhance diversity or maintain a desirable plant community. Therefore, it may be most productive to consider management in terms of a prescribed fire regime. Additionally, even with the best information available and the best prescriptions written and applied, outcomes are uncertain. Some effects are unknown or not well understood, and second-order effects caused by factors other than the fire itself (i.e., post-fire weather events, insect and disease outbreaks, and unusual levels of herbivory) may contribute to unexpected outcomes. I am not a fire application specialist, so I will not address the technical aspects of setting fires. I am a plant ecologist, so I will attempt to highlight important fire effects on understory plants in longleaf pine woodlands.

Once the manager understands these effects, they can be used to guide management and to describe the outcomes of certain prescribed fire regime choices, for example, choices of fire season, frequency, and "on-average" intensity.

Fire Effects on Ground-Layer Vegetation in Fire-Maintained Communities

It is widely accepted that frequent burning increases species richness and enhances the vigor of the herbaceous layer in longleaf pine woodlands. Various authorities have suggested that burning does this by (1) increasing light by reducing the canopy, (2) providing a pulse of nutrients that are rapidly taken up by ground-layer species, (3) stimulating flower and seed production, and (4) increasing populations of ground-layer species. There are differing opinions about the relative importance of these mechanisms (Brockway and Outcalt 1998; McGuire and others 2001; Means 1997; Platt and others 1988a, 1988b). All are probably important to some degree. Regardless of specific mechanisms, changes in resource availability associated with burning will benefit or enhance only those populations already present when the burning occurs. If the vegetation consists of large numbers of native species, they will benefit. If the vegetation includes populations of old-field species, these too will likely benefit from increased resource availability.

Maintaining and Enhancing an Existing Native Ground Layer

In general, fire management recommendations to enhance existing ground cover are to burn frequently (every 2 to 3 years) and make sure that some of those fires occur during the growing season or during the lightning season, which is considered May to August in much of Florida (Robbins and Myers 1992). This general recommendation focuses on seasonality and frequency of burning, but choices about these two components of the prescribed fire regime will influence fire intensity by maintaining moderate fine fuel loads and by burning when air temperatures vary from cool winter temperatures (50 °F) to hot spring days (90 °F). Efforts to maintain and enhance ground layers and understories generally include operations that are designed to (1) remove midstory woody species or reduce them to ground layer components and (2) provide opportunities for sexual reproduction of understory plants, at least periodically.

Midstory Tree and Shrub Control

Many studies indicate that burning hardwood species in the early spring when trees are leafing out top-kills a greater proportion of stems than burning during other seasons (Glitzenstein and others 1995; Rebertus and others 1989a, 1989b; Robbins and Myers 1992). Top-kill rates vary with stem diameters. Smaller stems can be killed with relatively cool fires, while hotter fires are more likely to increase the kill of larger stems. However, if larger stems can be top-killed, they are less likely to resprout than smaller stems. Although top-kill success varies with season of burning, long-term studies show that repeated burns over long periods of time (even winter burns) reduce hardwoods to the ground layer and ultimately reduce the numbers of stems (Waldrop and others 1987). While fire may be used to manage hardwood and shrub stems, there may not be adequate fuels to carry fire through the stand where such stems are dense. In such cases, it may be necessary to couple a pre-fire mechanical treatment that puts woody fuel on the ground with prescribed burning. Ordinarily, a treatment that minimizes disturbance of the ground layer would be preferred over one that disrupts soils. However, exposing mineral soil (as where a tractor or drum chopper turns a corner) may provide establishment sites for grasses and forbs.

Increasing the General Vigor, Flowering, and Seed Production of Grasses and Forbs

Published accounts show that lightning-season burning results in abundant flowering of dominant bunchgrasses, such as wiregrass (*Aristida* spp.), toothache-grass (*Ctenium* spp.), and Indiangrass (*Sorghastrum* spp.), and many forbs in longleaf pine woodlands (Platt and others 1988a, 1988b). There is some evidence that a strong flowering response to growing-season burns results in greater viable seed production and seedling establishment of grasses or forbs than that obtained by burning at other times (Brewer and Platt 1994, van Eerden 1997). Evidence is increasing to indicate that species characteristic of longleaf pine ground layers exhibit a variety of responses to season of burning. In a recent publication, Hiers and others (2000) reported that the effects of season of burning vary among the legumes (one of the most diverse groups in Gulf Coastal Plain longleaf pine communities). At least one species showed maximum flowering production in each of the three experimental treatments: lightning-season fire, late winter burning, and no burning. Both the time of flowering and the duration of flowering period for some species were affected by fire treatment. Hermann and others (1998) provide more evidence of species-specific variation related to season of burn.

Collectively such studies support the proposal of Robbins and Myers (1992) for varying the return interval and season of prescribed burns on a site. Appendix II in their publication includes tables for scheduling a series of prescribed fires for a selected site. Scheduling tables allow longer return intervals for xeric sites than for more mesic sites. If burn units are large enough to contain a variety of sites types, schedule prescribed fires to maintain the most mesic sites. Dry sites where enough fuel has not accumulated to carry fire simply will not burn. If low fuel accumulations interrupt the spread of fire through the landscape, ignition patterns may have to be modified. Although this approach is based on fire season and frequency, variations in intensity are likely to occur across large burn units, and if special resources require special conditions, burning techniques can be modified to accomplish specific objectives.

In summary, overall plant community responses to burning are very dependent on (1) what is there when the fire is set, (2) what prescribed fire regime has been applied in the recent past, and (3) what fire regime is established for the ensuing decade. Responses to single fires may be interesting, but maintaining and enhancing the ground layer in longleaf pine communities is really a cumulative effect of multiple fires and the climatic context in which they are embedded.

Research Needs and Opportunities

Existing information provides adequate general guidance for using fire to maintain the ground layers of longleaf pine communities. Longleaf pine communities, however, harbor a large number of rare plant species. Research may not yet be able to provide specific information about fire effects for all included special plants. Two kinds of new information are needed: (1) information about fire effects for individual understory plant species, both at the individual plant level and the plant population level, and (2) a better understanding of the mechanisms by which plants respond to burning. The species-specific work must also include possible effects of fire on necessary mutualists like pollinators and seed dispersers.

Forest Manager: (33) ***Where feeder roots have extended into unburned duff layers for 60 years or more, can we use fire to gradually reduce the duff layer with resultant regrowth of feeder roots in the upper soil layers, without unacceptable damage to overstory trees?***

