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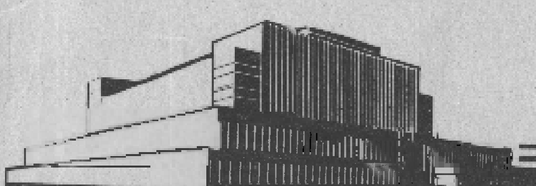

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

THE EFFECT OF ENVIRONMENTAL FACTORS ON WOOD QUALITY

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Introduction

A number of environmental factors influence the growth of trees, and certain structural characteristics of wood affect its quality. Often these factors interact, so that the specific influence of one or another is not indicated definitely. However, under certain extreme conditions of soil type, seasonal soil dryness or wetness, and stand and tree development, the resulting wood characteristics may be largely attributed to either a scarcity or an abundance of one activating cause. Thus, on extremely dry sites, growth may be slow and thin-walled cells predominant; in wet locations, trees may form buttresses containing atypical wood structure; and, in combination with other factors, the relative sizes of tree crowns may affect the proportional formation of thin-walled to thick-walled cell structure.

Attempts have been made to determine the effects of one or more factors by assessing their relationship to annual ring width or to the density of the wood. The combined effect of several factors of a particular environment may be indicated either by growth rate (that is, annual ring width or number of rings per radial inch), by proportional amounts of springwood and summerwood, or by specific gravity (density). Sometimes relationships of ring width to specific gravity are sufficiently clear to warrant rather definite quality evaluations if one or the other factor is known for a given species. More often, however, this relationship varies during the life of a stand, so that a history of environmental changes or fluctuations must be considered (32).[2]

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[1]Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2]Underlined numbers in parentheses refer to Literature Cited at the end of this report.

On the basis of the results and relationships of numerous tests of wood, growth rates of trees can be evaluated in terms of the quality of wood. However, careful periodic observations coupled with systematic application of silvicultural practices will be required to attain a specified quality objective under varying environmental conditions.

"Quality," as the term is used in the lumber trade, does not always have definite meaning with respect to lumber characteristics. High quality for one purpose may be low quality for another; for example, wood of soft texture may be of high quality for interior trim and various other uses, but of low quality for strength in bending or shock resistance. The term must be limited by more meaningful adjectives that define specific characteristics of wood.

Quality variations due to defects are classified in grading rules and specifications for lumber, poles, and ties for important commercial species. The terminology for variations in specific gravity, shrinkage, and other strength properties is published in "Standard Terms for Describing Wood" (8). However, other terminology may be used for expressing quality characteristics within a species; for example, "soft-textured white oak" denotes a certain quality, and "dense longleaf pine" denotes the heavier, stronger pieces of that species.

Sometimes wood is specified on the basis of suitability for a customary use. For example, "tough-textured white ash" identifies the wood used for handles, ball bats, oars, and articles requiring high bending strength and shock resistance, and "cabinet ash" refers to uses not requiring high mechanical strength.

In broad-leaved and coniferous species the unit weight of wood--commonly expressed as specific gravity[3] -- is often a determining index of appropriate use or of satisfactoriness in use; wood of high specific gravity (density) for a species is suitable for some purposes and that of low specific gravity for others. Certain environmental and stand conditions are known to influence specific gravity of wood during the growth of stands and trees (16).

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[3] Specific gravity values quoted for various species represent material mainly between 8 and 16 feet above the stump; they are based on the weight of specimens when moisture free and their volume when green.

Conifers

The wood of a species frequently exhibits highly variable characteristics due to environmental conditions. Some of the factors of environment that are reflected in wood quality are a part of the stand itself and will vary in their effect during its development. The growing space of individual trees influences crown development, and competition among both crowns and roots of trees causes important differences in the specific gravity of wood. Soil type and soil moisture supply are exceedingly important, since the actual time of growth within the growing season may vary with the moisture content of the soil. Thus, cessation of growth during a dry summer season may result in curtailment of the summerwood portion of the annual growth ring. Distinctive summerwood rings are a means of cross-dating to establish the time of prehistoric events. Whereas one dry year may not noticeably influence the wood quality of a piece of lumber, a soil nonretentive of moisture or a region generally deficient in rainfall year after year may have a marked influence upon wood quality.

