Silvicultural Approaches for Thinning Southern Pines: Method, Intensity, and Timing

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By
Timothy B. Harrington[1]

Cover photograph - A 13-year-old plantation of loblolly pine located near Bainbridge, Georgia that has just been thinned to leave a basal area (total cross-sectional area of stems at 4.5' height) of 60 ft^2 per acre and pruned to leave a crown ratio of 50%. As typified by this stand, thinning is most effective at accelerating production of sawtimber when it is done at a relatively high intensity to young stands soon after crown closure, when crowns are large and vigorous.

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Introduction

A variety of approaches currently exist for thinning stands of southern pine. These approaches vary in method, intensity, and timing of thinning and can differ substantially in cost, feasibility, and potential response. A thinning method can be defined as a specific strategy for selecting trees to be removed. A selective method is one in which trees are removed according to specifications of size, spacing, or quality. Selective methods generally remove trees of lower growth potential, such as smaller, diseased, or overtopped trees. A systematic method removes a fixed proportion of a given stand in rows or corridors to facilitate movement of logging equipment.

Stand responses improve with selectivity of a thinning treatment, because as trees are removed, more emphasis is placed on quality of the residual stand (uncut trees) than on access of the logging equipment. Also, systematic methods remove a fixed proportion of the best trees in the stand, which limits subsequent stand responses. A method that combines selective and systematic removal of trees probably is the best compromise because it considers objectives of both biological response and feasibility to result in the most cost-effective approach for thinning.

Intensity (proportion of the stand removed) and timing (stand age at thinning) are critical features to consider if a thinning treatment is to accomplish the desired silvicultural objectives. Thinning at the appropriate intensity can prolong thinning responses without leaving the stand understocked for an extended period of time. Thinning at the appropriate timing can maintain stand growth at its expected rate and prevent stagnation. Poor choices of intensity and timing of thinning can limit increases in stand value or result in significant losses in stand vigor. A variety of indices have been developed for determining at what intensity and when a given stand should be thinned. These indices vary in their ability to quantify competition among trees and in their ease of calculation.

This report presents an overview of general silvicultural approaches for thinning loblolly (*Pinus taeda*), slash (*P. elliottii*), shortleaf (*P. echinata*), and longleaf pine (*P. palustris*). The discussion is

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divided into three parts: 1) selecting a thinning method, 2) selecting intensity and timing of thinning,and 3) combining thinning with other silvicultural treatments, such as weed control, fertilization, and pruning. For information on the principles of thinning, please refer to the companion report entitled, *Silvicultural Basis for Thinning Southern Pines: Concepts and Expected Responses* (7).

Selecting a Thinning Method

Selective removal of trees involves identification and cutting of those that are smaller in stem diameter or height, diseased (those with stem cankers of fusiform rust, *Cronartium quercuum*) or have poor stem form (those with leaning, bent, or excessively branchy stems). When selective removal is focused on trees of the lower size classes, this method of thinning is called "thinning from below" or "low thinning" (Figure 1).