Outcalt: Research and practical experience to date indicate the answer may be no. Nearly everyone who has reintroduced growing-season fires into longleaf pine communities that have not been burned for a long period has had increased mortality of large trees. Are there things that can be done to minimize these losses? I believe there are. First, a couple of dormant-season burns (timed as closely together as the availability of fuels needed to carry the fire will allow) under cool conditions with relative humidity of 60 to 70 percent can be used to reduce litter buildup. This should be followed by a growing-season burn, again as soon as there is sufficient fuel to carry a good fire. It is also important to pay attention to duff moisture levels, as this determines whether the duff layer around larger longleaf pines will ignite and burn, causing excessive feeder root damage and possibly even girdling the tree by killing the cambium at the root collar. Often in the early part of the growing season, many areas in Florida are coming out of the spring dry period, and the duff layer around the base of the trees is dry all the way to the mineral soil. As the summer rains begin and the drought index drops, conditions are suitable for prescribed burning. However, if there has not been sufficient rainfall to completely re-wet the duff layer at the base of trees, there is often enough heat from a prescribed burn to dry out the moist top portion of the layer. This allows the layer to ignite and slowly burn for many hours, producing temperatures high enough to cause cell death in roots and at the base of the tree. Thus, when determining whether it is safe to burn, it is important to make sure that the duff at the base of larger trees is wet on the bottom, with only the very top layer being dry. This may not occur until July in Florida, as it takes substantial precipitation to re-wet the duff layer once it has become completely dry. This technique of checking for moisture deep in the duff layer should allow you to burn these areas when conditions are optimal, so the fire only consumes the dry top layer of the duff, while the wet lower layer will protect the roots and root collar. If carefully applied, this technique may be used to gradually reduce the duff layer at the base of trees after four or five burns and still keep tree mortality at an acceptable level. This is only a possibility, and the procedure has not been tested on a large scale to see if it really works. It may turn out that high mortality in older longleaf pine trees is something that is going to happen when we reintroduce growing-season fires to long unburned sites. Such mortality may simply be the cost of doing business. These fire-killed trees can be salvaged to realize some of their economic value, and the ecosystem will eventually replace them over time. The negative impact on the forest plant community from not burning is going to be much worse than the loss of some of the older trees. Without prescribed burning, the problem will only continue to get worse with time, and if a wildfire occurs, most of the older trees will be killed.

Forest Manager: (34) ***What are the best methods for reintroducing prescribed fire into stands where fire has been excluded for over 20 years?***

Brockway: After such a prolonged period of fire exclusion, an accumulation of potentially hazardous fuel is likely present. Increased fuels not only include a larger mass of finer fuels (leaves on the forest floor and suspended needles) but also a changed understory and midstory. The understory and midstory probably now contain a greater number and mass of woody plants that form a fire ladder to the tree canopy. Burning such a forest during the growing season could result in a catastrophic stand replacement fire. If a long-unburned stand is burned using a cooler fire during the winter months, major damage to the ecosystem might be avoided (but then there are no guarantees, and burning such a stand at any time is dangerous). If a fuel ladder is present, the stand structure should be altered by mechanical or chemical methods prior to burning with prescribed fire. Mechanical treatment will immediately reduce the catastrophic fire hazard, while chemical treatment will require 2 to 3 years for mortality and decomposition processes to reduce the undesirable woody plants. Perhaps the safest strategy is to mechanically reduce the woody plants and soon follow this treatment with at least one cool winter burn to reduce the fuel load. Growing-season burns on about a 2- to 5-year cycle can thereafter be implemented for ecosystem maintenance. The actual burning technique used will be based on ambient conditions, with backing fire, flanking fire, and strip headfire all being possible alternatives. If a headfire method is selected, it should be a strip headfire (with a short burning width to avoid the adverse cumulative downwind effects of a fire that begins moving too fast and burns out of control) that burns toward a reliable firebreak (i.e., a river, lake, tilled cropland, transportation corridor, or wide blackline) that will safely stop a runaway fire.

Jose: Under certain circumstances, it may be desirable to remove a hardwood midstory by using herbicides and mechanical methods. If the expense of herbicide treatments and mechanical treatments is a constraint, initial cool-season burnings would be preferable. Once the fuel load reaches a manageable level, growing-season fire can be introduced (Provencher and others 2001).

Forest Manager: (35) *What are the best ways to monitor the long-term effects of prescribed fires on ground cover, soils, hydrology, timber stocking, and root zones of trees?*

Boyer: To monitor the long-term effects of prescribed fire, establish and periodically monitor permanent plots in areas of concern. However, under most management schemes, this should not be necessary. Considerable data on long-term fire effects are already available for the plant communities and soils of Coastal Plain sites (Boyer 1990, 1993a, 1993c, 2000; Boyer and Miller 1994; Brockway and Lewis 1997; Haywood and others 1998; Heyward 1936, 1939; Kush and others 1999, 2000; McKee 1982; Ralston and Hatchell 1971; Wells 1971).

Forest Manager: (36) *What are the effects of dormant-season and early growing-season fires on postburn survival and growth of grass-stage longleaf pine seedlings (2-year-old plantations or naturally regenerated seedlings)?*

Boyer: At least two published papers indicate that grass-stage seedlings burned in the spring (i.e., May) grow significantly better than seedlings burned during the winter or not burned at all (Grelen 1978, Maple 1977). Refer once again to above data showing improved ingrowth survival with spring burns as compared with winter burns, summer burns, and no burns.

Forest Manager: (37) *What is the most efficient spatial configuration of timber stand and prescribed burning unit boundaries, in terms of both staff management efforts and ecological integrity?*

Boyer: The most efficient configuration of prescribed burning units is one that makes maximum use of existing boundaries such as streams and roads in order to minimize the need for supplemental fire lines. For longleaf pine, any number of management units may be included within a single burn unit. The size of burn units and management units will depend on management goals and total area under management.

Outcalt: For ecological integrity, artificial boundaries must be kept to a minimum. This means avoid putting roads and fire lines around every stand. It also means burning in large blocks. Naturally ignited fire was once able to burn across the landscape until it came to a natural barrier or was extinguished by rain. Managers can mimic this natural process by burning blocks between existing roads and natural fire breaks on the landscape. This allows fire to burn into areas as it should and skip those that will not burn at that particular time. This lets fire determine where transition zones should be and how often wetter areas are burned. It also avoids all of the problems and expense of plowing lines around areas the manager thinks should not be burned. Burning larger blocks also promotes efficiency of scale because aerial ignition can be used to get many acres done on days with suitable conditions. What you want to avoid is trying to burn individual stands. Some managers have done this in the past in an attempt to protect newly planted seedlings or small regeneration. With the selection harvest method and uneven-aged management, you are going to have regeneration everywhere. Thus, a more efficient system is to periodically concentrate selective harvest in a portion of the large blocks, creating gaps in all the stands in a selected block that are ready for removals. Then, if you later get a good seedfall and catch, you can keep fire out of those blocks for a period to allow seedlings to become large enough to survive a burn. This has the added advantage of limiting disturbance from harvest to a short period followed by a longer period when there would be no entry into the entire area.

Guldin: Prescribed burn unit boundaries should be much larger than timber stand unit boundaries. Timber stands must be managed to be robust under landscape applications of prescribed fire. The acreage that should be burned annually far exceeds the acreage that can be custom burned on the average district. This suggests that stands under regeneration should be clustered together for management purposes more than is currently the case on most national forests.

