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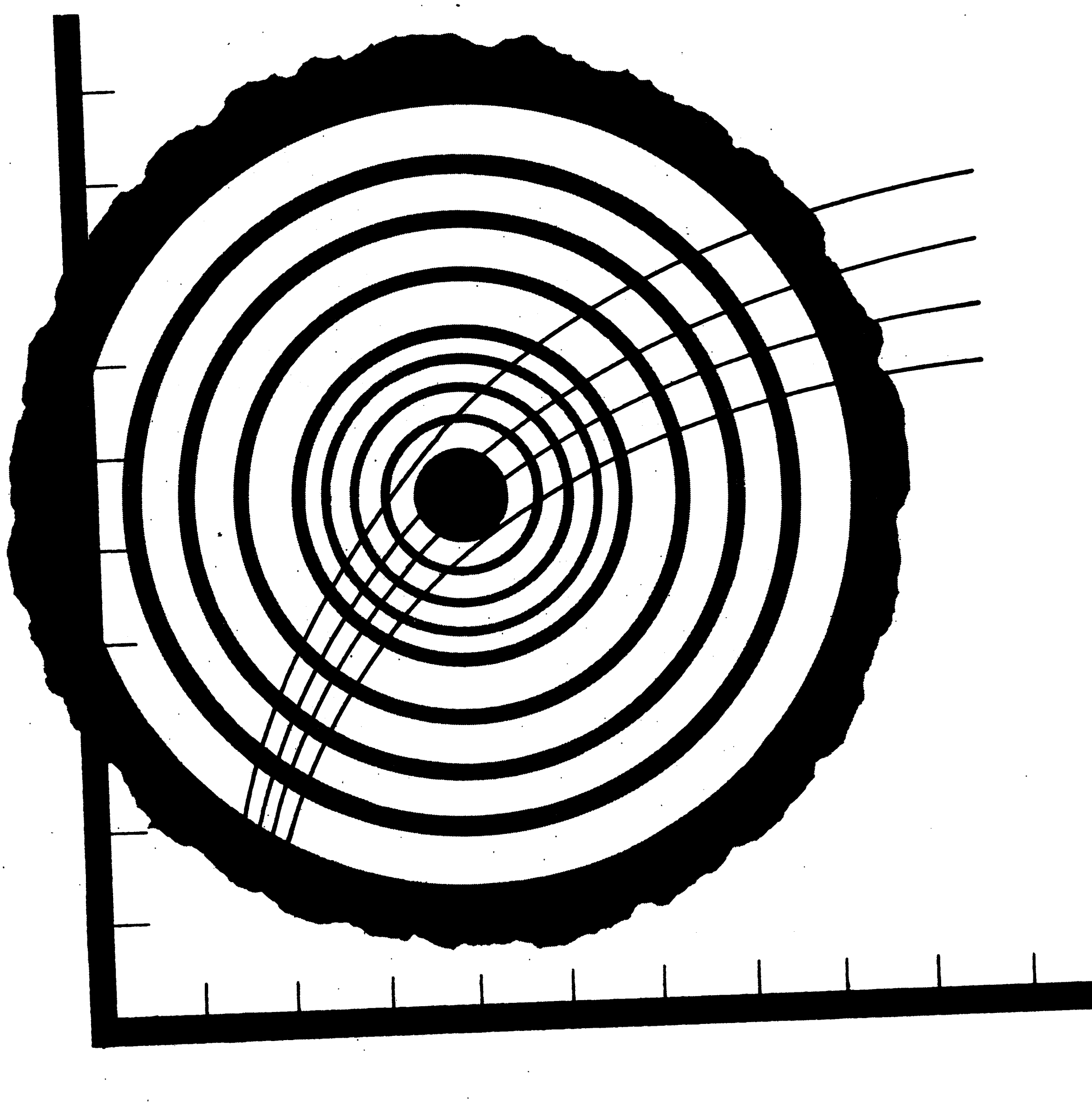

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NORTH CENTRAL FOREST EXPERIMENT STATION
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Manuscript approved for publication November 5, 1973

HARDWOOD LOG QUALITY IN RELATION TO SITE QUALITY

Willard H. Carmean and Stephen G. Boyce

Excellent hardwood sites can quickly produce large yields of high-value veneer and saw logs. Field foresters are usually aware of the general relations between site quality and yield quality, and these relations have been confirmed by a few formal studies (Campbell 1959a, Campbell 1959b, Crow 1962). However, quantitative information is limited, and the reasons for site quality-log quality relations have not yet been well defined.

