STAND DENSITY MANAGEMENT OF SOUTHERN BOTTOMLAND HARDWOODS

J.C.G. **Goelz**
J.S. Meadows
Southern Hardwoods Laboratory
USDA Forest Service
Southern Research Station
P.O. Box 227
Stoneville, MS 38776

ABSTRACT

We present tools to guide stand density management of southern bottomiand hardwoods and we provide guidance in their implementation. We present stocking guides for southern bottomland hardwoods and variants for associated forest types, water tupelo (*Nyssa aquatica* L.) and sweetgum (*Liquidambar styraciflua* L.). The A-line represents 100% stocking, and can be used to identify stands that will benefit from thinning. The B-line, or suggested lower limit for stocking, can be used as a target for conducting thinning. C-lines of stocking guides identify stands that are deficient in stocking. We provide a key to help guide decisions to conduct intermediate silvicultural practices. When intermediate practices are conducted, stand improvement should always be the paramount concern. Based upon equations to predict crown radius for open-grown trees, we present alternative, species-specific B-lines. These B-lines can be constructed for any species or specific species composition. We use the stocking equations to provide suggestions for initial spacing of hardwood plantations.

INTRODUCTION

Growth of stands of trees is largely determined by three factors, site quality, stand density and species composition. Of these factors, stand density is much more easily affected by management decisions than is site quality. Stand density is invariably affected by any practice that affects species composition. Initial spacing of plantations, timing and intensity of precommercial and commercial thinnings, timber stand improvement, and rotation age are management decisions that directly affect stand density. When these decisions are made, they should reflect actions that maximize, or at least increase, the value of the forest. An optimal stand density management regime could be solved for any stand, given a suitable economic criterion such as land expectation value and methods to predict stand growth and change in log quality or value. When the objectives of management are strictly to maximize the monetary returns from timber, and where the stands are monospecific plantations with appropriate growth and yield models available, it is relatively easy to provide optimal stand density management regimes for any level of site quality. When objectives include both economic and noneconomic values; where existing stand composition, stand density, and tree quality vary greatly among stands; and where prediction models for growth and tree quality are nascent, the problem is more difficult to solve and the solution is specific to a given stand rather than common to all stands of the same site quality.

Clearly, stand density management for southern bottomland hardwoods falls into the latter alternative, where the situation is complex and no single stand density management regime is best for all stands. Until growth and yield prediction systems for southern bottomland hardwoods are mature, we offer tools to guide stand density management such that stands will be maintained within a range that is “reasonable’:. What is “reasonable” will be determined by expert opinion and by equations that predict crown radius of open-grown trees. Crown radius of open grown trees can be used to determine the lowest density of trees that can still fully utilize the site.

In this paper, we present tools to help a land manager keep his stands in the reasonable range. These tools are based upon: (1) expert opinion, largely John Putnam, who was one of the primary advocates of management of bottomland hardwoods, (2) open-grown crown radius relationships, and (3) practical concerns. Rather than stand density, *per* se, this paper will thus center on estimation of stocking and uses of stocking in determining management of stands. Although stand density is determined from some direct measurement of the stand, stocking includes a relationship to some other measurement considered as a "norm". The norm may represent maximum stocking, minimal full stocking (from open-grown crown radius relationships), some objective or subjective "ideal" conditions, or average (normal) conditions. All classical estimates of stocking provide an aid to keep a stand within reasonable limits of stand density, however none provide a solution to identifying the best stand density management regime for a given stand (Goelz 1991).

STOCKING GUIDE FOR SOUTHERN BOTTOMLAND HARDWOODS

Goelz (1995a) provided a stocking guide for use in southern bottomland hardwoods (Figure I). The form of the stocking guide follows Gingrich (1967), with a y-axis of basal area per acre, an x-axis of trees per acre, and a z-axis comprised of contour lines of equal stocking. Lines for quadratic mean diameter are given to facilitate use of the guides. The 100% stocking, or A-line stocking, represents stands immediately prior to scheduled thinnings as described in Putnam and others (1960). The B-line represents suggested stocking after thinning as described in Putnam and others (1960), and thus differs somewhat from the format of Gingrich (1967), which uses open-grown crown radius to define minimal full stocking. The user can interpolate stocking from the figure, or can calculate it exactly from equations provided in Goelz (1995a). In addition to Figure 1, Goelz (1995a) provides a stocking guide applicable to stands of smaller average diameter.