Forest Manager: (38) *How do various burn frequencies affect pine regeneration, ground cover quality, and diversity in uneven-aged stands? Can a desirable range of frequencies be defined for different ecosystem types (e.g., sandhills, mesic flatwoods, scrubby flatwoods)?*

Outcalt: I think the real question some managers have is, If we need to burn every 3 to 5 years to maintain the ground cover diversity and health, will we get any longleaf pine regeneration? The answer is most definitely yes. If longleaf pine (which we consistently state is a fire-adapted species) were unable to reproduce with frequent fire, it would not have dominated over 90 million acres in North America when the Europeans first arrived. Frequent burning is required for readjustment of understory composition in communities where it is out of balance. However, once this has occurred, maintenance burning does not have to be quite so frequent. In addition, fire frequency depends on site productivity, with better sites needing more frequent burning to control competition and maintain forest health. Thus, mesic upland sites need fire about once every 3 years, flatwoods once every 3 to 4 years, and xeric sandhills once every 4 to 6 years. It is quite likely that the frequent burning that is required to readjust understory composition will kill many longleaf pine seedlings. However, in the maintenance mode, when the community is in a healthy state, we already know how to get all the regeneration we want. Managers have been doing exactly this with the shelterwood stand reproduction method (Boyer 1993b). Burns should be timed to match seedfall in the stands where regeneration is desired. Then, if you get a good catch, exclude fire for 3 or 4 years to allow a good portion of the seedlings to become large enough to survive the next prescribed burn. These same techniques will work just as well with group selection in an uneven-aged management approach. Even burning every 3 years will allow 1 to 2 percent of the seedlings to survive fire, and this is enough to fill gaps created by group selection harvests (Outcalt 1998). It should be noted that with uneven-aged approaches, it is not necessary to immediately obtain regeneration within the gaps of a stand. Longleaf pine is a long-lived tree, and the growth is going to be occurring on the larger trees and not the seedlings (Boyer 1993a). The seedlings are only needed to replace trees that are harvested or die in the areas surrounding the gaps. Thus, if a cycle of regeneration only occurs once every 20 years, this is not a problem because the manager can compensate by not enlarging gaps until regeneration is obtained. Trees harvested in the interim should be from the matrix between gaps, and harvesting should be designed to reduce competition for superior trees and to capture potential mortality.

Forest Manager: (39) *What prescribed burning regime is best to establish slash pine regeneration in uneven-aged stands?*

Boyer: There is very little information on this. A fire-return interval of about 8 years supports slash pine regeneration in stream bottoms and wet flats in Coastal Plain longleaf pine forests. The same burn interval also supports development of canebrakes, which were once so common in the Southeastern United States. Exclusion of fire from wet flats and bottoms has resulted in a hardwood invasion trend that has been very detrimental to the ecosystems that originally occupied these sites.

Outcalt: By the time slash pine seedlings reach 8 to 10 years old, they are quite resistant to fire-caused mortality. Slash pine is also a fairly consistent seed producer. Therefore, whenever slash pine regeneration is wanted in forest openings, the manager needs to keep fire out of the area for at least 8 years. This will allow adequate time for the regeneration to become large enough to survive prescribed burning. The first burning following this period should be a dormant-season fire conducted under mild conditions to reduce fuel loads. A second burning should be applied about 2 or 3 years later. Then the normal maintenance fire regime, with burning once every 3 to 5 years, can be resumed until another wave of regeneration is desired.

Forest Manager: (40) ***What factors and relationships influence tree mortality, morbidity, and pest attack as a result of fire (prescribed burning and wildfire) where fuels have accumulated over a long period of time and during periods of drought?***

Rudolph: I am not familiar with the literature in this area. However, several individuals dealing with management of these types of situations have experienced problems with tree mortality. Bill Boyer has some insight, especially from the Flomaton, AL, site. Ike McWorter of The Nature Conservancy in Texas has also had experience with tree mortality problems associated with fires in areas with a long history of fire suppression. Anecdotal observations suggest that fire can increase tree susceptibility to bark beetles. Kier Klepzig of the Southern Research Station in Pineville, LA, is considering a proposal to investigate this issue.

Boyer: The principal factor affecting pine mortality seems to be fire intensity. For longleaf pine, tree age also seems to be a factor. In one study, a summer burn that was intended to wipe out some hardwoods killed a substantial number of pines, but mortality varied by size class (Boyer 1990). The summer burn killed a large number of longleaf pines in the 4-inch and smaller d.b.h. classes, didn't kill any pines in the 5-inch to 15-inch d.b.h. classes, killed 12 to 13 percent of longleaf pines in the 16-inch to 21-inch d.b.h. classes, and killed 25 percent of the longleaf pine in 22-inch and larger d.b.h. classes. The fire was a hot fire with high air temperatures (99 °F) and low humidity (34 percent). The area had been burned by a winter fire 2 years earlier. Crown scorch on the large trees was not a factor in this mortality, averaging < 10 percent.

A growing-season wildfire burned through part of the old-growth longleaf pine stand at Flomaton, AL, in August 1992. This fire killed all trees, which were up to 350 years old and 36 inches d.b.h.. Some of the younger pines (50 to 60 years old) survived briefly but were soon killed by black turpentine beetles. Fire had been excluded from this stand for more than 40 years. However, another study has shown that organic litter on the forest floor reaches a steady-state after a time, with a balance between accretion and decay. The load is much less in low-density than high-density stands, with sunlight seeming to speed the decay process. Accumulation did not exceed 2 years' deposition in any of the stands observed (Boyer and Fahnestock 1966). These results were found in longleaf pine stands on a sandy Coastal Plain site with densities not exceeding 50 square feet per acre. Results may differ on other site types. These results do, however, suggest that fuel loads (organic litter on forest floor, not living material) 2 to 3 years after a burn in these low-density stands could be as great as those found in stands not burned for 20 to 30 years.

Observations of a late summer burn at a study area on the Kisatchie National Forest in Louisiana indicated that the fire was so intense that saplings of 4 inches and smaller d.b.h. were killed along with many large grass-stage seedlings, which are normally resistant to fire-kill. These results suggest that surface soil temperatures reached lethal levels at the ground line, girdling seedlings at the root collar. I believe this may be the factor responsible for the death of large trees in the summer burn study. Older trees with slower growth and thinner bark near ground line are susceptible to damage or mortality from an intense, lingering fire in the accumulated bark and needles found at the bases of the trees. These large trees were in essence thermally girdled. This possible relationship is the reason some managers like to rake around red-cockaded woodpecker cavity trees before burning. Without raking, these old trees would be more vulnerable to fire kill. Another hypothesis that has been advanced to explain high mortality of old trees in long unburned stands has to do with fine root density. This theory suggests that increased fine root density near the surface, just under or in the lowest litter layer, is susceptible to damage from high-intensity fire. Damage to these roots presumably leads to the death of trees. While this could have been a factor in the Flomaton old-growth stand, it was not a factor in the Boyer (1990) study or the Kisatchie study, since both of these sites were burned regularly, and burning removed the accumulated litter. Obviously, more research is needed on this subject. Based on my experience, I would guess that high fire intensity produces lingering lethal temperatures at the ground line, girdling the trees, with greatest impact on those trees with thinnest bark near the ground line. Summer burns generally produce the highest fire intensities, which is probably why H.H. Chapman once said that August was the most dangerous month to burn in longleaf pine forests. For that reason, I would avoid summer burning. Besides, spring burns are more effective for hardwood control.

Normal mortality in mature longleaf pine stands, based on observations in our shelterwood stands throughout the South, averages 0.4 trees per acre per year (Boyer 1979). The causes of about 60 percent of this mortality could be identified. Of this 60 percent, about two-thirds was caused by lightning, about one-tenth by wind, and the remaining portion by beetles and pathogens. This is normal attrition. All study areas were subjected to careful prescribed burning, and no fire-related mortality was observed.