In some cases, a poor site affects lumber grades more than it does the specific gravity of the wood. Short, stunted, and misshapen trees from the unfavorable sites are of low quality for most uses because of their excessive knottiness, crook, cross grain, and the like, even though the small amounts of clear wood present may be close to the average specific gravity of the species.

Specific studies of the variability of wood as influenced by some environmental conditions have been made on a number of important commercial species (16). In addition, data from the standard strength tests afford considerable information on annual ring width and on physical and mechanical properties (9). All available data concerning ring width and specific gravity for the species under consideration are classified according to rings-per-inch groups and are presented in table 1. Comparison of related species or species of similar wood characteristics makes possible a more general application of available data, and suggests relationships of species for which data are lacking.

The True Firs (Abies spp.)

The true firs include eight species of considerable importance:

Balsam fir (*Abies balsama*)
California red fir (*A. magnifica*)
Grand fir (*A. grandis*)
Noble fir (*A. procera*)
Pacific silver fir (*A. amabilis*)
Shasta red fir (*A. magnifica* var. *shastensis*)
Subalpine fir (*A. lasiocarpa*)
White fir (*A. concolor*)

Wood characteristics of these species 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 ascending order, the average sepcific gravity of these species, based on green volume and ovendry weight, is: Subalpine fir, 0.29; white fir, 0.34; balsam fir, 0.35; California red fir, 0.36; Pacific silver fir, 0.37; grand fir, 0.37; and noble fir, 0.37 (9). There is much overlapping of specific gravity values among species, among sites and stands of the same species, and particularly among and within individual trees of a stand. Since specific gravity also varies with ring width, control of ring width in forest management may produce a more uniform product.

Among the true firs, wood of very low density for these species is coincident with rapid growth near the center of the trees. Specific gravity of such material may be around 0.30 or lower when growth rings are five or less 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. With more than 20 rings per inch, a continued decrease in ring width is accompanied by a consistent reduction in specific gravity in the species studied. Thus, the heaviest wood of many virgin-growth trees is found in a zone about midway between the pith and bark, with lighter wood constituting the inner and outer zones.

Ring widths of less than 5 per inch were not encountered among samples of balsam fir, Pacific silver fir, and subalpine fir. This probably was due to close stocking of young trees in natural stands and, particularly in the case of subalpine fir, to high altitudes 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 quality, close initial stocking followed by thinnings to maintain an even growth rate is helpful. If exceptionally high density for the species is desired (for example, in the case of noble fir for the production of ladder stock) a ring width of 10 to 20 rings per radial inch is most suitable.

Pacific silver fir from an area of high rainfall in the Olympic National Forest averaged 0.38 in specific gravity; samples from two other areas of lower precipitation but higher elevation -- the Gifford Pinchot National Forest and the Snoqualmie National Forest -- averaged 0.35. In all three locations specific gravity varied considerably among and within trees. When trees from the Olympic and Gifford Pinchot forests were about equally divided into two groups each on a basis of age and average ring width, the younger trees averaging about 15 rings per inch were found to contain wood of much lower average specific gravity than trees about 100 year older. In all three stands, wood with 20 or more rings per inch averaged heaviest, 0.41, and that with 6 to 10 rings per inch lightest, 0.35. In most trees, particularly the older ones, the heaviest wood occupied an intermediate radial position between pith and bark.

True firs growing at high elevations are often subjected to heavy snow loads and consequent bending when young; thus, much compression wood forms on the under sides of the bent trees (53). Trees that become so badly bent that they are unable to straighten themselves continue to form compression wood indefinitely. Thus, removal of bent and leaning trees is an important phase of thinning and improvement cutting.

As a rule, the true firs prune themselves naturally after lateral branches have been killed by shading.

