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THINNING PRACTICES IN SOUTHERN PINES - WITH PEST MANAGEMENT RECOMMENDATIONS
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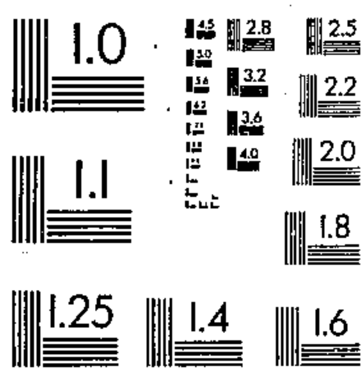

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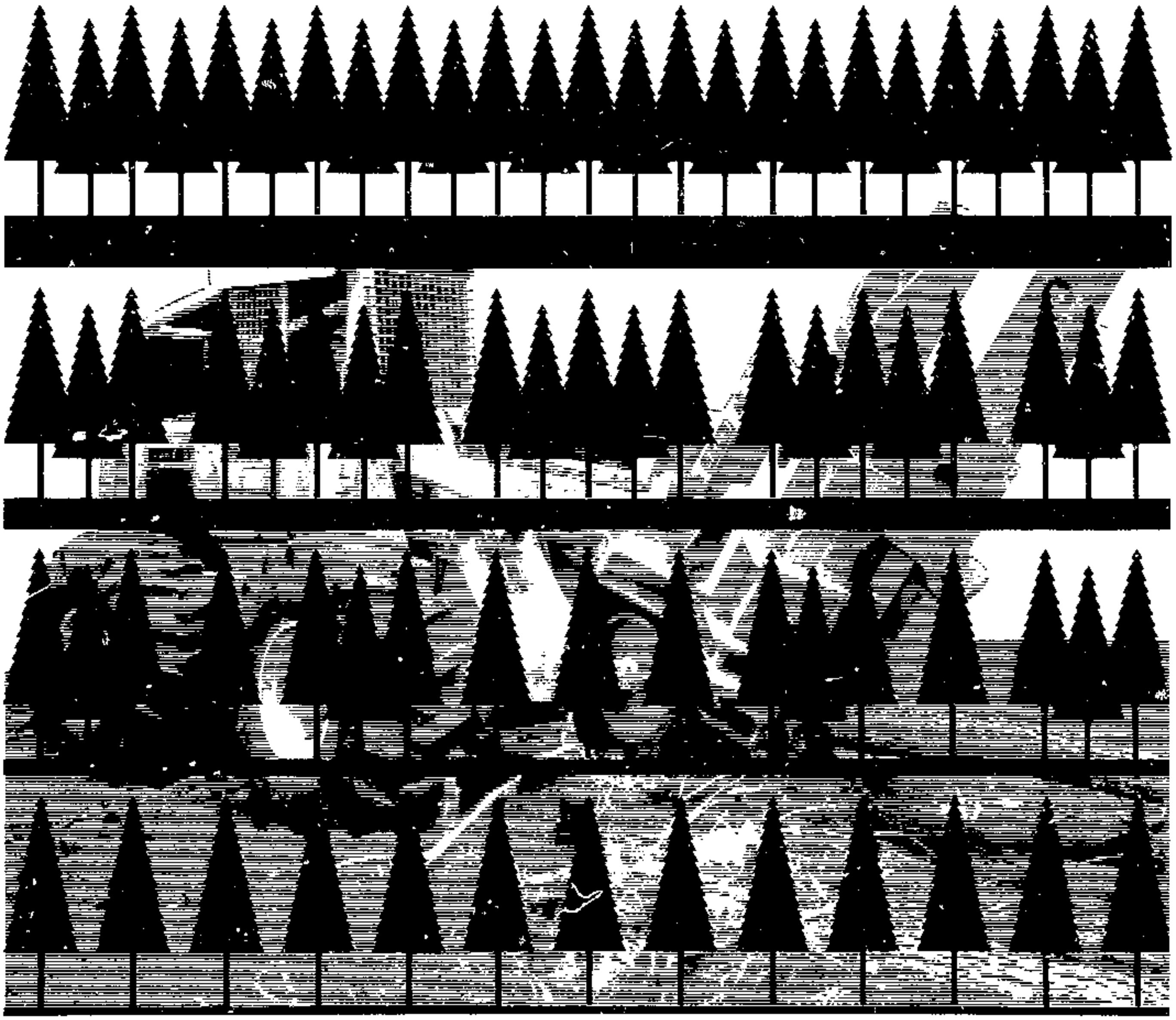
Technical Bulletin 1703

Thinning Practices in Southern Pines—With Pest Management Recommendations



Acknowledgments

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With special tribute to the late D. M. Moehring, who brought us together and envisioned the ideal of improved forestry practices through better interdisciplinary understanding.

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Thinning Practices in Southern Pines — With Pest Management Recommendations

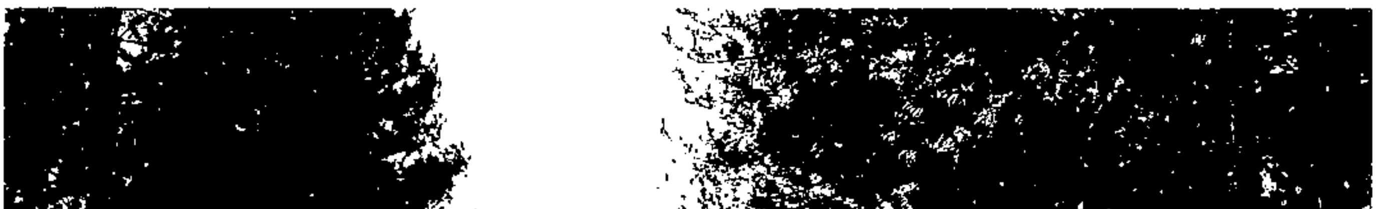
T. Evan Nebeker, John D. Hodges,
Bob K. Karr, and David M. Moehring[1]

[1]Respectively, professor, Department of Entomology; professor, assistant professor, and professor (deceased), Department of Forestry, Mississippi State University, Mississippi State, MS.

Introduction

The management of pine forests in the southern United States has intensified on some ownerships 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 sawlogs, 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 30 years. This has led, in turn, to a significant accumulation of literature on thinning of the major southern pine species. This treatise presents the concept of thinning, reviews and summarizes thinning research, and surveys current field practices. The positive and negative aspects of these practices on current or potential problems are discussed based on recent research. Management approaches are suggested that will help minimize losses caused by damaging organisms and logging injuries.



Intensively managed forest on Vernon Ranger District, Kisatchie National Forest.

Growth of Trees and Stands

The principles of forest management are not greatly different from those affecting other agricultural crops. Trees, like other crops, require light, water, nutrients, space, and protection from insects and diseases. The fundamental growth processes are quite similar. The major difference is the length of time required to reach maturity. Given this difference, the economics of intensive management of a system as extensive as a forest has not always seemed favorable.

The growth potential of a tree is determined genetically, but actual growth is determined largely by the environment. Numerous environmental factors affect growth; of these, water, nutrients, and light intensity are most easily manipulated.

Height and Diameter Growth

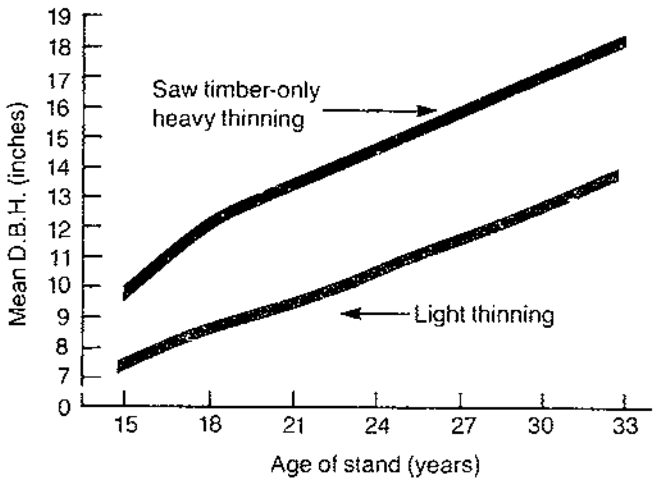
Height growth in the four major pines of the Southeast is indeterminate. Additional flushes (multinodal growth), particularly during midseason, reflect current soil moisture conditions. However, the initial terminal bud is formed in the year before extension, and the height growth from the extension of that bud is closely related to availability of soil water during the late summer of bud formation. If height increment is plotted against age, growt. begins slowly at first, climbs more steeply, then flattens out (Prodan 1968). It is in these steeply climbing intermediate years, the grand period of growth 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. Across this ring of annual growth, early wood cells are abruptly followed by late wood cells whose greater density increases the specific gravity. Although the transition from early to late wood is not a well-understood process, a decrease in soil water availability usually precedes the formation of late wood cells and a continued moisture deficit stops cell division. However, cell division may begin again in midsummer to late summer with increases in soil moisture, as evidenced by false annual rings. In addition, late wood cells continue to form until late summer or early fall if soil water is available (Moehring and Ralston 1967). It is partly through these biological principles that growth increments of individual trees can be regulated through thinning practices or stand density control.

Stand Development

Growth of stands is influenced by site quality, age, species, stocking level, and forestry practices.

A tree's environmental standing can be expressed through the concept of site quality. The 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 increased site index. Thus, the carrying capacity of a given unit of land for tree production increases with increasing site quality.



Growth response as a result of thinning (from Burton 1982).

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

Part of the popularity of even-aged silvicultural management is the simplicity of stand structure. By definition, most trees are of similar age, reaching sapling status—and to a lesser extent, pole and sawlog status—at roughly the same time or stage in stand development. However, taller trees with larger diameters and crowns suppress the growth of neighboring trees, which may become overtopped and eventually die. (Four standard crown classes are recognized in forestry: dominant, codominant, intermediate, and overtopped or suppressed.) As a stand matures, the natural process of competition concentrates the growth potential of the stand in the dominant and codominant trees.

Uneven-aged southern pine stand, showing size classes.

Stocking

What are the implications of stocking and stand development? Proper stocking is a term commonly used but as difficult to apply as to define. First of all, proper stocking is the number of trees per acre that fully utilizes the site's potential to grow trees. It follows that a high-quality site has a higher carrying capacity and, if properly stocked, would carry more trees per acre than a low-quality site. Second, a given site may be properly stocked, once the carrying capacity is reached, with an initial spacing as low as 450 trees/acre or as high as 1,000 or more trees/acre. Third, the rate of diameter growth on individual stems and of stand development differs considerably with spacing. Both the rate of diameter growth and the age at which carrying capacity, in basal area, is reached are greater at wide spacings than at narrow spacings. It is these concepts of stocking, carrying capacity, and stand dynamics that form the biological basis for spacing and thinning to achieve management objectives.

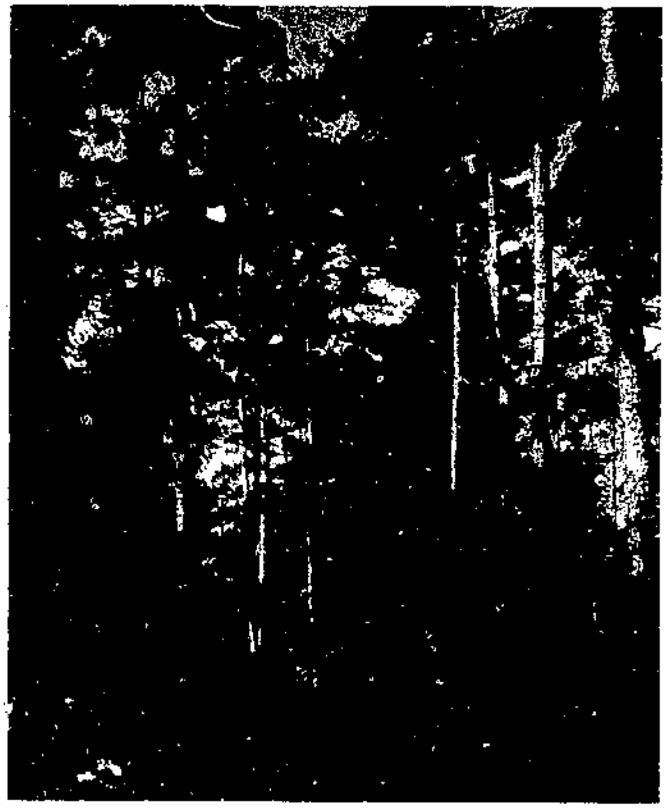
The preceding discussion establishes the following premises:

- Stand differentiation, or stages of development, occurs at earlier ages on high-quality than on low-quality sites.
- 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 the carrying capacity of a site is reached, total volume is similar over a wide range of stocking.

Insect problems intensify as stands become crowded and vigor declines. Southern pine beetle infestations, for example, have long been associated with high stand density. Studies have shown that silvicultural techniques such as thinning offer the most promising and long-lasting means of preventing this situation. But by the same token, we know that the above- and below-ground injuries caused by harvesting and thinning operations serve as infection courts for disease organisms causing decay and deterioration. In fact, thinning can increase the incidence of annosus root rot. Wounded trees tend to be more susceptible to insect infestation as well. These conditions (which will be addressed in more detail later), together with a thorough understanding of the technology and effects of thinning operations, must be taken into account in the development of appropriate management recommendations.