Outcalt: Mortality following prescribed burns or wildfire is a function of fuel loads, fuel moisture content, weather during the burn, burning technique, tree condition prior to burning, and postfire conditions. High mortality can result from high-intensity fires caused by high fuel loads, low fuel moisture, low humidity, high winds, and high temperatures. In these situations the burn will be intense enough to cause significant mortality from crown and bole damage. Excessive tree mortality can also result from low-intensity but high-severity fires that creep or back through a stand with high loads of very dry forest floor fuels. Even though intensity may be low with very little crown damage, the long residence time of smoldering combustion can cause significant cell death in root and bole cambium. This loss of roots or actual girdling results in high morality. For guidance on how to deal with stands that have not been burned for long periods and have high fuel loads, see Wade (2002).

Part G. Regeneration

Forest Manager: (41) *What is seedling survival in relationship to opening size, shape, and solar path?*

Boyer: Longleaf pine seedling survival is independent of opening size, shape, and solar path. A study of seedling survival in relation to overstory density indicated that after 8 years, survival under overstories of 90 square feet per acre was as high as in clearcut openings (Boyer 1963). The same was true for all overstory densities in between these extremes. The only variable affecting seedling survival was the timing of fire. The seedling survival study referred to here was unburned. Burns should be deferred until longleaf pine seedlings have reached a fire-resistant size (> 0.3-inches in diameter at root collar). Many if not most grass-stage seedlings larger than this can sprout at the root collar if top-killed by fire.

Jose: I do not believe the shape of the opening has anything to do with survival patterns. Brockway and Outcalt (1998) found that the size of the opening is an important factor for seedling survival in xeric longleaf pine forests. However, I observed no significant correlation between opening size and seedling survival in an open longleaf pine–wiregrass forest community in northwestern Florida.

Guldin: The experience in Coastal Plain loblolly-shortleaf pine stands suggests that with good mineral soil exposure, minimal openings are needed to establish pine regeneration. Certainly I'd expect similar results in longleaf pine during good seed years, but I defer to Bill Boyer and his experience on the EEF for any data relating to longleaf pine.

Perhaps it would be useful to compare the effects of seedbed condition (such as exposed mineral soil) in good to poor seed years and to determine whether supplemental scarification can result in acceptable establishment of longleaf pine seedlings during marginal seed production years. It is easier to manipulate overstory conditions above an established regeneration cohort than it is to configure openings when regeneration is absent.

Forest Manager: (42) *What is the best timing and frequency of prescribed burning after seed-fall to reforest group-selection openings?*

Boyer: The best time to regenerate a group-selection opening is before it is created. New gaps should be created to release seedlings already present. Conduct a seedbed burn prior to a good seed crop. Do not burn again until at least 2 years after trees are cut (give seedlings time to respond to release and logging slash a chance to decay, eliminating the extra fuel load).

Forest Manager: (43) *How much exposed mineral soil is necessary to get regeneration within group-selection openings?*

Boyer: A good seedbed burn within a year of seedfall exposes sufficient mineral soil for seedling establishment. Two-year and older roughs create a problem for establishment. Longleaf pine has a large seed that retains its wing and is easily suspended in even a relatively light ground cover. Understory hardwoods should be controlled in advance of regeneration.

Guldin: Group openings get heavy use by loggers. Experience in the Ouachita Mountains suggests that loggers use the group openings as in-the-woods decks to concentrate loads from the adjacent between-group matrix. As a result, group openings are characterized by a high degree of mineral soil exposure. Moreover, empirical evidence and inspections show that the mineral soil exposure that occurs as a result of skidding is sufficient to support seedling establishment. Because of this, it has been suggested that one should avoid supplemental rehabilitation of skid roads by direct seeding with wildlife grass and forb mixtures.

Part H. Optimum Stand Structure for Management Objectives

Forest Manager: (44) ***How many openings should be created when group selection is used to regenerate longleaf pine and slash pine, and how large should the openings be?***

Brockway: There is no single answer to this question, since the optimum size and number of openings in longleaf pine and slash pine regenerated with the group selection reproduction method will depend on the forest site type (i.e., xeric sandhills, mesic uplands, flatwoods, etc.), competition intensity, and current stand conditions. With group selection, the general size range for gap openings created by cutting varies from 0.25 to 2 acres. On xeric sandhills, where the zone of intraspecific competition between adults and seedlings is relatively wide (about 52 feet), larger gap sizes are probably more appropriate. On more mesic sites, where this competitive zone is thought to be somewhat narrower, smaller gap sizes may suffice. When properly executed, the group selection method will result in gaps of a number that is not predetermined, of a size that is variable, and of a spatial distribution that reflects the practice of generally taking the worst trees and leaving the best trees within the age classes that the prescription specifies.

Our research on gap-phase regeneration in longleaf pine forests on xeric sandhill sites indicates that minimum diameters for circular gaps should range from 131 to 165 feet to ensure adequate seedling relief from competition with overstory adults (Brockway and Outcalt 1998). Measured from tree bole to tree bole (not canopy edge to canopy edge), these dimensions produce forest gaps that are approximately 0.3 to 0.5 acre in size. The lower portion of our recommended size range concurs with studies on mesic uplands (Palik and others 1997); however, other studies conducted on mesic uplands and flatwoods suggest that gaps as small as 0.25 acre may be suitable for longleaf pine regeneration (Gagnon and others 2003, McGuire and others 2001). Forest gap diameters > 328 feet would exceed the 2-acre upper limit typically used in the group selection method and therefore should be considered with caution. In observing the geometry of naturally occurring forest gaps, researchers generally agree that gaps created by cutting can range widely in shape from circles to ellipses to various irregular polygons.

Outcalt: We have done research directly on the question of opening size for regeneration in longleaf pine stands on xeric sandhills. The mature trees surrounding gaps reduce seedling survival near the gap edge. The minimum size for an opening is about 0.25 acre, with a diameter of 118 feet if circular, on sandhill sites (Brockway and Outcalt 1998). However, the ideal size is about 0.5 acre for a round gap with a diameter of 165 feet, because a 0.5-acre gap has 27 percent of its area in the zone where seedlings are likely to survive vs. just 11 percent for a 0.25-acre gap. When gaps larger than 0.5 acre are desired, they should be elliptical with a maximum width of 165 feet so longleaf pine seeds do not have to travel more than twice the height of dominant seed trees. On more moist sites, it is possible to obtain regeneration in even small openings, because intraspecific competition for soil moisture is lower and thus has less adverse influence on seedling survival and growth. Palik and others (1997), however, recommend gaps exceeding 0.35 acre in size to minimize overstory competition with regeneration in uneven-aged management of longleaf pine on moist sites in southwestern Georgia.

Not all trees need to be cut in groups. If there are poor trees or at-risk trees that need removal, they can be included in the selection harvest. Also, not all gaps need be created in a single cut. It is okay to select trees from groups to partially open up the area and then remove the remainder of the group during subsequent entries to actually create the gap. The key thing to avoid is high-grading the stand during the marking and harvest phase (i.e., do not take out the good trees and leave the bad ones).

The number of openings to create depends on site productivity and minimum harvest level to make an entry economical. This can be handled using standard silvicultural techniques. If you want to reduce the basal area from 80 square feet per acre to 65 square feet per acre, then you need to create enough gaps to cover 10 to 15 percent of the area and take additional trees from intervening areas to yield the 15 square feet per acre you want removed. This translates to one 0.5- to 0.75-acre gap per 5 acres of the stand plus some single-tree selections. Then the stand is not entered until the average basal area has again reached 80 square feet per acre. This can be continued indefinitely, always keeping trees of many size classes on the land, yet having fairly even harvests and a system that can easily be taught to marking crews.