Site index curves and soil-site methods are available for estimating site quality for many of our eastern hardwoods (Carmean 1970, 1972). Normal yield tables also have been developed for the more common hardwood species, and research now underway will produce yield tables for managed hardwood stands. Thus, both quality of site and the quantity of yield from hardwood forest lands can be estimated. However, we still have no dependable means for estimating the quality of yield produced from different hardwood sites. Knowing only the total yield of fiber may be adequate for pulpwood management, but for valuable hardwood species we must also be able to estimate quantity and quality of veneer and high-grade saw logs that can be produced on different sites.

Hardwood log grades rate logs on the basis of defects, on the diameter and length of the clear log, and on the size and shape of the interior knotty core (Lockard et al. 1963, USDA Forest Service 1965, Vaughan et al. 1966). Relationships between these log features and lumber yield are well established. Less well known is how these same log features are related to hardwood site quality. Damage from insects, disease, and other agents certainly affects log grade, and the grade and amount of clear lumber recovered from logs and trees. Assuming that the occurrence of injury is similar on all sites, the amount of clear lumber is largely dependent upon the length and diameter of the clear bole of standing trees, and on the size and shape of the interior knotty core. These are determined by tree age and by growth patterns for tree height, crown length, and bole diameter.

Tree height and bole diameter growth are in turn closely related to site quality, and crown length and bole diameter growth are closely related to stand density. Accordingly, for a given age the amount of clear lumber in a log is a function of site quality and stand density.

Stand density obviously influences tree diameter growth--this well-known fact is the basis for stocking guides and thinning recommendations. Also well known is that stand density influences crown length--dominant trees in dense stands have shorter crowns, and trees in open stands have longer crowns. The influence of stand density on crown length and tree diameter growth has been illustrated for yellow-poplar trees growing on similar sites over a wide range of stand densities (Holsoe 1950). Stem analyses illustrated how stand density was related to live crown length, clear bole length, tree diameter growth, and size and shape of the knotty core.

Holsoe's yellow-poplar study used trees growing on areas of similar site quality so as to better study relations between stand density and bole development. Thus the relation between site quality and bole development has yet to be illustrated. Accordingly, for similar stand densities (fully stocked stands) we will illustrate how site quality determines total height growth which, in turn, determines length of live crown, clear bole length, and size and shape of the knotty core.

The site quality-log quality model we use is based upon research, experience, and some logical assumptions. We hope this model will be a useful hypothesis for future studies concerned with those portions of the model where knowledge is now deficient.

SITE QUALITY AND LENGTH OF THE CLEAR BOLE

Site index curves for four species of upland oaks in the Central States describe the variable height-growth patterns for dominant and codominant trees growing on different sites (Carmean 1972). These new site curves, based on stem analyses, reveal that black oaks on good sites have height-growth patterns different from those on poor sites (fig. 1). On good sites (better than site index 70) early height growth for black oak is very rapid; this early height growth surge continues for 20 to 30 years. In contrast, trees on poor sites (less than site index 60) have much slower early height growth. These different patterns of early height growth are crucial because ultimate log quality is largely determined by the height and diameter growth achieved during these formative years.