In the South, the decision to thin or not is based primarily on product objectives. If pulpwood is the sole objective, the value of thinning(s) is questionable (Bennett 1963; Goebel et al. 1974; Schultz 1975), especially if there are no size restrictions on the product (e.g., when whole-tree chipping is used). Most studies indicate that, for pulpwood rotations, thinnings of normal intensity will have no influence on cubic volume yield or, more commonly, will reduce the 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 near stagnation of the stand and much 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).

When sawlogs or multiple products are desired, thinnings should be an integral part of southern pine stand management (Bennett 1963). Under such circumstances, the issues that must be addressed include: 1) The relationship between initial spacing and the need for thinnings, 2) the time to thin (age), 3) the intensity and frequency of thinnings, and 4) the most appropriate method of thinning.



Southern pine beetle infestation in dense sawtimber stand in southeast Texas.

Black turpentine beetle problem following logging damage.

Initial Spacing and the Need for Thinnings

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 (table 1) and the carrying capacity of the site.

At close spacings, the basal area carrying capacity is reached earlier, but once 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 the diameter growth of individual trees and thus on value of the final product, as well as the length of time necessary to produce a product of a desired size.

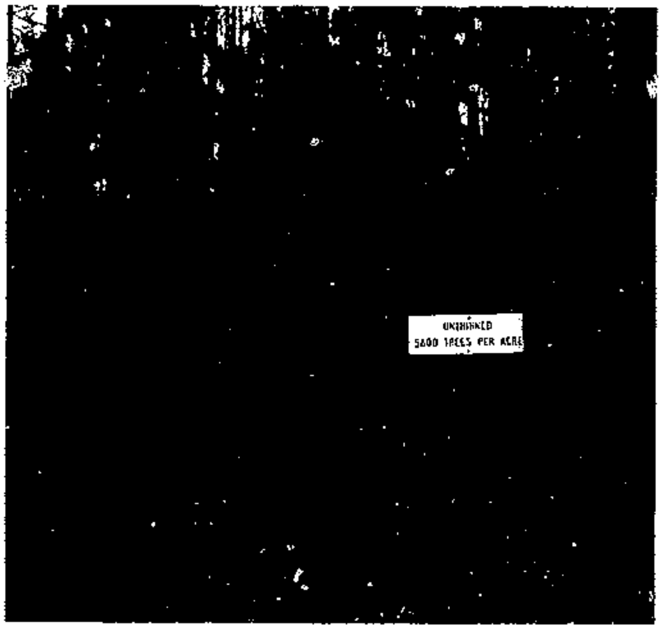
Choice of initial spacing for a given site will probably be determined primarily by the product(s) to be grown in the area. When sawlogs or multiple timber products are the objective, the owner has three alternatives: plant at wide spacing and do no thinning, plant at closer spacing and accept a somewhat longer rotation to get a product of the desired size, or plant at a closer spacing and thin to keep trees growing at an acceptable rate.

Wide spacings (10 by 10 feet or more) will produce more board foot volume on relatively short rotations (25 to 35 years) than will the more usual, closer spacings (Arnold 1978; Bennett 1963, 1969, 1971; Burton 1982; Shelton and Switzer 1980; Shepard 1973), but total volume will likely be less and the quality of the logs lower unless trees are artificially pruned (Bennett 1969; Box et al. 1964; Brender 1965; Feduccia and Mosier 1977; Ware and Stahelin 1948). Intermediate spacings (600 to 800 trees/acre, depending on site) coupled with thinnings will probably offer the best compromise where multiple products are the objective. For rotations of 25 to 35 years, such spacings will yield about as much cubic foot volume as closer spacings and as much board foot volume as wider spacings, although the average tree diameter will be smaller. Stem quality, expressed in terms of branch size and number, sweep and fusiform cankers, will also be better with intermediate spacings in the absence of thinnings. Intermediate spacings with thinnings are also best for production of sawlogs plus cordwood (Feduccia and Mosier 1977; Ware and Stahelin 1948; Williston 1979). Frequent light thinnings (e.g., every 5 years) may yield a higher quality end product and perhaps more board foot volume than heavier thinnings (Farrar 1968; Feduccia and Mosier 1977; Fender 1968). However, economics may dictate heavier, less frequent thinnings. Some work has shown that a single thinning might be acceptable for rotations designed to produce sawlogs (Fender 1968; Hardie 1977; Parker 1979). Timing and frequency of thinnings should be determined to a large extent by site quality and length of rotation.

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

Residual stand density (ft^2/acres)	Yield (ft^3/acre)			
	80 SI	90 SI	100 SI	110 SI
300 trees/acre				
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 trees/acre				
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 trees/acre				
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 trees/acre				
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 trees/acre				
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.; Mann, W.F. Jr. Growth following initial thinning of loblolly pine planted on a cutover site at five spacings. Res. Pap. SO-120. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1976. 8 p.



Dense young stand in need of precommercial thinning.

Dense, stagnated, older pine plantation.

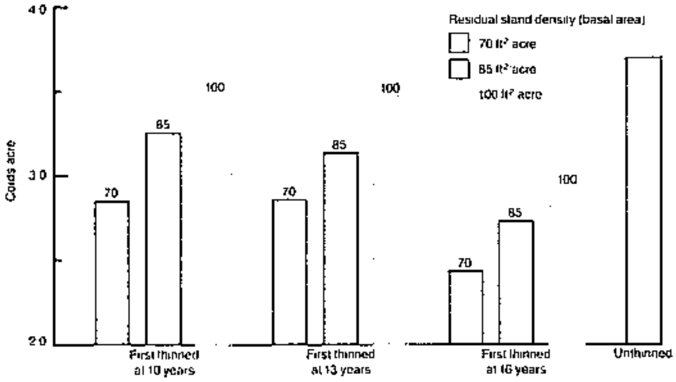
Configuration of the initial planting is also an important consideration. Growth of individual trees appears to be a function of available growing space (stocking density). Within reasonable limits, configuration (square or rectangular spacing) will have little or no effect on tree growth (Bennett 1960; Harms and Collins 1965) but may influence such future operations as the thinning method used in the stand. If very wide spacings (greater than 10 feet) are used, the manager may be limited in the type of mechanical thinning that can be employed to avoid reducing stocking to below the desired level (Bennett 1965).

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 thinnings in dense, natural stands and in plantations established by direct seeding or supplemented with natural regeneration from surrounding stands. Precommercial thinning is probably justified if there are 1,500 or more well-spaced seedlings per acre (Balmer and Williston 1973). In such cases, tree growth can be accelerated by this practice (Lohrey 1972, 1973, 1977; Mann and Lohrey 1974), especially in slash pine, which has a greater tendency to stagnate at an early age than other southern pines. Thinning is best performed as soon as the 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 a rotary mower or light chopper. 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 trees/acre (Grano 1969; Gruschow 1949; Jones 1977; Lohrey 1973; McMinn 1965).

First commercial thinning. The timing of the first commercial thinning should consider management objectives, operability, site quality, stand density, probability of subsequent thinnings, and rotation length.

Once management objectives are determined, other thinning variables are readily defined. If sawlogs 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), especially with shorter rotations in dense stands (600+ trees/acre) and on good sites where residual growth potential is high.



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

Wahlenberg (1946) suggested that intervention usually should be deferred in stands intended for sawlog production until the stems are clear of live branches or can be pruned to a height of 25 feet or more. With a desirable live crown ratio of 35 to 40 percent, this means that first thinnings should be delayed until total height is 38 to 42 feet. Corresponding tree ages would be 12 to 14 years on land with a site index of 95 and 20 to 22 on land with an index of 65. These guidelines, designed to insure desirable crown characteristics and provide rapid diameter increment, apply when tree density exceeds 90+ trees/acre. Mean crown ratios normally exceed 35 percent through age 25 at lower stand densities, even on land with a site index of 95 (Feduccia et al. 1979).

It is generally accepted that the first thinning should be delayed until revenue received from the trees removed will pay the cost of the operation (Wahlenberg 1960). An exception is dense stands (1,000+ trees/acre), in which stagnation is likely, especially if slash pine is the favored species (USDA Forest Service 1971). First thinnings should be made just prior to overcrowding, reduced diameter growth, and heavy mortality and before the live crown ratio is reduced to below 35 percent of total height (Mann 1952; Wakeley 1954). The beginning of suppression-caused mortality in 4- to 5-inch-diameter trees serves as a good signal for a first thinning in most stands (Mann 1952). Generally, this occurs between 18 and 20 years for average density and site conditions, but may be as early as 13 to 15 years at closer initial spacings and on highly productive sites (Wakeley 1954).

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. The significance of site in bringing about the first intervention, however, is better understood when considered with stand density. Time of the first thinning, even on the best sites, can be delayed in stands with poor survival and low initial planting density. Site occupancy and stand differentiation are 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 generally poorer, except when surviving trees occur in dense patches (Wakeley 1954). Similarly, increased stand density (600+ trees/acre) would move the initial thinning date forward in time when sawlogs and multiple products are the management objectives.

Little information is available on the influence of rotation length and use of additional thinnings on the timing of the first thinning. However, yield simulation work[2] has shed some light on the relationships. These simulations verified earlier observations relative to time of thinning and site and stand density relationships. The results indicate that, to maximize total and sawlog volumes, stands with 450 trees/acre on land with a site index of 80 and stands with 300 to 600 trees/acre on land with an index 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+ trees/acre) on the better sites. With two thinnings, the first is done at a younger age to reduce mortality and to increase subsequent average diameter of residual stems. For lower densities on the same sites, single thinnings appear best in maximizing sawlog production. On lower density sites, benefits from second thinnings are limited by unworkable stand volumes until late in the rotation. In all instances, average tree size is greater with two thinnings than with one.

Increasing rotation length delays the time of the first thinning. Yield simulations indicate that the first thinning can be delayed for 2 to 4 years when rotation length is increased from 30 to 36 years. Delay time increases as density increases from 300 to 750 trees/acre. The first thinning should take place 7 years later on poor sites than on good to excellent sites. Site has no effect in altering volume differences between the two rotation options.

[2]Matney, T.G. Unpublished data. Mississippi State, MS: Mississippi State University.

Intensity

Biological considerations in defining thinning intensity concern the 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 (Nelson 1961). Obviously, d.b.h. 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 with resultant 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 stated tree size goals (Wahlenberg 1946). Wakeley (1954) cautions that no attempt should be made to reduce stand density to final sawlog trees without additional thinning. Intensive thinning, like wide initial spacing, wastes growing space, lowers product quality, and allows undesirable vegetation to occupy the site.

Light frequent thinnings are recommended for maximum pulpwood plus sawlog production. The strategy is to keep the stand open enough to prevent mortality from suppression. Earlier and more frequent thinnings 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 interventions, such that on better, more densely stocked sites, two thinnings could be achieved in a 30-year rotation.

Thinning guidelines for southern pines frequently suggest removing 30 to 45 percent of the stand basal area (Farrar 1968; Morris 1958). The percentage of the basal area to be left tends to increase with increasing site quality because of the greater productive capacity and as the age of intervention is increased. Residual basal areas range from 60 to 90 square feet/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 interventions than for late.

As thinning intensity increases, the method used becomes more important because of its effect upon the growing stock left (Brender 1965). This relationship increases in importance as densities drop below 450 trees/acre.

Frequency

Thinning frequency is influenced by management objectives, stand density, and site quality. The number of thinnings is determined by stand density at the time of the first thinning (Andrulot et al. 1972). 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 of 600+ trees/acre (Fender 1968). Such thinnings salvage trees that are likely to die early and maintain good diameter growth on crop trees. At extreme stand densities (often true of direct seeded stands), a precommercial thinning may be necessary to achieve multiple product goals over short rotations. For dense stands, the first thinning should be earlier on better quality sites to capture the full growth potential of the site (Jackson 1970). Regardless of intensity, the longer initial thinnings are deferred, the slower will be the response in diameter growth (Mann and Enghardt 1972).

Methods

Two considerations are paramount in choosing a thinning method for southern pine plantations: 1) The growth response and quality of residual trees, and 2) the costs involved in marking and harvesting. Unfortunately, the method that results in the greatest growth response and best quality trees may also be the most expensive. The best choice will often represent a compromise between cost and quality.

Thinning methods for the southern pines include:

Selective methods. Trees to be removed are marked individually based primarily on their position in the crown canopy, although other considerations (e.g., damage from disease, insects, and wind) may take precedence. These are the classic European methods of low, crown, and selection thinning, or some combination of the three ("free thinning").

