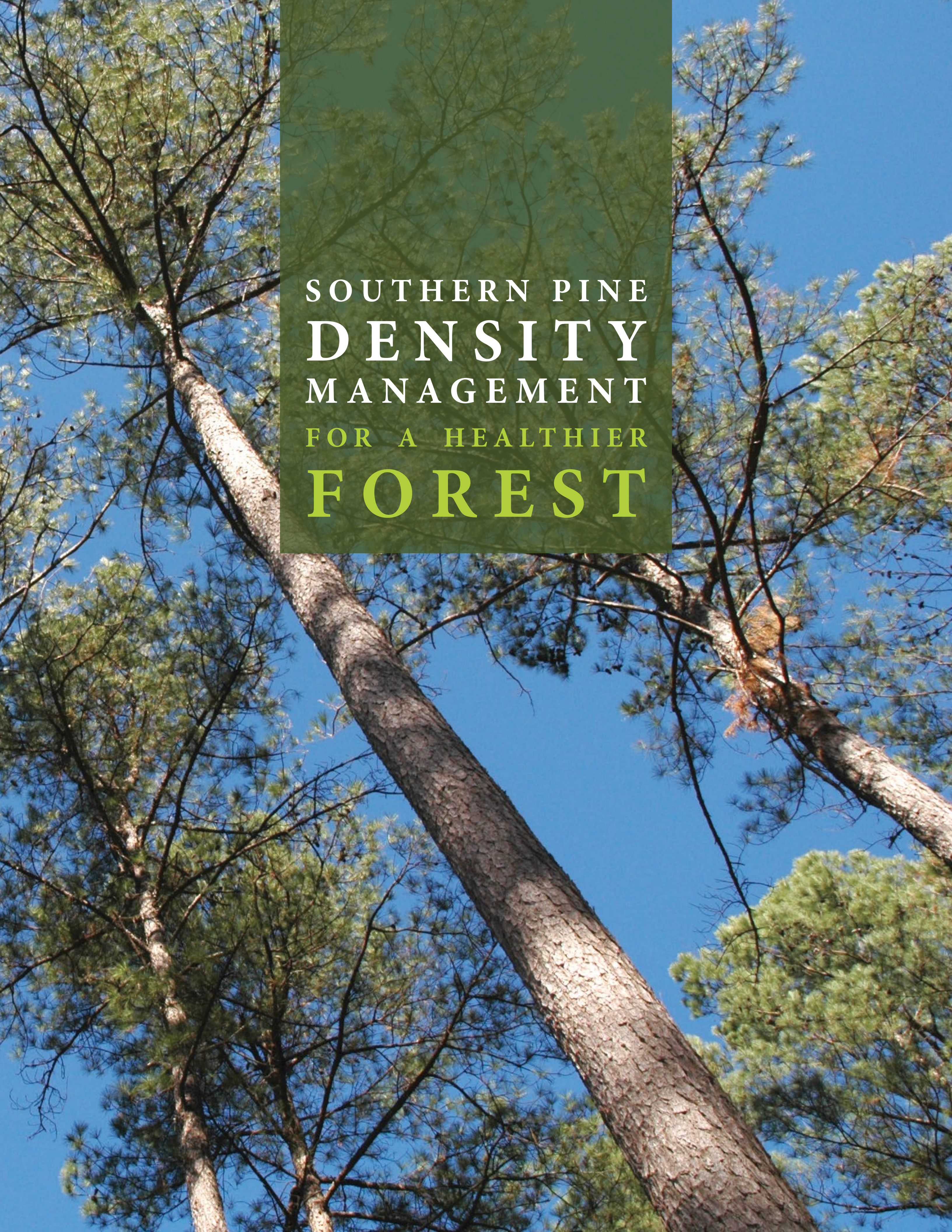
SOUTHERN PINE DENSITY MANAGEMENT FOR A HEALTHIER FOREST



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INTRODUCTION

Management of pine forests in the southern United States has intensified as timber resource value has increased and the need for sustained production has become evident. Recent increased demands for wood products, widening price differentials between pulpwood and sawtimber, and greater utilization of both small material and a larger number of tree species have increased the attractiveness of forestry investments.

The practice of thinning to improve growth rates has received increased attention as forest management has accelerated during the past 35 years. This has led, in turn, to a significant accumulation of literature on thinning southern pines. This publication presents the concept of thinning, reviews and summarizes research, and assesses current field practices. Positive and negative aspects of these practices on current or potential problems are discussed based on recent research. Management approaches that will help minimize losses caused by damaging organisms and logging injuries are suggested.

Figure 1. Intensively managed pine forest. *Photo by Brady Self*

GROWTH OF TREES AND STANDS

Forest management principles do not differ greatly from those for agricultural field crops. Similar to other crops, trees require light, water, nutrients, space, and protection from insects and diseases. The fundamental growth processes are comparable. The major difference is the length of time required to reach maturity. Given this difference, the economics of intensive forest management has not always seemed favorable.

Growth potential of a tree is strongly influenced by genetics, but environmental variables play a large role in determining expression of genes and, thus, actual growth. Numerous environmental factors affect growth; of these, water, nutrients, and light intensity are most easily manipulated.

Height and Diameter Growth

Height growth in the four major pines of the Southeast is indeterminate. Additional flushes (multinodal growth), particularly during midseason, reflect current soil moisture conditions. However, the initial terminal bud is formed in the year prior to extension, and height growth from the extension of that bud is closely related to soil water availability during the late summer of bud formation. If height increment is plotted against age, growth begins slowly and then climbs more steeply, finally flattening out as the tree matures (Prodan 1968). It is during the quickly growing intermediate years (between ages 10 and 30) that foresters try to regulate growth through thinning.

Diameter growth is also closely related to availability of soil water. Cambial cells begin dividing in early spring when soil water is not limited and stop in late summer when conditions are reversed. Observing an annual growth ring, early wood cells are abruptly followed by late wood cells whose greater density increases the specific gravity. The transition from early to late wood is not well understood. A decrease in soil water availability usually precedes formation of late wood cells, and continued moisture deficits stop cell division. However, cell division may begin again in midsummer to late summer with increased soil moisture, as evidenced by false annual rings. Additionally, if soil water is available, late wood cells continue forming until late summer or early fall (Moehring and Ralston 1967). Knowledge of these biological principles allows for the regulation of growth increments through thinning practices or stand density control.

Stand Development

Site quality, age, species, stocking level, and forestry practices influence stand growth. The concept of site quality has an immense bearing on growth and survival of individual trees. Site index is an integration of several environmental factors but emphasizes the quality and quantity of soil nutrients and water. The rate of stand development increases with increasing site index. Thus, the capacity of a unit of land for tree production increases with increasing site quality.

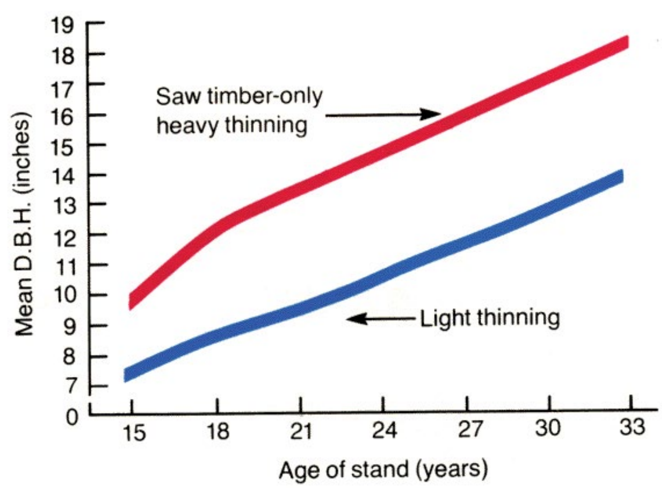

Figure 2. Growth response as a result of thinning. From Burton 1982

In an even-aged pure stand, the stage of development is similar throughout the stand at a given age, although a more advanced stage is reached earlier on a better-quality site compared to one of low-quality. For similar stockings, stands on high-quality sites will require thinning earlier compared to those on low-quality sites.

Stand structure is simplified under even-aged silvicultural management. By definition, most trees are of similar age, reaching sapling, pulpwood, and sawtimber status at roughly the same time or stage in stand development. However, taller dominant and codominant trees with larger diameters and crowns suppress growth of smaller neighboring trees, which often become overtopped and eventually die. As a stand matures, the natural process of competition concentrates the growth potential of the stand in the tallest trees.

Figure 3. Even-aged loblolly pine stand, showing stand development similarity.
Photo by Brady Self

Stocking

Proper stocking is important, but application of the concept can prove difficult. Optimal stocking is simply the number of trees per acre (TPA) that fully utilize a site's potential to grow trees. Higher-quality sites have greater carrying capacity and, if properly stocked, are capable of supporting more TPA than lower-quality sites. Consequently, a given site may be properly stocked with an initial seedling density as low as 450 TPA or as high as 1,000 or more TPA. Finally, the diameter growth rate of individual stems varies considerably with different densities. Overall stand development differs with variable densities, as well. Both diameter growth rate and the age that carrying capacity is reached are greater at low tree densities compared to greater tree densities. It is these concepts of stocking, carrying capacity, and stand dynamics that form the biological basis for spacing and thinning to achieve management objectives.

