23

Silvicultural Considerations in Managing Southern Pine Stands in the Context of Southern Pine Beetle

James M. Guldin

Supervisory Ecologist and Project Leader, SRS-4159,
Ecology and Management of Southern Pines, USDA Forest Service,
Southern Research Station, Hot Springs, AR 71902

Abstract

Roughly 30 percent of the 200 million acres of forest land in the South supports stands dominated by southern pines. These are among the most productive forests in the nation. Adapted to disturbance, southern pines are relatively easy to manage with even-aged methods such as clearcutting and planting, or the seed tree and shelterwood methods with natural regeneration. In addition, most species of the southern pines can be managed using the uneven-aged selection method, which maintains continuous canopy cover on the site. Because southern pines grow so rapidly across a wide variety of conditions, stands can quickly become overstocked to the point where competition results in reduced growth, decline in vigor, and mortality—including mortality from infestations of southern pine beetle (SPB). Thinning is an effective silvicultural practice designed to avoid the problems associated with overstocked stands, and can be used in immature sapling stands through mature stands of large trees. When a stand is properly thinned, the crowns obtain more sunlight, root systems get a larger share of soil moisture and nutrients, and trees maintain acceptable rates of growth and individual vigor. The best silvicultural defense against SPB is to manage forest stands so that individual trees are vigorous and stands are not overstocked. Active forest management is important, based on timely thinning treatments and other silvicultural practices appropriate for the local species and site conditions that optimize current stand developmental dynamics, manage species composition, and promote tree vigor and forest health.

Keywords

disturbance
overstocking
silviculture
southern pines
southern pine beetle
thinning
tree vigor

23.1. THE SOUTHERN PINE FOREST RESOURCE

The Southern United States has about 535 million acres (216.5 million ha) of land, of which 214.6 million acres (86.8 million ha) is forested; of that, 202.7 million acres (82.0 million ha) is considered to be commercial timberland capable of producing wood products (Smith and others 2004). This area of forest is about 60 percent of that which existed at the onset of European colonization in 1630 (Conner and Hartsell 2002). Slightly more than half of the commercial timberland in the South is in hardwood-dominated forest types, and the balance—about 96 million acres (38.9 million ha)—is found in southern pine or oak-pine forest types (Smith and others 2004).

23.1.1. Distribution of Southern Pines

The southern pines consist of four major species: loblolly pine (*Pinus taeda* L.), shortleaf pine (*P. echinata* Mill.), slash pine (*P. elliottii* Engelm.), and longleaf pine (*P. palustris* L.). Thirty percent of the forest land area in the South—some 66 million acres (26.7 million ha)—is dominated by two major southern pine forest types. About 52 million acres (21.0 million ha) is in the loblolly-shortleaf forest type, and 14 million acres (5.7 million ha) is in the longleaf-slash forest type; another 30 million acres (12.1 million ha) is classified as oak-pine forest type, in which the southern pines are found in mixtures of varying percentage with oaks (Smith and others 2004).

The loblolly-shortleaf forest type includes pure stands of loblolly pine of natural or planted origin, and mixed stands of loblolly and shortleaf pine primarily of natural origin, in the Piedmont, Atlantic Coastal Plain, the upper Gulf Coastal Plain east of the Mississippi River, and the upper West Gulf Coastal Plain west of the Mississippi River. The type also includes stands dominated by shortleaf pine of natural or planted origin, or by loblolly pine plantations, in the Ouachita and Ozark Mountains in Arkansas, Oklahoma, and Missouri.

The longleaf-slash pine forest type is generally found in pure stands of either slash or longleaf pine of natural or planted origin, with minor occurrence of naturally regenerated stands with both species present.

Oak-pine stands are a minor and varying component of virtually all these pine-dominated forest types across the South. They are usually of natural origin, and there is often consideration given in these mixed stands to managing either for the hardwood component or, more commonly especially on forest industry ownership, to manage for the pine component so as to simplify species composition and to increase pine growth and yield.

23.1.2. The Major Species of Southern Pines

Loblolly pine is found in 14 States, growing from southern New Jersey to East Texas. Its natural range includes the Atlantic Coastal Plain, the Piedmont Plateau, parts of the Cumberland Plateau and Appalachian Mountains, and across the eastern and western Gulf Coastal Plain (Baker and Langdon 1990). Loblolly is the preferred species for plantation forestry in the South, and millions of acres of native mixed pine, pine-hardwood, and hardwood-pine stands across the South have been converted to genetically improved and intensively managed loblolly pine plantations for use in timber and fiber production.

Shortleaf pine is the most widely distributed of the four southern pines; it is found in 22 States, typically in mixture with other pines (especially loblolly) or hardwoods. However, in the Ouachita Mountains of Arkansas and Oklahoma, the species is the only dominant naturally occurring pine (Guldin 2007, Lawson 1990).

Slash pine has the smallest native range of the four species, found from southern South Carolina, through the hills of south Georgia and virtually all of Florida, and west along the lower Gulf Coastal Plain to southern Louisiana. It is not native to the trans-Mississippi, but has been widely planted and direct-seeded in western Louisiana and eastern Texas on cutover longleaf pine sites (Lohrey and Kossuth 1990).

Longleaf pine is native along the lower Atlantic and Gulf Coastal Plains from Virginia to East Texas, and once occupied an estimated 92 million acres (37.2 million ha) of the South. Today, it is much less widely distributed over roughly 3.2 million acres (1.3 million ha) due to cut virgin stands, fire exclusion, and reforestation of cutover areas with loblolly and slash pine (Boyer 1990, Landers and others 1995). However, earnest efforts are under way to restore longleaf pine ecosystems, especially on Federal and State lands such as national forests and lower Coastal Plain military bases.

The four southern pines are occasionally found in association with minor pine species such as spruce pine (*Pinus glabra* Walt.) in the lower Gulf Coastal Plain, pond pine (*P. serotina* Michx.) in the lower Atlantic Coastal Plain, and the pines having a more northerly distribution that are found in the Appalachians: table mountain pine (*P. pungens* Lamb.), Virginia pine (*P. virginiana* L.), pitch pine (*P. rigida* Mill.), and eastern white pine (*P. strobus* L.). Throughout the South, pines are found in intimate mixture with hardwoods, especially the oaks and hickories that comprise the potential natural vegetation communities (Keys and others 1995) that would eventually dominate the forests of the South in the absence of disturbance.

23.1.3. Natural Disturbance in Southern Pine Ecosystems

The southern pines are early-successional species adapted to disturbance events of varying size and scale, especially at larger scales. The climate of the South features a variety of large-scale disturbance events, any one of which can result in the devastation of an existing stand and create open conditions for establishment of a new age cohort of pines. Tornadoes, hurricanes, ice, drought, and fire are all prominent to varying degrees as major and minor disturbance events in the southern forest.

But the importance of the native southern pine beetle (*Dendroctonus frontalis* Zimmermann) (SPB) should not be overlooked in any discussion of disturbance ecology of southern pines. Outbreaks of the SPB can, if unchecked and under the proper conditions, grow to cover thousands of acres, and even if controlled can affect hundreds of acres of pines in any part of the region at any time.

Fire Ecology of Southern Pines

Fire, whether as a result of natural or anthropogenic occurrence, is the single most important ecological element in southern pine stand dynamics and development. Presettlement descriptions of southern pine forests commonly described mature pines with virtually no midstory, and understory plant communities dominated by grasses, annuals, and perennials such that one could easily ride a horse through the woods and not be impeded by vegetation (Hedrick and others 2007).

Before European settlement, there were two dominant sources of ignition of fires in forests of the South—lightning strikes and anthropogenic activity. Lightning is a common disturbance agent in southern forests. A thunderstorm passing through a forested landscape can produce many lightning strikes, any one of which can result in wildfire (Coulson and others 1999b). In addition, pines struck by lightning undergo a physiological response to that event that attracts SPBs to the tree—an important trigger in the epidemiology of infestations (Coulson and others 1983, Coulson and others 1999b).

Anthropogenic use of fire is important both in presettlement and post-settlement times. Native Americans used understory burning to promote hunting and community defense (Guyette and others 2006). Early settlers adopted the practice as well to promote forage for feral and domesticated livestock. No doubt both the Native American and European cultures appreciated the benefits that understory burning provides for control of the ticks and chiggers that infest humans who live and work in southern forests.

Fire is especially important in southern pine ecosystem dynamics. Each of the four southern pine species has developed interesting and unique adaptations to prescribed fire that can result in favorable conditions for seedling establishment and development.

Shortleaf pine is the only one of the four whose saplings will reliably resprout if the crown of the sapling is topkilled (Figure 23.1), a trait that was described as an adaptation to fire early on (Mattoon 1915). Thus, in sapling-sized shortleaf pine stands, a new age cohort develops after fire through resprouting and some added seedfall if a seed source remains nearby.

On the other hand, loblolly and slash pine saplings are quickly and effectively killed by fire, which may explain why these species are thought to be the more mesic of the southern pines. For example, slash pine is found naturally only in the wetter areas of the Atlantic Coastal Plain (Lohrey and Kossuth 1990), and loblolly pine has a reputation also of a species that thrives naturally on moist to wet sites (Baker and Langdon 1990).

Both loblolly and slash pine are abundant and regular seed producers, producing adequate or better seed crops at least half the time. The loblolly-shortleaf pine type in the western Gulf Coastal Plain is arguably the most prolific pine type in North America (Figure 23.2), producing

Figure 23.1—Shortleaf pine sapling resprouting after being topkilled by prescribed fire. Poteau Ranger District, Ouachita National Forest. (USDA Forest Service photograph by Richard Straight)

Figure 23.2—Natural regeneration of loblolly and shortleaf pine beneath a mixed loblolly-shortleaf pine overstory, Crossett Experimental Forest, Ashley County, Arkansas. (USDA Forest Service photograph by James M. Guldin)

adequate or better seed crops 4 years in 5 and having bumper crops with more than a million seeds per acre (Cain and Shelton 2001).

Essentially, the regeneration dynamics for Coastal Plain loblolly-shortleaf pine mixtures and for slash pine are for mature trees to produce enough seed on a sufficiently frequent basis to establish seedlings within any new opening in the forest shortly after it is created, and to have those saplings grow fast enough to survive the next surface fire.

One might speculate that these respective strategies of resprouting vs. reseeding work together in mixed loblolly-shortleaf pine stands of natural origin, and may suggest a reason why shortleaf is retained in the mixture. If a newly established loblolly-shortleaf pine cohort has the opportunity to grow fast enough to escape the next fire, the species mixture would favor loblolly pine, whose saplings grow faster than shortleaf pine. But if a surface fire occurs in a mixed pine sapling stand, the loblolly will be killed and would require a nearby seed source to reseed the area, whereas the shortleaf saplings would simply resprout—a dynamic that might confer an adaptive advantage to shortleaf in circumstances where loblolly would normally outgrow shortleaf.

Longleaf pine has a different strategy entirely, featuring extended irregularity in seed crops and the famous grass stage. While in the grass stage, the seedling emphasizes root growth rather than shoot growth, and the terminal bud is protected from surface fire by the physiognomic pattern of bud scales and needle architecture. In those early years, grass stage seedlings require occasional surface fires to prevent grasses and other understory herbaceous and woody vegetation from suppressing the pines. Those fires also serve to control brown spot needle blight (*Mycosphaerella dearnessi* Barr.) that infects pine needles and that, if uncontrolled, can prevent seedling emergence from the grass stage (Boyer 1979). After several years and under proper conditions, longleaf seedlings break the grass stage and initiate height growth rapidly (Figure 23.3).

Other Disturbance Agents in Southern Pines

Four other disturbance agents are sufficiently important to warrant special mention in southern forests: windstorms, ice storms, drought, and SPB. It is likely that all featured some degree of interaction with fire in presettlement forests, but there is little direct evidence of this.

Windstorms include two very different events. The first and by far the most devastating on a regional basis are hurricanes, which generally occur from June through October. With winds near the eye of a Category 4 hurricane in excess of 130 mph, the devastation wrought upon landfall in Atlantic and Gulf Coastal Plain forest types is tremendous. Stands in the path of the center of the hurricane are virtually certain to be completely lost, and stands in a wider band are also subject to considerable windthrow and breakage. In natural conditions, the degree to which scattered trees survive the storm and subsequent disturbances such as wildfire may determine the future species composition of the area.

Equally devastating on a local basis are tornadoes, which generally occur from April through June. More common in the western part of the region than the eastern, these storms develop during extreme transitions between cold fronts and warm fronts. The windspeeds found in tornados exceed those in hurricanes, with a midscale F3 tornado producing winds of 158-206 mph. Although the area affected by tornadoes is much smaller regionally than hurricanes, the damage from tornadoes can be dramatic locally (Figure 23.4), exceeding hundreds of acres of damage in an F3 event with a majority of trees broken or uprooted along the path of the storm.