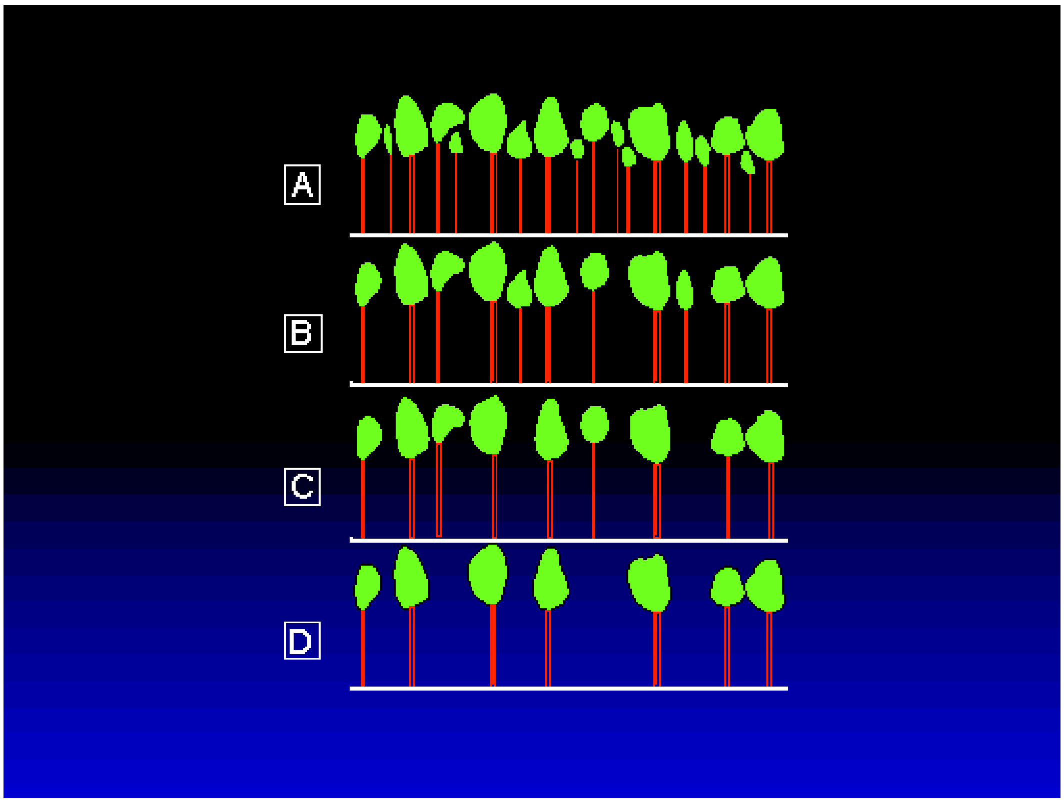

Figure 1 - Diagram of various intensities of low thinning with progressive removal of trees from the overtopped, intermediate, co-dominant, and dominant crown classes.[2] In the A-level thinning intensity, only overtopped trees are removed (this portion of the diagram actually shows the unthinned stand, because little or no thinning response will result from this intensity). Trees of the overtopped and intermediate crown classes are removed in the B-level intensity, while some co-dominant trees are also removed in the C-level intensity. At the highest thinning intensity (D), a few dominant trees are also removed to benefit crop trees. The C-level intensity is probably most appropriate for the southern pines.

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[2] Adapted from *The Practice of Silviculture: Applied Forest Ecology* by D.M. Smith, B.C. Larson, M.J. Kelty, and P.M.S. Ashton, ©1997. Reprinted by permission of John Wiley & Sons, Inc.

Intensity of low thinning can be classified according to progressive removal of trees of greater crown class or access to direct sunlight (15). At the lowest intensity of thinning, only trees of the overtopped crown class (those not receiving any direct sun) are candidates for removal. At the highest intensity of thinning, trees of the overtopped, intermediate (those receiving direct sun from the top only), and co-dominant (those receiving direct sun from the top and sides) crown classes are candidates for removal. The southern pines do not thrive in partial or full shade. Therefore, low thinning methods are appropriate because they remove those trees most likely to die as a result of their subordinate status within the stand.

When selective removal is focused on trees of the upper size classes, this method is called "thinning from above" or "crown thinning" (Figure 2). The goal of this thinning method is to remove trees of the upper crown classes that have a low potential for growth in value because of disease, poor

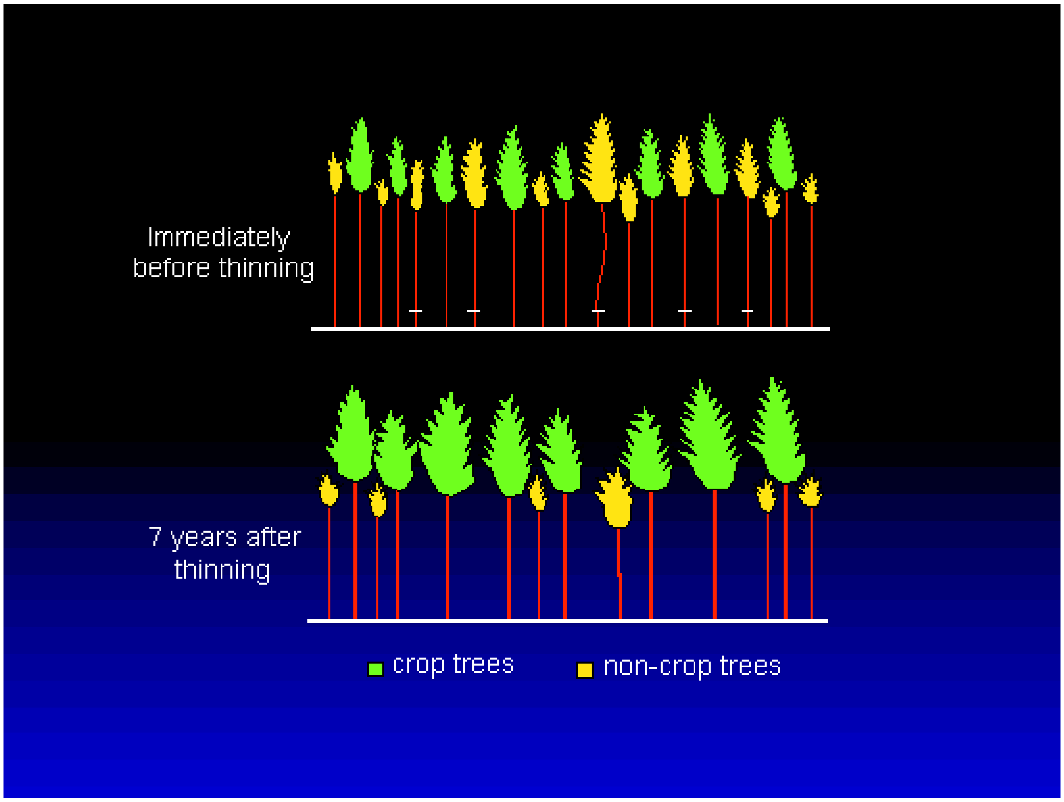

Figure 2 - Diagram of a forest stand immediately before and seven years after a crown thinning in which trees of the dominant and co-dominant crown classes were removed to reallocate stand growth to the best dominant crop trees.[3] Horizontal lines on trees indicate those that are to be removed. Trees of the overtopped and intermediate crown classes were not cut because their removal would stimulate only marginal responses in stand growth.

