by Benjamin A. Roach

A Stocking Guide for Allegheny Hardwoods and Its Use in Controlling Intermediate Cuttings

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ABSTRACT

A stocking guide for stands of Allegheny hardwoods (sugar maple or sugar maple-beech with varying admixtures of black cherry, red maple, white ash, sweet birch, and other species) on the Allegheny Plateau in northwestern Pennsylvania. Included are procedures for evaluating stocking and stand conditions, thinning even-aged stands, determining minimum residual stocking, distributing the basal-area cut in a stand, and using the guide for selection cutting.

A Stocking Guide for Allegheny Hardwoods and Its Use in Controlling Intermediate Cuttings

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INTRODUCTION

CONTROL OF STAND DENSITY is the principal means that foresters have for regulating stand growth. Ideally, to grow a full crop of wood products as quickly as possible, we should always have in our stand the minimum number of trees that will just use all of the light, moisture, and nutrients that are available on the site each growing season. The problems have always been how to define this ideal, and then how to achieve it.

Through the years many stocking guides have been developed to aid the forester in judging how well his stand is stocked compared to some prescribed standard, and, consequently, how the stocking would have to be changed to approach the ideal. In my opinion the best of the modern guides is the one developed by Gingrich *(1967)* for the oaks. It describes the maximum stocking to be expected and the minimum stocking that is needed for full yield, in basal area per acre, for a stand of a given average diameter. The guide has a rational biological basis; it is generally independent of the influence of site, age, or stand structure; and the measurements that are needed for its application can be easily and quickly obtained in the field. Similar guides have since been developed for use in the Northeast: northern hardwoods *(Leak, Solomon, and Filip 1969);* paper birch *(Marquis, Solomon, and Bjorkbom 1969);* spruce-fir *(Frank and Bjorkbom 1973);* and white pine *(Philbrook, Barrett, and Leak 1972).*

Following Gingrich's lead I have developed stocking guides for stands of Allegheny hardwoods (sugar maple or sugar maple-beech with varying admixtures of black cherry, red maple, white ash, sweet birch, and other species) on the Allegheny Plateau in northwestern Pennsylvania. This guide differs from the others listed in that I found it necessary to incorporate a measure of stand composition—specifically, the basal area in black cherry, white ash, and yellow-poplar expressed as a percentage of the total basal area of the stand.

BACKGROUND

The growth rate of a healthy tree is determined largely by the amounts of light, moisture, and nutrients that are available to it year after year. If these elements are continuously available in amounts equal to the tree's ability to use them, the growth rate of the tree should be at a maximum. If their availability becomes less than optimum, the growth rate of the tree is reduced; if their availability is reduced too greatly the tree will die.

The larger the tree, the greater are the amounts of light, moisture, and nutrients required for its survival and growth. But (if we ignore variables such as fertilization, irrigation, and climatic variation) the total amounts of these elements that are available on a site can be considered constant year after year. So as the trees increase in number or in size, undisturbed stands tend to reach and maintain a maximum degree of crowding. As some trees grow, others must die. The surviving trees receive less than optimum amounts of light, moisture, or nutrients, and their growth is relatively slow.

The area of a given site is, of course, constant. And if the amounts of light, moisture, and nutrients that reach the site can also be considered constant, they may be thought of collectively as the growing space available. This growing space can be expressed in area, and the area can be allocated mathematically among the trees present according to size. The tree-area ratio *(Chisman and Schumacher 1940)* is useful for this purpose.

TREE-AREA RATIO FOR ALLEGHENY HARDWOODS

I collected data on 106 natural hardwood stands throughout Warren, McKean, Forest, and Elk Counties in Pennsylvania. Some data came from measurements of temporary plots; other data were gleaned from research records dating as far back as 1928.[1]

The criteria for selecting the stands were somewhat subjective. Primarily there had to be no reason to believe that the stand was not at the maximum degree of crowding permitted by the site; that is, the stands had to show no evidence (on direct examination or in the records) of past cutting or other disturbance. The only exceptions were six research plots on which there had been a very light cutting more than 30 years earlier. However, no stands were excluded just because they seemed to have fewer trees or less basal area than others, if there was no evidence of disturbance. Because the tree-area ratio seems to be generally independent of site quality, I made no attempt to determine site quality.

The stand data consisted of tables of numbers of trees per acre that were 1.0 inch in diameter at breast height (dbh) or larger, by species and 1-inch diameter class; the data were compiled from diameter tape measurements of every tree on the plot. The plots ranged in size from 1/4 acre to 20 acres, and totaled 175 acres with about 125,000 trees. Stand age ranged from 18 to more than 100 years; basal area ranged from 60 to 175 square feet per acre, and number of trees from 200 to 5,000 per acre. From these tables I calculated the number of trees per acre, the sums of the diameters per acre, and the sums of the squared diameters per acre, by species for each plot.

These data were used to solve the tree-area equation:

$$\text{Tree area} = (a_1N_1 + b_1\,\Sigma D_1 + c_1\,\Sigma D^2_1) + (a_2N_2 + b_2\,\Sigma D_2 + c_2\,\Sigma D^2_2)\ldots$$

where a, b, and c are regression coefficients.

The subscript numbers indicate different species or species groups.

N is the number of trees.

ΣD is the sum of diameters.

ΣD^2 is the sum of squares of the diameters.

If all figures are calculated on a per-acre basis, *then* tree area should be 1 acre or 1,000 milacres.

The best regression (highest R^2 and lowest standard error of the estimate) was based on six species groups: sugar maple/beech/black cherry-white ash-yellow-poplar/red maple/yellow birch-sweet birch/miscellaneous. The miscellaneous group consisted of pin cherry, hemlock, basswood, aspen, cucumbertree, striped maple, American hornbeam, hophornbeam, and serviceberry. Except for pin cherry in young stands, trees of the miscellaneous group occurred as scattered individuals.

The equation is: Tree area (milacres) = $-18.4188 - .1754\,N_{sm} + .1953\,\Sigma D_{sm} + .0353\,\Sigma D^2_{sm} + .2537\,N_{be} - .1256\,\Sigma D_{be} + .0628\,\Sigma D^2_{be} + .4172\,N_{bc\text{-}wa\text{-}yp} + .1690\,\Sigma D_{bc\text{-}wa\text{-}yp} + .0075\,\Sigma D^2_{bc\text{-}wa\text{-}yp} - .4342\,N_{rm} + .2726\,\Sigma D_{rm} + .0162\,\Sigma D^2_{rm} + .8288\,N_{bir} - .2012\,\Sigma D_{bir} + .0630\,\Sigma D^2_{bir} - .2878\,N_{misc.} + .2263\,\Sigma D_{misc.} + .0017\,\Sigma D^2_{misc.}$

This regression is highly significant with a coefficient of multiple determination (R^2) of 99.6 percent. The standard error of estimate is 43.8 milacres or about 5 percent of the mean tree area of the plots.

SO WHAT?

From the high R^2 and small standard error, we can be reasonably confident that undisturbed stands of Allegheny hardwoods do indeed achieve an average maximum degree of stocking, and that we can describe this average maximum mathematically. By plugging into the equation the appropriate per-acre measurements for any stand, we can determine the number of milacres that the stand occupies when each tree is allocated the average minimum growing space that it needs to survive. If we divide that figure by 10, we will obtain the stocking percentage in the stand compared to the average maximum stocking (100 percent) for an undisturbed natural stand of the same composition and average diameter.

[1]I thank personnel of the Pennsylvania Bureau of Forestry and of the School of Forest Resources of The Pennsylvania State University for the use of stand data that they generously made available for this study.

Unfortunately, this stocking equation is not very useful for determining relative stocking in the woods. The number of trees can be obtained easily by counting them on sample plots. The sum of the squared diameters can be obtained easily by conversion from basal-area estimates; the latter can be made quickly with a wedge prism.[2] But the sum of diameters term requires a measure, or at least an estimate, of the diameter of many individual trees, and this takes much time and computation. Therefore, it would be convenient if a reasonably accurate estimate of stocking could be obtained without using the sum of diameters term.

The sum of diameters is useful primarily for indicating the differences in stocking between stands that have the same basal area and number of trees, but different structures. Gingrich *(1967)* found that differences in structure among oak stands resulted primarily from differences in species composition. But, with the exception of yellow-poplar, the species usually encountered in oak stands all had about the same requirements for growing space. That is, a 12-inch white oak required about the same amount of growing space as a 12-inch black oak or a 12-inch hickory. Therefore, if the amount of yellow-poplar in an oak stand were relatively low, both structure and composition could be ignored. Stocking estimates could be based on only the number of trees and basal area per acre.

This is because the number of trees per acre and the basal area per acre, taken together, mathematically define the diameter of the tree of average basal area (hereafter referred to as the average stand diameter). As nearly every normal yield table will show, there is a close relationship between the average stand diameter and the maximum basal area per acre. Therefore there must be an equally close relationship between the maximum basal area per acre and the number of trees per acre. So, for any forest type with a particular typical structure (so that the sum of diameters term becomes insignificant), a regression of maximum basal area per acre on number of trees per acre provides a means for displaying graphically the tree-area equation for average maximum stocking in that type. If we superimpose on that graph the lines that indicate the average stand diameter, we can see the relationship between average stand diameter and maximum basal area.

Then it becomes a simple matter to determine the relative stocking of any stand, if its average diameter is known, by comparing the basal area of the stand with the basal area shown on the chart for a stand of the same average diameter. Also it is easy to determine the residual basal area that is needed for any degree of stocking, as long as cutting does not cause a significant change in stand structure. Finally, the degree of stocking and the average stand diameter should provide an excellent basis for predicting future growth and development—both for individual trees and for stands—once the necessary data are accumulated.

Although the structure of Allegheny hardwood stands varies much more than that of oak stands, I had hoped that a stocking guide based only on number of trees and basal area might be accurate enough for field use, but this hope proved illusory. The regression of basal area on number of trees per acre, though highly significant, had an R^2 of only 34 percent, and a standard error of the estimate of 16 percent. It seemed logical that the low R^2 and the high standard error were due to large variations in structure among the sample stands. Obviously, some measure of structure had to be included.

I couldn't think of any indicator of structure that promised reasonable accuracy and that would be any easier to obtain than the sum of diameters. But it seemed likely that the variation in structure was caused primarily by two factors: differences in stand age, and the wide range in species composition.

There was a modest improvement in results after I incorporated stand age in the regression of basal area on number of trees per acre, but it was considerably less than I had expected. So I investigated a number of possible indicators of composition.

The best indicator that I found was the percentage of basal area in the stand that was contributed by each species. In fact, when this variable was included the effect of stand age disappeared. This indicator was convenient because it promised to eliminate the practical difficulties of determining stand age in the field, or trying to assign a specific age to stands con-

[2]Because basal area and the sum of squared diameters are essentially the same, it makes sense to use basal area directly rather than perform a needless conversion to sum of squared diameters.

taining more than one age class. And by tallying number of trees and basal area by six species groups, I found that relative stocking could be estimated with the same accuracy as it could with the complete tree-area equation.

But trouble developed when I tried to use this method in the woods. I found that I would have to carry a large number of charts to cover the many possible species combinations, or carry one of the more sophisticated pocket calculators to solve the complex equation for each combination. Also, this method required a detailed marking inventory and complicated calculations to determine residual stocking. In short, the method was accurate, but too unwieldy; I found that two species groups were the most I could handle without difficulty.

So I tried many combinations to find the two species groups that gave results that were the most consistent with the full tree-area equation; these two groups proved to be one containing black cherry, white ash, and yellow-poplar, and another containing all other species.