Drought is the most insidious of the common disturbance events, and generally contributes to a malaise in forest growth and development that can result in significant effects if sufficiently prolonged. For example, there was a drought of several years' duration in southern forests west of the Mississippi River in the early 1950s, and reports are that mortality of white oak (*Quercus alba* L.) was widespread; recent data suggest that the effects of such droughts can last for decades after the drought has ended, and can predispose forest stands to other disturbance events (Dwyer and others 1995).

Ice storms can be especially damaging in the more northerly distributed forests of the South, especially in mountainous regions. Ice and glaze events are relatively common, and while they generally do not cause widespread devastation across the landscape, stands during certain periods of development seem especially vulnerable (Bragg and others 2003). Accumulations of ice are especially likely to damage pine stands younger than 25 years old, that are densely stocked with low live crown ratios, and that have recently been thinned (Figure 23.5).

The SPB is the single most damaging insect in southern pine forest types. It is known for episodic outbreaks in high-hazard stands that, if unchecked, can expand to cover thousands of acres. Outbreaks of the SPB tend to be more common in the lower Coastal Plain than in the upper Coastal Plain and Piedmont, although recent outbreaks in the southern Appalachians and the Cumberland Plateau suggest that where there are pines in a high-hazard condition, the beetle will find them.

Figure 23.3—Planted longleaf pine saplings between age 5 and 8 at different stages of release from the grass stage. Winn Ranger District, Kisatchie National Forest. (USDA Forest Service photograph by James M. Guldin)

Stand Development in Southern Pines

All four species are generally considered intolerant of shade as mature trees, but shade tolerance is more pronounced at younger ages especially in loblolly and shortleaf pine, both of which can tolerate more overstory shade when young than can longleaf and especially slash pine.

The southern pines also share the interesting attribute of being able to respond to release from adjacent or overtopping competition at relatively advanced ages. This enables the pines to maintain site occupancy under partial disturbance events such as ice storms or wind events. The four species also show

Figure 23.4—Stand conditions after an F3 tornado on 27 November 2005 in a mature even-aged shortleaf pine stand, Winona Ranger District, Ouachita National Forest. Note how the residual stem density approximates the seed cut in the seed-tree reproduction cutting method. (USDA Forest Service photograph by James M. Guldin)

good ability to differentiate in height, which helps minimize extended periods of sapling stagnation. However, stagnation can occur to a certain degree in densely stocked naturally regenerated sapling stands, especially in shortleaf pine stands.

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

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

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

Thus, the entire gradient of natural disturbance events, from severe events that give rise to continuous regeneration cohorts across the stand to localized events that give rise to discontinuous regeneration cohorts within the stand, are reflected in the reproduction cutting methods used to naturally regenerate managed stands.

23.2. SILVICULTURE FOR SOUTHERN PINES

Silviculture is defined as the theory and practice of controlling forest composition and development (Smith and others 1997). The practice of silviculture is generally subdivided into three general areas: the regeneration of the desired species from germination through early development, the intermediate treatments or

Figure 23.5—Ice damage from a December 2000 ice storm in a recently thinned poletimber stand of shortleaf pine, Winona Ranger District, Ouachita National Forest. (USDA Forest Service photograph by James M. Guldin)

tending of established stands from immediately after the regeneration phase up to the point of maturity, and the reproduction cutting methods used to harvest a mature stand and concomitantly to establish the succeeding stand.

The individual treatments in the practice of silviculture can fit in several categories: treatment of the forest site, the forest floor, the woody vegetation in the main canopy, the woody and nonwoody vegetation in subordinate canopy positions, or the residues of vegetation. All have some degree of influence in stand development, stand structure, rates of growth, and yield. Different treatments also have different degrees of usefulness in reducing the hazard and the rate of change of hazard in relation to SPB.

A silvicultural system is the collection of individual silvicultural treatments conducted over time to transform a forest stand from its existing condition to a desired future condition. The system is identified by the reproduction cutting method that initiates the new stand, because of the inordinate ecological influence that the initial reproduction cutting creates, especially in the first decade or two after the new stand or age cohort is established (Smith and others 1997).

The silvicultural system encompasses the specific regeneration treatments designed to prepare the site and establish a new generation of seedlings either naturally or artificially, the intermediate treatments designed to promote stand development, and the subsequent reproduction cutting method at the end of the rotation to establish the succeeding stand. Systems can be amended or changed as needed if a given forest landowner decides on different objectives, or if ownership of the land changes hands.

Generally speaking, the silvicultural systems a landowner applies in southern pine stands depend on a host of objectives related to timber and fiber growth and yield, recreation, aesthetics, range, agroforestry, watershed, and other values that combine to satisfy the goals of ownership across the landowner's forest holdings. The kinds of treatments that are prescribed, the intensity with which they are applied, and the timing by which they are implemented can have profound differences in achieving the landowner's goals.

That spectrum of treatments also results in different levels of hazard in a given stand to SPB, and can result in different rates of change of SPB hazard as well. Further, that hazard might change depending not only on what the landowner chooses to do, but also on what adjacent landowners may choose to do in their pine stands.

There is no better set of forest types to practice diverse silvicultural prescriptions than those dominated by the four major southern pines: loblolly pine, shortleaf pine, slash pine, and longleaf pine. The greatest two silvicultural advances of the 20th century were, arguably, the development of genetically improved pine planting stock with which to reforest cutover stands or abandoned agricultural lands, and the development of chemical amendments such as fertilizers and herbicides with which to promote rapid pine growth and discourage the development of woody and herbaceous vegetation competing with the pines (Fox and others 2007).

Concurrently, though, many landowners seek ownership goals that are difficult to achieve using pine plantations. The four southern pine species, again with generally good success, also respond quite well to even-aged and in some cases to uneven-aged silvicultural systems that rely on maintaining some degree of continuous overstory cover, and that rely on natural regeneration rather than planting to reforest the site when a new age cohort is sought (Guldin 2004).

These different silvicultural systems and the tools used to manage them can create very different stand conditions that run the gamut from an age cohort of seedlings of genetically identical origin planted on the same day, to stands having many different ages and size classes on the same acre of land. Thus, the challenge and the fun of being a silviculturist for a landowner is to interpret the landowner's ownership goals using this spectrum of available silvicultural systems across the forested landscape that includes the owner's forest lands, as well as some consideration of what the owner's neighbors are doing.

The science of silviculture is knowing the technical details that underlie the individual practices prescribed in a given stand, in what part that specific prescription plays in the larger silvicultural system for the stand being managed, and in how the landowner's forest lands can be managed to be healthy, sustainable, and productive in the context of the forest landscape within which the owner's lands occur. The art of silviculture is in the details—the ways in which the orchestration of the combined benefits produced among the many individual stands concurrently achieve the landowner's goals.

Excellent summaries of the silviculture of southern pines have been developed over the past 4 decades and are still appropriate references for landowners and the foresters who advise them. Burns (1983) includes general discussions for most of the important forest types in North America, including the southern pines. Overviews of the general principles of plantation silviculture and silviculture of naturally regenerated stands were recently published (Fox and others 2007, Guldin 2004). State-of-the-art summaries of the selection method are also available, one for longleaf pine (Farrar 1996) and the other for loblolly and shortleaf pines (Baker and others 1996).

23.2.1. Reproduction Cutting Methods

Eventually there comes a point in the life of a forest stand where the forester decides to harvest all or part of the overstory, and to obtain a new age class or cohort of regeneration for the future. The success of this process is fundamental to the concept of forest sustainability. The first indicator of sustainability is whether, when a reproduction cutting is made, a new cohort of the desired species is successfully established in conditions that will allow it to grow and develop in an acceptable manner.

Overall, there are two broad categories of reproduction cutting methods: even-aged methods and uneven-aged methods. The even-aged methods (clearcutting, seed tree, and shelterwood methods) result in a new crop of seedlings of proper density distributed uniformly across the entire stand. That new age cohort is then managed through immature stages of development to maturity, and eventually to some predetermined final harvest age generally identified as the rotation age. In these even-aged methods, then, the forester is usually dealing with one age class, but some modifications of the even-aged methods allow for two age classes to be concurrently present either during the establishment of the new cohort or throughout the rotation (Smith and others 1997).

The even-aged silvicultural system applied to establish and manage the new stand is generally identified by the reproduction cutting method used to establish the stand, and calls for a successive series of age- or size-appropriate silvicultural treatments from the point of planning for the new stand through its maturity. Each prescription is applied more or less homogeneously across the entire stand of trees.

The second category of reproduction cutting methods is the uneven-aged methods (single-tree selection and group selection), which are managed under an indefinite time horizon rather than a specific rotation, mediated by use of a regularly occurring cutting cycle that guides the silvicultural treatments in the stand. Uneven-aged stands have three or more age cohorts of trees of the desired species intermingled to varying degrees throughout the stand, from identifiable groups of the same age class interspersed through the stand under the group selection method to a more intimate and unmappable mixture of trees of different ages occurring across the stand in the single-tree selection method. Cutting cycle harvests are used to concurrently satisfy the need for reproduction cutting, to create growing space of a new age cohort, for intermediate treatment of immature trees, and to prepare mature trees for their role as progenitors of new age cohorts in subsequent cutting cycle harvests.

The uneven-aged silvicultural system is usually identified by whether group or single-tree selection is prescribed. Under either method, the prescription is implemented using a repeated series of cutting cycle harvests of appropriate pattern for establishment of the new age cohort. These harvests also serve to conduct concurrent treatments in both immature and mature age cohorts, and to stimulate growth of seed-bearing mature trees.

Even-Aged Reproduction Cutting Methods

Even-aged reproduction cutting methods harvest all or nearly all of the mature trees in the overstory, with the intent of creating a new cohort across the entire stand. The three most common even-aged methods are the clearcutting method, the seed tree method, and the shelterwood method, with variations of each that allow for natural or artificial regeneration, and retention or removal of seed trees as appropriate.

The clearcutting method

In the last half of the 20th century, the predominant application of reproduction cutting methods in southern pine stands across the South focused on one silvicultural system—clearcutting and planting. This focus has been made possible by two great advances during that time—the development of genetically improved planting stock and the advent of herbicide technology for control of unwanted vegetation in planted stands.

The silvicultural system of clearcutting, planting, and associated intensive treating has come to define intensive forest management. Forest industry, nonindustrial private forest (NIPF) landowners, and government agencies have all employed variations of this prescription, and as a result the area in plantations in the South has gone from virtually none to roughly 31 million acres (12.5 million ha) in the last 50 years (Conner and Hartsell 2002).

It is unequivocally true that if one seeks to maximize fiber production, the clearcutting reproduction method followed by plantation establishment using genetically improved planting stock and properly timed herbicide and fertilizer treatments is far and away the best approach to use. In 1995, plantations occupied 15 percent of the forest land in the South but provided 35 percent of the harvested volume (Wear 2002). By 2040, pine plantations will occupy approximately 50 million acres (20 million ha), or 25 percent of the southern forest area. This will represent roughly half of the projected pine-dominated forest area at that time (Wear 2002).

Modern silvicultural practices using clearcutting and planting are extraordinarily efficient. Intensive practices prescribed with careful attention to month and year will produce pine stands that grow from two to three times as fast in early height growth, and up to four times as rapidly in total merchantable volume in the first several decades, as naturally regenerated pine stands in the region (Fox and others 2007).

The dominant application of the clearcutting method is in association with artificial regeneration using genetically improved planting stock, and the practice is the mainstay of forest industry and forestry investment land managers across the South. The typical silvicultural prescription is to clearcut the stand, utilizing as much biomass as can be removed, and then to conduct supplemental silvicultural treatments that dispose of logging slash, eliminate or reduce competing vegetation as needed, and treat the forest floor or mineral soil if necessary. This sets the stage for planting genetically improved pine seedlings selected for rapid growth and other favorable attributes such as stem straightness, small branches, and crowns that photosynthesize efficiently.

Clearcutting is also occasionally used on public lands in the region, with a somewhat less intensive set of site preparation treatments. On national forested lands, the practice has been applied with all of the four major southern pines, generally such that the planted species is native to the site.

It is on public lands where shortleaf pine and longleaf pine plantations are most commonly planted. With the reductions in clearcutting on public lands, most shortleaf plantations are generally older, but are commonly found in the southern Appalachians, the Piedmont, the Ouachitas, and to a lesser extent the Ozarks. On the other hand, there is keen interest in restoration of longleaf pine on the lower Gulf Coastal Plain from Florida to Texas, and one key element of that restoration will involve rehabilitation of understocked stands or clearcutting stands dominated by other species such as slash pine.

Slash pine is not native west of the Mississippi River. However, afforestation with slash pine by planting and direct seeding was important to rehabilitate cutover longleaf stands that had utterly failed to regenerate naturally to longleaf pine after the highgrading of virgin stands in the first half of the 20th century. Today on public lands especially, efforts are under way to convert those slash pine stands outside the native range of the species back to longleaf pine through clearcutting, and planting containerized longleaf pine planting stock is a key to the success of the prescription.