The preceding discussion establishes the following premises:

- Stand differentiation, or stages of development, occurs at earlier ages on high-quality sites compared to those of lower quality.
- Competition directs growth potential of the stand toward dominant and codominant trees.
- Competition promotes crown differentiation in the stand.
- Realized growth potential is a function of site, stand, and environmental conditions.
- Stand development is a predictable process.
- Site quality, as an integration of environmental factors, is a major determinant of the rate of stand development.
- Once carrying capacity of a site is reached, total volume is similar over a wide range of stocking.

THINNING PRACTICES IN SOUTHERN PINES

Insect problems intensify as stands become crowded and vigor declines. Southern pine beetle (SPB) infestations, for example, have long been associated with high stand density. Silvicultural techniques such as thinning offer the most promising and long-lasting means of preventing these conditions. By the same token, above- and belowground injuries caused by harvesting and thinning operations serve as infection courts for disease organisms that cause decay and deterioration. In fact, thinning can increase the incidence of annosus root rot (Sinclair et al. 1993). Wounded trees tend to be more susceptible to insect infestation, as well. These conditions (addressed in detail later), together with a thorough understanding of the technology and effects of thinning operations, must be taken into account when developing appropriate management recommendations.

Figure 4. Southern pine beetle infestation in mixed pine-hardwood stand. *Photo by Randy Rousseau*

In the South, the decision to perform a thinning is based primarily on product objectives and stumpage prices. Unless prices are very high, pulpwood is rarely the sole timber management objective. Typically, size restrictions on pulpwood are open-ended, but it is normally the lowest-valued product removed from a timber stand (Londo et al. 2002). Most studies indicate that, for pulpwood rotations, thinning of normal intensity will either have no influence on cubic volume yield or, more commonly, will reduce total yield (Crow 1963, Mann 1952, Nelson and Arnold 1976, Wakeley 1969, Wheeler et al. 1982, Williston 1979). An exception would be extremely dense young stands where precommercial thinning may be necessary to prevent stagnation of the stand and vastly reduced volume growth (Balmer et al. 1978, Balmer and Williston 1973, Bower 1965, Brender and McNab 1978, Cooperi 1955, Debrunner and Watson 1971, Grano 1969, Gruschow 1949, Guttenberg 1970, Lohrey 1972, 1973, 1977, Mann and Lohrey 1974).

Most pine stands are managed for multiple products, including chip-n-saw and sawtimber-size material. Consequently, proper timing and application of thinning operations, especially first commercial thinnings, are very important to long-term productivity and stand value (Bennett 1963, Dean and Baldwin 1993, Murphy and Guldin 1987, Schultz 1997). In particular, issues that must be addressed include: 1) the relationship between initial spacing and the need for thinning, 2) the time (age) to thin, 3) the intensity and frequency of thinning, and 4) the most appropriate method of thinning.

Initial Spacing and the Need for Thinning

The choice of initial spacing is critical in plantation management, especially for large product rotations. Numerous studies have shown that, for a wide range of initial stocking (e.g., 300 to 1,000+ seedlings/acre) and for rotations of 20 years or longer on given sites, tree heights and total volume production are essentially independent of initial stocking. These observations simply reflect the relationship between stocking and the carrying capacity of the site (see **Table 1**).

When seedlings are closely spaced (i.e., high density), basal area carrying capacity is reached earlier. However, once carrying capacity is reached, the rate of volume production will be the same regardless of initial stocking. Although volume production may be independent of initial spacing, stocking will have a marked effect on diameter growth of individual trees. Thus, the value of the final product, as well as the length of time necessary to grow a product of a desired size is strongly linked to initial spacing.

Choice of initial spacing is typically determined by ownership goals (in particular, the products to be grown in the area) and whether a cost-share program is used for the planting. Currently, the forest industry typically plants fewer trees using a wider spacing than the average nonindustrial private landowner. Economic efficiency, improved genetics, and equipment operation considerations have driven this trend toward planting lower seedling densities. When sawtimber or multiple timber products are the primary objective, owners have three alternatives: 1) plant at wide spacing and do not thin, 2) plant at closer spacing and accept a somewhat longer rotation to obtain a product of the desired size, or 3) plant at a closer spacing and thin to maintain an acceptable growth rate of residual trees. State and federal cost-share programs specify a required planting density, and this number is typically greater than stocking used by most land managers not participating in a cost-share.

Table 1. Estimated total yield of loblolly pine at age 22 for five planting densities, several residual stand densities, and four site indices (SI) (base age 50).

		Yield (ft³/acre)			
Trees/acre	**Residual stand basal area (ft²/acre)**	**80 SI**	**90 SI**	**100 SI**	**110 SI**
300	60	1,671	2,086	2,504	2,939
	80	1,876	2,286	2,709	3,144
	100	2,031	2,441	2,864	3,299
440	60	2,004	2,444	2,882	3,332
	80	2,209	2,644	3,087	3,537
	100	2,364	2,799	3,242	3,692
540	60	2,144	2,600	3,052	3,513
	80	2,349	2,800	3,257	3,718
	100	2,504	2,955	3,412	3,873
	120	2,634	3,085	3,537	3,998
680	60	2,258	2,739	3,210	3,687
	80	2,463	2,939	3,415	3,892
	100	2,618	3,094	3,570	4,047
	120	2,748	3,224	3,695	4,172
	140	2,853	3,334	3,805	4,282
1,200	60	2,267	2,838	3,381	3,917
	80	2,472	3,038	3,586	4,122
	100	2,627	3,193	3,741	4,277
	120	2,757	3,323	3,866	4,402
	140	2,862	3,433	3,976	4,512

Adapted from Feduccia, D.P. and Mann, W.F. Jr. 1976. Growth following initial thinning of loblolly pine planted on a cutover site at five spacings. U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station, New Orleans. Res. Pap. SO-120, 8 p.

Initial spacing at planting can have large impacts on stand development and the need for future thinnings (Baldwin et al. 2000). Spacings in the 10- to 12-foot range will produce more board foot volume on relatively short rotations (25 to 35 years) compared to the 6- to 8-foot spacings used in the 1960s and 1970s (Arnold 1978, Bennett 1963, 1969, 1971, Burton 1982, Shelton and Switzer 1980, Shepard 1973), but total volume will likely be less and log quality will be lower unless trees are artificially pruned (Bennett 1969, Box et al. 1964, Bender 1965, Feduccia and Moiser 1977, Ware and Stahelin 1948).

Intermediate spacings (550 to 700 TPA) coupled with thinning probably offer the best compromise where multiple products are the objective. For rotations of 25 to 35 years, such spacings will yield volumes similar to those found in closer spacings. Additionally, intermediate spacings will typically produce as much board foot volume as wider spacings, albeit with some reduction in average tree diameter. In the absence of thinning, stem quality (expressed in terms of branch size and number) will typically be greater in stands with intermediate initial seedling spacing compared to those planted using lower densities. The presence of stem sweep and fusiform cankers is normally reduced, as well. Intermediate spacings with thinnings are also best for production of chip-n-saw and sawlog-size material (Feduccia and Mosier 1977, Moorehead et al. 1997, Ware and Stahelin 1948, Williston 1979).

Frequent light thinning (e.g., every 5 years) may yield higher-quality end products and perhaps more board foot volume compared to heavier thinning (Farrar 1968, Feduccia and Mosier 1977, Fender 1968). Conversely, they also increase chances of negative forest health effects from soil compaction, annosus root rot, pine beetle infestation, and other factors that can be sensitive to thinning, especially if conducted in less than ideal conditions. However, economics may dictate heavier, less frequent thinning. Some work has shown that a single thinning might be acceptable for rotations designed to produce sawlogs (Fender 1968, Hardie 1977, Parker 1979). Currently, most pine stands are managed with only one or two thinnings per rotation. These thinning regimes are designed to produce mixed products with an emphasis toward chip-n-saw and sawtimber. Timing and frequency of thinning should be determined by site quality, length of rotation, and initial stocking.

Figure 5. Dense young loblolly pine stand in need of precommercial thinning.
Photo by Brady Self

Figure 6. Dense, overstocked plantation at high risk for bark beetle infestation.
Photo by Brady Self

Initial planting configuration is also an important consideration. Growth of individual trees appears to be a function of available growing space (stocking density). Within reasonable limits, configuration will have little or no effect on tree growth (Bennett 1960, Harms and Collins 1965) but may influence future operations such as the thinning method used in the stand. If very wide spacings are used, managers may be limited in the type of mechanical thinning that can be employed in efforts to ensure stocking is not reduced below the desired level (Bennett 1965). In contrast, narrow spacings typically dictate row thinning, which leaves no control regarding which trees are removed within thinning rows.

