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The Application of Silviculture in Controlling The Specific Gravity of Wood

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The Application of Silviculture in Controlling the Specific Gravity of Wood

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(Mr. Paul retired December 31, 1959. The Laboratory is maintained by the U.S. Department of Agriculture in cooperation with the University of Wisconsin at Madison)

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INTRODUCTION

A number of environmental factors appear to influence the growth of trees and certain standard characteristics related to wood quality. These factors may be interacting so that the direct specific influence of one or another is not obvious. However, the combined effect of several factors of a particular environment may be indicated by amount of annual growth (ring width), by proportional amounts of springwood and summerwood, or by specific gravity (density).

Sometimes the relationship of ring width to specific gravity for a given species is sufficiently clear to warrant rather definite quality evaluations, but more often this relationship varies during the life of the stand. Because of this variation, a history of environmental changes must be considered (*50*).[1] It has become very important, therefore, to learn what conditions of growth influence wood properties most noticeably and to find out how silvicultural practices can improve wood quality (*38*).

This bulletin contains the results of studies conducted at the Forest Products Laboratory that reveal the great variability in wood quality as indicated by specific gravity determinations and other tests. It also explains how, within natural limits, the quality of wood can be improved through the art of silviculture.

HISTORY

Research relating to tree growth and wood properties was begun in Europe nearly a century ago. Among the more important early investigations, the works of Robert Hartig (*17*, *18*, *19*, *20*) are preeminent. Working with both broad-leaved and coniferous species, he sought to determine the influence of climate and of soil fertility upon the weight of dry wood. He also studied the relations between the rate of growth of trees in diameter and the resulting specific gravity of the wood produced.

After a great many experiments, Hartig formulated his conclusions into a system which he termed the nourishment theory (Ernährungs Theorie) (*18*). In this theory, he held that the specific gravity of wood is dependent upon the relationships of soil fertility, transpiration of water by the tree crown, and assimilation. He asserted that the anatomical structure of wood conforms to the needs of the tree as influenced by external conditions and that the quantity of the growth depends upon the total amount of foliage and upon the assimilative energy of the leaves, which is affected by the quality of the soil, the sunlight, and the temperature. Furthermore, the specific gravity of wood is influenced by the proportional quantity of conducting tissue to supporting tissue. The greater the transpiration as compared with the production of wood substance, the greater the amount of porous tissue formed and the lighter the wood. Therefore, heavier wood results when the most abundant assimilation possible accompanies a normal transpiration.

[1] Italic numbers in parentheses refer to "Literature Cited," p. 93.

The large number of factors included in Hartig's nourishment theory makes it difficult to state which factor or factors may be most important in controlling wood quality. In discussing the weight and structure of wood, Busgen (*6*), probably on account of this uncertainty of factors, gives little credit to the results of research by Hartig, Sanio (*69*), and Bertog (*4*). He summarizes the "present state of experimental research on the influence of external conditions upon wood structure" by saying: "In this direction but little has been done, although attention has for a long time been directed toward the dependence of anatomical relations upon environment."

The works of other early investigators had a much more restricted scope than the research of Hartig. Ciesler (*8*) found that spruce grown in the optimum of its natural habitat showed higher lignin content than that grown in locations outside its natural limits of distribution. Later (*9*) he investigated the properties of rapidly grown spruce in contrast with slowly grown spruce, basing his study upon a comparison of wood from two stands. A dominant, a codominant, and a suppressed tree were selected from each stand. In both stands, he found that the more rapidly growing dominant spruce trees produced wood lower in specific gravity than did the codominant trees. In one stand, however, the suppressed tree produced wood of high specific gravity, while in the other the wood was about the same weight as that of the dominant trees. He found that the higher specific gravity figures corresponded to the wood that contained a greater proportion of summerwood in the annual rings. The results of this work agree with Hartig's ideas that differences occur in the quality of the wood in the same stand, and yet it cannot be said that either the larger or the smaller trees produce the better wood.

Janka (*9*) made additional investigations upon the hardness of the wood in the same trees studied by Ciesler. His work showed that spruce wood of rapid growth was softer than that of the slower or more normal growth. In investigating the quality of larch wood (*23*), he could find no relation between the rate of growth and the specific gravity, but he was able to show that the weight depended upon the relative proportion of summerwood in the annual rings.

During the past decades many investigators have worked in the field of variability of wood and have sought to attribute it to one or more factors of growth and environment. An exhaustive review of such literature is not possible here, but the works of several researchers are mentioned briefly. More recent works that deal wholly or in part with the application of silviculture in controlling the specific gravity of wood are mentioned, together with an indication of some of the important results obtained.

Beginning with white pine, Burger made a long series of investigations under the subject "Wood, Leaf Quantity, and Growth." In his first report (*5*), he showed a higher percentage of needles by weight in young trees (20 years old) than in trees of greater age up to 70 years. In the same trees, the specific gravity of the wood increased from the pith toward the periphery. The heavier wood was not found in trees growing alone or in trees with weakly developed crowns, but it was present in trees occupying an intermediate position between the two extremes. The higher proportion of needles in the young trees and the lower wood density at that age, as well as in older isolated trees or in those with weak crowns, indicates an optimum specific gravity wood relationship for trees with an intermediate crown position.

Trendelenburg (*73*) explained specific gravity variations in conifers by differentiating between crown- and stem-formed wood in the cross sections and longitudinal sections of intermediate trees. The crown-formed, low-density wood was formed at a time when the active crown was in close proximity to the cambial areas of growth.

In a study of spruce and balsam fir (*16*), Hale and Prince in eastern Canada showed that the trees from rapidly growing stands produced lighter wood than the more slowly growing trees. The trees of smaller size, however, produced less weight of wood per unit of basal area of the stem than the more rapidly grown trees. No data were presented to show yield in wood weight per acre per year. In a comparison of stands, the wood tended to be of higher density when the rate of growth was slow.

On the other hand, Turnbull (*74*), reporting on pine plantations in South Africa, concluded that the density of wood in a particular year is not determined by ring width, but rather that it is proportional to a function of age. Accordingly, a rapidly grown central core of low-density wood will provide a greater surface for later laying on of a heavier zone. Turnbull found that this combination produced the largest volume of individual stems in a 30-year rotation when following the silvicultural recommendations of Craib (*10*). More recently, Scott and MacGregor (*70*) assessed the features and values of rapidly grown wood in coniferous plantations by saying that the number of annual rings per inch alone is not an adequate or safe index of wood quality, but along with other factors, such as specific gravity, percent of summerwood, ring age, and position in the tree, the annual rings per inch are a useful index.

In British Columbia, Wellwood (*76*) found dominant Douglas-fir trees in second-growth stands to have significantly lower specific gravity values than the codominant or the intermediate trees, which showed no significant differences. He found also that the trees on good sites had significantly lower specific gravity values than those on average sites, but on good sites the crown classes showed no significant differences. By regulating the growth within limits, Wellwood concluded that the forester could produce wood of the desired quality.

Chalk (*7*) in Great Britain reported that the wood in the individual growth rings of a very fast-grown Douglas-fir stem 19 years old with an almost constant ring width of about one-third inch had a uniform density from pith to bark, without an increase outward as was reported by Turnbull for fast-grown South African pines. More slowly grown material with about $1/10$-inch-wide rings gave similar results. Chalk found no general relation between density and ring width, but the highest densities occurred in rings less than 6 millimeters in width and at the outside of a tree with access to river water.

Spurr and Hsiung (*72*), after a rather exhaustive review, said that the many papers written over the past century on the effect of growth conditions or the specific gravity of conifers are in basic agreement when such factors as age and position of the tree are taken into consideration. They placed great confidence in the effect of age when specific gravity increases progressively in young trees but did not explain specific gravity decreases that occur later. They credited major differences in site quality but depreciated the influence of ring width on specific gravity and questioned the economics of its control. Moreover, they omitted consideration of wide-ringed juvenile wood with its relatively low strength, excessive longitudinal shrinkage, and low pulp yield. They ended their review by pointing out that the highest rate of growth commensurable with good form, small knots, natural pruning, and other silvicultural considerations is desirable and should give a maximum of high-grade lumber.

Hildebrandt (*21*), studying specific gravity of spruce in Europe, found two kinds of relationships between age and specific gravity: (1) A regular increase in specific gravity from the first decade on, and (2) an initially high specific gravity that declined to a minimum value in about 30 years, after which the initial specific gravity was attained again about 40 years later. He attributed individual differences in single trees to variable growing conditions and observed that "a generalization to the effect of increase in specific gravity with age is not possible."

Iablokoff (*22*) attributed the unfavorable quality of wide-ringed ligneous material to a relationship between cambial activity and certain hormonal secretions from the buds. This relationship, he said, is influenced by excessive crown volume that causes a break in the equilibrium of cell formation and a resulting disorganization of the wood structure. He called this a new hypothesis on the mechanism of wood formation.

Penistan (*63*) summed up a prescription for wood quality as: Careful choice of species; thinning to concentrate growth on the finest stems, not the largest ones; and control of early ring width by raising new crops in side shade whenever possible.

Ziegler (*81*) expects a large variation in the correlation of wood characteristics and site, unless other dependent quality characteristics interact to bring about a correspondingly smaller variation.

Rendle and Phillips (*68*), in a comparison of wood formed later, showed that the older wood is invariably denser, indicating that the higher density of the older wood is an age effect rather than a diminishing of ring width. This confirms Turnbull's findings on widely spaced softwood in South Africa, which could be applied in Great Britain where rapid growth can be maintained.

Fry and Chalk (*14*), after an investigation of 13-year-old trees of *Pinus patula*, concluded that their results did not show that specific gravity variation is determined by either (*a*) ring width or (*b*) age from the pith, but rather that both factors operate simultaneously. They did not recommend a general acceptance of their results because the springwood in the young trees with which they worked was of unusually high density and large differences between springwood and summerwood were lacking.

Von Pechmann (*62*) says that the characteristics of wood structure are not only a natural product but are influenced by silvicultural practices. In spruce, he contends, restriction of growth at the younger ages must be considered if one desires to obtain compact, dense, strong wood with few knots by methods of natural regeneration over a long period of time. In pine, the possibility exists of increasing the proportions of high-quality wood by limiting branching. Stems grown under shade present the best results.

The gross specific gravity of Douglas-fir in Germany was reported by Knigge (*24*) to decrease similarly for increasing and decreasing ring width from a maximum ring width of 2 millimeters. These relationships correspond to those between annual ring width and the proportion of summerwood. He found them to be statistically more significant than the relation of specific gravity to age or the position of the sample in the trunk. After mathematically excluding the influence of annual ring width on the change in specific gravity, an increase in specific gravity with increasing age (contrary to Turnbull and others) could no longer be detected.

Göhre (*15*) said that in the literature of well-known research workers the influence of locality and region of growth on the specific gravity of trees is judged very differently and that some of their conclusions show considerable contradiction. The specific gravity values in individual trees of Douglas-fir, pine, beech, and poplars vary greatly. Mathematical and statistical comparisons of individual trees in the same locality give such a large number of significantly differing values that differences between trees of different localities are unimportant.

In discussing wood density, Anderson (*3*) states that the minimal number of rings per inch should be 10 for conifers, the ideal being 15 to 20, say 16 rings. This agrees well with Knigge who found that best ring width for Douglas-fir in Germany is approximately 12 to the inch. Anderson says that it is advisable to crowd a stand when it is young and to open it up gradually so that no wide rings are ever formed in the trees. In speaking of ring-porous hardwoods, like oak and ash, he states that the wider the ring, again within limits, the stronger the timber. If strength is desired in these broad-leaved trees, the aim should be for fast growth but for not more than eight rings per inch of radius. For softer textured wood, such as that used in furniture work, narrower rings would be better, about 16 to the inch.

Aldridge and Hudson (*1*, *2*) do not confirm Turnbull's (*74*) work. In released trees 40 years of age or more, the faster grown outer wood was less dense than that of the inner, slowly grown core. In relatively uniform-grown material, they found no evidence of increasing density from the pith outward that could be attributed to distance from the pith or to age. The customary rapid to slow growth, however, showed an increase in density as ring width decreased. Aldridge and Hudson seek to remove the confusion arising from the discussions of slowly grown juvenile and fast grown adult wood by recommending more research into the nature of these wood types.

Rendle (*67*), after discussing summerwood formation and density of softwoods, names a number of possible contributing factors. He concludes by saying that with so many factors operating, no simple direct relation exists between any one factor, such as ring width, and the technical properties of the timber.

To sum up the foregoing assumptions, results, conclusions, and recommendations, it appears that formation of wood is one of the most complex physiological processes of nature and that the many factors involved act sometimes in harmony, sometimes in opposition. Furthermore, the relative effects of these factors are for the most part only inaccurately measurable and, as a result, that which sometimes appears under one condition as a significant correlation may under other circumstances prove valueless. In other words, the basic physiology of wood formation is not yet fully understood.

SIGNIFICANCE OF SPECIFIC GRAVITY AS AN INDEX OF WOOD QUALITY

The specific gravity or weight per unit volume of wood under normal conditions provides a good estimation of strength and other properties of wood. In making specific gravity determinations, knots and the wood close to them should be avoided. Pitch-soaked conifer specimens should either have the pitch extracted or not be used. Scar tissue, tension wood, and compression wood also influence specific gravity and, when present, must be taken into account.

In silvicultural studies relating to specific gravity, care must be taken to get representative samples of trees or stands and to compare wood from designated positions in the trees, since wood may vary considerably horizontally in a tree and with distance above the ground. To fulfill this requirement, the U.S. Forest Products Laboratory's comparisons of specific gravity and strength are for wood at 8- to 16-foot heights. When data for other portions of the trees are compared, the heights are shown.

For most of our native commercial species, considerable data have been published on relationships of specific gravity to mechanical strength. An example is given in table 1. Additional data can be found in U.S. Department of Agriculture Bulletin 479 (*27*) and the Wood Handbook (*75*).

TABLE 1.—*Relation of specific gravity to strength tests*

Species	Specific gravity [1]	Kind of test				
		Static bending, modulus of rupture	Impact bending, height of drop causing complete failure with 50-pound hammer	Compression parallel to the grain, maximum crushing strength	Hardness, load required to embed a 0.444-inch ball to ½ its diameter	
					End	Side
		P.s.i.	*Ins.*	*P.s.i.*	*Lbs.*	*Lbs.*
Pignut hickory (*Carya glabra*)	0.50	8,200	54	3,600	850	780
Do	.62	10,800	70	4,540	1,130	1,200
Loblolly pine (*Pinus taeda*)	.41	6,870	24	3,050	390	400
Do	.56	8,740	36	4,230	460	500

[1] Based on volume when green and weight when ovendry.

Data in table 1 show that a difference of 0.12 in specific gravity in pignut hickory was accompanied by differences of 2,600 pounds per square inch in modulus rupture, 16 inches in height of drop of a 50-pound hammer in the impact bending test, 940 pounds of maximum crushing strength in compression parallel to the grain tests, 280 pounds in end hardness, and 420 pounds in side hardness tests. Similar differences may be noted also for the data on loblolly pine.

The influence of geographic habitat upon specific gravity of wood within the natural range of a species has been recognized for some species that have a wide distribution. A difference in habitat, however, is likely to be accompanied by changes in site quality, which in itself could exert greater influence on wood quality than latitude or longitude.

Investigations have shown that sufficient growing space is of primary importance among growth factors, since it influences the development of the crown and roots, and hence the ability of a tree to obtain and use plant food elements and moisture from the soil. This is emphasized in the open-grown trees. Therefore, lack of growing space has a retarding effect upon the volume growth of trees, even when other factors such as soil type, soil fertility, and soil moisture are sufficient. In any young stand there is a gradual increase in size of crowns until all the space between the trees is occupied. After that, unless the stand is thinned properly, a continual struggle takes place for more growing space and sunlight. As a result, the weaker trees are suppressed, their crowns become completely shaded, and eventually they die. Even the trees that are able to extend their uppermost branches to the sunlight lose many lateral branches because of crowding from the side, and their capacity for wood production is decreased accordingly.

RESEARCH METHODS

The silvicultural studies described in this bulletin include both broad-leaved and coniferous species. The wood collected consisted of cross sections taken from the stems at intervals of about 15 feet, sometimes less, with care to include material from the 8- to 16-foot height for purposes of comparison. The north-south direction on each section was marked. Before each tree was felled, a description of it was recorded on an appropriate form, photographs were taken when practical, and the principal factors of the site, soil, topography, and species of the forest were described. Individual trees from which specimens were to be cut were designated by numbers, and each section obtained was given its tree number and an identifying letter.

The specimens used for specific gravity determinations were taken from flitches or wedges, usually extending north and south through the pith of each tree (fig. 1). They were 4 to 6 inches along the grain, 2 to 2½ inches in width (tangentially), and of varying radial dimensions conforming to certain groups of annual rings taken in pairs from each side of the pith. The grouping of rings selected for a tree was used as much as possible for sections at all heights in the tree; the results gave specimens that were representative of definite periods of growth at the heights sampled. Each specimen in the cross section was identified so that its original position in the tree was accurately known.

The radial dimension of each specimen, the number of annual growth rings comprising it, and the time of growth were recorded. Weights and volumes of specimens in the green condition were recorded and measured, the volume being determined by immersion. Specimens were seasoned slowly by air drying or by conditioning under controlled humidity for several weeks and finally brought to constant weight by drying at a temperature of 100° to 103° C.

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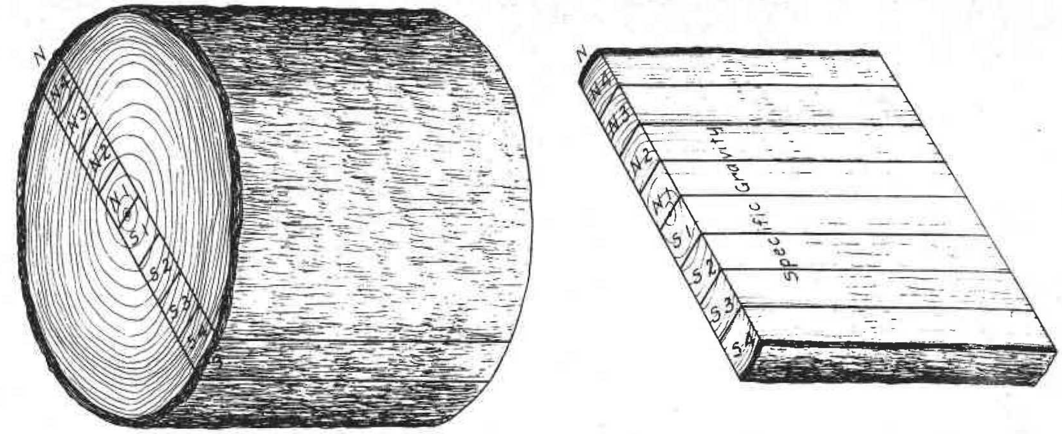

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Figure 1.—Cutting diagram for specific gravity specimens.

Weights and volumes were again recorded. From the data, shrinkage in volume was also computed. The specific gravity values in this bulletin are based on the ovendry weight of the specimens and their volumes when green, and again when moisture free. They were determined by dividing ovendry weight by green volume, unless otherwise noted. For some specifications, it was desirable to divide ovendry weight by ovendry volume.

BROAD-LEAVED SPECIES (HARDWOODS)

Broad-leaved species, on a basis of wood structure, are classified as ring porous, semiring porous, and diffuse porous, depending upon the general arrangement of the large vessels or pores in the growth rings.

Species of the ring-porous group included white ash, hickories, elms, and red and white oaks. Semiring-porous species were represented by black walnut. The diffuse-porous species included maples, birches, yellow-poplar, and several others.

Ring-Porous Hardwoods

White Ash

An initial study of white ash (*Fraxinus americana*) compared the specific gravity of white ash growing under entirely different conditions of topography and soil, ranging from New York and New England to the high slopes of the southern Appalachians, the bottom lands of the Mississippi River, and to the Ozarks in Arkansas. Three to seven trees were represented from each of 12 locations (table 2).

Average specific gravity values for white ash from these different regions did not show striking differences. In general, young stands produced heavier wood than the older ones. Considerable variation was evident among trees in the same stand and within trees at different periods of growth. One outstanding result was that the specific gravity averaged 6.1 percent lower at the base than at 16 feet, and higher for the trees from the overflow delta bottom lands of the Mississippi River. This difference is in contrast to the variation vertically in the trees from upland locations where wood near the stump is heaviest (fig. 2). Green ash from Louisiana had wood of much lower density in the bottom parts of trees that grew in Delta areas subjected to periodic inundation (*33*, *55*, *64*).

TABLE 2.—*Description of stands, and average specific gravity of white ash*

Locality	Elevation	Soil type	Character of stand	Average annual precipitation	Trees	Age (range)	Diameter at breast height (range)	Annual rings per inch	Height of sample in tree	Average specific gravity [1]
	Ft.			*Ins.*	*No.*	*Yrs.*	*Ins.*	*No.*	*Ft.*	
New York, Oswego County.	700	Red sandy loam	Second growth.	36	5	48– 65	13. 3–18. 5	8. 8	12–16	0. 582
Massachusetts, Berkshire County.	150	Alluvial sandy loam.	do	40	3	53– 58	9 –11	12. 2	12–16	. 531
Vermont, Bennington County.	1, 800	Stony loam	do	34	5	44– 76	9 –17	10. 6	12–16	. 562
North Carolina:										
Buncombe County.	2, 000	Alluvial sandy loam.	Plantation	49	5	18– 20	3. 0–5. 0	8. 6	8–16	. 627
Do	3, 500	Black loam	Mixed ages, old growth.	49	7	41–143	8 –14	15. 8	16	. 578
Tennessee:										
Shelby County	250	Silt loam	do	50	6	93–181	9 –25	17. 6	16	. 541
Do	50	Alluvial silty clay loam.	Delta bottom land.	50	6	41–119	11. 3–19. 2	10. 8	16	. 567
Scott County	1, 750	Black sandy loam.	Mixed ages, old growth.	50	3	70– 80	16 –28	11. 3	15–16	. 596
West Virginia, Pocahontas County.	3, 300	Clay loam	Old growth	42	5	156–303	18 –31	17. 2	12–16	. 495
Arkansas:										
Stone County	1, 100	Stony, gravelly loam.	do	45	5	90–122	14 –18	14. 8	12–16	. 550
Pope County:										
Sycamore Creek.	1, 800	Stony loam	Mixed ages, old growth.	45	7	63–133	7. 5–19. 6	16. 9	16	. 566
Callan Hollow	1, 800	do	do	45	6	51–167	11. 7–18. 8	15. 4	16	. 582

[1] Based on volume when green and weight when ovendry.

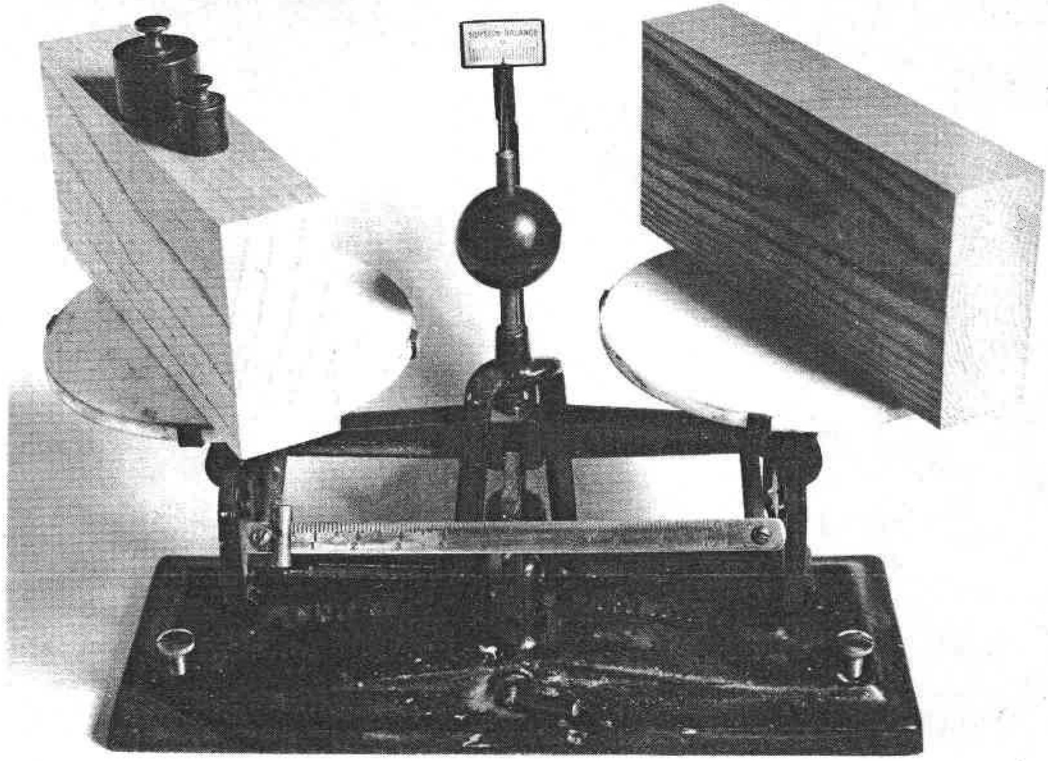

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Figure 2.—Comparison of density of lowland (left specimen) and upland grown ash.

Specific gravity values for wood produced at different stages of growth were obtained by separating the annual rings into groups of 10, 20, or more, and by separating the specimens in such a way that the faster and slower periods of growth would be evident. A general application of ring width data to specific gravity did not indicate any constant relationship; however, when individual specimens that exhibited low specific gravity were considered with respect to the whole life history of the tree, they corresponded with a retardation of the diameter growth (*29*) (fig. 3). This retardation suggested a lack of growing space and, since slow diameter growth is associated with a dense forest stand, steps were taken to learn whether crowding of the trees would influence specific gravity and whether any beneficial effects would result from thinnings.

Stands that represented the desired combinations of growth conditions were investigated. They comprised three woodlots on soils of about equal quality in northeastern Ohio. Two were even-aged, densely stocked stands in which the trees had reached a stage of keen growth competition. In the third woodlot a cutting that had the effect of a heavy thinning had been made about 30 years earlier. In both of the crowded woodlots, ring width near the circumference of the trees was very narrow and was accompanied by production of wood of progressively decreasing specific gravity. In one woodlot this reduction in specific gravity from the center to the outside of the trees averaged 11.4 percent, and in the other crowded woodlot it was 8.3 percent. In the thinned woodlot the average change in specific gravity after thinning was only 1 percent, corresponding with a very large increase in the diameter growth of the trees. Specific gravity values for different periods of growth in the three woodlots are presented in table 3 and figure 4.

Hickories

A study of hickory included samples from the mountain forests of western North Carolina, the Cumberland foothills in Kentucky, the north and south slopes of Mount Logan in southern Ohio, and from

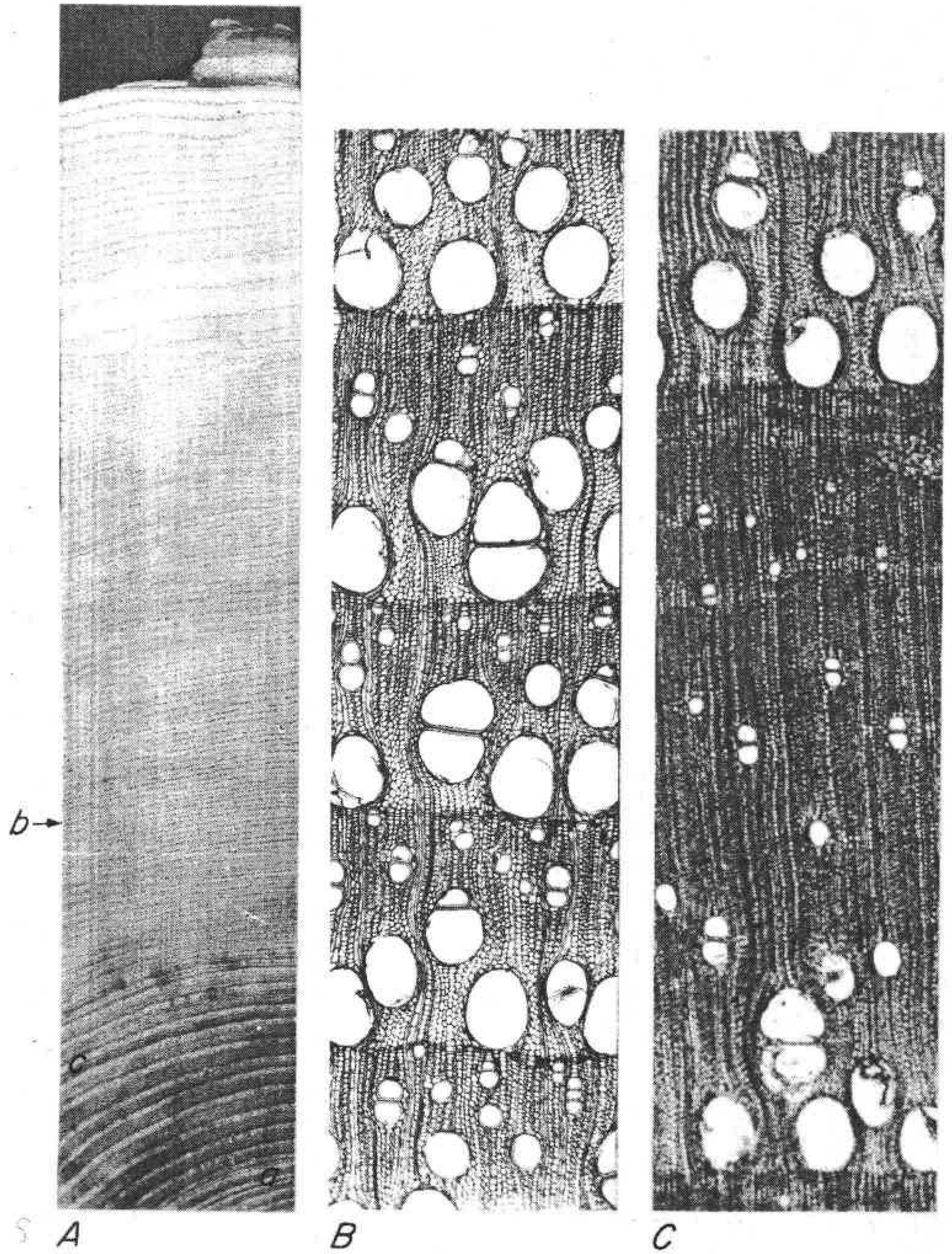

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Figure 3.—Changes in rate of diameter growth and structure of annual rings of white ash: *A*, Cross section showing transition from wood of rapid growth and high specific gravity near center of the tree, point *a*, to wood of slow growth and low specific gravity; *B* and *C*, photomicrographs of the structure of narrow and wide rings at points *b* and *c* in *A*. The specific gravity of the wood in *B* is only 0.48; *C* is 0.65 (based on weight and volume when ovendry).

TABLE 3.—*Comparison of rate of growth and average specific gravity*[1] *of white ash for different periods of growth in unthinned and in thinned stands (all bolts)*

Stand	Description of stand			Trees	Period of growth	Annual rings per inch	Specific gravity	Period of growth	Annual rings per inch	Specific gravity	Change in specific gravity
	Average age	Average height	Average diameter breast high								
	Yrs.	*Ft.*	*Ins.*	*No.*		*No.*			*No.*		*Pct.*
Unthinned	60	88	13	5	Before crowding (first 30–35 yr.).	10. 1	0. 550	After crowding (last 15 yr.).	21. 4	0. 487	−11. 4
Do	50	81	12	5	do	8. 5	. 551	do	15. 2	. 505	−8. 3
Thinned	65	85	15	5	Before thinning (first 35–40 yr.).	12. 6	. 539	After thinning (last 30 yr.).	9. 0	. 547	+1. 5

[1] Based on volume when green and weight when ovendry.

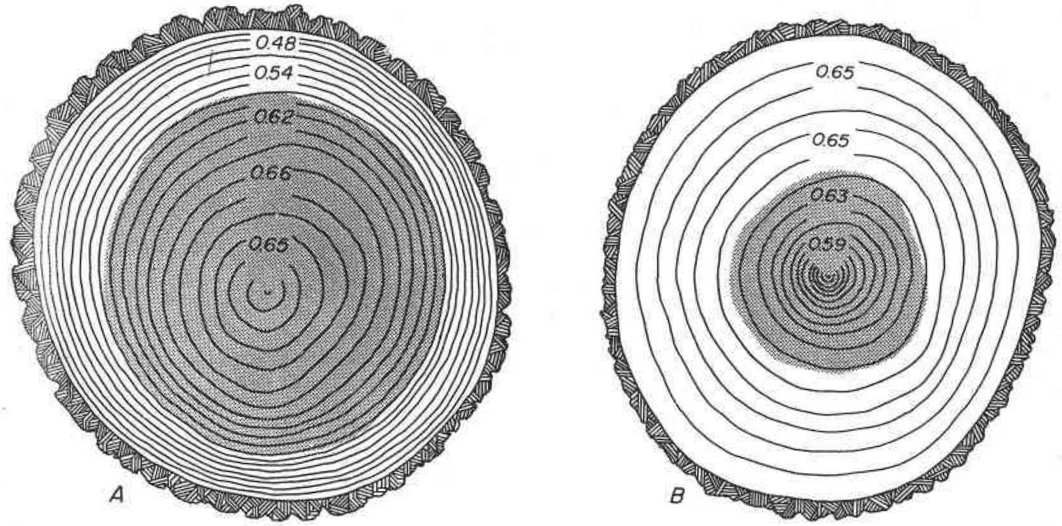

Figure 4.—Cross sections of logs showing range of specific gravity and rate of growth: *A*, Rapid growth when the tree was young, and slow growth in later years when it was crowded in an unthinned stand; *B*, more rapid growth in a properly thinned stand. Numbers are comparative specific gravity values based on weight and volume of ovendry wood.

woodlots in southern Indiana. Each stand sampled was represented by five trees or more. Two species, shagbark (*Carya ovata*) and pignut (*C. glabra*), were included. The relationship of ring width and specific gravity followed a pattern similar to that for white ash. A sustained or accelerated diameter growth produced wood of uniform specific gravity, and a retardation of growth rate from crowding or from the deterioration of the site resulted in a decrease in specific gravity.

The effect of unfavorable site conditions was evident in a comparison of the trees from the north slope of Mount Logan with those from the south slope. The trees on the south slope were stunted in height and had made slow growth in diameter during recent years. This slow growth was attributed to a poor, dry soil condition, the result of frequent forest fires for a considerable number of years. The trees on the north side of the same mountain were favored by excellent soil and growing conditions, although the stand was beginning to show the influence of gradual crowding (table 4).

Comparisons of old- and second-growth hickory from the southern Appalachian region (*31*, *32*) supported the assumptions concerning ring width in relation to the stand history and fluctuations of specific gravity values concurrently with ring width (*39*) (figs. 5, 6, and 7). Descriptions of stands and average specific gravity for two species of hickory appear in table 5 (figs. 8 and 9). Site classification is based upon the total height of dominant trees at the age of 50 years with quality I representing superior sites.

Rock Elm

Rock elm (*Ulmus thomasii*), less conspicuously ring porous than ash and hickory, was investigated as a species intermediate in structure between typical ring- and diffuse-porous woods. Samples were collected from two woodlots in southern Michigan. The trees in one

TABLE 4.—*Comparison of rate of growth and corresponding average specific gravity*[1] *for different growth periods in shagbark hickory from north and south slopes of Mount Logan, Ross County, Ohio*

Situation	Trees	Average age	Total height	Initial growth period		Final growth period	
				Annual rings per inch	Specific gravity	Annual rings per inch	Specific gravity
	No.	*Yrs.*	*Ft.*	*No.*		*No.*	
North slope	6	90	80	12.3	0.677	19.6	0.645
South slope	5	70	45	15.9	.658	25.0	.611

[1] Based on volume when green and weight when ovendry of wood taken at 12- to 16-foot heights in tree or equivalent.

woodlot were over 200 years old and had undergone a long period of suppression that was subsequently relieved by thinning. In the other woodlot the growth of the trees had been well sustained throughout their lives. The effect of suppression and release, and comparative data for the two groups of rock elm trees, are presented in table 6 and figure 10.