To a lesser extent, similar practice will be increasingly common on industry lands acquired by the Federal government in Arkansas and Oklahoma. Here, the native shortleaf pine stands were converted to loblolly pine by forest industry in the past 4 decades, despite the fact that the Ouachitas are just to the north of the natural range of loblolly pine. Some of those industry lands are now being brought into Federal ownership through purchase and land exchange. Where this occurs, plans are to grow the loblolly to appropriate maturity, then clearcut those stands and convert them back to shortleaf pine through planting. Prescribed burning will then be done a few years after planting to eliminate any naturally seeded loblolly pine regeneration from the sites.

Across both public and private lands, clearcutting has been a controversial practice, mostly because of cutover appearance of recently harvested stands. But there is no question that, silviculturally, clearcutting is a very effective reproduction method that quickly results in the establishment of a new fast-growing stand of species that are sought by land managers and landowners, especially those primarily interested in fiber production and return on investment, and increasingly by those who seek to restore species to sites where no seed source locally exists.

The seed tree method

In the seed tree method, a few mature pine trees of good form, evidence of fruitfulness, and an appearance of windfirmness are retained on the site after harvest to serve as a seed source for the cutover stand. Typically, seed trees are distributed more or less uniformly across the site in such a way that the entire area of the harvested stand is within an acceptable dispersal distance of one or more of the residual seed trees. However, the exact spacing of the residual trees is less important than the attributes of form, fruitfulness, and sturdy appearance.

A reasonable estimate for the number of seed trees depends on tree size, but it is not unusual to reserve 4-10 trees per acre (10-25 pine seed trees/ha), with a corresponding residual basal area (BA) from 5 to 15 square feet per acre (1-3 m^2/ha). The harvest that takes all but the seed trees is called the seed cut, and the subsequent harvest that removes the seed trees is called the removal cut (Smith and others 1997).

The modern application of the seed tree method has nothing in common with the retention of seed trees codified during the cutting of the virgin southern pine forest in the early 20th century. Those laws mandated retention of a few trees per acre after harvest, and led to nothing more than leaving the poorest trees of marginal size to reforest the site, which was largely ineffective.

Under modern prescriptions, proper application of the seed tree method includes the retention of trees with good form, acceptable branch characteristics, and evidence of past seed production. These attributes are easier to determine in some species than others. For example, in shortleaf pine, cones tend to persist for a number of years after seed are shed (Lawson 1990), whereas loblolly and longleaf pines tend to drop their cones after seedfall (Baker and Langdon 1990). In shortleaf pine stands, marking crews must inspect tree crowns to find evidence of past fruitfulness, whereas in loblolly or longleaf pines, marking crews must look on the forest floor beneath a tree to judge whether it is a good cone producer.

The biggest limitation in applying the seed tree method is ensuring that the residual trees can produce enough seed to adequately reforest the site. Of the four major southern pines, the seed tree method works best with loblolly pine in the West Gulf region, where adequate or better seed crops are produced, on average, 4 years in 5, and where bumper crops produce more than a million seed per acre (Cain and Shelton 2001). Slash pine, which also tends to produce abundant seed, can also be managed quite easily with the seed tree method.

Conversely, seed production in longleaf pine is highly periodic, and use of the seed tree method is rarely successful with this species. Empirical evidence suggests that the seed tree method can also be made to work in shortleaf pine, which falls between loblolly and longleaf in periodicity of seedfall (Guldin and Loewenstein 1999).

The archetypal example of the seed tree method in application to southern pines has been described for the mixed loblolly-shortleaf pine type in the upper West Gulf Coastal Plain (Zeide and Sharer 2000), and captures the silvicultural system widely used by a major forest industry landowner in the region during the last 4 decades of the 20th century. Prescriptions called for retaining 10-20 square feet per acre (2.3-4.5 m^2/ha) of BA of trees with good form and with dbh of 16-20 inches (40-50 cm). The seed trees were usually taken in a removal cut 3-5 years later, which produced an operable harvest of 500-1,500 basal feet per acre (2.9-8.8 m^3/ha) of sawlogs.

Removal of the seed trees also thinned the excessive pine regeneration that was common in this forest type. The first commercial thinning occurred between the ages of 17 and 20 years, leaving about 70 square feet per acre (16 m^2/ha). The next thinning, at age 25, included some small sawlogs. Subsequent thinnings on a 5-year cycle averaged 2,000 basal feet per acre (11.7 m^3/ha) in each thinning. The final seed cut produced between 5,000 and 7,000 basal feet per acre (29.2-40.8 m^3/ha). Thus, growth for the rotation averaged more than 300 basal feet per acre (1.75 m^3/ha) annually.

Late-rotation thinning also released the crowns of the future seed trees, which increased cone and seed production for subsequent reproduction cutting. Regularly scheduled prescribed fires on a 3-5 year cycle, coupled with hardwood control on a 5-10 year cycle, promoted visibility within the stand that enhanced subsequent thinning treatments, and if carried through the end of the rotation, reduced the need for intensive site preparation in the subsequent rotation.

The shelterwood method

The shelterwood method is similar to the seed tree method in that residual trees are retained to reforest the site after harvesting occurs, but more trees are retained. In their description of the shelterwood method, Smith and others (1997) include three specific elements: the preparatory cut, the seed cut, and the removal cut.

The preparatory cut is designed to enlarge the crowns and root systems of the future seed trees so as to optimize their ability to produce cones. Late-rotation thinning commonly conducted in pine sawtimber stands generally fulfills the intent of the preparatory cut. But if the stand has not been thinned for an extended period, a preparatory cut 5-10 years prior to the seed cut to a residual BA of 75-90 square feet per acre (17.2-20.7 m^2/ha) is warranted. During the seed cut, 15-30 trees per acre (35-75 trees/ha), having 20-40 square feet per acre (4.5-9 m^2/ha) of BA, are selected for retention (Figure 23.6). Favorable traits for residual pines include stem form, windfirmness, and evidence of past seed production. The removal cut harvests the seed trees after the new stand has developed past the point of risk from seedling-related mortality.

One operational advantage of the shelterwood over the seed tree method in southern pines is that the volume of the residual trees in the shelterwood is greater than that of the seed tree method, and thus is more likely to attract interest from loggers during the removal cut. Conversely, if carelessly done, logging during the removal cut can adversely affect stem density of the regeneration, especially at higher residual BAs

Depending on management objectives, the final harvest may be deferred for half or more of the rotation length, resulting in a two-aged

Figure 23.6—Several years after the seed cut in a shelterwood reproduction cutting method applied in a shortleaf pine stand, Wimble Ranger District, Ouachita National Forest. (USDA Forest Service photograph by James M. Guldin)

stand; this method is referred to as an irregular shelterwood (Helms 1998, Smith and others 1997).

Under traditional application of the shelterwood method, microclimatic ecological conditions are ameliorated relative to those found in fully open conditions (Valigura and Messina 1994). Thus, one reason to apply the shelterwood is to moderate conditions that might be too harsh for seedlings to survive under a clearcut or a seed tree prescription. But as a practical matter, the shelterwood method is popular for species in which seed production is erratic or unreliable; the added numbers of seed trees that remain in the shelterwood often make the difference between adequate stocking and less-than-adequate stocking.

Among the most prominent examples of the shelterwood method in southern pines is the experience with longleaf pine developed for the lower Atlantic and Gulf Coastal Plain (Figure 23.7). Longleaf pine has the deserved reputation of being the most difficult of the southern pines to regenerate naturally, but clever research has identified the practices needed to naturally regenerate the species using the shelterwood method (Boyer 1979, Croker and Boyer 1975). Seed production in longleaf is optimal when the seed cut retains 30-40 square feet per acre (6.9-9.2 m^2/ha) of BA (Maple 1977). Fewer trees result in fewer cones per unit area, and more trees do not enhance cone production.

Figure 23.7—Longleaf pine saplings established after the seed cut in the shelterwood method. Savannah River Forest Site, Aiken, South Carolina. (USDA Forest Service photograph)

Prescribed fires are essential to control brown spot needle blight, and thereby to release seedlings from the grass stage (Boyer 1979). However, seedling mortality is highest beneath the crowns of residual trees because the buildup of pine straw promotes prescribed fires sufficiently intense to kill them. All of these factors have led scientists to conclude that the need for available growing space, the need for frequent prescribed fire, the optimal development of cones in the canopy, and the ability to store seedlings in a seedling bank beneath the overstory of longleaf pine could be achieved using the shelterwood method.

Uneven-Aged Reproduction Cutting Methods

Uneven-aged methods harvest a small portion of the mature and immature trees in the stand, with the intent being to promote the growth of the trees that remain, as well as to encourage regeneration establishment and development in the openings that are created from the harvest of the mature trees. The two most common variants of uneven-aged reproduction cutting methods are single-tree selection and group selection, which vary largely based on the size of the opening created during the harvest and the manner in which subsequent harvests are made.

Applying uneven-aged reproduction cutting methods in species that are intolerant seems counterintuitive, but the earliest successful examples of the selection method were in pines. The Dauerwald in Germany (Troup 1952) was implemented to convert plantations of Scots pine (*P. sylvestris* L.) to a more naturalistic system, and the improvement selection method was developed in Arizona (Pearson 1950) to meet unique stand conditions in ponderosa pine (*P. ponderosa* Dougl. ex Laws.).

In the South, uneven-aged silviculture has been used in the region since the 1950s by family lumber companies and forest industry landowners. The longest record of success with the method has been in west Gulf Coastal Plain loblolly-shortleaf pine stands in southeastern Arkansas (Baker 1986; Baker and others 1996; Guldin 2002, 2004; Guldin and Baker 1998; Reynolds and others 1984), with other long-term demonstrations reported in Mississippi (Farrar and others 1989) and southwestern Arkansas (Farrar and others 1984). Uneven-aged methods have also been used in longleaf pine in Florida and Alabama (Brockway and Outcalt 1998, Farrar 1996, Mitchell and others 2006), and in shortleaf pine stands in the Ouachita Mountains (Guldin and Loewenstein 1999, Lawson 1990).

There has been virtually no research on uneven-aged reproduction cutting in slash pine, but the group selection method has been suggested (Langdon and Bennett 1976), and other methods suitable for longleaf pine should also work with slash pine. In short, the selection method can be used in southern pines if attention is paid to marking, regeneration, and stand structure (Guldin and Baker 1998).

By definition, uneven-aged reproduction cutting methods create discontinuous stand conditions. They provide a temporally and spatially transient distribution of logging slash and debris within the stand, resulting in a heterogeneous distribution of volatile fine fuels. This reduces the need to treat fuels, since there is less of a chance that the entire stand will have fine fuels throughout, but it also makes it difficult to treat those fuels if one should decide to do so. The added complication is that regeneration is being recruited in a discontinuous spatial pattern as well, and recruitment is repeated following every cutting-cycle harvest.

Stand-wide treatments such as prescribed burning are difficult to implement in uneven-aged stands. On the one hand, fuels are sufficiently heterogeneous to confound uniform fire effects and fuels treatment. On the other, the logging debris is concentrated in the openings where the desired regeneration is found, and the saplings won't survive the fire. More research is needed to better understand the degree to which uneven-aged stands can be managed with fewer age cohorts obtained every 2 decades rather than 1, which might provide a window during the second decade when prescribed burning would not kill the youngest age cohort.

The single-tree selection method

The single-tree selection method is still occasionally used to manage for large high-quality pine sawtimber. The standout experience over 7 decades with the Farm Forestry Forty demonstrations at the Crossett Experimental Forest in south Arkansas had its origins in the rehabilitation of understocked stands (Baker and Shelton 1998) and was imposed using a simple marking rule—cut the worst trees and leave the best, regardless of diameter or pattern of occurrence. Stands that had initially been understocked recovered to full stocking within 2 decades (Figure 23.8).

Figure 23.8—Classic uneven-aged stand structure after 69 years of implementation in west Gulf Coastal Plain loblolly-shortleaf pine stands, Crossett Experimental Forest, Ashley County Arkansas. (USDA Forest Service photograph by James M. Guldin)

Details of the implementation of the selection method in these mixed loblolly-shortleaf pine stands have been outlined elsewhere (Baker and others 1996, Guldin 2002, Guldin and Baker 1998), and serve as appropriate mensurational guidelines for any of the intolerant southern pines managed using either volume regulation with a guiding diameter limit or structural regulation using the BDq method. Similar guidelines have been developed explicitly for longleaf pine (Farrar 1996, Guldin 2006).

Expressed in the customary units of measure used in the United States and specifically in field forestry applications nationwide, stands are marked every 10 years to leave about 5,000 basal feet per acre (29.1 m^3/ha) of volume in 60 square feet per acre (13.8 m^2/ha) of BA of the best trees across all size classes with about 45 square feet per acre (10.3 m^2/ha) in sawtimber-sized trees and the balance in smaller size classes. The residual BA should include the best looking trees, and the poorer trees should be harvested.