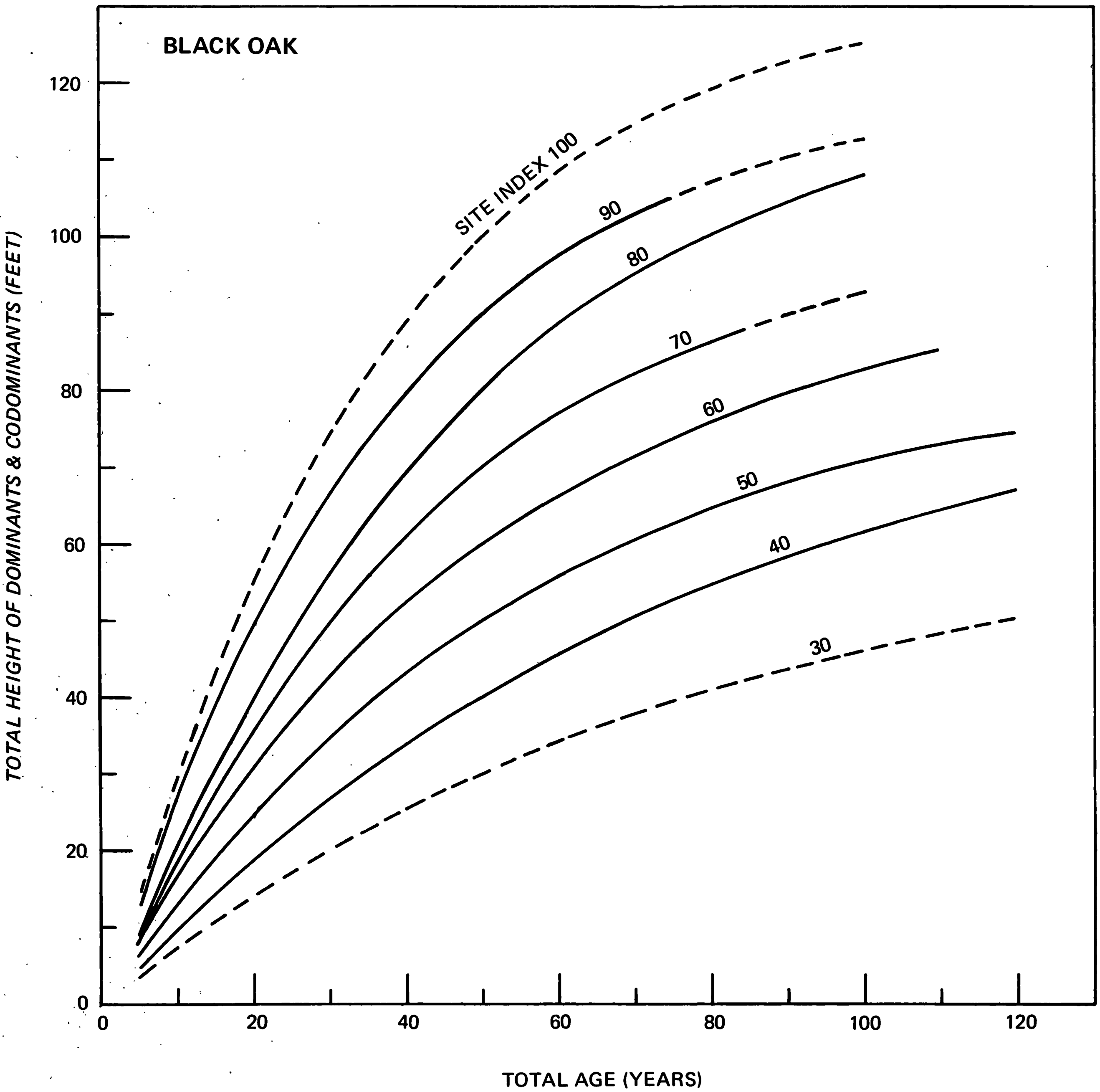

Figure 1.--*Site index curves for black oak in the Central States. These site curves are based on stem analysis data from 300 dominant and co-dominant black oaks growing in the unglaciated portions of Ohio, Kentucky, Indiana, Illinois, and Missouri (Carmean 1972).*

Dominant and codominant trees in even-aged, well-stocked upland oak forests are assumed to have clear bole lengths constituting about one-third of the total tree height. The upper two-thirds of the stem includes live crown, dead limb stubs, and limb scars not yet healed. In well-stocked stands the length of the live crown and persistence of dead stubs may vary depending upon tree age, species, crown class, site quality, and stand history; however, a clear bole length of about one-third total tree height characterizes red oak trees growing in well-stocked, even-aged stands in Massachusetts and Pennsylvania (Holsoe 1947, Patton 1922, Ward 1964). Yellow-poplar in well-stocked stands also have clear bole lengths varying between one-third and two-fifths of total tree height (Holsoe 1950).