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[3] Adapted from *The Practice of Silviculture: Applied Forest Ecology* by D.M. Smith, B.C. Larson, M.J. Kelty, and P.M.S. Ashton, ©1997. Reprinted by permission of John Wiley & Sons, Inc.

stem form, or excessively close spacing. Crown thinning reallocates stand growth to the better quality trees of the upper crown classes. Trees of the lower crown classes can be removed as well, but only if their removal contributes to stand responses. Often the effort required to remove trees of the overtopped and intermediate crown classes can be costly and may provide little or no benefit to the growth responses of the dominant crop trees. Crown thinning is an appropriate method for southern pine stands that contain trees varying widely in size and spacing, because it stimulates development of a more uniform stand structure having relatively predictable growth responses. A combination of low and crown thinning methods should be prescribed for natural stands or for plantations containing large and irregularly spaced volunteer pines. In such stands, low thinning should be applied where size and spacing of crop trees are relatively uniform, while crown thinning should be applied where they are non-uniform.

As mentioned previously, a combination of systematic and selective methods of thinning provides the best compromise between operational feasibility and biological response. A common approach for combining systematic and selective methods of thinning consists of the removal of all trees within 10'-wide corridors centered every 50' along one dimension of the stand. Because the corridors result in the cutting of 20% of the stand, additional trees are removed selectively on either side of the corridor to achieve the desired final density. This approach has been labeled, "fifth-row removal" (with operator selection of additional trees between corridors), although strict removal of trees in rows is not generally practiced because of irregularities in row straightness.

In an alternative approach, corridors are centered every 30' ("third-row removal"), and 33% of the stand is removed systematically. In these two examples, a higher proportion of the stand is removed selectively in fifth-row removal than in third-row removal. Computer simulations of these two thinning methods indicate that a residual stand of better quality (larger average stem diameter) will result from fifth-row removal, because selective removal of trees is being practiced over a greater proportion of the stand (R.L. Lanford, Auburn University, Auburn, Alabama, personal communication).

Selecting Intensity and Timing of Thinning

In prescribing a thinning treatment, a measure of density is needed to determine if stand volume is sufficient to support a thinning and if the degree of competition among individual trees has begun to influence their growth. Stem density (number of trees per acre) is not an adequate measure of stand density because it fails to account for differences in stem diameter. Stand basal area (total cross-sectional area of stems measured at breast height, 4.5' aboveground) integrates measures of stem density and size to provide an excellent measure of stand density. Basal area can be measured easily by the prism sampling method, and it is a commonly used index for prescribing a given thinning intensity.

In general, a uniformly stocked stand 10 to 15 years of age with a basal area of 100 ft^2/acre or more is likely to respond to thinning because at this density inter-tree competition is limiting diameter growth. Typically, a first thinning removes about half of the trees and a third of the basal area (and volume) of a stand. Therefore, residual basal areas after a first thinning are commonly 60 to 80 ft^2 per acre (see cover photograph). In order to make a first thinning feasible to a contractor, average stem diameter (quadratic mean diameter, diameter of tree of mean basal area) of trees must be at least 6.5", since 4" is generally considered the smallest diameter of merchantable material. Also, at least 6 cords of wood must be available for removal per acre, where a cord is a stack of wood 4' x 4' x 8' in dimension. In addition, the stand should be 20 acres in area or more if it is to yield enough wood to support a thinning operation.

Basal area has several shortcomings as a measure of stand density. First, stands of equal basal area can be under different levels of competition depending on their stem density. This is because as stem density increases for a given amount of stand basal area, a higher number of individual trees must compete for the same finite supply of resources (light, water, and nutrients). Second, values of basal area that indicate the need for thinning, as well as residual values to leave after a thinning, will vary with stand age and site quality. In older stands or stands growing on better sites, thinning should occur when the stand has achieved a higher basal area and it should leave a higher residual value. Older stands will have fewer trees per acre; therefore, a higher basal area is needed to indicate that inter-tree competition is underway, and a lighter intensity of thinning should be practiced. Better sites, such as areas recently in agriculture, support higher stand basal areas and should be thinned at somewhat lower intensity (fewer trees removed) and with greater frequency (two or more thinnings) to take advantage of their greater productivity.

Another approach for determining if a stand should be thinned, as well as its potential thinning response, is to measure the average crown ratio of a stand. Crown ratio, or crown length expressed as a percentage of total height, provides an index of a tree's carbohydrate balance, and therefore, its ability to expend photosynthate on diameter growth (7). Normal rates of diameter growth are maintained as long as crown ratio is 40% or greater, and ideally, a thinning treatment should be scheduled soon after average crown ratio drops below 50%. This is because crown ratio can change rapidly within several growing seasons as inter-tree competition increases in response to good growing conditions or overstocking of the stand. As discussed later in this report, once the crown ratio of a tree drops below 40%, it is difficult for it to recover to this target value, resulting in a long-term loss of potential tree vigor.