Timing of the First Thinning

Precommercial thinning: Most foresters believe that precommercial thinning is unnecessary in plantations established at spacings now commonly used in the South. However, there may be a need for such thinning in dense, natural stands and in plantations established by direct seeding or those supplemented with undesirable natural regeneration from surrounding stands. The value of precommercial thinning has been well documented and justified in stands of this type (Cain and Shelton 2003, Guldin and Shelton 2010). Precommercial thinning is best performed as soon as seedlings are well established, usually between ages 2 and 5 (Balmer and Williston 1973, Grano 1969, Guttenberg 1970, Jones 1977, Mann and Lohrey 1974), before they have experienced severe intraspecific competition and while they still are small enough to permit thinning with relatively light equipment such as hand-held brush saws or bush hogs (Demers et al. 2010). If stocking is fairly uniform, seedlings can be removed in strips. Where stocking is extremely high, cross-stripping can be used to further reduce their numbers. The best response appears to be obtained with a residual stocking of 500 to 750 TPA (Grano 1969, Gruschow 1949, Jones 1977, Lohrey 1973, McMinn 1965).

First commercial thinning: Proper timing of the first thinning is one of the most important factors affecting long-term productivity and value of pine stands. Thinning at the proper time maintains growth on high-quality residual stems while reducing the threat of southern pine bark beetles and other forest pests and diseases (Traugott and Dicke 2006). The timing of the first commercial thinning should consider management objectives, operability, site quality, stand density, probability of subsequent thinning, and rotation length.

Once management objectives are determined, other thinning variables can be readily defined. If sawtimber or multiple products are the objective, early intervention may be required to increase the proportion of large, quality, merchantable stems in the final harvest (Burton 1982, Wahlenberg 1960). Early action is especially important with shorter rotations in dense stands (>600 TPA) and on good sites where residual growth potential is high.

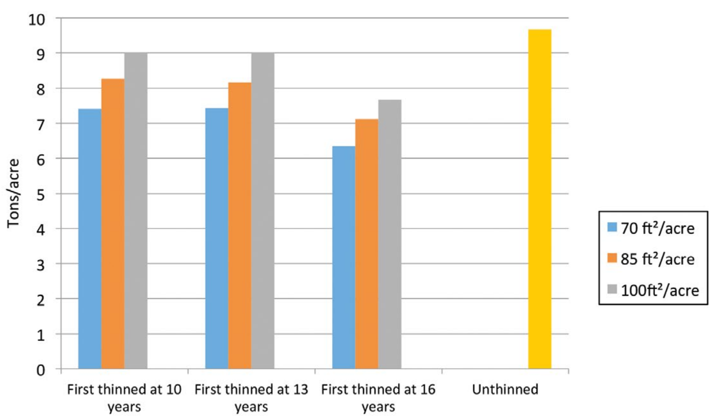

Figure 7. Relationship of age at time of thinning, various stand densities (basal area), and annual pulpwood production per acre.

Traugott and Dicke (2006) recommended the following basic guidelines in stands intended for sawtimber production: 1) natural pruning is at least 18 feet in height, 2) mean stand diameter at breast height (DBH) (4.5 feet aboveground) is at least 6 inches, 3) the last 3 years' annual growth rates are less than 10 percent, and 4) average total tree height is at least 40 feet.

It is common for timberland owners to neglect thinning pine plantations at the optimal timing. In some cases, thinning is intentionally delayed in the hope of receiving a higher price for the lower-valued pulpwood product, which is harvested at thinning and at greatest volumes at first thinning. This practice is not a sound approach for long-term pine plantation investment strategy. Almost always, any short-term gain will result in long-term loss (Henderson and Londo 2012).

By delaying thinning, the growth of the remaining trees is slowed, resulting in longer rotations and reduced investment value in the plantation. The reduction in growth results from trees being subjected to density-related stress and can also cause tree mortality from direct competition between trees. An additional negative density-related side effect resulting from delayed thinning is the increased probability of pine beetle infestation. All factors considered, delaying thinning, either because of negligence or waiting for higher pulpwood prices, brings increased risks or reduced long-term value to the pine plantation investment (Henderson and Londo 2012).

The decision to conduct a first thinning should be made based on the criteria listed earlier. Certainly, the beginning of suppression-caused mortality in 4- to 5-inch-diameter trees is a good indicator of the imminent need for a first thinning in most stands (Mann 1952). Historically, this has occurred between 18 and 20 years for average stand density and site conditions in stands comprised of woods-run seedlings (Wakeley 1954). However, the use of genetically improved seedlings and better establishment procedures has decreased the time required to reach the first thinning. Plantations on average-quality sites are now typically thinned at age 15 to 17, with higher-quality sites undergoing thinning as early as age 10 to 12.

As indicated above, the need for a first thinning can be earlier on land with high site quality than on land with low site quality. However, the significance of site quality's effects in influencing the timing of the first thinning is better understood when considered with stand density. Even on the best sites, timing of the first thinning can be delayed in stands with poor survival and/or low initial planting density. Site occupancy and stand differentiation is often delayed under these conditions, and maintenance of high crown ratios sustains better diameter growth than can be attained in more dense stands. However, stem quality relative to natural pruning length will be poorer generally, except when surviving trees occur in dense patches (Choi et al. 2008, Wakeley 1954). Similarly, increased stand density (>600 TPA) would move the initial thinning date forward when sawtimber and multiple products are the management objectives.

Little research is available regarding the influence of rotation length and use of additional thinnings on timing of the first thinning. However, yield simulation work has shed some light on the relationships. These simulations verified earlier observations about time of thinning and site and stand density relationships. The results indicate that, to maximize total and sawtimber volumes, stands with 450 TPA on land with a site index (SI50) of 80 and stands with 300 to 600 TPA on land with an index (SI50) of 95 should be thinned at 16 to 20 years of age. Stands with higher densities on both sites should be thinned between 13 and 16 years of age.

Additional thinnings increase net total volume yield over the rotation by harvesting more of the trees that are likely to die early. Potential gains are greatest in dense stands (>600 TPA) on better sites. When using two thinnings, the first is performed at a younger age to reduce mortality and increase subsequent average diameter of residual stems. Single thinnings appear best in maximizing sawtimber production for lower densities on the same sites. On lower-density sites, benefits from a second thinning are limited because stand volumes are so low that they preclude operational efforts until late in the rotation. In all cases, average final-harvest tree size is greater with two thinnings than with one.

Intensity

Biological considerations in defining thinning intensity concern tradeoffs between net volume production and average tree size. Stand volume growth is directly proportional to the residual basal area left after thinning, whereas diameter growth is the reverse (Enghardt and Mann 1972). For loblolly pine, there is a broad range of residual densities over which maximum net volume growth occurs after thinning (Gou et al. 2010, Nelson 1961). DBH per unit volume is maximized near the low end of this range.

Heavy thinning promotes rapid diameter growth by favoring large live crown ratios and improved canopy exposure, but the result is underuse of site resources, reduced net volume production, and increased risk of mortality and quality reduction from damaging agents. Light thinnings increase site utilization and volume increment but require greater frequency to achieve desired tree size goals and stem quality (Wahlenberg 1946). Mechanical pruning may be needed in cases of heavy early thinnings to ensure the quality of residual stems for sawtimber production (Clark et al. 2004).

Multiple thinnings (two or three) are recommended for maximum pulpwood plus sawtimber production. The strategy is to keep the stand open enough to prevent suppression-related mortality while allowing trees to fully occupy the site. Earlier and more frequent thinning may be required in high-density stands on good sites than in those on poor sites with low growth potential. Increasing thinning intensity would delay subsequent thinnings so that on better, more densely stocked sites, two thinnings could be achieved in a 30-year rotation.

Thinning guidelines for southern pines frequently propose removing 30 to 45 percent of the stand basal area (Farrar 1968, Morris 1958, Traugott and Dicke 2006). Suggested residual basal area percentages increase with increasing site quality because of greater productive capacity. Residual basal areas range from 60 to 90 square feet per acre (Bull 1950, Nelson 1961) and tend to be lower on poor than on good sites. For the same site, residual basal areas are somewhat lower for early thinnings than for those occurring later in the rotation. Currently, the majority of pine stands are thinned to a residual basal area of 70 to 90 square feet per acre.

As thinning intensity increases, the thinning method used becomes more important due to lasting effects on residual growing stock (Brender 1965). This relationship increases in importance as stand densities decrease.

Frequency

Management objectives, stand density, and site quality influence thinning frequency. Stand density at the time of the first thinning primarily guides the number of thinnings (Andrulot et al. 1972, Guo et al. 2010). The interval of cutting is influenced by economic factors associated with operability, but the biological interval is frequently defined by the length of time required for trees to grow 10 feet in height (Brender 1965). From the biological viewpoint, the interval between thinnings will increase as site quality decreases and stand age at the first thinning increases.

To maximize multiple product yields in short rotations, early and frequent thinnings are needed in stands with greater than 600 TPA (Fender 1968). Early, frequent thinnings salvage trees that are likely to die and help maintain good diameter growth on crop trees. In extremely dense stands (often true of direct-seeded or naturally regenerated stands), a precommercial thinning may be necessary to achieve multiple product goals over short rotations. For dense stands, the first thinning should be performed earlier on higher-quality sites to capture full growth potential of the site (Guo et al. 2010, Jackson 1970). Regardless of thinning intensity, the longer initial thinnings are postponed, the slower the response in diameter growth will be (Mann and Enghardt 1972).