STOCKING GUIDE FOR ALLEGHENY HARDWOODS

The overall stocking regression for Allegheny hardwoods produced the following equation (for 106 plots):

> Basal area per acre for 100 percent stocking = 272.5248 - 59.7549 (Log_{10} of number of trees per acre) + 0.7032 (percentage of total basal area in the stand contributed by black cherry, white ash, and yellow-poplar).[3]

This regression has a coefficient of determination (R^2) of 67.4 percent, and a standard error of estimate of 13.77 square feet of basal area, or about 11 percent of the mean basal area of the plots. This standard error is a little more than twice that for the tree-area equation. I believe that most of the additional error resulted because the differences in stand structure and composition cannot be accounted for adequately when only two species groups are used.

Although the degree of accuracy of this regression may be adequate for field use, or at least better than guessing, it seemed desirable to improve it if possible. Also stocking percentages that were calculated for individual stands with this equation differed considerably from the stocking percentages calculated from the tree-area equation at the extremes of diameter and composition.

So I stratified the data by using the percentage composition and calculated new regressions for each 10-percent change in composition from 0 to 40 percent; I used an additional regression for curves from 50 to 80 percent. These new regressions made an excellent progression, and none crossed any other within the range of the data. The R^2 (coefficient of multiple determination) of these regressions is 70 percent; the standard error of the estimate is 10.5 percent. I accepted the 0- and 80-percent curves as the extremes, and the original regression (average composition of 40 percent) as the mean, and distributed the curves of 10, 20, 30, 50, 60, and 70 percent progressively throughout the range. Figures 1A and 1B are versions of this chart that have been condensed for easier use in the field.

As the chart shows, when a fully stocked stand grows older, overcrowding causes mortality (mostly among the smaller trees) and reduces the number of trees per acre. This, combined with continued growth of the remaining trees, increases the average stand diameter. Because larger trees use growing space more efficiently than smaller trees, the total basal area of the stand continues to increase toward the maximum that the site can carry. This maximum depends on the sizes of the trees in the stand, which are reflected by the average stand diameter.

The A-level curves on figure 1 show the average maximum basal areas per acre that will be attained by undisturbed Allegheny hardwood stands with given average diameters when various percentages of the basal areas are contained in black cherry, white ash, and yellow-poplar. If the percentage composition does not change, successive plots of the basal area-number of trees relationship for a heavily stocked stand should fall progressively to the left

[3]In exploring the shape of the regression curve of basal area per acre on number of trees per acre, I found that three transformations gave better correlations than the straight line: Log X, Log Y, and the quadratic. The quadratic gave the best correlation (by a very small amount) within the range of the data; however, when the curves were extrapolated beyond the limits of the data, the quadratic and Log Y forms produced entirely unrealistic estimates (as, of course, does the straight line). The Log X estimates looked very reasonable so I used Log X (Log_{10} of number of trees per acre).

along the appropriate A-level curve on the chart. Usually, though, the cherry-ash-poplar group grows faster than the birch-beech-sugar maple component, so the percentage composition tends to increase; and the stand tends to be represented by a higher curve.

These curves should be thought of as averages. Many times the plot of a stand will fall somewhat above or below the appropriate curve, and the stand might still be considered perfectly "normal". One reason for this, of course, is the normal biological variation, and the statistical error that is inherent in the curves—the standard errors of the estimate are around 10 percent. Another reason is the variation in growing conditions from year to year. For example, if soil moisture in the summer is a limiting factor for growth, a period of wetter-than-average growing seasons will permit stocking to increase above the A level. Conversely, a period of drought years will increase mortality and cause the stand to drop below the A level. This became very apparent when I was examining stand records spanning the drought of the early 1930's. But whether it is currently above or below A level, the long term trend of the stand should be toward that level.

The B-level curves on figure 1 are not based on field data; they are my preliminary estimate (guess, really) of the minimum stocking that is needed for full utilization of the site.

Gingrich *(1967)* calculated a minimum stocking level for the oaks from crown measurements of open-grown trees. His B level is the stocking at which the sum of the cross-sectional areas of the oak crowns would just equal the ground surface area of the stand if each tree had its maximum crown size. His B-level basal areas range from 55 to 58 percent of the A levels. The B level that is recommended for northern hardwoods in New England ranges from about 54 to 69 percent of the A level *(Leak et al. 1969)*. In the United States generally, the recommended basal area to be left after thinning ranges from about 50 to 70 percent of the maximum that is encountered. For maximum wood production, European foresters recommend slightly higher "B levels", ranging from about 60 to 80 percent of maximum. The upper part of this range is recommended primarily for the more intolerant species (especially Scotch pine) or for stands in the latter part of relatively long (by U.S. standards) rotations *(Assmann 1970; Braathe 1957)*.

I have not made a study of crown diamters of Allegheny hardwood species, and growth studies are too recent to indicate the stocking level that produces the maximum net basal-area growth. From general observation I recommend 60 percent of A-level stocking as an estimated average B level that should be adequate until data are available from which to derive a better one. Thus the B levels (dashed curves) on the stocking chart (fig. 1) are calculated at 60 percent of the A levels for stands of the same average diameter.

THE STAND INVENTORY

Use of the stocking chart requires the following stand data: (1) the total basal area per acre; (2) the percentage of that basal area that is contributed by black cherry, white ash, and yellow-poplar (hereafter referred to as *percent CAPs);* and (3) the *average stand diameter* (diameter of the tree of mean basal area). These can be determined from data that are required during a sample cruise of the stand.

The following procedure is not the only one that can be used, but of those that I investigated, this procedure was the simplest and most convenient one that still provided acceptable accuracy.

Planning the Sample Cruise

The first step is to determine the stand boundaries; they should be set primarily to keep the stand as uniform as possible in composition, age, site quality, and structure. But some consideration also should be given to ease of future management. If the boundaries coincide with easily recognized features of the terrain, field work will be more efficient, records will be more reliable, and there will be less danger that the stand boundaries will be "lost" in the administrative records of stand treatments. It is often impossible to satisfy both objectives, but a small compromise will often simplify administration without causing a great increase in variability.

The optimum size of the stand will vary with many factors, especially the size of the property, the objectives of the owner, the ease of access, the nature of markets, and the need to protect or improve other resources—for example, wildlife habitat. It will often prove convenient if the

STOCKING GUIDE FOR ALLEGHENY HARDWOODS
FOR TREES 6 TO 15 INCHES IN DIAMETER

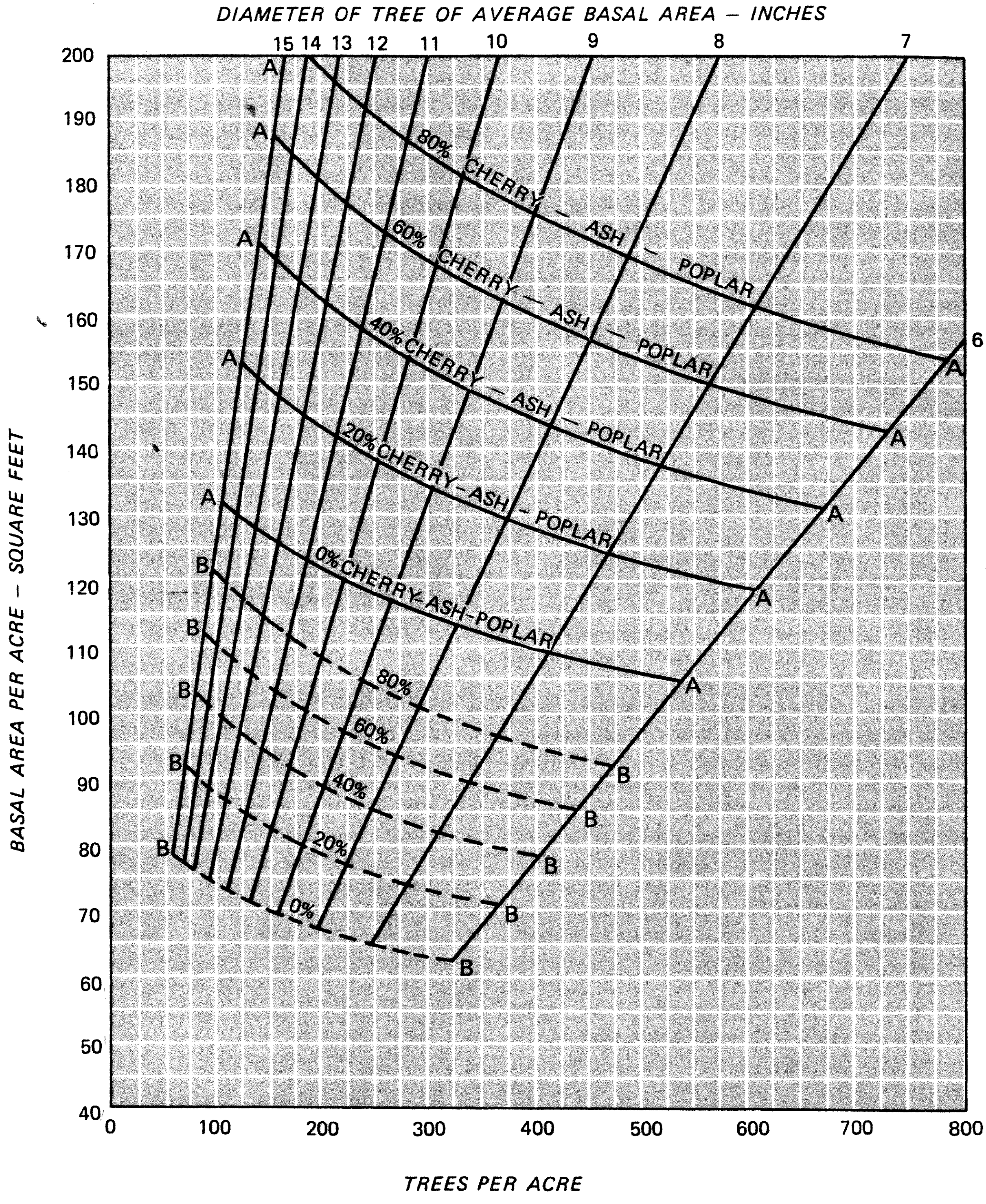


Figure 1A.—Stocking guide for Allegheny hardwoods, for trees 6 to 15 inches in diameter.