It is feasible to operate on a 10-year cutting cycle if stands have annual growth rates of approximately 200 basal feet per acre (1.2 m^3/ha) and 2 square feet per acre (0.5 m^2/ha) of BA, which give operable cutting cycle harvest volumes of about 2,000 basal feet per acre (11.7 m^3/ha) every 10 years. Thus, the stands grow back to about 7,000 basal feet per acre (40.8 m^3/ha) of volume and 80 square feet per acre (18.4 m^2/ha) of BA prior to the subsequent cutting cycle harvest. All four of the major southern pines meet this rate of growth, and Coastal Plain loblolly and slash pine stands exceed it.

The scarification from logging is usually sufficient to expose a mineral soil seedbed for optimum germination and establishment of pine seedlings. However, site preparation treatments targeted to control competing vegetation are difficult to do; as a result, periodic herbicide treatment to control hardwoods is highly recommended (Baker and others 1996). One effective hardwood control treatment per decade, generally a year or two after a cutting cycle harvest, is usually sufficient to suppress fast-growing hardwood sprouts so that the slower growing pine seedlings are not overtopped and shaded out.

It is difficult to firmly conclude that the single tree selection method will be successful in converting even-aged pine and pine-oak stands to balanced uneven-aged structure because the process will require several cutting cycles to achieve. Uneven-aged stands are defined as supporting three or more age classes (Helms 1998, Smith and others 1997), and balanced stands probably have closer to six or eight different age cohorts separated in age by a decade or two from one to the next.

When converting an even-aged stand to uneven-aged structure, a major goal of the first entry is to obtain desired regeneration within some parts of the stand so as to begin the process of recruiting new age cohorts as soon as possible. That is best accomplished by marking the stand to leave a variable pattern of residual stem density and BA, which creates locally understocked conditions in parts of the stand within which regeneration might become established.

A common problem in the first cutting cycle harvest of an even-aged to uneven-aged conversion is marking the stand with insufficient attention to spatial heterogeneity. If marking crews have experience thinning even-aged stands, they are prone to mark the first cutting cycle harvest as a free thinning conducted with attention to a uniform distribution of trees across the stand, which fails to create an appropriate degree of spatial heterogeneity within the stand. This can delay the establishment of the first new age cohort in the stand, which adds a cutting cycle's worth of time to the period of conversion.

The biggest disadvantage of the selection method in intolerant southern pines is the management commitment required to maintain proper stand structure, especially with single-tree selection. The concept is to manage size classes rather than age classes, relying on the assumption that diameter approximates age in stands with three or more age classes. To maintain adequate sunlight in the understory for development of the seedling and sapling classes, the overstory and midstory diameter classes of the stand must be deliberately maintained in a slightly understocked condition.

Most uneven-aged stands of southern pines grow from 2 to 3 square feet per acre (0.5-0.7 m^2/ha) annually, and regeneration becomes suppressed beneath a stand carrying roughly 75 square feet per acre (17 m^2/ha) or more. Cutting cycle harvests usually leave between 45 and 60 square feet per acre (10.3-13.8 m^2/ha) immediately after harvest, which suggests that cutting cycle of 10 years or less will be needed to maintain acceptable understory development.

If timely cutting cycle harvests are not repeatedly maintained, the understory development needed to maintain stand structure will be lost. This will lead to a reversion of the midstory and overstory crown classes to a homogeneous canopy profile more typical of a late-rotation even-aged stand, rather than the heterogeneous canopy profile that characterizes a well-regulated uneven-aged stand.

The group selection method

In the group selection method, prescriptions call for the first cutting cycle harvest to create an initial set of group openings and to conduct the equivalent of a light low thinning in the matrix between the group openings. Operational implementation of group selection in this region usually results in the group openings being used as logging decks, with the result being that they are heavily scarified and become excellent seedbeds for establishment of pine reproduction.

If needed, release treatments using individual stem application of herbicide are prescribed to control the fast-growing hardwood sprouts competing with the slower growing pine seedlings. These treatments are usually conducted only within the group openings because the main effort to secure regeneration is within the openings rather than in the matrix between the openings.

Another reason some practitioners prefer group selection to single tree selection when converting even-aged stands to uneven-aged stands is the efficiency of administrative operations. Follow-up treatments such as individual-stem herbicide applications or regeneration surveys are easier to conduct under group selection where the only area to be treated is the group vs. single tree selection where the entire stand must be evaluated.

Finding the way to the group opening can be simplified using a good sketch map, or by locating the opening with a handheld geographic positioning system receiver. Administratively, follow-up treatments such as cleaning or precommercial thinning should be targeted specifically to the openings, an easy process to work into operational contracts using maps or geographic locations of the openings where treatments are to be conducted.

On the other hand, there has been virtually no experience in the South with long-term repeated application of group selection to determine whether the group identity can be retained in the long run so as to control stand operations indefinitely as in an area regulation context. If not, the group selection methods will probably gravitate more toward a single tree selection method as multiple age cohorts are established and stand structure becomes more balanced.

The group selection method offers ecological advantages in managing the intolerant southern pines as well (Figure 23.9). The relatively open conditions found in group openings resemble the early seral conditions that are best for regeneration establishment and development in the southern pines, and this would further suggest that larger group openings rather than smaller ones would be more favorable (Fischer 1980).

Figure 23.9—Longleaf pine seedling and sapling development in a group opening under the group selection method, Winn Ranger District, Kisatchie National Forest. (USDA Forest Service photograph by James M. Guldin)

The openings created using group selection can be made without residual trees, relying on existing advance growth or natural seedfall from adjacent trees or by supplemental planting within the group opening. Retaining some residual trees at shelterwood BAs within group openings is also an option for longleaf pine (Farrar 1996, Guldin 2006), and would probably work nicely in shortleaf pine as well.

The major disadvantage to group selection is that the methods works well early in the installation of group openings, but are difficult to maintain over repeated cutting cycles without strictly adhering to an area-based regulation system—which may fall more into the realm of an even-aged patch clearcutting system rather than an uneven-aged selection system. That is not important to the trees, but might be important to managers if commitments have been made about the proportions of even-aged vs. uneven-aged area being managed across an area, as is often the case in national forest management plans.

23.2.2. Regeneration Treatments

Both natural and artificial regeneration can be used to regenerate pine-dominated forests in the South. Natural regeneration refers to methods designed to take advantage of the natural seedfall produced by trees in the forest through treatments that promote seed production, prepare the site to be receptive to seedfall, and nurture the establishment and development of the new seedlings that occur. Artificial regeneration refers to the deliberate collection of seed, either from trees growing in the wild or, preferably, from a seed orchard established expressly for the purpose. Those seeds are then handled in one of two ways—scattered as-is on the site through a practice called direct seeding, or planted under controlled nursery conditions to produce seedlings for outplanting in the field.

Artificial Regeneration

The vast majority of silvicultural prescriptions in pine stands on forest industry land or intensively managed forestry investment ownerships in the South rely on clearcutting, followed by intensive mechanical site preparation, herbicide and/or fertilizer application, and planting genetically improved nursery-raised pine seedlings at predetermined spacing. Coastal Plain and Piedmont sites across the South are highly suited to this practice because of gently rolling terrain. This supports conditions suited to mechanized harvesting operations, efficient and effective site preparation treatments, and easy access either for hand planting or machine planting.

Genetically improved planting stock is the mainstay of the southern pine industry in the South. The high-grading of forests in the South at the turn of the 20th century had, among other effects, an extraordinary removal of genetic material in the harvested trees. High-grading involves removing the biggest and best trees and leaving the worst.

There is a strong association of genetic quality of trees with growth rates and size on a given site especially in even-aged stands, where if all trees start at the same time, the largest in diameter and volume after a period of time are likely to have favorable genetic attributes that promote growth and vigor on the particular site where they are found. The widespread high-grading of the biggest and best trees across the region unquestionably had deleterious effects on the prevailing genetic quality of all of the southern pines in the South.

However, southern pines have a broad genetic base (Dorman 1976), and the forests that recovered from that high-grading still retained a wealth of genetic potential. Growth of the new stands that accidentally followed high-grading, as well as the response of trees that escaped the high-grading harvests of the day, provided a biotic refugium of genetic material that scientists in the middle of the last century were able to tap using the principles and practices of forest genetics, a quantitative field of study that concurrently required a highly advanced understanding of pine tree biology and physiology.

Careful field selections of superior trees across the South and careful breeding trials using the many families represented by those trees have resulted in the identification and widespread application of a variety of improved families for each of the southern pines. These are maintained in seed orchards across the South where seeds are produced and collected. Seeds are then planted under controlled nursery conditions, and seedlings are carefully tended for one growing season in the nursery. In the dormant season, seedlings are lifted from the nursery beds, stored, and transported to the field sites under highly controlled conditions, and outplanted on recently harvested sites that have been site-prepared appropriately for planting.

Most harvested sites on the Piedmont and Coastal Plain are able to be planted with relative ease (Wakeley 1954). Effective planting requires a number of steps to prepare the site prior to planting, and the number of these steps varies according to site conditions and the judgment of the forester about the ability of seedlings to survive.

At the least, site preparation involves the reduction or removal of harvest residues and other debris from the harvest of the previous stand. Removal of varying levels of competing woody, perennial nonwoody, and herbaceous vegetation through mechanical treatment, burning, or herbicide application is commonly done depending on the degree of vegetation control that is sought. Supplemental treatment of the forest floor or mineral soil is often prescribed if needed to ameliorate compaction or to alter microtopographic relief on the site for some reason. Fertilization is also used if needed to ameliorate or restore nutrient content of a site, or to boost early height growth of seedlings (Allen 1987).

If site preparation is sufficiently complete to allow machine access to a site, or if abandoned agricultural fields are being reforested, planting can be done by machine, typically a small crawler tractor or skidder that pulls a planting machine with a plow that creates a furrow, a cab for the field worker to sit and insert the seedling into the furrow, and a set of coulter wheels to close the furrow.

Hand-planting using a dibble is far more commonly used across the South, for the simple reason that sites are typically not clean enough to allow access to the equipment for machine planting. Planting crews can better negotiate the typical harvested site than the machine.

Direct seeding is occasionally used to reforest cutover sites. The heyday of direct seeding was the middle of the last century, when vast areas of the South, especially in the lower west Gulf Coastal Plain, remained unforested after harvest of virgin stands of longleaf pine (Derr and Man 1971).

In some of the mountainous terrain in the South, planting after clearcutting is not a trivial matter because of the high stoniness of the soils. The Ouachita Mountains of west-central Arkansas and eastern Oklahoma are arguably the most difficult planting environment in the South because of the stoniness of the thin soils that only marginally cover the underlying jumbled geological substrate throughout this rugged region. Hand-planting is tiresome, inefficient, and impractical because of the difficulty workers have working around the surface and subsurface rocks using a dibble or other tool.

It's virtually impossible to make a hole large enough for a seedling with only a hand tool.

In addition, late summer on a south-facing ridgetop in the Ouachitas presents such hot and dry microclimatic conditions for newly planted seedlings that plantation survival rates without supplemental site preparation averaged roughly 50 percent (Walker 1992), and some plantations simply did not survive the drier growing seasons with acceptable stocking.

Two changes were made in reforestation prescriptions to enhance seedling survival in the Ouachita Mountains. The first was to grow a larger seedling in the nursery that had previously been used (Brissette and Carlson 1992), which alters root-shoot biomass relationships favorably to enhance survival. This has been an increasingly common practice in the past 15 years for both pines and hardwood species in the South.

The second was to enhance the planting environment for the seedling using a site preparation treatment called ripping or subsoiling. This consists of using a bulldozer with a vertical steel bar attached to it to essentially plow a furrow 12-18 inches deep in the rocky hillside soil during the late summer of the year prior to planting, a practice that alone increased seedling survival by 10-30 percent (Walker 1992).

Ripping works in several ways. First, it breaks through surface rocks and provides roots with access to subsurface soils that retain moisture longer than surface soil layers. Second, rainfall dislodges soil particles from the sides of the furrow to the bottom, filling the ripped furrow with several inches of soil fines, into which the seedlings are planted in the dormant season. That small amount of microcolluvium provides an enhanced rooting medium for the seedling, allowing its roots to grow more quickly into the subsoil, and thus reduces the risk of mortality during the summer months.

Natural Regeneration

Given the interest and effectiveness of planting as a means of reforestation in the Southern United States, one might think that planting is required to properly manage southern pines. But this is not the case. All four of the major southern pines can be managed using natural regeneration methods.

Natural regeneration has particular advantages for the private forest landowner because it is far less costly to establish a new stand using natural regeneration than planting, especially using the modern planting prescriptions that include mechanical treatment followed by herbicide application and fertilization. A new stand can be established using natural regeneration for 10-25 percent of the cost of establishing a new plantation. Many landowners find this an attractive alternative.

The added benefit of natural regeneration is that residual seed trees are retained on the site after harvest, especially when using the shelterwood or selection methods. The ability to obtain timber revenues from a stand and yet have the stand retain continuous forested cover is highly sought by many landowners.

Natural regeneration can be obtained in any number of ways. The most common are through direct deposition of seed from trees on a recently harvested site, germination of seed stored in the forest floor, response of seedlings that have become established in advance of harvest, or stems that sprout after being cut or damaged in logging. The pattern followed by a given species varies, and depends upon the frequency of adequate or better seed crops.