Methods

Over time, improvements in equipment and the advent of “operator select” thinning have greatly changed the approach to thinning pines and the associated economics. The objectives of thinning remain the same: to reduce stand basal area, remove undesirable/smaller trees, and improve residual stand quality for higher-valued products later in the rotation.

Following are some thinning methods for southern pines:

Selective methods. Trees are removed individually based primarily on spacing and stem quality.

Row thinning. Trees are removed strictly on the basis of spacing with little or no regard to crown position. Row or corridor thinnings are examples of this type of thinning. Row thinnings have become the standard in pine plantation management for a number of reasons. First, the current equipment used for thinning operations lends itself to this kind of operation. Secondly, removing rows allows this large equipment access into the stand. In order to maximize the value and volume of residual stems, minimize the number of rows removed.

Figure 8. Heavy or intensive thinning near Starkville, Mississippi.
Photo by Johnathan Reeves

Figure 9. Light thinning in a younger stand near Grenada, Mississippi. *Photo by Brady Self*

Mechanical plus selective method. Using this technique, the stand is mechanically thinned, typically by rows, and then selectively thinned within the leave rows. The majority of first thinnings are currently conducted with this approach.

Mechanical thinning methods (such as row thinning) remove trees of different crown classes, growth rates, form, and so forth in proportion to their occurrence in the stand. Therefore, a mechanical thinning that removes every third row of trees would, in theory, remove one-third of the "best" and "worst" trees in the stand. Consequently, most comparisons have shown that selective thinning results in higher growth rates and better quality compared to pure mechanical-type thinning (Belanger and Brender 1968, Boggess and McMillan 1955, Collicott and Strickland 1967, Enghardt 1968, Gilmore and Boggess 1969, Grano 1974, Whipple 1962). Research also indicates that mechanical methods generally leave the stand more susceptible to damaging agents such as wind and ice (Belanger and Brender 1968, Enghardt 1968, USDA Forest Service 1971). Furthermore, in stands with high incidences of diseased or damaged trees, mechanical methods may be ineffective (i.e., leave too many defective trees at the expense of better ones). However, mechanical thinning is efficient and economical. It also creates excellent stand access, which results in decreased injury to residual stems.

Figure 10. Row thinning with a feller-buncher. *Photo by James Floyd*

From a biological standpoint, selective thinnings appear more desirable than mechanical ones. However, for owners who have the option of using mechanical harvesting equipment and must harvest large areas over short periods, row thinnings are more economical (Enghardt 1968).

Some of the biological disadvantages of strict row thinning can be overcome by a combination of row thinning and selective thinning within leave rows at little additional harvesting cost (Bennett 1965, Brender 1965, Collicott and Strickland 1967, Enghardt 1968, Grano 1974, Russell et al. 2010). Using this method, complete rows of trees are removed at selected intervals (e.g., every third, fourth, or fifth row), and a selective thinning is performed within leave rows. The distance between cut rows is determined primarily by equipment limitations. The wider the distance, the closer the cut is to a selective type thinning. The most common application of this method involves harvesting every fifth row and selective thinning within leave rows (Collicott and Strickland 1967). Trees removed in the selective thinning are primarily those in the lower crown classes and poorly formed or diseased trees. For that reason, post-thinning mortality should be less than that for row thinning alone and comparable to that for selective thinning alone (Collicott and Strickland 1967).

Initial spacing, tree condition (in terms of disease incidence and severity and deformities), and stand age have strong bearing on the choice of a thinning method for plantations. Wide spacings (15 feet and wider) will usually dictate the use of selective thinning (or possibly no thinning) because removal of entire rows will create a situation where remaining trees are unable to use all the growing space (Bennett 1965, Enghardt 1968, USDA Forest Service 1971). In stands with a high incidence rate of diseased or malformed trees, row thinning alone would be inappropriate, but row plus selective thinning might be satisfactory (Collicott and Strickland 1967, Enghardt 1968).

There is little information on the relationship between age and thinning method. However, if row or row plus selective thinning is used, thinning should be performed when trees are fairly young, before much crown differentiation has occurred and before competition has resulted in serious crown reduction on most trees. For loblolly pine on average or better sites and plantings of ≥700 TPA, this will usually mean that thinning should be performed before age 17 (usually between ages 12 and 17).

Thinning Systems

Significant advances have been made in the past 30 years in both logging and mill equipment. This has enabled logging professionals to fully mechanize their pine operations. Most pine harvested in the South is harvested in this manner. The traditional shortwood trucks and chainsaws have been replaced.

Overall, mechanized harvesting systems have a number of advantages. They result in higher production rates and worker productivity, thus lowering harvesting costs per unit of production. They are non-labor intensive, mechanically reliable, and, if implemented correctly, adaptable to adverse weather and ground conditions. However, they have the disadvantage of having high equipment costs. They also require relatively large timber volume and tract size for their use to be profitable. Additionally, their use requires relatively extensive operator training, and, if used improperly, they may cause extensive residual stand damage and soil disturbance.

The use of various machines, systems, and techniques for thinning is being continuously evaluated. The most important factor in cost-effective thinning to be emphasized here is planning. The planning process should be continuous and flexible, begin before the establishment of a new stand, and recognize that all operations are interconnected and that each could affect all others through the rotation.

Modern mechanized harvesting systems are safe, efficient, and perfectly capable of completing a well-planned and clean thinning operation with very little residual stand damage. All operations can be divided into four distinct areas: cutting, skidding (or yarding), loading, and transporting to the mill.

Cutting. Harvesting standing trees is typically accomplished using a feller-buncher (also known as a cutter). This machine does what its name implies—it harvests and bunches stems into piles. A saw head is the most common form of feller-buncher, and it can be mounted on a wheeled or tracked machine. Machinery size varies depending on application and average tree size. Feller-bunchers used for thinning are smaller and more agile than machines used in the harvesting of larger, older trees encountered in later cuts. This smaller equipment is ideal for fifth-row thinning with select thinning between rows. A typical operation will use one feller-buncher.

Figure 11. Mechanized thinning with a feller-buncher. *Photo by James Floyd*

Skidding. Skidding is the means by which bunched logs are taken to the loader. The most commonly used skidder in pine operations is the grapple skidder. The skidder is used to pull trees to the landing. A grapple is mounted on the rear of the machine and is used to pick up an entire pile of cut trees at once. During fifth-row thinning, piles of trees are placed in the cleared row, thus limiting skidder operation to small areas of the tract. Once the skidder drops trees at the loader, it picks up tops and branches and scatters them along skid trails throughout the stand. This serves two purposes. First, the ground effect of logging equipment is reduced through lightening of its footprint. This helps reduce soil compaction and erosion. Second, biomass is distributed back into the stand, which promotes nutrient cycling in the soil. A typical operation will have one or two skidders.

Loading. A piece of equipment called a loader is responsible for sorting trees into product class. On most first thinnings, all harvested material is pulpwood. Later thinnings may include other products such as chip-n-saw and small saw timber. A good loader operator with the ability to sort properly helps maximize profits for both the logging company and the landowner. The loader also delimbs harvested trees and cuts them to proper mill-specified lengths. Once cut trees are delimbed and cut to length, logs are loaded onto trucks for shipment to the mill.

Transporting. Pine harvested in first thinning operations is commonly transported as tree-length material. At this stage, the trees are still young and relatively small. After being cut to the mill-specified minimum top diameter, the entire tree is loaded onto a specially designed log trailer. Trees harvested from second thinnings have more product-sorting potential and will be cut accordingly. The same tree may contain both sawtimber and pulpwood, for example.

Figure 12. Typical logging equipment: grapple skidder, loader, and trees loaded on a truck awaiting transport. *Photo by James Floyd*

Cut-to-length systems. Cut-to-length systems are gaining popularity in some areas. In this system, a processor takes the place of the feller-buncher. The processor cuts, delimbs, and bucks the tree, enabling operators to stack logs according to product onsite. There are some advantages to this system if a pure selection thinning is desired. These machines are agile and able to operate without removing entire rows.

Once logs are sorted and piled, a forwarder is used to pick them up and transport them out of the stand to the road or landing. A forwarder has an attached loader and carries logs as opposed to dragging them like a skidder. A forwarder can also load trucks directly, reducing material handling.

However, there are some limitations with this system. These machines are much more expensive than traditional equipment. This system also works most efficiently when there are several products to sort. If tree-length pulpwood is the only product (most first thinnings), then this system is not practical. In these situations, a feller-buncher with two skidders is more efficient.

With very few exceptions, thinning pine stands in the South is a mechanized operation. On occasion, hand-felling and manual yarding and loading may still be used by landowners who thin their own stands or by novelty crews using horses or mules. The advances in technology over the past few decades have made mechanized thinning safer, more reliable, and less damaging to the residual stand.