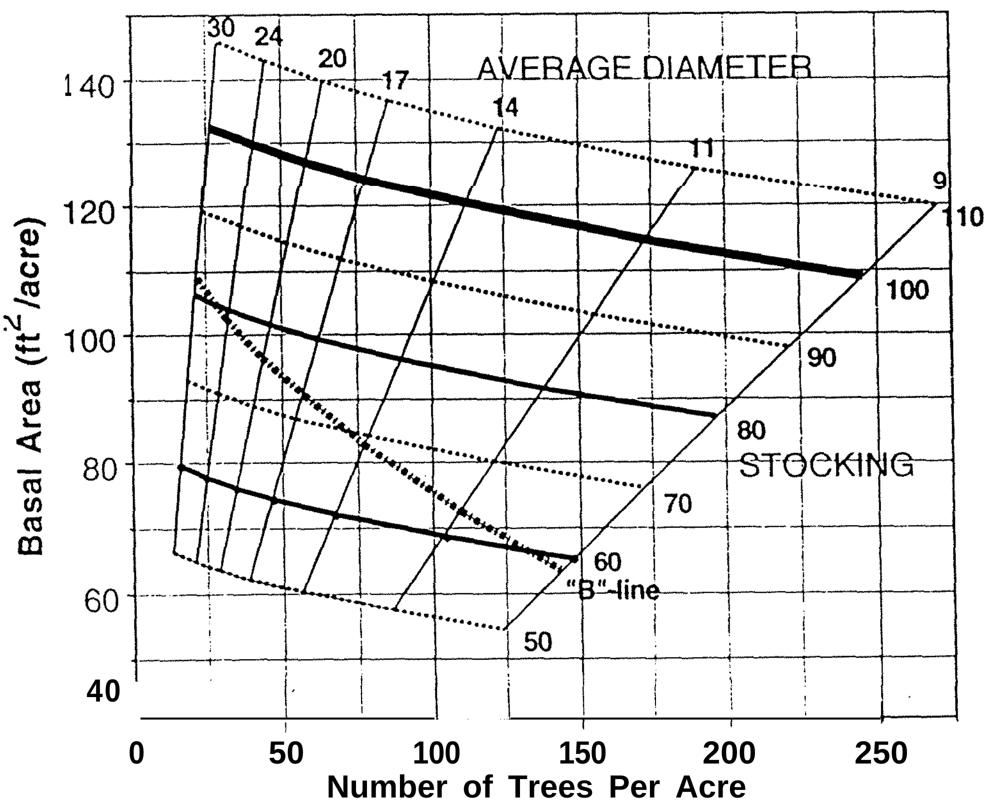

Figure 1. Stocking guide for southern bottomland hardwoods, from Goelz (1995a).

C-LINES OF STOCKING FOR BOTTOMLAND HARDWOODS

Goelz (1997) expanded upon his earlier work to provide "C-lines" of stocking for bottomland hardwoods. C-lines represent stands that will achieve the B-line in a fixed length of time. Gingrich (1967) used a period of 10 years--C-lines would grow to the B-line in 10 years. Goelz (1997) relaxed the concept of C-lines by producing C-lines for periods of 10, 15, 20, and 25 years to achieve the B-line (Figure 2). The choice of which C-line to use would depend on what decision a manager was attempting to make. Thus the C- 10 line might indicate stands that require no intervention for twenty years while the C-20 line might identify those stands-that are so deficient that they should be regenerated.