Mechanical methods. Trees are removed strictly on the basis of spacing with little or no regard to crown position. Row or corridor thinnings are the primary examples of this type of thinning. Leave-tree or D + x

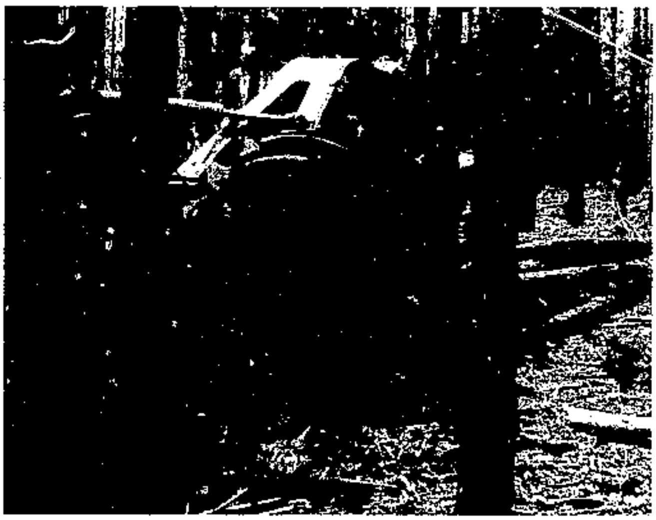
A

B

Heavy, or intensive, thinning (A) and light thinning (B).

thinnings[3] are also mechanical-type thinnings, but some emphasis is placed on selecting better trees for the residual stand.

Mechanical plus selective method. In this technique, the stand is first thinned mechanically, usually by rows, and then selectively within the leave rows.



Row thinning involving a grapple skidder.

Mechanical thinning methods (such as row thinnings) remove trees of different crown classes, growth rates, form, etc., in proportion to their occurrence in the stand. Therefore, a mechanical thinning that removes every third row of trees would in effect remove one-third of the "best" trees in the stand and leave two-thirds of the "worst." For this reason, most comparisons have shown that selective thinning will result in higher growth rates and better quality than mechanical-type thinnings (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 a high incidence of diseased or damaged trees, mechanical methods may be ineffective (i.e., leave too many defective trees at the expense of better ones).

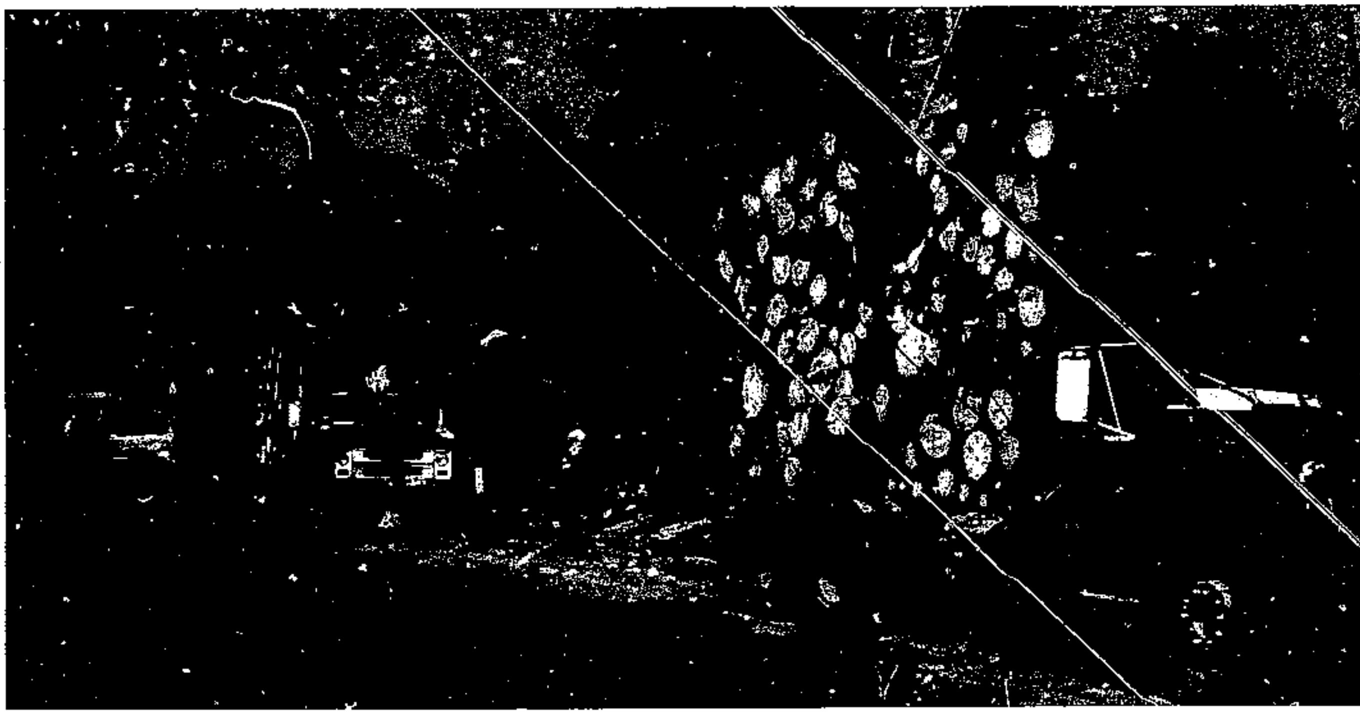
Thus, from a biological standpoint, selective thinnings appear more desirable than mechanical ones, and for some landowners (e.g., the private nonindustrial owners who mark and harvest their own timber), selective thinning is no doubt the best approach (USDA Forest Service 1971). For owners who have the option of using mechanical harvesting equipment and must harvest large areas over short periods, row thinnings may be more economical (Enghardt 1968).

If strict row thinning is employed (no thinning in residual rows), it appears that, for 8- by 8-foot or closer spacings, removal of every third row will give the best results (Belanger and Brender 1968; Collicott and Strickland 1967; Little and Mohr 1963). Third row thinning will give some release to all residual trees and, unlike alternate row thinning, will usually not reduce stocking below acceptable levels, nor will the residual stand be as susceptible to wind and ice damage (Belanger and Brender 1968).

Some of the biological disadvantages of strict row thinnings can be overcome by a combination of row thinning and selective thinning within the leave rows (Bennett 1965; Brender 1965; Collicott and Strickland 1967; Enghardt 1968; Grano 1974) and at little additional harvesting cost. With 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 the leave rows. The distance between cut rows will be determined primarily by equipment limitations. The wider the distance, the closer the cut will be to a selective type thinning, but harvesting costs will also increase. The most common application of this method involves harvesting of every third row and selective thinning within the 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 a 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

[3]In the D + x method, the average spacing between residual trees in feet is equivalent to the average tree dimension in inches plus a constant, usually about 6 feet. If the average diameter of dominant/codominant trees is 10 inches, the spacing between residual trees would be 16 feet. In the line tree method, the square spacing for each residual tree is determined based on age and site index. As for marking, the stand is divided into these imaginary squares (e.g., 17 by 17 feet), and the *best* tree in each square is selected as the leave tree. All others are cut.



Bobtail truck system for harvesting pulpwood.

situation where the remaining trees are unable to utilize all the growing space (Bennett 1965; Enghardt 1968; USDA Forest Service 1971). When the incidence of diseased or malformed trees is high, row thinnings 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, but if either row or row plus selective thinning is used, it should be done when the trees are fairly young, before much crown class differentiation has occurred and before competition has resulted in serious loss of crowns on most trees. For loblolly pine on average or better sites and plantings of 700 or more trees/acre, this will usually mean that the thinning should be done *before* age 17, usually between ages 12 and 17.

Thinning Systems

Many types of thinning systems are used in southern pine plantations but they can be divided into two major categories: Labor-intensive systems, and mechanized systems.

Labor-intensive systems. Labor-intensive systems are distinguished by the high number of workers required relative to productivity. The predominant system in this category is the "bobtail truck" system, which is used by over half the pulpwood producers in the region. The bobtail truck (single- or double-axled) system employs a chainsaw for felling, limbing, topping, and bucking trees into 5.25-foot shortwood lengths. Advantages of this system include: 1) The capital investment required is low. 2) High maneuverability is possible, allowing selective thins with little residual stand damage. 3) Soil disturbance is minimal. 4) It can be used to harvest small, remote tracts not economically harvested by other systems. The disadvantages are: 1) It is labor intensive with a low productivity rate. 2) It is sensitive to adverse weather or ground conditions, with the result that production potential is lost. 3) Harvesting costs are comparatively high as a result of low production.

A second labor-intensive thinning system introduced into the South is the Nordfor system,[4] which employs a five-person crew (three cutters and two winch operators), and the Nordfor Tiltwinch. The system is designed to per-

[4]Originally developed for the Westvaco Company in the Southeast (Nonnemacher 1982).

form a first thinning of natural stands or plantations on areas where terrain conditions are unsatisfactory for conventional systems. The system's advantages are: 1) Residual stand damage and soil disturbance are minimal. 2) It can be used where terrain or soil conditions prevent a more conventional system. 3) It requires relatively low total capital investment. The disadvantages are: 1) It is highly labor intensive, requiring considerable manual labor and resulting high worker turnover. 2) It requires a continuous, expensive training program due to high worker turnover. 3) It achieves a low production rate resulting in a comparatively high harvesting cost. 4) It is sensitive to stand factors, such as tree spacing or density, average d.b.h., and planting quality.

Mechanized systems. In the last two decades, the forestry industry has moved toward mechanization of harvesting because of labor shortages, high wood product volume requirements, advances in technology to meet rising costs, and potential gains in efficiency through use of large-scale systems.

As this move toward mechanization has advanced, it has become evident that few machines, either existing or under development, are really suitable for thinning. With few exceptions, existing machines have been designed for use in a final harvest and, when used for thinning, cause extensive site and residual stand damage. Consequently, equipment manufacturers have begun to develop and market some machines designed especially for thinning southern pine plantations.

A typical mechanized system consists of felling, primary transport, loading, and secondary transport units. Most of these mechanized systems produce tree-length material.

Primary transport, from the stump to the loading area, is usually handled by either skidding or forwarding equipment. In skidding, the log is dragged on the ground with only the butt end elevated, while forwarding involves loading and carrying the entire stem or bucked-up section. Although skidding is the most popular form of primary transport, forwarders are used in many thinning operations in the South.

The major advantages of forwarders are that they reduce residual stand damage and soil disturbance because the wood is in short lengths and is carried off the ground; they are more flexible in laying out the logging plan, because travel corridors need not be straight lines; and they have an integral loading capability. The major disadvantage is that wood has to be bucked and bunched to achieve good production rates, resulting in higher labor requirements and harvesting costs.

Though used extensively, few skidders are really suited to thinning operations because of their large size, which restricts maneuverability in densely stocked stands. Some equipment companies have produced and marketed smaller skidders better suited to thinning activities.

Although other machines, such as farm tractors, crawler tractors, and track-type skidders, are often used for skidding, the articulated rubber-tired skidder is the primary equipment used in the South. Two main types of rubber-tired skidders are the *cable skidder* and the *grapple skidder*.

The cable skidder is able to recover all stems cut and, with its winching capability, to keep away from the immediate vicinity of residual trees. With proper use of the skidder, residual damage to stems and roots is minimal. However, extensive residual stand damage and soil disturbance can result when many trips are made over the same skid trail.

The grapple skidder (named for the armlike assembly mounted on the rear) is used to pick up and drag logs to the landing site. Its major advantage is high production rates (when used with bunched stems), resulting in a lower harvesting cost and fewer trips through the stand, thus reducing soil and residual stand damage. Again, the major disadvantage is the considerable soil disturbance and residual stand damage that occur when many trips are made.

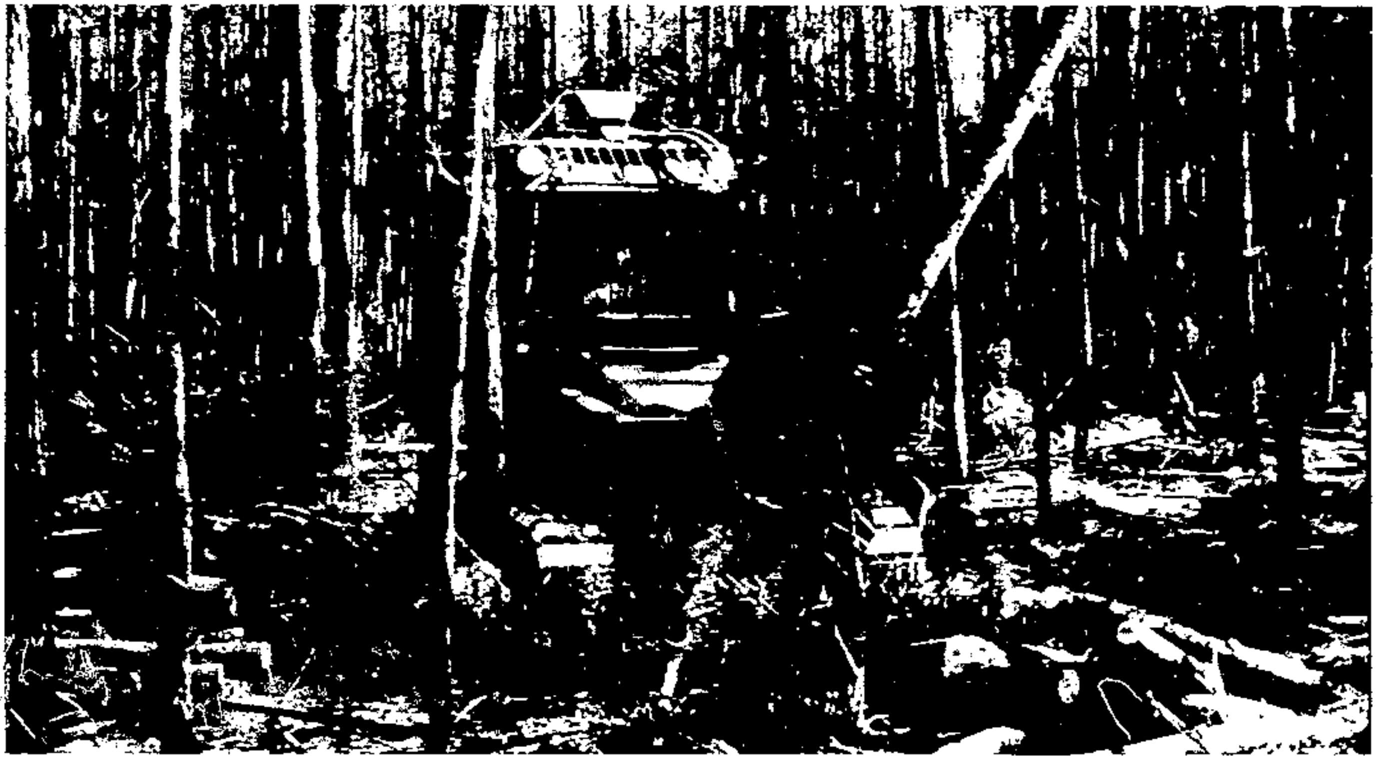
Most mechanized operations use some type of feller-buncher, which consists of two pieces of equipment, the cutting head and some type of carrier. The directional shear and the chainsaw are still commonly used, chainsaws most often for selective thinnings.