Guldin: Optimum size would be determined by silvical characteristics for optimum longleaf pine development. The question of the optimum number of openings is not the way to approach the layout of groups. Group selection is implemented according to the BDq and the VGDL regulation methods, as is single-tree selection. Therefore, there should be no plan prior to marking with regard to the number or size of openings. It is especially important to avoid installing regularly shaped openings in a regular pattern, since such an approach is properly classified as patch clearcutting rather than group selection.

Forest Manager: (45) ***What is the smallest forest opening in which a longleaf pine seedling can become established, survive, and grow into a codominant or dominant tree?***

Brockway: According to our research on the xeric sandhills of Florida, any circular gap with a diameter < 98 feet and an area < 0.17 acre is probably too small (because of fine root competition from nearby adult longleaf pine trees) to allow many longleaf pine seedlings to survive and eventually ascend into the overstory. This is why we recommend that the smallest circular gaps created in the longleaf pine forest through harvest range from 131 to 165 feet in diameter (0.3 to 0.5 acre). Note that this recommended minimum gap size should be smaller on higher quality mesic sites, where adult tree roots may be less widespread and the corresponding competition for seedlings may be somewhat diminished.

Outcalt: See my answer to question 44, as this question is essentially a subset of that question. Our research at sandhill sites indicates that the smallest opening that is likely to allow the establishment of longleaf pine seedlings is 0.25 acre. On sites with higher soil moisture levels, it may be possible to get seedlings established directly beneath the crowns of mature trees. These seedlings have the potential to become dominants or codominants if the mature trees are later removed.

Guldin: I have a bit of a problem with the wording of this question. Available canopy space does not remain constant over the life of a seedling. In the absence of further harvest, crown space narrows with lateral development of the crowns of adjacent trees. But it's difficult to imagine a situation under any even-aged or uneven-aged silvicultural system where timely harvests could not be made that would expand the size of the canopy gap within which the new tree was growing. The key to ensuring that longleaf pine seedlings and saplings maintain acceptable height growth is to develop studies that relate height growth of trees of different d.b.h. classes to overstory basal area affecting those trees. Then, silvicultural tactics can be developed to ensure that periodic cutting-cycle harvests maintain overstory conditions that permit continued seedling and sapling development.

Forest Manager: (46) ***What is the understory vegetation response to the creation of forest openings?***

Brockway: Since the canopy of a longleaf pine forest is typically quite open (< 60 percent cover), the forest floor is almost never shrouded in dark shadows as long as periodic fire continues to exclude invasive woody plants. So increased light to the forest floor within a canopy gap may increase the growth of understory plants only marginally. However, removing overstory trees creates a below-ground gap in the adult root systems that typically extend throughout a site. This root gap is a refuge where longleaf pine seedlings more easily survive and grow. Thus, it is quite reasonable to expect that understory plants might also benefit from the competition relief afforded within a root gap. To date, little is known about such understory plant dynamics in canopy gaps created through harvesting.

Jose: After a forest opening is created, the understory vegetation responds positively to increased light availability. This increase in understory can significantly reduce light availability to young longleaf pine seedlings, especially when they are in the grass stage. Larger gap size and increased light availability may not translate into successful establishment and growth of longleaf pine seedlings in the presence of severe understory competition.

Outcalt: The understory response depends on understory composition before the opening is created. If you have a healthy grass- and forb-dominated understory, it will respond with some increase in growth. If the understory is shrub dominated, it can and often does respond with prolific growth in the newly created opening. This can be a real problem, since these woody plants inhibit longleaf pine regeneration. They are also difficult to control with prescribed burning, because fuel levels of grass and needle litter are often too low to carry an intense fire through the opening. Therefore, it is better to readjust plant composition before creating openings; if this is not done, it will be necessary to undertake site preparation to control woody vegetation before adequate regeneration can be obtained.

Forest Manager: (47) ***How do we favor longleaf pine in uneven-aged management when we are starting with a mixed longleaf pine and slash pine stand?***

Brockway: First, slash pine trees that are too large to be killed by fire should be removed by harvesting, in one or more entries depending on the rate at which the manager wishes to reduce the slash pine component of the forest.

This will yield a volume of usable wood and prevent additional dissemination of slash pine seed. Second and perhaps most important, keep burning the site at frequent intervals (every 2 to 3 years) during the growing season so that young fire-susceptible slash pines are killed before they reach sexual maturity. This combination of actions should cause slash pine numbers to decline and longleaf pine numbers to increase over time. From the larger ecological perspective, slash pine is known to naturally occur in mixed stands with longleaf pine on flatwoods sites. Therefore, on these forest site types, a component of slash pine may be retained (at the landowner's option) and managed along with the longleaf pine.

Outcalt: First, we should realize that slash pine is native to Florida and did co-occur with longleaf pine on many flatwoods sites (Schultz 1983). On wetter sites, where the interval between fires is at least 8 years, slash pine seedlings can become large enough to survive subsequent ground fires and remain part of the stand. Thus, we do not need to remove it from all stands. Alternatively, there are a number of areas where changes in the natural fire regime or past management, or both, have favored slash pine over longleaf pine. On these sites, use your management and silvicultural actions to favor longleaf pine. This means preferentially selecting slash pine for harvest when the stands are marked for partial harvest. It also means burning on a regular basis, allowing fire to determine which longleaf pine and which slash pine seedlings will survive to be part of the next overstory.

Guldin: There are several ways that this can be done, through alteration of the proportion of longleaf pine to slash pine in the overstory and in the regeneration cohorts of various ages. Overstory treatments that favor longleaf pine and discriminate against slash pine increase the proportion of overstory longleaf pine immediately and also change the proportion of natural seedfall in favor of longleaf pine. If this is the desired outcome, one should manage the stand so that the longleaf pine component becomes acceptably stocked as soon as possible. If there is enough longleaf pine in the stand so that minimum stocking standards in the pine component can be met with longleaf pine alone, the situation is simple—remove the slash pine component as soon as possible (through commercial harvest or injection).

If there is not enough longleaf pine in the overstory to meet minimum stocking standards, some proportion of slash pine must be retained to bring the stand up to acceptable minimums. If this is the case, remember that cone production is a highly inherited trait genetically. Tom Croker's colorful advice for longleaf pine seed producers was to "leave fruiters, not neuters" in order to enhance longleaf pine seed production. Croker sought to leave longleaf pines that showed evidence of past seed production. If you must leave some slash pine overstory, try taking the inverse of Croker's advice. Leave the slash pines that are growing fastest (so volume production remains acceptable) but show evidence of being poor cone producers. In this way, the proportion of slash pine in the annual pine seedfall should be minimized.

Finally, there will probably be a need to influence the species composition of existing regeneration as well. Practices that kill more slash pine seedlings and saplings than longleaf pine seedlings should be employed. Prescribed fire may be highly effective in increasing the relative proportion of longleaf pine to slash pine. However, you could use other release treatments also, such as selective chemical (injection) or mechanical (chain-saw felling) treatments.

Forest Manager: (48) *What are the optimum ranges for the size, distribution, and frequency of harvests and new openings during the maintenance phase?*

Guldin: These ranges depend on a balance between aftercut stand structure, the expected growth of the stand, and the number of years between cutting-cycle harvests. The longer the time between cutting-cycle harvests, the bigger the expected growth and volume that can be cut, and therefore the lower will be the after-cut volume and basal area.