Over sixty years ago, a paper was published that described a measure of stand density free of the shortcomings of basal area and stem density (13). This index utilizes a species-specific relationship of average tree size to stem density (the "self-thinning" line) as a standard by which to judge the

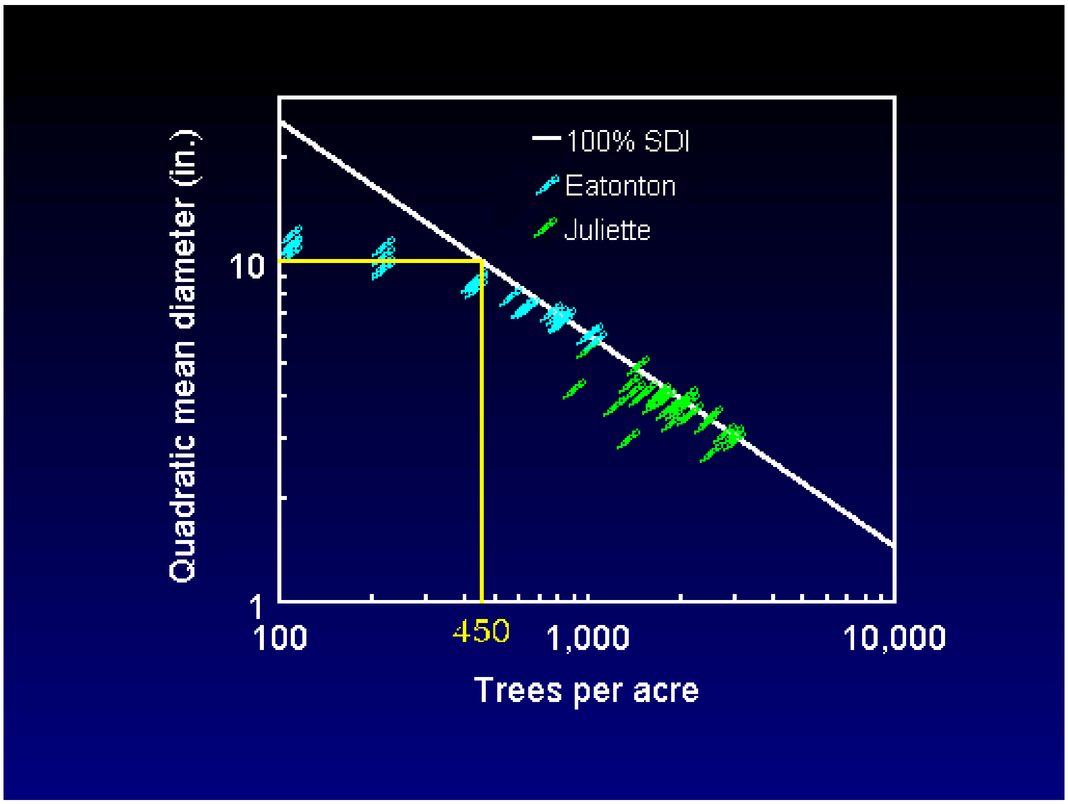

Figure 3 - Relationship of quadratic mean diameter (diameter of the tree of mean basal area) to stem density for loblolly pine. Stand density index (SDI) is derived as the equivalent number of 10" diameter trees per acre and has a maximum value of 450 for loblolly pine. Plotted points include a variable planting density study near Eatonton, Georgia (blue points) and a site preparation study near Juliette, Georgia (green points). Planting densities in the Eatonton study (14) include 100, 200, 400, 600, 800, and 1000 trees per acre; note that the two highest densities are close to the maximum SDI for loblolly pine. Stem densities in the Juliette study (8) vary because of differences in recruitment of volunteer pines. Several stands have maximum SDI, one of which was destroyed by southern pine beetles in 1997 [see Figure 4 in (7)].

density of an individual stand (Figure 3). Self-thinning is the death of individual trees in a stand in response to over-crowding. For a given stem density, average stem diameter of the stand is bounded by an upper limit. Stands growing at this upper limit (i.e., those on the self-thinning line) are at the highest density possible for that species and are designated as having a stand density index (SDI) equivalent to the maximum number of trees 10" in stem diameter that an acre is capable of supporting. Stands growing in the region below the boundary line are at less than the maximum density, and it is within this range of densities that stands typically are managed. SDI can be calculated for an individual stand using the following general formula (3):

$$SDI = TPA \times (QMD/10)^{1.6}$$

SDI is stand density index (equivalent number of 10" trees per acre), TPA is actual trees per acre, and QMD is quadratic mean diameter (in.), the stem diameter of the tree of mean basal area. QMD can be calculated for an individual stand using the following general formula, where BA is basal area (ft^2 per acre):

$$QMD = [(BA \div TPA)/0.005454]^{0.5}$$

Maximum SDI values are approximately 450, 400, 400, and 460 for loblolly, slash, longleaf, and shortleaf pines, respectively (13, 3, 16). Often stand density is expressed as a percentage of maximum SDI, designated here as % SDI. Because it is based on the self-thinning line, SDI is independent of age. As QMD of a stand increases with age and approaches the upper limit for a given density, trees die from self-thinning of the stand, permitting further increases in QMD. SDI is also independent of site quality. Stands growing on better sites do not have higher values for maximum SDI, but rather they undergo self thinning more rapidly and track closely just below the self-thinning line as their QMD increases. When expressed on a percentage basis, SDI values can be compared among species to provide relative indices of stand competition. Thus, relative densities for stands of different age, site quality, and species can be compared with % SDI, making it the superior index for estimating stand density. Table 1 provides values of SDI for various levels of basal area and trees per acre. Note that for a given basal area, stand density index increases with trees per acre. As discussed previously, when stands of different stem density are thinned to the same basal area, residual stands will result which differ by degree of inter-tree competition.