Loblolly and slash pine, with their frequent seed crops, are the most easily regenerated of the southern pines, using the simple tactic of having residual seed trees cast seed in the autumn in recently harvested stands that have been properly site-prepared so as to expose mineral soil, which is the best seedbed upon which seed can germinate and become established.

The tactic for longleaf pine involves more attention to monitoring seed trees in late spring so foresters can get advance warning of an impending good seed year (Boyer 1979), which is relatively rare in longleaf pine. That triggers extra effort in site preparation, especially prescribed burning in units where regeneration is sought, to prepare a suitable seedbed. But with the grass stage of longleaf, one must plan for several years of nurturing seedlings to the point where they escape the grass stage and initiate height growth. All in all, the regeneration dynamics in longleaf pine are far more complicated than in loblolly and slash pine—which may help explain the dreadful decline in the natural range of the species in the early part of the 20th century.

Fully stocked shortleaf pine stands are not reliable seed producers. In the Ouachita Mountains, studies show 3-5 adequate or better seed-crops per decade, with an average of 100,000 seed per acre (247,000 seed/ha) annually (Shelton and Wittwer 1996, Wittwer and others 2003). These studies also report considerable geographic variation in seedfall, with higher amounts in the eastern Ouachitas and lower amounts in the western Ouachitas.

The sprouting habit of shortleaf pine might be useful in silvicultural applications in the context of pine regeneration accumulation, where foresters might rely upon both new seedlings and sprouts from established sapling rootstocks to regenerate a stand (Guldin 2007). A properly timed surface fire in a stand with some existing shortleaf pine saplings will result in topkilled seedlings that subsequently resprout, and will also create exposed seedbed conditions favorable to germination of new seedlings. Repeated fires of proper intensity should result in a bioaccumulation of pine seedlings and sprouts that serves essentially as a stored seedling bank ready to be released as a new age cohort after a natural disturbance event affecting the overstory—or after a properly timed reproduction cutting.

Site Preparation Treatments

Site preparation consists of the different kinds of treatments used to prepare the understory of the stand or the forest floor so as to promote the germination, establishment, and growth of the desired species. The intent of site preparation is to create microclimatic, edaphic, or physiographic conditions on the site that benefit establishment and development of seedlings and saplings of the desired species.

Site preparation typically falls into three classes of treatments: treatment of the slash remaining after reproduction cutting, control of competing vegetation, and treatment of the forest floor (Smith and others 1997). The goal of site preparation treatments is to reduce logging slash and competing vegetation, and to prepare the seedbed. Usually, the intensity of treatments prescribed depends on whether natural regeneration or planting is to be used, with more intensive site preparation activities usually being conducted for plantation establishment. In even-aged reproduction cutting, harvest activity removes all of the commercial timber, and the noncommercial residual biomass is removed by mechanical felling (shearing, chopping, or chainsaw felling), sometimes concentrated by piling, and then either broadcast burning or burning of piles is conducted to eliminate slash from the site. If needed, ripping usually follows again in late summer, with planting feasible in the following spring.

Bedding is an increasingly common practice as a tool for site preparation to rehabilitate soils from compaction during logging, and to provide a more stable soil structure for establishment of new plantations. The process involves the use of specialized equipment to create the bed, which then lies fallow for several months prior to planting (Figure 23.10).

Figure 23.10—Bedding as a final step in site preparation prior to planting on an upper west Gulf Coastal Plain site in Bradley County, Arkansas. (USDA Forest Service photograph by James M. Guldin)

Treatments of the woody and nonwoody vegetation are often species-specific. Some are intended to promote the development of the best trees of the desired species by removing more poorly formed trees of the same species, or to better regulate stem spacing so that tree crowns of the best trees are free of intraspecific competition. Others seek to remove different species with aggressive growth patterns or foliar canopy distribution, such as sprouting species when seedlings of a different species are sought.

In southern pines, two kinds of control of competing vegetation are typically practiced, and they commonly depend upon whether artificial or natural regeneration is used. The intensive site preparation applied in plantations prior to planting generally eliminates any residual woody vegetation, but herbaceous vegetation can impede seedling development if not controlled with herbicides.

With natural regeneration in southern pines, control of competing vegetation typically means controlling hardwoods, especially sprouting hardwoods that aggressively compete with seedling or sapling pines. This can be done with mechanical means, such as by cutting, with herbicides applied directly to competing vegetation, or with a broadcast herbicide timed to affect hardwoods that are still actively growing late in the growing season after pines have become dormant (Figure 23.11).

Soil displacement as a result of site preparation is a concern for cumulative watershed effects of silvicultural activity. Prescriptions which require raking, pushing, or dragging logging debris into rows or piles cannot be accomplished without some degree of soil movement. The less of this activity that is prescribed, the less of a problem there will be with soil movement. Ripping is designed to deliberately promote soil movement so rainfall can wash soil particles from the sides of the rip into the furrow, thereby creating an ideal planting medium and increasing the survival of planted seedlings. Cumulative watershed effects can be minimized by ripping along the contour, by creating periodic discontinuities of the rip along the contour so flow of water within the rip is interrupted, and by stopping the ripping before sensitive watershed areas such as stream zones are encountered.

Foresters see advantages in using prescribed fire as a site preparation tool both before and after harvest. Prior to harvest, burning is best conducted in spring or fall as a tool to prepare the seedbed for natural seedfall and, in shortleaf, to promote resprouting. If used after harvest, burning is used in late summer to dispose of slash often after it has been raked into piles. It

Figure 23.11—Effects of an August herbicide application for hardwood control in uneven-aged loblolly-shortleaf pine stands on the Crossett Experimental Forest, Ashley County, Arkansas; the stand to the left of the fireline was treated, the stand to the right was not treated. (USDA Forest Service photograph by James M. Guldin)

is not wise to use prescribed burning for site preparation before harvest during summer months or after harvest if a residual stand is in place because the heat of the fire might kill the residual stand.

When using uneven-aged silvicultural systems, site preparation is easier to impose under group selection rather than single tree selection. The reason is that regeneration in group selection is only expected in the groups, so site preparation can be concentrated in the groups to achieve the desired effect. Moreover, the groups are often located on a map, which makes it easy for field crews to work efficiently. In single tree selection, regeneration is often scattered across the stand, and there is no way to advise field crews where to go to apply the proper site preparation method. As a result, the entire stand must be examined, which results in inefficient fieldwork.

23.2.3. Intermediate Treatments

Intermediate treatments are intended for application in immature pole-sized or sawtimber stands. The goal of these treatments is to optimize the development of trees in the existing stand rather than to promote new regeneration (Smith and others 1997). Three basic practices comprise the bulk of intermediate silvicultural treatments for the southern pines: release, thinning, and prescribed burning. All have effects to be considered in silviculture because some of the byproducts of intermediate treatments are often of marginal commercial value.

Release Treatments

Release treatments are intended to promote development of the desired species by removing competing species that threaten to suppress individuals of the desired species (Smith and others 1997). In the southern pines, this usually means removing small hardwoods or herbaceous plants competing with small pines that are less than 10 years old. Release can be done using either chemical, mechanical, or ecological methods. Herbicides offer the most permanent solution to the elimination of competing vegetation because both shoots and roots of the hardwoods are killed and there is no resulting resprouting.

When one seeks a more permanent approach to sprout control through cleaning, weeding, or release treatments, the best is the use of herbicides designed to kill both the tops and the roots of the sprouts. Aerial application of herbicides is effective when the goal is to control hardwoods competing with pines; a number of chemicals and application methods exist that allow for control of hardwoods with minimal effect on pines. For example, late-summer herbicide application targets the seasonal window when hardwoods are still photosynthetically active but pines are dormant. This concentrates the herbicidal effect on the hardwoods rather than the pines in a way that allows stands to be treated with a single treatment that is easy to apply over large areas either by helicopter or skidder.

Individual-stem treatment methods are more labor-intensive but have several advantages in specificity of target application and minimized nontarget effects. These treatments are usually done in one of two ways: through mechanical felling of a tree with hand tools followed by applying herbicide directly to the cut stump or by using a backpack sprayer to apply herbicide directly on the foliage of the tree targeted for removal. Although these methods are labor-intensive, they minimize the volume of herbicide applied across a stand, and are specific to a target tree rather than a target species—meaning that they can be used in pine-hardwood, hardwood-pine, or hardwood stands to release a desired tree from competitors that will impede its development. These differences in application often reflect ownership differences as well; the broadcast methods are more typically conducted on private lands, and the individual-stem applications are more common on public lands.

The cumulative effects of herbicide applications are considerably lower than decades ago. Modern herbicides are developed to act specifically on plant metabolism by inhibiting photosynthesis or inhibiting the synthesis of amino acids that are limited to plants. Thus, they have much lower nonplant effects than herbicides used in the past. A short half-life in the environment is also a desirable attribute. Watershed effects are generally limited to the movement of soil solution containing the herbicide prior to its degradation in the environment, and by the general chemical activity of the inactive ingredients of herbicide formulations such as carriers and surfactants. The common safety precautions used in applying herbicides should be applied to limit cumulative watershed effects, such as application setbacks from sensitive areas, no direct application to streams, and attention to environmentally safe loading and cleanup procedures

But achieving the silvicultural objective of releasing pines from overtopping hardwoods may not necessarily require killing the entire hardwood; topkilling alone (in which the plant subsequently resprouts) may provide a sufficient elimination of competition, allowing the pine to gain the upper hand competitively. Both mechanical and prescribed burning treatments fit this pattern. They have been increasingly used on national forest lands in the region as a substitute for herbicides (Guldin and Loewenstein 1999), which are often unpopular with the public. Mechanical treatments include cutting or felling the tree, either with a sharp-edged hand-held tool such as a machete or axe, or a power tool such as a small circular saw or a chainsaw. The treatment is usually done by contract crews who specialize in this work and are efficient in conducting it.

Prescribed burning in young stands for release requires an experienced burning crew and a cool fire because of the risk of excessive heat killing the pines. Backing fires ignited using hand tools in the coldest months of the dormant season is a good combination of intensity and timing to apply in these stands. If properly done, there is an added benefit—the stand will not carry a fire later in the growing season. Thus, conducting a series of prescribed burns in all of the regeneration areas within a large watershed in January of a given dormant season is a good way to protect them when that watershed is burned several months later using aerial ignition (Figure 23.12).

Thinning

Thinning is a treatment conducted in immature and mature stands to reduce stem density of trees primarily by removing trees of poor quality, form, or vigor, or that are otherwise at risk of density-dependent mortality. These activities are intended to promote the vigor of the trees that remain and thereby improve stand growth and forest health (Helms 1998). Thinning can be conducted using one of several methods, which are outlined in Helms (1998) and explained in considerable detail in Smith and others (1997).

Low thinning or thinning from below removes trees in the lower part of the canopy to favor those in the upper canopy. Crown thinning or thinning from above removes dominants and codominants of comparatively poor form or quality to favor better dominants and codominants. Selection thinning (not to be confused with the selection method of reproduction cutting) removes trees of poor form in the dominant crown classes to favor better-formed trees in the subordinate crown classes. Mechanical or geometric thinning removes

Figure 23.12— Landscape-scale prescribed burning for pine-bluestem woodland restoration on the Big Piney Ranger District, Ozark-St. Francis National Forest. (USDA Forest Service photograph)

trees according to a geometric pattern, such as rows or strips, simply to reduce stem density in a predetermined pattern. Finally, free thinning, which is that most commonly done, combines elements of several of the above methods, such as when a mechanical thinning removes every fourth row in a plantation followed by a low thinning between the rows.

In the past, thinning (especially when stands are pulpwood-sized) has been far more common in pine stands than in hardwood stands for a number of reasons. First, small pines had value as pulpwood that exceeded that of small hardwoods, although this has changed in the past decade or two. Second, there is little need to be selective about species in southern pine stands, where the trees thinned and retained are usually the same. However, there are important reasons to retain one species rather than another when thinning hardwood stands. This effect leads to a far easier mechanization of operations in pine stands than in hardwood stands.

Almost by definition, thinning is the major tool foresters have to reduce the volume of fuels in a forest stand. At the stand level, thinning reduces biomass in rough proportion to BA; retaining 75 percent of BA after thinning will result in about the same proportion of biomass being retained. The pattern of thinning might affect the size class and distribution of the biomass being removed, which may result in some treatments being more effective than others for purposes of reducing fuels. A key consideration is whether the thinning can be conducted using a commercial timber sale. Payments made to the landowner from timber sales can then be reinvested in treatments to further reduce fuels, especially fine fuels such as branches and tops that might not have been hauled from the stand during logging.

Thinning that is prescribed in stands too small to sell commercially is called precommercial thinning, and is the biggest single challenge in managing sapling-sized pine stands. Stands that are candidates for precommercial thinning in southern pines are usually of natural origin because the initial spacing in planted stands is often selected so as to render the first thinning a commercially feasible operation (Figures 23.13A and B). But if plantations are planted at too dense a spacing, precommercial thinning will also be needed.