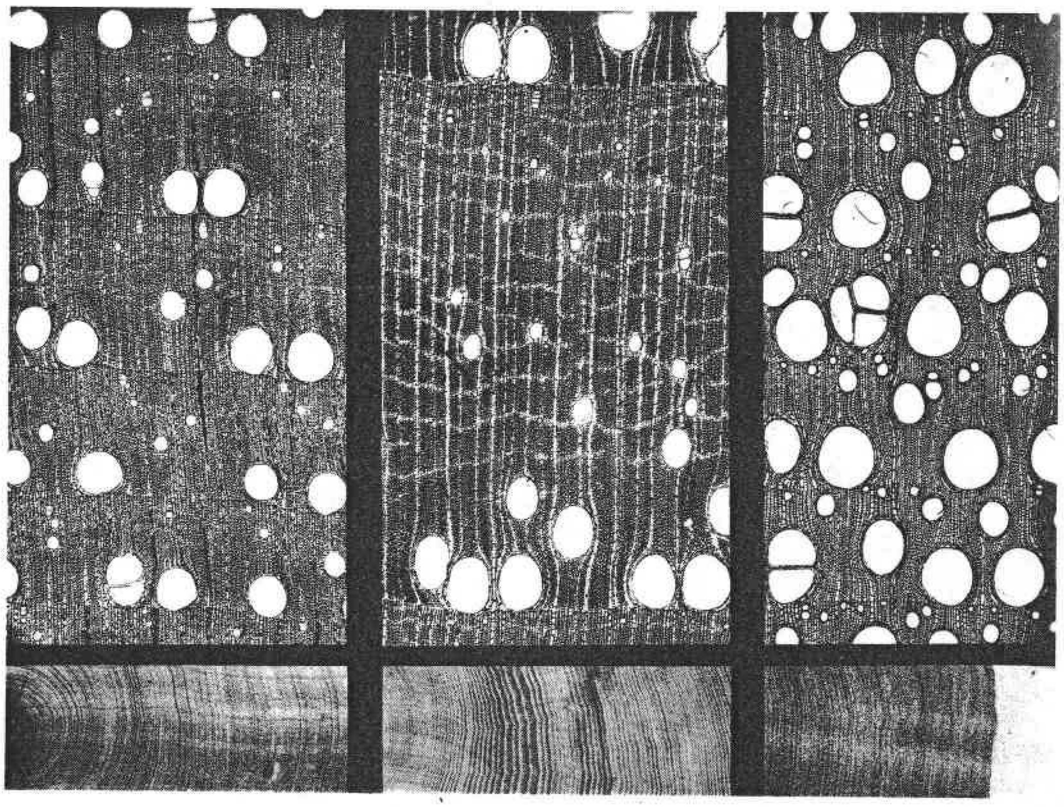

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Figure 5.—Relation of wood quality to ring width of old-growth hickory trees. Cross sections and corresponding photomicrographs show, left to right, narrow growth rings near pith—wood of high density; then wider growth rings—wood of high density; and subsequent narrow growth rings—wood of low density.

TABLE 5.—*Description of stands, and average specific gravity of hickories*

Locality	Species	Elevation	Character of stand	Site quality	Trees	Age (range)	Diameter at breast height (range)	Height of sample in tree	Annual rings per inch	Average specific gravity[1]
		Ft.			*No.*	*Yrs.*	*Ins.*	*Ft.*	*No.*	
Kentucky, Madison County.	Shagbark	1, 200	Second growth	I	6	80–92	9–15	16–18	14. 0	0. 677
Ohio, Ross County:										
Mount Logan:										
North slope	do	1, 000	do	I	6	82–101	11–15	15–16	13. 8	. 666
South slope	do	1, 100	do	III	6	50–75	7. 5–9	8–13	17. 3	. 641
Indiana, Clark County	do	600	Old growth	II	5	153–217	10–16	14–15	28. 9	. 615
North Carolina:										
Haywood County	do	2, 500	do	II	2	115–127	20–21	12–16	17. 0	. 673
Buncombe County:										
Bent Creek	Pignut	2, 500	Old growth, mixed ages.	I	5	67–180	14–30	16–17	17. 6	. 667
Beaverdam Creek	do	3, 000	Old growth	II	5	125–185	10–18	16–18	27. 3	. 615
Kentucky, Madison County:										
North slope	do	1, 200	Old growth, mixed ages.	I	5	88–235	9–19	14–17	21. 2	. 675
South slope	do	1, 100	do	II	5	69–107	9–11	14–18	19. 5	. 673
Indiana, Clark County	do	600	Old growth	II	5	130–173	12–16	12–16	24. 8	. 657
North Carolina, Macon County:										
Rainbow Springs	do	2, 500	do	I	5	150–260	17–26	10–16	22. 5	. 566
Coweeta:										
Second growth	do	2, 500	Second growth	I	6	35–85	7–15	8–10	8. 0	. 680
Old growth	do	2, 500	Old growth	I	4	140–225	12–20	8–13	27. 0	. 626
West Virginia, Hardy County.	do	1, 600	do	II	5	133–268	16–20	12–18	25. 5	. 653

[1] Based on volume when green and weight when ovendry.

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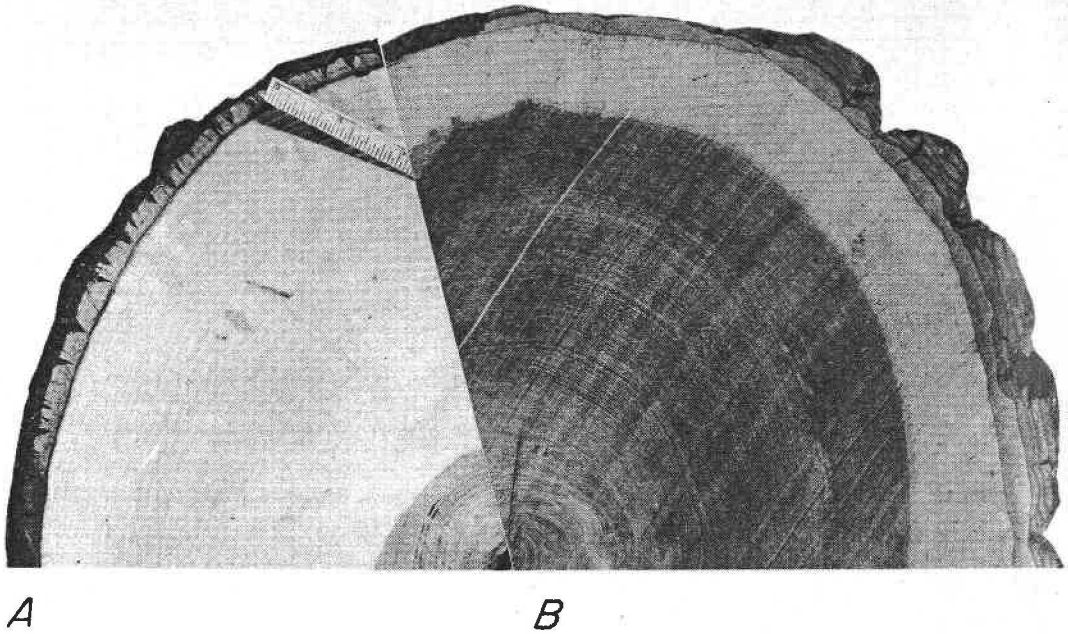

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Figure 6.—Second- and old-growth hickory: *A*, Second growth shows rapid rate of growth, wide sapwood, dense and strong wood; *B*, old growth shows slower rate of growth, narrow sapwood, and is lighter and weaker in the outer part.

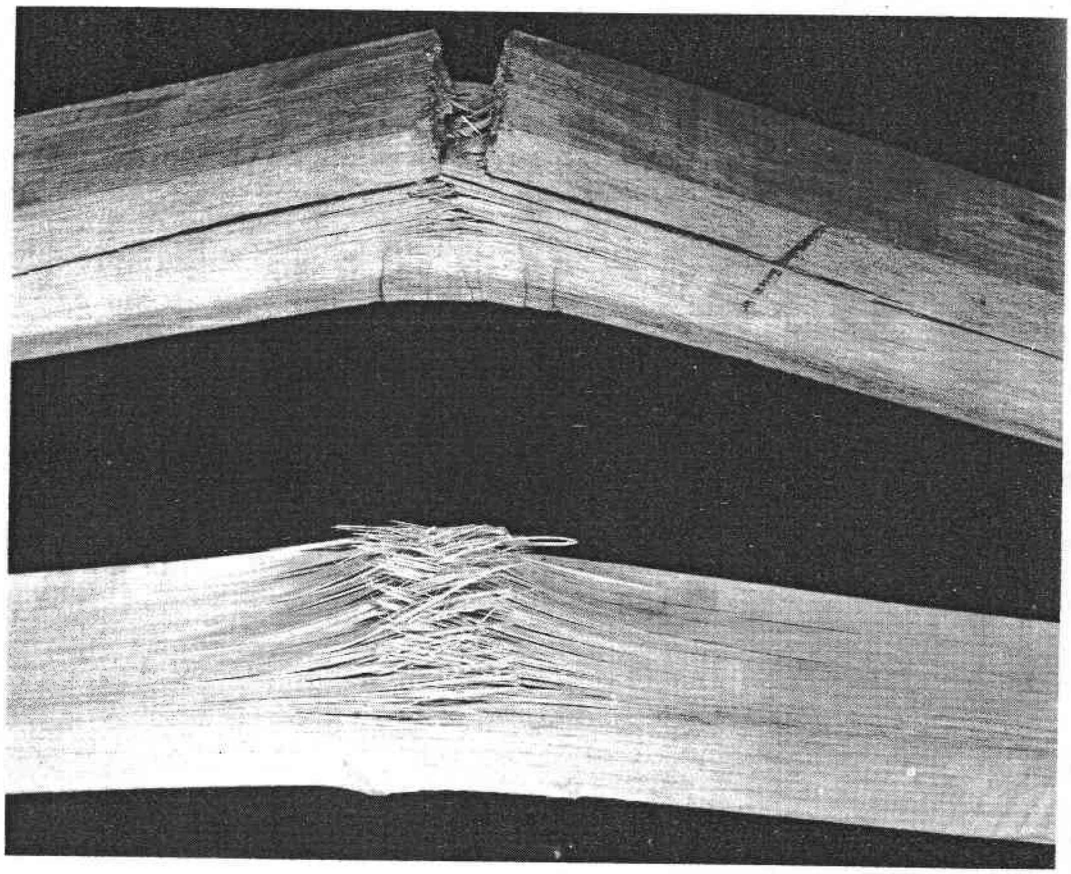

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Figure 7.—Characteristic failures of brash and tough hickory: *Top*, narrow-ringed wood of low density and strength; *Bottom*, wide-ringed wood with great toughness.

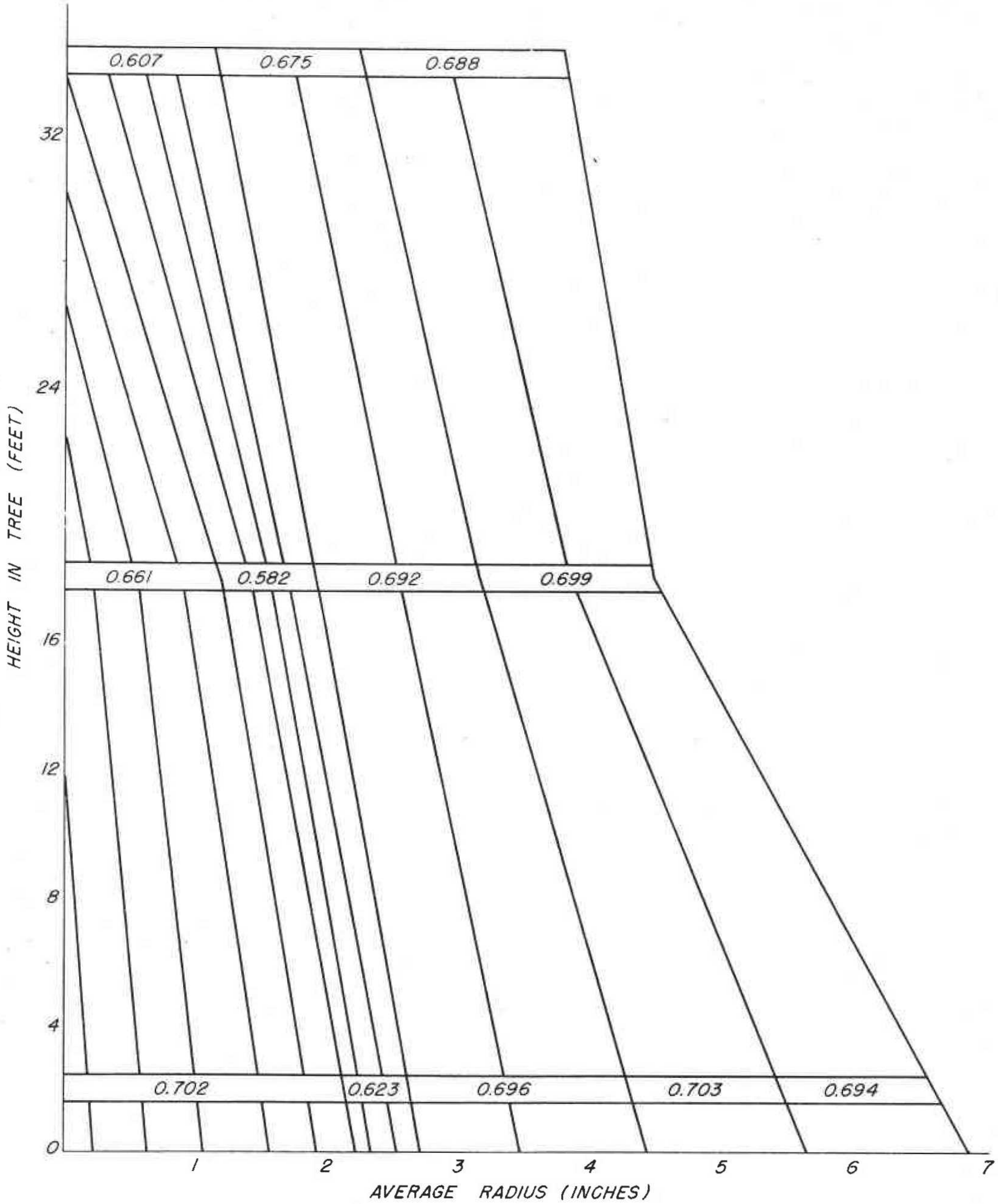

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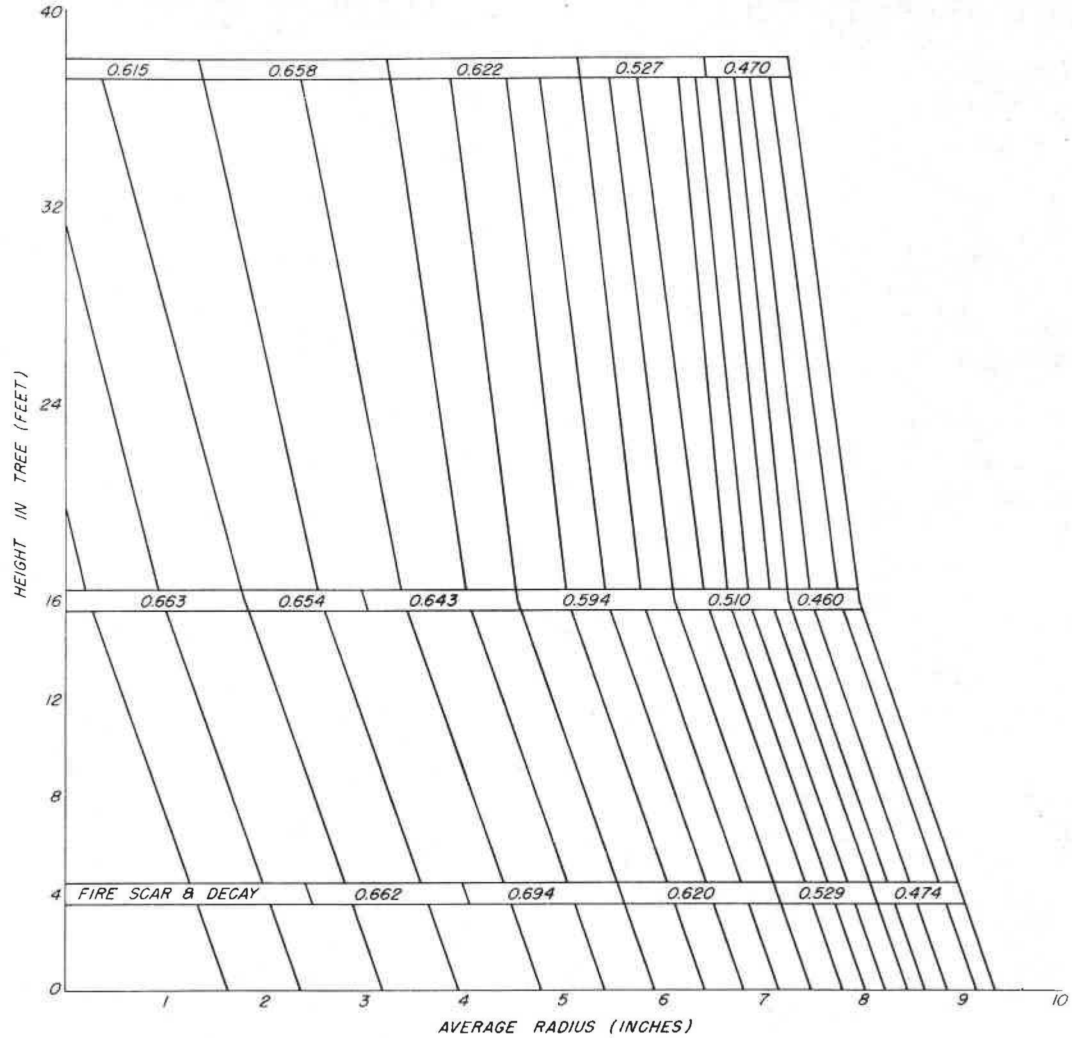
Figure 8.—Variable growth diagram of a hickory tree by 10-year periods (diagonal lines), showing accompanying specific gravity variations at three heights.

Red and White Oaks

The need for comparative data of second- and old-growth Appalachian oaks (*Quercus* spp.) led to a comprehensive study of second-growth trees from 10 locations in the Appalachian region of Kentucky, West Virginia, and North and South Carolina. In the past, much has been said about "soft-textured" Appalachian oak which was eagerly sought on the lumber market. This soft-textured material originated from old-growth stands in trees up to 300 years of age.



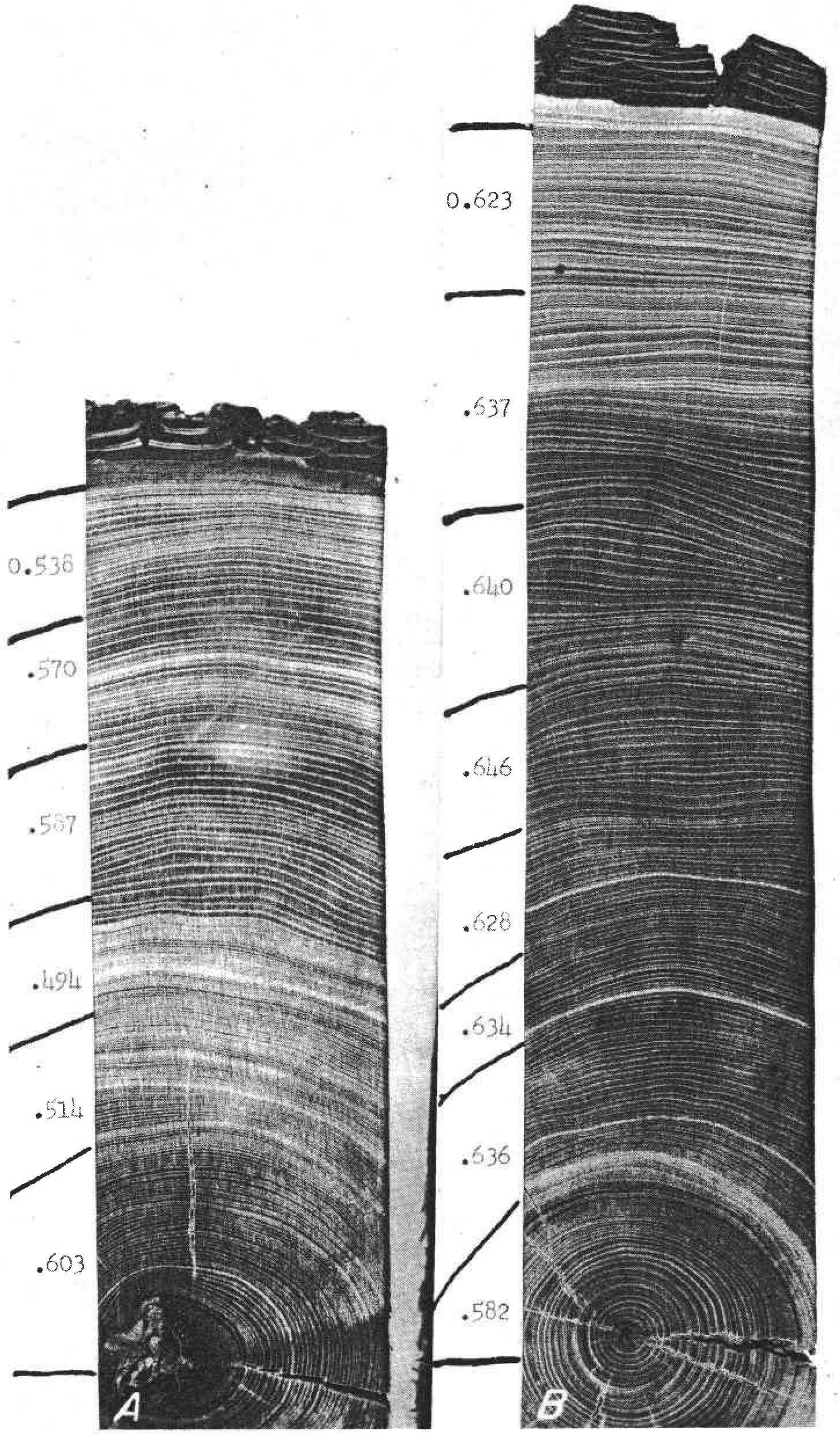
M–116615

Figure 9.—Variable growth diagram of a hickory tree, showing decreasing specific gravity values along with decreasing growth rate toward the bark.

TABLE 6.—*Average specific gravity* [1] *for successive growth periods in rock elm trees from Clinton County, Mich.*

Condition	Trees	Average age	Initial growth period		Intermediate period of growth		Final period of accelerated growth	
			Annual rings per inch	Specific gravity	Annual rings per inch	Specific gravity	Annual rings per inch	Specific gravity
	No.	*Yrs.*	*No.*		*No.*		*No.*	
Trees crowded, then thinned	4	240	35.2	0.603	37.8	0.540	21.7	0.554
Sustained growth	4	235	30.6	.595	28.0	.584	16.7	.586

[1] Based on volume when green and weight when ovendry.



M—116591

Figure 10.—Growth and specific gravity in cross sections of rock elm: *A*, Typical 220-year-old tree that had experienced a long period of crowding, which decreased the specific gravity of the wood. As a result of thinning, a rapid growth period followed; *B*, typical tree that maintained a dominant position in the stand throughout its life and at 200 years of age was growing rapidly and producing wood of high specific gravity.

The second-growth stands investigated were located within a geographic range extending 350 miles from north to south and 200 miles from east to west, situated at elevations of from 500 to 3,250 feet. The average annual precipitation of the different areas of sampling ranged from 44 to 57 inches, and the growing season from about 150 to 230 days. Forty-three white oak trees, five from each of eight stands and three from another, were sampled (table 7). Eighty-five red oaks representing five species were sampled from the same forest areas and one additional area (table 8, fig. 11). Site index, or average height at 50 years, for white oak ranged between 54 and 72 feet and for red oak from 49 to 84 feet.

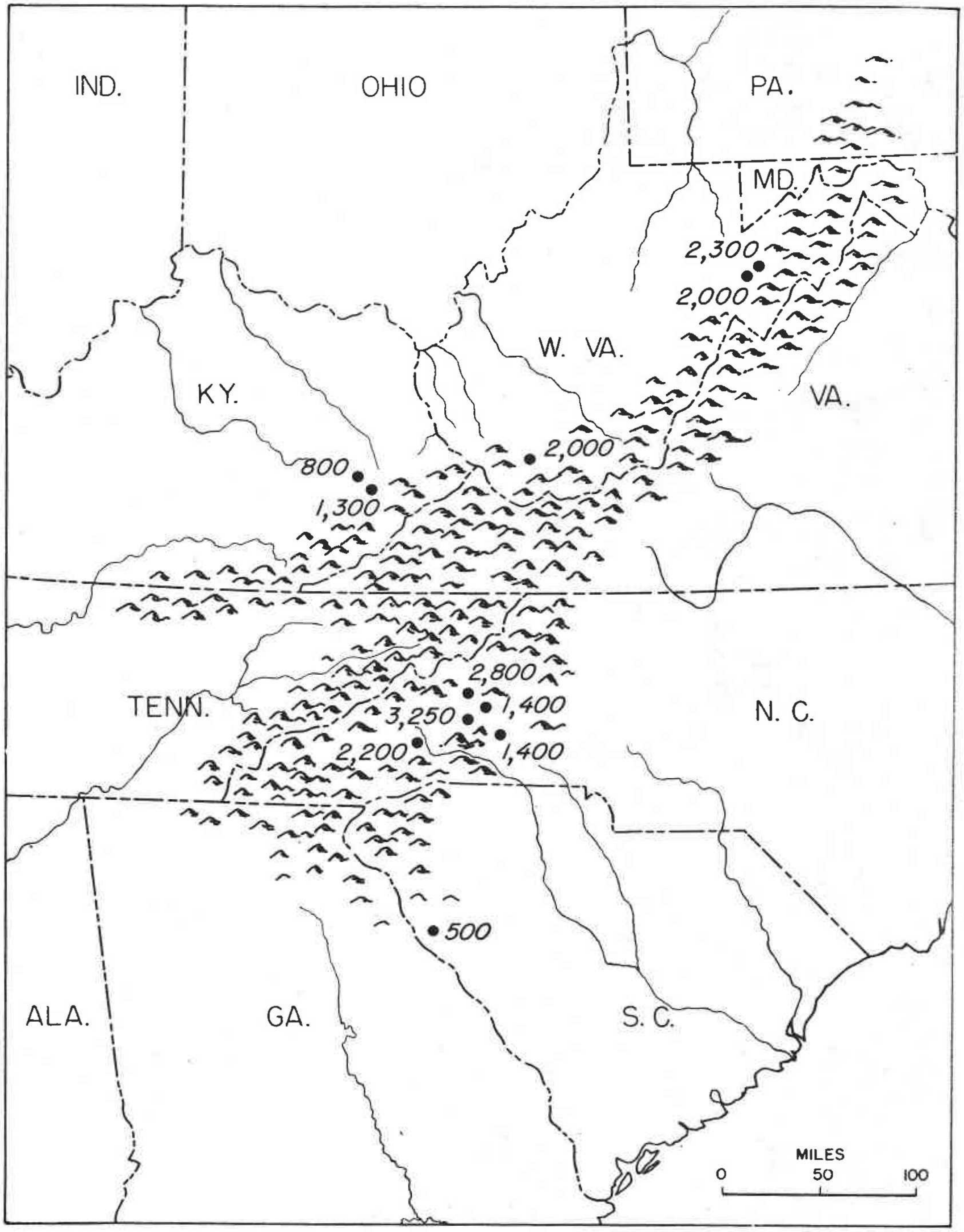


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Figure 11.—Locations and elevations of samples of second-growth red and white oaks.

TABLE 7.—*Description of stands, and average specific gravity of second-growth white oaks*

Locality	Trees	Elevation	Soil type	Site index [1]	Age (range)	Diameter at breast height (range)	Annual rings per inch (average)	Specific gravity [2]	
								Average	Standard deviation
	No.	*Ft.*		*Ft.*	*Yrs.*	*Ins.*	*No.*		
Kentucky, Breathitt County	5	800	Stony loam	55	46– 70	10. 0–12. 0	13. 6	0. 640	0. 0288
West Virginia:									
Randolph County	5	2, 000	Stony clay loam	58	52– 81	8. 5–13. 5	13. 4	. 636	. 0255
Do	3	2, 300	do	58	65– 80	12. 0–15. 0	10. 6	. 649	. 0313
Wyoming County	5	2, 000	Loam	72	47– 69	10. 0–12. 5	9. 8	. 649	. 0312
North Carolina:									
Buncombe County	5	2, 200	Clay loam	64	67– 76	11. 5–13. 1	13. 2	. 619	. 0349
Yancy County	5	2, 800	Alluvial stony loam	64	65– 80	12. 5–19. 0	10. 8	. 628	. 0298
McDowell County	5	1, 400	Clay	54	54– 78	8. 5–13. 5	16. 9	. 610	. 0294
Do	5	1, 400	Clay loam	57	65– 89	11. 0–13. 5	12. 8	. 633	. 0260
South Carolina, McCormick County.	5	500	Red clay	60	93–125	13. 4–15. 7	16. 3	. 623	. 0392

[1] Average height of trees at 50 years.
[2] Based on volume when green and weight when ovendry.

TABLE 8.—*Description of stands, and average specific gravity of second-growth red oaks*

Locality	Trees	Elevation	Soil type	Site index [1]	Age (range)	Diameter at breast height (range)	Annual rings per inch (average)	Specific gravity [2] Average	Specific gravity [2] Standard deviation
BLACK OAK									
	No.	*Ft.*		*Ft.*	*Yrs.*	*Ins.*	*No.*		
South Carolina, McCormick County.	5	500	Red clay loam, clay	61	90–93	12. 2–19. 2	11. 6	0. 600	0. 0382
Kentucky, Breathitt County	5	800	Stony loam	65	49–61	8. 5–11. 0	12. 0	. 617	. 0214
West Virginia, Wyoming County.	5	2, 000	Brown loam	84	45–52	13. 0–16. 5	7. 9	. 603	. 0244
North Carolina:									
Yancy County	5	2, 800	Black alluvial loam	70	63–74	12. 5–20. 5	10. 2	. 604	. 0326
McDowell County	5	1, 400	Clay, clay loam	68	72–88	12. 5–15. 5	11. 3	. 602	. 0272
Buncombe County	5	2, 200	Reddish sandy loam	60	67–82	10. 0–13. 0	17. 4	. 568	. 0441
NORTHERN RED OAK									
West Virginia, Randolph County.	5	2, 300	Light-brown loam	64	71–79	13. 5–15. 5	8. 5	0. 592	0. 0238
North Carolina, Yancy County.	5	3, 250	Black alluvial loam	75	62–70	13. 5–16. 5	9. 4	. 569	. 0222

SOUTHERN RED OAK									
South Carolina, McCormick County.	5	500	Red clay loam, clay	73	35– 61	10. 7–16. 4	8. 1	0. 587	0. 0263
North Carolina:									
McDowell County	5	1, 400	Light-brown clay	49	76–128	10. 2–19. 5	15. 5	. 560	. 0354
Do	5	1, 400	Clay loam	55	97–123	13. 5–16. 0	17. 1	. 576	. 0297
Buncombe County	5	2, 200	Reddish sandy loam	64	73–108	11. 0–15. 7	15. 6	. 557	. 0338
SCARLET OAK									
West Virginia, Randolph County.	5	2, 000	Light-brown loam	70	50– 58	11. 5–15. 3	9. 3	0. 590	0. 0209
South Carolina, McCormick County.	5	500	Red clay loam	58	71– 99	13. 4–19. 3	11. 6	. 587	. 0325
Kentucky, Breathitt County	5	1, 300	Shallow loam	75	74– 78	15. 0–19. 0	10. 7	. 576	. 0279
North Carolina, McDowell County.	5	1, 400	Light-brown clay	73	41– 67	11. 0–17. 5	8. 2	. 575	. 0209
WATER OAK									
South Carolina, McCormick County.	5	500	Red loam	83	30– 40	12. 2–12. 7	8. 3	0. 595	0. 0235

[1] Average height of trees at 50 years.
[2] Based on volume when green and weight when ovendry.

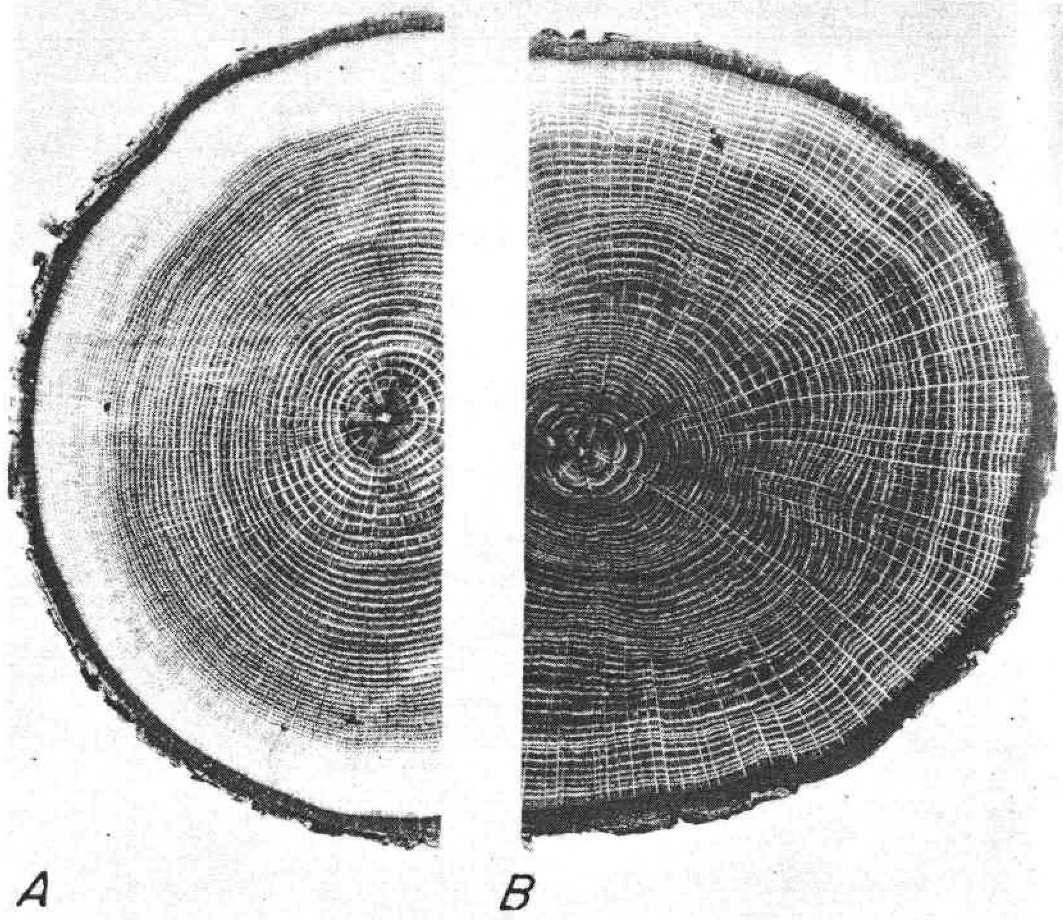

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Figure 12.—Contrasting cross sections of second-growth white oak: *A*, Outer rings are not so wide as inner rings and specific gravity decreased from pith to bark; *B*, ring width and specific gravity are well sustained from pith to bark.

Diameter growth of the white oaks showed variable patterns of ring width, but in a majority there was a trend of narrowing ring width from the center toward the bark. This was accompanied also by a decline in specific gravity. In some trees, the pattern of ring width was well sustained or it increased and, in such trees, specific gravity values were fairly constant throughout a cross section (fig. 12). A composite tree diagram of five second-growth white oak trees 80 years old (fig. 13) is compared with a similar diagram of five old-growth trees 250 years old (fig. 14), and specific gravity distribution by 0.03 zones is indicated by shading. In the old-growth trees, two more 0.03 specific gravity zones are present at the lower end of the scale than occur in the younger trees.

Two second-growth black oak (*Quercus velutina*) stands are compared in similar specific gravity diagrams, one stand of thrifty growth about 50 years of age and the other of retarded growth about 80 years of age. In the retarded trees, the outer zones of wood are of lower specific gravity than are those of the thrifty trees (figs. 15 and 16).