STOCKING GUIDE FOR ALLEGHENY HARDWOODS

FOR TREES 3 TO 10 INCHES IN DIAMETER

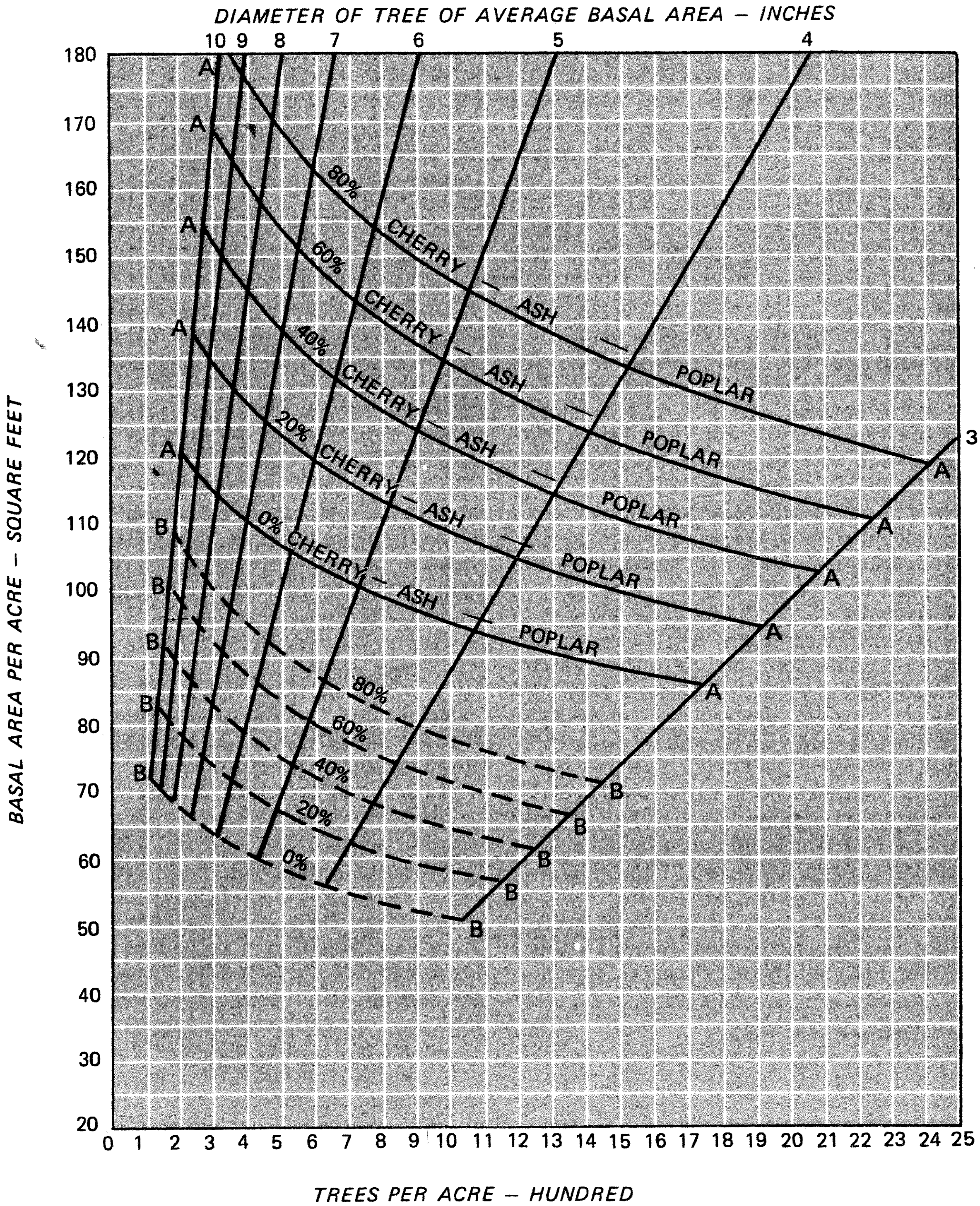


Figure 1B.—Stocking guide for Allegheny hardwoods, for trees 3 to 10 inches in diameter.

stand is large enough to provide a reasonably efficient field operation by itself, but not so large that variability is increased greatly. Generally I would not consider a stand that is smaller than 3 to 5 acres as a separate entity; and stands this small may be difficult to regenerate if there are many deer around. At the other extreme, I would rarely accept a stand as large as 50 acres.

The shape of the stand can also be an important factor when it is time to regenerate it. Deer seem to hit a long narrow stand harder than they hit a shorter, wider stand of equal area (unless the area is so small that the deer eliminate reproduction regardless of the stand's shape).

After the stand boundaries have been determined, the next step is to lay out a travel route for the sampling. Usually, several trips should be planned through the stand, and on parallel lines that are spaced several chains apart. Sample points should be spaced along the lines mechanically. Of course, the lines should be laid out to provide reasonable coverage of the whole stand, not just its most accessible areas.

The number of lines, the spacing between them, and the spacing between sample points must be set so that there are enough samples to provide accurate averages for the stand. Experience in previously unthinned 50-year-old stands indicates that 10 to 12 sample points are required to reduce the standard error of the mean basal area to 10 percent or less. Older stands, especially those that have been previously thinned, require more sample points.

I use 10 sample points as the absolute minimum for a stand, and then only if the stand is small (less than 15 acres) and if the basal area and structure are nearly uniform from point to point. In stands that are larger than 15 acres, I usually shoot for one sample point per 1 1/2 to 2 1/2 acres, and plan on a maximum of 20 points.

The Basal-Area Tally

At each sample point a wedge prism is used to obtain a dot tally of basal area per acre (trees 1.0 inch in dbh or larger), by two species groups (CAPs and other) and by four major size classes (saplings, poles, small and large sawtimber). When the sample cruise is completed the dot count is totaled and converted to a per-acre basis (fig. 2A).

It is necessary to tally the basal area by the two species groups to determine the percentage composition: basal area in CAPs divided by total basal area equals the *percent CAPs* (fig. 2A).

It is not necessary to break down the tally by size class to determine present stocking, but this breakdown provides a good, quick picture of stand structure. It also is useful later in guiding the stand prescription and in distributing the cut among the size classes. Because the size classes are broad, and because our objective is primarily to provide a picture of average stand structure, it is not necessary to measure the diameters of the sample trees for this tally; visual estimates are satisfactory.

Diameter ranges for the size classes (fig. 2A) may be changed as desired, though they should be consistent throughout a property. Also it may be helpful to identify certain tree classes on the tally—for example, using x's instead of dots to designate culls, or wolf trees, or misshapen members of sprout clumps.

In tallying the basal area, one precaution is especially important: Don't overlook the small trees. The stocking guide is based on all trees that are 1.0 inch in dbh or larger; if the small trees are overlooked or deliberately ignored, the guide will give you a wrong answer.

The Tree Count

We cannot determine the average stand diameter directly from the basal-area data that was obtained on the cruise, *and it must not be estimated visually.* However, there is a direct mathematical relationship between the average diameter and the number of trees per acre for a given basal area. During a cruise, we can obtain a good estimate of basal area per acre by using a wedge prism. Therefore, if we count the trees on enough sample plots to obtain a good estimate of the number of trees per acre, we can calculate the average stand diameter; or we can determine it accurately enough directly from the stocking chart.

The easiest method that I have found for determining the number of trees per acre is counting the trees on 1/20-acre circular plots (radii of 26 1/3 feet) that are centered on the sample points used for the basal-area tally. I place a marker at the center of a plot, go out 26 1/3 feet from that point, and walk around the circumference, counting the trees (live trees only) as the line between me and the center of the

Kane Exp. For.
UNIT

Cherry-Maple
TYPE or SPECIES

4/17/75
DATE

Bl. II, Plot 7, 10ac.
STAND AREA

54
AGE

BR

BASAL AREA AND TREE TALLY

Sample Point Number	LARGE SAWT. 17+		SMALL SAWT. 11 – 16		POLES 6 – 10		SAPLINGS 1 – 5		TREE COUNT 1/20 acre	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
1			4		4	3	1	1	6	34
2	1		2	1	1	5		5	3	39
3			5		2	4		1	5	43
4			6		3	1		1	7	36
5			3	2	3	3			4	49
6			3		2	4		4	4	39
7			2		2	3	1	4	4	35
8	1		1	3	2	2		5	3	45
9			3	1	3	3			5	41
10			4	1	3	3		1	6	41
11										
12										
13										
14										
15										
TOTAL		---							47	402
TOTAL per acre	2		33	8	25	31	2	22	94	804
TOTAL per acre	2		41		56		24		898	

DISTRIBUTION OF THE CUT

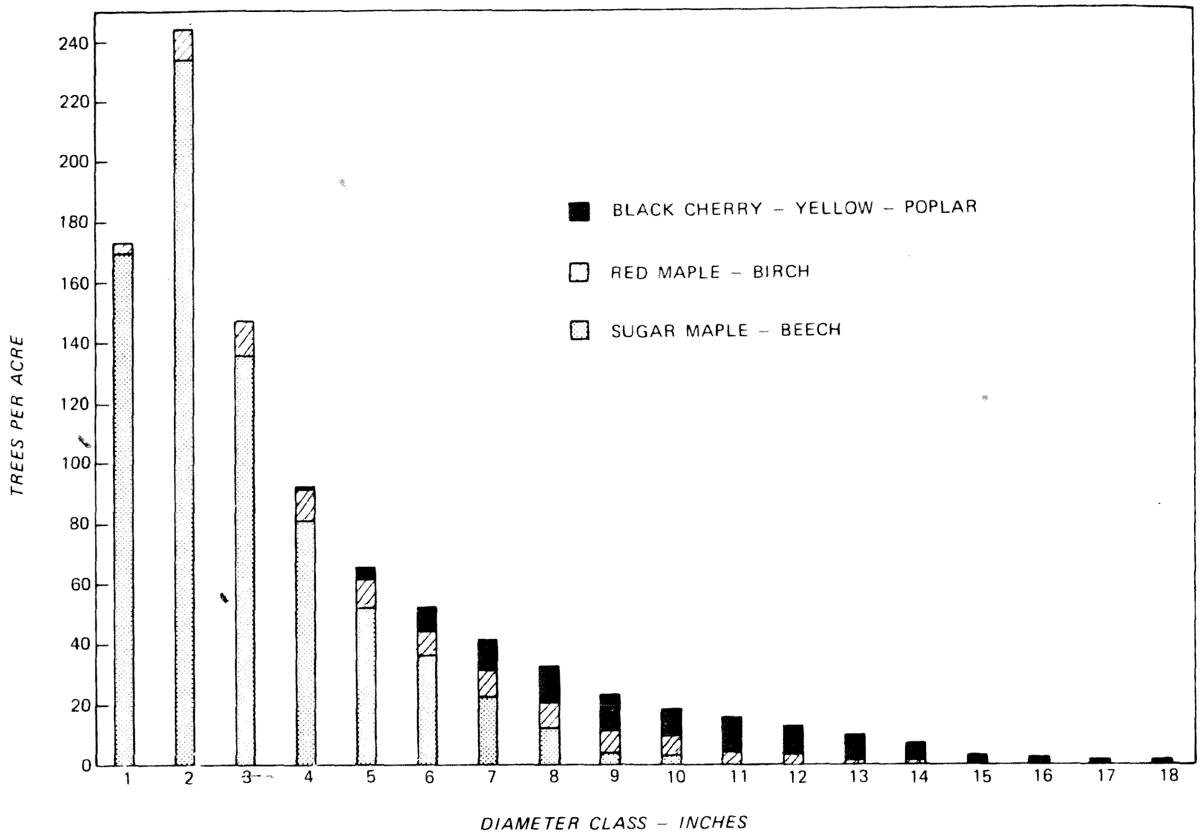
	LARGE SAWT.		SMALL SAWT.		POLES		SAPLINGS	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
Cut Basal Area								

STAND CALCULATIONS

	Trees per acre	Basal Area per acre			Percent CAPs	Average Stand Diameter	Basal Area for 100 % Stocking	Stand Stocking Percent
		TOTAL	CAPs	Other				
ORIGINAL Stand	900	123	62	61	50	5.0	129	95
RESIDUAL Stand								
CUT Stand								

Figure 2A.—A sample of summary stand tally sheet after cruise.

Figure 2B.—Diameter distribution in sample stand used in figure 2A.



plot passes them. After a little experience (especially learning to mark your starting point) this procedure can be completed for each plot in about 1 1/2 to 2 minutes.

The wedge prism also makes a handy rangefinder for keeping yourself on the plot circumference *(Nyland and Remele 1975).* At 26 1/3 feet, a 10-factor prism will exactly subtend a target of 9.57 inches. The target can be a 9.57-inch length of stove pipe fastened to a pole, or painted rings of different colors spaced 9.57 inches apart on the pole. The former is a little easier to see; the latter is handier to carry in the woods. After a little experience the prism is needed only two or three times per plot for checking borderline trees.There is one precaution: calibrate your prism; not all prisms have the exact factor they're supposed to have.

As with the basal-area tally, it is important to count all trees that are 1.0 inch in dbh or larger because these are the tree sizes that the stocking guide is based on. Failure to count the small trees will guarantee an error. "Trees" means all forest trees including hophornbeam, striped maple, and American hornbeam, but not shrubs such as witchhazel.

Although it is not necessary for determining total stocking, keeping the tree count separately for each of the two species groups will be very helpful later.