Curves showing when clear boles emerge on different sites (fig. 2) for dominant and codominant black oaks in well-stocked, even-aged stands were calculated merely by reducing the new black oak site index curves by two-thirds. Development of clear boles on contrasting sites can be illustrated as follows: for site index 90 a dominant black oak in an even-aged, well-stocked stand will be about 58-feet tall at 25 years (fig. 1). Assuming the clear bole length is one-third of total tree height, the lower 19 feet of this tree should be free of live limbs and dead branch stubs (fig. 2). At 70 years this tree will be about 103-feet tall and probably will have a clear bole of 34 feet. Thus, at 25 years, this superior-site tree already has produced a 19-foot clear bole; at 70 years it has a 34-foot clear bole—more than two log lengths. In contrast, a site index 50 black oak will only be about 30-feet tall at 25 years of age, and only the lower 10 feet will be free of live limbs and branch stubs; at 70 years it will be only about 60-feet tall, and will have produced only a 20-foot clear bole (figs. 1 and 2).

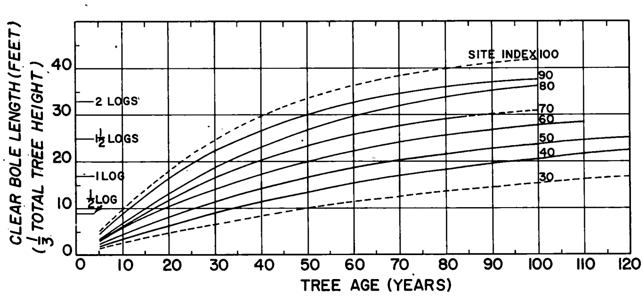

Figure 2.--*Curves showing the development of clear boles for dominant and codominant black oaks growing in even-aged, well-stocked stands differing in site quality. Clear bole lengths are assumed to be one-third of total tree height.*

The curves in figure 3, adapted from figure 2, show the years required for clear boles of 9, 13, 17, 25, and 33 feet to naturally emerge from the crowns of dominant and codominant black oaks growing on different sites. The 17-foot clear bole (one clear log) first appears at about 19 years on extremely good sites (site index 100). This same clear log length appears at about 21, 27, 31, 39, 52, and 71 years for site indices 90, 80, 70, 60, 50, and 40 feet, respectively. Only the best sites can naturally produce trees having a 33-foot clear bole (two clear logs). A 33-foot clear bole first appears at about 49 years on site index 100 lands; this same clear log length

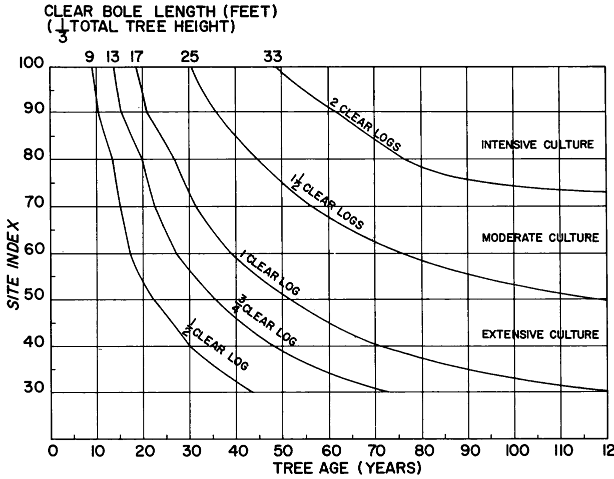

Figure 3.--*Estimated time required for clear boles (one-third total height) of 9, 13, 17, 25, and 33 feet to naturally emerge from the crowns of dominant and codominant black oaks growing in even-aged, well-stocked stands on different sites.*

appears at 62 and 76 years for sites indices 90 and 80, respectively. Black oak site indices 70 and poorer will seldom naturally produce clear two-log boles.

Figures 2 and 3 are for dominant and codominant black oaks growing in fully stocked stands. When accurate site index curves are available, similar curves could be constructed for other species, or for shorter clear bole lengths that may naturally occur in stands less dense than the fully stocked stands used in our model. Furthermore, pruning to perhaps half total tree height might be recommended for certain intensively managed stands (Skilling 1958, Clark and Seidel 1961). For these stands curves showing when dominant and codominant trees could be pruned could be constructed merely by reducing site index curves by half. For example, black oaks could be pruned to 17 feet at 12, 23, and 41 years in stands having site indices of 90, 60, and 40, respectively (fig. 1).