Stands in need of precommercial thinning are overstocked with small trees of marginal to no commercial value, with foliage in the canopy close to the ground. Dead needles shed during needlefall in autumn often drape over the lower dead branches of the trees. The number of stems and the volume and distribution of fine fuels create conditions that put these stands at high hazard with respect to wildfire, and the forester responsible for the stand has no easy decision.

In southern pine stands that require pre-commercial thinning, the best decision is almost always to do it—even if that requires out-of-pocket investment. Research in southern pines in the West Gulf region shows that precommercial thinning is more than offset by

Figure 23.13—A 22-year-old naturally regenerated loblolly-shortleaf pine stand, Crossett Experimental Forest. Ashley County, Arkansas; (A) unthinned, (B) thinned at age 20 to 100 trees per acre (247 trees/ha). (USDA Forest Service photograph by James M. Guldin)

faster growth in diameter and volume, with a favorable return on investment (Cain 1996). The earlier the precommercial thinning is conducted, the better. Stands treated earlier will respond more quickly, and the costs of conducting the operation in trees of small size are lower. The alternative—waiting until the stand grows to commercial size and then conduct a commercial thinning—requires no out-of-pocket cost by the landowner, but at the cost of delayed stand development and a longer period of time before financial returns can be obtained in thinning (Cain and Shelton 2003).

Prescribed Burning

Prescribed fire is generally applied as an intermediate treatment, with a goal of removing midstory vegetation in even-aged naturally regenerated pine, pine-hardwood, and hardwood stands, as well as in pine plantations (Van Lear and Waldrop 1989, Waldrop and others 1992). It also has excellent benefits for wildlife habitat (Komarek 1974). The prescription is usually applied on Federal lands, where burns in the dormant season through the early part of the growing season typically are conducted from January through April. Forest industry avoids using prescribed fire on their lands because of concerns about unwanted reductions in growth and yield in the loblolly pine plantations that they manage. Private nonindustrial landowners similarly tend to avoid the method, partly because they do not have access to the personnel required to efficiently burn large areas, and partly for reasons related to liability in the event that the fire should escape to neighboring property.

When prescribed fire is used, the ignition source depends on the condition of the landscape being burned, the possibility of young stands within the landscape that need special attention to withstand prescribed fire, and the proximity to private land. Burn units near or interspersed with private land are usually burned with drip torch ignition earlier in the burning season to better control the intensity of burning and the area covered by the fire. Young stands are often burned very early in the growing season, again using drip torches, to consume fine flashy fuels that might create too hot a fire if burned later in the growing season. Otherwise, especially in large well-burned landscapes where sensitive stands have been preburned, aerial ignition is preferred because of the efficiencies gained in cost and labor that result from burning large areas.

The watershed effects of prescribed fire are usually minimal. Vegetation recovers quickly after prescribed burning, and the risk of direct erosion through overland flow is minimal. Smaller fires ignited directly with drip torches are often imposed at a stand level, and in these cases permanent and intermittent stream channels usually provide an opportunity to establish one of the boundaries of the burn unit. The intensity of larger fires ignited by aerial ignition can be adjusted by the spacing of the incendiary spheres dropped from the helicopter, and stream channels are likely to burn with lower intensity if no spheres are dropped within them or if soil conditions in the stream zone are wet, as they usually are in the spring. The greatest likelihood of unwanted watershed effects is if firelines directly cross the perennial or intermittent stream, and this can be avoided as conditions warrant.

23.3. SILVICULTURE IN THE CONTEXT OF SPB

From a forest management perspective, the use of silviculture to control the SPB is a subset of the larger field of silviculture generally, and specifically for those practices appropriate for southern pines. Outbreaks of the SPB occur as spots of dead and living infested trees in southern pine stands having a high hazard for infestation based on tree and stand attributes. SPB spots expand quickly, usually in a discrete direction and at a rapid rate. When this occurs, there is an immediate and urgent need to conduct some kind of silvicultural treatment to suppress the outbreak, which emphasizes cutting of infested and uninfested trees at the active margin of the spot. This reactive silviculture is critically important to limit the spread of the infestation within and between stands, and is explored in detail elsewhere in the Southern Pine Beetle II.

The long-term view is that southern pine stands can be managed in a proactive manner using appropriate silvicultural systems that not only satisfy the goals of a landowner, but also maintain forest health and minimize losses from any of the biotic and abiotic natural disturbance agents and events that occur in the region. Few landowners would be comfortable with an explicit ownership objective that promotes the loss of standing timber from SPB, but landowners can and do differ about the degree of risk of SPB infestation they are willing to assume to achieve their goals of forest ownership. More and more foresters are coming to the realization that damaging agencies of regional scope such as the SPB are important to evaluate not only within a given landowner's ownership but across ownerships as well.

Natural disturbance events such as an infestation of the SPB complicate the job of the land manager. When outbreaks of the SPB are active within a forested landscape, silvicultural control of damaging agencies is triggered by exposure, which turns trees with high hazard into trees at risk. Emergency silvicultural treatments are used to quickly stop a given beetle spot, and these are discussed elsewhere in great detail in the Southern Pine Beetle II. Generally, those measures fall in the discussion of silvicultural control of damaging agencies (Smith and others 1997).

23.3.1. Immediate Silvicultural Treatments to Control SPB Outbreaks

When an active SPB spot is detected, the best silvicultural plans of the forester to meet the long-term objectives of the landowner are quickly dismissed, and the stand faces a natural disturbance event of destructive potential similar to that created by a tornado, hurricane, wildfire, or ice storm. The only advantage to the landowner is the length of time required for the insect epidemic to run its course. Windstorms and other severe weather events act within a very short period of time; in some cases, a stand is destroyed in a matter of minutes. In an SPB infestation, the landowner will have a few weeks or months to limit the spread of the infestation, and quick emergency action can be the difference between saving and losing a stand.

The fact that an outbreak of the SPB takes several weeks to develop gives a landowner a chance to respond with emergency silvicultural treatments to limit the spread of the infestation. These treatments are typically labeled as direct control treatments. They have been discussed thoroughly in the literature (Billings 1980b, Swain and Remion 1981, Wood and others 1985), and are a major topic elsewhere in the Southern Pine Beetle II.

Silviculturally, the emergency treatments to control an active or imminent threat to forest health are a subset of silvicultural treatments called improvement cutting (Smith and others 1997), a general category of silvicultural treatments intended to improve the species composition or health of immature or mature forest stands. The specific improvement cuttings imposed as direct control for the SPB fall into three categories: sanitation cutting, salvage cutting, and presalvage cutting (Smith and others 1997). Each is important and an element of the direct control tactics used to suppress SPB spots.

Sanitation cutting is defined as treatments to remove trees being attacked by the damaging agency but still alive (Helms 1998, Smith and others 1997). The theory behind sanitation cutting is that cutting these trees might alter the underlying epidemiology of the damaging agency. The archetypal example of sanitation cutting is cutting the green infested trees in an SPB spot; removing these still-living infested trees is highly effective in eliminating the brood of beetles that cause spots to continue to expand.

Salvage cutting is defined as treatments to harvest trees killed by the damaging agency, primarily for fuel reduction or economic reasons (Helms 1998, Smith and others 1997). With the SPB, salvage cutting is mostly an effort to capture and utilize volume already dead but still usable for timber or fiber production. There is usually little reason epidemiologically to cut the dead trees at the center of an SPB spot because the beetles no longer infest dead trees. However, there may be operational value for loggers engaged in salvage and sanitation cutting to cut and haul not only the green infested trees to the mill, but also the usable recently killed trees.

Presalvage cuttings are designed to remove trees in stands that are not yet affected by the damaging agency, but that are at high risk and lie in the expected path of the disturbance (Smith and others 1997). Presalvage cutting is triggered by the interaction of hazard, risk, and exposure; trees and stands that are high-hazard become at high risk of loss only when the SPB is active within a landscape. Presalvage is a low priority in the context of SPB direct control methods. Operationally, if the SPB becomes active, most of the emergency response will be directed at sanitation and salvage cutting; presalvage in stands not yet attacked is a lower priority. However, in the absence of SPB, any treatments intended to reduce hazard fall outside of the scope of presalvage treatments.

23.3.2. The Influence of Silvicultural Systems on SPB Hazard

The larger question in this chapter is to explore the silvicultural systems and the prescriptions that implement them over time to meet a landowner's goals and that, while being applied, concurrently reduce the hazard of infestation by the SPB. The necessary direct control treatments to control the SPB specifically such as sanitation and salvage cutting are, paradoxically, very disruptive in the context of long-term management plans and efficient conduct of silvicultural operations during the period between outbreaks.

Some landowners deliberately choose to manage stands in ways that meet their specific goals but that concurrently maintain a high SPB hazard. In some cases, these landowners understand the loss that they might face should the SPB become active and have factored that potential loss into their management planning. In other cases, landowners do not realize the hazard they face. For landowners who seek to manage their forest lands to be resistant to SPB, the better approach might be to practice forestry using silvicultural systems that maintain stands in a low-hazard condition.

Foresters have a relatively good understanding of stand-level silvicultural treatments that can reduce SPB hazard in the short term, to alter the behavior of the SPB should they occur. But the more profound impact created through forest management in stands and landscapes is not through short-term stopgap solutions to the SPB when the insect is active, but in long-term programmatic management practices that integrate treatments to reduce SPB hazard with the larger long-term ownership objectives of the landowner. Hazard reduction treatments are therefore more robust if they are examined within the context of the silvicultural system (Smith and others 1997).

Because of the rapid growth rates found in southern pine stands, ecological conditions can change rapidly. It is not unusual for southern pine stands on good sites to grow 3 square feet per acre (0.7 m^2/ha) in BA annually. This means that immature poletimber pine stands thinned to a residual BA of 80 square feet per acre (18.4 m^2/ha), for example, will grow to 110 square feet per acre (25.3 m^2/ha) in 10 years, and change from low SPB hazard to high SPB hazard. A forester should not only pay attention to a given estimate of hazard at a given point in time, but should also pay attention to the hazard trajectory of a given stand—that is, the rate of change in hazard over time.

Some silvicultural systems will result in steep hazard trajectories that change rapidly in a short period of time. Other silvicultural systems are characterized by relatively flat hazard trajectories. An understanding of the rate of the elements that condition whether stands are high-hazard or low-hazard, and the rate of change in hazard, is important to make good management decisions.

A number of elements are key indicators of susceptibility to the SPB. These include excessively dense stocking, growing conditions that result in the reduced vigor of individual trees relative to their potential, and stands combining these traits with a high degree of uniformity. The three silvicultural practices most useful in reducing the probability of beetle attack and spot growth are thinning, regenerating mature and overmature pine stands, and favoring resistant species (Belanger and others 1993).

Overstocking

High-hazard stands are often overstocked, and this feature is an important consideration in any discussion of hazard ratings. SPB infestations are frequently reported in overstocked stands (Bennett 1965, Lorio 1980a). Dense stocking and slower radial growth are common characteristics of high-hazard stands across the South (Coster and Searcy 1981), and thinning these stands is consistently noted as a tool to reduce their susceptibility to the SPB (Brown and others 1987, Burkhart and others 1986, Nebeker and Hodges 1983). A number of residual BA targets have been suggested.

The lower limit of residual BA generally mentioned in SPB studies reported in the literature is 70 square feet per acre (16.1 m^2/ha). Belanger and others (1993) reported that at or below a residual BA of 70 square feet per acre (16.1 m^2/ha), there is a very low probability of spot expansion spread. Brown and others (1987) used 70 square feet per acre (16.1 m^2/ha) as their lowest residual BA in a plantation thinning study, concluding that all three levels of thinning showed less induced SPB activity than the control stands. This residual BA is also appropriate as a lower limit in typical even-aged intermediate treatments in both poletimber and sawtimber stands (Figure 23.14).

The upper limit of residual BA appropriate to consider in the context of SPB hazard reduction probably falls at about 100 square feet per acre

(23.0 m^2/ha). For example, Belanger and others (1993) note that thinning to a residual BA of 80-100 square feet per acre (18.4-23.0 m^2/ha) is useful to reduce SPB hazard. Others report that plantations should be thinned periodically to BA <100 square feet per acre (23.0 m^2/ha), which reduces susceptibility (Burkhart and others 1986, Hedden 1978).

Hazard-rating systems are used to identify high-hazard stands (Lorio 1980b, Mason and others 1985, Stephen and Lih 1985), and nearly all of them rely upon stand or pine BA in one form or another as part of the hazard calculation. In some models total BA is used (Ku and others 1981); others use pine BA as the key variable (Hicks and others 1980, Kushmaul and others 1979), and still others use both pine BA and total BA (Daniels and others 1979). In all instances, higher total BA and higher pine BA contributed to increased susceptibility to the SPB.