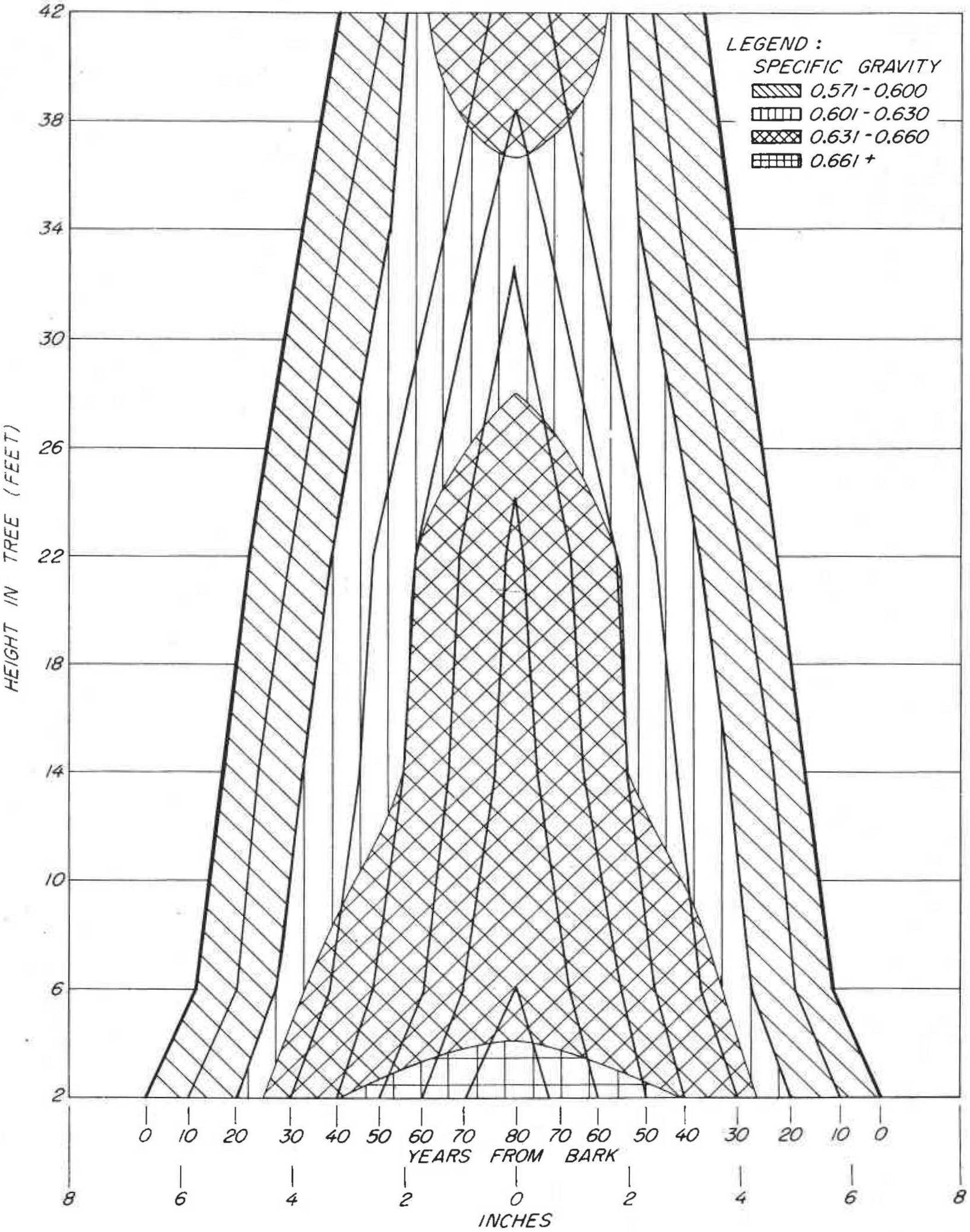

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Figure 13.—Composite diagrams of growth and specific gravity for five second-growth white oaks, showing average decrease in specific gravity from center to bark.

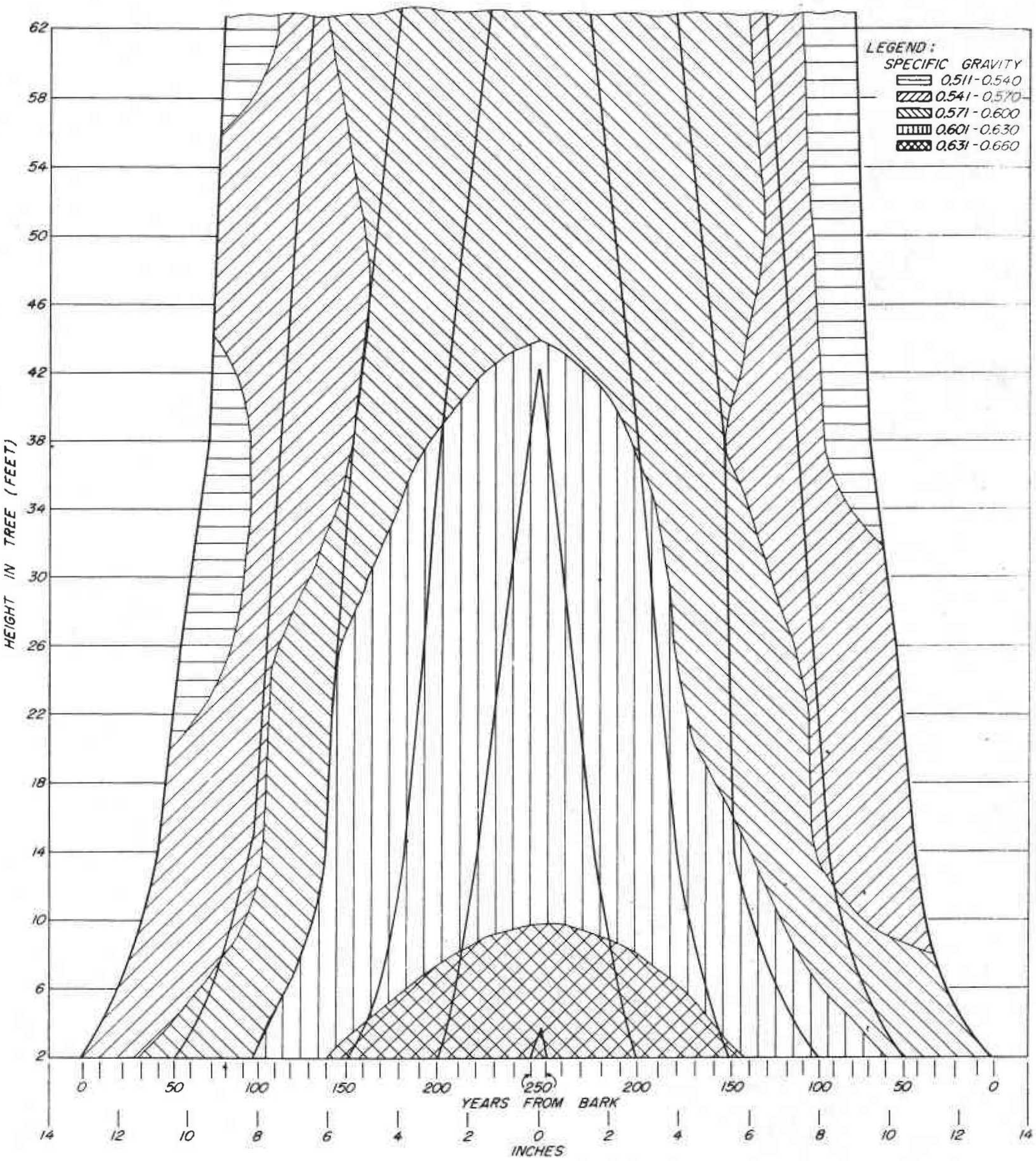

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Figure 14.—Composite diagram of growth and specific gravity for five old-growth white oaks, showing average decrease from center to bark.

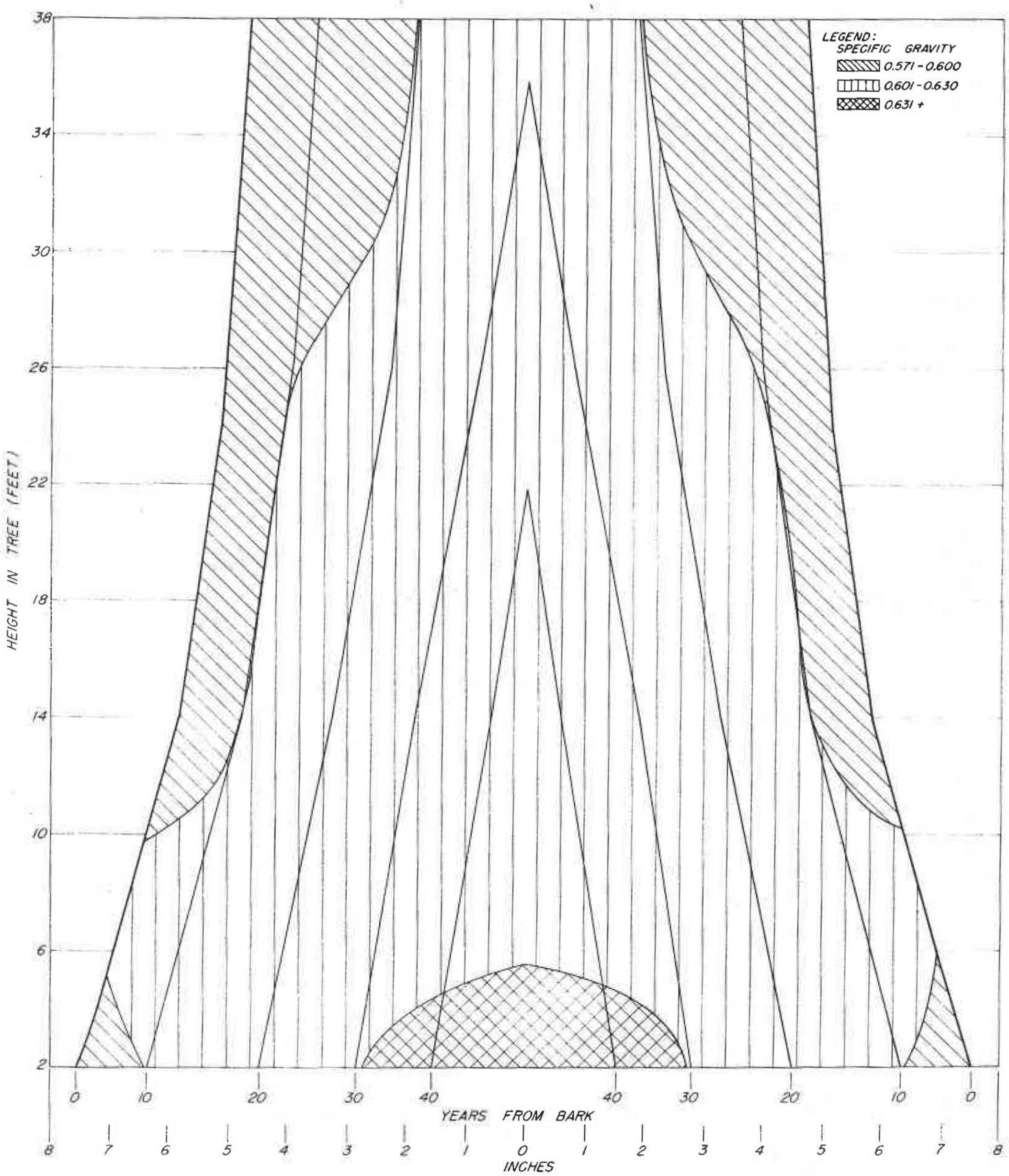

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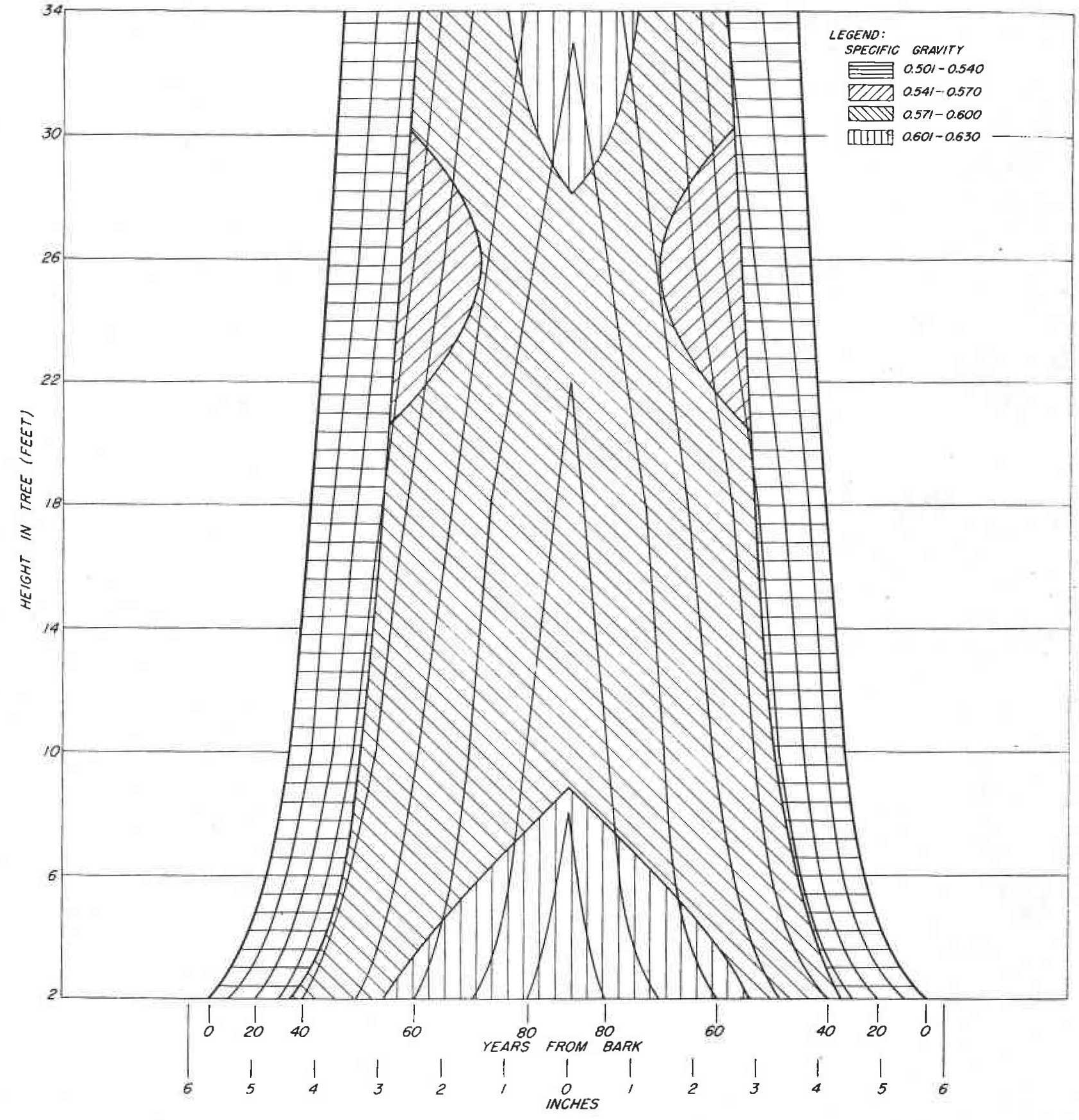
Figure 15.—Composite diagram of growth and specific gravity for five second-growth black oaks in thrifty young stand that grew at uniform rate.



M-113739

Figure 16.—Composite diagram of growth and specific gravity for five second-growth black oaks, showing greatly retarded growth rate during last 40 years.

Although the more slowly grown outer zones of second-growth white oak are of higher specific gravity than are the outer zones of the old growth, the specific gravity change is in the same direction. If the stands were left without further silvicultural treatment, specific gravity would probably fall to the level of the old-growth material. The second-growth white oak, with an average of 12 rings per inch, averaged 15 percent greater in specific gravity than old-growth white oak (table 9). Among the red oaks, specific gravity of second-growth material in the five species averaged 4 to 8 percent greater than that of old-growth trees. Differences in averages of rings per inch ranged between 9 and 34 percent.

Second-growth oaks were also harder than old-growth (table 9).

TABLE 9.—*Comparison of rings per inch, specific gravity, and hardness of old- and second-growth oak*

Species	Trees	Annual rings per inch (average)	Specific gravity [1]		Hardness [2]			
			Average	Increase of second growth over old growth	End	Side	Increase of second growth over old growth	
White oak:	*No.*	*No.*		*Pct.*	*Lbs.*	*Lbs.*	*Pct.*	*Pct.*
Old growth	15	19	0.55	------	1,120	1,060	------	------
Second growth	43	12	.63	15	1,307	1,202	16.7	13.4
Black oak:								
Old growth	8	15.7	.554	------	1,000	1,060	------	------
Second growth	27	11.7	.599	8.1	1,267	1,102	26.7	4.0
Northern red oak:								
Old growth	23	11.1	.556	------	1,020	966	------	------
Second growth	20	8.5	.578	4.0	1,120	1,070	9.8	10.0
Southern red oak:								
Old growth	9	15.4	.542	------	910	860	------	------
Second growth	21	14.1	.570	5.4	1,143	1,006	25.6	17.0
Water oak:								
Old growth	5	9.5	.556	------	------	------	------	------
Second growth	2	8.3	.595	7.0	------	------	------	------

[1] Based on volume when green and weight when ovendry.
[2] Load in pounds to embed a 0.444-inch ball to one-half its diameter.

In nearly all of the oak trees investigated, a progressive decrease in ring width and specific gravity occurred from the pith outward; yet in most species exceptions of sufficient magnitude were found to give contrasting regressions of specific gravity and rings per inch when growth patterns were unlike (fig. 17).

In the unmanaged natural stands of second-growth red and white oaks, the variation in specific gravity was significantly related to changes in ring width with increasing ages of the trees. Ring width in itself did not appear to be the controlling factor in specific gravity, since wood with narrow growth rings near the center of the trees was of average or higher specific gravity. When growth, as exhibited by ring width, declined progressively toward the bark, the specific gravity decreased concurrently (*49*).

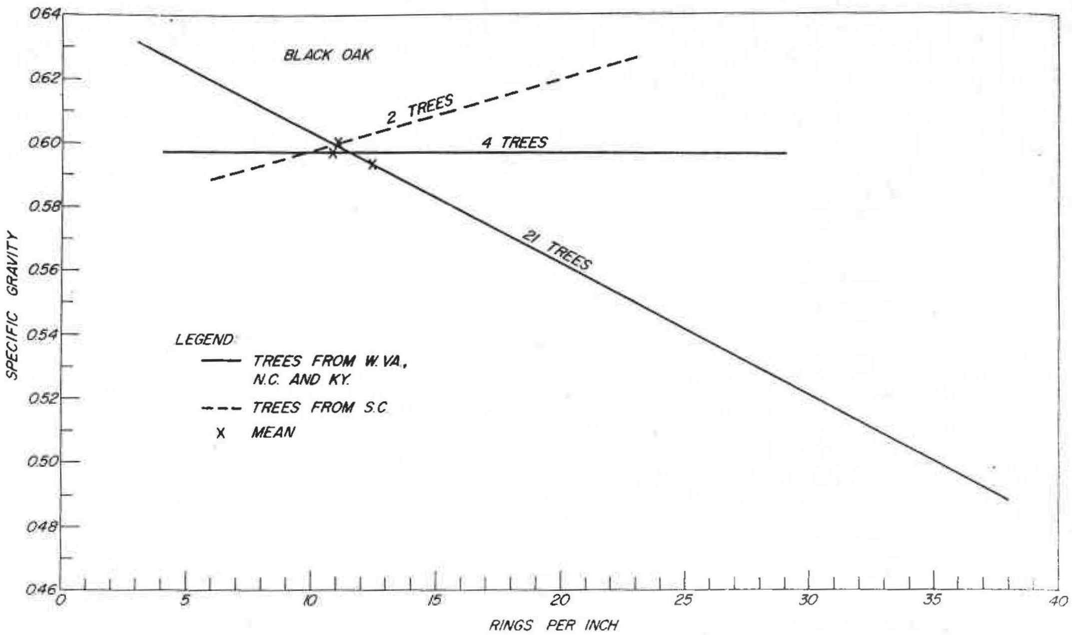


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Figure 17.—Regression lines for specific gravity on rings per inch in second-growth black oak (material between 9- to 16-foot heights).

In all of the ring-porous hardwood species tested, the same relationship of growth to specific gravity was found. This relationship, however, did not always apply unless taken in connection with the changing environmental conditions prevailing during the life of the tree. For example, slow growth during the early years of a tree or stand produced wood of average or higher weight for the species, and as long as radial growth was maintained or increased, the specific gravity along the radius remained uniformly high. When ring width became greatly retarded, either gradually or abruptly, the specific gravity showed a corresponding decrease. Acceleration of growth after a period of declining growth was accompanied by an increase in specific gravity.

In the ring-porous species, a retardation of growth in diameter brings the rows of large pores closer together in successive annual rings, as seen in cross sections, and reduces the development of the part of the ring containing the thicker summerwood cells. Since the thin-walled part varies less in amount than the thick-walled part under unfavorable growth conditions, the narrow rings contain a higher proportion of the thin-walled porous wood, causing lower specific gravity.

Thus, silvicultural measures that maintain a well-sustained ring width will help to produce wood of greater uniformity throughout the cross section. In most specimens studied, such wood in second-growth trees was considerably heavier than that in old-growth trees of the same species and locality. Some wood near the center of old-growth oak trees, however, equaled the specific gravity of second growth. Even in second-growth stands, if the radial growth has decelerated noticeably, it may be found that the most recent years produced wood approaching old-growth quality. Since radial growth can be regulated within certain limits by silvicultural practices, it lies within the realm of forest management to control timber quality in future stands.

Semiring-Porous Hardwoods

Black Walnut

Black walnut (*Juglans nigra*) has a wood structure intermediate between ring and diffuse porous, and it is classified by some authors as semiring porous. Black walnut samples from 71 trees, representing 13 stands and 11 localities within this species' natural range, were investigated. Both open- and forest-grown trees were represented, most of them belonging to age classes that might be designated as second growth; three trees were from an old-growth forest. A list of the sample trees, their place of origin, and some characteristics of the stands and sites are given in table 10.

The specific gravity determinations indicated that wood of open-grown trees was somewhat heavier than that of forest-grown trees, corresponding with a more rapid diameter growth. Material taken throughout the merchantable lengths showed an average specific gravity for open-grown trees of 0.55 and for forest-grown trees of 0.51. Specific gravity values of all specimens ranged from a low of 0.40 to a high of 0.67. Sapwood had a lower average specific gravity than heartwood in both open- and forest-grown specimens. The average sapwood specific gravity was 0.51 for open-grown trees and 0.49 for the forest-grown trees. Heartwood of open-grown trees averaged 0.57 in contrast to an average of 0.52 for that of the forest-grown trees.

Lower specific gravity of sapwood may be explained in two ways: retarded growth during recent years in both open- and forest-grown trees in most localities, and the presence of considerable quantities of infiltrated materials in the heartwood. Samples of heartwood leached in a laboratory for 14 days lost as much as 3 percent of their dry weight.

Geographic location did not indicate a controlling influence upon the specific gravity of black walnut. While three old-growth trees in northern Georgia contained the lightest wood of any of the trees tested, other adjacent young trees contained wood near the average specific gravity. The heaviest wood came from open-grown trees on a moist slope in the Arkansas Ozarks, but wood of next-to-lowest specific gravity was obtained from a limestone area in southern Missouri.

The general trend of lower specific gravity with decreasing ring width is illustrated in figure 18 for 1,179 specific gravity specimens. The rings per inch were grouped in class intervals of five, except in the last class, in which all specimens with a ring count above a certain number were placed; average specific gravity was found for all specimens in these classes. The number of specimens used to determine the average for each class interval is shown on the individual bars of figure 18. Average values according to position in the tree are shown in figure 19.

No significant shrinkage differences were found between specimens of open- and forest-grown black walnut. As a rule, sapwood shrinkage was somewhat greater than that of adjacent heartwood (fig. 19).

Variation in hardness of black walnut followed specific gravity differences. In both open- and forest-grown trees, heartwood was harder than sapwood, with the heartwood of open-grown trees show-

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TABLE 10.—*Locality of origin and distinctive features of environment of black walnut sample trees*

Locality	Trees	Elevation	Topography	Underlying rock formations and soil type	Description of stand
	No.	*Ft.*			
Ohio, Hocking County.	5	850	Hilly with narrow ravines and steep slopes.	Sandstone and shale rocks covered by glacial drift-clay loam soil.	Open-grown trees with short trunks and large crowns.
Indiana:					
Lawrence County	5	400+	Moderate to steep slopes to East Fork of White River.	Upper slope shale and sandstone. Limestone outcrop on lower slope—clay loam soil.	Walnut trees with long, clear trunks in farm woodlot of mixed hardwoods.
Do	5	400+	do	do	Open-grown trees with wide crowns and short boles; these trees adjacent to above woodlot.
Crawford County	6		Fairly level creek bottom.	Alluvial soil with gravel deposits.	Moist site hardwoods—logged 6 years earlier.
Perry County	5		Short steep slope. Northerly exposure.	Outcrops of limestone	Heavily cut in the past. Many saplings of mixed hardwood species.
Georgia:					
Fannin County	5	2, 200	Mountainous, upper slopes steep, lower slopes moderate.	Crystalline rocks, stony loam soil.	Open-grown trees at upper edge of former old field. Moderate slope becoming steep above. Trees have short boles and wide crowns.

Do	5	2, 200	do	do	Forest-grown trees at foot of steep slope on north side of Sids Mountain. Logged 3 years earlier for dead chestnut and oak stave bolts. Trees numbered 35 and 36 were much younger than the others of this group.
Arkansas:					
Madison County	5	1, 800	Mountainous, moderate slopes above rock ledge near Baldwin Creek.	Sandstone-shale rocks. Very stony loam soil.	Old woodlot of mixed hardwoods in which walnut trees have been favored.
Do	5	1, 800	do	do	Open-grown walnut trees in pasture adjacent to woodlot.
Missouri:					
Ozark County	5	800	Level flood plain below high cliffs.	Limestone region alluvial soil.	River-bottom hardwoods culled over for best timber several years ago.
Douglas County	7	900	Small creek valley	Limestone rocks, gravelly to stony dry soil.	Trees on edges of small openings along creek and among adjacent upland hardwoods.
Do	2	1, 200	Summit of broad ridge	Limestone region, stony clay loam soil.	Open-grown trees along a fence.
Wisconsin, Iowa County.	11	1, 100	Steep slopes of narrow ravine.	Driftless area, limestone region, clay loam soil.	Woodlot of mixed hardwoods.

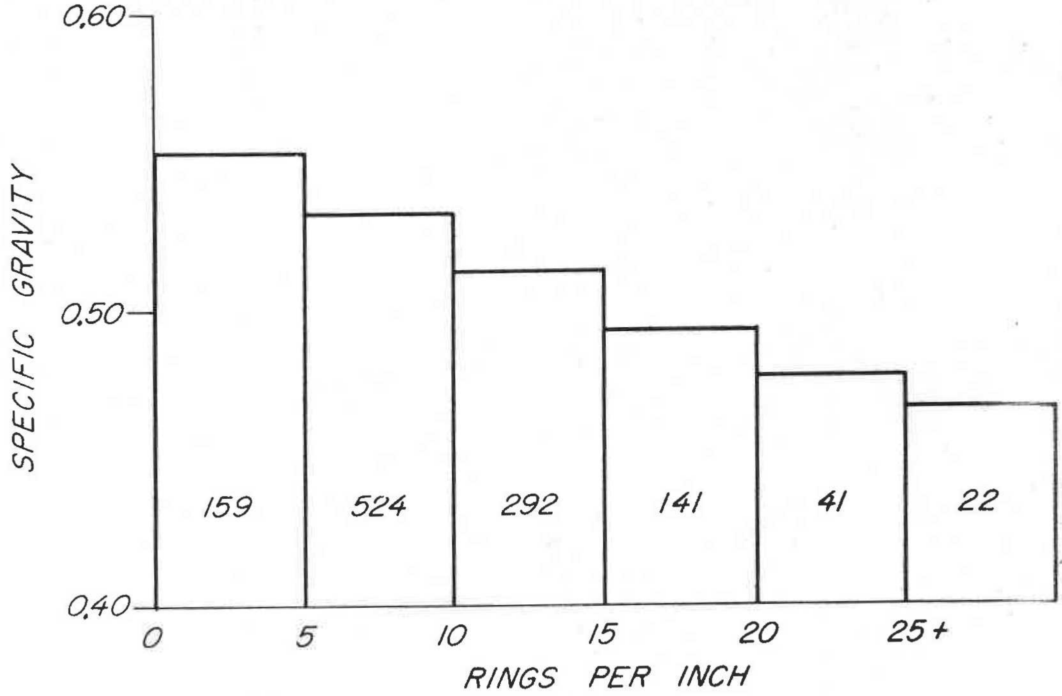

Figure 18.—Relationship of specific gravity to rate of growth (rings per inch) range of all black walnut specimens. The figure on each bar indicates the number of specimens in that particular range of rings per inch.

ing the highest values (table 11). It is believed that infiltrated materials tended to influence the hardness of the heartwood as well as the specific gravity.

TABLE 11.—*Average hardness values for three surfaces of green material at the 8- to 19-foot height, black walnut*

Material	End	Tangential	Radial
Forest-grown trees:	*Lbs.*	*Lbs.*	*Lbs.*
Heartwood	918	901	880
Sapwood	821	731	719
Weighted average	899	853	844
Open-grown trees:			
Heartwood	1, 033	1, 040	1, 003
Sapwood	881	773	801
Weighted average	1, 005	969	961

Except in plantations, management is desirable that provides conditions similar to those under which open-grown black walnut occurs. Black walnut can be grown rapidly in rather open stands, in margins of woodlots, and along fences. Pruning will help to develop clear trunks that in most cases will be relatively short. In slicing veneers, advantage may be taken of swellings, cross grain from tapering logs,

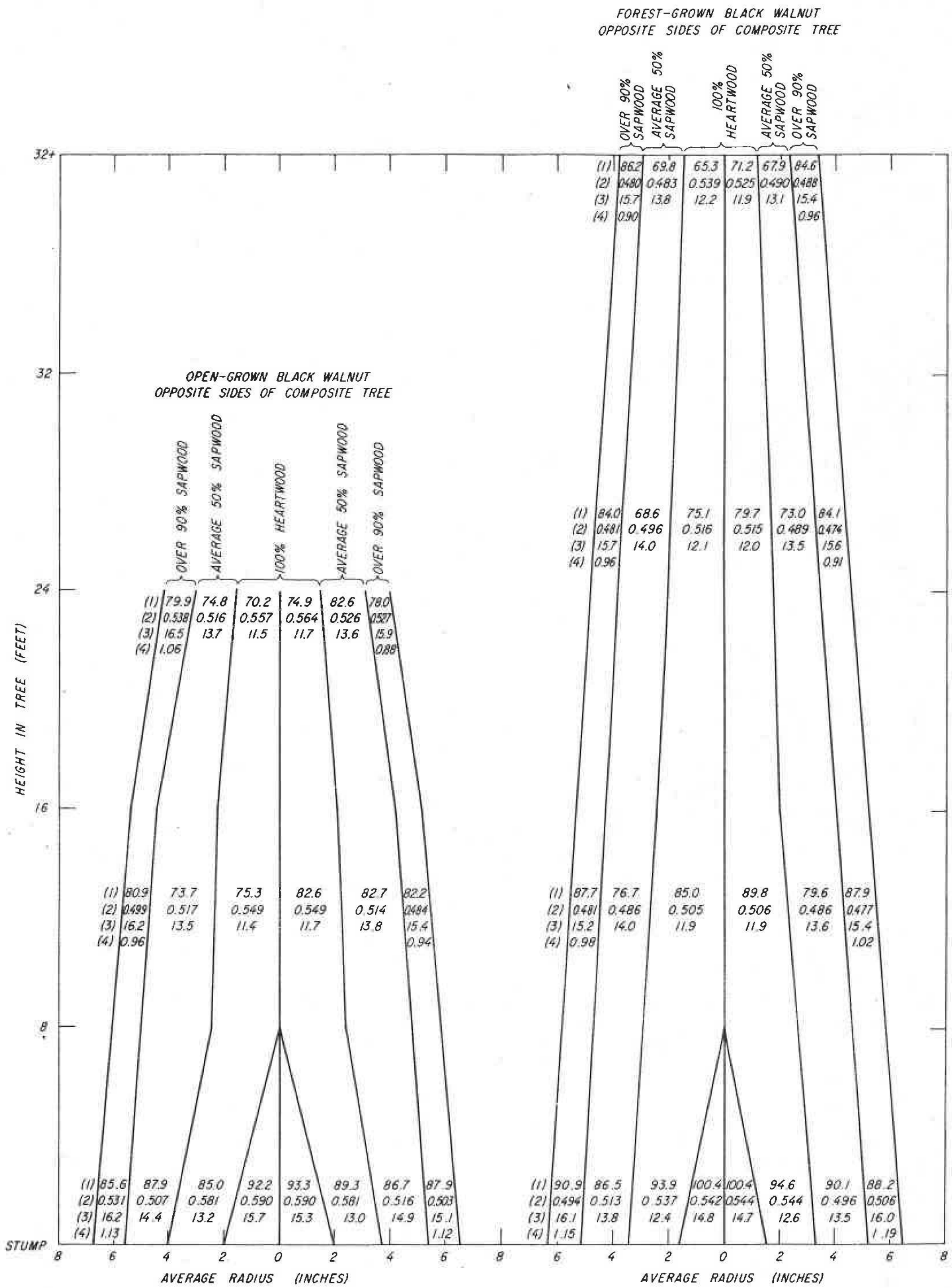

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Figure 19.—Composite diagrams of open- and forest-grown black walnut trees with average values for (1) moisture content (percent), (2) specific gravity, (3) shrinkage in volume (percent), and (4) width of sapwood (inches) at the respective heights and positions in the cross section.

and other irregularities in order to obtain patterns suitable for matched figure. Diameter growth of the trees studied ranged from 5 to 23 rings per inch. A growth rate of 8 to 10 rings per inch will provide highly uniform material with above-average-strength properties (*37*).

Diffuse-Porous Hardwoods

Among diffuse-porous hardwoods, the species studied most thoroughly were sugar maple (*Acer saccharum*), yellow-poplar (*Liriodendron tulipifera*), quaking aspen (*Populus tremuloides*), and big-tooth aspen (*Populus grandidentata*).

Sugar Maple

Specific gravity determinations based upon 1,887 samples from 70 trees, representing 12 stands in 8 States, show the variations in weight most likely to be found in this species (fig. 20). Old-growth stands, second-growth stands, and woodlots containing trees of mixed ages and sizes were investigated.

The investigations have supplied information with respect to the following subjects: (1) The characteristics of the wood, as shown by specific gravity and hardness tests, from widely separated localities; (2) differences in wood from old- and second-growth stands, including open-grown trees; (3) causes of variation in the wood of sugar maple; and (4) the variability in the weight of sugar maple.

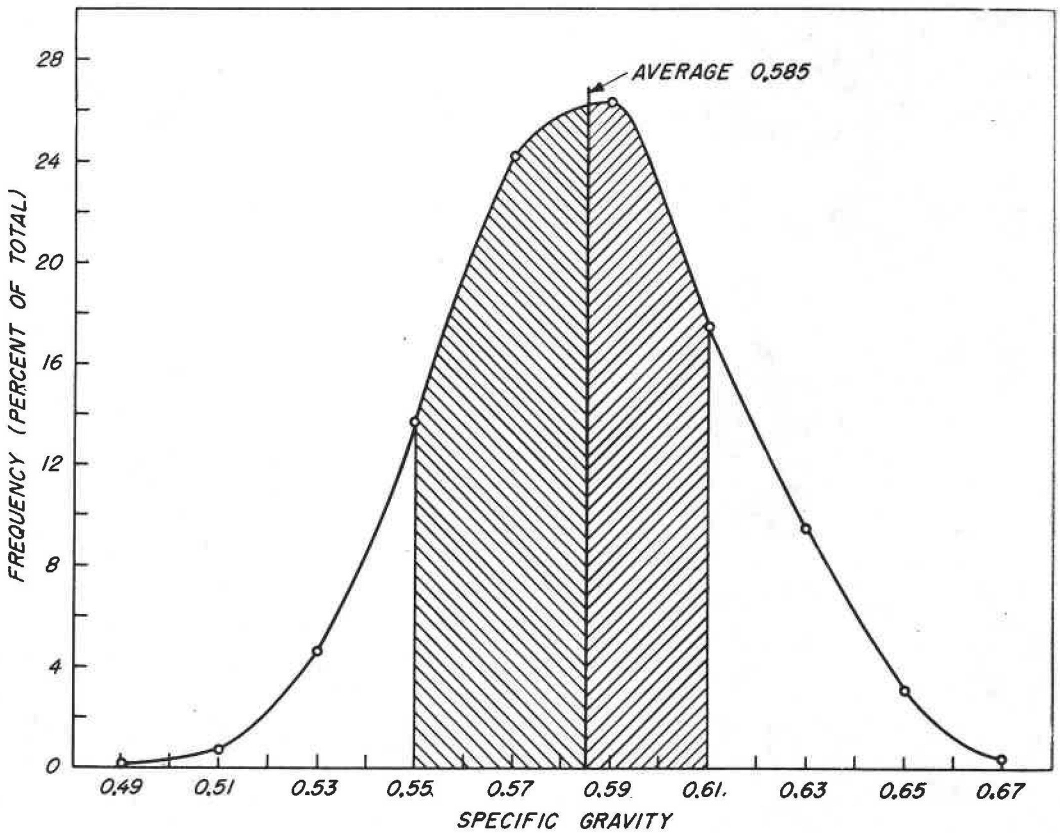

Figure 20.—Variation in specific gravity of sugar maple, based on material from 12 stands in 8 States.