Some foresters like to convert the basal-area tally to a tree count. If we know the diameter of each sample tree that is picked up through the wedge prism, we can make a direct estimate of the number of trees per acre through conversion factors that are unique to the diameters. But I have found that this method is unsatisfactory for several reasons:

First, the number-of-trees factor varies widely among the diameters, so visual estimates of diameters are not accurate enough; measuring the diameters will provide a better estimate but this takes more time than counting the trees on a 1/20-acre plot.

Second, even if the diameters of the trees are measured, this method produces a much smaller sample of the trees under 9.6 inches than is obtained by counting the trees on the 1/20-acre plot. For example, to pick up a 1.0-inch tree as a sample tree through the 10-factor wedge prism means that that tree must be within 2.75 feet of the sample point. In effect, 1-inch trees are being sampled on a circular plot that has an area of only about 1/1800 acre. An average of 1 sample point per 2 acres of stand means a sampling intensity of about 3/100 of 1 percent for 1-inch trees, and about 1/10 of 1 percent for 2-inch trees. If the same number of plots are 1/20-acre in size, we can obtain a sample of 2 1/2 percent for all diameter classes.

A third factor of a practical nature further reduces the prospects of correctly sampling small trees with a wedge prism. Forest technicians (and even most foresters) are smart enough not to walk through brush if they can avoid it. Therefore it is a rare sample point that ends up in a clump of saplings, and, consequently, very few 1-inch trees are ever found within 2.75 feet of a plot center (or 2-inch trees within 5.5 feet).

In a typical 50-year-old unmanaged Allegheny hardwood stand, there will be between 700 and 900 trees per acre that are smaller than 9.6 inches, and only about 50 to 80 trees per acre that are larger. With an equal number of samples, the small trees are sampled much more intensively on the fixed 1/20-acre plots than they are by the wedge prism; and with the relatively small number of samples commonly used for stand inventory, fixed plots provide a much better estimate of the total number of trees per acre.

When the cruise is completed, the number of trees is totaled for all sample plots and converted to a per-acre basis (fig. 2A).

Determining Average Stand Diameter

If your pocket calculator has a square-root key, it is now easy to compute the average stand diameter: Basal area per acre divided by number of trees per acre equals the average basal area per tree. Multiply this number by 183.35 (a constant that converts square feet of basal area to the square of a diameter in inches) and take the square root. The result is the average stand diameter (diameter of the tree of average basal area).

The average stand diameter also can be determined directly from the stocking chart (fig. 3). Follow upward along the line that denotes the number of trees per acre until this line intersects the horizontal line that signifies the particular basal area per acre. Note where this point falls with reference to the adjacent slanting lines that designate average stand diameter. The average stand diameter can usually be estimated this way within 1/10 inch, which is accurate enough.

EVALUATING STOCKING AND STAND CONDITION

The sample cruise has yielded the data—basal area, *percent CAPs,* and average stand diameter—needed to determine relative stocking in the stand. The first step in this process is to determine the basal area that would be expected in the stand if it were 100 percent stocked. On the stocking chart (fig. 4) follow down along a line (real or imaginary) that represents the average stand diameter until the line intersects an A-level curve (real or imaginary) that corresponds to the *percent CAPs* in the sample stand. Read the basal area for this point. This is the basal area that a stand of that average diameter and with that *percent CAPs* would usually have if it were at the average maximum stocking found in nature (100 percent). If we divide this basal area into the basal area that was determined for the sample stand, and multiply by 100, we will obtain the *percent stocking* of the sample stand.

By using the summary sheet that results from the stand inventory, we can now make an objective evaluation of stand condition. If we use the stand described on the summary sheet (fig. 2A) as an example, a glance at the sheet will show us that the stand is obviously immature: the average diameter is only 5.0 inches, and there are only 2 square feet of basal area per acre in large sawtimber. It is apparent that the bulk of the basal area is split between the small sawtimber and poletimber sizes, so these are the size classes that we should look to to provide the final crop. We can also see that the stand is very well stocked; in fact it is near the maximum stocking to be expected, so natural mortality must be heavy and net growth relatively low. We can see that half the basal area is in the cherry-ash-yellow-poplar group, and that this group, which is mostly small sawtimber, is run-

Figure 3.—Determining average stand diameter from cruise data.

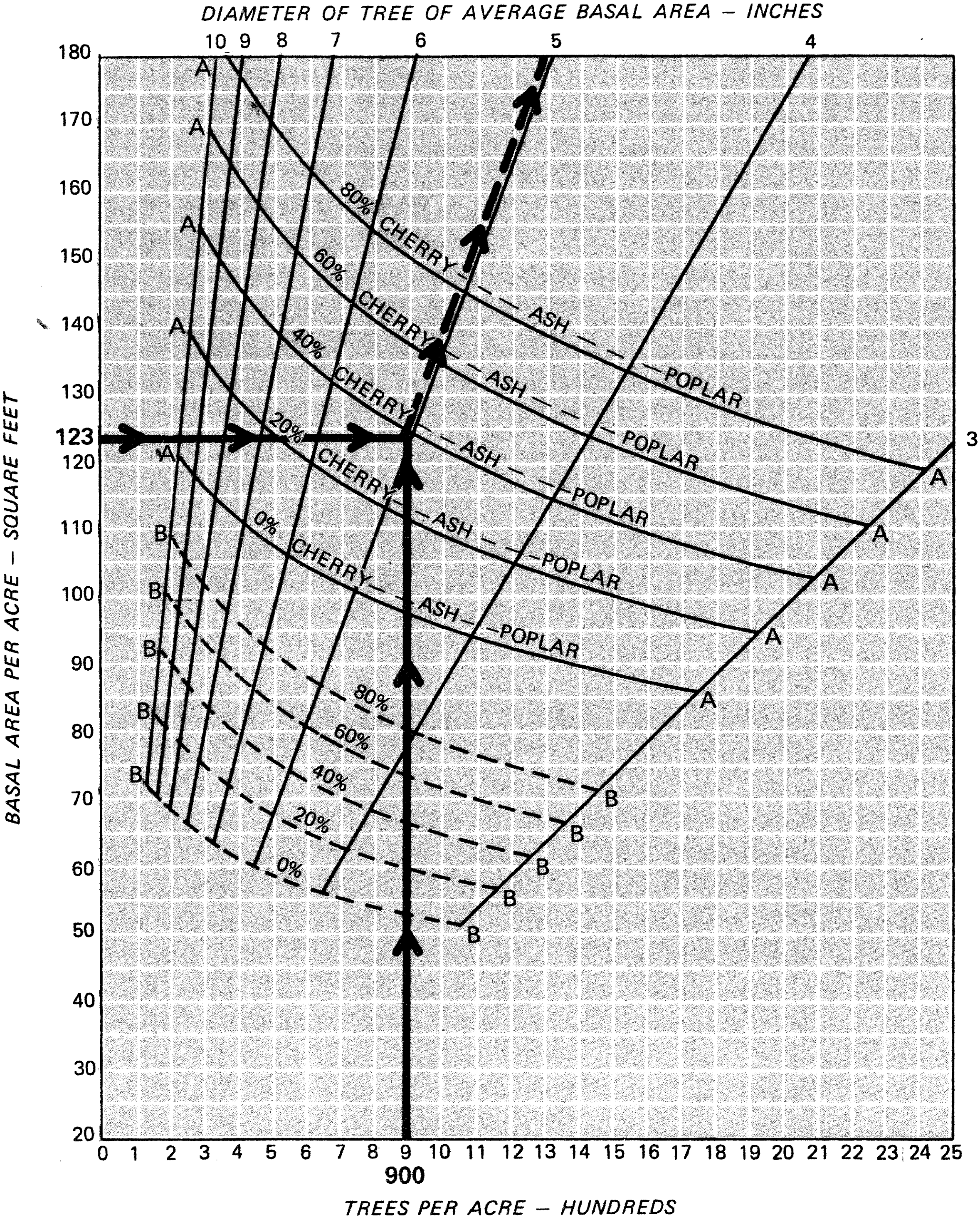
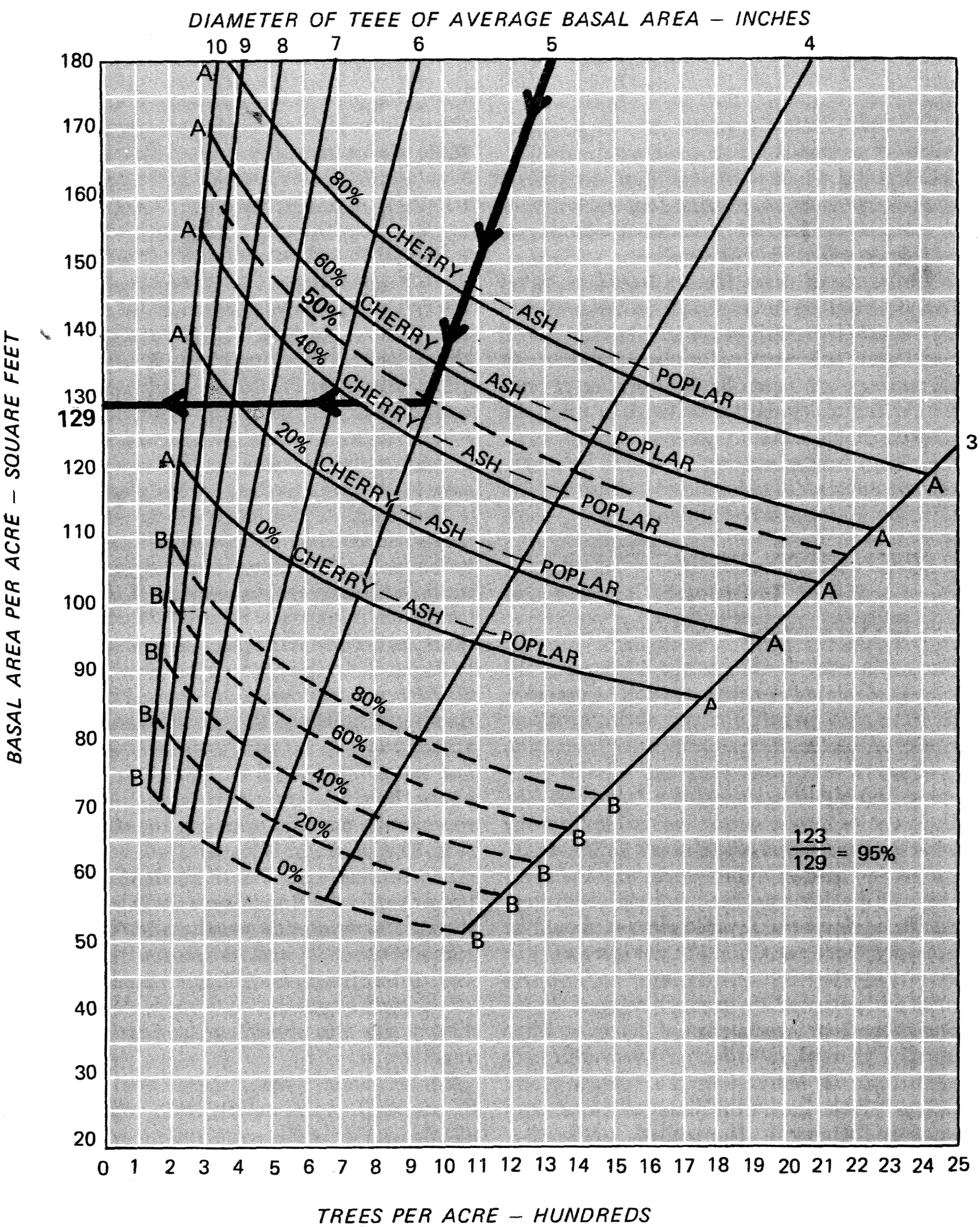


Figure 4.—A-level stocking percent for stand determined from stocking guide.



ning away from the other species. which are mostly poles. If we failed to observe it during the inventory, we can tell from the large number of trees per acre, and the sizeable basal area in the sapling class, that there must be a large number of small trees in the stand (probably 400 to 600 per acre in the 1- to 3-inch range).