Table 1. Values of stand density index (13) for various levels of stand basal area and trees per acre

Basal area (ft^2 per acre)	Trees per acre									
	100	200	300	400	500	600	700	800	900	1000
40	78	90	97	103	108	112	115	118	121	124
50	93	107	116	123	129	133	138	141	145	148
60	108	124	134	142	149	154	159	164	167	171
70	122	140	152	161	168	175	180	185	189	194
80	136	156	169	179	187	194	200	206	211	215
90	149	171	186	197	206	214	220	226	232	237
100	162	187	202	214	224	232	240	246	252	257
110	175	201	218	231	242	251	259	266	272	278
120	188	216	234	248	259	269	277	285	292	298
130	200	230	250	264	276	287	296	304	311	318
140	213	244	265	280	293	304	314	322	330	337
150	225	258	280	296	310	321	332	340	349	356
160	237	272	295	312	326	338	349	359	367	375
170	248	285	309	328	343	355	366	376	385	394
180	260	299	324	343	359	372	384	394	403	412
190	271	312	338	358	374	388	401	411	421	430
200	283	325	352	373	390	405	417	429	439	448

In one application of SDI, a procedure was developed as follows for scheduling the thinning of a loblolly pine plantation (3). First, the user defines upper and lower % SDI thresholds for a given stand (described below). When the stand's volume and QMD are of sufficient size to sustain an operational thinning, the stand is thinned to the lower % SDI threshold. A subsequent thinning occurs when the stand reaches the upper % SDI threshold. Timing of thinning is determined according to dominant height development of the stand, and not age. Final harvest occurs when the stand reaches the desired QMD.

Using information on stand development for various regions of the self-thinning relationship, logical values for the upper and lower % SDI values were developed (3) (Figure 4). Crown closure of loblolly pine plantations begins at about 25% SDI, and stands begin to undergo self-thinning at 50% to 55% SDI. Therefore, lower and upper threshold values of 30% and 45% SDI, respectively, provide the conditions of full stocking, absence of self-thinning, and enough volume recovery to make a thinning operational. The region of the self-thinning relationship between these two threshold values may be considered a zone of optimum density for managing loblolly pine plantations.

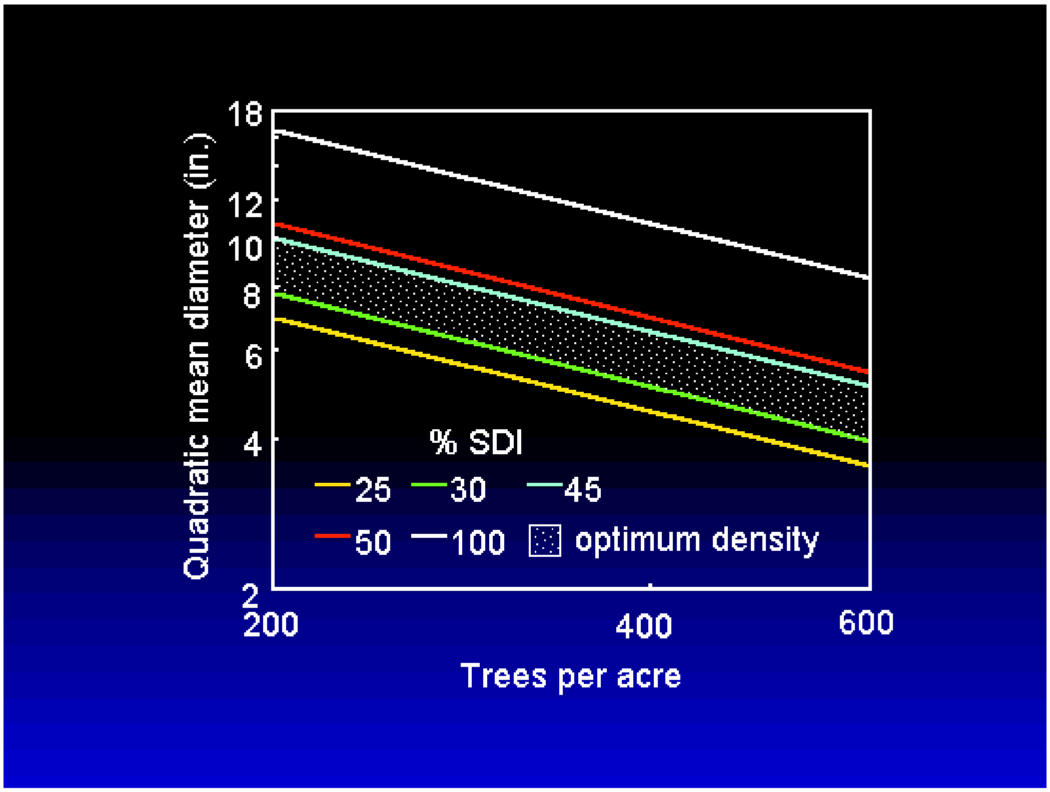

Figure 4 - Relationships of quadratic mean diameter to stem density for various values of % SDI (percentage of maximum SDI) relevant to thinning loblolly pine. Crown closure begins at 25% SDI, while self-thinning (death of individual trees in response to over-crowding) begins at 50% SDI. To manage for conditions of full stocking, absence of self-thinning, and enough volume recovery to make a thinning operational, stands should be thinned when their % SDI is about 45, leaving a residual density of 30% SDI (3).