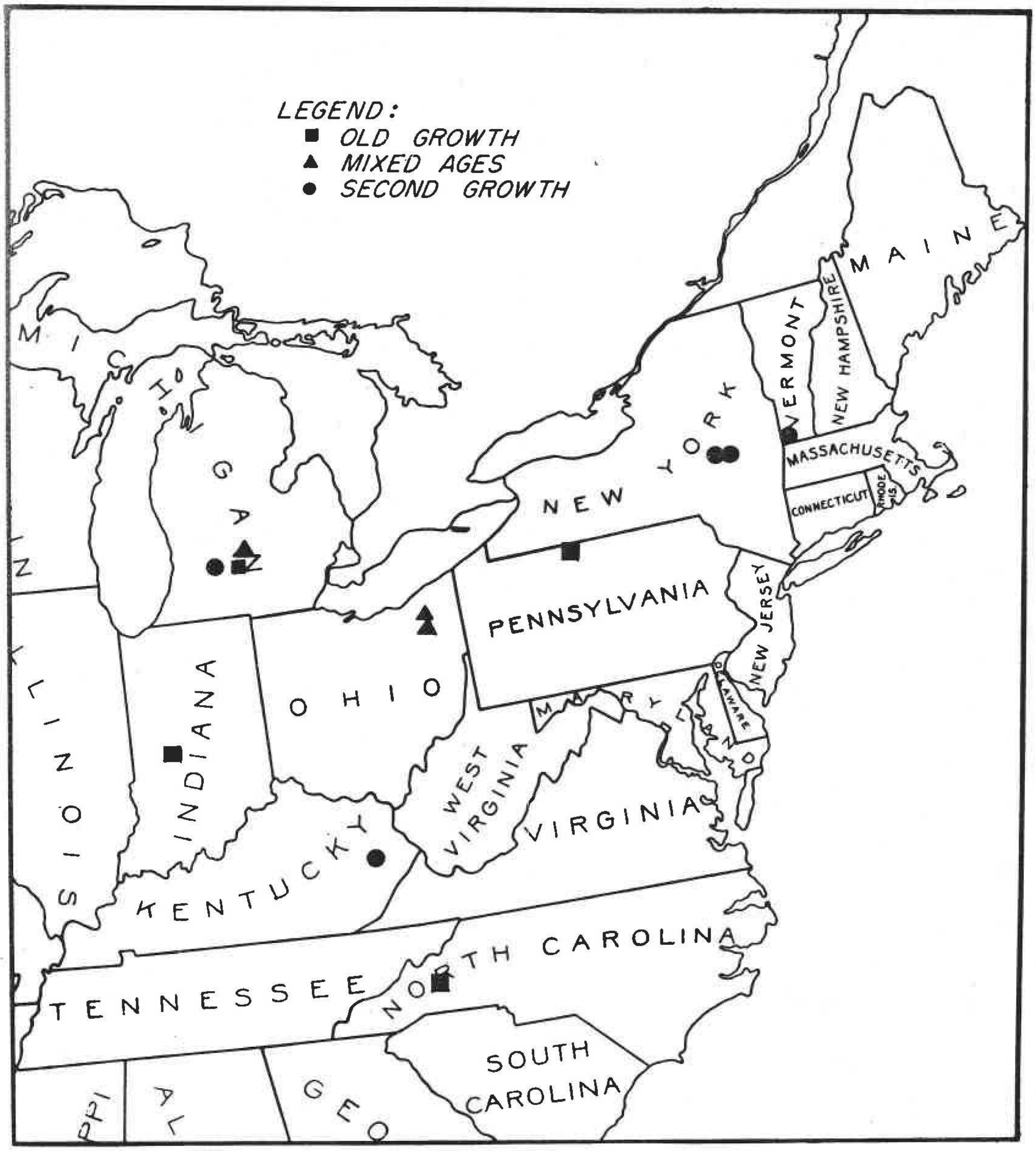

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Figure 21.—Location of sampled sugar maple stands.

The locality of growth in itself is not an important factor in determining the quality of sugar maple. This is shown by the results of specific gravity and hardness tests of specimens from Vermont, New York, Pennsylvania, Ohio, Michigan, Indiana, Kentucky, and North Carolina (fig. 21). Both old- and second-growth stands from these widely scattered sources were investigated (*36*).

Specific gravity determinations, which also indicate the relative strength and hardness of sugar maple, show a considerable range in the weight of the wood for nearly all the stands investigated (table 12). Diagrams illustrating the specific gravity variability of sugar maple in 12 different stands are compared in figure 22. To insure comparison on an equal basis, only material taken between heights of 8 and 16 feet above the stump in each tree is included.

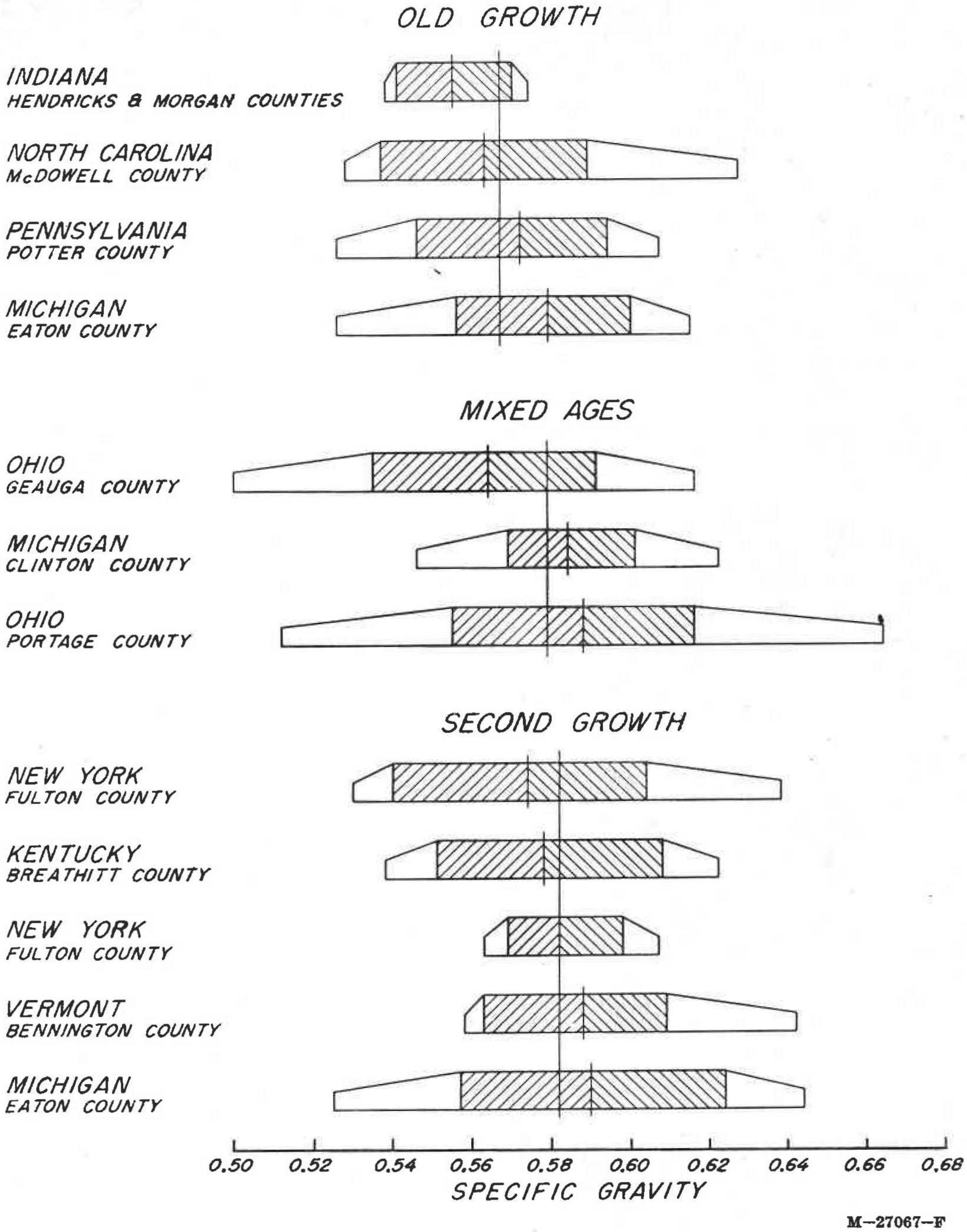

Figure 22.—Specific gravity values of sugar maple from old-growth, second-growth, and mixed stands in different localities. The total specific gravity range in each stand is shown by the limits of the accompanying diagram; the crosshatched portion represents the range of the middle 75 percent of the test pieces; the short vertical line in each diagram shows the average specific gravity for the stand; and the longer vertical line in each group represents the average for the group.

From the data presented, no general prediction can be made as to the superior or inferior quality of maple from any particular locality or region. This statement is supported by the results of earlier specific gravity determinations upon 75 random samples of maple flooring obtained from various localities throughout Wisconsin and Michigan. The specific gravity range as shown by the Wisconsin tests was from 0.55 to 0.67, and by the Michigan tests from 0.53 to 0.65.

TABLE 12.—*Comparison of specific gravity*[1] *values of sugar maple at a height of 8 to 16 feet in trees from various stands and localities*

Character of stand and locality	Total range	Range of middle three-fourths	Stand average
Old growth:			
Indiana, Hendricks and Morgan Counties	0.538–0.574	0.541–0.570	0.555
North Carolina, McDowell County	.528–.627	.537–.599	.563
Pennsylvania, Potter County	.526–.607	.546–.594	.572
Michigan, Eaton County	.526–.615	.556–.600	.579
Average			.567
Mixed ages:			
Ohio:			
Geauga County	.500–.616	.535–.591	.564
Portage County	.512–.664	.555–.616	.588
Michigan, Clinton County	.546–.622	.569–.601	.584
Average			.579
Second growth:			
New York:			
Fulton County	.530–.638	.540–.604	.574
Do	.563–.607	.569–.598	.582
Kentucky, Breathitt County	.538–.622	.551–.608	.578
Vermont, Bennington County	.558–.642	.563–.609	.588
Michigan, Eaton County	.525–.644	.557–.624	.590
Average			.582

[1] Based on volume when green and weight when ovendry.

Average values alone indicate some differences in the wood from different localities, but the differences are small and probably accidental. The minimum and maximum averages of the stands investigated, including both old and second growth (except open-grown trees), were only about 4 percent below or above the middle of the range of the averages. The variations themselves, even when restricted to the middle three-fourths of the specimens, overlap to such an extent that the selection of maple on the basis of locality alone would not insure distinctly superior timber.

Hardness values show the load in pounds required to embed a ball 0.444 of an inch in diameter into the wood to a depth of one-half of its diameter. Separate tests were made on radial, tangential, and end surfaces of the specimens.

Hardness evaluations were made on green material from five of the stands investigated for specific gravity. They were the old-growth stands in North Carolina, Pennsylvania, and Indiana, and second-growth stands in Kentucky and Vermont. These results are presented in table 13. The findings showed no significant differences in the hardness of the wood among the old-growth stands, the average variation of both end hardness and side hardness being less than 5 percent in either direction from the median. In the two second-growth sugar maple stands, the difference in average hardness values was even smaller than it was in the old-growth stands.

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In other work, wood from the short boles (6 to 9 feet) of open-grown sugar maple from Rutland County, Vt., greatly exceeded the hardness and specific gravity of any sugar maple formerly tested (*53*). Samples at 12 percent moisture content gave end-hardness values of 2,570 pounds, compared with 1,840 pounds for forest-grown sugar maple, and end- and side-hardness values of 2,180 and 1,450 pounds, respectively. The wood from the open-grown trees averaged as high in specific gravity as dogwood, which is the standard for use as textile shuttles. Therefore, sugar maple was recommended as an alternate species for this purpose.

TABLE 13.—*Evaluation of hardness of sugar maple, in green condition, from various localities*

Character of stand and locality	End hardness	Side hardness		
		Radial	Tangential	Average of radial and tangential
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*
Old growth:				
Indiana	1, 006	931	925	928
Pennsylvania	1, 035	923	918	920
North Carolina	1, 060	1, 035	999	1, 017
Second growth:				
Kentucky	1, 154	1, 084	1, 060	1, 072
Vermont	1, 200	1, 103	1, 087	1, 095

In the specific gravity determinations of old and second growth, it was shown that although average differences in the weight of wood from different stands were not significant, there was a tendency toward heavier wood in the second-growth stands. The hardness values, while from only three of the old-growth stands and two of the second-growth stands, amplify somewhat the differences in old growth and second growth, with the second-growth material averaging much harder (table 13).

The weight (specific gravity) of sugar maple when moisture free is an index of the actual amount of wood substance present per unit volume of wood. Favorable growth factors, such as fertile soil, plentiful soil moisture, and ample growing space both for roots and crown, exert an influence upon the rate of growth and development of a tree and the character of the wood currently formed.

While the rate of growth of a piece of sugar maple may not in itself afford a measure of the relative weight of hardness, it may be useful in appraising the relative quality of the wood if it is considered with respect to the development of the tree or stand. The explanation of this relationship is as follows:

The wood produced by young sugar maple is heavy and hard whether the growth rate of the trees is rapid or slow. These trees continue to produce wood of similar quality as long as the growth rate is well sustained or increased. When, however, retardation of growth

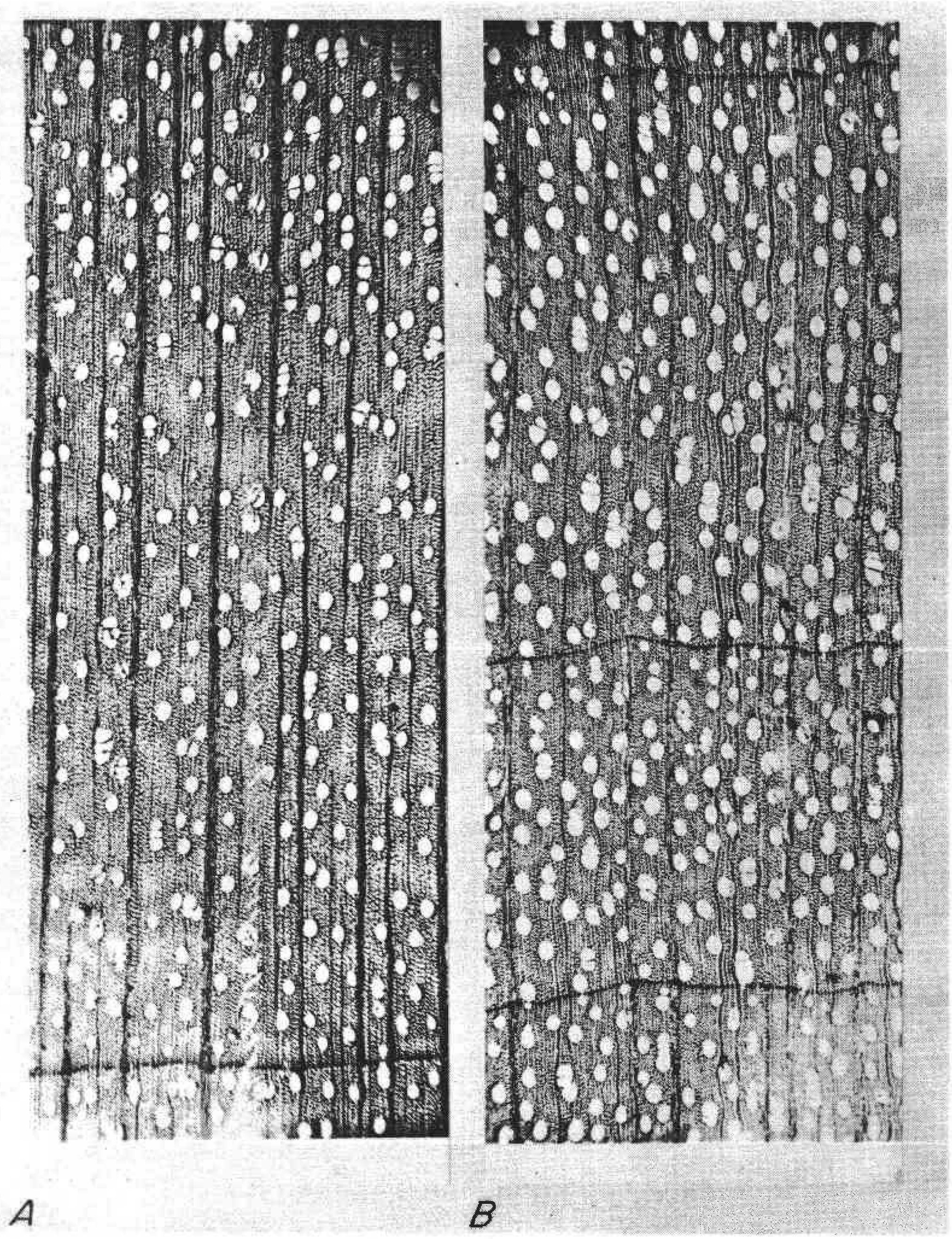

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Figure 23.—Cross sections of sugar maple, showing pore content per unit area: *A*, High specific gravity; *B*, low specific gravity.

occurs as a result of crowding and reduction in size of the crowns, the amount of wood formed each year is less. Moreover, because of the smaller proportion of dense thick-walled cells and a larger number of pores, it is relatively lighter and softer (fig. 23). This explanation accounts for the lower density and more open structure of wood from old-growth stands that have been growing for many years under conditions of severe competition for space, water, and nutrients (fig. 24). Even in second-growth stands, close stocking and severe crowding will result in slower growth and a progressive falling off in the weight and hardness of the wood (table 14) (*58*).

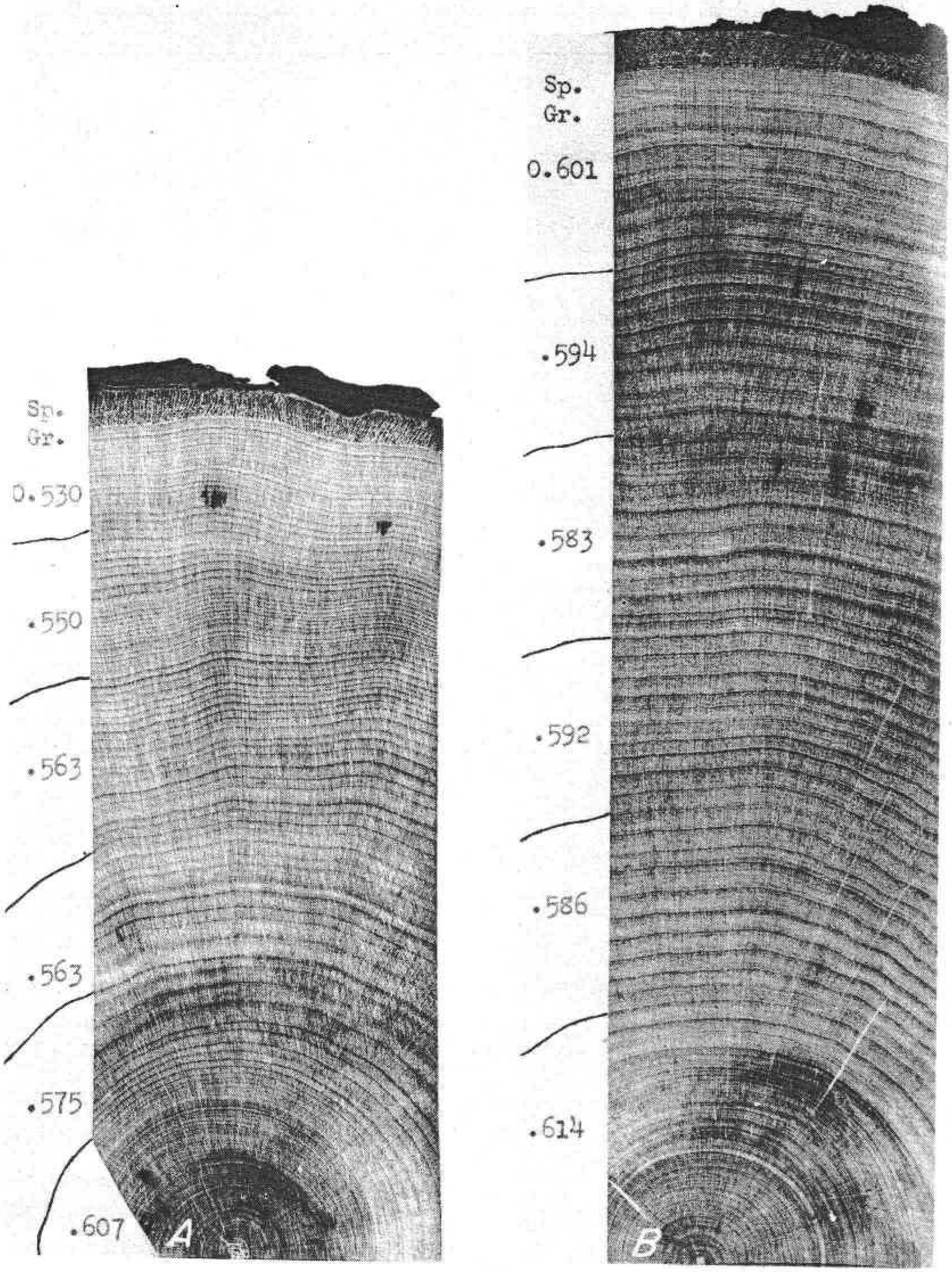

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Figure 24.—Growth and specific gravity in cross sections of sugar maple under different conditions: *A*, This tree, 134 years old, produced wood of high specific gravity until the period of maximum rate-of-diameter growth was reached. Afterwards, as a result of crowding and reduction of crown size, specific gravity decreased; *B*, this 100-year-old tree had more growing space, developed a larger crown, maintained rapid diameter growth, and produced wood of uniformly high specific gravity.

TABLE 14.—*Average specific gravity*[1] *values for successive growth periods in sugar maple trees*

GROUP 1

Locality	Trees	Average age	Initial growth period		Final growth period	
			Annual rings per inch	Specific gravity	Annual rings per inch	Specific gravity
Michigan:	*No.*	*Yrs.*	*No.*		*No.*	
Eaton County	3	180	24. 5	0. 581	26. 5	0. 544
Do	4	95	14. 6	. 584	22. 6	. 562
Ohio:						
Geauga County	7	133	19. 1	. 570	25. 9	. 535
Portage County	4	145	16. 9	. 580	29. 4	. 542
Average			18. 8	. 579	26. 1	. 546

GROUP 2

Locality	Trees	Average age	Initial growth period		Final growth period	
			Annual rings per inch	Specific gravity	Annual rings per inch	Specific gravity
Michigan:						
Eaton County	2	165	22. 5	0. 588	18. 5	0. 584
Do	2	84	13. 2	. 606	17. 0	. 603
Clinton County	6	152	18. 0	. 586	14. 9	. 579
Ohio, Geauga and Portage Counties	6	130	16. 5	. 602	15. 1	. 589
New York:						
Fulton County	5	82	11. 1	. 574	14. 0	. 568
Do	5	56	8. 8	. 581	17. 4	. 583
Average			15. 0	. 590	16. 2	. 584

[1] Based on volume when green and weight when ovendry.

Yellow-Poplar

Yellow-poplar was collected in North Carolina, Tennessee, Kentucky, and West Virginia. Samples representing the entire cross section of the trunk were taken at intervals throughout the merchantable length of 60 trees from 9 stands. The material was collected not only from typical old- and second-growth trees, but also from young, vigorous trees that had come into the old-growth stands as replacements.

For purposes of comparison, the trees were classified into three groups according to the character of the stands; namely, old growth, young trees in old-growth stands, and second growth. To make this comparison on an equal basis, only material taken between the heights of 8 and 20 feet was used. Results of the specific gravity determinations are presented in table 15 and figure 25.

Wood from the old-growth trees gave a lower average specific gravity than that from the younger trees in the same forest. The average specific gravity range of the middle three-fourths of the samples from the old-growth trees was from 0.32 to 0.39 and in the younger trees from 0.36 to 0.46. In typical second-growth stands on

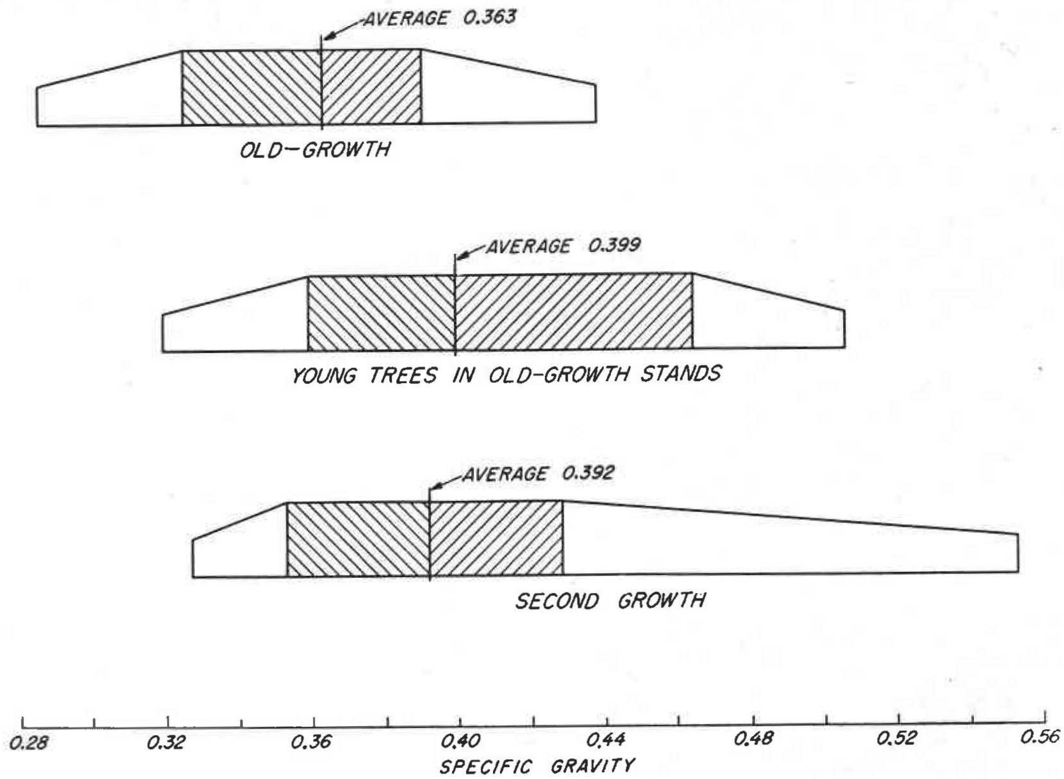

Figure 25.—Specific gravity values of yellow-poplar from old-growth, second-growth, and young trees in old-growth stands. The total range in specific gravity in each type of growth is shown by the limits of the accompanying diagram, and the crosshatched portion represents the range of the middle 75 percent of the specimens; the short vertical line in each diagram shows the average specific gravity for the type of growth.

cutover areas, the middle three-fourths of the samples ranged in specific gravity from 0.35 to 0.43 and averaged a little lower than the young forest-grown trees. This lower average is explained by the occurrence of wide annual rings that contain wood of lower specific gravity near the pith in trees originating in fairly open stands.

Although the wood from second-growth yellow-poplar shows as much variation in specific gravity as that from old growth, the average specific gravity is higher for second-growth than for the old-growth material. In other words, the average old-growth yellow-poplar trees contain a preponderance of lighter and softer wood, and the young, vigorous trees growing either in old-growth or in typical second-growth stands usually contain the heavier pieces.

A comparison of the hardness of old- and second-growth yellow-poplar appears in table 16. The data show that the hardness values are more variable than the specific gravity values. For example, while second-growth yellow-poplar averages 8 percent heavier than the old-growth wood, it is 42 percent harder on the end grain and 33 percent harder on the side grain. Ordinarily a difference in specific gravity of 8 percent would be expected to give a difference in hardness of only about 20 to 25 percent. This means that rather small differences in the specific gravity of yellow-poplar may be significant in manufacturing articles in which either ease of working or resistance to indentation are important.

Although differences in climate, soil, and elevation occur among the various localities from which the yellow-poplar was collected,

TABLE 15.—*Comparison of the specific gravity values*[1] *of yellow-poplar at a height of 8 to 20 feet in the trees from different stands and localities*

OLD GROWTH—150 TO 300+ YEARS

Locality	Trees	Total range of specific gravity	Range in specific gravity of middle three-fourths	Average specific gravity of stand
	No.			
Kentucky, Breathitt County	14	0.321–0.416	0.342–0.408	0.378
Tennessee:				
Scott County	2	.331– .420	.348– .410	.377
Sevier County	5	.334– .423	.345– .398	.371
North Carolina, Jackson County	4	.293– .438	.324– .400	.359
West Virginia, Greenbrier County	4	.285– .415	.313– .383	.349
YOUNG TREES 70 TO 150 YEARS OF AGE IN OLD-GROWTH STANDS				
Tennessee, Scott County	4	0.359–0.506	0.372–0.482	0.430
North Carolina, Jackson County	2	.342– .414	.365– .397	.381
West Virginia, Greenbrier County	5	.319– .429	.344– .409	.379
SECOND GROWTH—75 YEARS OR LESS				
West Virginia, Randolph County	5	0.327–0.553	0.342–0.476	0.409
North Carolina:				
Buncombe County	5	.358– .404	.369– .401	.384
Yancy County	5	.332– .436	.346– .418	.381
Kentucky, Breathitt County	5	.332– .419	.357– .411	.381

[1] Based on volume when green and weight when ovendry.

no definite correlation was established between these factors and specific gravity or hardness. The forest type for all the stands was mixed hardwoods. The areas from which samples were selected in North Carolina contained a relatively high percentage of yellow-poplar. All sites were classified as quality II, except that in West Virginia, which was quality III.

Examination of the data presented for the five old-growth stands in table 15 seems to indicate that yellow-poplar from Kentucky and Tennessee is heavier than that from either North Carolina or West Virginia. This same order is found for the young trees in old-growth stands. The order is reversed, however, when the values for the four second-growth stands are studied. Although the average specific gravity values for both old and young growth show differences in the wood from the various localities, this does not indicate that selection of yellow-poplar timber on the basis of locality alone would insure obtaining the quality desired for any specific need of manufacture.

The average specific gravity for successive periods in the growth of four yellow-poplar trees that averaged 280 years in age was as follows:

Growth period	*Annual rings per inch*	*Specific gravity*
Initial growth	17. 1	0. 354
Intermediate period of suppression	31. 3	. 342
Final period of accelerated growth	20. 6	. 356

Growing space influences the root and crown development of the tree and thereby its ability to obtain and assimilate plant food and water from the soil for the formation of wood. Management of yellow-poplar to obtain about 10 growth rings per inch no doubt will produce a very satisfactory product of somewhat higher specific gravity than that of typical old-growth timber.

While in general there is not a very close relationship between rate of growth (rings per inch) and specific gravity in yellow-poplar, a study of the growth rate may be useful in appraising the quality of the wood of a stand if the stand's history of development is considered. In yellow-poplar, the wood lowest in specific gravity usually consists of that part of old-growth trees in which the diametrical growth of the trunks has been exceedingly slow. The wood of highest specific gravity has been found in young trees that maintain a fairly rapid-to-moderate growth rate. In stands originating in the open, very wide rings near the center of the tree trunk are likely to contain wood of somewhat lower than average specific gravity. Wood of low specific gravity in old trees results when competition for moisture, soil nutrients, and light causes a reduction in the size of the crowns and a marked narrowing of the annual growth rings. Even in second-growth stands, overstocking and severe crowding will exert a similar influence. Not only is the amount of wood actually formed much less but also, since it contains a greater proportion of large thin-walled cells, the wood is lighter and softer (fig. 26).

The relationship between specific gravity and rate of growth (rings per inch) is illustrated in figure 27. In general, the specific gravity is lower at each end of the diagrams; that is, in specimens showing

TABLE 16.—*Average hardness of yellow-poplar from old- and second-growth stands* [1]

Character of growth and locality	Specific gravity	End hardness	Side hardness: Radial	Side hardness: Tangential	Side hardness: Average of radial and tangential
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Old growth: Tennessee and Kentucky	100	100	100	100	100
Second growth: West Virginia, North Carolina, and Kentucky	108	142	130	135	133

[1] In green condition. Each old-growth value is rated 100 percent, and the corresponding second-growth values are expressed accordingly.

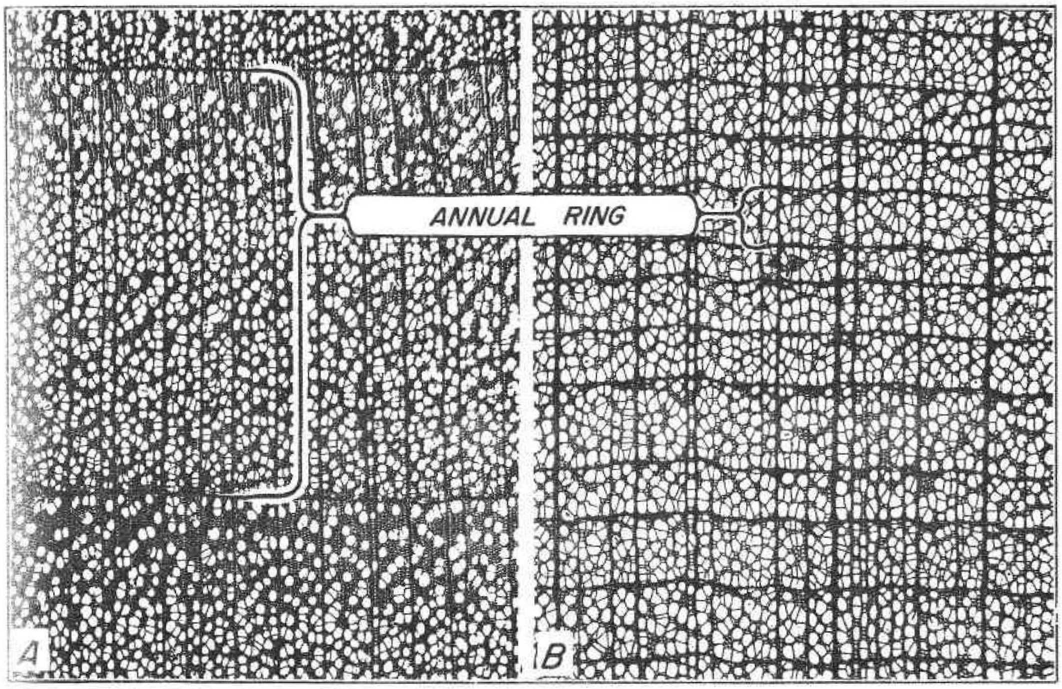

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Figure 26.—Structure of wood produced during periods of rapid and of slow growth in an old-growth yellow-popular tree: *A*, Has a specific gravity of 0.41 and was produced during the early life of the tree while it had sufficient growing space; *B*, was produced during a time when the trees of the stand were keenly competing for growing space and moisture. The wood has a specific gravity of 0.31 (based on weight and volume when ovendry).

either very fast or very slow growth. In the old-growth yellow-poplar, the highest specific gravity is in the specimens with a count of 10 to 20 rings per inch. The young trees in old-growth stands show the highest specific gravity between 10 and 15 rings per inch. The typical second-growth material shows no important variation in the wood that has more than five rings per inch (*59*).

Rate of growth in itself does not indicate the relative weight and hardness of any individual piece of yellow-poplar timber; however, as has been stated, if the history of the stand is considered, the quality of its wood may be appraised. If a timber grower desires light, soft material, he can produce it by retarding growth through competition. If, on the other hand, he desires the harder, heavier wood, he should allow young trees to maintain a fairly rapid rate of growth.

Populus Species and Hybrids

Investigations of aspen and other species of the genus *Populus* and some of their hybrids reveal somewhat different patterns of growth and specific gravity from many other hardwoods in which wide growth rings were associated with the higher specific gravity values.

Comparative specific gravity values for various species of *Populus* and hybrids are presented in table 17. Data in the table show that large variations in specific gravity were found among stands and within sites. The wide-ringed hybrids fall toward the lower end of the specific gravity range. A regression of ring width and specific gravity for the genus *Populus* appears in figure 28.