Another type of carrier that has been used with some success in thinning operations is a small, highly maneuverable skid-steer-type machine, usually rubber-tired, with either a braking or hydraulic drive system for steering.

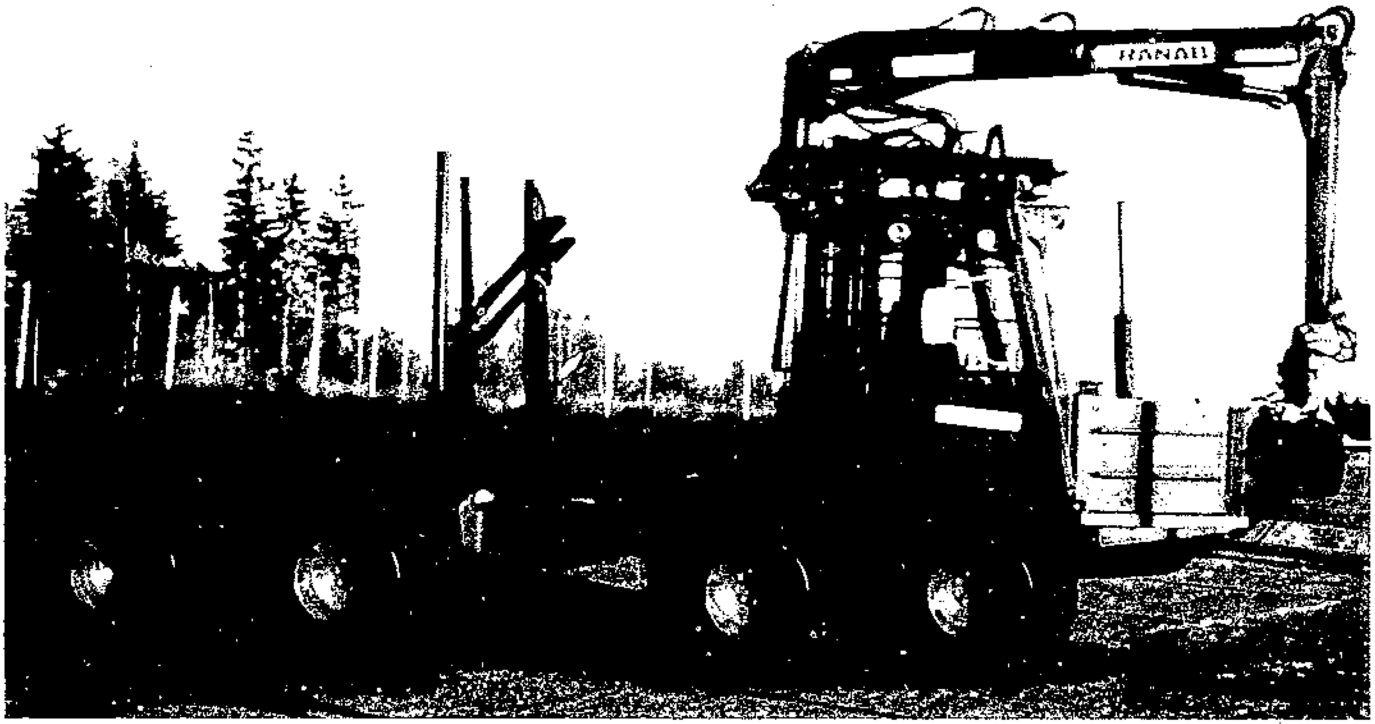
Secondary transport equipment used in harvesting operations is selected on the basis of the planned end product. However, diesel tractors predominate because of their reliability and good fuel economy in comparison with gasoline tractors. The trailer depends on the end-product, e.g., pole trailers for tree-length (longwood) stems, chip vans for chips, etc.

Loading equipment includes front-end loaders with a log grapple, side loaders, pallet rigs, and knuckle-booms. Although not technically a loader, the in-woods chipper chips and loads felled material into vans for hauling.

Overall, mechanized harvesting systems have a number of advantages: 1) They result in higher produc-



Mechanized thinning system (Makeri feller-limber-bucker).



Forwarder (Brunnett Mini).

Skidder.

In-woods chipper at work (Morbark Chipper).

tion rates and worker productivity, so that harvesting costs per unit of production are lower. 2) They are non-labor intensive and, with proper maintenance, mechanically reliable. 3) They are insensitive to adverse weather and ground conditions. However, they have the disadvantages of being capital intensive because of high equipment costs, requiring relatively large timber volume and tract size to be profitable, requiring extensive operator training, and causing extensive residual stand damage and soil disturbance if improperly used.

A last piece of equipment that may be used in thinning operations is the multifunction processor, which is designed to completely or partially process the stem, in some combination of felling, limbing, bunching, and forwarding. Examples of this type of machine are the Timberjack RW 30, which fells, delimbs, and can either forward and/or accumulate bunches, and the Koehring Shortwood Harvester, which fells, limbs, bucks, and forwards the stems to the loading area. Multifunction systems presently consist of technically complex equipment with relatively low output and high cost.

Future thinning operations will most likely require small equipment that is better suited to perform a selective type thinning than present-day equipment. In addition, silvicultural techniques like variable row spacing or wider spacing will be considered. At least one company is now planting rows at 11-foot intervals to allow for machine access and maneuverability and also spacing trees wider within rows to eliminate the first thinning, which is usually of limited commercial value.

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.

Beneficial Effects of Thinning

The purpose of thinning is to increase economic gain. The gain may be achieved by offsetting the expense of carrying establishment costs to rotation age, increasing the value of the product, and/or increasing stand utilization. Large trees are more valuable than small ones because they are cheaper to transport and the resulting products have a greater value than those from small trees, particularly ones below sawlog size. Across the South, the value of sawlogs is two to seven times that of an equal pulpwood volume (Holley 1979). The landowner, whose only return on the raw material is the stumpage value, should be particularly aware of this differential when setting long-range management goals or determining end products from the land.

Although thinning is primarily aimed at improving the value of the residual stems, other benefits now being recognized are risk reduction for insect infestations, disease epidemics, and damage from abiotic agents. The mechanics by which thinning reduces these risks is not fully understood.

Increased Growth

Thinning increases the size of individual trees through redistribution and concentration of a site's growth potential on fewer stems (Shepard 1973). Some studies, however, have shown that thinning or wide spacings may not increase total volume and, for short rotations (20 years or less), may decrease total cubic foot volume (Mann 1952; Smith 1967; Wakeley 1969). For rotations of 35 years or more on good sites, the volume differential may be greater in thinned stands (Williston 1979). Again, the value of the wood is 200 to 700 percent greater, depending on local demands.

As a silvicultural practice, thinning concentrates the growth potential of a stand on crop trees and removes suppressed and dying trees. Although stem quality and total utilizable yield may be increased, the effect of thinning may provide marginal economic returns and only limited growth response in the stand over the rotation. Response to thinning is tempered by most of the factors that influence tree and stand growth—species, age, site index, and the number of trees/acre.

Precommercial thinnings/natural stands. Studies have shown large increases in rate and amount of diameter growth of precommercially thinned natural stands with densities of 1,500 or more stems/acre (Balmer and Williston 1973; Mann and Lohrey 1974). Many trees in such stands are unmerchantable, and the stands continue to grow at a reduced rate until competition takes its toll or until they are thinned. After thinning, diameter and basal area increments may triple within 3 years (Bower 1965). Maximum growth of residual trees occurs when thinning takes place at the onset of competition. Increases in height increment following thinning may also be significant in these very dense stands.

Perhaps the most significant thing noted in the precommercial thinning of natural stands is the importance of stand age at the time of thinning. Responses have been noted in first thinnings from 2 to 15 or more years of age. However, stands thinned at age 2 or 3 years have a greater time for response than do older stands. Delaying precommercial thinning can sharply reduce growth and increase costs.

Precommercial thinnings/plantations. Density control is one of the advantages of planting over direct seeding or natural regeneration. In the South, plantings seldom exceed 890 trees/acre. Consequently, with current spacings and where multiple products are desired, precommercial thinning is usually unnecessary. If thinning is undertaken in precommercial stands, it should be done early, certainly before age 10, to reduce operational costs and obtain the greatest growth response from the residual trees.

Increased Utilization

Increased utilization through the removal of suppressed trees increases economic gain from managed forests. Intermediate and suppressed pine trees can be utilized for pulp. Usually, they are taken with the larger codominant or dominant stems in a "free" thin, common in southern forest management. A "low" thin that takes only intermediate or suppressed trees would be of minimal commercial value. Their removal would do little to reduce competition between dominant and codominant trees. Consequently, economic gain is probably minimal with this type of low thin.

Reduced Susceptibility to Diseases and Insects

Maintaining proper stand density has been long recognized in the South as a means of reducing insect damage. Bennett (1968) presented general guidelines for identifying areas of high risk to southern pine beetle (SPB) attack and for reducing potential losses. Good forest management was his message, and maintaining proper stand density was the most important of several silvicultural recommendations. Dense stands with slow radial growth and reduced tree vigor were subsequently shown to be highly susceptible to SPB attack (Bennett 1971; Hicks et al. 1978). Most hazard-rating systems assign heavy weight to the pine basal area component (Ku et al. 1980; Lorio 1978).

Stand with conditions highly favorable to southern pine beetle attack on Evangeline Ranger District, Kisatchie National Forest.

The message from hazard-rating systems is clear. Healthy trees are less susceptible to attack by SPB than unhealthy ones. Uninfested trees are generally larger, have thicker bark, greater crown/bole ratios, larger crowns, and faster growth rates, and occur in less dense stands. Ku et al. (1980) noticed this difference between noninfested trees and trees infested with SPB in Arkansas. The infested trees were usually located in heavily stocked stands that were under stress. Lightning strikes and logging damage contributed significantly to the stressed state and susceptibility to attack, but high stand density was the most important factor predisposing stands to SPB attack. Therefore, he recommended that basal areas be maintained at not more than 100 square feet/acre on good quality sites. Others have given similar recommendations with the allowable basal area decreasing to 80 square feet/acre on lower quality sites (Belanger 1980; Hicks et al. 1979). Lorio (1980), using stocking levels rather than stand density, showed that loblolly pine stands infested with SPB were overstocked (i.e., overcrowded).

From these early recommendations up to the present, good forest management with scheduled thinning has continued to be recognized as a means of maintaining healthy stands and promoting resistance to SPB attack.

Genetic Improvement

Some genetic improvement may also be achieved through thinning. Trees removed in thinnings from below are usually less vigorous (not growing as well), diseased, or have undesirable form, sometimes due to genetic factors. By removing such trees prior to regeneration of the stand, the forester can minimize undesirable traits.

Other Benefits

Thinning changes the environment of the forest. The penetration of light, the temperature of mineral soil, and the availability of moisture and nutrients are all increased (Blair 1969). Understory vegetation quickly responds to these changes, producing a more favorable habitat for wildlife and cattle (Blair 1967; Halls and Schuster 1965). A relationship between forage increase and reduced basal area has been demonstrated. The diminished canopy that results from thinning allows greater amounts of rain to reach the forest floor, which increases the quantity of water from the watershed (Rogerson 1968; Ursic 1974).

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, 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 the best thinning prescription, the forester must have a perspective of thinning impacts gathered from published information and from experience. The primary focus of this section is to identify the negative effects of thinning involving such factors as logging damage, insects, and diseases.