As discussed previously, responses to thinning will be greatest if stand vigor is high, as indicated by an average crown ratio of 40% or greater. In order to reach this goal, we must consider how the relationship of average crown ratio to % SDI varies with age (Figure 5). In the first two decades of stand development, a strong linear relationship exists between crown ratio and % SDI. It is during this time that thinning should be considered carefully so that stands are allowed to developed to their greatest potential, because in the third decade of stand development, the relationship of crown ratio to stand density is no longer statistically significant (4).

The relationships shown in Figure 5 imply that early effects of density on crown ratio are carried late into stand development, setting an upper limit to the rates of growth that will occur throughout the remaining life of the stand. Therefore, stands with excessively high stem densities (800 trees per acre or more) from planting or in-growth (volunteer trees) will not be able to respond fully to a thinning treatment because of their diminished crown ratio. Similarly, stands that receive a first thinning late in their development (after 25 years of age), will have a limited or delayed response to thinning.

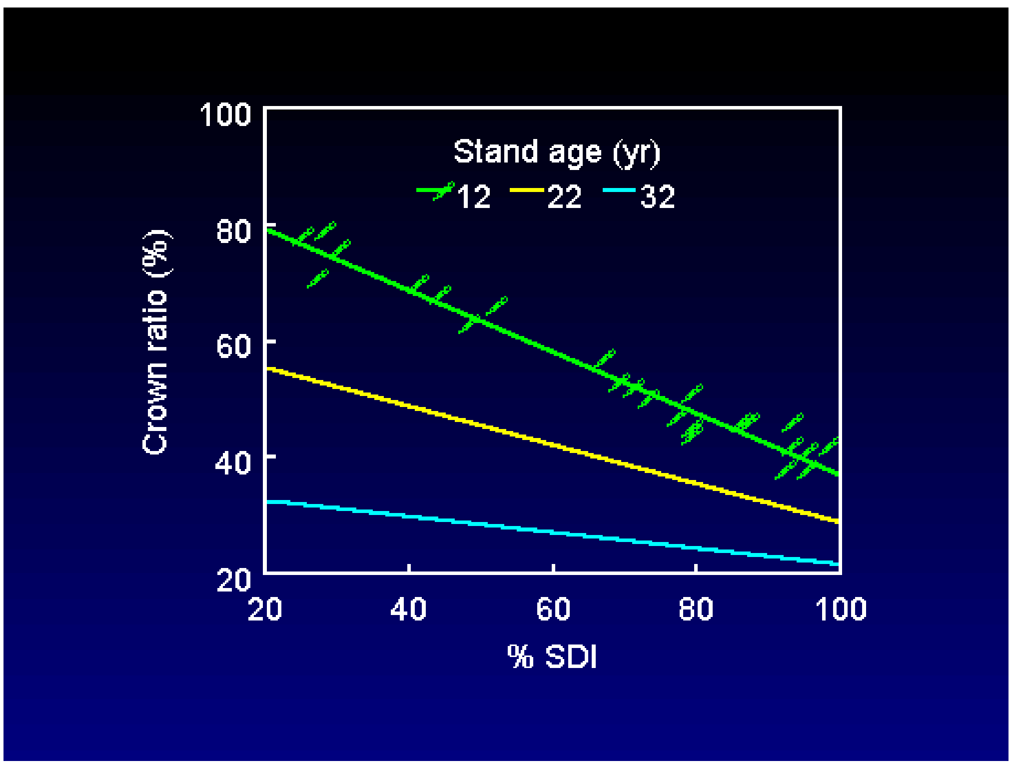

Figure 5 - Relationships of average crown ratio to % SDI for 12-, 22-, and 32-year-old loblolly pine plantations (14, 4). A significant linear relationship exists only during the first two decades of stand development, indicating that this is the period in which stand density should be managed to maintain average crown ratio at values of 40% or greater. In the 12-year-old plantation, various planting densities (100, 200, 400, 600, 800, and 1000 trees per acre) are plotted, and presumably because of complete weed control during stand development, crown ratio was maintained at 40% or greater even at the highest density.

The stand shown in Figure 6 originated from an abandoned agricultural field in which loblolly pine seeded in at an extremely high stem density beginning in 1972. It has a basal area of 199 ft^2 per acre and a stem density of 668 trees per acre. Referring to Table 1, estimated SDI for this stand is about 412 or 92% of the maximum value for this species. Long ago the stand passed the optimum density for thinning (45% SDI), and as a result, its crown ratio has dropped below 40%. Therefore, it probably will respond slowly to thinning, and cumulative yields for the rotation will be less than if the stand had been thinned at the appropriate timing.