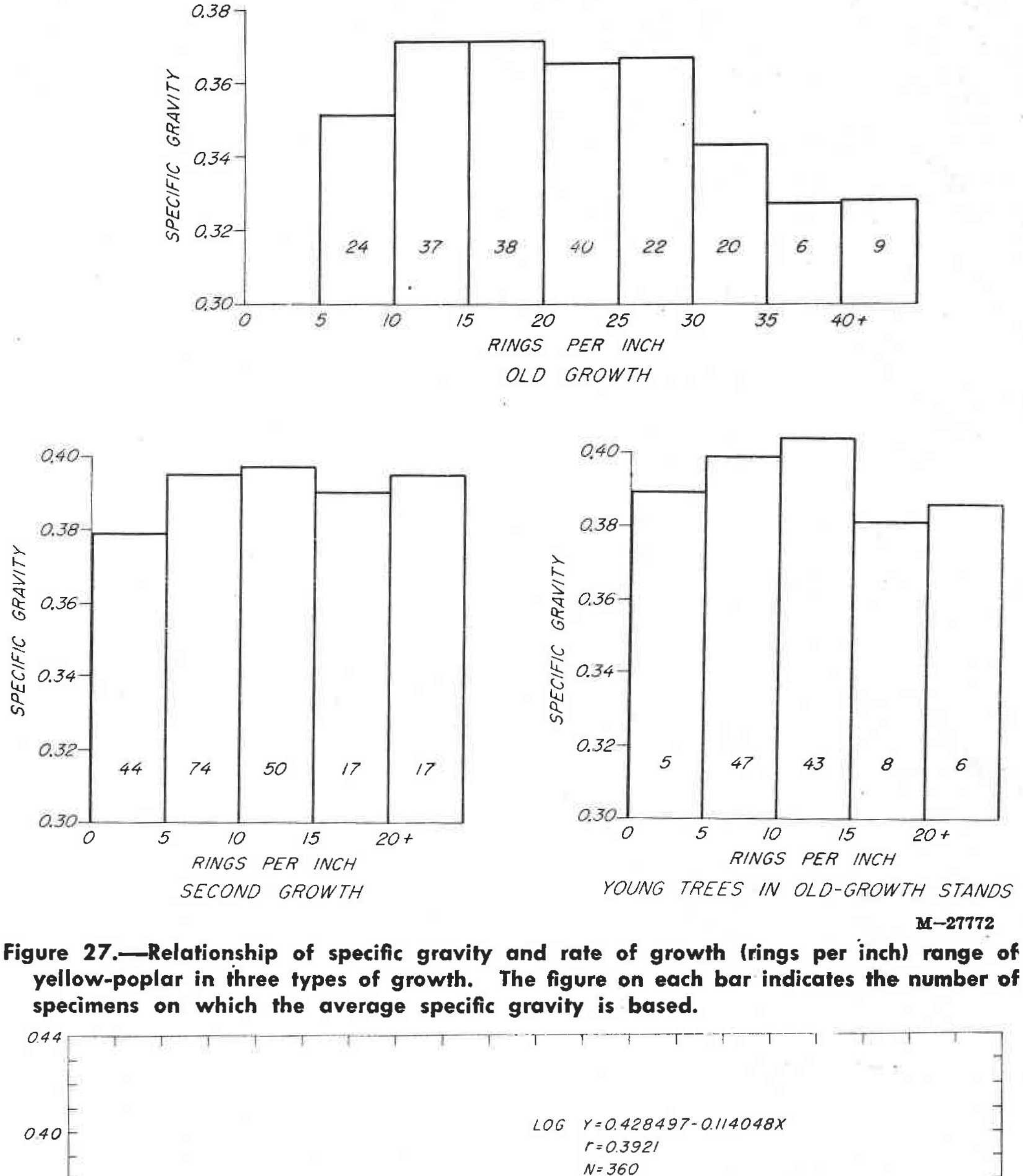

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Figure 27.—Relationship of specific gravity and rate of growth (rings per inch) range of yellow-poplar in three types of growth. The figure on each bar indicates the number of specimens on which the average specific gravity is based.

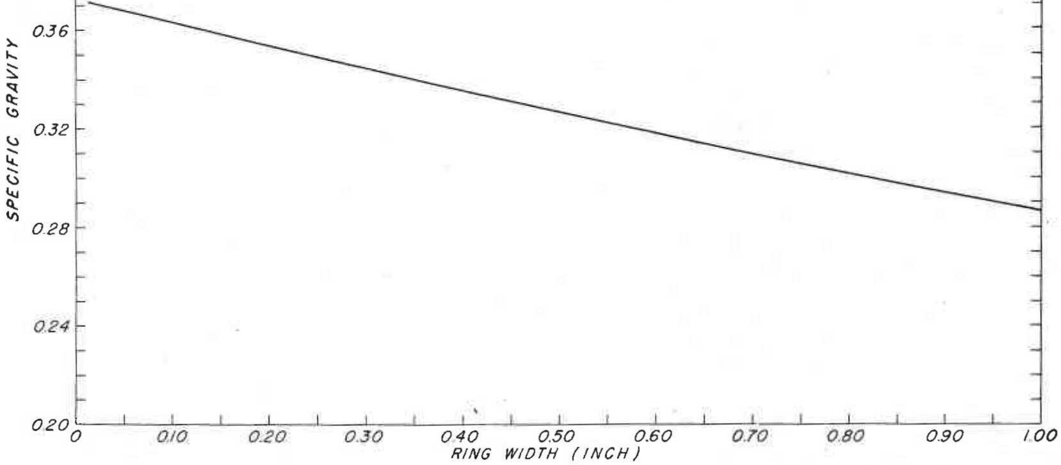

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Figure 28.—Relationship between specific gravity and ring width for 360 specimens from hybrids and 5 species of the genus *Populus*. The correlation coefficient is highly significant.

TABLE 17.—*Comparative specific gravity values for Populus hybrids and species*

Locality	Hybrids and species	Trees	Age (range)	Height in tree	Annual rings per inch (average)	Specific gravity [1] (average)
		No.	*Yrs.*	*Ft.*	*No.*	
Iowa	Sherrill hybrid	4	16– 36	4–16	4. 6	0. 328
Do	Shimek hybrid	3	25– 28	12–16	7. 6	. 368
Maine	Hybrid clones	17	7– 12	8–12	2. 8	. 322
Massachusetts	do	2	15	4– 8	1. 6	. 287
New Mexico	Quaking aspen	5	45– 55	8–16	7. 3	. 344
Wisconsin	do	5	35– 65	8–16	8. 5	. 360
Do	Quaking aspen, poor site	20	23– 25	4– 8	11. 5	. 383
Do	do	15	44– 56	4– 8	12. 6	. 368
Do	Quaking aspen, medium site	25	23– 27	4– 8	10. 9	. 391
Do	do	5	48	4– 8	10. 5	. 382
Do	do	5	54	4– 8	11. 0	. 371
Do	Quaking aspen, good site	15	20– 27	4– 8	10. 7	. 393
Do	do	5	27	4– 8	9. 5	. 444
Do	do	20	39– 48	4– 8	9. 6	. 372
Do	Bigtooth aspen, medium site	5	29	4– 8	8. 1	. 340
Do	do	5	40	4– 8	13. 0	. 400
Do	Bigtooth aspen	5	50	8–16	8. 2	. 354
Vermont	do	5	36– 45	8–16	8. 1	. 343
Do	Balsam poplar	5	25	8–16	4. 6	. 301
Alaska	do	5	------	8–16	9. 7	. 296
Do. (inland)	do	10	131–176	16–20	32. 0	. 355
Missouri	Eastern cottonwood	5	70– 90	8–16	5. 6	. 372
Washington	Black cottonwood	5	74– 85	8–16	5. 6	. 315

[1] Based on volume when green and weight when ovendry.

Tests of big-tooth and quaking aspen, made in cooperation with the Soils Department of the University of Wisconsin, showed considerable differences in average specific gravity among stands. Site quality of the areas did not show a consistent relation to specific gravity. There appeared to be a tendency for the heaviest wood to be produced on sites of intermediate quality, and somewhat lighter wood on the poorer and also sometimes on the better soils. Age of the trees, in itself, also did not show a consistent relation to the specific gravity of the wood. The heaviest wood of quaking aspen on fertile sites was in a 27-year-old stand and the lightest in a 54-year-old stand. Five trees from the 27-year-old stand produced wood that averaged 0.440, while wood from five trees from a 54-year-old stand averaged 0.371. Both groups were on good-quality sites. Some stands that grew more slowly in diameter within a site produced heavier wood than those that grew more rapidly (*77*).

Balsam poplar (*Populus balsamifera*) from Vermont and coastal Alaska had a fairly low average specific gravity (0.301 and 0.296). Another Alaska sample from farther inland was of exceedingly slow growth (32 rings per inch) and had a higher average specific gravity (0.355). Black cottonwood (*P. trichocarpa*) from Washington also had a fairly low average specific gravity (0.315). The specific gravity of eastern cottonwood (*P. deltoides*) averaged about midway in the range for the genus.

The large variations in specific gravity found among stands and within sites have an important bearing on the production of solid wood substance. For example, a specific gravity of 0.30 for a volume growth of 80 cubic feet per acre per year equals 1,497.6 pounds of dry wood substance. A specific gravity of 0.35 on the same basis equals 1,747.2 pounds, while a specific gravity of 0.40 amounts to 1,996.8 pounds and 0.45 amounts to 2,246.4 pounds. These differences may be expressed also in cords required to yield 1 ton of dry wood. Figure 29 shows that only 0.89 cord is required to produce 1 ton of dry wood substance when the specific gravity is 0.45, and 1.33 cords are required when the specific gravity is 0.30, a difference of 0.44 cord (*45*).

Many hybrid poplar clones have been used recently in experimental plantations. From these plantations, it should be possible within a few years to select those hybrids that have the most desirable characteristics for various specific uses. If any hybrids systematically produce wood of high density, they may prove to be suitable for a source of pulp, since pulp yields on a cord basis increase with an increase in the dry weight of the wood.

On the other hand, for a source of lumber or veneer, rapid growth may be desirable because of the greater economy of production from large logs and the general preference for wide boards over narrow ones, even though high strength may be lacking.

In the diffuse-porous hardwoods, a considerable difference in the pattern of ring width and specific gravity was exhibited between sugar maple, a representative of the dense broad-leaved species, and the aspens that represent the soft-textured hardwoods. While a prevalent opinion exists that wider rings in hardwoods denote higher density wood and that the reverse is true in conifers, it must be pointed out that there are many exceptions to this rule. It was shown, for exam-

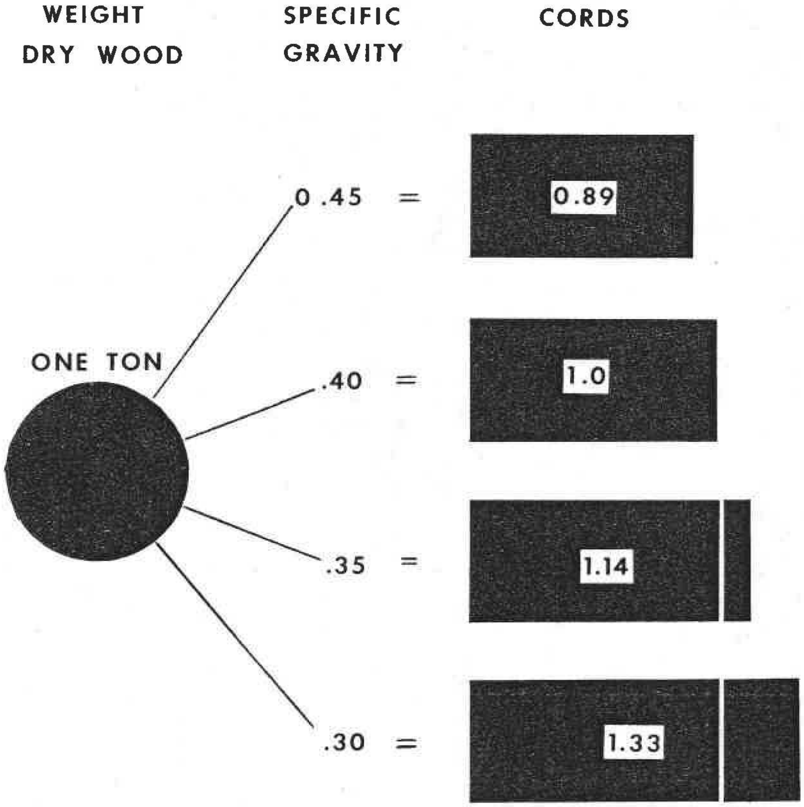

Figure 29.—Volume of *Populus* in cords required to yield 1 ton of dry wood for a specific gravity range of 0.45 to 0.30.

ple, in yellow-poplar that both old- and second-growth wood with the widest growth rings, occurring near the pith, was somewhat lower in specific gravity than the wood with narrower rings that grew immediately afterwards. A continued retardation of growth in the older trees, however, resulted in a progressive decrease in specific gravity toward the bark. Other examples besides aspen in which similar behavior has been found are red maple (*Acer rubrum*), American sycamore (*Platanus occidentalis*), and basswood (*Tilia americana*). This effect appears to be a possible site and crown relationship where, under certain conditions, young trees on a good site have an early opportunity to develop large crowns.

Summation for Broad-Leaved Species

In broad-leaved species, wood with the most uniform properties and the highest quality is produced when the trees are grown sufficiently close together while young to cause removal of lateral branches and are later thinned sufficiently to maintain or increase their rate of diameter growth. Where dry sites or soils low in fertility are involved, the silvicultural treatment should aim also to benefit the water-holding capacity and the fertility of the soil.

Forest management may not anticipate a sustained or accelerated growth in diameter throughout the entire rotation—a maintained volume increment may be all that is desired. However, with such species as hickory and ash, where the strength of the wood is of paramount importance, the additional effort required to maintain diameter increment during a practical rotation should be well worthwhile.

CONIFEROUS SPECIES (SOFTWOODS)

General Characteristics

Many coniferous species exhibit highly variable wood characteristics in response to different or changing environmental conditions. Basic causes of the differences in wood density or specific gravity, especially when occurring within a tree, are not clearly understood. Some of the more obvious factors of environment that appear to be reflected in wood quality, however, include those that are a part of the stand itself. They vary in their effect during the early years of establishment and later development of a stand. Such things as growing space affecting competition among both crowns and roots of individual trees, soil type, and soil moisture supply may cause important differences in the specific gravity of the wood. Soil type and soil moisture supply are exceedingly important, because when water is a limiting factor the actual time of growth within a growing season may vary with moisture content of the soil. Cessation of growth in a dry summer season may result in curtailment of the summerwood in the annual growth ring. Distinctive growth rings of this kind are a means of establishing a stand's history. Although abnormal growth of one dry year may not materially influence wood quality in combination with normal ring growth, the effect of a soil nonretentive of moisture or a region generally deficient in rainfall may have a marked influence. A poor site may affect lumber grades more than it does the specific gravity of the clear wood by causing short or misshapen crooked trees with cross grain and many knots.

Like the annual growth ring of ring-porous hardwoods, that of conifers consists of springwood and summerwood, with the summerwood being more prominent in such species as the hard pines, Douglas-fir, and larch. The cells that compose springwood are thin walled, whereas those of summerwood are relatively thick walled; the total weight of the wood is influenced by the proportions of the two kinds of wood layers. Both very wide and very narrow annual rings in conifers usually contain a larger proportion of springwood so that, in these species, wood consisting of either extreme of growth may be low in specific gravity. The wood of intermediate ring width usually is heavier.

Initial Growth Factors

Getting coniferous forest trees off to a good start is of paramount importance from the standpoint of the production of wood with uniformly high specific gravity (*51*). This matter is becoming increasingly important because of extensive tree-planting projects on primarily open areas where initial growth in young trees usually begins with a maximum ring width of low-density wood. Some foresters accept this kind of woody growth as inevitable up to a tree diameter of 4 to 6 inches or more. They assert that quick initial volume growth affords a larger overall surface for more adult growth in subsequent years (*68*, *72*, *74*). While this is true, the advisability of this kind of silvicultural management is open to question when compared with management that would produce initial narrow-ringed growth. Such growth was found in many old-growth forests and is present also in young trees that originate under greater competition and shade than

TABLE 18.—*The effect of crown size, as influenced by stocking, on ring width and specific gravity*[1] *in loblolly pine trees of comparable ages in the same or adjacent stands*

Locality and character of stand	Site class	Trees	Age of section (range)	Diameter at breast height (average)	Height in tree of sample	Annual rings per inch (average)	Average specific gravity		
							Trees with large crowns	Trees with small crowns	Difference between large and small crowns
Louisiana, Tangipahoa Parish:		*No.*	*Yrs.*	*Ins.*	*Ft.*	*No.*			*Pct.*
Fully stocked, old field	I	5	13–14	4.5	12	9.0	---	0.440	---
Sparsely stocked, old field	I	5	9–13	---	12	3.2	0.391	---	12.5
South Carolina, Berkeley County:									
Dense, mixed with hardwoods	I	5	21–25	10.2	12	6.0	---	.470	---
Medium stocking	II	5	19–24	12.0	12	4.7	.436	---	7.8
Sparsely stocked, old field	I	5	18–25	17.8	12	3.2	.413	---	13.8
Texas, Newton County:									
Well-stocked codominant trees	II	5	17–18	5.0	12	4.3	---	.453	---
Well-stocked dominant trees	II	5	15–18	8.0	12	2.5	.422	---	7.3

[1] Based on volume when green and weight when ovendry.

exists in young plantations. This latter second-growth pattern is more difficult to attain in establishing new forests on open land (*52*).

Open-grown stands will produce merchantable-size trees in a shorter length of time than dense stands, but the average annual production per acre will not necessarily be greater. Moreover, trees from widely spaced plantations contain much larger knots than those grown under crowded conditions. Branches too are larger and more extensive so that more wood substance is wasted in harvesting and manufacture (*61*). Not only is the wide-ringed core of lower density, but also the wood structure is typically inferior to that of slower growth. Severe warping occurs if such wood is used for lumber or building materials (figs. 30 and 31). Wood grown under short rotation management is suitable for fiber products only (*34*, *25*).

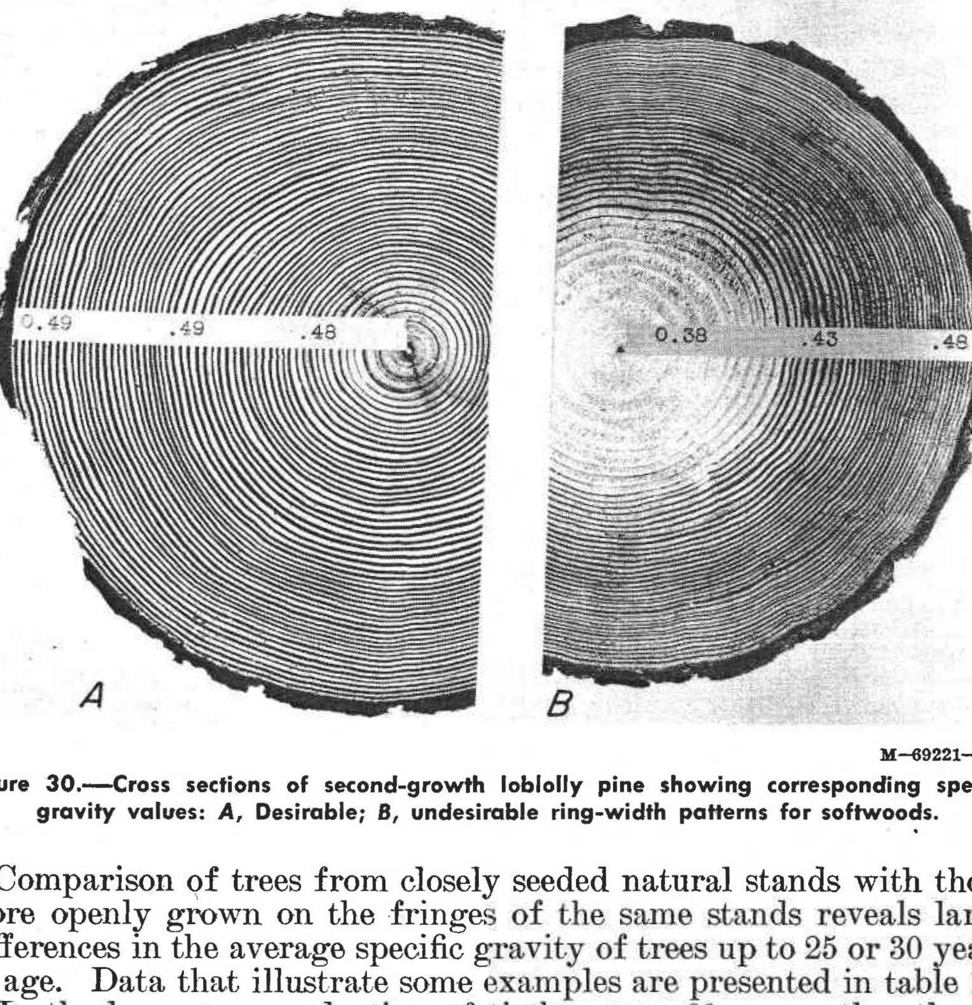

Figure 30.—Cross sections of second-growth loblolly pine showing corresponding specific gravity values: *A*, Desirable; *B*, undesirable ring-width patterns for softwoods.

Comparison of trees from closely seeded natural stands with those more openly grown on the fringes of the same stands reveals large differences in the average specific gravity of trees up to 25 or 30 years of age. Data that illustrate some examples are presented in table 18.

In the long run, production of timber on a 60-year rather than a 30-year rotation in southern pine may not necessarily be more expensive. The short rotation requires two planting operations to one for a 60-year stand. With a 60-year rotation, natural seeding methods may be used for succeeding crops. In naturally seeded stands, natural selection will eliminate certain undesirable trees, and others can be removed in thinnings. With many stems per acre in the young stand, trees can be selected for seed and the final cut can be of wood of a quality best suited for the most exacting uses. A long look ahead is desirable in forest management.

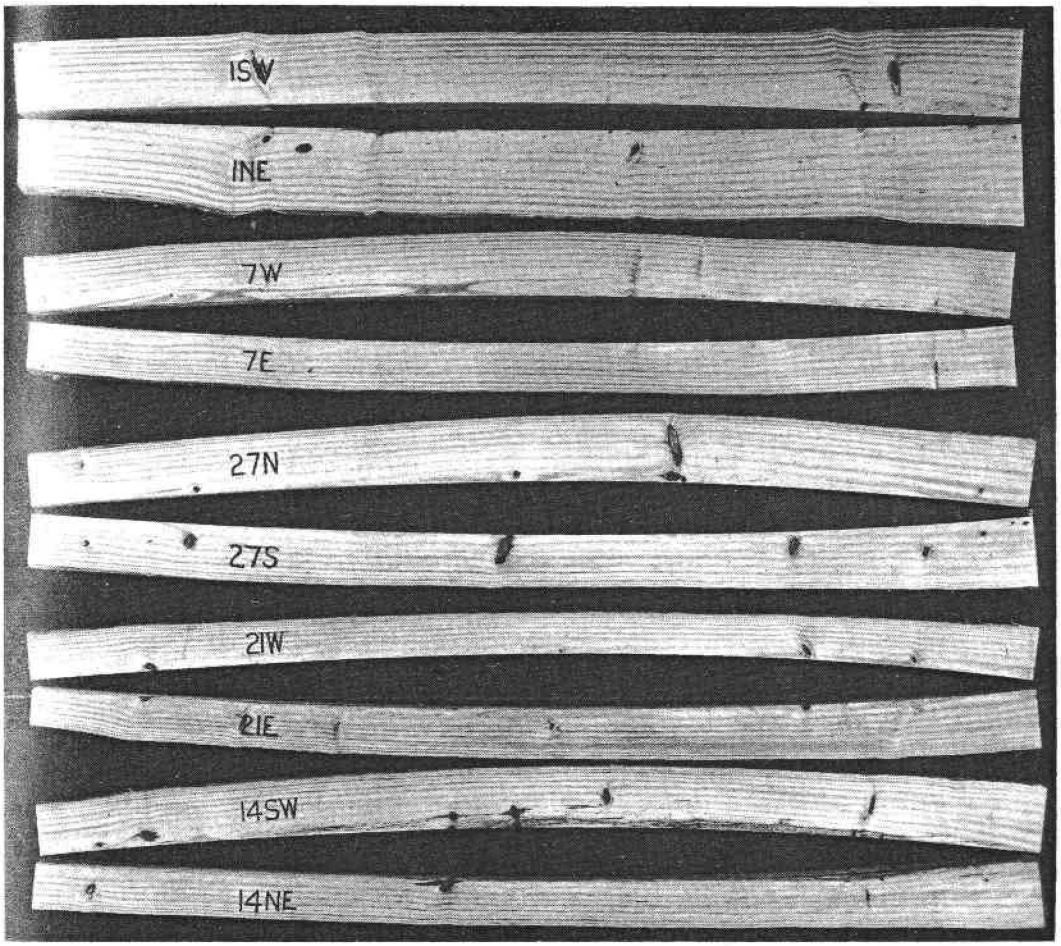

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Figure 31.—Crook that occurred during drying of plantation-grown slash pine with initially wide growth rings.

Effect of Thinnings

Trees released when surrounding trees are removed in thinnings or partial cutting respond to this more open environment by stimulated crown development and the formation of wider growth rings along the length of the bole. Often the wood of accelerated growth is of higher specific gravity than that formed just prior to thinning, but sometimes there is a noteworthy decrease in specific gravity (*48*). The accompanying diagrams, figures 32 and 33, show alternating specific gravity changes with corresponding changes in ring width.

Slowly growing longleaf pine (*Pinus palustris*) trees—80 to 100 years of age—in Walton County, Fla., responded by greatly increased growth during a 5-year period after larger trees were logged off. Current ring width of sample trees averaged 0.023 inch (43 rings per inch) when released. Ring width accelerated to 0.08 inch, and the specific gravity increased 6 percent over that of the radial inch preceding release (fig. 32). In the same area, groups of small unreleased trees had continued to grow at an average ring width of 0.024 inch, yet they were producing wood as heavy as the new growth of the released trees. The specific gravity of these trees, however, had decreased about 9 percent from that of the preceding 15-year period for which ring width equaled 0.029 inch.

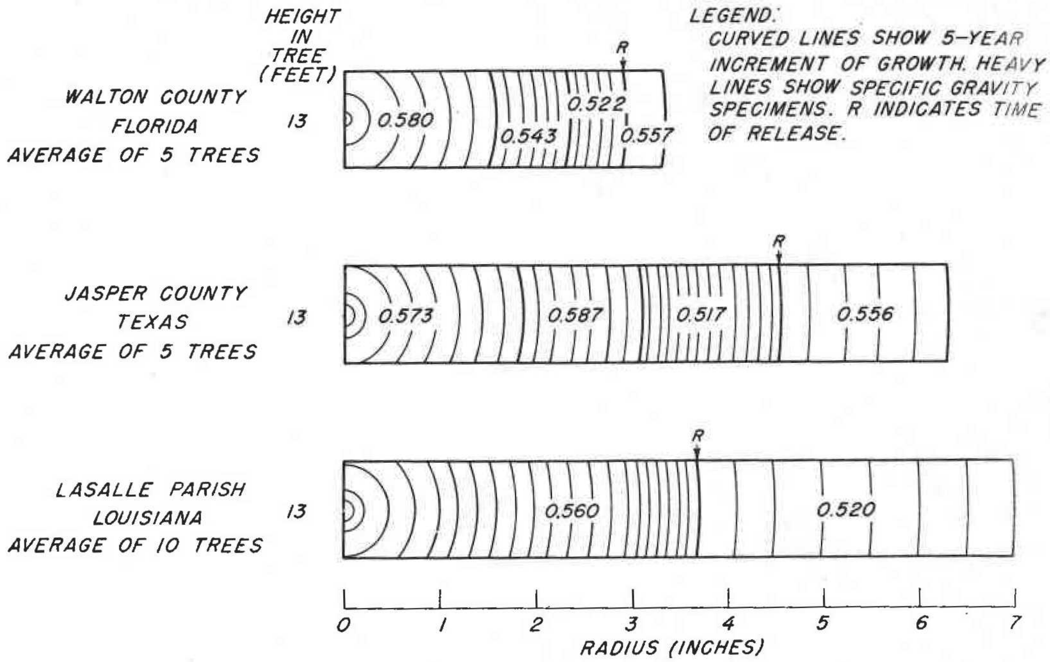

Figure 32.—Specific gravity changes with accelerated growth in longleaf pine trees.

In Jasper County, Tex., longleaf pines 125 to 200 years of age, left when the old-growth stand was logged, responded to release over a 25-year period by a change in average ring width from 0.022 to 0.071 inch. Specific gravity of the wood that had been decreasing toward the bark before logging increased an average of 8.1 percent during the 25 years of release (fig. 32).

During a 36-year period following release, 10 longleaf pine trees in an old-growth forest in LaSalle Parish, La., decreased in average specific gravity by 6.4 percent at the 13-foot height (fig. 32). These trees were each sampled at three heights—1, 13, and 26 feet. The specific gravity decrease was least at the base—about 4 percent—and greatest at 26 feet—8 percent (table 19). The average increase in diameter growth of these trees was 178 percent at the 13-foot height (*35*).

In the three longleaf pine areas just discussed, it may be seen that accelerated growth following release sometimes resulted in an increase in specific gravity and sometimes in a decrease, and still at other times, a considerable fluctuation occurred.

In an old-field stand of shortleaf pine (*Pinus echinata*) in North Carolina, diameter growth had become greatly suppressed because of crowding before the stand was 35 years old. At that age, trees of sizes suitable for telephone poles were cut. This cutting released some trees but not others. Those released increased their diameter growth during a 10-year period to more than double that of the preceding 10 years (fig. 34). The specific gravity of the wood of released growth, however, decreased in four out of five trees sampled. The average decrease for the four trees was 4.6 percent (fig. 33, *B*). The fifth tree, with a smaller ring width, increased in specific gravity by 6 percent. Trees that were not released by the thinning continued a restricted diameter growth, the ring width averaging 0.02 inch. This

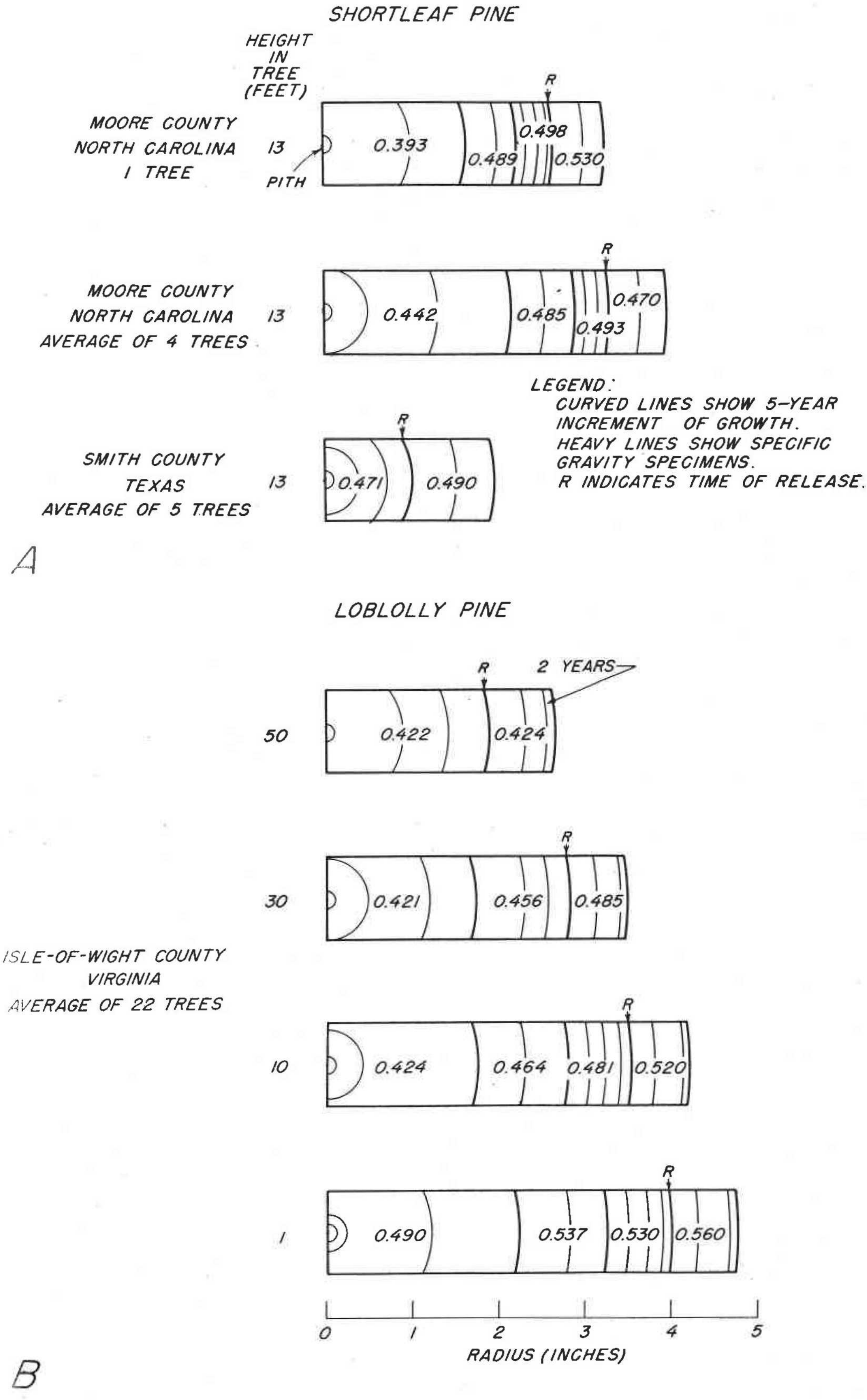

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Figure 33.—Specific gravity changes with accelerated growth: *A*, At the 13-foot height in shortleaf pine; *B*, at four heights in loblolly pine.

TABLE 19.—*Specific gravity* [1] *of longleaf pine wood before and after release*

Tree	Specific gravity at—					
	Stump height		13 feet		26 feet	
	Before release	After release	Before release	After release	Before release	After release
1	0.57	0.57	0.58	0.53	0.51	0.52
3	.54	.49	.52	.49	.51	.45
13	(2)	.54	.54	.50	.51	.47
14	.60	.57	.57	.57	.55	.53
15	(2)	.52	.64	.56	.60	.54
20	(2)	.56	.60	.54	.53	.52
21	(2)	.55	.60	.54	.56	.51
23	.55	.59	.51	.48	.49	.47
25	(2)	.57	.57	.53	.59	.52
36	.61	.50	.51	.47	.51	.43
Average	.57	.55	.56	.52	.54	.50

[1] Based on volume when green and weight when ovendry.
[2] Specimen omitted because of resin.

slow growth, however, was accompanied by a continued rise in specific gravity. The general effect of release in the stand, therefore, was a definite specific gravity decrease.

Samples of shortleaf pine from two adjacent situations in Smith County, Tex., showed contrasts in specific gravity because of environmental conditions. One lot of samples represented dominant trees 25 to 35 years old in a stand of medium spacing. For the first 20 to 25 years, these trees averaged 0.139 inch in ring width and 0.432 in specific gravity. For the last 10 to 15 years, growth slowed to about one-half the ring width, or 0.076, and at the same time specific gravity increased to 0.463. Codominant trees in the same stand evidenced slower initial growth with a ring width averaging 0.063 and an average specific gravity of 0.47. When these codominant trees were released by a thinning, growth accelerated 53 percent to a ring width of 0.097 for the succeeding 10 years; during this period the specific gravity increased to 0.490, an average of 4 percent (fig. 33, *A*). In this case, the codominant trees that initially grew slowly produced heavier wood from their beginning than the dominant trees and, after release, continued to produce relatively heavier wood.

In Virginia, loblolly pine (*Pinus taeda*) trees were investigated that had been left standing for 12 years after an old-field stand was cut (*48*). Twenty-two trees, 47 to 56 years of age, were each sampled at four heights, 1, 10, 30, and 50 feet above the stump. Averages of ring width in the released zone at the respective heights were 0.063 inch at 1 foot, 0.055 inch at 10 feet, 0.054 inch at 30 feet, and 0.062 inch at 50 feet. In comparison with average ring width for the 20 years preceding release, the increases were 64.4 percent at the base and 50 percent at 10 feet; no increase occurred in ring width at 30 feet,

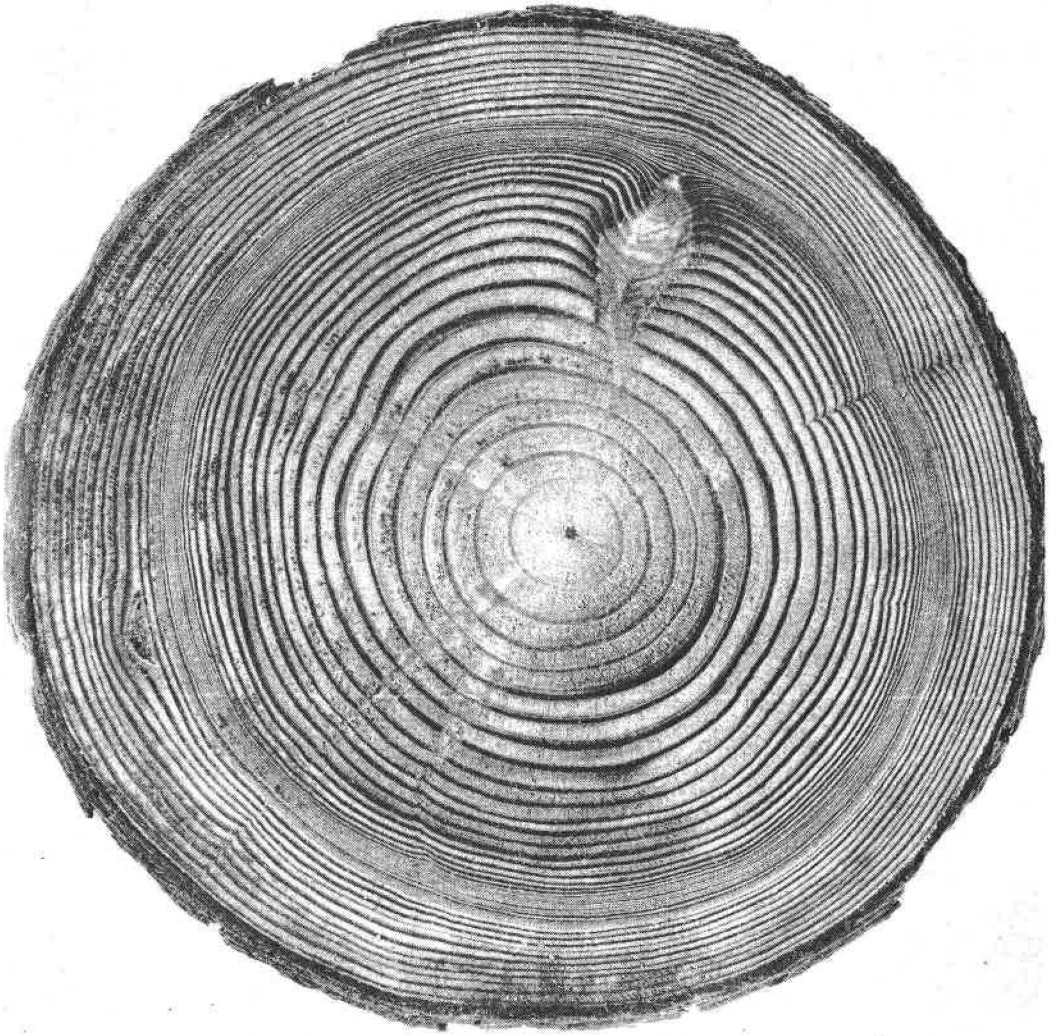

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Figure 34.—Cross section of a shortleaf pine tree, showing increased growth 11 years after thinning.

and at the top the ring width was slightly less than that during the previous 18 years, extending to the pith. Ring width in the released zone at the top, however, was practically the same as at the base and somewhat greater than that at the two intermediate heights.