Felling-Related Damage to Residual Trees

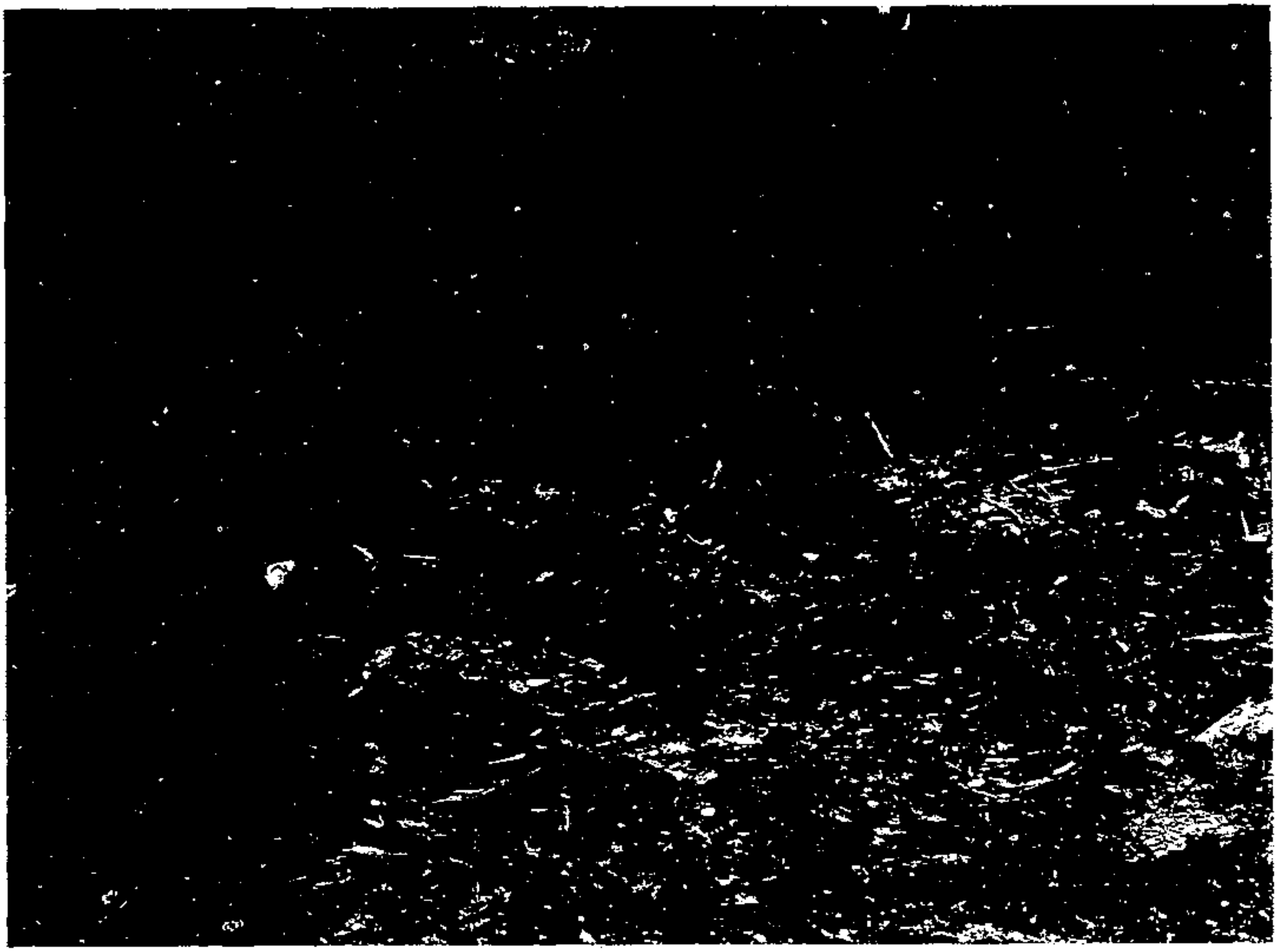
The degree of felling-related damage is influenced by several factors: the method of felling, the equipment and its configuration, tree species, spacing (density) and size class (age), and ground conditions. The type of damage encountered is usually in the form of limb breakage, bole wounding (upper 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 the residual stems. All types of felling injury (bark abrasion, stem bending or breakage, broken limbs) are minimal in trees 12 inches d.b.h. 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). 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 the size of equipment increases, damage to the residual stand increases, and stem injuries are greater where arches are used than where logs are ground skidded (Benzie 1959). The same study also found that tree-length arch-skidding knocked over residual trees more often than log-length ground skidding but that ground skidding severed and bruised a higher percentage of the roots. In general, using rubber-tired skidders and skidding tree-length were the most damaging practices.



Skidding damage.

Volume loss in skid trails is significantly 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 (Dickerson 1976; Foil and Ralston 1967; Hatchell 1981; Hatchell et al. 1970; Moehring and Rawls 1970; Perry 1964; Pomeroy 1949), with volume growth affected more than height.

Some tree species may be more sensitive to logging damage under certain seasonal and soil moisture conditions. For example, the 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).

As log length increases, damage to the residual stand increases. Doubling the length of a log quadruples the turning area, thus increasing the potential for damage (King 1963). Further, increasing traffic intensity correspondingly increases loss in basal area growth of loblolly pine during wet-weather logging (Moehring and Rawls 1970).

Indirect Thinning Damage

Thinning in southern pine plantations may increase the likelihood of indirect damage due to environmental factors or damaging organisms.

Wind. The severest wind damage appears to occur in larger diameter trees regardless of thinning intensity, with these trees tending to be more prone to windthrow and breakage (Nelson and Stanley 1959). Smaller diameter trees tend to sustain more severe lean without being windthrown. The presence of pathogens predisposes trees to windfall, with root rot the most important, followed by butt rots and trunk rots (Boyce 1948; Nelson and Stanley 1959; Powers and Verrall 1962). A greater chance of windthrow and wind damage is also related to geographic location, with particular reference to the Atlantic and Gulf Coastal Plains and hurricane frequencies.

Ice damage.

Ice. In addition to wind-related problems, ice-related damage is also of concern following any silvicultural treatment. Abel (1949), Brender and Romancier (1965), McKellar (1942), Muntz (1947), and Williston (1974) suggest that susceptibility to glaze 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 than smaller ones in dense stands (Shepard 1975), and trees with a low diameter/height ratio are more vulnerable to glaze.

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 than in selectively thinned or unthinned stands of loblolly pine (Shepard 1975). In unthinned loblolly, denser stands suffer less damage, while in row-thinned loblolly, denser stands have more damage after thinning. Brender and Romancier (1965) suggested that increased thinning intensity affects the degree of glaze damage.

Insects and disease. The most damaging insects in thinned stands include the black turpentine beetle and the three southern *Ips* engraver beetles found in the southeastern United States. Anderson and Mistretta (1982) suggested that these species, plus the southern pine beetle 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 the oleoresin produced on stumps of recently cut and injured trees (Feduccia and Mann 1975). Infestations of the black turpentine beetle can be reduced substantially by minimizing injuries to residual trees during logging and avoiding harvesting on waterlogged soils to prevent excessive root damage (Bennett and Ostmark 1959; Feduccia and Mann 1975).

The relationship between stand manipulation (i.e., thinning) and pest organisms has been noted in general, with few specific studies to evaluate this relationship. Mason (1969) investigated the behavior of *Ips* spp. populations after summer thinning in a loblolly pine plantation. He reported that thinning attracted large numbers of *Ips avulsus* (Eichh.) and *I. grandicollis* (Eichh.), which infested slash in the experimental area. However, the beetles did not attack residual trees and upon emergence dispersed to new sources of attraction. Mason concluded that in pulpwood stands in the mid-

South, *Ips* spp. rarely pose a problem to residual stands following summer thinning (1969). Similar observations[5] were made following thinning of a loblolly pine plantation on an experimental forest in Mississippi during the winter and spring of 1977-78. Large numbers of *Ips* spp. were attracted to the slash and freshly felled trees, and little residual stem mortality occurred. However, during 1981 and 1982, some mortality of residual stems occurred when thinning slash was left around the base of residual trees.[6] Others observed mortality in precommercially thinned plantations but could not clearly associate it with the distribution of logging slash and an *Ips* spp. buildup. *Ips* spp. may also attack living trees after natural catastrophes such as ice storms or severe drought (Brender and Romancier 1965; Mason 1969).

The southern pine beetle 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.[7] Several studies (Hicks et al. 1980; Ku et al. 1980; Lorio 1978) have shown that infestations most often occur in denser stands. Trees in such stands are more apt to be under stress and to be less vigorous than trees in less dense stands. Thus, thinning may improve the vigor of residual trees and make them more beetle resistant.

The impact of thinning on host susceptibility to bark beetles has been recently explored by Nebeker et al. (1983) and Nebeker and Hodges (1983). Preliminary findings indicate that, if properly done, thinning can result in increased growth rates and improved resistance to pest attack. However, if there is considerable disturbance, there can be initial severe damage to the site, reduced growth in residual trees, and increased susceptibility to pest attack. Additional studies have also focused on the influence of harvesting on the forest ecosystem and associated pest damage (Hedden 1983).

Recent studies have focused more closely on the changes in host condition resulting from silvicultural practices (Blanche et al. 1983) than does this discussion. In addition, a broader treatment of the host is presented in the proceedings of a recent symposium (Kellison and Gingrich 1982).

In thinned loblolly and slash pine stands, disease may be a more serious problem than insects on certain sites. Annosus root rot can enter previously healthy stands, primarily after thinning, where it colonizes freshly cut stumps and eventually spreads to adjacent trees through root contact (Campbell 1965; Hodges 1974). In the latter study, annosus root rot was present in 59 percent of all thinned loblolly pine plantations and 44 percent of slash pine plantations on high-hazard sites in the southeastern States. Losses averaged 2.8 percent of the loblolly trees examined and 2.2 percent of the slash. Losses in some plantations exceeded 30 percent. A southwide study (Powers and Verrall 1962) showed that mortality associated with annosus root rot increased with the number of thinnings and the years after thinning. Mortality, however, is only part of the problem, for growth (height and diameter) in some trees may be reduced by a third even though the crowns appear vigorous and there is no outward sign of infection (Bradford et al. 1978; Froelich et al. 1977).

The probability of serious annosus root rot infection occurring after thinning is highly dependent on site. Froelich et al. (1966) developed methods for assessing site hazard in the Gulf South. In general, soil texture or texture-related variables provide the best indication of disease hazard (Kuhlman et al. 1976). Low-hazard sites include Piedmont soils, lowland flatwood soils (poorly drained, silty or sandy surface soil, heavy clay subsoil), and shallow upland Coastal Plain soils. High-hazard sites include both deep sandy and silty soils. Deep, well-drained sandy soils are extremely hazardous in the Southeast. These soil types occur mainly in the Sand Hills and well-drained areas of the Coastal Plain. Thick loessial deposits in north Mississippi represent high-hazard silty soils.

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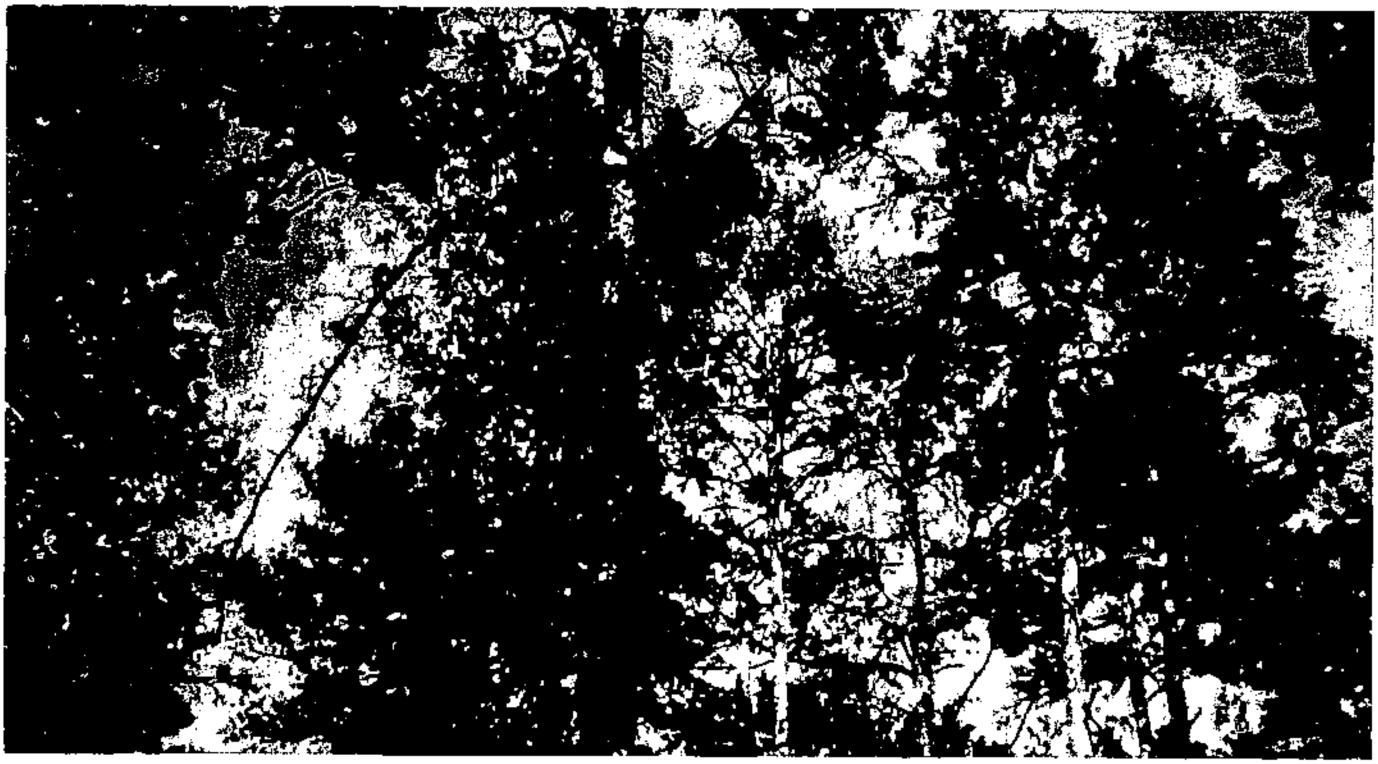
[5] Nebeker, T.E. Unpublished report. Mississippi State, MS: Mississippi State University.