Douglas-fir (*Pseudotsuga menziesii*)

The relative merits of Coast-type, Intermediate-type, and Rocky Mountain-type Douglas-fir have been of interest to foresters and lumber users for a long time. Names have been proposed to signify more than one species, as well as several varieties within the species, according to areas of distribution. However, the wood alone does not possess a strictly identifying structural characteristic that shows where a given piece of Douglas-fir may have originated. Width of growth rings is perhaps a partial indication, 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. As the stands develop, growth slows gradually at first in the lower part of the bole and then more abruptly as the living crown is limited to the upper portions of the bole. In densely stocked stands, mortality among pole-sized trees is high. These suppressed trees may contain wood of greater average density than that of the more rapidly grown survivors.

After the first 100 years, height growth falls off. In fully stocked stands the wood laid on year after year is of fairly even growth, in which density fluctuates slightly in subsequent years -- 300 to 600 or more. Some very old trees are known as yellow fir, and characteristically have very narrow-ringed and soft-textured wood. On lower quality sites in the coastal area, growth rings of young trees are narrower, unless grown in fairly open stands (36). During the early life of the trees, the density of wood from the poorer sites may be higher than that of wood on better sites.

On the basis of many tests, wood density of Douglas-fir may be classified into three broadly overlapping categories: coast, inland, and mountain. The first two can be further separated into old growth and second growth; second growth of Mountain-type Douglas-fir has not yet been tested.

Specific gravity values of Coast-type virgin growth average around 0.45; the Inland type averages about 0.42 and the Mountain type 0.39 (9). In many trees and stands the average value is reached only after the width of growth rings has narrowed to about 10 or more rings per inch. Second growth and old growth of 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.

Wide-ringed (3 to 5 rings per inch) Coast-type samples ranged from 0.35 upwards in specific gravity and averaged about 0.38 for both old growth and second growth. These values are much lower than the average specific gravity for many Inland- and Mountain-type stands, which never produce such wide-ringed material. Second-growth stands of different site quality in the Coast type showed rather definite average differences in specific gravity,a site II stand averaging 0.43 and a site IV stand 0.47. On each site the trees of smaller diameter contained the heavier wood (35).

To produce wood of the highest specific gravity throughout the cross sections of Coast-type trees, 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 (4).

Thinnings should make it possible to keep growth in the range of 10 to 20 rings per inch. This rate would shorten rotation ages over the present natural stands and yet yield comparable quality and sizes. By maintaining large crowns, wider growth rings and wider sapwood will be developed in the trees, which are advantages in securing adequate preservative treatment. Because of slow height growth, Mountain-type Douglas-fir contains more knots per unit length of tree, and persistence of dead branches in this type 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 and for that of high density, 10 to 15 rings per inch. For Inland and Mountain territory, well-managed stands may average 15 to 20 rings per inch. Timbers having less than 6 rings per inch usually will not qualify for structural uses specifying dense stock with at least one-third summerwood. In laminated timbers, the denser, slower growth portions of trees can be used where greatest strength is needed; but whether the wood is from trees entirely of a medium growth rate or from the outer parts of trees having initially more rapid growth, at least 8 to 10 years growth will be required for addition of 2 inches of high-density wood to the tree diameter. Thus, at least 48 years are needed to add a 6-inch radius on a more rapidly grown core of 20 to 25 years, establishing a minimum rotation of 70 to 75 years in this case, or about 100 years for the production of a 24-inch tree of more uniform growth and density. An analysis of knots in Douglas-fir has shown that, even in fully stocked stands, dead limbs usually remain for 100 years or more before they are broken off and overgrown (34). Therefore, pruning is essential in trees less than 100 years old. Production of material of satisfactory form and high strength for large-size poles and piling would require an equal length of growing time.

In the production of rotary veneer of face grade, it has been reported that 10 or more rings per radial inch are essential for a well-balanced sheet (5). When wide-ringed bolts are cut into veneer, the alternate low-density springwood and high-density summerwood portions of the growth ring are the cause of nonuniformity in the sheet. However, in narrow-ringed wood such structural variations 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 as many as 20 patches per inch of knot length would be avoided in veneer sheets.