BENEFICIAL EFFECTS OF THINNING

Timely thinning of southern pines is important from both forest health and financial perspectives. Thinning a pine stand prior to the threshold of density-related mortality ensures that the forest remains healthy. Thinning promotes tree growth of the residual stand because selected trees are allowed to mature into more valuable trees. While thinning time and intensity is determined primarily based on biological criteria, for many, the long-term objective of timely thinning is to increase economic gain. Thinning allows remaining trees to grow from smaller or pulpwood-sized stems into more valuable product classes such as chip-n-saw and, ultimately, sawtimber. Sawtimber stumpage historically has been worth four to six times as much as pulpwood and chip-n-saw up to three to five times as much as pulpwood (Dickens et al. 2004). Thus, correctly performed, timely thinning is critical to maximizing the financial return of a southern pine forest.

Much of the incentive for thinning is to increase value of the residual stand before final harvest. However, there are other benefits, including reducing the risk of insect infestations, disease epidemics, and damage from abiotic agents.

Increased Growth

The primary objective of thinning is to promote growth of residual trees. Stand density can inhibit tree growth when trees increase in size and TPA remains constant. Thinning allows residual trees to grow without being limited by competition with neighboring trees for water, nutrients, and light. Trees compete with each other for these resources necessary to maintain vigor and growth. When stands become too dense, competition for resources can result in reduced growth rates and eventual tree mortality. As a stand ages, the average diameter increases, and if TPA remains relatively constant, a density related mortality threshold may be reached. The point of this threshold (combinations of diameter and TPA) varies depending on initial stand density. As tree diameters increase and approach this threshold of density-related mortality, growth of trees begins to slow. By reducing the TPA, residual trees have sufficient space to continue growing, resulting in increased diameters.

Increased Utilization

Thinning also results in increased utilization of timber yields from a pine forest over time. A typical first thinning of a pine plantation results in removal of entire rows (to allow entry of timber harvesting equipment) and selective removal of trees between rows. Subsequent thinnings will be purely selective. Consider that trees harvested in a mid-rotation thinning would otherwise be lost to density-related mortality if no action were taken. By removing these trees, yields that would be lost are captured and contribute to the cash flow of the timber investment. This "low thinning" removes suppressed trees, allowing co-dominant and dominant trees to continue to grow.

Reduced Susceptibility to Diseases and Insects

Timely thinning of pine forests promotes tree growth and vigor and is often recommended to reduce the risk of an SPB infestation (Fettig et al. 2007). An analysis of existing pine beetle infestations of loblolly pine plantations across the southeastern U.S. found that the occurrence of pine beetle attacks was greater in stands of high density (Zhang and Zeide 1999). Since SPB infestations are more likely to occur where stand density is greater, the importance of timely thinning is apparent.

The ability of trees to resist insects or diseases is reduced if trees are stressed. Maintaining forest health and vigor through thinning when stands become too dense can prevent overly stressed forests. There is wide agreement that susceptibility to SPB infestation and the occurrence and proliferation of SPB attacks are positively correlated with increased stand density (Brown et al. 1987, Burkhart et al. 1986, Cameron and Billings 1988, Hedden and Billings 1979, Nebeker and Hodges 1983). Clearly, reducing stand density by thinning when necessary can greatly reduce the risk of timber loss due to insects and diseases.

A common stand density management recommendation for minimizing SPB risk is thinning stands with basal areas ≥120 square feet per acre to a residual stand basal area below 80 square feet per acre (Belanger and Malac 1980). For additional guidance on thinning intensity, consider that the U.S. Forest Service Southern Pine Beetle Prevention Initiative program sets the residual TPA for precommercial thinning at 450 stems and for first thinning to a residual basal area of 80 square feet per acre (Nowak et al. 2008). Numerous studies recommend thinning stands to a basal area of approximately 80 square feet per acre to reduce both frequency and intensity of SPB infestations (Belanger and Malac 1980, Brown et al. 1987, Fettig et al. 2007, Nebeker 1981, Nebeker et al. 1983, Nebeker and Hodges 1983, 1985).

Tree Quality Improvement

Tree quality improvement may also be achieved through thinning. Trees removed in thinning include less vigorous and diseased stems. Additionally, those having an undesirable form, often due to genetic factors, are removed. By removing such trees during thinning operations, the quality of residual timber is typically improved, resulting in a more valuable future timber harvest.

Impacts of Thinning on Nontimber Values

Thinning can influence forest values besides timber. In southern forests, the nontimber values most often affected by thinning include wildlife habitat, recreation, aesthetics, grazing, and water quality and quantity. These values are generally improved through the thinning of dense stands.

Cutting of any type may diminish recreational values for a short period of time. Freshly cut stands are typically not thought of as aesthetically pleasing, and their recreational uses such as for hunting and hiking may be impacted. However, given time, thinning to a relatively low basal area will create a more favorable environment for recreation (Halls 1978).

While thinning may not be aesthetically pleasing, the benefits, particularly regarding wildlife habitat, will be realized very quickly. Thinning opens the forest canopy and allows more sunlight to reach the forest floor, stimulating growth of ground-level vegetation. Increased forest floor vegetation enhances wildlife habitat by producing more browse for deer and other wildlife. Thus, thinning can greatly enhance the recreational value of any pine forest.

Other Benefits

The overall objective of this publication is to promote forest thinning operations as a way to prevent SPB attack and optimize forest productivity. However, the forest health benefits associated with thinning are not exclusive to SPB prevention. Several other groups of native and introduced forest pests can be controlled using properly timed and executed thinning operations. This offers added benefits to those choosing wisely to implement thinning to minimize SPB hazard.

Thinning dense stands opens up the understory and allows the flowering herbaceous layer to flourish. Some research has indicated that this provides nectar sites for parasitoids and predators of forest insect pests. Increasing the abundance of nectar sites in the flowering herbaceous layer has been linked to greater abundance and longevity of natural enemies of the SPB (Drumtra and Stephen 1999) and other forest pest species. Along with promoting growth and diversity of herbaceous plants, corridors and skid trails created during thinning offer an ideal opportunity for high-diversity seeding of native plants. This increase in plant diversity benefits natural enemies of forest insect pests by providing floral nectar for several years.

Pine wilt is a serious disease in many species of pines and is caused by the pine wood nematode (*Bursaphelenchus xylophilus*) (Mamiya 1983). The nematode is transported between trees by several species of native longhorned woodboring beetles, most notably the southern pine sawyer beetle (Monochamus titilator) (Mamiya 1983). The disease occurs throughout the eastern half of the United States, scattered localities in the western U.S., and Ontario. The nematode can cause rapid death in pines due to its fast reproductive capabilities and subsequent damage caused to resin ducts in trees. Little can be done to save trees once they are infected, but nematode populations sometimes stabilize or decrease within infected trees during cool and moist conditions, resulting in a lack of wilt symptoms. However, hot weather, drought, and attack from other insect pests will result in a buildup of nematode numbers that eventually cause the death of infected trees. Properly timed and executed thinning operations can help prevent pine wilt spread by minimizing activity of the sawyer beetle that carries nematodes between trees. Pine sawyer beetles typically reproduce in stressed, dying, recently dead, or felled trees (Baker 1972). Forest thinning techniques can minimize the amount of suitable host material for beetle reproduction, ultimately reducing the abundance of sawyer beetles across the landscape. Unfortunately, because adult sawyer beetles also sometimes feed on the bark of healthy pines, silvicultural techniques will not completely remove the risk of pine wilt activity in pine stands.

Compared to the SPB, Ips engraver beetles are less likely to attack and kill healthy trees. Outbreaks can sometimes occur and are usually associated with dense, unthinned pine stands (Fettig et al. 2007). Typically, Ips attack and cause mortality of unhealthy, stressed, or damaged trees (Connor and Wilkinson 1998). Thinning operations and subsequent logging residuals (slash) left on-site can attract and harbor large numbers of Ips beetles (Craighead 1927). However, these population increases are usually temporary and do not outweigh the long-term benefits of thinning (Ward and Mistretta 2002). Additionally, Ips beetles rarely attack undamaged trees in properly executed thinning operations (Mason 1969). Logging practices that minimize soil compaction, minimize damage to residual trees, and avoid leaving large amounts of slash in contact with or close to standing trees reduce chances of subsequent Ips damage. Thinning offers a chance to remove damaged, unhealthy, or stressed trees that might otherwise harbor Ips beetles and allow their populations to grow. Maintaining overall stand health and low Ips population levels helps to minimize risk of damage following future disturbances such as wind, ice, or fire.

Figure 13. Typical single-tree Ips beetle infestation. Note undamaged trees nearby. *Photo by Andrew Ezell*

The European woodwasp (*Sirex noctilio*) is another potential threat to southeastern forests that preventive thinning could minimize (Dodds et al. 2007). Several species of native woodwasp occur in the southeastern United States, but they typically do not cause extensive tree mortality or wood quality degradation. However, the European woodwasp has posed a significant threat to southeastern pine forests since its discovery in New York in 2004. Sirex noctilio has a track record of destruction that spans the globe. It has caused extensive mortality to pine plantations around the world after being introduced to Australia, New Zealand, and portions of South America (Dodds et al. 2007). Currently, little is known regarding the preference of this exotic woodwasp for southern pine species or its ability to successfully reproduce in them (Dodds et al. 2007). However, South American plantations of North American pines (mostly *Pinus* spp.) experienced greater than 80 percent mortality after the woodwasp was introduced there. Research is currently under way to determine which species of southern pines are preferred by S. noctlio (Ghandi and Riggins unpublished data).