[6] Ibid.

[7] Ibid.



Bark beetle damage.

Aerial view of thinned planted stand with annosus root rot damage.

Impacts of Thinning on Nontimber Values

Thinning may influence forest values other than timber. In southern forests, the nontimber values most often affected include wildlife habitat, recreation (esthetics), grazing, and water quality and quantity. As previously pointed out, these values are generally improved by thinning dense stands.

But any type of cutting, including thinning, may diminish recreational values, at least for a short period. Freshly cut stands are not esthetically pleasing, and their recreational uses such as for hunting and hiking may diminish for a time; however, in the long run, thinning to a relatively low basal area will create a more favorable environment for recreation (Halls 1978).

Likewise, the increased precipitation reaching the forest floor when the canopy cover is reduced by thinning can influence quality as well as quantity of water flow.

Discussion

Stocking, carrying capacity, and stand dynamics are the concepts that form the biological basis for spacing and thinning to achieve management objectives. A thorough understanding of the positive and negative impacts of thinning operations must be taken into account in the development of appropriate management recommendations.

Growth Factors

If thinnings are properly performed, they will have beneficial effects, not only in the form of increased product values and increased stand utilization, but in terms of increased resistance to damage by both biotic and abiotic agents as well as genetic improvement. Increased values and resistance are largely due to increased growth rates and improved vigor of the residual stand. The end result is increased economic gain. In addition, the changed forest environment resulting from thinnings is usually considered beneficial for wildlife habitat management, watershed management, recreational uses, grazing, and other amenities.

Damage Factors

Conversely, poor thinning practices can 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 also damage the site. Site damage includes soil compaction, puddling, and rutting, conditions that all influence both tree growth and soil erosion. Variables that determine the intensity of such damage are equipment used, soil moisture, soil type, slope, presence 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 usually greater on wet than on dry soils because wet soils are more susceptible to compaction and puddling. Erosion damage is greater on 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 damage potential greater after a mechanical thinning than after a selective-type thinning.

Minimizing Damaging Agents

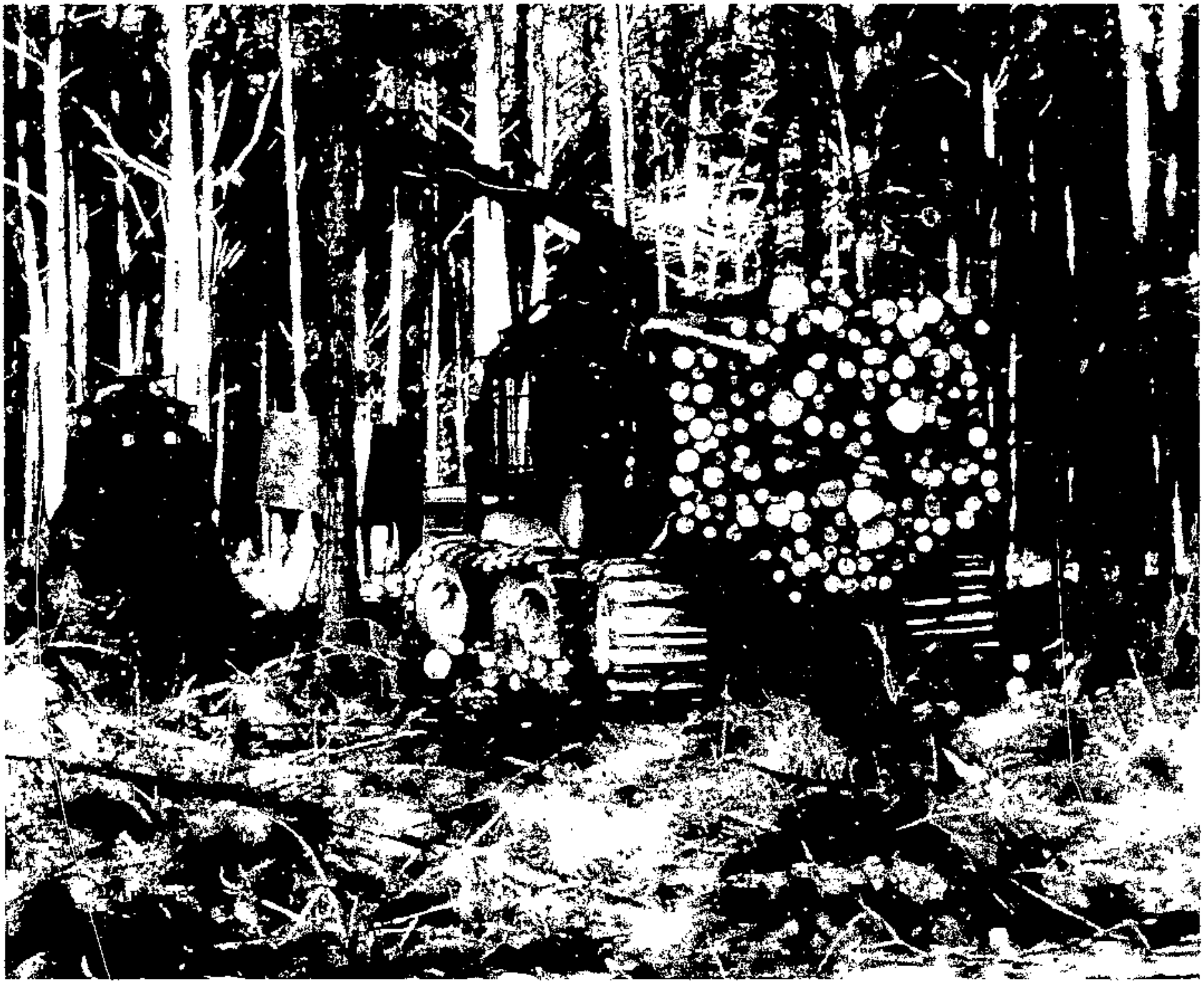
Any thinning strategy must consider the potential hazards associated with intensive silvicultural practices. The following management practices are recommended to minimize the impact of damaging organisms and environmental factors on pine stands.

Southern pine beetle. Southern pine beetle infestations are often associated with poor tree vigor. Because tree vigor is basically related to site, tree, stand, and environmental conditions, the development of southern pine beetle 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, conditions readily alleviated by thinnings, especially those that remove the lower crown classes. These types of thinnings eliminate the less vigorous or weakened trees that are the prime targets of southern pine beetle attack. Reduced competition pressure enhances the vigor of residual trees. Thinning stands back to 70 to 100 square feet/acre basal area reduces the risk of attacks and may also help to slow spot growth if an attack does occur. For greater effectiveness, thinning is generally timed in winter when the beetle is least active. Thinning to reduce southern pine beetle hazard is recommended when basal area approaches 120 square feet/acre or when live crown ratios drop to about 40 percent. A carefully carried out thinning will stimulate radial growth, reduce evapotranspiration, and increase rain throughfall. The reduction in evapotranspiration slows down the exhaustion of groundwater supply and favors continued diameter growth. The prevention of severe 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).

Pine stands in low-lying areas are frequently subjected to flooding and become attractive to southern pine beetle. 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 southern pine beetle attack should be compatible with management goals and consider such things as site and stand factors, equipment, seasonality, and product objective. Management of other potential hazards (e.g., annosus



Thinning densely stocked stand to reduce threat of southern pine beetle.

root rot, *Ips* spp., and black turpentine beetle) that might conflict with recommendations for southern pine beetle must also enter into the decisionmaking process.

Annosus root rot. Thinning is the single most important factor contributing to annosus root rot in pine stands, since cutting exposes stump surfaces to infection. Damage due to the fungus increases with time after thinning up to about 8 years, after which the damage level stabilizes. Because annosus spore production is at its highest level in January and February, thinning during the winter increases the likelihood of infection. In addition to thinning, species susceptibility, virulence of the disease, deep sandy soils, low soil organic matter, air temperatures below 70°F, 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 throughout 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 (9 of 46 cords/acre). In general, volume loss following thinning ranges from 0.1 to 0.5 cord/acre/year (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 on cut stumps for the most positive control. Borax is not effective at a second thinning if not used for the first.
- Thin from April to August south of 34° N latitude to provide passive control because of high air and stump temperatures (which are lethal to disease spores) and low numbers of spores.
- Don't take any special precautions when replanting previously infected sites. The disease does not persist in the soil.
- Plant more resistant species on high-hazard sites, e.g., longleaf pine is more resistant than loblolly pine.

Treating stump with borax to control annosus root rot.

There is some evidence that prescribed burning will reduce the severity of annosus root rot in thinned plantations (Froelich et al. 1978). On low-hazard sites, chemical treatment of the stumps is of doubtful value (Hodges 1974). It is generally believed that on sites rated low hazard for annosus root rot, no restrictions on thinning are necessary. Although the best strategy for reducing the disease on high-hazard sites may be to delay or do no thinning, stands on low-hazard sites may be thinned based on normal silvicultural prescriptions dictated by product objectives, biological constraints, and desired capital recovery. As recommended above, stumps on high-hazard sites should be treated with borax and, in stands with confirmed root rot, *Peniophora gigantea* (Fr.) Massee, a saprophytic fungus, and, when possible, thinning should be done during the hottest months of the year (May-August) to take advantage of high temperatures and low spore production and survival conditions. Prescribed burning may be done before and after thinning to further insure the protection of residual stands from infection.

If spacing is wider than 8 by 8 feet, and the product objective is pulpwood, thinning may be foregone, particularly on high-hazard sites. Chemical thinning should be done for precommercial thinning on high-hazard sites.

Because thinning to reduce the hazard of southern pine beetle incidence conflicts with management recommendations for annosus root rot, foresters should be aware of the tradeoffs in areas where both pests are likely to occur. Benefits must be weighed against potential losses for any chosen thinning strategy. In most cases, thinning should be done in the winter to reduce the hazard of southern pine beetle infestation, and the stumps should be treated with borax to prevent annosus infection.

Fusiform rust. Losses due to fusiform rust have been estimated to exceed $25 million annually in value, making it the most economically damaging disease of southern pines. Slash and loblolly pines are the preferred hosts, 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.

Interestingly enough, 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 and economically sound. It has been claimed that even a 50-percent rust infection rate in a stand can be offset by an increase in volume resulting from such intensive cultural practices as site preparation and fertilization.

Thinning has little or no practical value in reducing the incidence of fusiform rust because infection occurs at the early stages of stand development. It must, therefore, be practiced for a different purpose—to minimize losses due to rust, i.e., salvage. The first 5 years after planting are the critical period. Precommercial thinning may not be justified and may aggravate the problem by increasing the surface area for infection and by preventing natural pruning. This implication is supported by the finding that close spacing reduces fusiform rust incidence. Heavy thinning may also have an adverse effect by favoring the growth of alternate hosts (oaks), thereby enhancing rust incidence. Thinning of heavily infected stands, on the other hand, can profoundly affect total wood production if heavily infected trees certain to die before final harvest are removed. If rust incidence is less than 25 percent, the first thinning should remove the majority of the diseased trees. Opening up the stand too much can have unfavorable consequences on the residual stand in terms of growth and damage from ice and wind.

Wind/windthrow. Wind and windthrow are natural phenomena that cause extensive damage to southern pine stands. The severity of damage depends on geographic location, wind gustiness, and other factors.

In a number of studies, thinning influenced the amount of damage due to wind and windthrow. The heavier the thinning, the greater the wind damage. More crown damage (limbs and small branches broken off, needles and bark whipped off) occurred in heavily thinned stands. Although thinning in general increases wind and windthrow damage, it can potentially reduce such damage by removing diseased, high-risk trees. Because bigger trees are more prone to windthrow, an early thinning will improve the stability of stands after the remaining trees have adapted to greater exposure.