The higher the residual BA target after thinning, the greater the need for frequent thinning to maintain acceptable low-hazard conditions. A pole-sized stand of loblolly pine in the west Gulf Coastal Plain thinned to a residual BA of 100 square feet per acre (23.0 m^2/ha) will reach 120-130 square feet per acre (27.5-29.8 m^2/ha) of BA in 10 years, and will quickly need another thinning to reduce SPB hazard. For example, Zeide and Sharer (2000) captured the prescription for typical industry practice in mixed naturally regenerated loblolly-shortleaf pine stands on the upper West Gulf Coastal Plain in the late 20th century. This prescription called for repeated thinning on roughly a 5-year cycle to residual BA less than 100 square feet per acre (23.0 m^2/ha) from age 15 through age 45, which met a number of resource needs including reduced SPB hazard.

All other things being equal, plantations established with lower planting densities will be less susceptible than plantations established with higher planting densities (Clarke 2001). The decision to use a given plantation spacing is informed by a number of silvicultural considerations including individual tree characteristics (shape of the crown, branchiness, size of the stem, and individual tree growth rate). However, a key consideration is often whether a stand can develop rapidly enough so that the first thinning will produce commercially viable sale of pulpwood for which the landowner would be paid, rather than require a precommercial thinning to avert stagnation of the new stand, but that would require the landowner to pay for the treatment. Because of this, the general trend in plantation establishment, at least up to the end of the 20th century, was to strive for lower planting densities.

Figure 23.14—Thinned loblolly pine plantation on the left, and the same plantation but unthinned on the right, on the Cold Springs Ranger District, Ouachita National Forest. (USDA Forest Service photograph by James M. Guldin)

Tree Vigor

Tree vigor is related to stocking. A tree growing in the open without competition from other trees is able to obtain a maximum amount of sunlight, atmospheric carbon dioxide, soil moisture, and soil nutrients; it will grow at its maximum rate, and is at its optimum vigor. But a given site only has a certain amount of sunlight, soil, and water resources. Competition with other trees of the same species, or trees of different species, will determine the degree of vigor a tree has at any point in its life. The ability of the tree to survive and dominate its surroundings depends on its genetics, its ability to adapt to the local environment, and the competitive environment in which the tree exists.

Generally speaking, there is a wide range of stem density within which a given forest site will grow roughly the same amount of biomass (Assmann 1970). It follows that if the overall level of stand biomass is constant, one can distribute that biomass in a stand of a given age in several ways—either in a large number of trees that have a small average diameter or in a small number of trees that have a large average diameter. But even though the stand volume growth will be similar across a wide range of stem density, individual tree vigor and volume growth will be different, with more vigorous trees being the larger ones with fast radial growth and the less vigorous trees being the smaller ones with slow radial growth. It is this latter situation—many trees with reduced vigor and slow radial growth—that finds a southern pine stand susceptible to the SPB.

Among the advantages in managed forest stands is that foresters can manipulate the number of trees and the BA within a stand to achieve goals of individual tree diameter growth and stand volume. Thinning removes some trees so the trees that remain have ample sunlight and soil resources to grow vigorously. Foresters cannot see root systems below the soil competing with one another, but the crowns of trees are readily visible, and foresters base relative decisions about the comparative attributes of trees almost entirely on two elements—spatial relationship of the crowns of the trees with one another and the rate at which the tree is growing, based on a quick examination of the tree's growth rings, with wider rings associated with healthy tree vigor (Figure 23.15).

Reduced radial growth in southern pines is a common factor in increased host susceptibility to the SPB (Coulson and others 1974). Slow radial growth is an indicator of reduced tree vigor. Physiologically, reduced vigor is manifest by an inability of the tree to produce pine resin, an important defense mechanism that when produced in abundance can kill or repel the

Figure 23.15—Wide spacing after commercial thinning and midstory removal in a mature shortleaf pine stand being managed as part of the shortleaf pine-bluestem management area, Poteau Ranger District, Ouachita National Forest. (USDA Forest Service photograph by James M. Guldin)

attacking beetle (Coulson 1980, Hodges and others 1979). It follows that a regular program of thinning in southern pine stands is important to maintain rapid radial growth and to promote individual tree vigor, and by implication to have trees capable of copious resin production as a primary defense against SPB attack.

For example, Cameron and Billings (1988) conducted a study examining 5- to 15-year-old loblolly and slash pine plantations in Texas, and observed that spots were more frequent in older plantations, in loblolly pine plantations, and in plantations that had recently been treated with prescribed burning. The association with prescribed burning, the authors suggest, is related to crown scorch commonly resulting from burning, and the associated slight reduction in individual tree growth and vigor while recovering from the crown scorch.

The pattern of earlywood to latewood growth may also be important. Lorio (1986) proposed a growth-differentiation process that may be important in understanding the reaction of trees to thinning. The oleoresin canals important in resin production upon wounding are more directly related to latewood formation than earlywood formation. If cultural practices are designed to optimize earlywood growth or to produce wide earlywood rings relative to latewood rings, the oleoresion production even of trees with rapid radial growth may be less than a tree of similar diameter and radial growth with a more equal distribution of earlywood to latewood. Thus, conditions that enhance earlywood formation and extend its duration may increase pine susceptibility to SPB attack (Lorio and others 1990). This could include natural weather events such as abundant rainfall in late spring and early summer, but it could also include cultural treatments designed to accelerate earlywood growth in spring, such as fertilizer application.

Susceptible Species and Sites

Managers have known for some time that some species of the southern pines tend to be more resistant to the SPB than others. A description of species susceptibility by region is shown in Table 23.1 (Kelley and others 1986a). Relatively speaking, slash and longleaf pine are more resinous species than loblolly or shortleaf, which may partially explain this general indication of resistance. In light of that, the transformation of the southern forest, especially in the lower Gulf Coastal Plain from a longleaf-dominated forest to a loblolly and slash dominated forest, may help explain the general increase in SPB outbreaks over time. Clarke (2001) speculates that one cause of the increased activity of SPB over the last century was the inability to regenerate cutover longleaf pine stands back to longleaf; the loblolly and slash pine stands that were established in place of longleaf are generally more susceptible to the SPB.

Stand, site, and tree characteristics associated with SPB attacks differ considerably among the Piedmont, the Coastal Plain, and the Southern Appalachian Mountains (Coster and Searcy 1981). Belanger (1980) provides an excellent summary of the general conditions associated with SPB in these different regions of the South. One way to quickly understand these issues is to examine the significant variables included in different hazard rating models (Lorio 1980b).

In the Piedmont, agricultural activity led to exhaustion and erosion of soils, and the forests that reclaimed or were established on abandoned agricultural land have been adversely affected as a result. Hazard rating models in the Piedmont include several soil variables—percent of clay in surface 15 cm of soil, depth in cm of the A horizon, and percent of clay per cm in the A horizon (Belanger and others 1980)—and suggest that higher hazard exists with thinner soils and higher levels of clay in the surface soil. This is most likely due

Table 23.1—The relative resistance and susceptibility of the major southern pines, by geographic region (Kelley and others)

Susceptibility	Geographic region		
	Coastal plain	Piedmont	Southern Appalachians
Most resistant	Slash, longleaf	Virginia, loblolly	Virginia, eastern white
Most susceptible	Loblolly, shortleaf	Shortleaf	Shortleaf, pitch

to the slow radial growth and lack of vigor in pines on these depauperate sites.

On Piedmont sites such as this, the best approach to minimize hazard is to shift from shortleaf pine to loblolly, especially on poorer sites. This will allow the forester to maintain low residual BA in the stands, to manage for live crown ration greater than 33 percent to ensure high individual tree vigor, and to regenerate overstocked stagnant stands because they have little hope of responding with improved individual tree vigor if thinned (Belanger 1980).

Southern Appalachian pine stands have also had SPB problems throughout the latter part of the 20th century. In this region, stands attacked by the SPB feature dense stocking, slow radial growth, and a high proportion of pine sawtimber. Recommendations include managing species composition toward resistant species of pines and including some hardwoods, and using intermediate treatments (thinning, improvement cutting, and salvage cutting) to lower stocking and increase individual tree vigor (Belanger 1980).

In the Coastal Plain, variables significant in several hazard models for mixed loblolly-shortleaf pine stands tend to be related to overstocking more than soils, and unlike Piedmont conditions, higher hazard tends to be associated with better sites (Ku and others 1981, Kushmaul and others 1979). These better sites are found in mesic or wet poorly drained sites where the abundance of soil moisture contributes to higher site indices but that have also been reported as more susceptible to the SPB (Belanger 1980).

Generally, mature Southern Coastal Plain pine stands of natural origin, especially on lands outside forest industry ownership, have been characterized by high density, a high proportion of sawtimber, and declining radial growth. In such stands, infestations are more common on poorly drained sites, the potential for problems is related to site quality (being worse on moist high-quality sites), and damage from windstorms and ice promote beetle attack and spot proliferation (Belanger 1980).

Mature Stands

Through the last half of the 20th century, forestry was a booming business in the Southern United States. Modern forest management is built upon a firm foundation of science and gives landowners and foresters excellent tools to manage forest stands to meet the needs of landowners. The inherently favorable humid temperature climate is ideal for growing southern pines across much of the South. At the end of the 20th century, virtually all of the metrics used to quantify forest timberland volume were at their highest level since the 1930s (Conner and Hartsell 2002).

Changes in management intent and philosophy, especially on government and nonindustrial private forest lands, have led to a maturing of the forest across the South. In some cases on Federal lands, stands are being deliberately managed with longer rotations to provide habitat in mature forest for species underrepresented on the landscape. In other cases on private lands, stands are simply getting older through reduced intensity of management. In both circumstances, inattention to stocking can allow dense stands of overmature pines to develop that are highly susceptible to SPB (Billings 1998, Clarke 1995). As growing stock increases, and as stand age increases, stand volume also increases, leading to more timber, more pine sawtimber, and older sawtimber (Belanger and others 1993), all indications of greater susceptibility to the SPB (Hedden 1978, Lorio and Branham 1988).

Over the past 2 decades, management of mature pine stands to provide habitat for the endangered red-cockaded woodpecker has encountered unique problems with SPB, which is a primary mortality agent of the large mature trees, especially loblolly pines, that serve as cavity trees (Belanger and others 1988, Conner and others 1991). Pine BA in cavity tree clusters, recruitment stands, and replacement stands should be kept at 60-80 square feet per acre (13.8-18.4 m^2/ha) (Figure 23.16), a stocking that is not conducive for expanding SPB infestations (Clarke 2001).

The challenge in the future will be to develop and sustain markets on Federal lands and lands in the nonindustrial private sector for large sawtimber pine products. Increasingly, the forest industry is turning to smaller diameter products that are available from plantations on the industrial land base, where trees are harvested before they reach large sawtimber size. As harvesting operations in the South become increasingly mechanized, equipment is designed for smaller tree sizes rather than large tree sizes; cutting and hauling large pine sawtimber is becoming somewhat specialized. In addition, modern mills are increasingly designed to operate using small diameter logs.

Figure 23.16—A mature shortleaf pine stand suitable for nesting and foraging habitat for the red-cockaded woodpecker as part of the shortleaf pine-bluestem management area, Poteau Ranger District, Ouachita National Forest. (Missouri Department of Conservation photograph by David Gwaze)

A challenge will be to maintain some forest manufacturing capability designed for large pine sawlogs and the dimension products they provide. This is especially critical because of the need to maintain proper stocking in mature stands, and because of the high potential for spot expansion that is found in mature pine stands containing trees of large size (Lorio 1984).

Attributes of Low-Hazard Stands

Throughout the literature describing the susceptibility of stands to the SPB, corresponding suggestions abound as to ways in which hazard and susceptibility can be reduced, and these tie in to many of the factors that have previously been discussed. Belanger (1980) summarizes three key elements in reducing hazard: manage to promote stand resistance, manage to promote individual tree resistance, and protect the site.

Individual tree resistance is promoted by favoring resistant species on appropriate sites, removing high-risk trees, and practicing cultural treatments that maintain good radial growth and vigor of individual trees in the stand (Figure 23.17).

Stand-level resistance is promoted by maintaining proper density and by getting that work on the ground in effective ways (Nowak and others 2008). Other silvicultural treatments that reduce competing vegetation and ultimately increase individual tree and stand vigor, such as prescribed burning, may decrease the impacts of SPB when applied judiciously (Clarke 2001). The SPB prefers susceptible stands that are uniform and continuous; managing stands in ways that increase within-stand and between-stand heterogeneity might act to limit spot expansion in the early part of an infestation (Figure 23.18).

Managing species composition includes not only managing for resistant pines as appropriate but also managing mixed pine-hardwood stands (Figure 23.19). Management practices such as planting less susceptible species, maintaining a mix of pine and hardwoods, and matching the pine species with the site also can reduce losses to the SPB (Belanger and Malac 1980). A mixture of pines and hardwoods is thought to promote resistance to attack and to deter the spread of endemic beetle populations (Belanger and others 1979, Kelley and others 1986a, Zhang and Zeide 1999). However, pine-hardwood mixtures provide little resistance to epidemic populations of the SPB; observations in Texas, Louisiana, and Georgia indicate that bark beetles can attack and kill pines widely distributed throughout such mixtures (Kelley and others 1986b).