The clear bole relationships portrayed in figures 2 and 3 also can be summarized to show when clear boles naturally appear in well-stocked stands, or when they might be produced by pruning on different forest sites (table 1). This summary lists years required to produce 17-foot and 33-foot clear boles on five different site classes. Similar tables also could be calculated for other site classes, log lengths, or other ratios of clear bole to total height.

Table 1.--*Estimated age at which clear boles of different lengths appear naturally or can be produced by pruning dominant and codominant black oaks growing on different sites*

(In years)

Site quality for black oak (site index)	Clear bole length natural[1/]		Clear bole length pruning[2/]	
	17 feet	33 feet	17 feet	33 feet
Superior sites (>80)	<27	<76	<17	<38
Good sites (71 to 80)	27-31	([3/])	17-19	38-47
Medium sites (61 to 70)	31-39	([3/])	19-21	47-61
Poor sites (51 to 60)	39-52	([3/])	21-28	61-86
Very poor sites (<51)	>52	([3/])	>28	([3/])

1/ Clear bole length assumed to be 1/3 total tree height in well-stocked, even-aged stands.

2/ Pruning to one-half total tree height.

3/ Clear boles can seldom be achieved on these sites.

SITE QUALITY AND THE KNOTTY CORE

Maximum yields of high-grade lumber and veneer are obtained from logs having large amounts of clear wood outside a small, knotty core. Log grades specify that the knotty core of a Grade 1 saw log should have a radius no larger than one-fifth the inside diameter of the small end of the log (Lockard et al. 1963, Vaughan et al. 1966). For example, a Grade 1 saw log 16-inches d.b.h. and 13-inches d.i.b. at 17 feet should have a knotty core no larger than 5.2 inches at 17 feet. Of course, as the diameter of the log increases, the allowable size of the knotty core also increases. Thus a Grade 1 saw log 23-inches d.b.h. and 20-inches d.i.b. at 17 feet should have a knotty core no larger than 8.0 inches in diameter at 17 feet.

These examples show that relatively small logs can qualify as veneer and first-grade logs as long as the knotty core is small. On good sites clear boles rapidly emerge, thus boles have small knotty cores, and high-quality logs can be produced at early ages even though logs may be relatively small in diameter. Furthermore, early thinning and pruning on good sites will produce both larger diameters and smaller knotty cores; as a result, high-quality logs can be produced using short rotations. In contrast, trees on poor sites have short boles, large knotty cores, and slow diameter growth. On these sites logs must be large in diameter before they can qualify as veneer or first grade. Producing large logs on poor sites requires long rotations and thus added interest on management investments.

The knotty core begins at the base of the tree and increases in diameter with increased distance from the ground (fig. 4). In effect, the knotty core in the butt log has the shape of an inverted cone with its apex at the base of the tree (Boyce 1966, Holsoe 1947, 1950). In the lower part of the bole the knotty core slowly increases in diameter with increased height because both tree height growth and the upward movement of the base of the live crown proceed at a rapid and almost linear rate. In the upper part of the bole the knotty core expands more rapidly because of slowed height growth and slowed upward movement of the live crown. Eventually the knotty core emerges at the bole surface where dead limb stubs still persist.

The early formation of the cone-shaped knotty core and the clear wood is illustrated for each of the first 7 years of tree growth (fig. 5). This tree grows 3 feet in height per year, thus the length of clear bole moves upward 1 foot per year,