For example, suppose you want either 7,000 board feet per acre or 75 square feet per acre in basal area or both immediately before a cutting-cycle harvest. The intensity of the marking prescription depends on the anticipated length of the subsequent cutting cycle. Assuming that stands grow at 400 board feet per acre per year and 3 square feet per acre per year (which is the case for Coastal Plain loblolly-shortleaf pine stands), the following stand conditions would be needed to grow back to 7,000 board feet per acre and 75 square feet per acre.

Cutting-cycle length	Volume	Basal area
years	*board feet per acre*	*square feet per acre*
3	5,800	66
5	5,000	60
7	4,200	54
10	3,000	45

You can plug in your own estimates of longleaf pine volume and basal area growth and obtain similar estimates of after-cut volumes and basal area.

Forest Manager: (49) ***At what density (basal area or trees per acre) can you get the best balance between merchantable timber growth and continuous longleaf pine regeneration?***

Boyer: The best density (basal area) for merchantable longleaf pine timber growth on average Coastal Plain sites is 60 to 90 square feet per acre. The best basal area for obtaining longleaf pine regeneration is 25 to 30 square feet per acre. This density will maximize cone production per acre. Cone production is very low under the higher densities that maximize timber volume growth per acre. Few seedlings established under the higher densities (60 to 90 square feet per acre) will survive any burning regime with less than a 5-year return interval.

Guldin: My experience is in using uneven-aged management on loblolly-shortleaf pine stands. In managing these forests, residual stands of 45 to 75 square feet per acre are best for establishment and development of loblolly pine and shortleaf pine regeneration. However, simply reducing overstory density is not enough. These reductions must also be coupled with effective competition control. I would suggest similar basal areas, perhaps slightly lower (40 to 70 square feet per acre during any point in the cutting cycle) as a starting point for implementing uneven-aged management in longleaf pine stands. This recommendation is subject to revision if empirical experience, new research, or application of new growth-and-yield models suggests otherwise.

Forest Manager: (50) ***At what density (basal area or trees per acre) can you get the best balance between merchantable timber growth and vegetation diversity?***

Guldin: Density is less likely to be important than within-stand habitat diversity in balancing growth and vegetation diversity. If you want to maximize vegetation diversity, you should maximize within-stand heterogeneity. Methods such as group selection or patch clearcutting might be most appropriate for achieving this objective. On the other hand, if you want a large block of similar habitat condition, the single-tree selection method might be better. Specific targets for vegetation diversity may also influence the form and intensity of site preparation and release treatments that are applied in a stand. Moreover, in both cases, questions about vegetation diversity should include assessments of conditions in adjacent stands and on larger spatial scales.

Forest Manager: (51) ***How do stand structural characteristics (spatial orientation, size, shape, density, age distribution, and diameter distribution) interact with each other and with management functions (timber inventory, prescribed burning, monitoring, administration)?***

Guldin:

Timber Inventory, Monitoring, and Administration

Stand structural characteristics are mostly independent of these administrative issues. Inventory work is conducted using plots and standards as described previously, and these are independent of whether stands are managed using single-tree or group selection. Age distribution is independent of inventory issues, but diameter distribution can be used as an indicator of stand heterogeneity and may affect the decision to use fixed area plots or prism samples. In group selection, there is no need to sample regeneration in the matrix between groups.

Prescribed Burning

Prescribed burning may be conducted differently in longleaf pine stands where group selection is employed than in those where single-tree selection is used. In the Ouachita Mountains, fire prescriptions for shortleaf pine are implemented in the same way in group-selection stands and single-tree-selection stands. However, large even-aged regeneration blocks (clearcut, seed-tree, and shelterwood blocks) are preburned in January prior to landscape burns in March. This tactic ensures that the March fires do not burn uncontrollably and do not damage regeneration severely in the preburned areas. Group openings in group selection stands are too small to be treated in the way.

Part I. Competition Tolerance and Release Potential of Various Age Classes

Forest Manager: (52) ***Will suppressed longleaf pine saplings and pulpwood respond once they are released?***

Boyer: Suppressed saplings will usually respond to release, but the time required will depend on their condition. Codominants will respond immediately, intermediates will take longer, and suppressed saplings will take much longer.

I don't believe there have been any studies on response of suppressed saplings and pulpwood-size material to release in terms of their initial crown condition, but it takes years for full response. More information is available on seedlings, as noted in the responses to earlier questions.

Guldin: Both loblolly pine and shortleaf pine respond to release if some degree of apical dominance is still apparent in the seedling or sapling. The standards that indicate potential for acceptable recovery are quite low for pulpwood-sized suppressed trees. If a suppressed loblolly pine has a live-crown ratio > 20 percent and an outside bark diameter of at least 2 inches at the base of the live crown, it will respond. Some research in understocked longleaf pine stands would be needed to obtain similar indications of the ability to respond to release.

Forest Manager: (53) *What degree(s) and duration(s) of shading can seedlings and saplings survive and, when released, still recover their full growth potential?*

Boyer: Longleaf pine seedlings can survive an extended period of suppression by overstory competition and still respond promptly to release and achieve full growth potential. Studies have reported response after 8 years of suppression, and informal observations have noted rapid recovery after 15 years of suppression and survival (of grass-stage seedlings) through 22 years of suppression.

Guldin: In loblolly and shortleaf pine stands, height growth of regeneration is a useful indication of the ability to recover full growth potential. Minimum acceptable annual height growth in these species is 0.5 foot. If seedlings or saplings < 4.5 feet in height are not growing at this rate, they will probably not survive.

Also the residual basal area that remains after a low thinning to the point at which accidental regeneration just begins to suffer suppression approximates the highest acceptable before-cut basal area in uneven-aged stands. In even-aged Coastal Plain loblolly pine stands thinned to 70 square feet per acre, regeneration of pine often becomes established. But by the time the stand grows above 75 square feet per acre, the regeneration ceases to make acceptable height growth. In uneven-aged stands, that 75 square feet per acre is distributed much less uniformly than it is in low-thinned even-aged stands, and the regeneration will not be suppressed in the holes in the uneven-aged stands. But repeated cutting-cycle harvests are needed to enlarge any existing holes in the stand and to create new openings and new zones of lower basal area within which regeneration can become established and develop.

Forest Manager: (54) *At what maximum age is release still possible?*

Boyer: There is probably no age limit for response to release. Observations of growth rings have shown that 200-year-old trees have responded rapidly to release.

Guldin: In loblolly-shortleaf pine stands, maximum age is less important than minimum size, as has been discussed in the responses to question 52.

Forest Manager: (55) *How shade tolerant are longleaf pines at different ages, spacings, and densities?*

Brockway: Shade tolerance (or more precisely competition tolerance) is an inherent physiological characteristic of each tree species. In some tree species, tolerance varies over the life span of the organism. For example, some species may be intermediate in tolerance as juveniles and then become intolerant as adults. However, this is not the case with longleaf pine. Longleaf pine is classified as very intolerant by most silvicultural authorities and apparently retains that status at all ages. The very intolerant status of longleaf pine is not altered by spacing or density within a forest stand. Because juvenile longleaf pines sometimes persist for many years beneath the crowns of adults, some people have come to regard these suppressed offspring as shade-tolerant. They are not. They are simply suppressed young awaiting an opportunity for release following a canopy-altering disturbance.