During the 20-year period before release, average ring width at the bases of the trees was much narrower for the same years than it was at the higher positions. In these trees, with few exceptions, the specific gravity had increased steadily from the pith outward up to the 30-foot level, but at the 50-foot level there was little change in specific gravity after release. Increases in specific gravity compared with 20 years of slower growth before release were 5.66 percent at 1 foot, 8.15 percent at 10 feet, 6.36 percent at 30 feet, and 0.05 percent at 50 feet. The average growth by periods and the average specific gravity pattern of the 22 trees are shown in figure 33 *B*, which is drawn to scale radially.

These examples indicate that an abrupt change in growing space in southern pine stands may cause a change in the specific gravity of the wood being currently produced in some of the trees while the wood in other trees is unaffected. In one loblolly pine stand, Yandle

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Figure 35.—Photomicrograph showing springwood and summerwood development of the outer 3 years of growth during irrigation, in comparison with that of several years preceding irrigation.

(*79*) found an average progressive increase in specific gravity from the pith outward that he ascribed to factors other than decreasing ring width related to age.

A consideration of some important growth factors that are expected to contribute to specific gravity variation may be worthwhile. Since in the southern pines such variation is closely related to proportional amounts of springwood and summerwood in the growth ring, factors that affect the development of these two parts are important. It has been observed and also shown experimentally that summerwood growth may be influenced by the soil moisture supply (fig. 35) (*56*). In addition, years of drought are recorded in the trees by narrow summerwood bands. The first effect of release could be a considerable increase in soil moisture available to trees left standing, because of removal of competition from other roots. Thus, the immediate increase in specific gravity is due to conditions more favorable to summerwood growth. When after a few years there is a decrease, it might occur because of renewed competition, first by herbaceous vegetation and second by reestablishment of woody growth. This renewed occupation of the ground may use water that otherwise would be available to the released trees (*80*).

While this is happening in the soil, other processes are at work above ground. The tree crowns, formerly codominant or otherwise somewhat limited in development in the uncut forest, receive more sunlight. This, together with more water and food elements available from the soil, expands the crowns, and growth of the foliage becomes more vigorous. In the course of this physiological growth, the enlarged crowns produce springwood more abundantly and, because springwood is of much lower density than summerwood, the specific gravity balance swings in a downward direction.

Thus, fluctuation in specific gravity takes place, depending upon whether environmental action swings the balance in favor of summerwood growth or in favor of springwood. To keep the factors that affect growth operating at an even balance with respect to specific gravity of the wood is the task of the silviculturist (*35*). This seems possible only when a stand is so fully stocked that its growing space and crown development can be regulated by a conservative thinning practice after the juvenile stage.

Species Characteristics Related to Environment

Old-Growth Southern Pine

The growth pattern in old-growth longleaf pine ranges from a medium growth rate of 8 to 10 rings per inch near the pith to as many as 50 or more near the bark. The accompanying specific gravity trend is generally decreasing, although exceptions may be found (table 20 and fig. 36). In the old-growth stands investigated, specific gravity changes within individual trees were small up to ages of 100 to 150 years, followed by a steady decline for trees reaching ages of 200 to 300 years or more. These data show that growth factors affecting ring width and summerwood formation in old-growth trees control the density of the wood during the later decades.

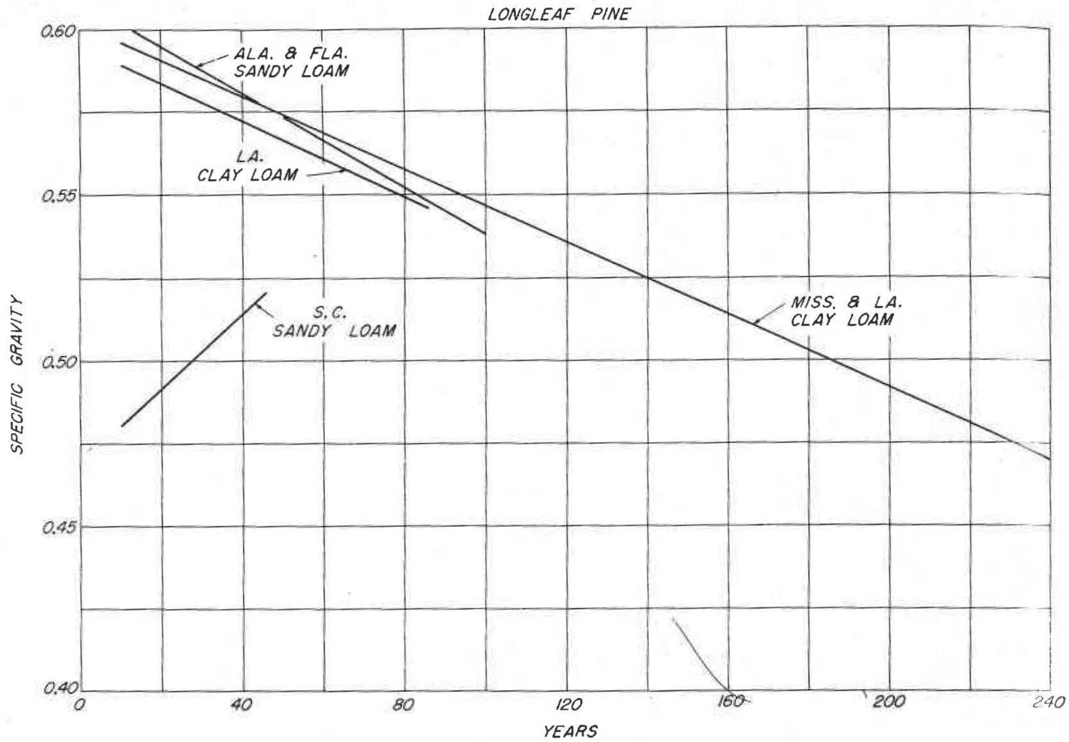

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Figure 36.—Regressions for specific gravity and ages of different longleaf pine stands, showing contrasts of forest-grown and old-field (South Carolina) types.

The influence of site quality upon specific gravity is less noticeable than its influence upon the size of trees. Effects of extremes of site, particularly with respect to soil moisture, however, are plainly evident. In the same locality in Arkansas, shortleaf pine growing in a valley

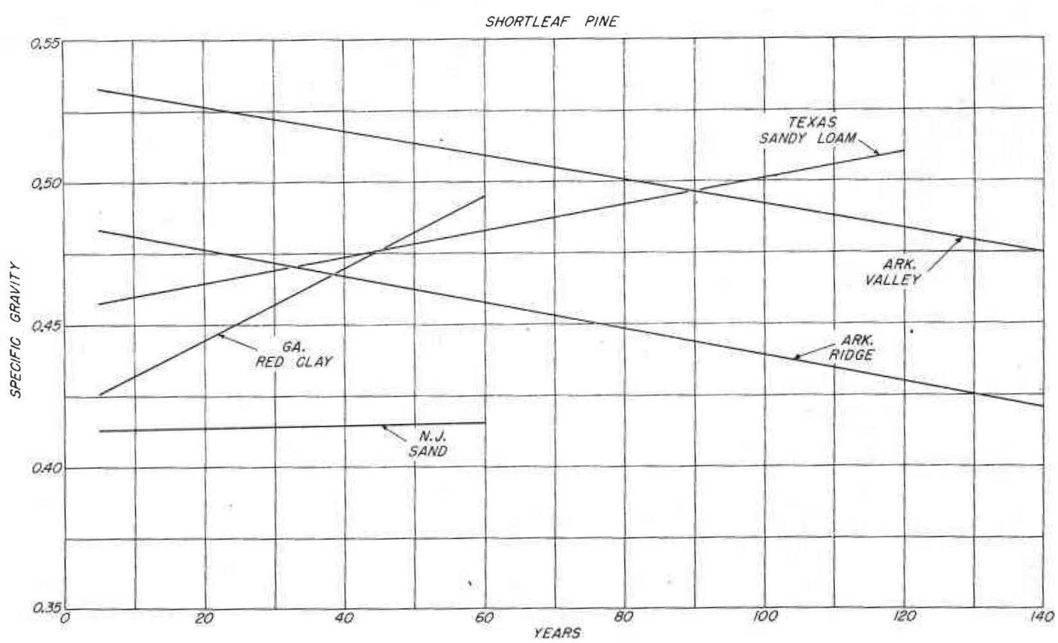

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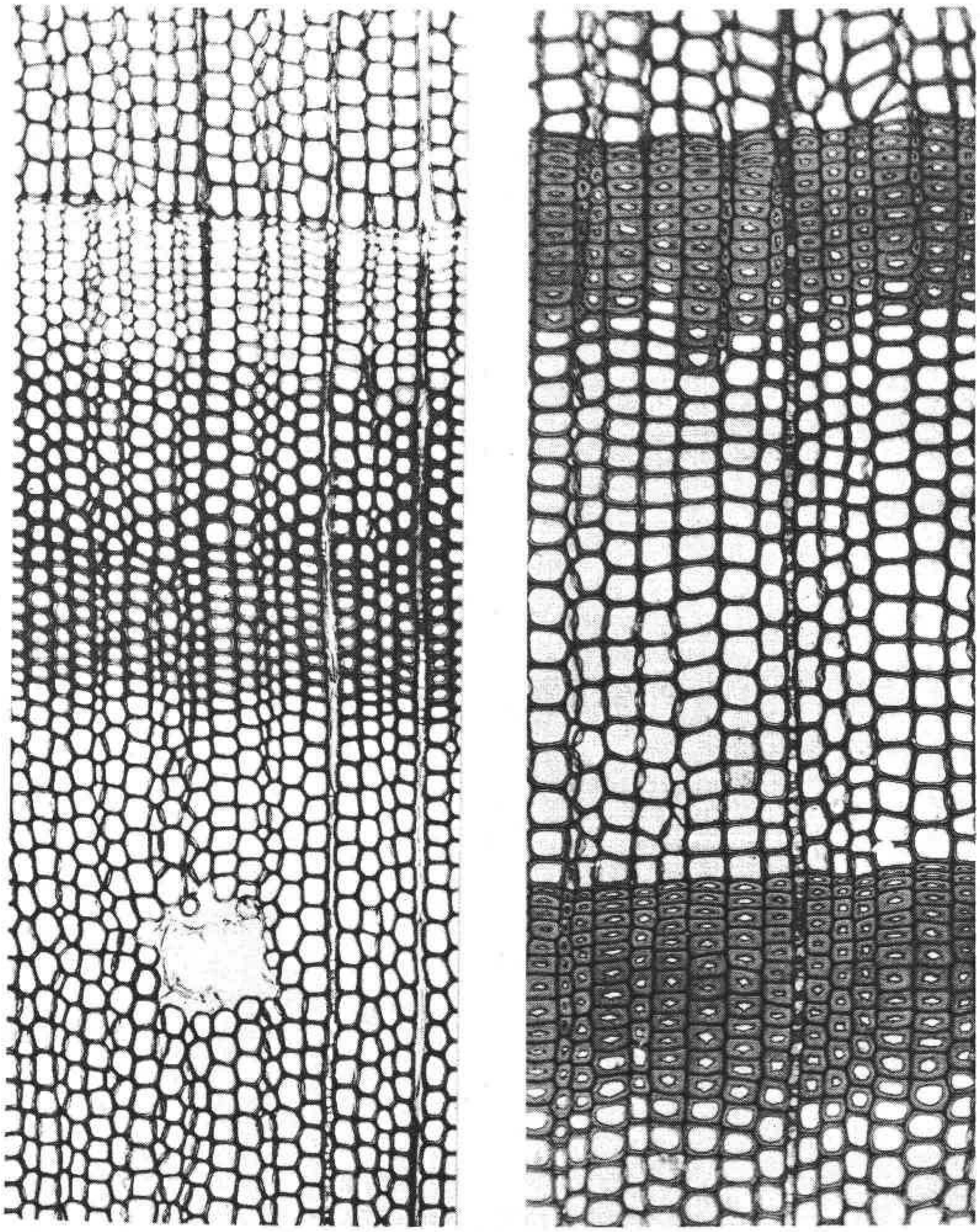
Figure 37.—Regressions for specific gravity and age of shortleaf pine in old- and second-growth (Georgia and New Jersey) stands of different site qualities.

bottom produced wood about 10 percent heavier than that from the trees on an adjoining dry stony ridge (table 21 and fig. 37). Jack pine (*Pinus banksiana*), grown in the sandhills of Nebraska, was largely lacking in summerwood and contained only wood of light weight that was low in strength (fig. 38). Shortleaf pine in the sandy areas of New Jersey failed to increase in density with decreasing ring width up to 60 years, although final ring width was less than one-fourth of its initial growth. In comparison, wood from trees of equal age from an old-field stand in the Georgia Piedmont not only had a heavier



A B

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Figure 38.—Comparisons of summerwood development in annual rings of jack pine grown in the Nebraska sandhills *A*, and in Minnesota, *B*.

TABLE 20.—*Relationship between age and specific gravity of longleaf pine from various localities*

Locality	Samples	Correlation coefficient (*r*)	Regression coefficient (*b*)	Regression intercept (*a*)	Standard error of estimate (*Sy·x*)	Average annual rings per inch	Average age	Average specific gravity [1]
	No.					*No.*	*Yrs.*	
Louisiana, St. Tammany Parish	28	−0. 406	−0. 00066	0. 595	0. 0306	13. 8	45	0. 565
South Carolina, Charleston County	56	+. 309	+. 00103	. 472	. 0327	8. 1	22	. 494
Alabama, Covington County and Florida, Walton County	92	−. 364	−. 00072	. 609	. 0481	26. 7	55	. 570
Mississippi, Smith County and Louisiana, Vernon Parish	61	−. 648	−. 00055	. 602	. 0548	22. 8	114	. 539

[1] Based on volume when green and weight when ovendry.

average weight for more rapid early growth, but showed a marked increase in specific gravity for the final growth period. Ring width for the Georgia stand, however, was more than twice that of the New Jersey trees.

Young trees in moist sites, particularly when in mixture with hardwoods, produce heavier wood initially than others growing on adjacent, drier sites. Examples of this kind are shown in figure 39.

Irrigation of longleaf pine growing on a deep, dry, sandy site in western Florida increased the diameter growth of the trees compared with that of trees on an unirrigated check plot (*56*). Irrigated trees also produced more summerwood than springwood. A plot given irrigation only over a 3-year period produced somewhat more than plots that received mineral fertilizer in addition to irrigation (table 22).

From the data at hand, it is evident that specific gravity of the wood of the southern pine can be influenced to a considerable degree by moisture, which controls growth rate, particularly in the younger ages.

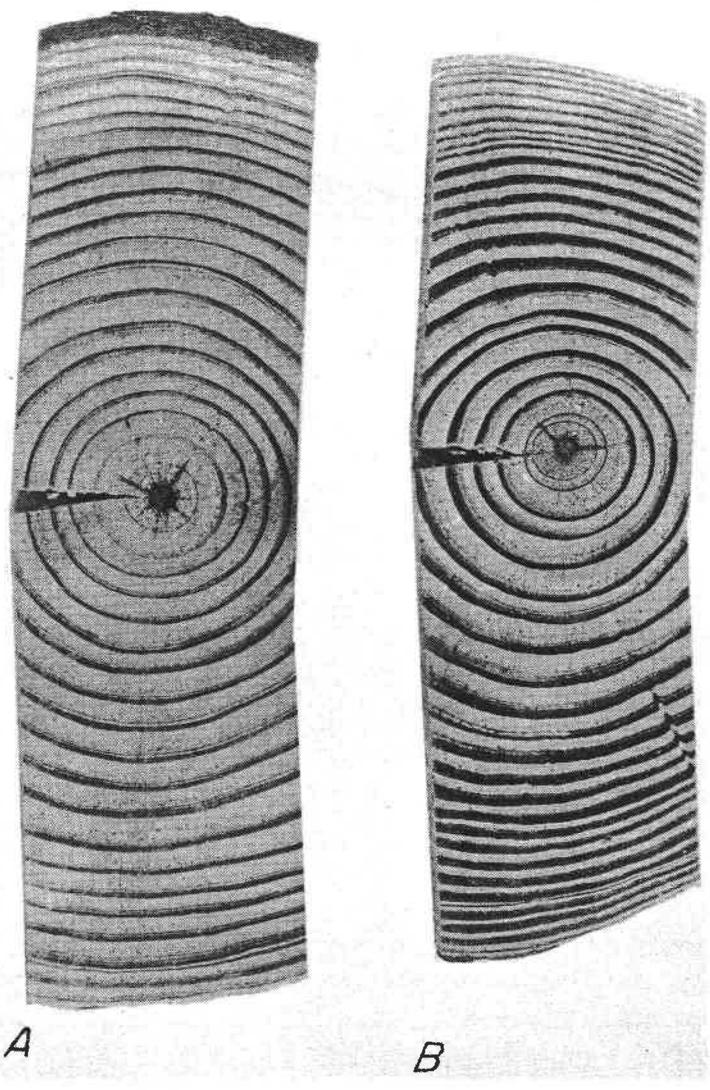

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Figure 39.—Cross sections of two longleaf pine trees grown on *A*, high, dry ground; *B*, a low, moist situation. The tree from the moist situation produced wider summerwood bands on individual annual rings and wood of greater density.

TABLE 21.—*Relationship between age and specific gravity of shortleaf pine from various localities*

Locality	Samples	Correlation coefficient (*r*)	Regression coefficient (*b*)	Regression intercept (*a*)	Standard error of estimate (*Sy·x*)	Average annual rings per inch	Average age	Average specific gravity [1]
	No.					*No.*	*Yrs.*	
New Jersey, Burlington County	73	0.057	0.00011	0.408	0.0337	18.9	33	0.412
Georgia, Jackson County	60	.519	.00117	.424	.0352	11.0	36	.466
Arkansas:								
Garland County (valley)	43	−.572	−.00042	.535	.0360	24.7	103	.492
Garland County (ridge)	69	−.493	−.00047	.484	.0378	22.5	82	.445
Texas, Angelina County	36	.341	.00046	.453	.0525	17.1	63	.482

[1] Based on volume when green and weight when ovendry.

Second growth that has restocked insufficiently over extensive areas tends to produce a minimum specific gravity in the wide rings of the first few years. Trees with an initial growth of 6 to 10 rings per inch, however, will attain a normal specific gravity for the site in considerably fewer years than the trees with very wide initial growth rings of one-half to three-fourths inch.

Increasing the summerwood percentage in the growth ring also will raise the specific gravity. This may be done in two ways: (1) By increasing the water-retaining ability of the soil, thus keeping the trees growing for a longer time toward the close of the season; and (2) by maintaining a stand so fully stocked that crown development will be restricted (figs. 30 and 31). Such restriction of crown development will also be accompanied by a lesser production of springwood (*30*).

TABLE 22.—*Average increase in the springwood and summerwood, and the total width of the annual growth ring of irrigated, fertilized, and check plots of longleaf pine trees during 3 years of treatment, 1927–29, in comparison with the average growth during the 14 years previous to 1927*

Treatment	Trees	Increase or decrease (—) in growth		
		Springwood	Summerwood	Total ring width
	No.	*Pct.*	*Pct.*	*Pct.*
Irrigation only	7	45.4	165.9	96.5
Irrigation, plus complete fertilizer	6	42.0	136.6	74.5
Irrigation, plus nitrate fertilizer	9	57.7	131.6	88.6
Check plot, no treatment	6	12.9	24.3	16.8
Irrigation only, July to December	6	40.0	94.6	61.5
Irrigation only, March to July	5	45.1	89.9	63.9
Complete fertilizer, no irrigation	7	40.4	—8.9	23.5
Nitrate fertilizer, no irrigation	7	31.6	86.8	50.1

In the southern pines, the forest manager must decide the pattern of growth that he wants to obtain in a given rotation. He cannot, however, expect to get wood of uniformly high density throughout a rotation without considerable effort to establish new stands under conditions that will at the same time allow a degree of silvicultural control over specific gravity (*44*, *60*).

Ponderosa Pine

Average locality values for ponderosa pine are less variable than for the southern pines, even though the species inhabits a much wider total range. The highest specific gravity average for a locality is reported from Stevens County, Wash., with 0.418, and the lowest from Coconino County, Ariz., with 0.35. Specific gravity tests of released trees from the same Arizona county gave an average of 0.415 before release and 0.396 after release, accompanying a growth-rate change from an average of 54 rings per inch before release to 16 rings per

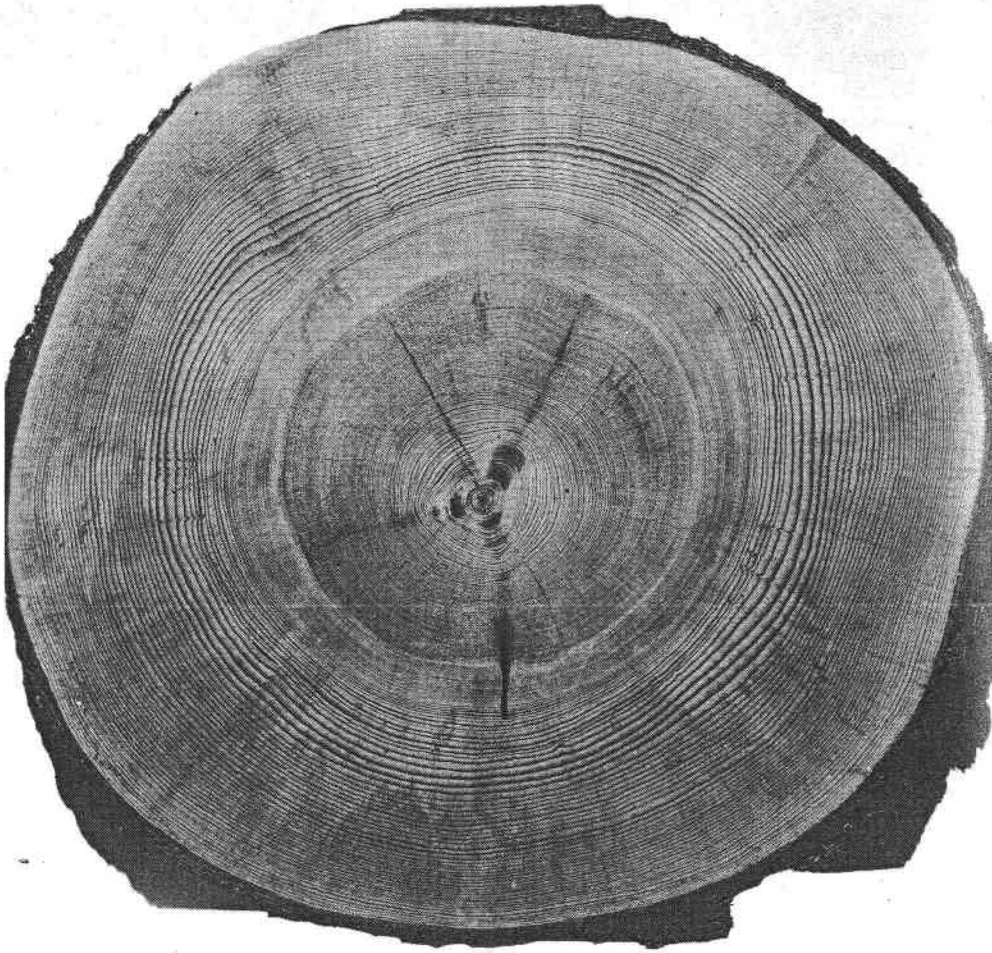

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Figure 40.—Cross section of ponderosa pine tree showing growth in the 55 years after release as compared to the 200 years before release.

inch after release (fig. 40) (*57*). An 80-year stand in Plumas County, Calif., contained wood highly variable in both growth rate and specific gravity. In this west Sierra site, trees grew initially at an average of 3 rings per inch and slowed to 20 or more in the cross sections of the trees. The initially wide growth rings in all the trees indicated a moderately wide stocking at first, although at 80 years the stand density ranged from fully to sparsely stocked. In the trees from this locality, the wood with between 6 and 20 rings per inch varied only moderately in specific gravity, with the lowest density wood represented by material of 5 rings or less per inch. The wide-ringed wood had a greater tendency for longitudinal shrinkage than the wood with narrower rings (*46*).

With the exception of the better sites, like those in the west slope Sierra region, growth rates for such western hard pine species as lodgepole (*Pinus contorta*), *ponderosa* (*P. ponderosa*), and Jeffrey (*P. jeffreyi*) probably do not often exceed 10 rings per inch and will average much slower in most stands unless intensive silvicultural measures are taken. Even then growth cannot be expected to exceed an average of 15 rings per inch, as was the case with released trees in Arizona. Ten to fifteen rings per inch will supply a satisfactory wood quality for either lumber or veneer. Slower growth will not affect quality unfavorably but, of course, will extend the rotation length required to produce trees of desired merchantable sizes.

Natural pruning is slow in ponderosa (*28*). The dense second-growth lodgepole stands favor natural pruning, but the growth retardation due to dense stocking lessens the value of natural pruning unless the stands are thinned to encourage production of larger trees that contain proportionally more high-grade lumber. If pruning can be done before lateral branches die, or soon after that time, the knots in the pruned stems will be limited to intergrown knots which are acceptable in knotty-finish lumber. In some places ponderosa pine originates in groups, the outer trees of which develop a considerable lean, thus promoting compression wood. Compression wood is a type of reaction wood that forms on the underside of leaning softwood trees and their heavy branches. Trees producing compression wood are characterized by eccentric growth of the tree trunk, the compression wood being located in the widest part of the annual rings. Such leaning trees should be removed in thinnings (figs. 41 and 42).

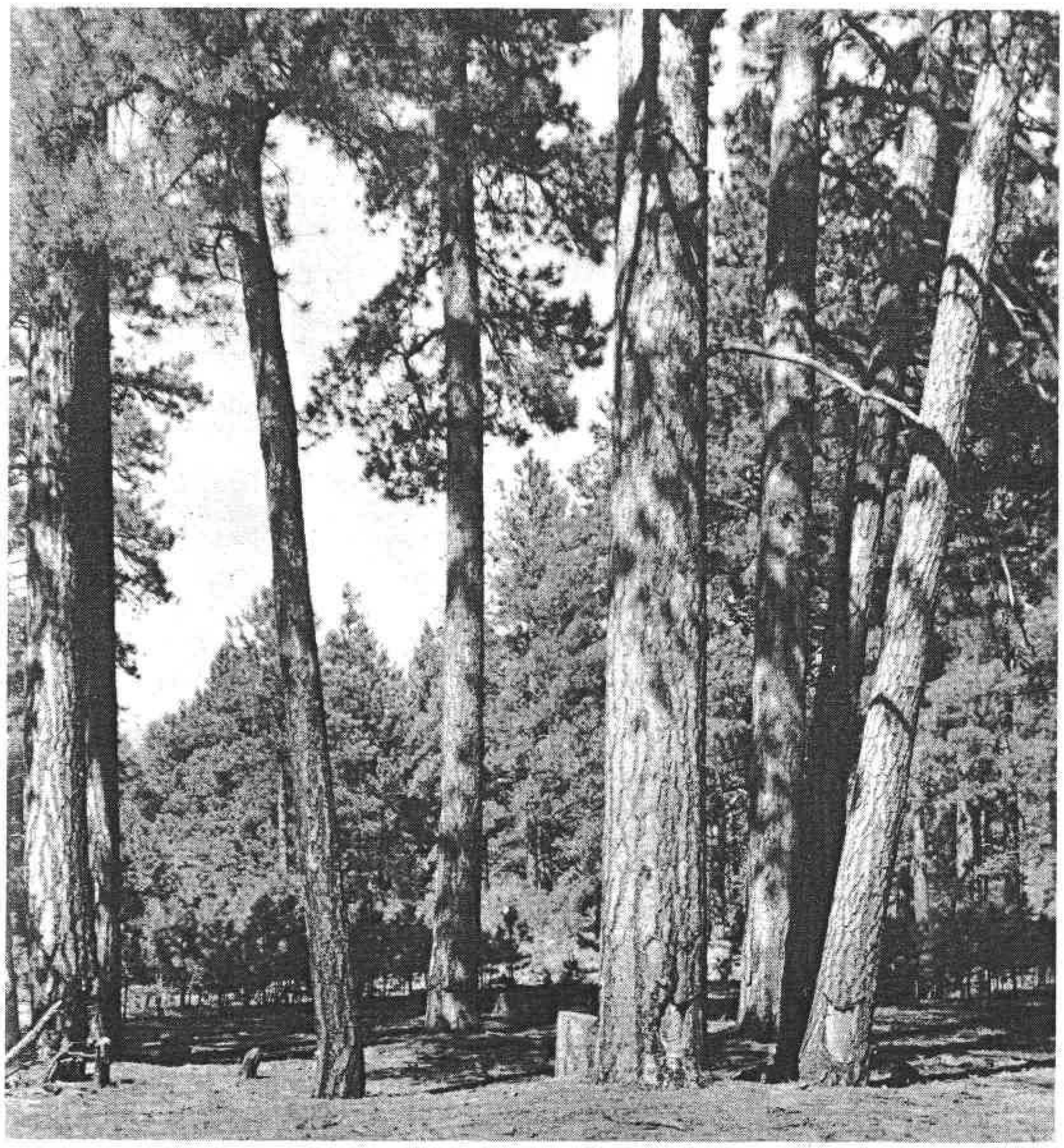

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Figure 41.—Group of ponderosa pine trees showing tendency of the outer trees of the group to lean, thus promoting formation of compression wood.

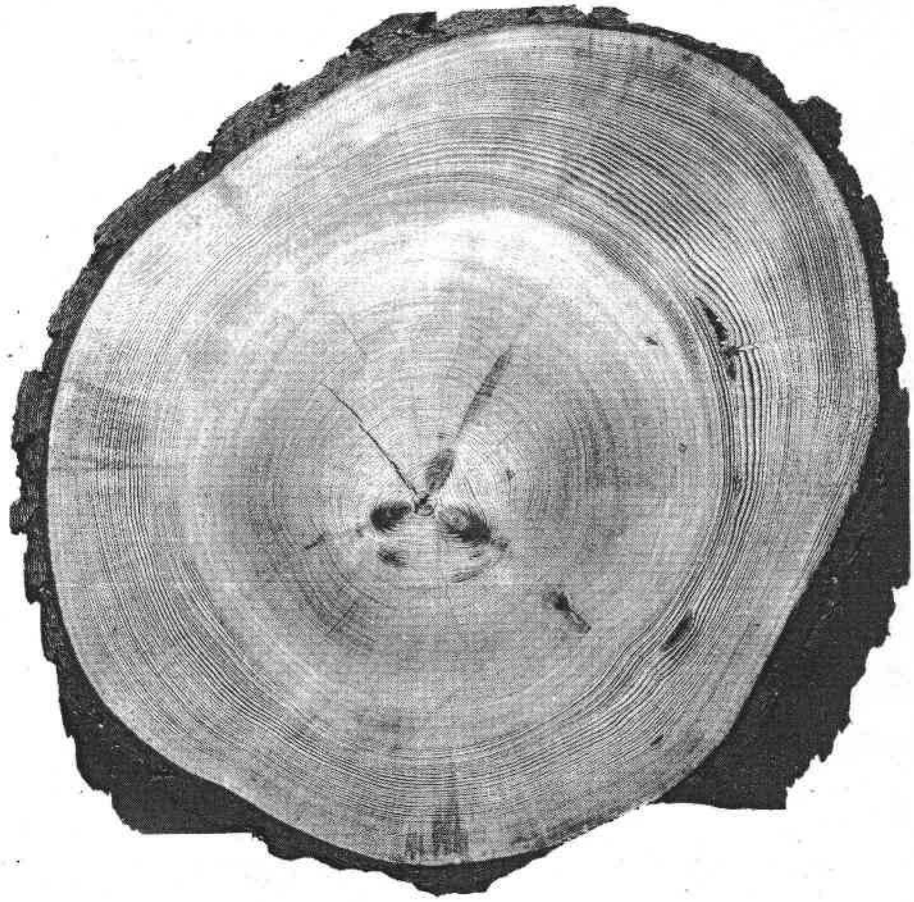

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Figure 42.—Cross section of released ponderosa pine showing increase in compression wood (upper-right-hand portion) with characteristically high longitudinal shrinkage. This tree leaned 2½° from the vertical.

Northeastern Hard Pines

Hard pines in the northeastern United States include red pine (*Pinus resinosa*), jack pine, and pitch pine (*P. rigida*), all of which have the capability of rapid growth in young stands when given plenty of growing space on good sites. Most of these species are characterized by production of wood of higher density than that of the western species of the hard pine group, although the northernmost species are only a little heavier. Jack pine in northern New England, New York, and the Lake States averages only a little heavier than logdepole and ponderosa (*78*). It occurs mostly on the drier sites throughout the regions of its natural distribution. Red pine also occurs characteristically on dry sites, probably because of intolerance to shade. Like jack pine, it could not compete with hardwoods on the better soils. In plantations, however, red pine grows well on heavier soils and, as a rule, early growth rings are wide and the wood of low density for the species.

Data revealed that virgin-growth red pine with an average of 22 rings per inch gave a specific gravity of 0.44 (*27*). Only 5 percent of the old-growth specimens had fewer than 5 rings per inch with most in the group of 20+ rings per inch. A stand of 75-year, second-growth red pine trees averaged 0.39 in specific gravity for a wide range of growth rates, mostly in the 11- to 15-rings-per-inch group. Plantations up to 30 years of age with progressively slowing growth had wood that averaged 0.35 in specific gravity. In an older plantation with the crowns restricted to the upper one-third of the trees, wood density became greater; for example, in a thinned 40-year plantation, wood of the last 6 years in the lower part of the stems was approaching the density of old-growth timber (fig. 43) (*47*). Full stocking appears to hasten an increase in specific gravity outward, but thinnings are necessary to maintain both density and growth rate, which are likely to fall off with too much competition.

The Soft Pines

Eastern white pine.—Eastern white pine (*Pinus strobus*) shows relatively small variations in specific gravity with changes in growth rate. The average specific gravity for the species is reported as 0.34, with some old-growth stands averaging a little heavier and some second-growth stands a little lighter. Among old-growth specimens, few occurred with less than 6 rings per radial inch, the average for 3 shipments being 14. One shipment of second-growth material averaged 10 rings per inch (*66*). Codominant trees from thinned sections of a plantation 30 years of age gave an average specific gravity of 0.303 and 5.1 rings per inch, while those from the unthinned section showed higher values—an average specific gravity of 0.325 and 6.7 rings per inch.

The specific gravity of intermediate trees cut at the same time averaged 0.303 from the thinned part of the plantation and 0.325 from the unthinned. The thinning did not increase growth or specific gravity greatly. Corresponding values for a 12-year period after thinning showed an average specific gravity of 0.317 and 14.5 rings per inch for trees from the area where the number of trees was reduced from 2,304 to 1,136 per acre. Trees from the unthinned section yielded an average specific gravity of 0.322 and 16.2 rings per inch. The wood grown during the last 12 years in this 30-year stand had a specific gravity close to that of old-growth timber.

Western white pine.—Wood of western white pine (*Pinus monticola*) and eastern white pine have properties so similar that the two species are used interchangeably. In specific gravity, western white pine averaged 0.39 from Montana and 0.35 from Idaho and Oregon, slightly higher than the comparable value for eastern white pine. Growth rate covered a wide range, averaging 28 rings per inch in Montana, 16 in Idaho, and 20 in Oregon. When this material was combined, the wood of 10 to 20 rings per inch averaged heaviest, about 0.37 (fig. 44). As in other pines, the wood averaged lighter in weight, both near the center of trees where growth ring width was greater and toward the circumference where ring width was very narrow (fig. 45).

Sugar pine.—Sugar pine (*Pinus lambertiana*), the third important species of the soft pine group, grows to larger sizes than other native species of the genus. The average density of the wood is about the same as the eastern and western white pines—its specific gravity averages 0.34 with little variation according to rate of growth in material having between 6 and 20 rings per inch (*27*). Specimens with more than 20 rings per inch were a little lower in specific gravity.