Figure 6 - A 27-year-old stand of loblolly pine near Eatonton GA that seeded in naturally at an extremely high stem density following agricultural land abandonment in 1972. The stand has a basal area of 199 ft^2 per acre and a stem density of 668 trees per acre. Referring to Table 1, this stand has an estimated SDI of about 412 or 92% SDI.

To illustrate how site quality and initial density can interact to affect the earliest age of a first thinning for loblolly pine plantations, stand projection equations (10) were used in a series of simulations for the Piedmont and Upper Coastal Plain. The earliest age of a first thinning was assumed to occur when a given stand reached the following threshold values: 45% SDI, 6.5" QMD, and the availability of 6 cords of wood per acre for removal during thinning.

Results of the simulations indicate that the earliest ages of a first thinning occur when 5th-year pine densities equal 450 to 500 trees per acre (Figure 7). These simulations emphasize the importance of establishing stands at lower densities that will rapidly achieve full stocking without delaying the development of QMD. In addition, the earliest age of a first thinning declines appreciably with site index (mean height of dominant and co-dominant trees at 25 years of age), indicating that high quality sites are those most adaptable to an intensive program of thinning. Similar relationships were observed for simulations of loblolly pine plantations in the Lower Coastal Plain, except that the earliest age of a first thinning occurred one to three years earlier, presumably because of more rapid rates of stand development in this region.

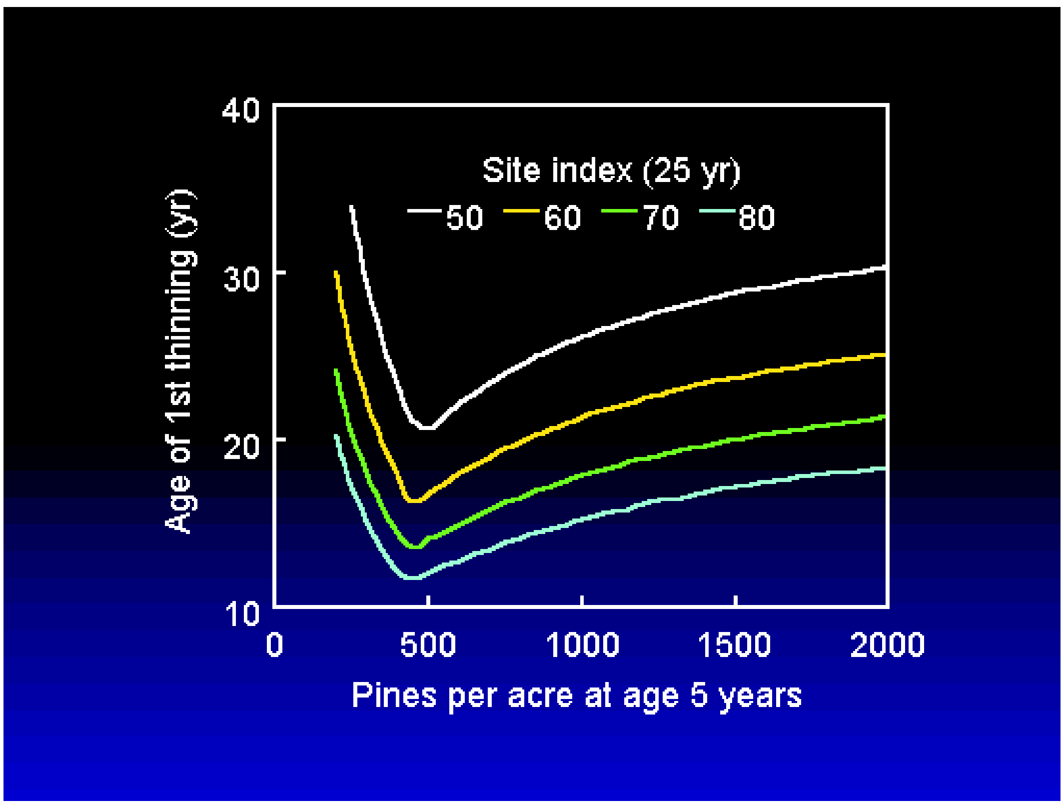

Figure 7 - Relationships of the earliest age of a first thinning to site index (mean height of dominant and co-dominant trees at 25 years of age) and fifth-year stem density for loblolly pine plantations in the Piedmont and Upper Coastal Plain. These simulations are based on stand projection equations from (10). A first thinning can occur sooner on sites of better quality because of their more rapid rates of stand development. At densities less than 450 trees per acre, earliest thinning age increases because lower stand densities delay accumulation of wood volume sufficient to support a removal of 6 cords per acre. At densities greater than 500 trees per acre, earliest thinning age increases because higher stand densities limit diameter growth and delay the attainment of a 6.5" average stem diameter needed to support a thinning.