Boyer: One study showed that light shading (about a 33 percent reduction in sunlight intensity) did not significantly affect the height growth of longleaf pine saplings over a single growing season.

Forest Manager: (56) *Does shade tolerance make any ecological or silvicultural difference over the long term in uneven-aged stands?*

Guldin: No. The most intolerant species can be managed using uneven-aged methods. However, once an uneven-aged prescription is initiated with intolerant species, cutting-cycle harvests must be made in a regular and timely way. Failure to execute cutting-cycle harvests means that the stand will continue to grow and that basal area will exceed the maximum at which regeneration development can be maintained.

Part J. Viability of Interplanting and Underplanting

Forest Manager: (57) *At what stocking level is underplanting economical?*

Barnett: Underplanting is probably not an economic management practice for most species. Research has shown that underplanted loblolly pine and slash pine seedlings never catch up with the original stand and usually become suppressed stock. However, longleaf pine's grass stage delays early height growth. This makes natural regeneration harder and makes underplanting or interplanting an option. The seedlings should be planted in openings, because they die or develop very poorly if they are planted within about 50 feet of a mature tree or in stands of trees that will be retained. However, if a stand has openings at least 0.25 acre in area, then underplanting or interplanting or both may be effective in increasing the stocking of that stand and developing a multi-aged condition.

Guldin: See my answer to question 60. There probably is a minimum number of seedlings that is operationally feasible to plant. If natural regeneration is inadequate and planting is needed, be sure to plant enough seedlings to ensure that there is a fully stocked stand of planted seedlings. That way, in the event that naturally regenerated seedlings fail to survive, the site will be fully stocked. Many of the existing naturally regenerated seedlings will not survive the site preparation necessary to ensure a successful planting job.

My views on this reflect my background as a dyed-in-the-wool natural-regeneration silviculturist. If efforts are being made to manage a stand using any of the even-aged or uneven-aged reproduction methods that leave residual trees on the site, natural regeneration should have two chances for success prior to planting. The first chance is associated with the initial harvest. The hope is that the harvest would occur in conjunction with a good seed year. However, the administration of sales on National Forest System lands makes it almost impossible to guarantee harvest in conjunction with seed crops, since logging contractors are typically given several years to harvest a timber sale.

The second chance is the first good seed crop after the sale closes. Site preparation can be conducted so as to catch the seed crop. This, too, is constrained by administrative procedures. The Knutsen-Vandenberg (KV) Act of 1933 allows national forests to retain a portion of the sale receipts from timber harvested within a sale area to reinvest in that sale area. Reforestation needs such as site preparation activities associated with obtaining natural regeneration qualify for such funding. However, these KV funds can generally be held for only 5 years, with some special exceptions. Thus, national forest managers must respond to a bumper seed crop within 5 years. Longleaf pine doesn't always produce a bumper seed crop every 5 years, so managers must sometimes decide whether to plant stands that show little likelihood of seedfall. Moreover, money for site preparation must be requested during the fiscal year before that in which it would be spent, and there is no way to predict a good seed year that far in advance.

Practically, then, a silviculturist with a national forest has 4 years after the harvest to try twice to obtain natural regeneration; the 5th year must be devoted to spending the available KV funds to prepare sites in advance of planting. We should tell silviculturists what conditions are likely to cause great difficulties with natural regeneration. Such conditions include the presence of poor seed producers left on the site, an absence of advanced growth, and the lack of adjacent stands that can contribute seed to cutover areas. Silviculturists could use this information to identify sites that might be good candidates for underplanting, and avoid the problem of timing site preparation to take advantage of seedfall.

Some research should be conducted on how to choose seedlings to use when underplanting. Efforts in genetic improvement and progeny testing have focused on developing seedlings designed to make rapid early height growth under open conditions with intensive site preparation. Will those families that have been successful under open conditions of intensive forestry be equally successful when underplanted beneath a residual overstory? Are there other families with desirable form and growth attributes that might better withstand the more challenging environment that seedlings face under partial overstories? I guess this would involve progeny tests under similar conditions, and I know of no such tests being conducted anywhere in the nation.

Research at the Hitchiti Experimental Forest in central Georgia suggests that slash pine seedlings that are interplanted a few years after the initial planting have a very low probability of surviving to become part of the codominant canopy unless the initial spacing is very wide. In longleaf pine, interplanted seedlings of good vigor might become part of the subsequent stand if the longleaf pine seedlings established previously have not yet initiated height growth. But, like slash pine, longleaf pine is an intolerant species. The likelihood of a newly planted seedling finding its way into the main canopy is probably low, although no research has been conducted in longleaf pine to verify this. On balance, interplanting as a supplement to natural regeneration is probably less effective than considering inadequate natural regeneration a failure, site-preparing the entire stand, planting, and relying on the planted seedlings to develop into the fully stocked condition.

Forest Manager: (58) ***What are the growth characteristics of longleaf pine seedlings that are either interplanted with other seedlings or underplanted in more mature stands?***

Barnett: Longleaf pine seedlings are very intolerant and require almost full sunlight to quickly initiate height growth and become vigorous saplings. The success of interplanting in young stands of established seedlings or saplings that are in height growth depends greatly on access to full sunlight and control of both woody and grass competition. If favorable conditions do not exist, planted stock will be slow to come out of the grass stage and will be slow to develop in competition with surrounding plants. Even when openings exist that are sufficient for good establishment and early growth, use of fire before and after planting will be important in controlling competition that will delay or prevent seedling development. Frequent prescribed fires will be an important management tool to make these plantings successful.

Jose: If there are further research questions here, I would be interested in working with someone on this important question.

Forest Manager: (59) ***Do interplanting and underplanting have any long-term silvicultural or ecological advantages?***

Barnett: When they are used with an understanding of the ecology of longleaf pine, interplanting and underplanting can have both silvicultural and ecological advantages. Such planting should be done in openings of sufficient size to allow successful establishment and development of longleaf pine seedlings. The appropriateness of this approach depends on the condition of existing stands and the management objectives of the organization. If objectives include the development of forest stands with potential for wood products production or restoration of longleaf pine ecosystems, you must establish stocked stands with which to work. If economics and time are not a principal concern, filling in the openings in existing stands is an option that should be considered. The management of such stands is more time consuming and expensive than harvesting the stands and planting, but it is an option that may be attractive if an uneven-aged condition is desired.

Brockway: Artificial regeneration is generally more expensive than natural regeneration. If time is crucial, then the higher expense of artificial regeneration may be justified. But if timber yield is not a priority, it is perfectly acceptable that openings in the longleaf pine forest persist for many years or even decades. As long as an aggressive program of prescribed fire keeps woody plants from invading and occupying these openings, longleaf pine seedlings will eventually establish there if a parent tree is nearby. In natural longleaf pine ecosystems, persistent openings are simply part of the normal landscape condition. We do not always have to obtain 300 evenly spaced longleaf pine trees per acre to fully occupy the site. The density of natural longleaf pine stands varies widely; for example, there are sparsely stocked stands in savannas and well-stocked stands on uplands. All of these conditions are perfectly acceptable and are good stewardship objectives for the prudent natural resources manager. Some managers are much more concerned about planting wiregrass and various forbs under their longleaf pine trees. It seems they are quite successful at restoring the longleaf pine trees, but the understory has been so degraded that many of the native plants that act as the most effective carriers of fire and add the greatest amount of biological diversity to the ecosystem are missing.