All of these factors together provide a typical picture of a middle-aged, even-aged, heavily-stocked stand of excellent composition that is just in the process of growing from poletimber into sawtimber. In such a stand, a thinning is desirable to speed this process.

While many of these factors would be noted by an experienced forester in a casual observation, it would be rare if he noted all of them; and casual observations are notoriously imprecise in determining quantities. The information provided by the summary sheet eliminates much of the subjective judgment and guesswork. The summary also provides a record that will help substantiate current decisions and permit future evaluation of stand development.

GENERAL PRINCIPLES FOR THINNING EVEN-AGED STANDS

The main goal of thinning is to develop the full yield of major products as soon as possible. This is the big payoff for the entire rotation. Therefore each thinning should favor trees from the larger size classes that are of sufficient number and quality to provide a full yield. The bulk of the cutting must be carried out among trees from the smaller size classes, thus satisfying a second goal of thinning: to use the trees that would die during subsequent stand development. Trees from the favored classes should be cut in only those amounts that are necessary to provide the desired spacing and to improve quality and composition as much as possible. So unless there is an overburden of defective large trees, the general rule is that every thinning should cause an increase in the average stand diameter, a decrease in the diameter range, and greater uniformity in the residual stand.

The stocking of previously unthinned natural stands will usually be near 100 percent or A level. At this level of stocking, the net growth of the stand is low. Trees in the upper crown classes may grow fairly well (though rarely at their maximum rate), but much of this growth is counterbalanced by mortality in the lower crown classes and in the species that are least able to survive this intense competition.

Total wood production of a stand is about the same at any degree of stocking between the A level and the B level. However at A-level stocking, this growth is distributed among many trees. Individual growth rates are slow, and some of this growth is wasted on trees that will soon die. At B-level stocking, the growth is distributed among relatively fewer trees. Individual growth rates are faster, and none of the trees will be in danger of dying from overcrowding for some time. Therefore net growth (and the rate of product development) is much better near B-level stocking. So intermediate cuttings should reduce stocking to the B level.

No thinning should be made that reduces residual stocking below the B level because this would reduce the total yield and encourage the development of a heavy understory, or the invasion of the area by herbaceous plants.

The length of the interval between thinnings should depend on how fast stocking and mortality build up. Mortality is usually insignificant until the stand reaches stocking of about 75 percent; then it begins to increase. Mortality rarely becomes serious until stocking reaches about 80 to 85 percent. Thus, a range of stocking of 75 to 80 percent provides a good breaking point in deciding whether to thin. If the stand is stocked at less than 75 percent, growth should be good and mortality should be light, and the margin above the B level may be too small to provide a commercial cut. If stocking in the stand is more than 80 percent, growth rates will be slow, mortality will increase, and there should be enough basal area in the stand above the B level to make the cutting operation worthwhile. When stocking is between 75 and 80 percent, thinning is a matter of judgment. If the stand is readily accessible and markets are good, thin it. If conditions are the opposite, you can wait a few years.

Unfortunately, young stands tend to increase in stocking more rapidly than older stands, which implies different thinning intervals for stands of different ages. This would greatly complicate planning and administration, which are commonly based on 10- or 20-year cutting intervals. This problem can be partially overcome by making lighter thinnings in older stands, and by bringing younger stands to a heavier stocking between thinnings.

Variations Needed for Allegheny Hardwoods

The foregoing principles are broadly applicable to any forest type, but the Allegheny hardwoods are unique in several respects. The combination of rapid-growing, relatively short-lived intolerant species in the same stand with slower-growing long-lived tolerants poses the problem of bringing the latter to merchantable size before all of the former have been cut or lost. The regeneration of the intolerant and intermediate species (except at times for birch and perhaps yellow-poplar) depends on advance reproduction *(Marquis et al. 1975).* But the advance reproduction is short-lived; it comes and goes. This requires that a seed source be present right up to the final harvest cut to maintain a good stocking of advance reproduction of the intolerant and intermediate species. If no advance reproduction of the other species is present at the final cut, the next stand will be composed only of sugar maple or sugar maple and beech, and there will be a consequent loss of value and variety.

A second complicating factor is that stand structure and stand growth vary not only with stand age and stand density but also with the percentages of the various species in the stand. Interestingly, the combination of slow-growing tolerants in the small diameter classes and rapid-growing intolerants in the larger diameter classes creates a reverse J-shaped distribution curve that usually is considered typical of an uneven-aged stand, even though the trees in the stand may differ in age by only 2 or 3 years (fig. 2B). These factors make thinnings much more complex in these stands than they are in stands that have the bell-shaped distribution considered characteristic of even-aged stands.

Growth studies are too recent to provide reliable information on growth rates of Allegheny hardwood species after thinning. Early (3-year) results from thinned 50-year-old stands indicate that there is an increase of only 1 1/4 to 1 1/2 percent per year in *stocking percent.* This rate, if it continues, indicates a minimum cutting interval of about 15 years.

Finally, a number of sites seem relatively "fragile". Stands on the more poorly drained soils seem to represent a tension zone between forest and herbaceous vegetation. Cutting that is too severe, with the high population of deer present—and especially if the cutting is followed by fire—can quickly convert a forest stand to an herbaceous field that may take a half century or more to return to trees.

The general rule that thinnings should reduce stocking to the B level is broadly applicable in Allegheny hardwoods, but there are two important exceptions. One exception is a stand that is threatened by invasion of grass, or especially ferns. A current study by Stephen Horsley supports the growing evidence that these plants produce chemicals that are inimical to the establishment and growth of tree seedlings. The development of a heavy herbaceous cover could seriously retard or even prevent the regeneration of the new stand when the present stand becomes mature. Although we do not yet know the relationship between canopy density and the rate of invasion by herbaceous plants underneath, it seems reasonable that the more open the overstory, the faster the invasion.

A previously unthinned stand is usually near maximum crowding, and average crown size will be small. If this stand is thinned to the B level in one operation, more growing space will be made available than the remaining trees can immediately use, and there will be an interval of several years before the crowns have expanded to fill all of the growing space. In the interim, the extra growing space will encourage the invasion of the herbaceous plants. Therefore, if clumps of these plants are already present (covering 10 percent or more of the ground), or if surrounding areas have a heavy cover of them, I would not reduce the timber stand below 70 percent stocking.

The second exception to the general rule is a stand in the last third of the rotation—say, one that is 60 or more years old. Such stands contain many large trees, and thinning to the B level will result in a wide spacing. It takes a long time for the crowns of a relatively few large trees to fill in the open spaces; in the meantime, much growth may be lost. Therefore, I usually would not reduce the stocking of a previously unthinned stand that is 60 or more years old below 70 percent—even if there is no danger of invasion by herbs—unless the thinning is essential for promoting the maximum growth of tolerant species.

Unless herbaceous plants seem to be a problem, I would not hesitate to thin a stand younger than 60 years of age to B-level (60 percent) stocking regardless of how densely it was stocked initially. Bole sprouting can be minimized in Allegheny hardwoods by selecting clean-stemmed trees to remain.

Also, a fairly heavy release is necessary to obtain a large growth increase in sugar maple and beech. These species grow well when they have sufficient space; but as soon as the stand becomes crowded—especially when there is a dominant canopy of intolerant species—the growth of sugar maple and beech nearly stops. By the time a heavily-stocked stand is 35 years of age, black cherry typically ranges from 3 to 12 inches in diameter; but the largest of the sugar maple that started at the same time will be only about 4 inches in diameter, and the largest beech only 3 inches (Table 1).

To bring any beech and sugar maple to merchantable size before the black cherry is in danger of overmaturity and decline, the tolerant species must have relatively heavy release. Otherwise an expensive Timber Stand Improvement (TSI) operation will be necessary after the main stand is harvested to remove excess maple and beech saplings, and small poles. The alternative is an inevitable conversion of stand type to sugar maple or sugar maple-beech.

DETERMINING MINIMUM RESIDUAL STOCKING

With the principles for making intermediate cuttings in mind, the next step is to determine what the residual stand should contain. There are three things that the prescriber must determine: (1) the level of stocking desired in the *residual* stand; (2)the *percent CAPS* desired in the *residual* stand; and (3) the probable average diameter of the *residual* stand.

To illustrate, I will use the stand that was previously outlined on the summary sheet (fig. 2). This stand is well-stocked, is less than 60 years old, and is not threatened by invasion of herbaceous plants. It can be thinned back to B level stocking (60 percent); this figure is entered on the summary sheet (fig. 5).

There are few data available to guide the choice of the *percent CAPs* for residual stands. As a practical matter, I have found it difficult to change the *percent CAPs* by more than 10—either way—by thinning. Tentatively, I recommend maintaining CAPs of about 50 percent, so I will plan to keep the *percent CAPs* in the residual stand about the same as it was—at 50 (fig. 5).

It is more difficult to estimate the average diameter of the residual stand than it is to estimate the *percent CAPs*. The change in average

Table 1.—*Diameter of tree of average basal area, by species, in fully stocked, even-aged, and previously unmanaged stands of Allegheny hardwoods (in inches)*

Stand age (years)	Yellow-poplar	Black cherry	Pin cherry	White ash	Red maple	Yellow and sweet birch	Sugar maple	Beech	Entire stand
10	--	--	--	--	--	--	--	--	1.04
20	2.9	3.3	2.9	--	2.4	2.5	1.2	1.1	**2.16**
30	5.3	5.5	4.1	3.5	3.7	3.7	1.9	1.6	3.30
40	8.1	7.7	**5.2**	4.8	5.0	4.8	2.4	2.0	4.46
50	**11.4**	10.1	6.5	6.5	6.4	5.9	3.0	2.4	5.64
60	14.9	12.6	--	8.6	7.8	7.0	3.6	2.7	6.83
70	--	**15.2**	--	11.1	**9.2**	8.0	4.1	**3.1**	8.04
80	--	17.8	--	13.9	10.6	9.0	4.7	3.4	9.25
90	--	20.6	--	**17.2**	12.0	10.0	5.3	3.8	10.46
100	--	23.4	--	20.8	13.5	**11.0**	**5.8**	4.1	**11.69**
Number of stands	16	97	28	23	84	79	101	63	101
R^2 (%)	93	79	54	92	73	77	59	52	80

[a]Limits of data indicated by lowest stand age and diameter figures in boldface.

Kane Exp. For.
UNIT

Cherry-Maple
TYPE or SPECIES

4/17/75
DATE

Bl. II, Plot 7, 10 ac.
STAND AREA

54
AGE

BJR

BASAL AREA AND TREE TALLY

Sample Point Number	LARGE SAWT. 17+		SMALL SAWT. 11–16		POLES 6–10		SAPLINGS 1–5		TREE COUNT 1/20 acre	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
1			4		4	3	1	1	6	34
2	1		2	1	1	5		5	3	39
3			5		2	4		1	5	43
4			6		3	1		1	7	36
5			3	2	3	3			4	49
6			3		2	4		4	4	39
7			2		2	3	1	4	4	35
8	1		1	3	2	2		5	3	45
9			3	1	3	3			5	41
10			4	1	3	3		1	6	41
11										
12										
13										
14										
15										
TOTAL									47	402
TOTAL per acre	2		33	8	25	31	2	22	94	804
TOTAL per acre	2		41		56		24		898	

DISTRIBUTION OF THE CUT

	LARGE SAWT.		SMALL SAWT.		POLES		SAPLINGS	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
Cut Basal Area								

STAND CALCULATIONS

	Trees per acre	Basal Area per acre TOTAL	Basal Area per acre CAPs	Basal Area per acre Other	Percent CAPs	Average Stand Diameter	Basal Area for 100 % Stocking	Stand Stocking Percent
ORIGINAL Stand	900	123	62	61	50	5.0	129	95
RESIDUAL Stand					50	6.4		60
CUT Stand								35

Figure 5.—Sample stand tally sheet shows goals for residual stand.

diameter depends on the relative proportions of the large and small trees that are cut. In general, if I thin mostly from below in both species groups, the average stand diameter will increase. In thinning 50-year-old stands generally from below, I find that I can increase the average stand diameter at the rate of about 0.4 inch for each 10 percent stocking that is removed. (In both older and younger stands, the amount is less—about 0.25 inch per 10 percent stocking removed).