Product objectives must be considered when selecting the planting density that is most appropriate for a given stand. If the goal is to maximize production of pulpwood (in which stand volume is more important than tree size), planting densities of 700 to 800 trees per acre should be used. Pre-commercial thinning may be necessary if volunteer trees increase stem density considerably above 800 trees per acre or else stand growth rates may slow. If the goal is to maximize production of sawtimber (in which tree size is more important than stand volume), planting densities of 400 to 500 trees per acre should be used, as shown by the simulations above. Many landowners will want to delay their choice of product objectives when establishing a new plantation, providing them with the opportunity to manage the stand according to market conditions. Planting densities of 600 to 700 trees per acre will provide a reasonable compromise in priority of growth allocated to stand volume versus tree size.

Combining Thinning with Other Silvicultural Treatments

A variety of forestry studies have identified the significant growth and yield benefits of applying weed control and fertilization treatments to plantations of southern pines (2, 12, 5). In one study, complete weed control and annual fertilization for 12 years after planting resulted in loblolly pine yields (5886 ft^3 of wood per acre) averaging over three and a half times that resulting from mechanical site preparation and planting alone (1562 ft^3 per acre) (1). These studies indicate the potential benefits of combining a first thinning with weed control and fertilization.

Since a given amount hardwood basal area will displace over twice that amount in pine basal area (12), the cumulative negative effects of hardwoods on pine yield can be substantial (6). Thus, weed control can be a critical mid-rotation treatment if pine yields are to be maximized following a thinning. However, a sufficient abundance of hardwood competition is needed in order to justify a weed control treatment. In general, weed control should be considered as a viable treatment if hardwood basal area is at least 5 ft^2 per acre.

A variety of herbicides can be applied safely to control competing vegetation in pine plantations. Imazapyr (Arsenal®), hexazinone (Velpar®), and metsulfuron (Escort®) can be applied aerially without damage to pines, while glyphosate (Accord®) and triclopyr (Garlon®) must be applied as a ground application to avoid foliage contact and potential injury to pines. Following a thinning operation, an herbicide application should be delayed for half or more of a growing season to ensure that hardwoods and shrubs have sufficient crown recovery for uptake and processing of the chemical. Hexazinone has been shown to be more effective at controlling woody plants in thinned stands than in unthinned stands, presumably because the competing vegetation is more physiologically active in the open canopy conditions of thinned stands (9).

In fast growing pine plantations, such as those that have received intensive weed control during their development, diameter growth rates can slow during the middle of the rotation (10 to 15 years) if the soil is unable to meet the nutritional demands of the stand. During this time, the crown of a pine tree is expanding rapidly in size yet much of the available soil nitrogen has already been incorporated into the stand (11). Therefore, fertilization should follow soon after a first thinning if rates of sawtimber production are to be maximized.

A typical fertilizer treatment for mid-rotation stands of loblolly pine is to apply 200 lbs./acre of nitrogen and 50 lbs./acre of phosphorus in early spring after a first thinning. Urea and diammonium phosphate are common fertilizer compounds in forestry use today. Because fertilization will stimulate increases in abundance and vigor of competing vegetation, resulting in some of the applied nutrients becoming unavailable for pine uptake, it is best to delay fertilization until a reasonable level of weed control has been achieved.

Pruning of the lower live branches will reduce the taper (conical shape) of a tree's stem by lifting the base of live crown, where rates of diameter growth are highest (17), resulting in a more cylindrical shape in the first log. Pruning also accelerates the production of knot-free wood, which may become a valuable commodity in wood markets of the future. However, in today's markets, knot-free logs of southern pines typically are not priced at a higher rate than conventional logs because diameter is the chief determinant of log value. Thus, the financial advantage of pruning southern pines has not yet been realized.

Assuming that a crown ratio of 40% is to be preserved to maintain tree vigor, pruning can occur as soon as a tree attains a height of about 29', or as early as 8 years of age, assuming height growth rates of 3' to 4' per year. Typically, trees are pruned to a height sufficient to produce clear wood on the first 16' log, or about 17.5' to allow for trim from the stump and top of the tree. Pruning of live branches will produce tight knots, which are better suited to lumber processing than the loose knots that result from pruning of dead branches. To minimize the size of the wound, pruning should be done without cutting into the branch collar (the swelling at the base of the branch).

Summary

Three criteria were considered for selecting the best intensity and timing of thinning: basal area, crown ratio, and stand density index. Although basal area is an easy-to-use and accepted measure of stand density, critical values indicating the need for thinning will vary with stem density, age, and site quality. Therefore, basal area is best used on a stand-specific basis. Crown ratio is a good measure of tree vigor, because it provides a relative index of a tree's carbohydrate balance. However, in high-density stands, it can change within several years from acceptable values (40%+) to critical values (<30%), indicating increasing tree susceptibility to mortality from disease, insects, or windthrow.

In contrast, stand density index (SDI) provides a measure of density that is independent of age, site quality, and species because it quantifies competition intensity relative to the maximum tree size possible for a given stem density. Although SDI is somewhat more difficult to calculate than other measures of density, it can be derived easily from tabled values using measurements of stem density and basal area for an individual stand.

When considering whether to combine thinning with other silvicultural treatments, such as weed control, fertilization, and pruning, timing of each activity can be critical. Thinning will stimulate understory development, and effects of this competing vegetation must be reduced if sawtimber production is to be maximized. Likewise, fertilizer applications should occur after thinning and weed control in order to ensure that crop trees are the primary benefactors of the treatment.

Acknowledgments

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