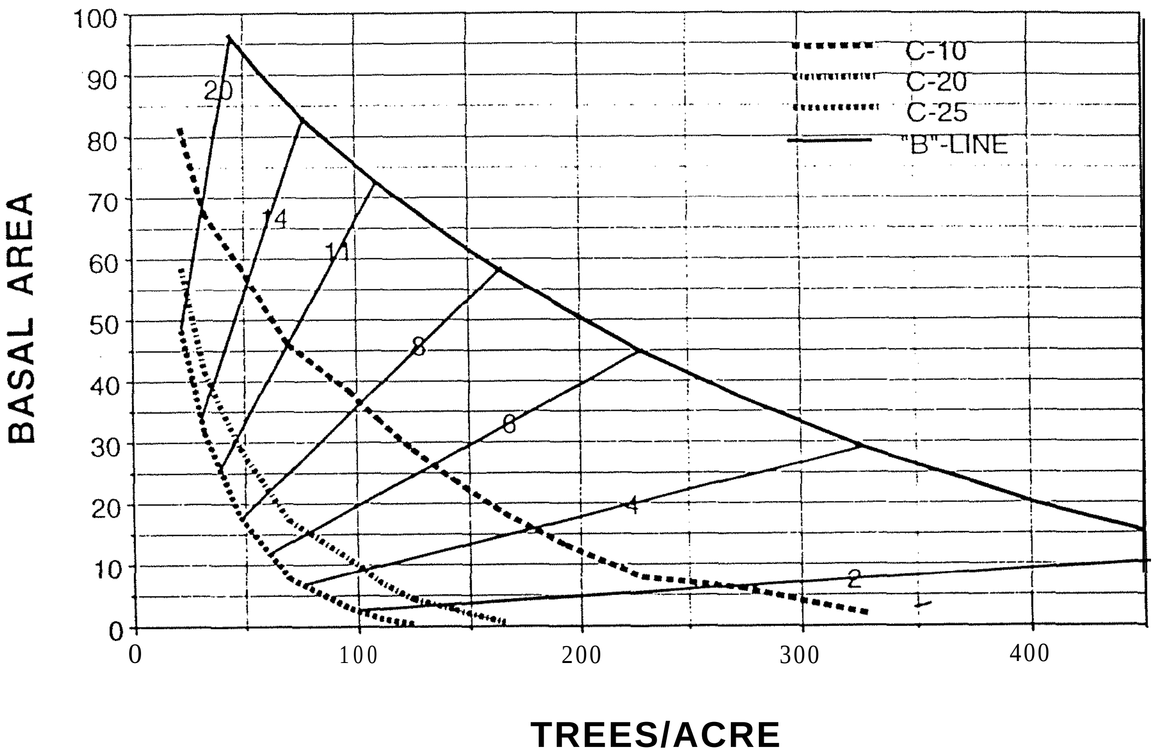

Figure 2. C-lines of stocking for southern bottomland hardwoods based upon 10, 20 and 25 years to achieve the B-line, from Goelz (1997).

A KEY TO CHOOSING INTERMEDIATE SILVICULTURAL PRACTICES

The following dichotomous key can be used to help a land manager choose an appropriate silvicultural practice for a stand. The manager must have the following data available: stand basal area per acre, trees per acre, basal area per acre of acceptable growing stock, trees per acre of acceptable growing stock, and quadratic mean diameter of acceptable growing stock. Quadratic mean diameter (QMD) may be calculated from basal area and trees per acre. These values will be used to determine stocking percentage either from the equation or figures of Goelz (1995a).

Acceptable growing stock (AGS) should be defined as those trees that are now or will be merchantable in the future, based on species and tree quality, and are not likely to die or degrade within 10 years. It generally would correspond to "preferred" and "reserve" growing stock tree classes (Meadows 1996). It should not be restricted to only preferred species. Living cull trees are generally not acceptable growing stock, although they could be if cavity-nesting birds were an objective of management. The decision as to what is acceptable is very subject to owner objectives and to the forest in question. Thus we provide no specific guidance as to which species or tree grades may be acceptable. However, if the manager finds that most of his stands are below the B-line when only acceptable growing stock is calculated, the manager is probably too restrictive in defining acceptable growing stock.