Figure 23.17—Regular cutting cycle harvests allow foresters to maintain excellent radial growth of sawtimber-sized trees in uneven-aged loblolly-shortleaf pine stands, as illustrated from this recently cut stump in the Poor Farm Forestry Forty demonstration area on the Crossett Experimental Forest in Ashley County, Arkansas. (USDA Forest Service photograph by James M. Guldin)

Figure 23.18—A thinned and burned mature longleaf pine stand treated with additional midstory removal to maintain radial growth and vigor of sawtimber-sized longleaf pines on the Sam Houston National Forest, National Forests and grasslands of Texas. (USDA Forest Service photograph by James M. Guldin)

23.4. STAND MANAGEMENT DECISIONMAKING IN THE CONTEXT OF SPB

The general conditions prevailing across the southern forested landscape have changed over the past 50 years. Old stagnant mature and overmature sawtimber stands were once a primary concern for managers wrestling with SPB, and such stands still merit careful management where they still exist. But in the 21st century, harvesting, species conversion, fire prevention and suppression, and short rotation plantation forestry have promoted the establishment and maintenance of forest structures that are highly susceptible to the SPB (Clarke and others 2000, Schowalter and others 1981).

23.4.1. Clearcutting and Planting

Clearcutting and planting have become the standard practice for management of forest industry and timber investment forest lands in the South. In 1993, Belanger and others reported that the increasing regional occurrence of the SPB was related to the fact that the South had 25 million acres (10.1 million ha) of plantations at that time, of which more than half were greater than 10 years old. As of 1999, data show that the 30 million acres (12.1 million ha) of planted pine stands across the South are nearly the equal of the 34 million acres (13.8 million ha) of naturally regenerated pine dominated stands (Conner and Hartsell 2002). Projections are that by 2050, 50 million acres (23.9 million ha) or 25 percent of the South's timberland will be in pine plantations (Wear 2002). The challenge that Belanger reported in 1993 is becoming more prominent, not less.

Figure 23.19—The retention of overstory hardwoods as part of the shortleaf pine-bluestem woodland restoration prescription may reduce hazard of SPB spot expansion. Poteau Ranger District, Ouachita National Forest. (USDA Forest Service photograph by Brian R. Lockhart)

Modern plantations are generally established following intensive site preparation that often includes use of bedding, use of herbicides to control herbaceous competition, use of fertilizers to boost early stand volume growth, and use of thinning early in the rotation to regulate stem density. The goal of these cultural practices is to optimize early growth and promote within-stand uniformity of tree size for efficiency in mechanized thinning and harvesting operations.

The advantage of pine plantations in the southern landscape is that they are not managed to old age. In 1999, forest survey data showed that of the 30.1 million acres (12.2 million ha) in pine plantations in the South, more than 99 percent were younger than 48 years of age. Thus, the likelihood that overmature pine stands containing trees of large diameter will develop in the planted forests of the South is low.

The disadvantage facing pine plantations relates to the possibility of delay in the timely application of silvicultural treatments, especially thinning. The rapid rates of individual tree and stand growth in plantations will be associated with rapidly changing hazard trajectories over relatively short periods of time. The question is the degree to which foresters can manage the steep hazard trajectories in these fast-growing stands continually below the threshold of high hazard.

An aggressive program of frequent thinning beginning early on (ideally before age 10) in these stands is essential to maintaining radial growth at an acceptable level and to keeping stand BA at or below 100 square feet per acre (23.0 m^2/ha). If pulpwood and small sawtimber markets remain strong, the ability to thin stands economically and in a timely way will be feasible. Questions remain whether the BA and volume in an increasing area of plantations in the region can all be thinned in a way to keep hazard trajectories low if markets weaken.

The organization of operations in the world of intensive southern forestry has also changed in the past decade, with forest industry lands changing hands to timber investment management organizations. A byproduct of this shift is a reduction in staffing because the investment organizations believe that efficient forest management can be done with fewer field staff. Part of this decision is based on reliance on State forestry organizations to provide support for fire suppression and pest management on private lands. This loss of ready labor to engage in suppression activities has been a gradual change, and State agencies have responded with the acquisition of additional firefighting assets. But the thin line of available State personnel to participate in future rounds of SPB control on a broader sector of private lands will be tested in future outbreaks that are certain to occur.

23.4.2. Even-Aged Methods Using Natural Regeneration

Management of even-aged stands through rehabilitation of naturally regenerated even-aged or two-aged cohorts on cutover lands and use of even-aged seed-tree and shelterwood methods of management in naturally regenerated stands have been quite effective as a tool to meet objectives for management of large sawtimber products. This is especially true on public lands, some industry lands (though fewer than supported these methods several decades ago), and also in the nonindustrial private forest land ownership sector. Even-aged methods have been especially useful in Coastal Plain longleaf pine, west Gulf Coastal Plain mixed loblolly-shortleaf pine, and Ouachita Mountains shortleaf pine.

The advantages in using even-aged methods revolve around tradeoffs between minimizing out-of-pocket costs in capital intensive stand management and rehabilitation, and maintaining structural conditions such as continuous overstory cover in mature forest stands that meet more than simply a financial return on investment. The tradeoff is slower growth rates of regeneration and reliance on the prevailing genetic expression of open-pollenated parent trees rather than the robust genetics associated with improved seedlings grown for planting. The stands are not necessarily optimal short-term investment portfolios, but often provide owners with values such as wildlife, recreation, and aesthetics that outweigh the bottom line on an investment calculation.

From the perspective of the SPB, the challenge in naturally regenerated stands is managing them to reduce stocking and maintain or develop acceptable rates of radial growth and individual tree vigor. Generally speaking, if one inherits an overstocked stand greater than 48 years in age, it will be difficult to apply thinning treatments that cause a similar response to release as one would see in younger stands. This is important in the context of managing the SPB hazard in mature and overmature stands. As a frame of reference, 1999 forest survey data showed that of the 33.1 million acres (13.4 million ha) of natural pine stands remaining in the South, slightly more than 20 percent are 48 years old or older.

When regenerating even-aged stands naturally, the forester has much less control over stem density and stocking than in a plantation. This increases the importance of timely precommercial thinning by age 10 if not before, in order to avoid stagnation and to develop vigorous dominant and codominant trees that have acceptable diameter growth rates in stands within acceptable limits of BA, to reduce hazard to SPB. The slower growth rates of naturally regenerated stands compared to plantations will result in slow to moderate rates of increase in hazard, especially after the initial precommercial thinning. However, as these stands grow into poletimber and small sawtimber sizes, the SPB hazard trajectory will change more rapidly, and attention to a timely program of thinning to appropriate residual stem density and BA is just as important in naturally regenerated stands as it is in planted stands.

A key in managing naturally regenerated pine stands in the South is to forego the opportunity for rapid pulpwood production and concentrate instead on development of sawtimber products. It would be a mistake, both for future development of the trees in the stand and in the evaluation of SPB hazard, to allow naturally regenerated stands to develop without precommercial thinning in order to eventually obtain a first commercial thinning. The precommercial thinning will forego some initial pulpwood return, but in truth the first commercial thinning in naturally regenerated stands often is designed simply to cover the costs of the harvesting, with future benefits from the added growth on the residual stand.

Landowners who seek guidance in the timely application of thinning during the life of the stand have a model in the prescriptions that codified the practice of forest industry in the naturally regenerated mixed loblolly-shortleaf pine stands of the upper west Gulf Coastal Plain. These prescriptions were used to grow sawtimber products on 45-year rotations in southern Arkansas and northern Louisiana (Zeide and Sharer 2000), and provided that the thinning schedules were maintained, SPB problems remained minimal.

23.4.3. Uneven-Aged Methods Using Natural Regeneration

The quiet alternative for landowners interested in continuously forested southern pine stands that produce high quality sawtimber on a regular basis is the application of uneven-aged silviculture. The refinement of the method for southern pines occurred on the Hitchiti Experimental Forest in Georgia with Ernst Brender (1973), and on the Crossett Experimental Forest in south Arkansas with

Russ Reynolds and his successors (Guldin and Baker 1988, Reynolds and others 1984). The fact that uneven-aged systems work is a tribute to the ecological flexibility of loblolly pine, which despite its reputation as the primary planted species in the South, is also uniquely suited for survival and growth in the unique ecological conditions created in uneven-aged stands.

Stem density and age are far less important in uneven-aged stands than working within the recommended BA constraints of from 60 to 75 square feet per acre (13.8-17.2 m^2/ha) during the cutting cycle, with 67 percent of that BA in the sawtimber size classes (Baker and others 1996). These stands are deliberately managed in a relatively understocked condition, which optimizes individual tree growth and vigor of sawtimber-sized trees and creates available growing space in varying locations within the stand for regeneration establishment and development.

The goal of uneven-aged silviculture is to optimize stand volume growth in the sawtimber component and to maintain acceptable periodic rates of sawtimber volume growth over time. As a result, radial growth even in the large diameter classes 18 inches in diameter and up remains relatively rapid. A key reason is the low BA in the sawtimber component of these stands, which results in healthy and vigorous crowns that retain a high live crown ratio. This condition produces rapid volume growth on big trees and is responsible for the reputation the method enjoys for producing high quality sawtimber.

That is also why the method is notoriously inefficient in the production of pulpwood (Guldin and Baker 1988), because a relatively small percentage of the stocking in the stand is devoted to the pulpwood-size classes. The trick in properly managing uneven-aged stands is to retain enough ingrowth from seedlings and saplings into the submerchantable classes, and then into the merchantable poletimber and sawtimber classes, in order to maintain the long-term sustainability of the system.

All other things being equal, group selection stand will have slightly greater hazard to SPB than single tree selection stands. The reason lies in the greater stand-level discontinuity represented by the gaps vs. the matrix between the gaps. The matrix is often managed essentially as an even-aged stand, and often carries a higher BA especially early in the process if the method is being used to convert stands from even-aged to uneven-aged condition. Managers should pay attention to residual BA in the matrix between the groups, and the same guidance to reduce SPB hazard in even-aged stands—BA less than 100 square feet per acre (23.0 m^2/ha), and preferably closer to 80 square feet per acre (18.3 m^2/ha)—should be applied in the matrix. In addition, it may be necessary to follow the establishment of pine regeneration within the group openings with timely thinning, including precommercial thinning if longer cutting cycles are being used.

These low residual BA levels in the sawtimber component are a key reason to suggest that the hazard trajectory of uneven-aged stands generally, and especially stands managed using single tree selection, will be relatively flat. At the end of a cutting cycle prior to harvest, the maximum BA in the stand will still be in the lower range of acceptable BA to minimize hazard. In addition, trees in the sawtimber-size classes are managed to maintain acceptable radial growth, and marking rules generally dictate cutting the worst trees and leaving the best. All these indications lead to the conclusion that well-managed uneven-aged southern pine stands will maintain an unusually low hazard of SPB outbreak over the long term.

23.5. CONCLUSIONS

SPB outbreaks are a natural event in southern pines. They are important insofar as their occurrence contributes to the risk of loss of the forest in the event of uncontrolled outbreak. Management of forest stands using proper silvicultural techniques can alter the natural population dynamics of this destructive insect. But it is more holistic not to think of silviculture for control of the SPB separately from the larger question of silvicultural practices applied within prescriptions designed to maintain forest health, productivity, and sustainability in the context of the goals of ownership of the landowner.

Silvicultural tools to prevent SPB outbreaks are most effectively implemented if they fall within the context of the larger silvicultural systems being imposed within stands and landscapes, rather than as stand-alone treatments applied at a given point in time. Active management under the guidance of professional foresters is the most effective way to integrate considerations for SPB in operational management programs, and to minimize the hazard to southern pine stands and landscapes as elements of a larger program of active forest management.

Managers have many silvicultural options for managing forests to provide the mix of commodities and amenities desired by society because of the diversity of tree species in the Southern United States, the large ecological amplitude and geographic distribution that most species exhibit, and the variety of uneven- and even-aged silvicultural systems available.

Silvicultural systems are designed to achieve multiple resource objectives often simultaneously within ecological, social, and economic constraints. Silvicultural systems are dynamic and can be adapted as better knowledge is gained, management goals change, and stochastic events occur that alter forest condition and succession from the desired pathways. Silvicultural stand prescriptions integrate resource objectives, apply ecological principles, and identify the system of treatments that are effective and efficient in attainment of forest goals with a degree of certainty.

The best long-term strategy to combat the certain future attack by any of the many threats to forest health, and especially threats of SPB outbreaks, is the proper application of silviculture within the framework of sound forest and regional planning. Silvicultural prescriptions can be developed to treat current stand conditions, to manage composition, and to promote tree vigor and forest health. Healthy forests are less susceptible to attack by insects and pathogens, are less vulnerable when attacked, and are more resilient to survive and recover from the biotic attack or stress from environmental extreme. Forest plans should seek to diversify composition and structure of forests, woodlands, and savannas across the landscape to buffer these effects.