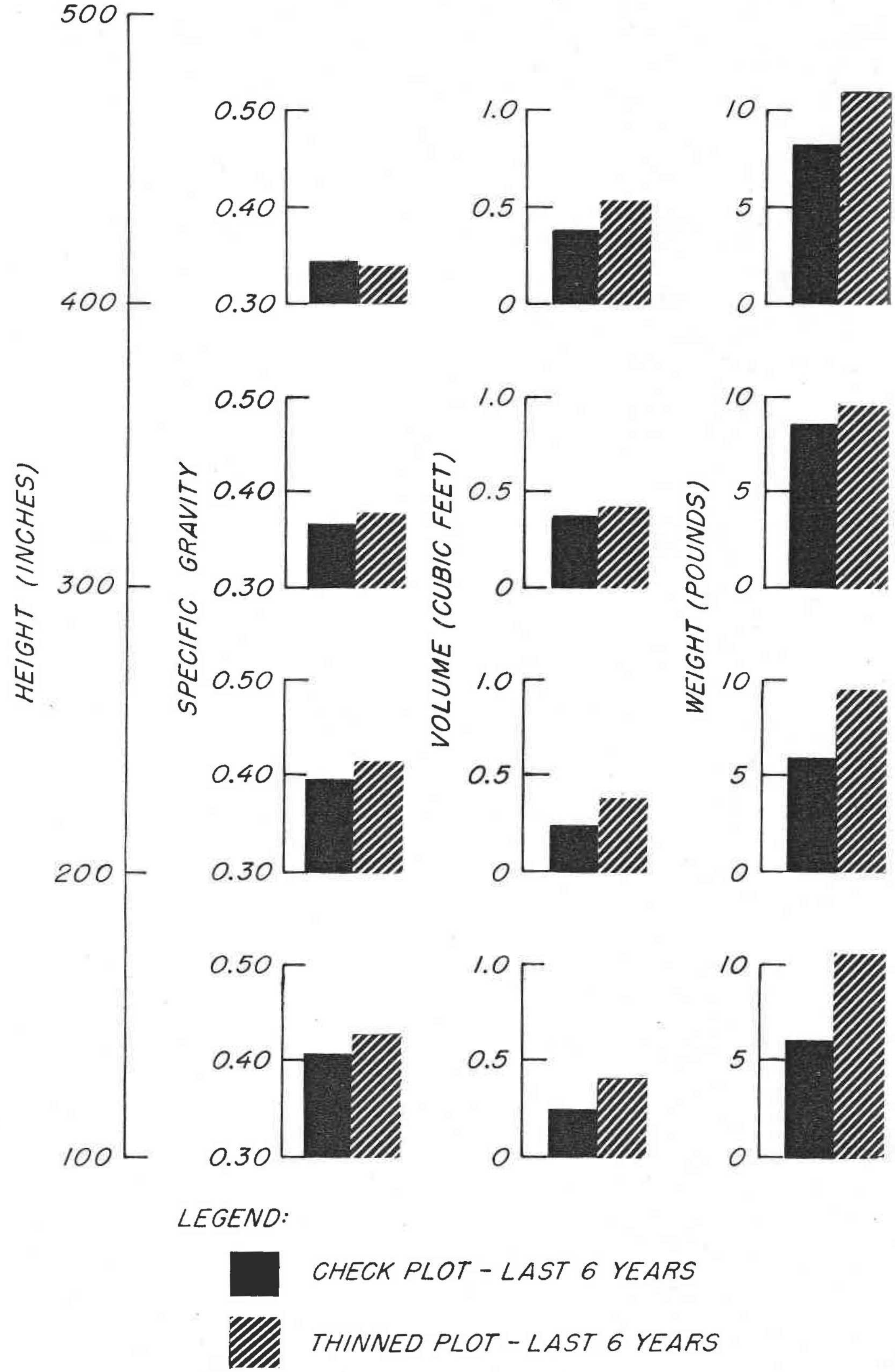

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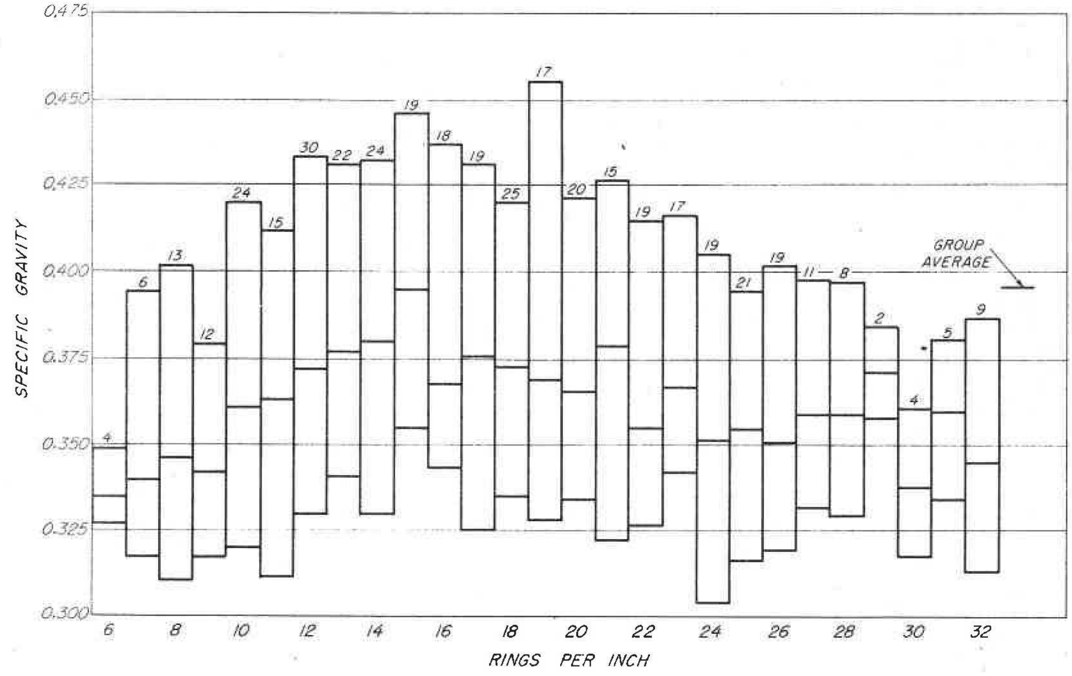
Figure 43.—Average specific gravity, volume growth, and weight of wood at four different heights in trees from an unthinned and a thinned plot in a red pine plantation.



M–34939–F

Figure 44.—Average specific gravity and specific gravity range, by rings per inch in western white pine. The vertical length of the bar shows specific gravity range and the horizontal line across the bar the average specific gravity for a given rate of growth. The number of specimens included appears at the top of the bar.

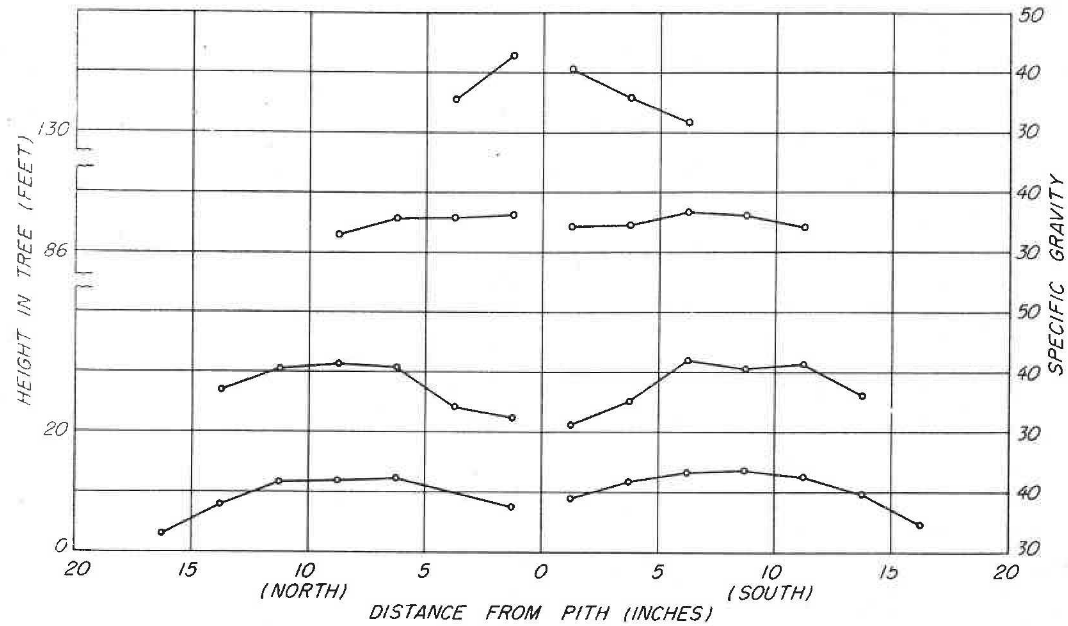


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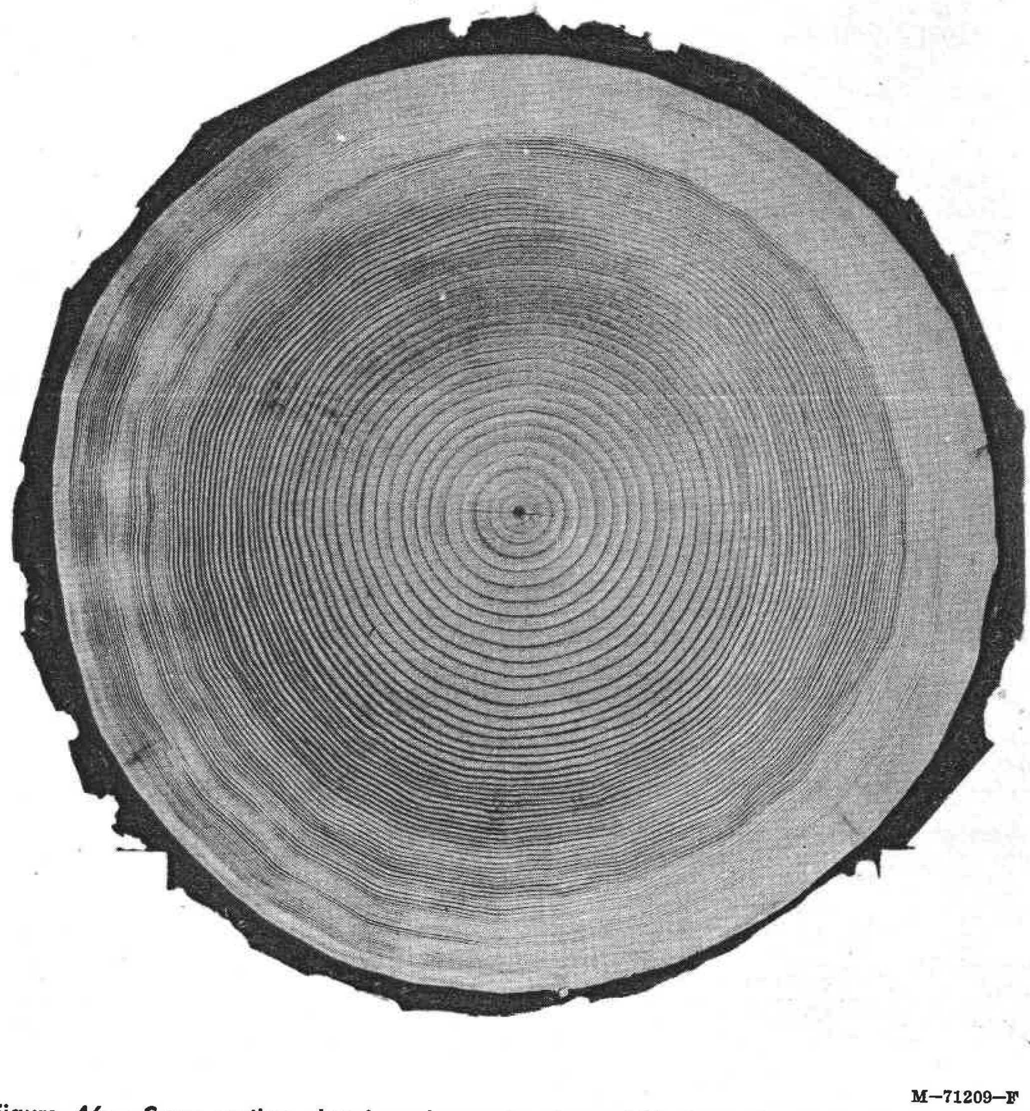
Figure 45.—Horizontal variation in specific gravity on opposite sides of the pith at different heights in a typical western white pine tree.

Douglas-fir

The relative merits of Coast-type, Inland (or Intermediate), and Mountain-type Douglas-fir (*Pseudotsuga menziesii*) have held the attention of foresters and lumber users for a long time. Recently a somewhat different geographic classification based on more extensive sampling was described (*11*). In this description, the Northern Rocky Mountain type is combined with the Intermediate type and called Interior North, the eastern slopes of the Cascade and the Sierra ranges form a new type, Interior West, and the Southern Rocky Mountain areas are separated from the Northern and called Interior South. This leaves the Coast type as before but excludes the Interior West. In this report, the areas are rated in a specific gravity sequence as follows:

Area	*Specific gravity*
Interior West	0.450
Coast type, second growth	.433
Coast type, old growth	.444
Interior North	.412
Interior South	.368



M–71209–F

Figure 46.—Cross section showing change in ring width from the center to the outside of second-growth Douglas-fir.

The Interior South type is rated lower than the original Mountain type, but in the main, other regional differences appear smaller. The varietal name *glauca* is now accepted for most of the interior types of Douglas-fir. From the structure of the wood alone, however, there is no identifying characteristic of Douglas-fir wood that shows definitely where a given piece may have originated or its variety. Width of growth rings is perhaps a partial indication of growth area, since very rapid growth occurs primarily in the coastal regions.

On the best sites, the wood of Coast-type Douglas-fir in natural stands is characterized by wide growth rings when trees are young, and as the stands develop, growth slows gradually at first and then more abruptly as the living crowns are limited to the upper parts of the boles (fig. 46). In densely stocked stands, mortality among pole-sized trees is high. These suppressed trees may contain wood of greater average density than the more rapidly grown survivors (*40*).

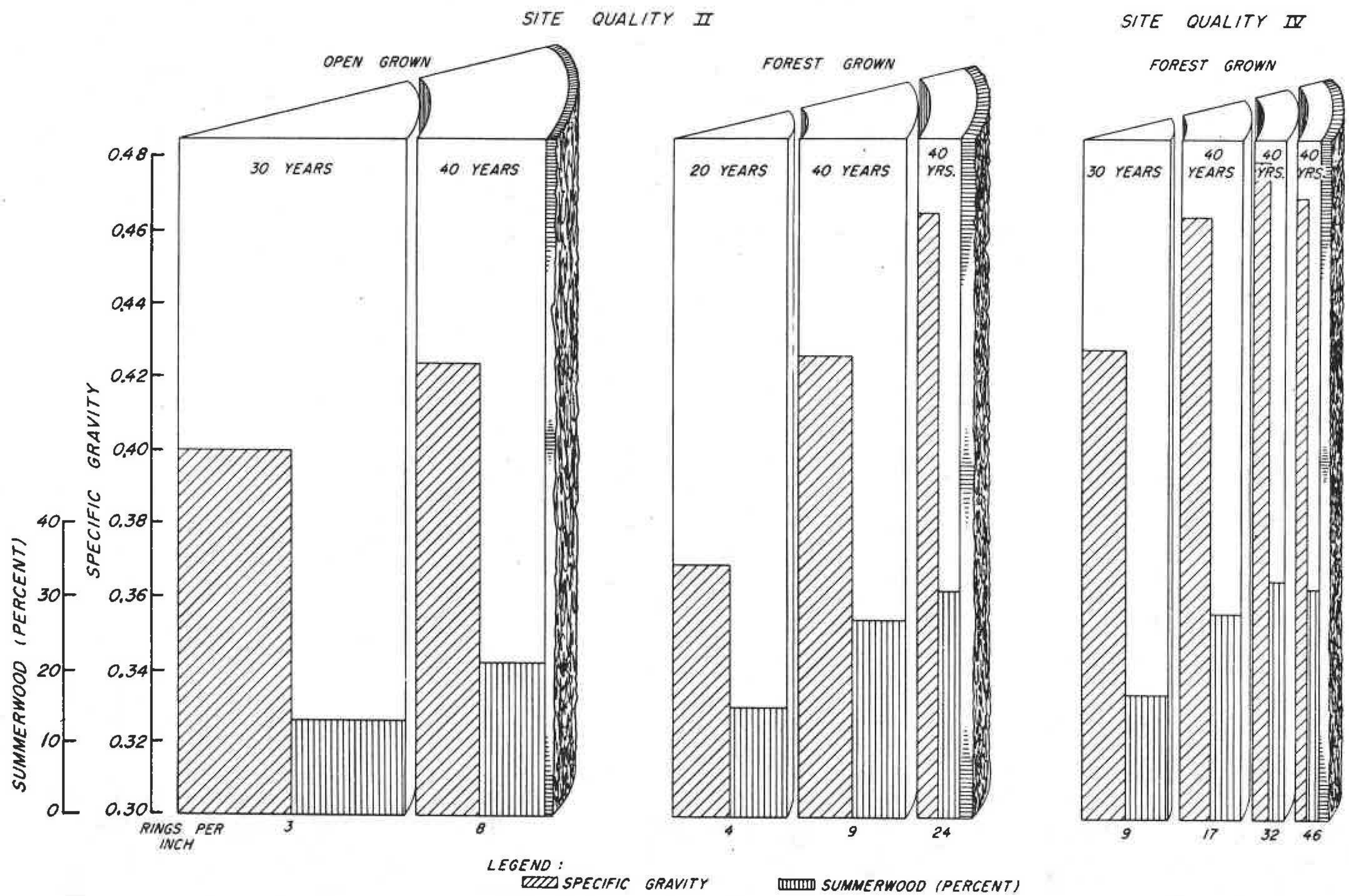
After the first 100 years, growth in height falls off and, in fully stocked stands, the wood laid on year after year constitutes a fairly even growth, with density fluctuating slightly in subsequent years—300 to 600 or more. Some very old trees are known as yellow fir, the wood of which is characteristically very narrow ringed and soft textured. On lower quality sites in the coastal area, growth rings of young trees are narrow unless grown in fairly open stands. During the early life of the trees, density of wood from the poorer sites may be higher than on better sites (table 23 and fig. 47) (*42*).

In many trees and stands, the average specific gravity value for the species is reached only after the width of growth rings has narrowed to about 10 rings or more per inch. Second- and old-growth stands

TABLE 23.—*Summerwood content of open- and forest-grown Douglas-fir trees*[1] *on sites of qualities II and IV*

Site and growth condition	Growth period in years				Summerwood content		
	20–30	First 40	Second 40	Third 40	Average	Maximum	Minimum
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
II. Open grown	13	22	------	------	19	32	10
II. Forest:							
Rapidly grown	15	26	28	------	25	41	14
Medium grown	16	28	32	------	27	43	11
Slowly grown	14	29	37	------	30	50	18
Average	15	27	31	------	27	50	11
IV. Forest:							
Rapidly grown	15	28	33	33	29	42	10
Medium grown	18	29	32	31	28	43	15
Slowly grown	16	27	32	31	28	47	11
Average	17	28	32	32	28	47	10

[1] Taken at the 20-foot level in the tree.



M–81638–F

Figure 47.—Diagrams showing average ring width (rings per inch), specific gravity, and percentage of summerwood for comparative age periods in second-growth Douglas-fir from sites II and IV. The data represent material taken at a height of approximately 20 feet in the trees.

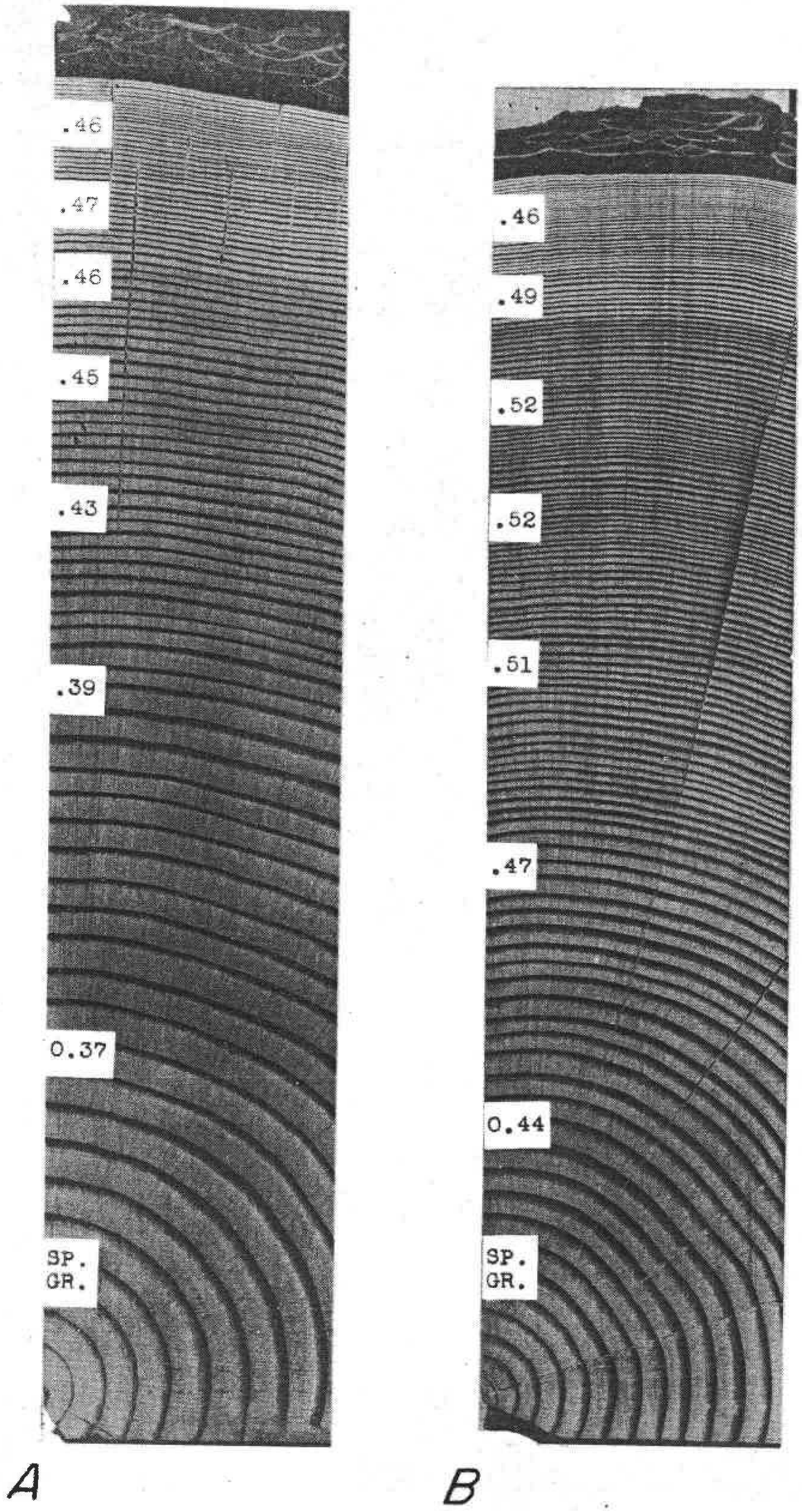


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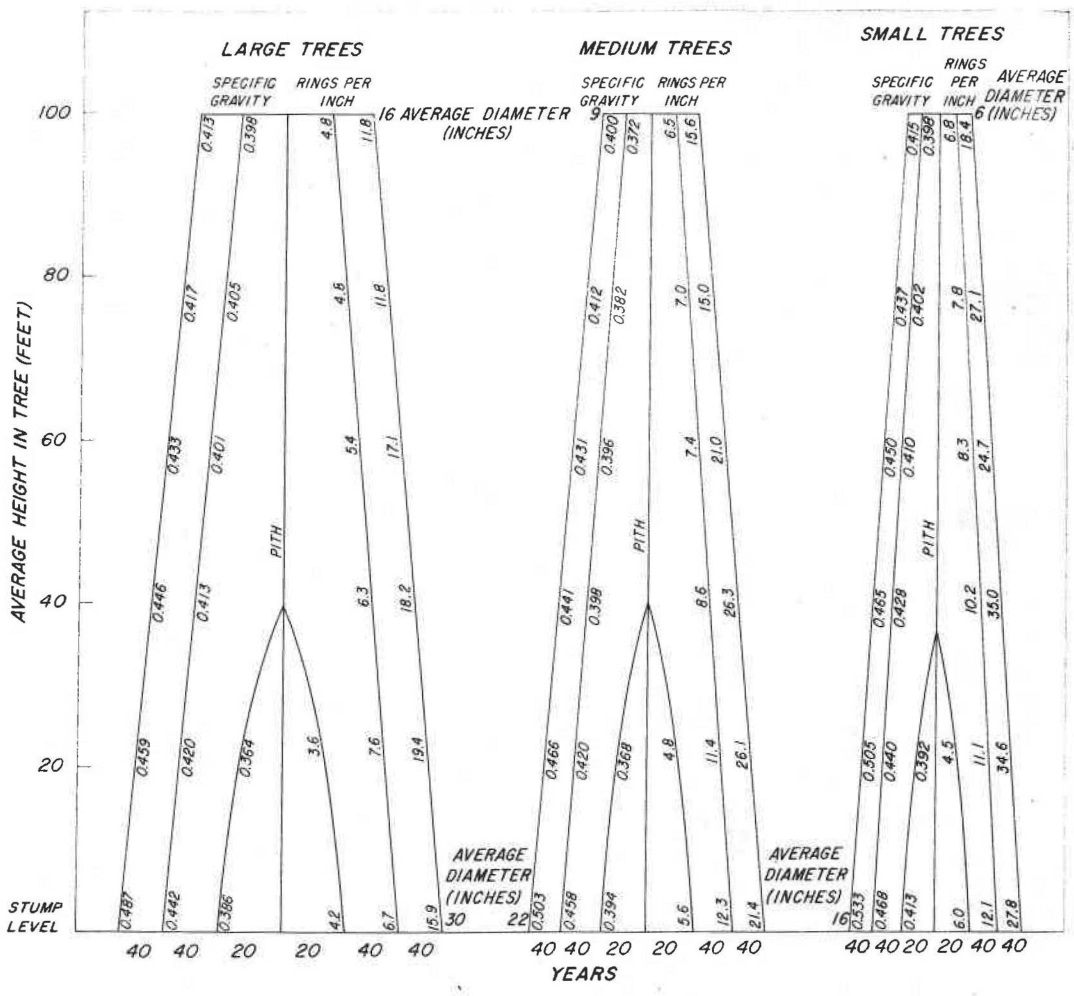
Figure 48.—Comparison of specific gravity values from pith to bark in young Douglas-fir trees: *A*, Tree 87 years old, grown on site II; *B*, tree 147 years old, grown on site IV.

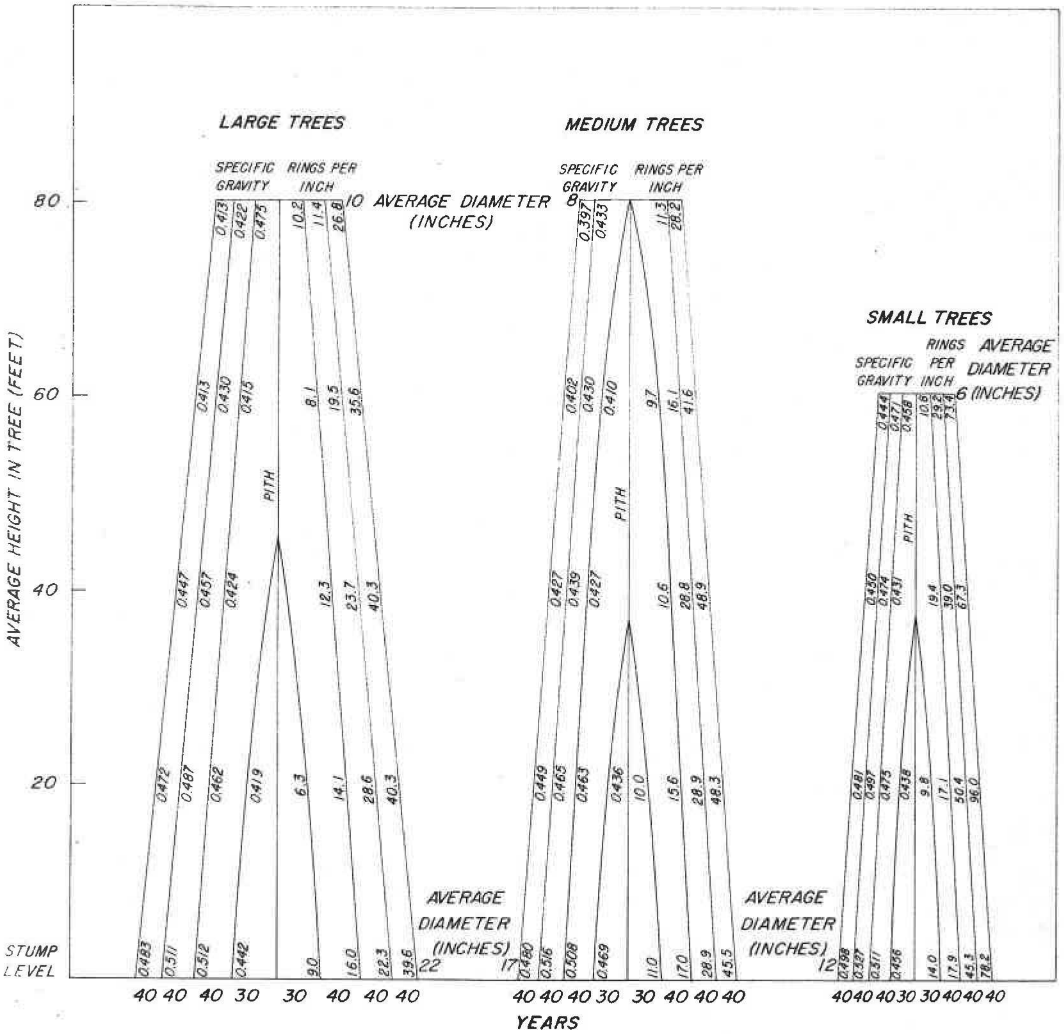
in the Coast type have similar relationships of ring width to specific gravity for material in the range below 15 rings per inch. As growth slows beyond that point, specific gravity of second-growth trees may increase while growth slows to as many as 35 rings per inch, sometimes exceeding the old-growth values for comparable growth rates (fig. 48).

Smith (*71*) found a definite relationship between specific gravity and the percentage of summerwood in the annual growth rings that did not change significantly with successive growth zones from the pith. Wide-ringed (three to five rings per inch) Coast-type samples ranged from 0.35 upward in specific gravity and, for that ring width, averaged about 0.38 for both old- and second-growth specimens. These values are much lower than the average specific gravity for many Inland- and Mountain-type stands, which never produce such wide-ringed material. In the Coast type, second-growth stands of different site quality showed rather definite average differences in specific gravity; a site II stand averaged 0.43 and a site IV stand 0.46 at the 20-foot height in the trees. On each site, the smaller diameter trees contained the heavier wood (table 24 and figs. 49 and 50).



M—116694

Figure 49.—Variation of rings per inch and specific gravity for Douglas-fir trees of large, medium, and small diameter on a site of quality II. Position in the tree is indicated for the different growth periods, outward from the pith, and with height in the tree.



M—116695

Figure 50.—Variation of rings per inch and specific gravity for Douglas-fir trees of large, medium, and small diameter on a site of quality II. Position in the tree is indicated for the different growth periods, outward from the pith, and with height in the tree.

To produce wood of the highest specific gravity throughout the cross sections of trees of the Coast type, an early limitation of diameter growth to 8 to 10 rings per inch is desirable but probably difficult to obtain on good sites. This should be followed soon by thinnings to maintain an even growth rate. Removal of larger, coarser trees in the first thinnings will favor codominants that contain less wide-ringed low-density wood near the center.

Inland and Mountain types of Douglas-fir do not grow so rapidly in diameter when young. In such areas there is little need to restrict early diameter growth, but maintenance of growth later in the rotation may require somewhat heavier thinnings than on the Coast. Growth rates as slow as 30 to 40 rings per inch are common in the present high mountain stands. Thinnings should make it possible to keep growth in the range of 10 to 20 rings per inch. This would shorten rotation ages over the present natural stands and yet yield comparable quality and sizes. Maintaining larger crowns will develop wider growth rings and wider sapwood in the trees, an advantage in securing adequate preservation treatments. Mountain-type Douglas-fir, because of slow

TABLE 24.—*Average and range of rings per inch, specific gravity, and summerwood percentage for second-growth Douglas-fir on site qualities II and IV*

Site quality	Average age of stand	Trees	Samples	Height in tree	Annual rings per inch			Specific gravity [1]			Summerwood		
					Average	Minimum	Maximum	Average	Minimum	Maximum	Average	Minimum	Maximum
	Yrs.	*No.*	*No.*	*Ft.*	*No.*	*No.*	*No.*				*Pct.*	*Pct.*	*Pct.*
II	70	3	30	36–40	6.4	3.0	19.0	0.409	0.351	0.441			
		5	32, 52	16–20	7.5	3.0	23.0	.411	.356	.444	19	10	32
		3	34	1–4	7.3	3.0	19.0	.441	.385	.482			
II	100	11	112	36–40	14.2	3.0	57.0	.419	.324	.505			
		14	120, 150	16–20	14.4	3.0	67.0	.430	.342	.574	27	6	46
		11	130	1–4	12.3	3.0	53.0	.458	.364	.553			
IV	150	11	96	36–40	27.3	6.0	100.0	.437	.369	.503			
		14	108, 140	16–20	27.1	5.0	118.0	.463	.390	.534	28	10	42
		11	117	1–4	26.9	7.0	89.0	.497	.419	.557			

[1] Based on volume when green and weight when ovendry.

height growth, contains more knots per unit length of trees than Coast type, and the persistence of dead branches reduces production of high-grade lumber.

A growth objective for Coast-type Douglas-fir of average density may be set at 6 to 10 rings per inch; for high-density wood, 10 to 15 rings per inch. For Inland and Mountain territory, well-managed stands may average 15 to 20 rings per inch. Pruning is essential if clear lumber is to be produced in Douglas-fir trees less than 100 years of age, since an analysis of knots has shown that even in fully stocked stands dead limbs usually persist for 100 years or more before they are broken off and overgrown (figs. 51 and 52) (*41*).

In the production of rotary veneer of face grade, reports indicate that 10 rings or more per radial inch are essential for a well-balanced sheet (*13*). When wide-ringed bolts are cut into veneer, the alternate

M–72677–F

Figure 51.—Second-growth Douglas-fir about 100 years old, showing the dead branches along the length of the trees.

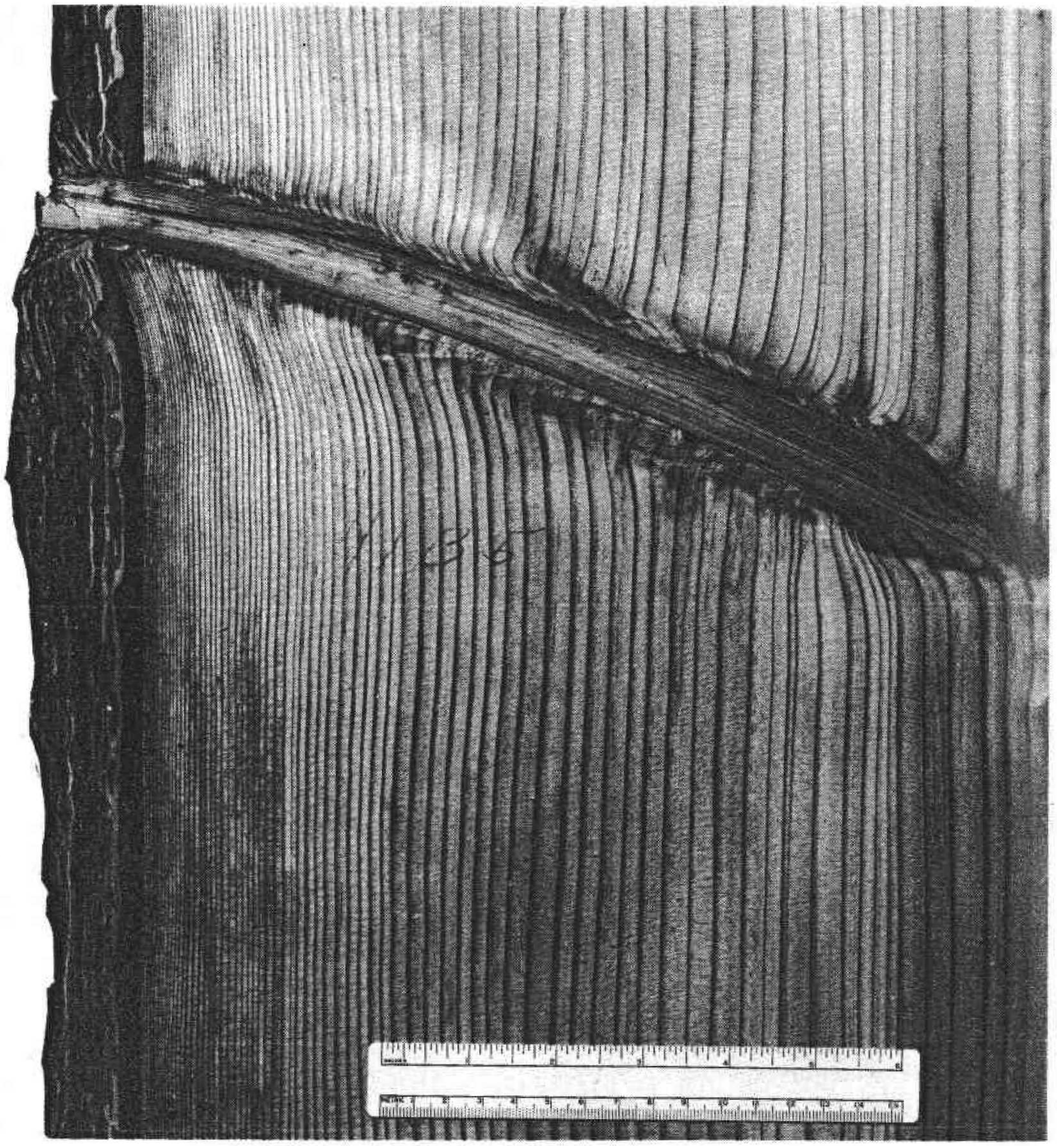


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Figure 52.—Longitudinal section of Douglas-fir branch that died at the early age of 10 years and has persisted 62 years more.

low-density springwood and high-density summerwood portions of the growth ring cause nonuniformity of the sheet. Such structural variations in narrow-ringed wood ordinarily do not extend through the entire thickness of the sheet. Pruning of stands intended for veneer should be profitable, since, for each branch removed in pruning, as many as 10 to 20 patches per inch of knot length could be avoided in veneer sheets.