Table 1. A key to choosing intermediate silvicultural practices.

- Stand is less than ten years from rotation age.
    - 1. Plan regeneration when appropriate.
- Stand is more than ten years from rotation age.
    - Stocking is < 100%.
        - Stocking of Acceptable Growing Stock (AGS) ≥ C-IO line.
            - 2. Do Nothing.
        - Stocking of Acceptable Growing Stock < C- 10 line.
            - Quadratic mean diameter of AGS ≥ 16".
                - 3. Consider regeneration.
            - Quadratic mean diameter of AGS < 16".
                - Stocking of AGS < C-20 line.
                    - 4. Consider regeneration.
                - Stocking of AGS ≥ C-20 line.
                    - Whole stand stocking is > the B-line
                        - 5. Consider Timber Stand Improvement.
                    - Whole stand stocking is ≤ the B-line.
                        - 6. Do nothing.
    - Stocking is ≥ 100%.
        - Stocking of Acceptable Growing Stock > B-line.
            - 7. Thin stand.
        - Stocking of Acceptable Growing Stock ≤ B-line.
            - Stocking of Acceptable Growing Stock ≥ C-10 line.
                - 8. Timber stand improvement.
            - Stocking of Acceptable Growing Stock < C- 10 line.
                - Stocking of AGS > C-20 line.
                    - QMD of AGS ≥ 16".
                        - 9. Consider Regeneration.
                    - QMD of AGS < 16".
                        - 10. Timber stand improvement.
                - Stocking of AGS ≤ C-20 line.
                    - 11. Consider regeneration.

DISCUSSION OF CHOICES LISTED IN KEY

When regeneration_ is listed as the alternative (choices 1, 3, 4, 9, 1 1), the land manager should choose whatever method is most suited to the objectives of the landowner. When regeneration is suggested for relatively young stands because acceptable growing stock is sparse, the land manager could substitute "do nothing" until most of the acceptable growing stock is salable as sawtimber, particularly when the manager believes it would be difficult to regenerate a new stand of suitable species composition, or when those few trees of acceptable growing stock have great potential for value growth. When "do nothing" is the choice in the key (choices 2,6), the stand should be re-evaluated within ten years or less. If the stand nearly had 100% stocking, plans could be made to thin within a few years. Timber stand improvement (choices 5, 8, 10) may be conducted by cutting or deadening undesirable trees or by harvesting less desirable stems in a selective pulpwood harvest. Thinning (choice 7) should principally center on improving the average quality of the residual stand, and secondarily on spacing the residual trees, although no large gaps should be formed. The assumption is that, on average, marking to the B-line will sufficiently release residual trees, thus spacing need only be considered in patches where acceptable growing stock is much more dense than the average throughout the stand.

The actions listed in the key provide guidance, particularly for less-experienced foresters. There are times when the suggested practice should not be applied; generally this will be when a given stand is very close to the threshold levels for making a decision. For example, if a stand had greater than 100% stocking, stocking just under the C- 10 line for acceptable growing stock, and a quadratic mean diameter of 16.1 inches, the key would indicate decision 9, consider regeneration. However, if the acceptable growing stock were truly excellent trees and the site was suitable for producing high-value, large sawlogs, then an alternative decision would be conducting a timber stand improvement. Thus, when one of the criteria for decision-making was very near the threshold, the manager should also consider the alternate decision. The suggested decisions may also be inappropriate due to some practical consideration. For example, thinning may be indicated. However, in a given stand, if the thinning was postponed for five years, the timber could be sold, while if it was done immediately the trees would be sub-merchantable in size. In that case, thinning should probably be delayed.