In the sample stand, to leave 60 percent stocking means removing about 35 percent stocking:

35/10 X 0.4 inch = 1.4-inch increase.

So I estimate the average diameter of the residual stand to be 5.0 plus 1.4 or 6.4 inches (fig. 5).

Now I can go to the stocking chart and determine the basal area per acre that I need in the residual stand.

Follow down along an imaginary line that represents a 6.4-inch average diameter until it intersects a B-level curve (in this case an imaginary dashed line) that represents 50 percent CAPs (fig. 6). Read the basal area for that point (85 square feet), and enter it on the summary sheet (fig. 7). This is the minimum basal area per acre needed for B-level stocking in a stand that has an average diameter of 6.4 inches and that contains 50 percent CAPs.

From this point drop straight down on the stocking chart to determine the number of trees per acre that should remain—390 (fig. 6). This last step is not really necessary, but it will be useful later.

Now it is possible to determine the basal area per acre that is needed in each species group. With 50 percent CAPs half of the 85 square feet should be in CAPs, the rest in the "other" species (fig. 7). (I rounded them off for easier figuring).

The cut stand can be determined by subtracting the residual stand from the original (fig. 8). The cut should amount to 38 square feet per acre: 19 square feet of CAPs, 19 square feet of "others".

If other than 60 percent stocking is desired in the residual stand, the above procedure must be modified. For example, if 70 percent stocking is desired in the residual stand, the cut will be lighter and the average stand diameter must be reestimated:

25/10 X 0.4 inch = 1.0-inch increase.

This increase added to the original stand diameter equals an estimated average diameter of 6.0 inches for the residual stand.

On the stocking chart follow down along the 6.0-inch average diameter line but find the basal area by using the A-level curves—137.5 square feet (fig. 9). This is the basal area that a 6.0-inch stand with 50 percent CAPs would have if it were 100 percent stocked. For this stand, 70 percent stocking equals 70 percent of 137.5, or 96 square feet.

The number of trees that should remain per acre can be found by following on down the 6.0-inch average diameter line until it intersects a line that represents 96 square feet, and then dropping down vertically as before (490 trees). The residual stand and the cut stand can now be determined as before. (Residual stand is 96 square feet: 48 square feet in CAPs, 48 square feet in others"; cut stand is 410 trees and 27 square feet: 13.5 square feet in CAPs, 13.5 square feet in "others".)

DISTRIBUTING THE CUT

Now you come to the fun part—deciding how the basal area to be cut in the stand will be distributed among the size classes.

As figure 8 shows, we will be cutting a little less than one-third of the basal area, but nearly two-thirds of the trees. (This is the reason for finding the number of trees per acre, as well as the basal area, for the residual stand—it shows the relative number of cut and leave trees.) Obviously, we must cut a large number of small trees to increase the average stand diameter to 6.4 inches.

We know also that we must cut generally from below in both species groups. Each species group has an average diameter of its own, and we need to remove more basal area from below those average diameters than from above them. As a general rule, I try to take about two-thirds of the basal area from below, about one-third from above the average diameter, in each species group. Now, if we just knew the average diameters of each group. . .

If the tree counts were kept separately for the two species groups, the average diameter of each group can be calculated or determined from the chart, as was shown earlier for the entire stand. (Don't try to average the average diameters of the two groups to get the stand average diameter, though; it doesn't work.)

If the tree counts were not kept separately, there are still several factors to guide us. Table 1 shows the average diameter, by species, for even-aged stands of Allegheny hardwoods; from table 1 we can estimate that 54-year-old black cherry will average about 11 inches in diameter.

Another way to estimate this quadratic mean diameter is to go back to the summary sheet (fig. 9). The stand contains 62 square feet per acre in CAPs, distributed as 2 feet in saplings, 25 feet in poles, 33 feet in small sawtimber, and 2 feet in large sawtimber. The midpoint of this basal area—31 square feet—falls in the lower part of the small sawtimber class, about 12 inches. On the average, the midpoint of the basal area will be about 1 inch larger than the average diameter. So again we can estimate an average diameter for the CAPs at about 11 inches.

So in distributing the CAP cut, I will plan to remove about two thirds of the cut basal area—say, 13 square feet—from the sapling and poletimber classes, and the remaining 6 square feet from the sawtimber.

CAP saplings in a 54-year-old stand have no future, so I will plan to remove all of them (2 square feet per acre). Eleven square feet will be removed in CAP poles, and 6 square feet will come from small CAP sawtimber (fig. 10).

Now I can compare the CAP cut, by size class, with what is present in those size classes to determine the relative proportions. I must cut all of the CAP saplings, a little less than half of the CAP poles, and about one out of five small sawtimber.

I'll follow the same principles in distributing the "other" cut. The "other" group has 61 square feet of basal area in 804 trees, which signifies an average diameter of 3.7 inches. So I'll plan to take two-thirds of the cut basal area—about 13 square feet—from the "other" saplings, saving 4- and 5-inch trees where there's a choice. I'll assign the remaining 6 square feet to the "other" poles, figuring on cutting about one out of six.

The above proportions make up only a general guide that will be modified as occasion demands. For example, I do not intend to mark any CAP large sawtimber, but if I run into a wolf tree, or a tree badly misshapen, or one badly damaged by wind or lightning, I'll not hesitate to mark it. Also, I intend to cut all the CAP saplings, but if I find one standing alone in what would otherwise be a hole in the stand, I'll leave it. I want to save all the "other" sawtimber, but if I find three sawtimber that are together in a sprout clump, I'll probably mark one of them. So I'll modify the marking guides as I go along, but I will keep the relative proportions in mind and use them to guide my marking throughout the bulk of the stand where there are no overriding factors.

There is one other important factor to remember during marking: The stand summary provides a good picture of the average stocking condition throughout the present stand. And through our stand analysis procedure, we should now have a good mental picture (after a little experience learning what different stocking percents look like in the woods) of what the residual stand should look like after cutting. However the present stand is not average everywhere; it will contain both dense and sparse patches. Since a major goal of thinning is to make the residual stand more uniform than the original, it is up to the marker to recognize these denser and lighter patches as he comes to them, and make his marking heavier or lighter, accordingly. This may sound difficult, but it is not; all you have to do is keep looking *at the stand* as well as at the individual trees.

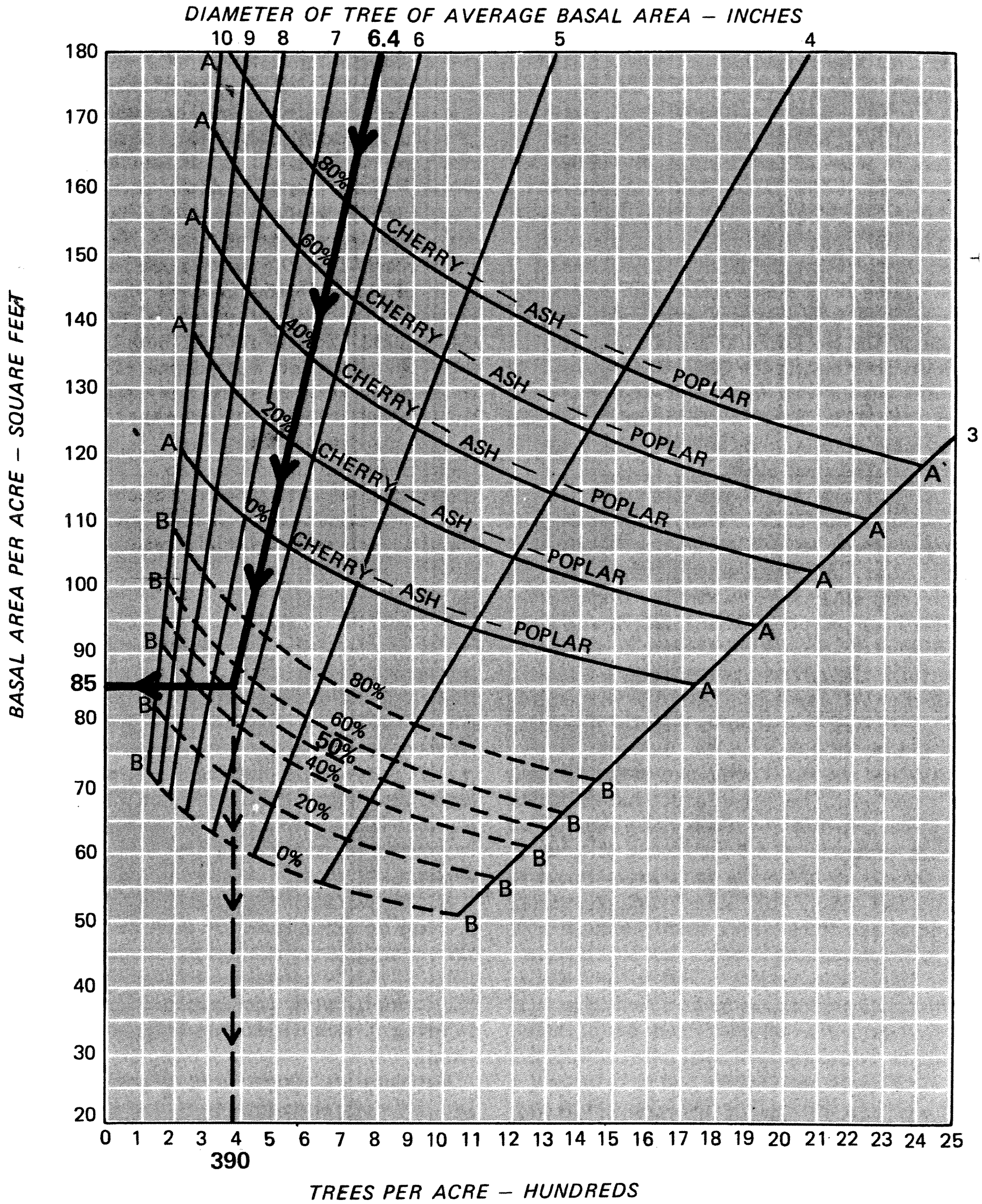
Is the Cut Practical ?

The prospective cut as determined above can be considered the ideal. In this stand it might amount to 400 to 600 board feet and perhaps 5 or 6 cords of pulpwood per acre. Where markets and access are good, it would probably just make a commercial thinning; with poor markets and access it probably would not. Even with a commercial thinning, a TSI operation would have to follow to remove 15 to 16 square feet of saplings.

At this point a compromise may be possible, perhaps by thinning a little more heavily in the sawtimber and a little less in the saplings and poles. If this is necessary in order to make the difference between a commercial thinning or no thinning, I would certainly not say that it is wrong.

But there are two factors to remember. First, you will not get the increase in average stand diameter that was estimated; so it will be necessary to go back and calculate new residual and cut basal areas. Second, if this process is carried too far—so that the final crop is reduced in value or is delayed for one or more

Figure 6.—Determining minimum basal area per acre required for B-level stocking in stand.