Guldin: Part of this question was addressed in my response to question 58. Many of the advantages of planting relate to timeliness of reforestation, ease of administration, reductions in the length of time a stand is understocked, better control of species composition, better control of tree spacing, and overall improvement in the genetic quality of a longleaf pine stand. Disadvantages relate to cost, spatial appearance (though spacing of underplantings could be varied in creative ways), and the opportunity to stock the site with progeny of trees that have been genetically successful on that given site.

Forest Manager: (60) ***What are acceptable rates of regeneration such that interplanting or underplanting are not necessary?***

Barnett: The answer to this question depends on the stage of regeneration being considered. Planting rates depend greatly on the type of stock being planted and may vary from 700 to 1,200 seedlings per acre. If bareroot stock is being used, the higher planting rates in this range should be used because levels of initial mortality are higher. Container stock can be planted in the 700 to 900 seedlings per acre portion of this range if adequate site preparation has been done.

A minimum of 400 to 500 seedlings per acre should have initiated height growth within 3 to 4 years to obtain a good, manageable stand. However, interplanting should be considered only in stand openings of about 0.25 acre or larger.

Boyer: The amount of regeneration needed so that reinforcement planting is not necessary varies with the management technique used. The goal with even-aged management is 3,000 seedlings per acre at least 1 year old after removal of the parent overstory. Since about 10 percent of the seedlings in a natural stand are resistant to the brown-spot needle blight, this will result in about 300 disease-resistant trees per acre for the next generation. The goal in an uneven-aged management method is much lower because a seed source is always available to supplement a limited population of established seedlings. A new stand in an opening may consist of seedlings from three or more different cone crops. Supplemental planting might be considered if part of the opening has < 250 well-distributed seedlings per acre and is beyond seeding range of the nearest mature trees.

Guldin: Minimum acceptable standards for regeneration (the 0-inch, 1-inch, 2-inch, and 3-inch size classes) in uneven-aged loblolly-shortleaf pine stands in the western gulf region and in shortleaf pine stands in the Interior Highlands are 200 stems per acre and 20 percent milacre stocking. By comparison, a plantation established at an 8- by 10-foot spacing has 544 seedlings per acre and a milacre stocking rate of 54 percent. Minimum acceptable standards for natural regeneration in even-aged stands in the Ouachita Ecosystem Management research study are 300 seedlings per acre at 30 percent milacre stocking. These are minimum standards, and the closer a stand is to them the more likely you will need to consider supplemental release treatments.

Standards similar to those described above for loblolly-shortleaf pine stands might be a place to start for assessing regeneration success in longleaf pine stands. A forester who is guided by these standards will not engage in underplanting or supplemental planting if natural regeneration in stands exceeds these levels.

Epilogue

As the above discussion shows, not all questions posed by forest managers can be fully answered at this time. In many instances, scientific study has already developed a considerable body of knowledge about longleaf pine that may be useful to managers. In other instances, only partial answers can be provided, since the topic under consideration has been only partly explored, and studies concerning the subject may yet be in progress. Clearly, this dialogue among managers and scientists was an opportunity to assess the current status of longleaf pine research and consider possible directions for its future development. The interaction during this dialogue not only enhanced the awareness of managers, but also stimulated the natural curiosity that encourages scientists to investigate those questions that, at this time, remain partially answered. This positive synergism is the very essence of a beneficial scientific research and technology transfer process.

That not all scientists are in complete agreement concerning the answers to some of these questions is also noteworthy. Although the authors hope to avoid creating confusion for those managers who may be seeking a single right answer, it should be recognized that such honest disagreements are not uncommon in scientific disciplines. Scientific research is a developmentally iterative process, in which the participating individuals often have differing viewpoints, areas of expertise, and levels of insight. Therefore, complete agreement is often rare until the preponderance of evidence allows preliminary findings and provisional concepts to coalesce into broader agreement among the many investigators. Through the process of (1) thesis, (2) antithesis, (3) synthesis, and (4) new thesis, scientific knowledge deliberately progresses through its developmental stages. The lack of complete agreement often means that scientists are working at the cutting edge of knowledge and that the synthesis needed to resolve differing viewpoints has not occurred yet but is likely to occur in the future.

A great deal of useful information about longleaf pine ecology and management has already been developed by scientists in a wide variety and large number of research organizations. Continuing research will improve our understanding of these longleaf pine forest ecosystems and the management options available for sustaining them in perpetuity. Ongoing longleaf pine research efforts are currently focused on a variety of subjects, including (1) safe reintroduction of prescribed fire into long-unburned forests, (2) methods for restoring native understory plants as well as overstory trees, (3) comparative analysis of even-aged and uneven-aged forest reproduction methods across a wide range of ecological site types, (4) natural gap-phase regeneration dynamics, (5) impacts of management treatments on biological diversity and wildlife habitat quality, (6) growth-and-yield modeling, and (7) carbon sequestration. The authors of this dialogue look forward to a bright future for longleaf pine forest ecosystems as they are restored and are more suitably managed to ensure that the ecological, economic, and social values associated with them are sustained well into the future.

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GLOSSARY OF ABBREVIATIONS AND ACRONYMS

A/r: area (A) divided by rotation length (r), normally yielding a rate of harvest in acres per year.

BDq: an uneven-aged method of regulating stand volume based on basal area (B), maximum d.b.h. (D), and the diminution coefficient (q).

CEF: Crossett Experimental Forest in southern Arkansas.

CTL: cut-to-length.

d.b.h.: diameter at breast height.

EEF: Escambia Experimental Forest in southern Alabama.

FVS: Forest Vegetation Simulator.

KV: Knudson-Vandenberg Act of 1933 and the funds allocated by this legislation to ensure that harvested sites on national forests are reforested.

VGDL: volume-guiding diameter limit method of regulating uneven-aged stands.

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Interest in appropriate management approaches for sustaining longleaf pine (*Pinus palustris* Mill.) forests has increased substantially during the recent decade. Although long-leaf pine can be managed using even-aged techniques, interest in uneven-aged methods has grown significantly as a result of concern for sustaining the wide range of ecological values associated with maintaining continuous crown cover in these ecosystems. Indeed, land managers have recently sought to restore and sustain the many habitat attributes upon which numerous at-risk species depend, while simultaneously producing high-quality wood products from longleaf pine forest ecosystems. Although earlier research produced a substantial body of knowledge to guide even-aged management, less is known about application of uneven-aged management methods in longleaf pine forests. Much of this information is yet in the developmental staage. However, managers from the Florida Division of Forestry and Florida National Forests, having a keen interest in applying what is currently known, encouraged scientists of the U.S. Department of Agriculture Forest Service, Southern Research Station and faculty members from the School of Forest Resources and Conservation at the University of Florida to engage in a dialogue that focused on addressing 60 of their key questions concerning uneven-aged management of longleaf pine. This dialogue addresses issues related to (1) methods for converting even-aged to uneven-aged stands, (2) growth and yield, (3) selection harvest techniques, (4) optimum logging practices, (5) effects on red-cockaded woodpeckers (*Picoides borealis*), (6) prescribed burning approaches, (7) regeneration, (8) optimum stand structure, (9) competition tolerance and release of various seedling age classes, and (10) the viability of interplanting and underplanting.

Keywords: Artificial regeneration, group selection, growth and yield, natural regeneration, prescribed fire, red-cockaded woodpecker, single-tree selection, stand structure.