CONSIDERATION OF TREE QUALITY AND SPATIAL DISTRIBUTION

Hardwood tree classes are an excellent way to describe tree quality (Meadows 1996). The four tree classes are: preferred growing stock, reserve growing stock, cutting stock, and cull stock. Species, tree vigor, and log quality determine the four tree classes. Thinning can improve average tree quality by removing defective trees or undesirable species. Thinning can also improve future tree quality by maintaining the vigor of individual trees. Tree vigor is associated with the production of epicormic branches; trees of low vigor produce more epicormic branches than trees of high vigor (Meadows 1995, 1996). However, a premature heavy thinning can adversely affect tree quality by keeping lower limbs in sunlight, thus prolonging their survival and ultimately producing a shorter merchantable height. We suggest that this reduction in ultimate merchantable height will only be a major problem if precommercial thinnings are done; the ultimate merchantable height will probably be fixed long before a tree reaches sawtimber size.

The assumption implicit in the stocking guides is that it is safe to thin from the A-line to the B-line. However, when stocking greatly exceeds the A-line, individual tree vigor will be low. These low-vigor trees will be prone to produce epicormic branches, particularly if they receive a sudden increase in sunlight. In that case, we suggest a lighter thinning; never removing more than 50% of the basal area is a reasonable rule of thumb for stands that have an average diameter of 6 inches or more. Stands that have an average diameter of less than 6 inches can be thinned more heavily for three reasons. First, younger trees tend to be more vigorous and can respond quickly to thinning. Second, if epicormic branches do occur, there will be no evidence of them by the time the trees are harvested as sawtimber, if vigor of the trees has been maintained. Third, the trees that do sprout heavily can be removed in subsequent thinnings.

When trees are marked, most of the residual trees should be in dominant or codominant crown classes. Well-formed trees in the intermediate crown class and of preferred species are also candidates for retention. Most commercially valuable species of bottomland hardwoods are intermediate or intolerant of shade. Thus, lower crown class trees are usually low in vigor, likely to produce epicormic sprouts, and unlikely to increase greatly in value. Intermediate crown class trees are acceptable candidates for retention when they are preferred species, existing in relatively young stands, and when they have full, well-formed crowns and few existing epicormic branches.

Thus, thinning in southern bottomland hardwoods should generally be a combination of stand improvement by removing damaged, diseased or undesirable stems as well as a selective thinning from below. However, small sub-merchantable trees adjacent to residual trees may be retained (Meadows 1996). These small trees provide shade to the bole of the residual tree and thus reduce the risk of producing epicormic branches. They also afford some protection from damage caused by skidding logs through the stand.

As we have said, the first priority of thinning should be to improve the average tree quality or value. Tree classes can be used to determine the priority when marking is done. Spacing trees is secondary. By achieving the desired residual stocking at the level of the stand, most of the desirable residual trees will receive some degree of release. However, two aspects of spacing are a concern. First, it is not beneficial to remove marginal-quality trees when there are no neighboring trees of better quality that will be able to utilize the space they occupy. In other words we should not produce large openings where the site is not utilized. Markets change and a marginal species today may be much more valuable in the future. Second, the best residual trees should receive some degree of release. Sometimes the release will be achieved by removing some intermediate crown class trees that compete with our residual tree, other times it will be achieved by removing one or two codominant trees that compete with the tree. It seems pointless to thin if we do not increase the growth of our best trees. On relatively rare occasions, the marker will even need to mark preferred trees to be cut when many preferred trees are clustered together and the long-term vigor of the trees would be in jeopardy if all were retained.