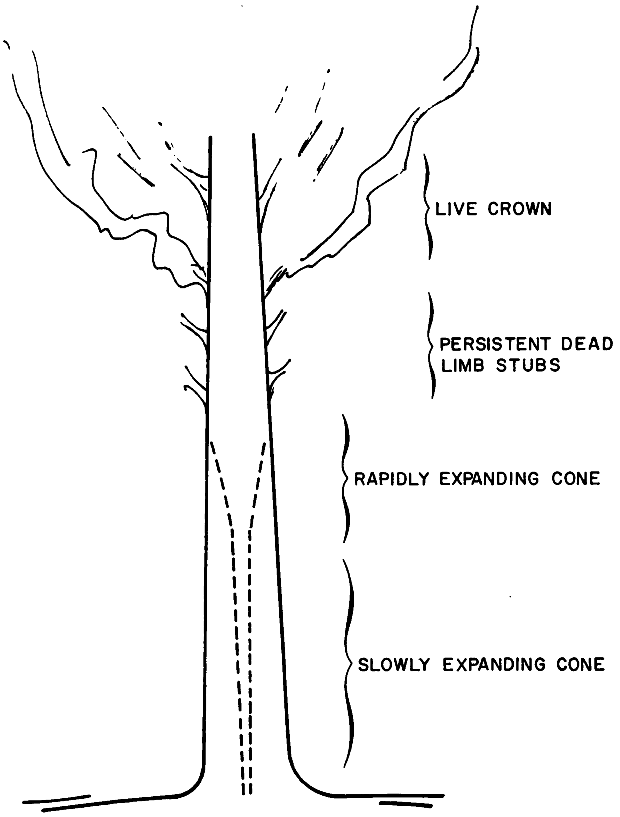

Figure 4.--*The knotty core is shaped like a slowly expanding inverted cone in early years when tree height growth is rapid. In later years height growth slows, the base of the live crown moves upward more slowly, and the knotty core is shaped like a rapidly expanding inverted cone. Eventually the knotty core emerges at the base of the crown where persistent dead limb stubs occur.*

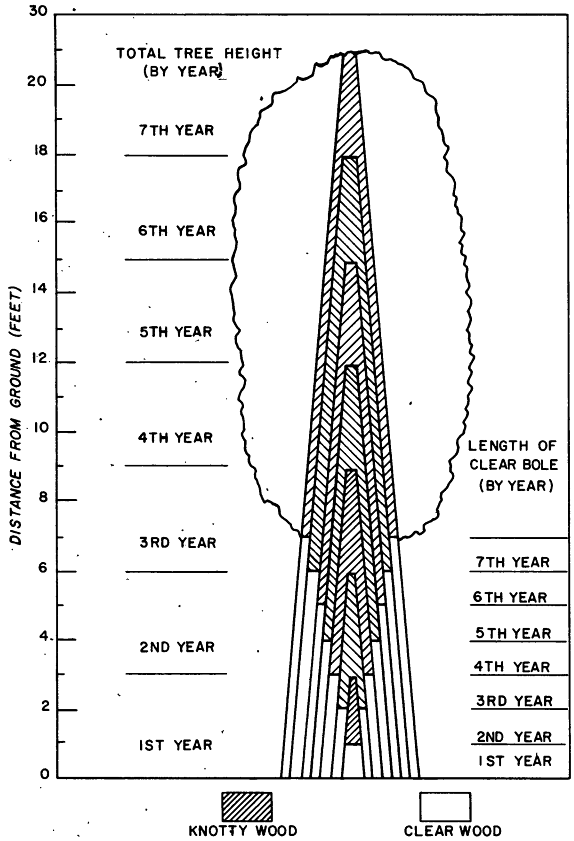

Figure 5.--*Schematic diagram showing the first 7 years of tree-height growth, the clear wood formed on the lower one-third of the bole after healing of the dead limb stubs, and the knotty core formed while live limbs and dead limb stubs are on the upper two-thirds of the bole.*

assuming that each year the clear stem is one-third of total tree height.

Dimensions of the knotty core, as well as the bole itself, can be estimated if we know tree age, annual height growth, annual diameter growth, and number of knotty rings. Annual height growth can be estimated from site index curves (fig. 1), and tree age and annual diameter growth can be estimated from increment cores. The number of knotty rings at any point on the bole can be estimated as follows:

$$\begin{array}{c}\text{Knotty rings}\\\text{at a given}\\\text{point on the}\\\text{bole}\end{array} = \left(\begin{array}{c}\text{Years for clear}\\\text{bole to emerge}\\\text{at the given}\\\text{point}\end{array}\right) - \left(\begin{array}{c}\text{Years for tip}\\\text{of tree to}\\\text{reach the}\\\text{given point}\end{array}\right)$$

For example, we can estimate the number of knotty rings at 7 feet from the ground for the schematic tree (fig. 5). For this tree the clear bole annually moves 1 foot upward, hence 7 years is required for the clear bole to emerge at 7 feet; the tree annually grows 3 feet in total height, hence 3 years is required for the tip of the tree to reach 7 feet. Accordingly, four knotty rings occur at 7 feet.