Timber losses due to the European woodwasp in Australia, New Zealand, and Brazil have been greater in overstocked commercial pine stands than in stands that had undergone thinning operations (Neumann et al. 1987). In these cases, populations of woodwasp typically begin and build up in stressed or weakened trees and spill over into healthy trees as the infestation worsens. Therefore, thinning pine stands for prevention of SPB likely has the added benefit of increasing resistance to S. noctilio.

ADVERSE EFFECTS OF THINNING

Thinning can produce positive and/or negative effects depending on how, where, when, and why it is conducted. The presence of more than one kind of hazard at any given time and place poses some problems in designing an optimum thinning strategy. Further complicating the situation are the species present, stage of stand development, anticipated direct damages to residual stems, site quality, growth rate, and susceptibility to such damaging agents as insects, disease, and windthrow.

As a prerequisite to making optimal thinning prescriptions, foresters must have a perspective of thinning impacts gathered from published information and from experience. The primary focus of this section is to identify negative effects of thinning involving such factors as logging damage, insects, and diseases.

Felling-Related Damage to Residual Trees

The degree of felling-related damage is influenced by several factors: the method of felling, logging equipment and its configuration, tree species, spacing (density) and size class (age), and site conditions. Typical damage encountered is usually in the form of limb breakage, bole wounding (upper and lower bole), and root breakage. Additional damage may involve bending and breakage of whole trees.

Spacing (density) and size class (age) influence the subsequent extent of injury to residual stems. All types of felling injury (bark abrasion, stem bending or breakage, broken limbs) are minimal in trees 12 inches DBH and over (King 1963). Timing, as it relates to season and weather conditions, can cause differences in levels of stand damage (Moehring and Rawls 1970). Periods with wetter conditions typically result in greater levels of damage to both soils and residual trees. Thinning during the period of most rapid growth (spring or early summer) can result in greater injuries to residual trees.

Skidding-Related Damage to Site and Residual Stems

In general, as equipment size increases, damage to the residual stand increases, and stem injuries are greater where arches are used compared to ground skidding logs (Benzie 1959). Benzie (1959) also noted that tree-length arch skidding typically knocked over residual trees more often compared to log-length ground skidding, but ground skidding severed and bruised a higher percentage of roots. In general, using rubber-tired skidders and skidding tree-length were the most damaging practices.

Volume loss in skid trails is related to soil moisture and terrain (greater damage in steep terrain) (Peters 1977) and varies with rut depth and distance from the residual tree (Nebeker et al. 1983). Soil characteristics and terrain also influence the extent of skidding-related damages because imperfectly drained soils are conducive to compaction (Moehring and Rawls 1970). Seedling survival is poorer on heavily compacted, light-textured soils. Likewise, seedling growth is significantly retarded in skid roads or compacted soils, with volume growth showing effects more readily than height (Dickerson 1976, Foil and Ralston 1967, Hatchell 1981, Hatchell et al. 1970, Moehring and Rawls 1970, Perry 1964, Pomeroy 1949).

Figure 14. Skidding damage typical of thinning operations. *Photo by John Auel*

Some tree species may be more sensitive to logging damage under certain seasonal and soil moisture conditions. For example, diameter growth of loblolly pine can be reduced following wet-weather logging (Hatchell et al. 1970, Moehring and Rawls 1970). Decreases in site index in pine plantations have been observed for trees growing on old woods roads. Significant losses in productivity also occur in disturbed areas following harvest (Peters 1977).

With regard to tree size classes, damage due to skidding is greatest on saplings, followed by poles and sawlogs (Benzie 1959, King 1963). Additionally, as log length increases, damage to the residual stand increases. Doubling the length of a log quadruples the turning radius, thus increasing the potential for damage (King 1963).

Indirect Thinning Damage

Thinning in southern pine plantations may increase the likelihood of indirect damage due to environmental factors or damaging organisms. The chief factors causing indirect thinning damage include wind, ice, and the possibility of increased incidence of insects and disease.

Wind. The most severe wind damage appears to occur in larger diameter trees regardless of thinning intensity. These trees tend to be more prone to windthrow and breakage compared to smaller-diameter stems (Nelson and Stanley 1959). Smaller-diameter trees tend to lean or bend without being thrown over. The presence of pathogens predisposes trees to windfall, with root rot being the most significant, followed by butt rots and trunk rots (Boyce 1948, Nelson and Stanley 1959, Powers and Verrall 1962). Increased chance of windthrow and wind damage is also related to geographic location, with particular reference to the Atlantic and Gulf Coastal Plains and increased hurricane frequency.

Ice. In addition to wind-related problems, damage resulting from ice buildup is also of concern following silvicultural treatment. Abel (1949), Brender and Romancier (1965), McKeller (1942), Muntz (1947), and Williston (1974) suggest that susceptibility to ice damage in the southeastern United States is related to tree species, with slash pine being most affected, followed (in order) by longleaf, loblolly, and shortleaf pines. Larger trees suffer more damage compared to smaller ones in dense stands (Shepard 1975), and trees with low diameter to height ratios are more vulnerable to ice. Other factors contributing to the severity of ice damage include stand density, crown class, presence of pathogens, and geographic location (Brender and Romancier 1965, McKellar 1942, Nelson 1951, Shepard 1975, Williston 1974).

Damage is more extensive in row-thinned stands compared to selectively thinned or unthinned stands of loblolly pine (Shepard 1975). In unthinned loblolly pine, less dense stands exhibit less ice damage when compared to those whose density has been reduced using row thinning. Brender and Romancier (1965) suggested that increased thinning intensity negatively affects the severity of ice damage.

Figure 15. Ice damage to loblolly pine. *Photo by Brady Self*

Insects and disease. The most damaging insects in thinned stands include the black turpentine beetle (*Dendroctonus terebrans* Olivier) and the three southern Ips engraver beetles found in the southeastern United States. Anderson and Mistretta (1982) suggested that these species, plus the SPB and the southern pine coneworm, commonly attack trees infected with fusiform rust, annosus root rot, and/or littleleaf disease. The black turpentine beetle is attracted to oleoresin produced on stumps of recently cut and injured trees (Feduccia and Mann 1975). Infestations of black turpentine beetle can be reduced substantially by minimizing injury to residual trees during logging operations. Additionally, avoid harvesting on waterlogged soils to prevent excessive root damage and subsequent attraction of black turpentine beetles (Bennett and Ostmark 1959, Feduccia and Mann 1975).

The relationship between thinning and pest organism infestation has been noted in general, with few specific studies to evaluate this relationship. Mason (1969) investigated the behavior of Ips species populations after summer thinning in a loblolly pine plantation. He reported that thinning attracted large numbers of southern pine engraver (*Ips avulsus* Eichh.) and eastern five-spined engraver (*Ips grandicollis* Eichh.), which infested logging slash in experimental areas. However, the beetles did not attack residual trees and, upon emergence, dispersed to new sources of attraction. Mason (1969) concluded that, in pulpwood stands in the Midsouth, Ips species rarely pose a problem to residual stands following summer thinning. Nebeker (1983) made similar observations of experimental efforts near Starkville, Mississippi. Following a winter/spring thinning of a loblolly pine plantation, large numbers of Ips beetles were attracted to slash and freshly felled trees, with little residual stem mortality occurring. However, during the following 2 years, some mortality of residual stems occurred when thinning slash was left around the base of residual trees. Others have observed mortality in precommercially thinned plantations but could not clearly associate it with distribution of logging slash and a subsequent buildup of Ips beetles. Ips species also attack stressed living trees after natural catastrophes such as ice storms or drought (Brender and Romancier 1965, Mason 1969).

The SPB is considered the most destructive insect of southern pines, but outbreaks are usually not associated with thinning in young stands unless there is severe damage to residual trees. However, thinning may be important in preventing losses to the SPB. Several studies (Hicks et al. 1980, Ku et al. 1980, Lorio 1978) have shown that infestations most often occur in dense stands. Trees in such stands are typically under greater stress and are often of lower vigor compared to trees in less dense stands. Thus, thinning may improve the vigor of residual trees and make them more beetle-resistant.

Figure 16. Southern pine beetle damage. *Photo by Stephen Dicke*

The impact of thinning on pine susceptibility to bark beetles has been explored by Nebeker et al. (1983) and Nebeker and Hodges (1983). Findings indicate that, if implemented properly, thinning can result in increased growth rates and improved resistance to pest attack. However, if there is a considerable stand disturbance, there can be severe damage to the site, reduced growth in residual trees, and increased susceptibility to pest attack. If additional information is desired, other studies have focused on the influence of harvesting on the forest ecosystem and associated pest damage (Hedden 1983), as well as on changes in host condition resulting from silvicultural practices (Blanche et al. 1983).