STOCKING GUIDES FOR OTHER BOTTOMLAND SPECIES

Goelz (1995b) also provided stocking guides for water tupelo and baldcypress (*Taxodium distichum* (L.) Rich.). The format is identical to the generic bottomland hardwood stocking guide of Goelz (1995a). These swamp species carry a much greater basal area than bottomland hardwood species. The A- and B-lines of the water tupelo stocking guide are compared to the A- and B-lines for bottomland hardwoods in Figure 3. Also on Figure 3 are A- and B-lines for pure or nearly pure stands of sweetgum. Putnam and others (1960) suggested that sweetgum could carry approximately 10% greater basal area than bottomland hardwoods. Based upon open-grown crown radius equations, Goelz (1996) found that smaller diameter sweetgum had much narrower crowns than other typical bottomland hardwoods. However, larger diameter (greater than 30" d.b.h.) sweetgum had crown radius as large as generic bottomland hardwoods. The information from Putnam and others (1960) was incorporated with the more recent findings of Goelz (1996) to provide A- and B-lines for sweetgum that are basically indistinguishable from the location of the corresponding lines of the bottomland hardwood stocking guide (Goelz 1995a) for stands of larger quadratic mean diameter, but which are approximately 10% higher in basal area for the stands of smaller quadratic mean diameter.

SPECIES-SPECIFIC B-LINES

Goelz (1996) showed how his equations to predict crown radius of open-grown trees could be used to produce B-lines for any of the eleven species that were studied, as well as B-lines for any specific combination of the eleven species. Four-B-lines are presented in Figure 4. One line represents pure stands of cherrybark oak (*Quercus falcata* var. ***pagodifolia*** Ell.) and another line represents pure stands of sweetgum. Two lines describe stands that are comprised of 25% cherrybark oak and 75% sweetgum; for one of these lines the average size of

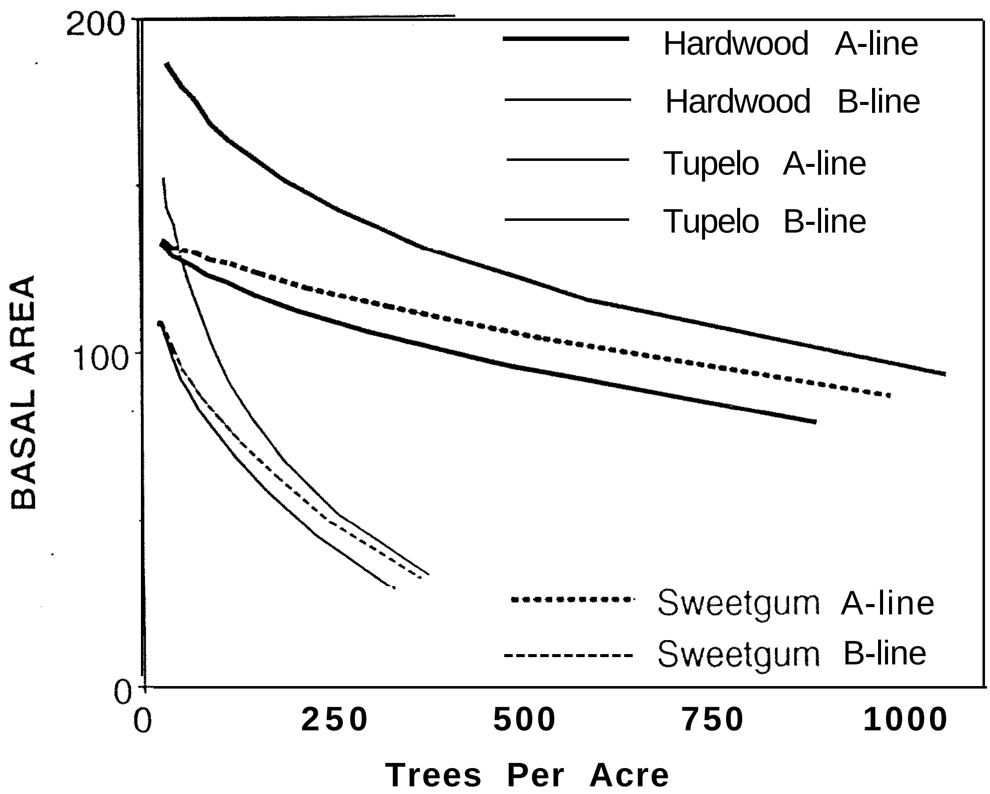

Figure 3. A comparison of the A- and B-lines for generic bottomland hardwoods (Goelz 1995a), water tupelo (Goelz 1995b), and for pure stands of sweetgum.

the species is equal while for the other, the sweetgum is only 75% as large as the cherrybark oak. Clearly, species can strongly influence stocking relationships, however, minor differences in average size of the two species has a negligible effect.