The black oak site index curves (fig. 1) can be used with the above formula to estimate the dimensions of butt logs and knotty cores when 17-foot clear logs first emerge on good and poor sites (table 2). If clear bole length is one-third total tree height, dominant trees on both site index 80 and site index 40 lands will be about 51-feet tall when a 17-foot clear bole emerges. But the rapidly growing site index 80 tree will reach 51 feet and produce a clear 17-foot bole in only 27 years, while an estimated 72 years will be needed for the site index 40 tree to reach 51 feet (fig. 1). The tip of the site index 80 tree reaches 17 feet in only 9 years; 18 years are needed for the slower growing site index 40 tree to reach 17 feet (fig. 1). Using the formula, at 17 feet the site index 80 tree is estimated to have 18 knotty rings, and the site index 40 tree 54 knotty rings.

Table 2.--*Estimated dimensions of butt logs and knotty cores when 17-foot clear logs first emerge on good and poor black oak sites. These estimates are for dominant and codominant black oaks growing in even-aged, well-stocked stands*

Item	Site index 80	Site index 40
Tree height when 17-foot clear bole appears (feet)[1]	51	51
Years for clear bole to emerge at 17 feet	27	72
Years for tip of tree to reach 17 feet	9	18
Number of knotty rings at 17 feet	18	54
Assumed average annual diameter growth (inches per year)	0.5	0.25
Estimated knotty core diameter at 17 feet (inches)	9.0	13.5
Estimated log diameter at 1 foot (inches)	13.5	18.0

[1] Assuming a clear bole length that is one-third total tree height.

Dimensions of the knotty core and of the butt log itself can now be estimated if the annual diameter growth rate is known. Assuming that the site index 80 tree has an even annual diameter growth rate of 0.5 inches in all portions of the butt log, then the 18 knotty rings at 17 feet have produced an upper log diameter of 9.0 inches (18 x 0.5). This knotty core emerges at the surface at the upper end of the log, but at the 1-foot stump height the knotty core tapers into the pith, and the log diameter is estimated to be 13.5 inches (27 x 0.5) for this 27-year-old tree. Assuming that the site index 40 tree only grows 0.25 inches in diameter per year, we then estimate that the 54 knotty rings at 17 feet have produced an upper log diameter of 13.5 inches (54 x 0.25); at 1 foot this knotty core tapers into the pith, and the diameter is estimated to be 18.0 inches (72 x 0.25) for this 72-year-old tree.

The final step is to calculate the additional time required for the butt log of the site index 80 tree to reach the same size as the site index 40 butt log. If we assume that diameter growth on the good site continues at 0.5 inches per year, then only about 9 additional years will be needed for the 13.5-inch site index 80 tree to reach the same 18.0-inch diameter as the site index 40 tree [(18.0 - 13.5)/0.5]. At 17 feet this tree probably would grow an additional 4.5 inches in 9 years, and thus have the same 13.5-inch diameter as that of the site index 40 tree.

These calculations illustrate that the good site produced an 18-inch log in only 36 years (27 + 9), while the poor site required 72 years to produce the same size log. Furthermore, the good-site log is better because at 17-feet the small knotty core is surrounded by a 2-1/4-inch thick sheaf of clear wood; for the poor site log the 13.5-inch knotty core emerges at the surface of the upper end of the 17-foot log.

This model illustrates that the patterns of both height and diameter growth in the early formative years largely determine clear bole length, log diameter, and the size and shape of the knotty core. This model also shows how tree height and diameter growth data can be used to estimate the dimensions of the knotty core and of the log itself. Tree height-growth values used in this model were taken from detailed stem analyses of black oak (fig. 1). However, for illustrative purposes, clear bole length was assumed as one-third of total tree height, and an even diameter growth was assumed for all portions of the log. The precision of this model could be improved by studies that better define diameter growth and clear bole length for different sites, stand densities, tree ages, crown classes, and tree species.