Growth factors. When thinnings are implemented properly, beneficial effects are evident both in the form of increased product values and stand utilization and in terms of increased resistance to damage by biotic and abiotic agents. Additionally, overall genetic improvement of the stand results through removal of inferior trees. Increased values and resistance are largely due to increased growth rate and improved vigor of the residual stand. The end result is increased economic gain. In addition, the changed forest environment resulting from thinning is usually considered to be of greater benefit for wildlife habitat management, watershed management, recreational uses, grazing, and other amenities.

Damage factors. Poor thinning practices often result in direct damage to residual trees in the form of stem breakage, limb breakage, bole wounding, and/or root damage. Indirectly, site damage may result in growth reduction and increased susceptibility to damaging agents. The kind and amount of damage will depend on felling methods and equipment used, spacing, and time of thinning.

The type of equipment used is the single-most important factor in the extent of direct damage, with mechanized felling of any type generally causing more damage than hand felling. Mechanized felling equipment can damage the site through soil compaction, puddling, and rutting. These conditions can influence tree growth negatively and increase soil erosion. Variables that determine the intensity of such damage include the type of equipment used, soil moisture, soil type, slope, presence/absence of an herbaceous layer, and slash distribution. In general, damage to the site and residual stand increases as equipment size increases. Regardless of the type of equipment used, damage is ordinarily greater on wet soils compared to dry soils. This is a function of the greater susceptibility of wet soils to compaction and puddling. Additionally, erosion potential and damage is greater on wetter soils and sloping ground.

Thinning may also subject the residual stand to indirect damage from abiotic factors such as wind and ice. This type of damage is most closely related to the thinning method employed, with greater damage potential after a mechanical thinning than after a selective-type thinning. Increased damage potential in mechanically thinned areas is the result of the greater distance between rows of trees.

MANAGEMENT RECOMMENDATIONS TO REDUCE LOSSES

Minimizing Damaging Agents

Any thinning strategy must consider potential hazards associated with intensive silvicultural practices. The following management practices are recommended to minimize the impact of damaging organisms and environmental factors on pine stands.

Southern pine beetle. SPB infestations are usually associated with poor tree vigor. Tree vigor is related to site, tree, stand, and environmental conditions; consequently, the development of SPB outbreaks is strongly influenced by these conditions. Though vigor is difficult to quantify, radial growth rate can serve as a strong indicator of tree condition or vigor. Other factors that affect vigor include age, stand density, species composition, soil texture and type, drainage patterns, and stand disturbances associated with cultural practices.

Poor tree vigor is usually associated with densely stocked stands and declining or slow radial growth. These conditions are readily alleviated by thinning, especially thinning methods that remove the lower crown classes. These types of thinnings eliminate the less vigorous or weakened trees that are prime targets of SPB attack. Reduced competition pressure enhances vigor of residual trees. Thinning stands to 70 to 100 square feet of basal area per acre reduces the risk of attacks and may also help to slow the growth of an infestation if a beetle attack does occur. For greater effectiveness, thinning is generally timed in winter when beetle activity is minimal. Thinning to reduce SPB hazard is recommended when basal area approaches 120 square feet per acre or when live crown ratios drop to about 40 percent. Carefully implemented thinning will stimulate radial growth, reduce evapotranspiration, and increase available precipitation through fall. Reduction of evapotranspiration slows down exhaustion of the groundwater supply and favors continued diameter growth. The prevention of water stress results in lower concentrations of monoterpenes and higher levels of resin acids, which could be involved in making the stand less attractive to beetles (Hodges and Lorio 1975).

Figure 17. Thinning a densely stocked stand to reduce the threat of southern pine beetle. *Photo by James Floyd*

Pine stands in low-lying areas are frequently subjected to flooding and can become attractive to SPB. In these areas, thinning alone may not correct the problem. Additional management actions, such as drainage to divert excess water, may be needed.

Any thinning strategy to reduce the risk of SPB attack should be compatible with management goals and consider factors such as site and stand variables, equipment, seasonality, and product objectives. Management of other potential hazards (e.g., annosus root rot, *Ips* spp., and black turpentine beetle) that might conflict with recommendations for SPB must also enter into the decision-making process.

Annosus root rot. Historically, annosus root rot (*Heterobasidion annosus* (Fr.) Bref.) was a major concern in pine management across the South. Incidence and severity of the disease has decreased dramatically due to changes in silvicultural methods and enhanced genetics of seedling stock. While not as prevalent as it once was, the following information regarding annosus root rot is still applicable for a complete understanding of possible damaging agents in southern pine stands.

Thinning is the single-most important factor contributing to annosus root rot in pine stands because cutting exposes stump surfaces to infection. Damage increases after thinning until around year 8, after which damage stabilizes. Annosus spore production is at its highest level in January and February. Consequently, thinning during winter months increases the likelihood of infection. Additionally, species susceptibility, virulence of the disease, deep sandy soils, low soil organic matter, air temperatures below 70ºF, duration of stump susceptibility, and pruning contribute to and/or facilitate infection.

A comprehensive survey of annosus root rot damage in planted and natural stands across the South revealed that 2.8 and 0.07 percent, respectively, were infected. In scattered high-hazard areas, the 5-year loss in volume following thinning was estimated to be 20 percent of the stand (3.6 of 18 tons per acre) (Alexander et al. 1981).

For high-hazard sites, the following measures are recommended for minimizing losses to annosus root rot (Kuhlman et al. 1976):

- Delay thinning or reduce the number of thinnings to reduce the risk of loss. Wider spacing and reduced thinning are beneficial practices.
- Use borax (sodium borate) on cut stumps for the most positive control.
- Thin from April to August south of 34ºN latitude to provide passive control. At this time, the air and stump temperatures are higher (lethal to disease spores) and the number of spores is lower.
- Special precautions are not necessary when regenerating previously infected sites. The disease does not persist in the soil.
- Plant species with greater disease resistance on high-hazard sites (e.g., longleaf pine).

There is some evidence that prescribed burning reduces annosus root rot severity in thinned plantations (Froelich et al. 1978). On low-hazard sites, chemical treatment of stumps is of doubtful value (Hodges 1974). It is generally believed that no thinning restrictions are warranted on sites rated low hazard for annosus root rot. Although the best strategy for reducing the disease on high-hazard sites may be to delay or eliminate thinning, stands on low-hazard sites may be thinned based on normal silvicultural prescriptions. As discussed above, stumps on high-hazard sites should be treated with borax, and, when possible, thinning should be done between May and August for full exploitation of high temperatures and low spore production. Prescribed burning may be performed before and after thinning to further ensure protection of residual stands from infection. If the product objective is pulpwood and the selected planting spacing is wider than 8 feet by 8 feet, thinning may not be needed, particularly on high-hazard sites. Chemical thinning should be used for precommercial thinning on high-hazard sites.

Thinning for hazard reduction of SPB may conflict with management recommendations for annosus root rot. Thus, foresters should be aware of tradeoffs in areas where both pests likely occur. Benefits must be weighed against potential losses for any chosen thinning strategy. In most cases, thinning should be done during the winter months to reduce the hazard of SPB infestation, and stumps should be treated with borax to prevent annosus infection.

Fusiform rust. Fusiform rust (*Cronartium quercuum* f. sp. *fusiforme*) is similar to annosus root rot in its lessened importance as a major problem in southern pine plantation management. Incidence of fusiform has been decreased due to changes in nursery practices and genetic selection in pine breeding programs. The following information regarding fusiform rust is intended as a brief overview of the scientific body of knowledge regarding the fungus.

Losses due to fusiform rust have been estimated in the millions in value, making it the most economically damaging disease of southern pines in history. Slash and loblolly pines are the preferred hosts, with slash pine being the more seriously affected. The disease is more severe in plantations than in natural stands, with mortality occurring primarily in the seedling stage.

Cultural practices that favor fast growth of stands increase the incidence of fusiform rust. However, to prescribe against cultural practices that improve growth is not silviculturally or economically sound. Thinning has little or no practical value in reducing fusiform rust incidence due to the early age at which infection occurs. Therefore, thinning must be used for a different purpose in management of fusiform rust (e.g., minimization of losses through salvage). The first 5 years after planting are the most critical. Precommercial thinning may not be justified and could potentially exacerbate the problem by increasing available surface area for infection. Additionally, thinning this early in the rotation may prevent natural pruning and result in lower stumpage value. Research indicating reductions in fusiform rust at close planting spacings supports this implication. Heavy thinning may also have an adverse effect by increasing growth of alternate hosts (oaks), thereby increasing rust incidence. Conversely, thinning of heavily infected stands can have major effects on total wood production due to the loss of infected trees before final harvest. If rust incidence is less than 25 percent, the first thinning should remove the majority of diseased trees. However, decreasing the density of a stand too much can have unintended consequences in terms of growth of the residual stand and damage from ice and wind.

Figure 18. Fusiform rust-infected loblolly pine. *Photo by Brady Self*

Wind/windthrow. Wind and windthrow are natural phenomena that can cause extensive damage to southern pine stands. The severity of damage depends on geographic location, wind speed, and a variety of other factors. Many studies have indicated that thinning worsens the damage due to wind and windthrow. More crown damage (e.g., broken limbs and small branches, stripped needles and bark, etc.) occur in heavily thinned stands.