Kane Exp. For.	*Cherry-Maple*	*4/17/75*
UNIT	TYPE OF SPECIES	DATE
Bl. II, Plot 7, 10ac.	*54*	*BR*
STAND, AREA	AGE	

BASAL AREA AND TREE TALLY

Sample Point Number	LARGE SAWT. 17+		SMALL SAWT. 11 – 16		POLES 6 – 10		SAPLINGS 1 – 5		TREE COUNT 1/20 acre	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
1			4		4	3	1	1	6	34
2	1		2	1	1	5		5	3	39
3			5		2	4		1	5	43
4			6		3	1		1	7	36
5			3	2	3	3			4	49
6			3		2	4		4	4	39
7			2		2	3	1	4	4	35
8	1		1	3	2	2		5	3	45
9			3	1	3	3			5	41
10			4	1	3	3		1	6	41
11										
12										
13										
14										
15										
TOTAL									47	402
TOTAL per acre	2		33	8	25	31	2	22	94	804
TOTAL per acre	2		41		56		24		898	

DISTRIBUTION OF THE CUT

	LARGE SAWT.		SMALL SAWT.		POLES		SAPLINGS	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
Cut Basal Area								

STAND CALCULATIONS

	Trees per acre	Basal Area per acre TOTAL	Basal Area per acre CAPs	Basal Area per acre Other	Percent CAPs	Average Stand Diameter	Basal Area for 100 % Stocking	Stand Stocking Percent
ORIGINAL Stand	900	123	62	61	50	5.0	129	95
RESIDUAL Stand	390	85	43	42	50	6.4		60
CUT Stand								35

Figure 7.—Sample stand tally sheet shows basal area and number of trees per acre desired in residual stand.

Kane Exp. For. — UNIT
Cherry-Maple — TYPE OF SPECIES
4/17/75 — DATE
Bl. II, Plot 7, — STAND
10 ac. — AREA
54 — AGE
BR

BASAL AREA AND TREE TALLY

Sample Point Number	LARGE SAWT. 17+		SMALL SAWT. 11 – 16		POLES 6 – 10		SAPLINGS 1 – 5		TREE COUNT 1/20 acre	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
1			4		4	3	1	1	6	34
2	1		2	1	1	5		5	3	39
3			5		2	4		1	5	43
4			6		3	1		1	7	36
5			3	2	3	3			4	49
6			3		2	4		4	4	39
7			2		2	3	1	4	4	35
8	1		1	3	2	2		5	3	45
9			3	1	3	3			5	41
10			4	1	3	3		1	6	41
11										
12										
13										
14										
15										
TOTAL									47	402
TOTAL per acre	2		33	8	25	31	2	22	94	804
TOTAL per acre	2		41		56		24		898	

DISTRIBUTION OF THE CUT

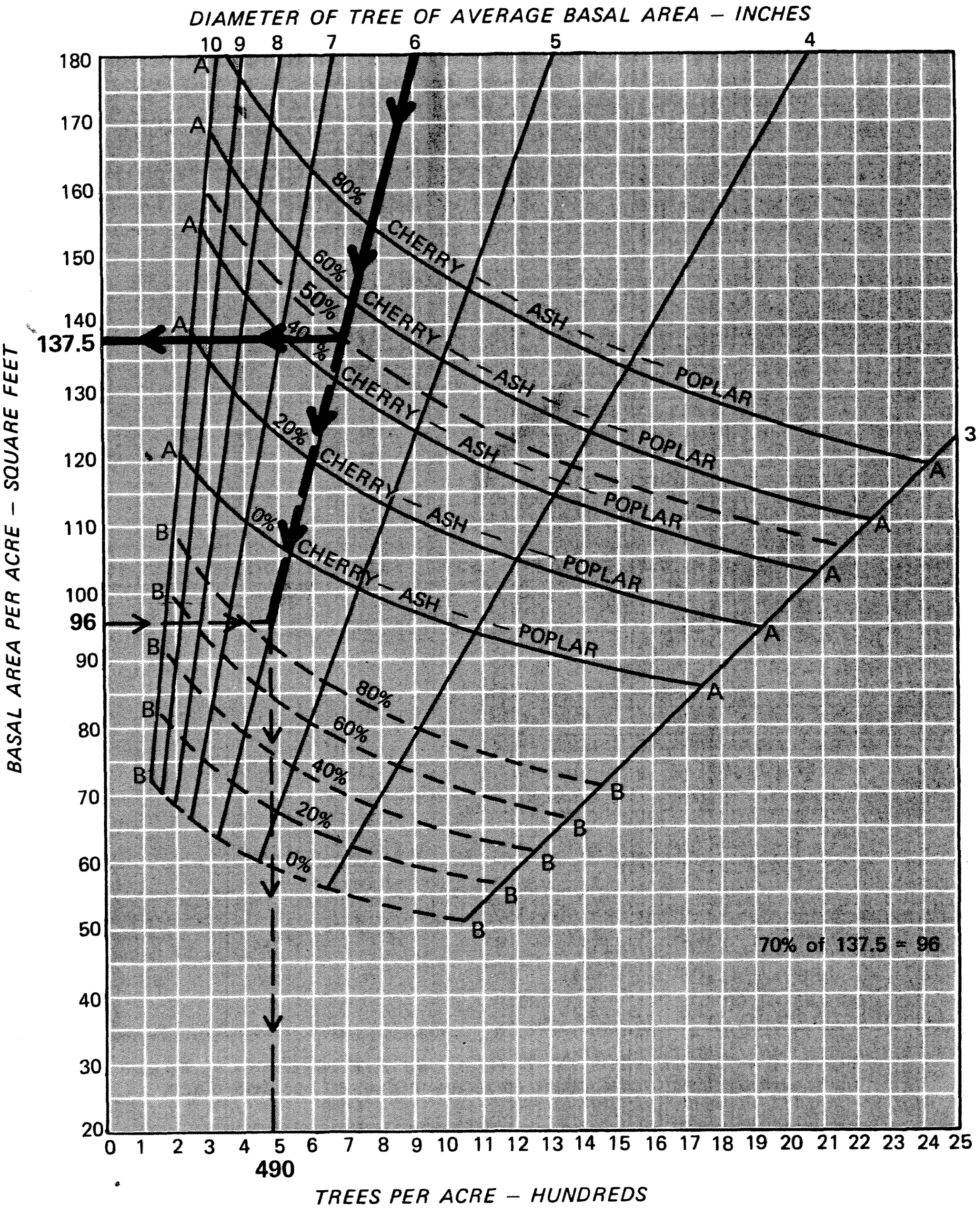
	LARGE SAWT.		SMALL SAWT.		POLES		SAPLINGS	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
Cut Basal Area								

STAND CALCULATIONS

	Trees per acre	Basal Area per acre TOTAL	Basal Area per acre CAPs	Basal Area per acre Other	Percent CAPs	Average Stand Diameter	Basal Area for 100 % Stocking	Stand Stocking Percent
ORIGINAL Stand	900	123	62	61	50	5.0	129	95
RESIDUAL Stand	390	85	43	42	50	6.4		60
CUT Stand	510	38	19	19				35

Figure 8.—Sample stand tally sheet shows number of trees per acre in cut stand and basal-area cut per acre by species group.

Figure 9.—Determining the residual basal area per acre required for any level of stocking.



Kane Exp. For. — UNIT
Cherry-Maple — TYPE OF SPECIES
1/17/75 — DATE
Bl. II, Plot 7, — STAND
10ac. — AREA
54 — AGE

BASAL AREA AND TREE TALLY

Sample Point Number	LARGE SAWT. 17+ CAPs	LARGE SAWT. 17+ Other	SMALL SAWT. 11–16 CAPs	SMALL SAWT. 11–16 Other	POLES 6–10 CAPs	POLES 6–10 Other	SAPLINGS 1–5 CAPs	SAPLINGS 1–5 Other	TREE COUNT 1/20 acre CAPs	TREE COUNT 1/20 acre Other
1			4		4	3	1	1	6	34
2	1		2	1	1	5		5	3	39
3			5		2	4		1	5	43
4			6		3	1		1	7	36
5			3	2	3	3			4	49
6			3		2	4		4	4	39
7			2		2	3	1	4	4	35
8	1		1	3	2	2		5	3	45
9			3	1	3	3			5	41
10			4	1	3	3		1	6	41
11										
12										
13										
14										
15										
TOTAL									47	402
TOTAL per acre	2		33	8	25	31	2	22	94	804
TOTAL per acre	2		41		56		24		898	

DISTRIBUTION OF THE CUT

	LARGE SAWT. CAPs	LARGE SAWT. Other	SMALL SAWT. CAPs	SMALL SAWT. Other	POLES CAPs	POLES Other	SAPLINGS CAPs	SAPLINGS Other
Cut Basal Area			6		11	6	2	13

STAND CALCULATIONS

	Trees per acre	Basal Area per acre TOTAL	Basal Area per acre CAPs	Basal Area per acre Other	Percent CAPs	Average Stand Diameter	Basal Area for 100% Stocking	Stand Stocking Percent
ORIGINAL Stand	900	123	62	61	50	5.0	129	95
RESIDUAL Stand	390	85	43	42	50	6.4		60
CUT Stand	510	38	19	19				

Figue 10.—Sample stand tally sheet shows distribution of cut, by size class and species group, required to leave desired residual stand.

decades—it becomes not a thinning but a highgrading. In that case you should be aware of this difference and at least use correct terminology.

USE OF THE GUIDE IN SELECTION CUTTING

The stocking guide is based on the principle of allocating growing space to the trees in a stand according to size. If every tree in the stand is allotted sufficient space to live and grow, it should make little difference to the tree whether it grows in an even-aged or an uneven-aged stand (except, of course, that the lack of shade tolerance prevents small CAPs from developing or surviving in either one). Therefore the stocking guide should be as useful for controlling selection cutting as it is for controlling even-age thinnings.

The same tally form and procedure may be used; the only differences are in planning the residual stand and distributing the cut.

Selection cutting is designed to maintain a specified diameter distribution in the residual stand, and various distributions are possible. The classic and more commonly used distributions are based on the ratio between the numbers of trees in successive diameter classes. The ratio has been designated as the Q factor and it usually ranges from 1.3 to 1.6.

When a Q and the largest diameter to be grown have been chosen, the number of trees and the basal area per acre can be determined for each diameter class. Then it's a simple matter to calculate by size class the average stand diameter and the basal area that are needed for any *stocking percent.* Table 2 lists a number of possible basal area goals by size class for Q's of 1.3 to 1.6 for several *percent CAPs*, and at two levels of stocking.[4] The maximum tree size in Table 2 is 24 inches.

To use the guide for selection cutting, you need only select an appropriate basal area goal from Table 2 and list it as the residual stand on the stand inventory sheet. In using the same stand that was used in previous examples, I selected a basal-area goal for a residual stocking of 60 percent with 50 percent CAPs and a Q of 1.5 (fig. 11). (Note that the Q selected determines the average diameter for the residual stand.)

The cut stand is determined by subtraction, as before, and a decision is made as to how the cut will be distributed. Because of the shortage of large sawtimber in the stand, it will be desirable to save as much sawtimber as possible, and some excess poles, to make up the deficit.

The distribution of the cut in figure 11 is a little unrealistic; some sawtimber will undoubtedly have to be removed because of defect, risk, poor form, or spacing. But distributing the cut as shown is the closest we can come to attaining the selection distribution in this cutting cycle without reducing yield.

It would have helped if I had selected a higher Q: the higher the Q the more small trees are required in the distribution; also the higher the Q, the smaller the average stand diameter—so the heavier the cut could be and the more of it that could be assigned to the poletimber and sawtimber classes.

Within a few cuts, of course, the *percent CAPs* will decline and the stand will be converted to sugar maple or sugar maple-beech. However the procedure provides a good picture of how the cut must be distributed to work toward a selection-cutting goal. And at any time it should lead to the best growth that the stand is capable of under the selection-cutting system.