Redwood

Relationships between old- and second-growth redwood (*Sequoia sempervirens*) are similar to those existing among the pines and Douglas-fir. Young trees with large, widespread crowns had wide growth rings and lower density wood than more crowded and more slowly grown second-growth and all old-growth trees.

The old-growth redwood trees that were investigated had grown slowly in diameter, many of them from their earliest years. Only 8 percent of the old-growth specific gravity specimens had fewer than

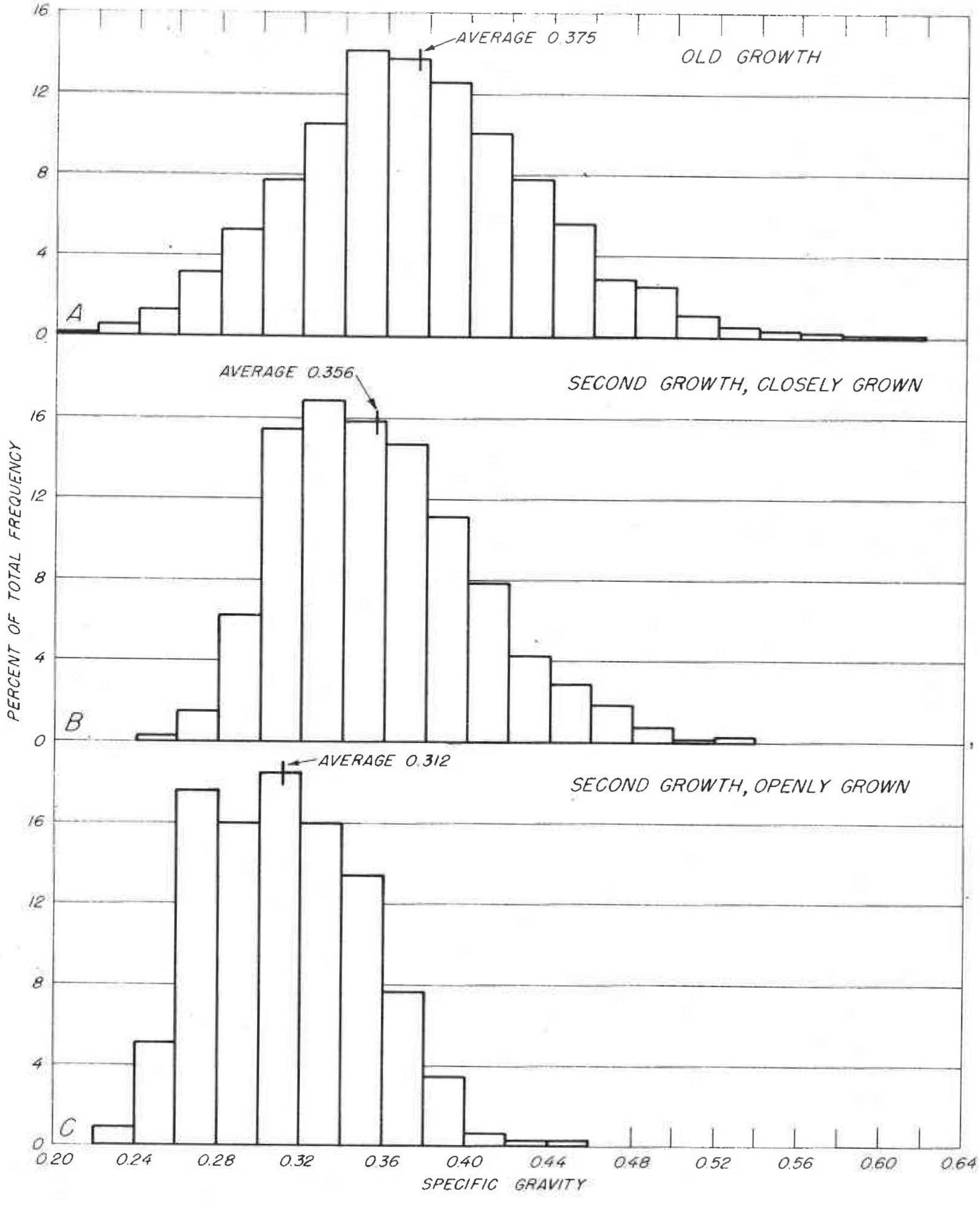

Figure 53.—Specific gravity range and distribution of specific gravity classes in redwood: *A*, Old-growth; *B*, closely grown second-growth; and *C*, openly grown second-growth.

10 rings per inch; those with 20 to 50 rings per inch were rather common, while again only 8 percent of the samples had 60 rings or more to the radial inch. In the closely grown second-growth timber, ring width varied mostly between 2 and 20 rings per inch, with as many as 30 rings per inch in a few samples. Only one of the samples of open-grown second-growth redwood had more than five rings per inch.

More than 4,000 specific gravity determinations were made on wood from 56 old-growth redwood trees representing Site Qualities I, II, III, and IV, and 987 more determinations were made from 42 second-growth trees representing Site Qualities II, III, and IV (*26*). The samples from the second-growth trees represented both fully stocked and understocked (openly grown) stands (fig. 53).

The specific gravity variation in old-growth trees extended over a wide range with the minimum being 0.21, the maximum 0.62, and the average 0.38. Considerable variation occurred in different parts of trees and between trees in the same stand. Average differences in the wood from stands representing different site qualities appeared to be relatively unimportant. In most old-growth trees, the lightest material comprised wood of exceedingly slow growth in which as many as 100 growth rings were found in a radial inch. Much of the heavier wood represented a medium ring width of 20 to 40 rings per inch, except in compression wood, which frequently contained fewer rings.

Specific gravity of second-growth redwood varied over a shorter range than that of the old growth. Closely grown second-growth trees averaged 0.36 in specific gravity, with a minimum of 0.25, and a maximum of 0.52. Specific gravity of the openly grown second-growth trees averaged 0.31, with a range of 0.23 to 0.44. In contrast with old-growth trees, the lightest wood in the second-growth timber consisted of the very wide-ringed material near the center of the openly grown trees. In the closely grown second-growth trees, as the rings became narrower from the center of the trees outward, there was a general increase in specific gravity. The openly grown trees had, for the most part, continued to grow rapidly in diameter, with five rings or less per radial inch. Sometimes the rings near the center of the trees equaled 1 inch in width. In the closely grown second-growth trees, initial growth was as little as 2 rings per inch, with subsequent rings gradually narrowing to more than 20 per inch in trees from the more closely crowded parts of the stands (*43*). This narrow-ringed wood in the outer parts of these trees was similar in appearance and density to that of equal ring width in old-growth trees. Magnified comparisons of structural appearances of the wood of the three types of growth are shown in figure 54.

The variations of strength and related properties with specific gravity follow the same general trends in redwood as have been observed in other species. For example, the heavier wood is stronger and harder. The relationship of specific gravity to bending strength for the three groups of redwood trees is shown in figure 55. In old-growth trees tested in a green condition, the bending strength, as measured by the modulus of rupture, varied from 3,100 to 10,800 pounds per square inch of cross section. The average of individual test specimens was 7,500 pounds. Bending tests for wood from the closely spaced second-growth trees averaged 6,100 pounds per square inch of cross section and ranged between 3,700 and 8,400 pounds. Wood from the openly grown second-growth trees was still lower in this strength property. It averaged only 4,600 pounds per square inch when green, with a range between 3,100 and 7,100 pounds.

Bending strength is somewhat lower for comparable specific gravity values for the openly grown second-growth redwood than for the closely grown second-growth and old-growth redwood. Similar results in mechanical properties were obtained from rapidly grown material of other coniferous species (*65*).

At 12 percent moisture content, comparative average values of modulus of rupture for the three groups of trees were 10,000 pounds per square inch for old-growth, 8,300 for closely grown second-growth, and 6,400 for the wide-ringed openly grown trees. Table 25 contains average data for specific gravity, bending strength, hardness,

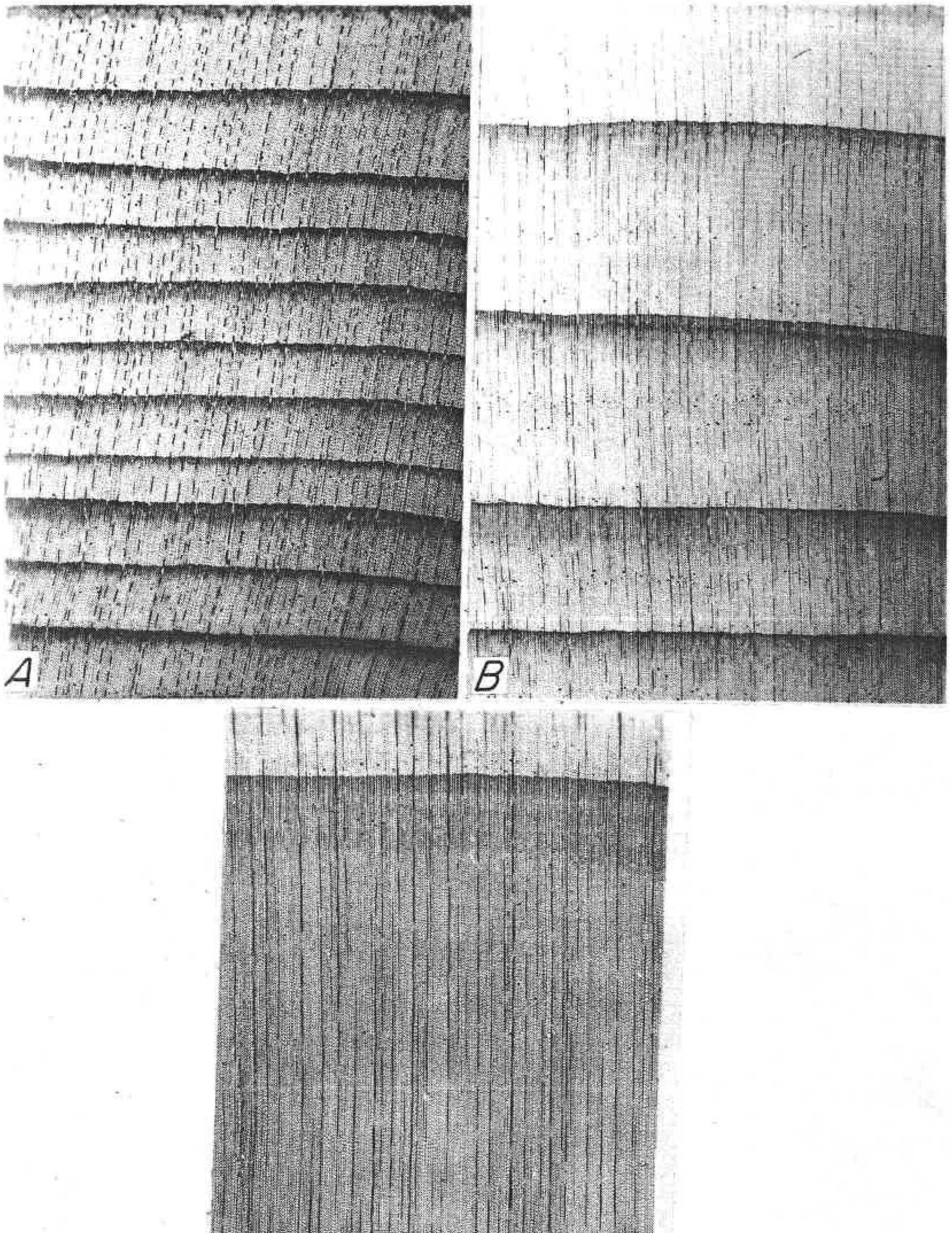

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Figure 54.—Proportional amounts of springwood (light-colored zones) and summerwood (darker zones of growth rings) in redwood grown under various conditions: *A*, Old growth, 24 rings per inch; *B*, closely grown second growth, 12 rings per inch; and C, openly grown second growth, 3½ rings per inch.

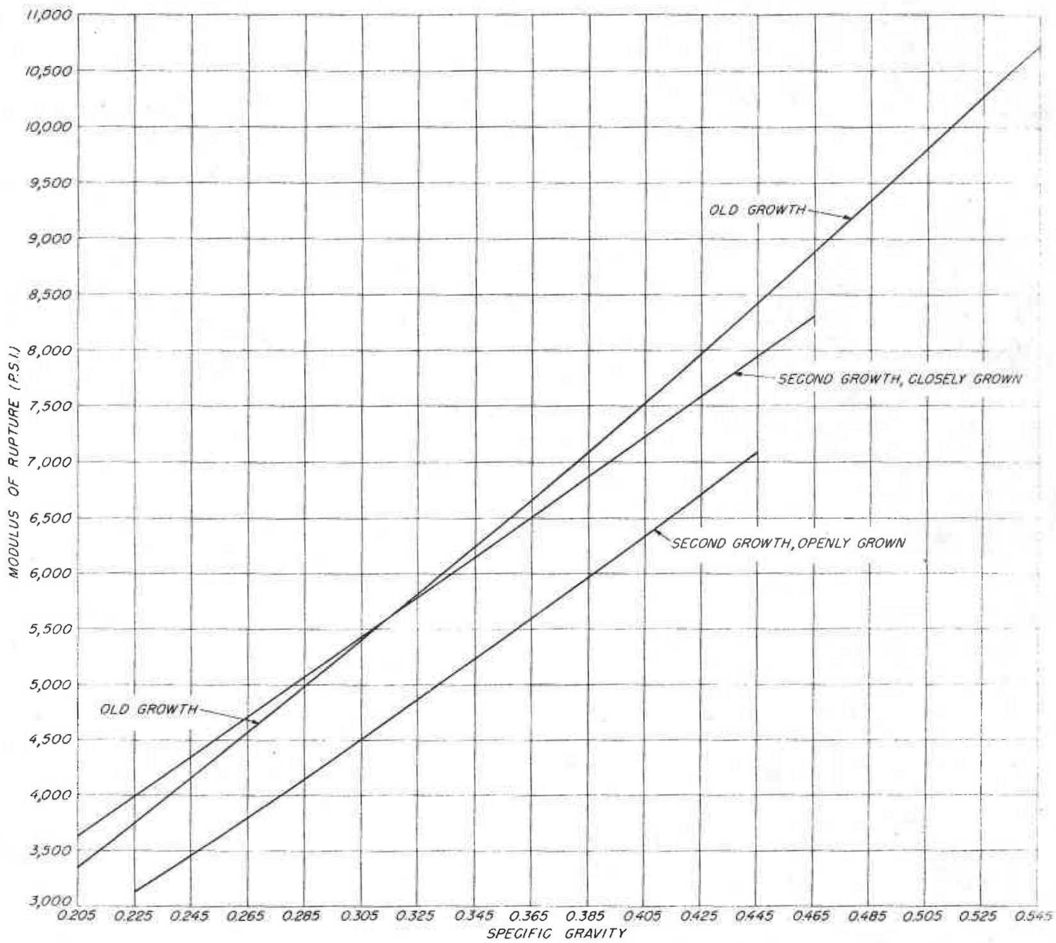

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Figure 55.—Relationships of specific gravity and modulus of rupture in bending of old-growth redwood, closely grown second-growth redwood, and openly grown second-growth redwood.

and compression parallel to grain for the three groups of redwood trees when tested green and at 12 percent moisture content.

Since it is characteristic for leaning trees of all coniferous species to produce compression wood on the underside, there may be a somewhat greater tendency for such wood to form in second-growth redwood trees that begin as sprouts about old stumps than in those that begin as seedlings. In the sprout groups, a tendency arises for the trees to lean away from each other at first to reach sunlight as they grow. This results in a sweep near their bases (fig. 56).

As in other species, redwood lumber of superior quality is in the relatively narrow-ringed, clear parts of the large old-growth trees. Production of this high-quality wood in old-growth redwood trees has taken from 1,000 to 2,000 years or more. Second-growth trees, many considerably less than 100 years old, have grown rapidly in diameter and are of comparatively large size for their ages. The wood of such second-growth trees, particularly that near the pith, is characterized by very wide growth rings with a very different natural appearance than that of old growth. Also, the second-growth trees contain numerous knots from branches not yet removed in natural pruning, reducing the proportion of clear lumber that can be cut from them. The wide-ringed wood, as has already been shown, is lower in density and strength. Only the outer, more slowly grown part of

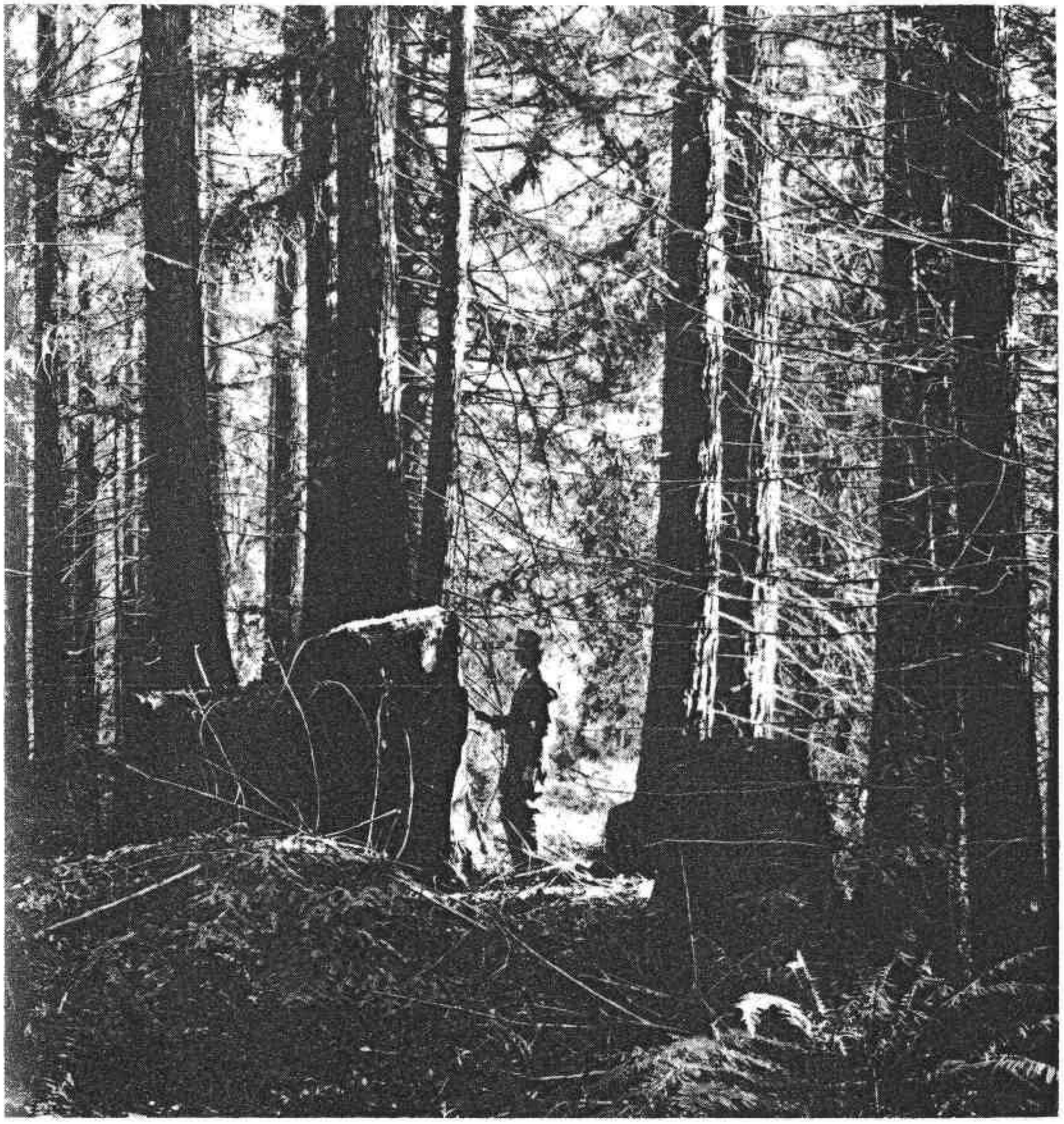

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Figure 56.—Second-growth redwood sprout stand, showing how the new stand has originated from old-growth stumps.

TABLE 25.—*Average specific gravity, bending strength, hardness, and compression parallel to grain for old- and second-growth redwood*

Type	Specific gravity	Modulus of rupture	Hardness	Compression parallel to grain (maximum crushing strength)
		P.s.i.	*Lbs.*	*P.s.i.*
Old growth:				
Green	0. 38	7, 500	410	4, 200
12 percent moisture content	. 40	10, 000	480	6, 150
Second growth, closely grown:				
Green	. 32	6, 100	350	3, 280
12 percent moisture content	. 34	8, 300	400	5, 240
Second growth, openly grown:				
Green	. 28	4, 600	280	2, 320
12 percent moisture content	. 30	6, 400	340	3, 810

second-growth redwood closely approaches the quality of old-growth redwood.

To produce redwood timber of high quality in comparatively short rotations, second-growth stands should be given assistance through the best silvicultural practices when they are yet in the formative stages. For the best timber quality development, very wide-ringed growth should be discouraged by keeping young stands densely stocked at first. When the desired growth rate is established, it may be maintained by thinnings designed to keep ring width fairly uniform throughout the cross section. Lumber with more than eight growth rings per radial inch is believed to be preferable and more satisfactory for many uses of redwood than that with wider growth rings. If young stands of redwood are pruned of lateral branches at an early age, further advantage will accrue by earlier production of clear lumber.

The True Firs

Wood characteristics of the true firs (*Abies* spp.) include wide to very narrow annual rings, light to medium-light weight, and small to moderately large shrinkage. Heartwood and sapwood are generally indistinguishable. In order of average wood density at 12 percent moisture content, weights per cubic foot by species are as follows: subalpine fir (*A. lasiocarpa*) 23 pounds, balsam fir (*A. balsamea*) 25, white fir (*A. concolor*) and noble fir (*A. procera*) 26, California red fir (*A. magnifica*) and Pacific silver fir (*A. amabilis*) 27, and grand fir (*A. grandis*) 28. Much overlapping of values occurs among species, among sites and stands of the same species, and particularly among and within individual trees of a stand. These variations indicate possibilities of control measures to modify the wood quality in forest management.

Wood of very low density for the species is coincident with relatively rapid growth near the center of the trees. Specific gravity of such material may be around 0.30 or lower when five or less growth rings are in 1 inch of radius. As ring width decreases from the center outward, specific gravity of the wood increases until there are 20 rings per inch of radius. After that, a continued decrease in ring width is accompanied by a consistent reduction in specific gravity. Thus, in many of the virgin-growth trees tested, the heaviest wood was found in the zone about midway between the pith and bark, with lighter wood constituting the inner and outer zones (fig. 57).

Ring widths of less than five rings per inch were not encountered among samples of balsam fir, Pacific silver fir, and subalpine fir. This probably was because of close stocking of young trees in natural stands and, particularly in subalpine fir, of local high altitude conditions unfavorable for rapid growth. When the initial growth was as slow as 8 to 10 rings per inch, the radial density in the cross section of a tree showed less variation. Thus, for the most uniform product, close initial stocking is required followed by thinnings to maintain an even growth rate. If wood of exceptionally high density is desired, for example, noble fir to be used in ladder stock, then a ring width of 10 to 20 per radial inch is needed (*54*).

In true firs growing at high elevations where young trees must experience heavy snow loads and consequent bending, compression wood forms in considerable amounts on the underside of the leaning

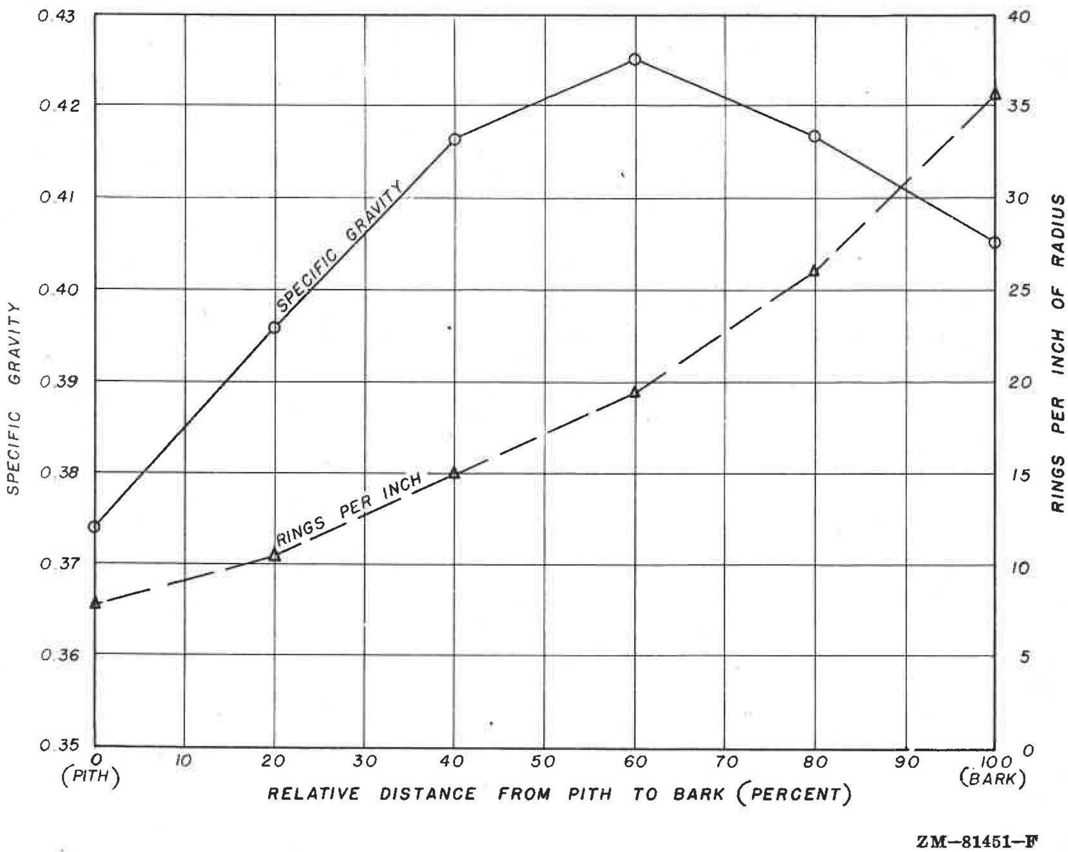

Figure 57.—Variation of specific gravity and growth pattern (rings per inch) with relative location between pith and bark for noble fir at all heights investigated. Specific gravity is based on weight and volume of the wood when ovendry. Points represent group averages.

trees. When trees become so badly deformed that they are unable to straighten themselves, compression wood formation continues indefinitely. Thus, thinnings and improvement cutting should be aimed toward removal of leaning trees.

The true firs, as a rule, prune themselves quite well naturally, since lateral branches are killed by shading.

Spruce

Sitka spruce.—Sitka spruce (*Picea sitchensis*) is the largest and most rapidly growing of the spruces. Wide-growth rings are characteristic of early growth, even in virgin-growth trees in which they become progressively narrower as the trees increase in size and the wood becomes heavier until there are 10 rings or more per inch. The data show a slight further increase in density with as many as 20 rings or more per radial inch. A comparison of samples revealed that Sitka spruce grew considerably slower in diameter in one location in Alaska than in Oregon and Washington. In another Alaskan location, the trees grew at about the same rate in diameter as the slowest ones in Oregon and Washington (*27*).

Average specific gravity for Sitka spruce was as follows:

Rings per inch:	*Specific gravity*
5 or less	0.31
6 to 10	.34
11 to 15	.37
16 to 20	.39
21 or over	.41

The data show that the best Sitka spruce from the standpoint of strength has a growth rate of 11 rings or more per inch. This growth rate could be used initially as an objective in management of second-growth stands by encouraging a high degree of stocking to restrict initial ring width and improve tree form. Later the desired ring width could be maintained by suitable thinnings. Pruning is advisable in second-growth stands to obtain clear wood by the time growth has been regulated to a desired ring width.

Engelmann spruce.—Engelmann spruce (*Picea engelmannii*) grows slowly, mainly at high elevations in the Rocky Mountains, and produces a fine, even-textured wood. Specimens with rings wider than 20 per inch averaged 0.34 in specific gravity. The published average specific gravity of the species is 0.32 (*27*). There were few samples that represented a growth rate of 10 rings per inch or less.

Engelmann spruce from two sites at over 9,000 feet in elevation in Wyoming averaged 0.34 and 0.35 in specific gravity, with corresponding average growth rates of 30 and 46 rings per inch. The stands were both more than 250 years old. The most rapid growth of individual test specimens was 12 rings per inch in one stand (Site Quality II) and 17 in the other (Site Quality I) (*12*).

Forest management that would promote a growth rate of about 15 rings per inch can be expected to produce wood of near-average density. This ring width would greatly shorten the time required to obtain trees of equal size and merchantability in comparison with present stands. Further improvement of stands could be obtained in thinnings by removal of leaning trees, particularly those bent by heavy snow loads when young, thus avoiding formation of large amounts of compression wood. Numerous small black knots can be eliminated by early pruning.

Red spruce and white spruce.—Relatively slow growth is characteristic of red spruce (*Picea rubens*) and white spruce (*P. glauca*), particularly when growing among hardwoods in dense, fully stocked stands. When released by thinning or by poisoning of competing hardwood species, the diameter growth of these trees accelerates considerably, sometimes reaching 6 to 10 rings per inch. Near average density of 0.38 to 0.39 may occur in trees growing at 11 to 15 rings per inch or slower. In the stands tested, the samples were most frequently in the classes of 16 to 20, or over 20, rings per inch. In a pulpwood sample of white spruce from the Lake States area, growth rates of individual log sections ranged from 8 to 24 rings per inch and averaged 16. These trees, 6 to 14 inches in diameter at breast height, ranged from 80 to 138 years at the stump. The average specific gravity was 0.36 and showed little average variation among groups of different sized trees.

Data for strictly second-growth stands of red and white spruce are not available, but the present information indicates that growth rates of 10 rings or more per inch will provide wood close to average specific gravity.

Black spruce.—Black spruce (*Picea mariana*) is known as a bog or swamp species that is able to persist under soil and water conditions few other species can tolerate. Under such conditions, growth is exceedingly slow, yet the narrow-ringed wood is of average density or above. Accelerated growth, following drainage of a site, produced wood of somewhat lower density. On better drained sites, growth rate is close to that of red and white spruce.

Data on black spruce gave an average growth rate of 15 rings per inch, evidently from trees not grown in swamps. A pulpwood sample from Michigan, representing trees 6 to 12 inches in diameter at breast height at ages of 45 to 138 years, gave average values of between 10 and 22 rings per inch for individual trees. These trees originated in a "highland" stand of mixed balsam fir, white spruce, paper birch (*Betula papyrifera*), and yellow birch (*B. alleghaniensis*). The specific gravity averaged 0.335 compared with 0.36 for white spruce from the same forest. Under such similar conditions, black spruce and white spruce may be given the same silvicultural treatment.

Of 2 other samples of black spruce pulpwood, 1 averaged 25 rings per inch and a specific gravity of 0.405, the other (growth rate not known) averaged 0.416 in specific gravity. Apparently these trees originated in a rather wet location, as indicated by the slow growth of one and relatively high density of both.

Summation for Coniferous Species

During the early years of a coniferous stand, the size of individual tree crowns appears to be the most important factor in determining the specific gravity of the wood for a species on a given quality of site. Trees with large crowns in fairly open stands produce greater amounts of springwood than summerwood in the annual rings, while trees of the same age in dense stands produce more summerwood in proportion to ring width.

In older stands where crowding results in a decline of specific gravity of the wood, a thinning caused a remarkable increase in the diameter growth of the trees. This was accompanied by an increase in specific gravity when conditions were favorable for summerwood development, or by a decrease in specific gravity when conditions were more favorable for springwood development. Sometimes an increase in specific gravity was later followed by a decrease in specific gravity, apparently in response to changes in soil and soil moisture conditions. Closely crowded trees on good sites continued to produce wood of high specific gravity under conditions of crowding that greatly reduced the ring width.

Where dry sites and soils low in fertility are involved, the silvicultural treatment should aim also to improve the water-holding capacity and fertility of the soil by maintaining a source of organic materials. Shortleaf pine growing on very poor, dry sites produced wood much below average specific gravity for the species.

APPLICATION OF RESULTS

The foregoing investigations show that regulation of growing space throughout the life of a stand is the silvicultural tool most readily available to the forester in controlling the specific gravity of wood. All species show a ready response to changes in the environmental conditions of the stand, whether it be crowding or thinning. Therefore, in silvicultural management, this response can be used to advantage within the productive limits of a site.

In all of the broad-leaved species, continued severe crowding in the stands will result in a decrease in the specific gravity of the wood, while relief from crowding will result in an increase. In addition, the production of wood of uniformly high specific gravity is concurrent with a well-sustained, usually fairly rapid growth rate. Thus, future crops of hardwood species may reach merchantable size in fairly short rotations where wood of uniformly high specific gravity is desired, as in oak, hickory, and sugar maple. A soft-textured wood, such as that comprising much of the virgin growth of the oaks and yellow-poplar, will require a moderately slow growth over a much longer rotation.

The method of control of specific gravity in conifers is somewhat different from that for hardwoods. In coniferous species, the specific gravity of the wood depends primarily upon the relative proportions of springwood and summerwood in the individual growth rings. In second-growth stands, the spacing and crown development of young trees have a predominate influence upon the width of the springwood portion of the growth ring; this portion is much narrower when crown size is much restricted laterally in crowded stands. With such severe crowding, the amount of summerwood becomes proportionally greater; thus, the wood is heavier and the trees largely lack the wide-ringed low-density core of widely spaced trees. Therefore, the production of timber with the highest density and strength properties requires a longer rotation than the production of timbers of lower density and strength.

A slowly developed initial stage in conifers is most readily obtained by use of natural seeding methods, which promote a high density of stocking. In some species, like spruce and some of the pines, partial shading by an overstory, such as is practiced in the shelterwood method, works out to the best advantage. In this way, no time is lost in soil productivity from the harvesting of one crop to the full establishment of another. With species of low tolerance to shade, natural seeding can be accomplished by seeding from the side or by block harvesting, as is practiced with Douglas-fir.

As soon as the stands have attained the necessary height growth for the desired clear merchantable length, they must be systematically thinned. This maintains growth at the best possible rate and keeps the stands from becoming too dense, with a resultant loss both of growth and summerwood development. To produce timber of high strength in the shortest possible time, it will be necessary to thin carefully, to prevent forest fires, and to maintain as good soil and soil moisture conditions as possible during the life of the stand. Thus, quantity and quality production may be combined on the higher quality sites.

The prevention of forest fires may be expected to increase the organic content of the soil, to supply nitrogen from the decomposition of organic matter, and at the same time to increase the water-holding capacity of the upper soil layers. With a proper balance between soil factors and crown development of the trees, the specific gravity of the wood may be maintained at a uniformly high level. For volume production of low-density wood, trees may be as widely spaced as possible, providing only for maximum use of sunlight by their crowns and a fair degree of natural pruning. As a result of such rapid-growth management, the trees will, on the whole, have shorter clear boles, more knots, and more sapwood than those in stands started and maintained under more restricted conditions of growth.

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