GUIDELINES FOR INITIAL SPACING OF HARDWOOD PLANTATIONS

The equations used to generate stocking guides may be used to guide initial spacing of hardwood plantations. We have used them for three different scenarios. Scenario One involves plantations that will be harvested without ever conducting a thinning, but before significant natural mortality occurs. We believe a plantation can achieve 133% stocking before such mortality occurs and we have calculated initial planting density for three different average diameters at rotation age. These diameters are small as we suggest that this scenario is appropriate for fiber farming rather than quality sawtimber production. We also include two levels of expected survival, 95% and 75%; this embraces the range that could be expected with the relatively intensive management suitable to fiber farming.

Scenario Two involves plantations that will be thinned for the first time when they achieve' 100% stocking. Again, we have calculated initial planting density for three different average diameters at the time of initial thinning, and for two different expected survival rates (90 and 70%). These survival rates probably embrace the range of survival for plantations with good potential for timber production. The three different average diameters represent the range from probably too small to provide for a merchantable thinning in most of the South

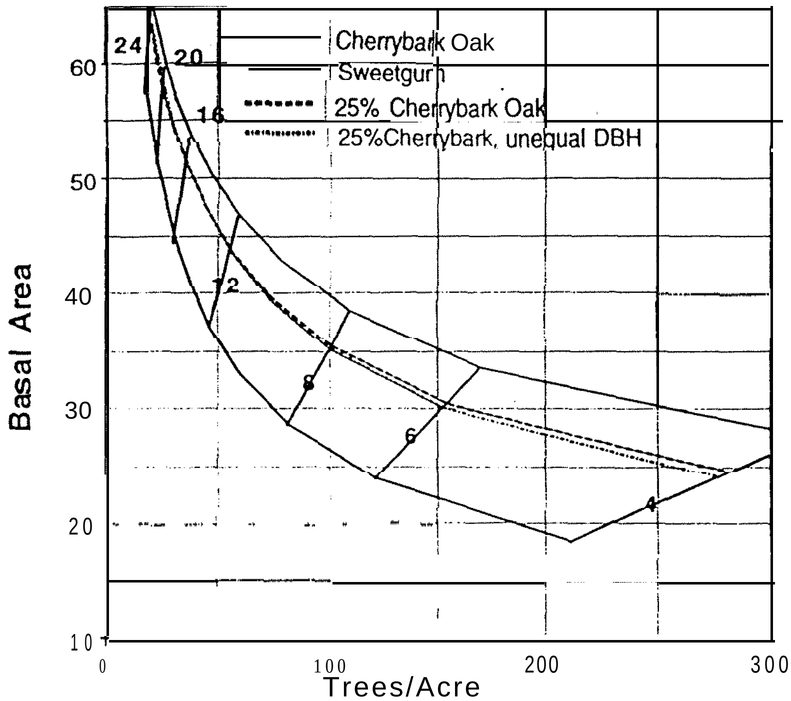

Figure 4. Comparison of B-lines derived from crown radius equations from Goelz (1996). Lines are drawn for pure stands of cherrybark oak and sweetgum and for two mixtures. Both mixtures include 25% oak and 75% sweetgum. For one of the mixtures, the average diameter is identical for both species. For the other mixture, sweetgum is only 75% as large as cherrybark oak.

(6.5 inches d.b.h.) to probably so large that the corresponding widely planted trees will retain low branches and log quality will be poor (9.5 inches d.b.h.).

Scenario Three is identical to Scenario Two except that we expect 33% percent of the stand (in units of stocking) to be provided by natural volunteer trees. We suggest that if you expect more than 50% of your stand to be comprised of volunteer trees, you do not need to plant trees to establish a forest; any planting is merely supplemental to modify species composition of the stand. As the density of volunteer seedlings generally varies greatly within a plantation, a manager should not rely on them when quality sawlog production is a priority.