While thinning typically increases damage from wind and windthrow, it can potentially reduce such damage by removing diseased, high-risk trees. Also, larger trees are more prone to windthrow, but an early thinning typically improves stability of stands after remaining trees have adapted to the greater exposure.

Thinning strategies should take into account the possibility of windthrow damage. The following considerations could help in developing an optimum thinning strategy:

- Trees infected with annosus root rot and fusiform rust are prone to wind damage.
- Shallow root systems increase susceptibility to windthrow.
- Edge trees are more stable compared to interior trees.
- Trees on extensively saturated soils are prone to windthrow.
- Stand density and height alter wind profiles.
- Wind is funneled through gaps and saddles on main ridges, resulting in greater wind speeds in these areas.
- Indentations in stand edges, especially V-shaped openings, produce a funneling effect.
- Logging injuries contribute to windthrow.
- Windfall losses are heavy following thinning.

Ice. Slash, longleaf, and loblolly pines are more susceptible to ice damage compared to shortleaf pine. The damage can be severe, depending on species, geographic location, age of trees, amount of ice formed on trees, stand density, presence of disease, crown characteristics, and the diameter to height ratio. Thinning has significant impact on ice damage severity. Increased thinning intensity results in increased ice damage.

Ice damage can be minimized by early manipulation of growing space (i.e., precommercial thinning) to develop trees with sturdy, compact crowns. Adequate stocking must be maintained to provide mutual support among trees (Brender and Romancier 1965, Lemon 1961). In ice storm belts, loblolly should be thinned lightly (no more than one-third of basal area at a time) and more frequently (from below or selectively). If selective thinning is not feasible or practical, row thinning at wider intervals (every eighth or tenth row) with selective thinning of trees in leave rows is a desirable alternative (Shepard 1975). Selective thinning should remove smaller, weaker trees, and bent trees should be pruned (Williston 1974).

Minimizing Felling Injuries

The following practices are suggested for limiting damage to pines resulting from felling:

- Thin in late summer and winter due to greater chance of severe injury to residual trees during spring and early summer. (Damage is reduced when soils are frozen and sap flow is reduced.)
- Continue to salvage high-risk trees in each cutting to reduce easily infected specimens.
- Mark leave trees instead of those to be cut. This calls attention to crop trees.
- Use directional felling wherever possible.
- Use smaller machines to minimize damage to residual trees.
- Establish stands at wider spacings to reduce the need for increased thinning frequency.
- Time operations to avoid wet weather logging to minimize stand productivity losses associated with soil compaction (Moehring and Rawls 1970).

Minimizing Skidding Injuries

The following practices are suggested to reduce skidding-related damage:

- Use skidding equipment that minimizes soil compaction on clay or saturated soils; otherwise, schedule skidding during dry weather (Moehring and Rawls 1970).
- Cut logs short enough to minimize scarring of residual trees during forwarding operations.
- Shift logging operations to better-drained, coarser-textured soils to avoid damage to low-lying areas with finer soils during wetter periods (Hatchell et al. 1970).
- Use smaller equipment to reduce the damage to soils and residual trees. If larger equipment is necessary, concentrate the impact on as few trails as possible to limit overall site damage.
- Use cultural techniques such as subsoiling for rehabilitating damaged areas.
- Hasten site recovery by loosening, revegetating, or mulching disturbed areas.

Hatchell and Ralston (1971) stated that as much as 40 years may be required for natural factors to restore soil conditions in loblolly pine stands of the southeastern United States (Hatchell and Ralston 1971). The presence of logging residues after delimbing helps prevent significant compaction (King and Haines 1979). Disking, ripping, and subsoiling also help correct compacted soil conditions (Hatchell et al. 1970, Moehring 1970, Peters 1977). Bedding has been shown to improve growth of loblolly pine on compacted soils (Hatchell 1981). The authors attributed improved growth to elimination of competing vegetation during skidding operations (Hatchell 1981). However, a dense herbaceous layer may help prevent soil compaction in much the same manner as logging slash placed on skid roads and over areas of heavier traffic. Increased herbaceous vegetation also reduces erosion, rain impact, vehicle impact, and high soil temperatures resulting from direct solar radiation.

SUMMARY

Although the principal goal of thinning is improving the growth and value of stands, other benefits are often simultaneously obtained. These benefits include hazard reductions for insect infestations, disease epidemics, and damage due to abiotic agents. Observations indicate that thinning can result in positive and/or negative effects, depending on how, where, when, and why it is implemented. The presence of more than one kind of hazard (e.g., SPB and annosus root rot) in a particular area at a given time poses some problems in designing an optimum thinning strategy. Other factors complicating the situation are the planted species, stage of stand development, anticipated direct damage to residual stems, site quality, growth rate, live crown ratio, available equipment, machine operation, and, ultimately, cost effectiveness of the operation. Additionally, soil compaction, water quality problems, wildlife habitat enhancement, weed problems, aesthetics, and other factors cannot be ignored if all aspects of thinning are to be considered.

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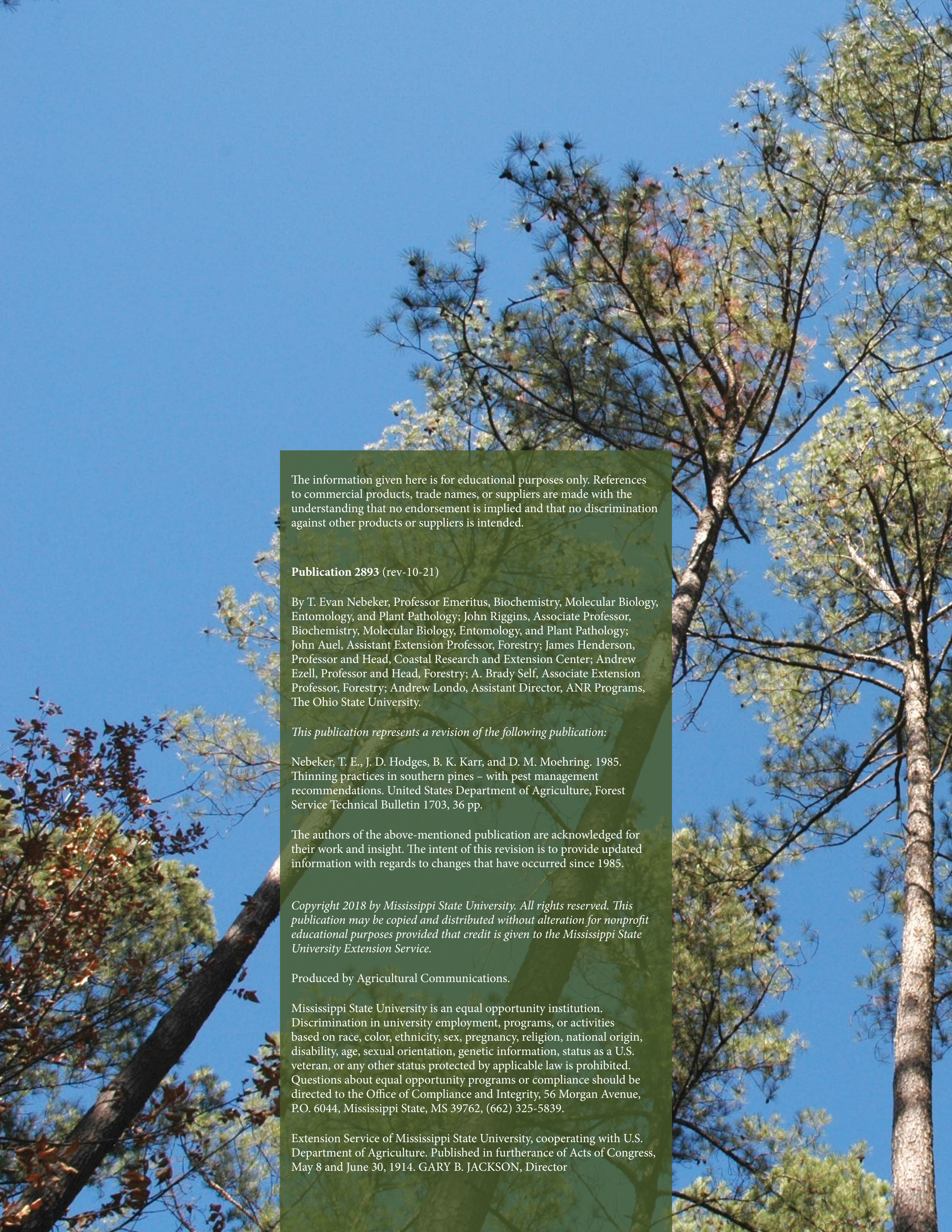

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By T. Evan Nebeker, Professor Emeritus, Biochemistry, Molecular Biology, Entomology, and Plant Pathology; John Riggins, Associate Professor, Biochemistry, Molecular Biology, Entomology, and Plant Pathology; John Auel, Assistant Extension Professor, Forestry; James Henderson, Professor and Head, Coastal Research and Extension Center; Andrew Ezell, Professor and Head, Forestry; A. Brady Self, Associate Extension Professor, Forestry; Andrew Londo, Assistant Director, ANR Programs, The Ohio State University.

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