PRECAUTIONS

Region of Applicability

Although this guide was developed from sample stands in a relatively small four-county area in northwestern Pennsylvania, I am hopeful that it will be applicable outside this area. The guide seemed to perform well in three areas in New York State; that is, estimates of original and residual stocking obtained from the guide conformed to visual estimates, and there were no obvious discrepancies. Also, the A level for 0 percent CAPs closely parallels the A level developed for northern hardwoods in New England *(Leak, Solomon, and Filip 1969).* The latter shows slightly lower basal areas, but this

[4]Traditionally, Q factors have been used to show the ratio of trees by successive 2-inch diameter classes, and no trees smaller than 5 inches have been considered. This seems like a sloppy way of doing business, so in preparing Table 2 I used the square root of Q to calculate numbers of trees by 1-inch diameter class, and included all trees down to 1 inch in diameter so that the basal area goals would conform to the stocking chart.

Kane Exp. For. — UNIT
Cherry-Maple — TYPE OF SPECIES
4/17/75 — DATE
Bl. II, Plot 7 — STAND
10 ac. — AREA
54 — AGE
BR

BASAL AREA AND TREE TALLY

Sample Point Number	LARGE SAWT. 17+		SMALL SAWT. 11 – 16		POLES 6 – 10		SAPLINGS 1 – 5		TREE COUNT 1/20 acre	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
1			4		4	3	1	1	6	34
2	1		2	1	1	5		5	3	39
3			5		2	4		1	5	43
4			6		3	1		1	7	36
5			3	2	3	3			4	49
6			3		2	4		4	4	39
7			2		2	3	1	4	4	35
8	1		1	3	2	2		5	3	45
9			3	1	3	3			5	41
10			4	1	3	3		1	6	41
11										
12										
13										
14										
15										
TOTAL									47	402
TOTAL per acre	2		33	8	25	31	2	22	94	804
TOTAL per acre	2		41		56		24		898	

NEED: 22 30 25 10

DISTRIBUTION OF THE CUT

	LARGE SAWT.		SMALL SAWT.		POLES		SAPLINGS	
	CAPs	Other	CAPs	Other	CAPs	Other	CAPs	Other
Cut Basal Area					16	6	2	12

STAND CALCULATIONS

	Trees per acre	Basal Area per acre TOTAL	Basal Area per acre CAPs	Basal Area per acre Other	Percent CAPs	Average Stand Diameter	Basal Area for 100 % Stocking	Stand Stocking Percent
ORIGINAL Stand	900	123	62	61	50	5.0	129	95
RESIDUAL Stand	330	87	44	43	50	6.9	144	60
CUT Stand	570	36	18	18				

Figure 11.—Sample stand tally sheet shows distribution of cut by size class for selection cutting.

Table 2.—*Basal-area goals for selection cutting of Allegheny hardwoods*

Q factor	Average stand diameter	CAPs	Diameter class (inches) 1-5	6-10	11-16	17+	Total
	Inches	%	------------ ft²/acre			--------------	
			RESIDUAL STOCKING AT 60 PERCENT				
1.3	9.0	0	4	14	24	29	71
		20	5	16	27	33	81
		40	5	18	30	37	90
1.4	7.8	0	6	17	23	22	68
		20	7	19	26	25	77
		40	7	21	29	28	85
1.5	6.9	0	8	19	22	17	66
		20	9	22	25	19	75
		40	10	24	28	21	83
1.6	6.2	0	10	21	20	13	64
		20	11	24	23	14	72
		40	12	27	25	16	80
			RESIDUAL STOCKING AT 70 PERCENT				
1.3	9.0	0	5	16	27	34	82
		20	5	19	31	39	94
		40	6	21	35	43	105
1.4	7.8	0	7	20	27	26	80
		20	8	22	31	30	91
		40	9	25	34	33	101
1.5	6.9	0	9	22	26	20	77
		20	10	26	29	22	87
		40	11	28	32	25	96
1.6	6.2	0	11	25	24	15	75
		20	13	28	27	17	85
		40	14	31	30	18	93

can be explained in part because it does not include all of the saplings that are covered in the guide for the Allegheny hardwoods. Nevertheless, if the Allegheny guide is used outside the area of its origin, caution and watchfulness are needed.

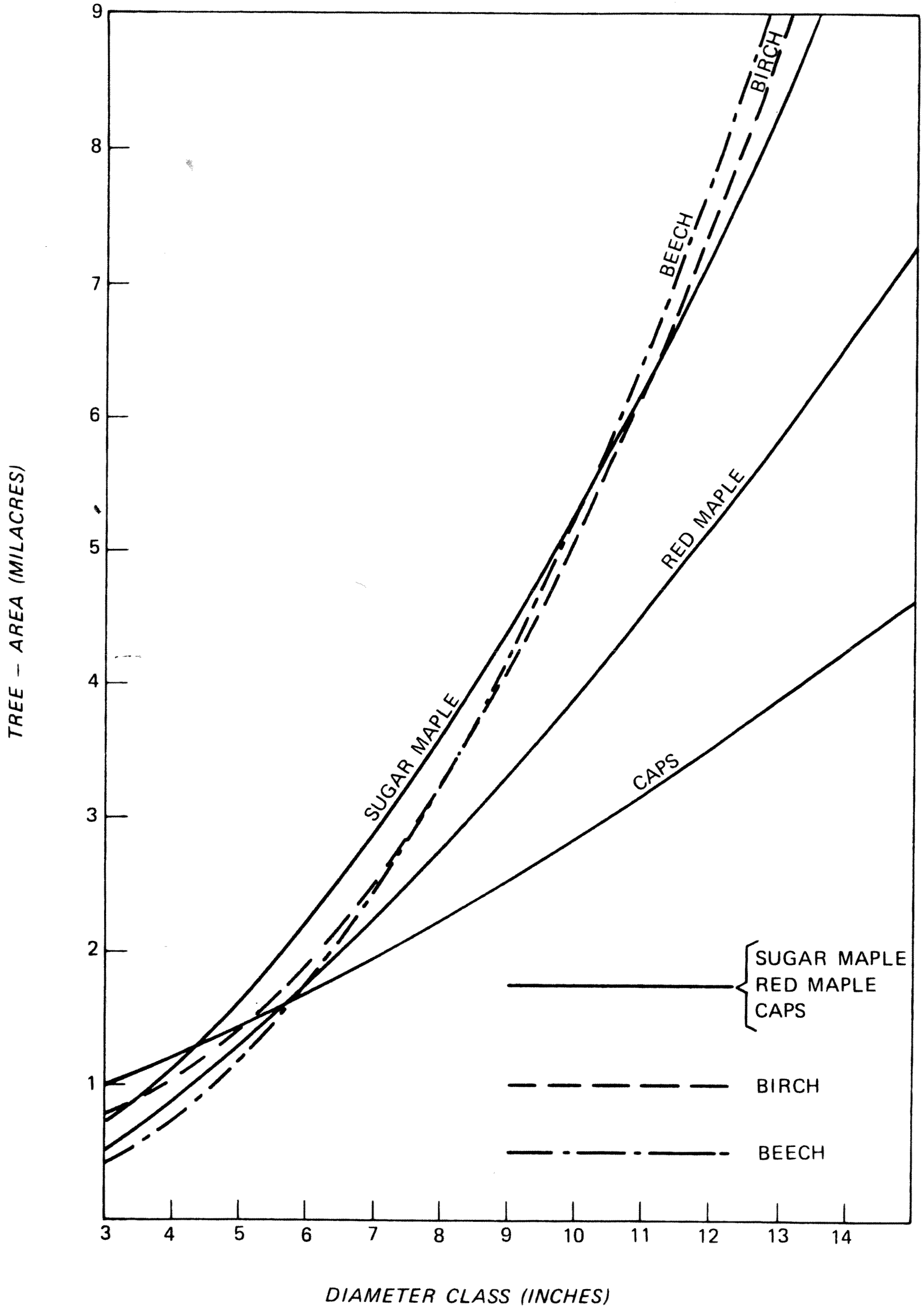
Species Composition

The sample stands that I used had a composition that was fairly typical. Sugar maple, black cherry, and beech were the most common species; red maple and birch ranked next. The stands contained relatively little white ash, yellow-poplar, hemlock, or other species. In fact, there were too few of these trees to treat the species individually in the tree-area equation. My best results were obtained after I lumped ash and poplar with black cherry, and hemlock with "others". This doesn't necessarily mean that ash and poplar have the same requirements for growing space that black cherry has—only that their requirements seem closer to cherry than to the other species. Therefore this guide should be applied cautiously in stands where CAPs are mostly white ash or yellow-poplar.

The same caution applies to stands with a high percentage of conifers. Hemlock, spruce, and other conifers grow in denser stands than cherry; this indicates that they require less growing space at a given diameter. If the guide is used in stands that contain a high proportion of hemlock (10 percent or more), the relative stocking will be overestimated.

Stands that have a large amount of red maple also pose a problem. Using the coefficients obtained from the tree-area equation, I plotted the

Figure 12.—Growing-space allocations for five species groups.



growing-space requirements for the five main species groups. The curves for three of them—beech, sugar maple, and the birches—were very similar (fig. 12); the curve for CAPs was much lower. The curve for red maple fell almost exactly halfway between, so red maple apparently requires more space than the CAPs, but less than beech, birch, and sugar maple.

Ideally, then, it would be desirable to use three species groups rather than two, but this makes the procedure much more complicated. And I don't think the extra precision is worth the effort.

I checked a number of stands with widely different percentages of red maple; I used both the stocking guide and the tree-area equation. Stocking percents were similar for stands that contained up to about 20 percent red maple. (The composition of red maple averaged 15 percent in the 106 sample stands.) In stands that had more than 20 percent red maple, the stocking guide tended to overestimate the *stocking percent.* But there seems to be a relatively simple correction: If the stand contains more than 20 percent red maple, calculate the B level the regular way; then increase it by 1 square foot for every 10 percent of red maple. For example, if the B level is at the 90-square-feet level, and the stand is 40 percent red maple, increase the B level to 94 square feet.

Field Checks on Marking

For either a selection cut or an even-age thinning I strongly recommend that, after marking and before cutting, you make a new stand inventory of the prospective residual stand—at least for the first few stands. If there are serious discrepancies between the planned and the actual stand, you can see what went wrong and correct the marking.

I also recommend that after cutting you make additional checks of stocking. In a short time you will develop the ability to judge relative stocking by eye, which is a great help in marking. After some experience and follow-up checking, I found that I could mark a stand to leave a certain *percent stocking* and usually be within 5 percent. I always make a stand inventory first, and I continue to check myself every chance I get, but it is easier to estimate *stocking percent* than basal area.

Be Sure to Include the Small Trees

It is essential that the understory trees (all saplings 1.0 inch in dbh and larger) be included when using the guide. Failing to do so will result in overestimating stand diameter and underestimating stocking. The B level will then be too high; the amount available for cutting will be reduced; and the real residual stocking will be higher than intended (table 3).

Table 3.—*Effect of excluding smaller trees from basal-area tally on differences in CAPs, diameter, and stocking in residual stand, basal area of permitted cut, and in estimated and actual residual stands*

Item	Minimum dbh included (inches)			
	1.0	1.6	2.6	4.6
Apparent parameters of original stand				
Percent CAPs	48	49	51	58
Average stand diameter (inches)	4.9	5.5	6.7	8.4
Stocking percent	101	96	85	68
Permitted cut				
Basal area (ft^2/acre)	43	40	32	14
Estimated residual stand				
Percent CAPs	50	50	50	50
Average stand diameter (inches)	6.5	7.0	7.7	8.7
Stocking percent	60	60	60	60
Actual residual stand				
Percent CAPs	50	49	47	41
Average stand diameter (inches)	6.5	5.5	4.8	4.7
Stocking percent	60	67	76	93

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