SILVICULTURAL IMPLICATIONS

This model is based upon dominant and codominant trees that achieve maximum, uninterrupted height growth (fig. 1). Such rapid-growing trees are most commonly found in even-aged stands. In addition, even-aged stands on good sites have greater numbers of valued intolerant species, such as yellow-poplar, white ash, black cherry, and black walnut. Accordingly, even-aged silviculture has been recommended as the best means to grow high-quality upland hardwoods(Roach and Gingrich 1968).

Hardwood forest management of the future will require more precise identification of site quality. On the best sites very intensive silviculture might be applied, including planting of superior genotypes and cultural practices approaching those used in agriculture and management of orchards. To produce the greatest volume of high-grade veneer and saw logs in the shortest time, we should concentrate our efforts on selected crop trees on the better sites. And then we should concentrate on the butt log, because this is the portion of the tree where the best grades of lumber and veneer can be produced; also, reducing the number of defects in the butt log will result in the greatest gains in log quality and log value (Boyce 1966, Boyce and Schroeder 1963, Allen 1964). For high-grade dominant and codominant trees the goal should be early formation of clear butt logs having small knotty cores surrounded by thick sheafs of rapidly growing clear wood.

High-quality upper logs can occasionally be produced on superior sites (site index 80+) because of very rapid early height growth (figs. 2 and 3). However, developing second logs into Grade 1 saw logs will mean longer rotations, because more years are required for the second logs to reach minimum scaling diameter. During the development of the Forest Service Standard Hardwood Saw Log Grades, it was found that butt logs had much more high-grade lumber than upper logs because diameters were larger, knotty cores smaller, knots fewer, and the proportion of clear wood to knotty wood larger (Vaughan et al. 1966).

Pruning selected crop trees on good sites (site index 70+) should be considered (Allen 1964, Boyce 1966, Clark and Seidel 1961, Crow 1962, Skilling 1958, Stern 1971). Species such as black walnut, cherry, white ash, and yellow-poplar should be given first consideration. Selected Grade 1 crop trees (Boyce and Carpenter 1968) of white, red, and black oak also might be profitably pruned on the better sites. Crop trees should be pruned to perhaps one-half total tree height when they are young (less than 25 years) so that knotty cores will be small and long, clear boles will be formed early. On superior sites (site index 80+) pruning selected black oaks to one-half total height can produce 17-foot clear boles in 17 years or less, and 33-foot clear boles in 38 years or less.

As soon as the clear butt log has been formed, stand density should be reduced to produce maximum diameter growth. Stand densities at or somewhat below the lower limit of full site utilization are recommended—this corresponds to the "B level" of stocking recommended by Roach and Gingrich (1968). Frequent thinning is recommended on superior sites (site index 80+) so that maximum diameter growth can be maintained on the selected crop trees. Occasional thinning is recommended for good (site index 70 to 80) and medium sites (site index 60 to 70). Thinning and other silvicultural treatments are not recommended for poor sites (site index 60-) because it is unlikely that trees on such sites will repay cultural investments for growing quality saw logs. However, initial rapid growth does produce limited amounts of pulp and fiber on poor sites, so possibly short rotations for these less valuable products is the best management goal.

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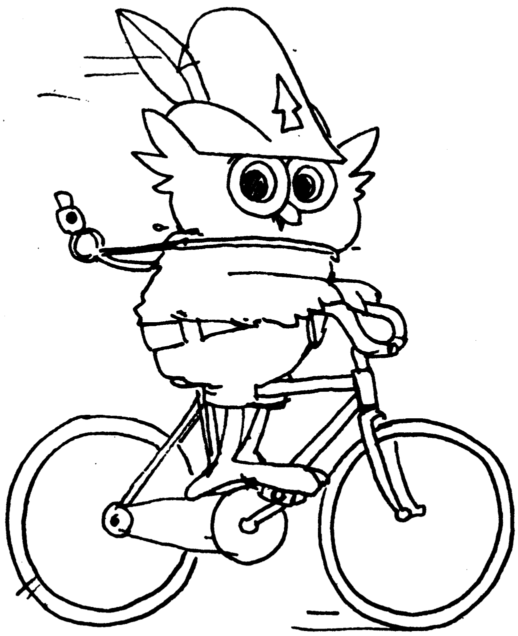

More bicycles and shoe leather...less smog.