The formulation of a thinning strategy within the Coastal Plain hurricane belt 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 favor windthrow.
- Edge trees are more stable than interior trees.
- Trees on soils extensively saturated with water are prone to windthrow.
- Stand density and height alter the wind profiles.
- Wind is funneled through gaps and saddles in main ridges, resulting in greater wind acceleration.
- Indentations in the edge of stands, especially V-shaped openings, produce a funneling effect.
- Logging injuries contribute to windthrow.
- Windfall losses are heavy following partial cutting.

Ice/glaze. Slash, longleaf, and loblolly pines are generally more susceptible than shortleaf pine to glaze damage. Glaze damage can be very serious, depending on species, geographic location, age of trees, amount of ice formed on trees, stand density, presence of disease, crown characteristics, and diameter/height ratio. Thinning has very profound effects in modifying the degree of glaze damage. Studies have shown that increasing thinning intensity causes increasing amounts of glaze damage.

Glaze damage can be minimized by early manipulation of the growing space (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 nor practical, row thinning at wider intervals (say every eighth or tenth row) with selective thinning within leave rows would be a desirable alternative (Shepard 1975). Selective thinning should remove the smaller, weaker trees. Bent trees should be pruned (Williston 1974).

Minimizing Felling Injuries

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

1. Thin in winter and late summer because trees are more severely injured during spring and early summer. (See #7 below.)
2. Continue to salvage high-risk trees after each cutting (or target for next thinning) to reduce infection courts.
3. Mark leave trees, instead of those to be cut, because this calls attention to the crop trees.
4. Use directional felling wherever possible.
5. Use smaller machines to minimize unacceptable damage to residual trees.
6. Establish stands at wider spacings to reduce thinning frequency.
7. Because damage is reduced where there is frozen soil and snow cover and little sap flow, thin at the end of autumn and the beginning of winter, the best months in more northerly areas.

Stand with rust-infected trees before (**A**) and after (**B**) sanitation salvage to remove severely infected trees.

8. Time operations so as to avoid wet weather logging to minimize stand productivity losses associated with soil compaction (Moehring and Rawls 1970).

Minimizing Skidding Injuries

Skidding-related damage can be reduced by adhering to the following practices:

- On clay soils or soils saturated with moisture use skidding equipment that minimizes soil compaction; otherwise schedule skidding during dry weather (Moehring and Rawls 1970).
- In stands that will tolerate little damage, consider using horses for skidding logs.
- Cut logs short enough to minimize scarring of residual trees during forwarding operations.
- Avoid damage to low-lying areas with fine textured soils by shifting logging operations to better-drained, sandy soils during wet periods (Hatchell et al. 1970).
- Use smaller equipment to reduce the impact on soils and residual trees where the trails are dispersed. With larger equipment, it would be better to concentrate the impact on as few trails as possible because heavy equipment affects the soil to a greater extent during the first few trips.
- Use cultural techniques such as ripping for rehabilitating damaged areas.
- Hasten site recovery by loosening, revegetating, or mulching the disturbed area.

It has been suggested that 40 years are required for natural forces to bring soil conditions in loblolly pine stands of the southeastern United States back to normal (Hatchell and Ralston 1971). With regard to ameliorative conditions and restoration, the presence of logging residues after delimbing contributes to the prevention of significant compaction (King and Haines 1979). Disking, ripping, and subsoiling also ameliorate compacted soil conditions (Hatchell et al. 1970; Moehring 1970; Peters 1977).

Bedding (or a moderate amount of fertilizer) has been shown to improve growth of loblolly pine on compacted soils with a greater growth response obtained than on uncompacted soil. This has been attributed to elimination of competing vegetation by skidding (Hatchell 1981). Other biotic factors important in natural recovery of compacted soil include increased percolation rates and noncapillary pore space attributable to deep-rooted species like kudzu and alfalfa (Uhland 1950).

Dense layers of herbage aid in preventing soil compaction, just as does slash placed on the skid roads and over areas of heavier traffic. Increased herbage also reduces the amount of 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 obtained, such as hazard reduction for insect infestations, disease epidemics, and damages due to abiotic agents. The mechanics by which thinning reduces these hazards is not completely understood. However, observations indicate that it can result in positive and/or negative effects, depending on how, where, when, and why it is conducted. The presence of more than one kind of hazard (e.g., southern pine beetle and annosus root rot) in a particular area at a given time poses some problems in designing an optimum thinning strategy. Other factors that complicate the situation are the species, stage of stand development, anticipated direct damage to residual stems, site quality, growth rate, live crown ratio, equipment, machine operation, and ultimately the cost effectiveness of the operation. Soil compaction, soil improvement, water quality problems, wildlife habitat enhancement, weed problems, esthetics, and the like cannot be ignored if all aspects of thinning are to be taken into account.

Literature Cited

Abel, G.W. Ice damage heavy in slash pine planting. Forest Farmer 8(5):11; 1949.

Alexander, S.A; Skelly, J.M.; Webb, R.S. Effects of *Heterobasidion annosum* on radial growth in southern pine beetle-infested loblolly pine. Phytopathology 71:479–481; 1981.

Anderson, R.L.; Mistretta, P.A. Management strategies for reducing losses caused by fusiform rust, annosus root rot, and littleleaf disease. Agric. Handb. 597. Washington, DC: U.S. Department of Agriculture; 1982. 30 p.

Andrulot, E.R.; Blackwell, L.P.; Burns, P.Y. Effects of thinning on yield of loblolly pine in central Louisiana. Louisiana Tech. Bull. No. 6. Ruston, LA: Louisiana Tech University, Division of Research; 1972. 145 p.

Arnold, L.E. Gross yields of rough wood products from a 25-year-old loblolly and shortleaf pine spacing study. Urbana, IL: Illinois Agricultural Experiment Station, Dixon Spring Agricultural Center 6:230–236; 1978.

Balmer, W.E.; Utz, K.A.; Langdon, O.G. Financial returns from cultural work in natural loblolly pine stands. Southern Journal of Applied Forestry 2(4):111–117; 1978.

Balmer, W.E.; Williston, H.L. The need for precommercial thinning. For. Manage. Bull. Atlanta: U.S. Department of Agriculture, Forest Service, Southeastern Area State and Private Forestry; 1973. 6 p.

Belanger, R.P. Silvicultural guidelines for reducing losses to the southern pine beetle. In: Thatcher, R.C.; Searcy, J.L.; Coster, J.E.; Hertel, G.D., eds. The southern pine beetle. Tech. Bull. No. 1631. Washington, DC: U.S. Department of Agriculture; 1980: 165–177 (Chap. 9).

Belanger, R.P.; Brender, E.V. Influence of site index and thinning on the growth of planted loblolly pine. Res. Pap. No. 57. Macon, GA: Georgia Forestry Research Council; 1968. 7 p.

Bennett, F.A. Spacing and early growth of slash pine. Journal of Forestry 58:966–967; 1960.

Bennett, F.A. Growth and yield of slash pine plantations. Res. Pap. SE-1. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1963. 23 p.

Bennett, F.A. Thinning slash pine. In: Wahlenberg, W.G., ed. A guide to loblolly and slash pine plantation management in southeastern USA. Rep. No. 14. Macon, GA: Georgia Forestry Research Council; 1965: 111–118.

Bennett, F.A. Spacing and slash pine quality timber production. Res. Pap. SE-53. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1969. 9 p.

Bennett, F.A. The role of thinning and some other problems in management of slash pine plantations. Res. Pap. SE-86. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1971. 14 p.

Bennett, W.H. Timber management and southern pine beetle research. Forest Farmer 27(9):12–13; 1968.

Bennett, W.H. Silvicultural techniques will help control bark beetles. In: Proceedings, 1971 southern regional technical conference; Jacksonville, FL. Washington, DC: Society of American Foresters; 1971: 289-295.

Bennett, W.H.; Ostmark, H.E. The truth about tessie terebrans. Occas. Pap. 174. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1959. 16 p.

Benzie, J.W. Small tractors, ground skidding reduce tree damage in selection harvest. Timberman 60(11):42-43, 54; 1959.

Blair, R.M. Deer forage in a loblolly pine plantation. Journal of Wildlife Management 31:432-437; 1967.

Blair, R.M. Timber stand density influences food and cover. In: Symposium Proceedings, white-tailed deer in the southern forest habitat; 1969 March 25–26; Nacogdoches, TX. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1969: 74-76.

Blanche, C.A. Southern pine beetle: the host dimension. Bull. 917. Mississippi State, MS: Mississippi Agricultural and Forestry Experiment Station; 1983. 29 p.

Boggess, W.R.; McMillan, F.W. Growth and yield from a second row-thinning in an 18-year-old shortleaf pine plantation in southern Illinois. For. Note No. 62. Urbana, IL: Illinois Agricultural Experiment Station; 1955. 4 p.

Bower, D.R. Precommercial thinnings accelerate growth of loblolly pine. Journal of Forestry 63:210; 1965.

Box, B.H.; Linnartz, N.E.; Applequist, M.B. Comparative growth and volume of loblolly pine planted at variable spacings. LSU For. Note 60. Baton Rouge, LA: Louisiana State University; 1964. 2 p.

Boyce, J.S. Forest pathology. New York: McGraw-Hill Book Co.; 1948. 550 p.

Bradford, B.; Alexander, S.A.; Skelly, J.M. Determination of growth loss incited by *Heterobasidium annosus* in thinned loblolly pine plantations in Virginia. Proceedings of the American Phytopathology Society 4:120; 1978.

Brender, E.V. Thinning loblolly pine. In: Wahlenberg, W.G., ed. A guide to loblolly and slash pine plantation management in southeastern USA. Rep. No. 14. Macon, GA: Georgia Forestry Research Council; 1965: 99-110.

Brender, E.V.; McNab, W.H. Precommercial thinning of loblolly pine by fertilization. Res. Pap. 90. Macon, GA: Georgia Forestry Research Council; 1978. 8 p.

Brender, E.V.; Romancier, R.M. Glaze damage to loblolly and slash pine. In: Wahlenberg, W.G., ed. A guide to loblolly and slash pine plantation management in southeastern USA. Rep. No. 14. Macon, GA: Forestry Research Council; 1965: 156–159.

Bull, H. Pointers on thinning southern pines. Southern Lumberman 181(2273):259–260; 1950.

Burton, J.D. Sawtimber by prescription—The sudden sawlog story through age 33. Res. Pap. SO–179. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1982. 9 p.

Campbell, W.A. Reducing losses from diseases in pine plantations. In: Wahlenberg, W.G., ed. A guide to loblolly and slash pine plantation management in southeastern USA. Rep. No. 14. Macon, GA: Georgia Forestry Research Council; 1965: 146–155.

Collicott, L.V.; Strickland, J.R. Row-thinning. For. Productivity and Res. Tech. Note 25. Bainbridge, GA: International Paper Company, Southlands Experimental Forest; 1967. 7 p.

Cooperi, R.W. Precommercial thinnings of pine bring earlier cash returns. Southern Lumberman 191(2386):32; 1955.

Crow, A.B. Why thin pine stands? Forest Farmer 23(2):8, 15–16; 1963.

Debrunner, L.E.; Watson, W.J. Precommercial thinning of loblolly pine stands. Alabama Highlights of Agricultural Research 17(4):6; 1971.

Dickerson, B.P. Soil compaction after tree length skidding in northern Mississippi. Soil Science Society of America Journal 40:965–966; 1976.

Enghardt, H.G. Early thinnings—by individual trees or by rows. In: Proceedings, symposium on planted southern pines. 1968 October 22–23; Cordele, GA. Atlanta: U.S. Department of Agriculture, Forest Service, Southeastern Area State and Private Forestry; 1968: 84–91.

Enghardt, H.G.; Mann, W.F., Jr. Ten-year growth of planted slash pine after early thinnings. Res. Pap. SO-82. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1972. 11 p.

Farrar, R.M., Jr. Thinning longleaf pine on average sites. Journal of Forestry 66(12):906–908; 1968.

Feduccia, D.P.; Dell, T.R.; Mann, W.F., Jr.; Campbell, T.E.; Palmer, B.H. Yields of unthinned loblolly pine plantations on cutover sites in the West Gulf Region. Res. Pap. SO-148. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1979. 88 p.

Feduccia, D.P.; Mann, W.F., Jr. Black turpentine beetle infestations after thinning in loblolly pine plantations. Res. Note SO-206. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1975. 3 p.

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

Feduccia, D.P.; Mosier, J. The Woodworth spacing and thinning study—an obituary. Forests and People 27(1):18–21; 1977.

Fender, D.E. Short rotation—up to 30 years. In: Proceedings, symposium on planted pines. 1968 October 22–23; Cordele, GA. Atlanta: U.S. Department of Agriculture, Forest Service, Southeastern Area State and Private Forestry; 1968: 11–22.

Foil, R.R.; Ralston, C.W. The establishment and growth of loblolly pine seedlings on compacted soils. Soil Science Society of America Journal 31:565–568; 1967.

Froelich, R.C.; Cowling, E.G.; Collicott, L.V.; Dell, T.R. *Fomes annosus* reduces height and diameter growth of planted slash pine. Forest Science 23(3):299–306; 1977.

Froelich, R.C.; Dell, T.R.; Walkinshaw, C.H. Soil factors associated with *Fomes annosus* in the Gulf States. Forest Science 12(3):356–361; 1966.