Please note that first thinnings in plantations will usually call for removal of about half of the stand. This can be expediently done by removing alternate diagonal rows. Although row thinning sacrifices the manager's ability *to* improve average tree quality, it is sometimes the only practical way to implement a first thinning. Subsequent thinning should be done to improve the average quality of the residual trees. We like removing diagonal rows because square spacing is maintained, for example from an initial IO-by- 10 ft. spacing to a subsequent 14.1-by-14.1 ft. spacing. An alternative to alternate row thinning is removing every third or fourth row to provide access for machinery and selectively thinning 1/4 to 1/3 of the trees in the other rows. Thus access is improved while allowing some improvement in residual tree quality.

The method to calculate the number of trees per acre to plant and the corresponding spacing is:
1. Specify the average diameter when partial or complete harvest is planned.
2. Specify the stocking that is desired when that partial or complete harvest is planned.
3. Solve equation (1) of Goelz (1995a) for trees per acre:

$$NS = \frac{\text{Stocking}}{b_1 + b_2\text{Diameter} + b_3(\text{Diameter}^2)} \quad (1)$$

Where the coefficients, b_1, b_2, and b_3 are given in Goelz (1995a) and NS is the number of surviving seedlings per acre.

4. Divide NS by expected survival percentage to get N, the number of trees/acre to be planted. The survival percentage should reflect survival until the time of first harvest and not merely initial survival of the seedlings.
5. If volunteer ingrowth is expected, multiply the result of step 4 by the percentage of the stand to be comprised of planted trees.
6. Divide resulting number into 43560. This provides the number of square feet for each seedling. If square spacing is used, take the square root of this number to obtain spacing between trees. Alternatively use trial and error to obtain a rectangular spacing that is closest to the calculated square feet of land per seedling. Round to a convenient distance, typically to the whole foot. Generally, unless the calculated number is very close to a whole number, it is better to round down to assure a well-stocked plantation.

Table 2 includes the results for the three scenarios. For all scenarios, both expected survival and merchantability limits for average diameter affect the number of trees to be planted. Although Scenario One is intended to be appropriate for a fiber farming situation, it does not identify the most profitable spacing to use, it only identifies a reasonable range. Scenario Two embraces the range in planting density used in plantations established for timber production. There is a common rule of thumb of 300 trees per acre or 12-by-12 ft. spacing for hardwood

Table 2. Trees per acre and approximate spacing (in parentheses) for hardwood plantations given three different scenarios, different levels of average diameter at the time of first complete or partial harvest, and different levels of expected survival.

	Scenario One	
Average d.b.h.	95% Survival	75% Survival
inches	*Trees/Acre (Spacing in Ft)*	*Trees/Acre (Spacing in Ft)*
5	896 (7x7)	1135 (6x6.5)
7	526 (9x9)	667 (8x8)
9	344 (11x11)	436 (10x10)
	Scenario Two	
Average d.b.h.	90% Survival	70% Survival
inches	*Trees/Acre (Spacing in Ft)*	*Trees/Acre (Spacing in Ft)*
6.5	471 (9x10)	606 (8x9)
8	334(11x12)	430 (10x10)
9.5	249 (13x13)	320 (11x12)
	Scenario Three	
Average d.b.h.	90% Survival	70% Survival
inches	*Trees/Acre (Spacing in Ft)*	*Trees/Acre (Spacing in Ft)*
6.5	316 (12x12)	406 (10x11)
8	224 (14x14)	288 (12x13)
9.5	167 (16x16)	214 (14x15)

plantations. This actually corresponds to a scenario of a merchantability limit of about 8 inches d.b.h. for the first thinning, and negligible mortality. Thus, that rule of thumb should only be used when that scenario is applicable.' Spacing should be less when mortality is expected. Scenario Three reflects a situation where quality timber production is secondary to merely producing a bottomland hardwood habitat. Thus the results for Scenario Three might be used for forested wetland restoration.

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