Froelich, R.C.; Hodges, C.S., Jr.; Sackett, S.S. Prescribed burning reduces severity of annosus root rot in the South. Forest Science 24(1):93–100; 1978.

Gilmore, A.R.; Boggess, W.R. Growth and yield from row thinning in a shortleaf pine plantation in southern Illinois. For. Note 126. Urbana, IL: Illinois Agricultural Experiment Station; 1969. 3 p.

Goebel, J.R.; Warner, J.R.; Van Lear, D.H. Periodic thinnings in loblolly pine stands: growth, yield, and economic analyses. For. Res. Ser. No. 28. Clemson, SC: Clemson University, Department of Forestry; 1974. 11 p.

Grano, C.X. Precommercial thinning of loblolly pine. Journal of Forestry 67:825–827; 1969.

Grano, C.X. Growth of planted loblolly pine after row and selective thinning. Res. Note SO-123. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1974. 3 p.

Gruschow, G.F. Results of a precommercial thinning in slash pine. Southern Lumberman 179(2249):230–232; 1949.

Guttenberg, S. Case for precommercial thinning. Forest Farmer 29:13–18; 1970.

Halls, L.K. Effect of timber harvesting on wildlife, wildlife habitat, and recreation values. In: McMillin, C.W., ed. Symposium proceedings, complete tree utilization of southern pine. 1978 April; New Orleans. Madison, WI: Forest Products Research Society; 1978: 108–114.

Halls, L.K.; Schuster, J.L. Tree herbage relations in pine-hardwood forests of Texas. Journal of Forestry 63:282–283; 1965.

Hardie, I.W. Optimal management plans for loblolly pine plantations in the mid-Atlantic region. MP906. College Park, MD: Maryland Agricultural Experiment Station; 1977. 107 p.

Harms, W.R.; Collins, A.B., III Spacing and 12-year growth of slash pine. Journal of Forestry 63:909–912; 1965.

Hatchell, G.E. Site preparation and fertilizer increase pine growth on soils compacted in logging. Southern Journal of Applied Forestry 5(2):79–83; 1981.

Hatchell, G.E.; Ralston, C.W. Natural recovery of surface soils disturbed in logging. Tree Planters' Notes 22(2):5–9; 1971.

Hatchell, G.E.; Ralston, C.W.; Foil, R.R. Soil disturbances in logging. Journal of Forestry 68:772–775; 1970.

Hedden, R.L. Evaluation of loblolly pine thinning regimes for reduction of losses from southern pine beetle attack. In: Jones, E.P. Jr., ed. Proceedings, second biennial southern silvicultural research conference. 1982 November 4–5; Atlanta, GA. Gen. Tech. Rep. SE-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1983: 171–181.

Hicks, R.R., Jr.; Coster, J.E.; Watterston, K.G. Reducing southern pine beetle risks through proper management planning. Forest Farmer 38:6–7, 18: 1979.

Hicks, R.R., Jr.; Howard, J.E.; Coster, J.E.; Watterston, K.G. The role of tree vigor in susceptibility of loblolly pine to southern pine beetle. In: Hollis, C.A.;

Squillace, A.E., eds. Proceedings, fifth North American forest biology workshop. Gainesville, FL: University of Florida, School of Forest Resources and Conservation; 1978. 177–181.

Hicks, R.R., Jr.; Howard, J.E.; Watterston, K.G.; Coster, J.E. Rating stand susceptibility to southern pine beetle in east Texas. Forest Ecology and Management 2:269–283; 1980.

Hodges, C.S. Symptomatology and spread of *Fomes annosus* in southern pine plantations. Res. Pap. SE-114. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1974. 10 p.

Hodges, J.D.; Lorio, P.L., Jr. Moisture stress and composition of xylem oleoresin in loblolly pine. Forest Science 21:283–290; 1975.

Holley, L. Grow a crop of money trees. American Forester 85(10):18–19, 50, 52–54; 1979.

Jackson, L.W.R. Growth of unthinned loblolly, slash, and longleaf pine plantings in Georgia. Res. Pap. 63. Macon, GA: Georgia Forestry Commission; 1970. 6 p.

Jones, E.P., Jr. Precommercial thinning of naturally seeded slash pine increases volume and monetary returns. Res. Pap. SE-164. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1977. 12 p.

Kellison, R.C.; Gingrich, S., eds. The loblolly pine ecosystem (east region). Proceedings, symposium; 1982 December 8–10; Raleigh, NC: North Carolina State University; 1982. 335 p.

King, T. Merchantable stem skidding and damage. Journal of Forestry 61:846–849; 1963.

King, T.; Haines, S. Soil compaction absent in plantation thinning. Res. Note SO-251. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1979. 4 p.

Ku, T.T.; Sweeney, J.M.; Shelburne, V.B. Site and stand conditions associated with southern pine beetle outbreaks in Arkansas—a hazard rating system. Southern Journal of Applied Forestry 4:103–106; 1980.

Kuhlman, E.G.; Hodges, C.S., Jr.; Froelich, R.C. Minimizing losses to *Fomes annosus* in the southern United States. Res. Pap. SE-151. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1976. 16 p.

Lemon, P.C. Forest ecology of ice storms. Bulletin of the Torrey Botanical Club 88(2):21-29; 1961.

Little, S.; Mohr, J.J. Five-year effects from row thinnings in loblolly pine plantations in eastern Maryland. Res. Pap. NE-12. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1963. 15 p.

Lohrey, R.E. Precommercial thinning of direct-seeded loblolly pine. Res. Note SO-139. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1972. 4 p.

Lohrey, R.E. Precommercial thinning increases diameter and height growth of slash pine. Res. Note SO-152. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1973. 4 p.

Lohrey, R.E. Growth responses of loblolly pine to precommercial thinning. Southern Journal of Applied Forestry 1(3):19-22; 1977.

Lorio, P.L., Jr. Developing stand risk classes for the southern pine beetle. Res. Pap. SO-144. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1978. 9 p.

Lorio, P.L., Jr. Loblolly pine stocking levels affect potential for southern pine beetle infestation. Southern Journal of Applied Forestry 4:162-165; 1980.

Mann, W.F., Jr. Response of loblolly pine to thinning. Journal of Forestry 50:443–446; 1952.

Mann, W.F., Jr. Thirty-six years of thinning research with loblolly pine. In: Proceedings, Louisiana State University first annual forestry symposium; 1952 March. Baton Rouge: Louisiana State University Press; 1952. p. 1–7.

Mann, W.F., Jr.; Enghardt, H.G. Growth of planted slash pine under several thinning regimes. Res. Pap. SO-76. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1972. 10 p.

Mann, W.F., Jr.; Lohrey, R.E. Precommercial thinning of southern pines. Journal of Forestry 72(9):557–560; 1974.

Mason, R.R. Behavior of *Ips* populations after summer thinning in a loblolly pine plantation. Forest Science 15(4):390–398; 1969.

McKellar, A.D. Ice damage to slash pine, longleaf pine, and loblolly pine plantations in the Piedmont section of Georgia. Journal of Forestry 40:795–797; 1942.

McMinn, J.W. Precommercial thinning. Forest Farmer 24(12):10–11; 1965.

Moehring, D.M. Forest soil improvement through cultivation. Journal of Forestry 68:328–331; 1970.

Moehring, D.M.; Ralston, C.W. Diameter growth of loblolly pine related to available soil moisture and rate of soil moisture loss. Soil Science Society of America Journal 31:560–562; 1967.

Moehring, D.M.; Rawls, I.W. Detrimental effect of wet weather logging. Journal of Forestry 68(3):166-167; 1970.

Morris, D.J. Basal area thinning guides for thinning in the South. Journal of Forestry 56(12):903-905; 1958.

Muntz, H.H. Ice damage to pine plantations. Southern Lumberman 175(2201):142-144; 1947.

Nebeker, T.E.; Hodges, J.D. Influence of forestry practices on host susceptibility to bark beetles. Zietschrift fur Angewandte Entomologie 96(2): 194-208; 1983.

Nebeker, T.E.; Moehring, D.M.; Hodges, J.D.; Brown, M.W.; Blanche, C.A. Impact of thinning on host susceptibility. In: Jones, E.P., Jr., ed. Proceedings, second biennial southern silvicultural research conference; 1982 November 4-5; Atlanta, GA. Gen. Tech. Rep. SE-24. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1983: 376-381.

Nelson, R.E.; Arnold, L.E. The effects of early thinning on a 38-year-old shortleaf pine plantation in southern Illinois. Urbana, IL: Illinois Agricultural Experiment Station; Dixon Spring Agricultural Center 4:179-180; 1976.

Nelson, T.C. Ice damage high for spindly residual seedlings. Forest Farmer 10(11):6; 1951.

Nelson, T.C. Loblolly pine growth as related to site, age, and stand density. Society of American Foresters Proceedings 1960:12-14; 1961.

Nelson, T.C.; Stanley, G.W. Hurricane damage related to thinning intensity on east Texas slash pine plantations. Journal of Forestry 57(1):39; 1959.

Nonnemacher, R.M. Pine pulpwood harvest and feasibility study for Northwest Mississippi. Mississippi State, MS: Mississippi Cooperative Extension Service; 1982. 136 p.

Parker, J. Selection thinning increases slash pine stand quality. Southern Journal of Applied Forestry 3(4):169-172; 1979.

Perry, T.D. Soil compaction and loblolly pine growth. Tree Planters' Notes 67:9; 1964.

Peters, C.M. Area and growth impacts of logging damage in the Ouachita Mountains of Arkansas/Oklahoma. Regeneration-Soils Internal Study Rep. Hot Springs, AR: Weyerhaeuser Co.; 1977. 28 p.

Pomeroy, K.B. The germination and establishment of loblolly pine under various soil surface conditions. Journal of Forestry 47:541-543; 1949.

Powers, H.R., Jr.; Verrall, A.F. A closer look at *Fomes annosus*. Forest Farmer 21(13):8-9, 16-17; 1962.

Prodan, M. Forest biometrics. New York: Pergamon Press; 1968. 345 p.

Rogerson, T.L. Thinning increases throughfall in loblolly pine plantations. Journal of Soil and Water Conservation 23:141-142; 1968.

Schultz, R.P. Intensive culture of southern pines: maximum yields on short rotations. Iowa State Journal of Research 49(3):Pt.2; 1975.

Shelton, M.G.; Switzer, G.L. The development of unthinned loblolly pine plantations at various spacings. In: Proceedings, symposium on thinning southern pine plantations; 1980 March 3-5. Long Beach, MS: Southern Forest Economics Workshop; 1980: 53-54.

Shepard, R.K., Jr. The effect of various initial spacings on the development of loblolly pine. For. Res. Rep. Calhoun, LA: North Louisiana Hill Farm Experiment Station; 1973: 15-35.

Shepard, R.K., Jr. Ice storm damage to loblolly pine in northern Louisiana. Journal of Forestry 73:420-423; 1975.

Smith, L.F. Effects of spacing and site on the growth and yield of planted slash pine. Res. Note SO-63. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1967. 4 p.

Uhland, R.E. Physical properties of soils as modified by crops and management. Soil Science Society of America Proceedings 14:361-366; 1950.

Ursic, S.J. Pine management influences the southern water resource. In: Symposium proceedings, management of young pines; 1974 October 22-24; Alexandria, LA. Atlanta: U.S. Department of Agriculture, Forest Service, Southeastern Area State and Private Forestry, Southern Forest Experiment Station, and Southeastern Forest Experiment Station; 1974: 42-48.

U.S. Department of Agriculture, Forest Service. Thinning pine plantations in 1971 and after. Forest Manage. Bull. Atlanta: U.S. Department of Agriculture, Forest Service, Southeastern Area State and Private Forestry; 1971. 6 p.

Wahlenberg, W.G. Management of longleaf pine forests. In: Longleaf pine. Washington, DC: Charles Lathrop Pack Forest Foundation; 1946: 243-265.

Wahlenberg, W.G. Thinning. In: Loblolly pine. Durham, NC: Duke University, School of Forestry; 1960: 321-341.

Wakeley, P.C. Planting the southern pines. Monog. No. 18. Washington, DC: U.S. Department of Agriculture, Forest Service; 1954. 233 p.

Wakeley, P.C. Single commercial thinnings in variously spaced slash and loblolly pine plantations. Res. Pap. SO-48. New Orleans: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1969. 12 p.

Ware, L.M.; Stahelin, R. Growth of southern pine plantations at various spacings. Journal of Forestry 46:267-274; 1948.

Wheeler, G.L.; Meade, F.M.; Russell, M.W. Growth of loblolly pine in the Arkansas Ozarks. Southern Journal of Applied Forestry 6:215-217; 1982.

Whipple, S.F. Early thinnings from pine plantations. Prog. Rep. Ser. No. 85. Auburn: Alabama Agricultural Experiment Station; 1962. 3 p.

Williston, H.L. Managing pines in the ice-storm belt. Journal of Forestry 72(9):580-582; 1974.

Williston, H.L. Growth and yield to age 37 in north Mississippi loblolly plantations. Southern Journal of Applied Forestry 3(3):127-130; 1979.

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