Western Larch (*Larix occidentalis*)

Although it maintains height growth sufficient to establish itself and hold its position among competing species, western larch is typically a tree of relatively slow growth in diameter (25 to 35 rings per inch). Its strength properties are usually equal to or slightly above comparable values for Coast-type Douglas-fir of the same growth rate (9). Its slow diameter growth appears to be a result of its small crown. Although it grows in regions of only moderate rainfall, its density averages higher than that of other western softwood species in the same areas. This may be due in part to its occurrence on cool and moist northern slopes. Its habit of growth adapts this species for use as transmission poles and piling. In managed stands, a somewhat faster diameter growth should be encouraged in order to shorten rotations, which in old-growth stands are often more than 200 years. Also, more rapid diameter growth may increase thickness of sapwood, which is an advantage in securing deep penetration of preservatives in round timbers.

Tamarack

Tamarack inhabits many bogs and wet areas in the Lake States and the Northeast, where growth is extremely slow. On high ground or drained swamps, growth rate is satisfactory. Very large increases in growth rate have been observed as a result of swamp drainage, although wood density decreased a little with the increase in ring width. The small amount of data available indicates that wood of average density will be obtained with growth of six or more annual rings per radial inch.

Hemlock

The three commercial species of hemlock are:

Eastern hemlock (*Tsuga canadensis*)
Western hemlock (*T. heterophylla*)
Mountain hemlock (*T. mertensiana*)

Eastern Hemlock

Eastern hemlock, a shade-tolerant species, has been known as a slowly growing tree. The slow growth is largely due to its competition for light among more rapidly growing associated species, including various broadleaved species and white pine; old-growth trees averaged 20 rings per inch and second growth 11. Specific gravity of Vermont second growth (0.39) was higher than that of old growth from New Hampshire (0.36), and Wisconsin (0.34), but somewhat lower than old growth from the mountains of Tennessee (0.43) (9). Tests do not include material having less than 6 rings per inch. For equal growth rates, second-growth and old-growth trees had about the same specific gravity, which varied little in a range up to 20 rings per inch. There was a small decrease in density of wood with more than 20 rings per inch, indicating a small advantage in uniformity of wood obtained by moderate thinning.

Western Hemlock

Western hemlock is frequently a slowly growing, understory tree in virgin Sitka spruce and Douglas-fir stands. It sometimes forms pure, densely stocked stands where diameter growth of trees is very slow. Only a small percentage of test specimens had growth rings as wide as one-fourth inch, and 10 to 30 rings per inch are common. Specific gravity values average the same as for eastern hemlock and show little fluctuation with changes in ring width when there are six or more per inch. The average specific gravity of both eastern and western hemlock is 0.39 (9). Western hemlock samples with five or fewer growth rings per inch averaged 0.36 in specific gravity. Growth with 8 to 10 rings per inch may be expected to produce timber of about average density in much shorter rotations than has been the case in old-growth, unmanaged stands.

Mountain Hemlock

Mountain hemlock has characteristically slower growth and denser wood than the other hemlock species. Some trees have as few as 11 rings per inch but the greatest proportion have more than 20. Tests of the wood show an average specific gravity of 0.46 (9), a value much higher than that of the other two hemlocks and equal to that of Douglas-fir.

Under forest management a growth rate of 10 rings per inch, where obtainable, would be expected to maintain specific gravity at a satisfactory level.

The Spruces (*Picea* spp.)

There are five commercial species of spruce:

- Black spruce (*P. mariana*)
- Engelmann spruce (*P. engelmannii*)
- Red spruce (*P. rubens*)
- Sitka spruce (*P. sitchensis*)
- White spruce (*P. glauca*)

Sitka spruce is the largest and most rapidly growing of the spruces. Wide growth rings were characteristic of young trees even in virgin-growth stands, in which the rings became progressively narrower as the trees increased in size and the wood became heavier until the ring width equaled 10 or more rings per inch. The data show a slight further increase in wood density with 20 or more rings per radial inch. In one Alaska location, Sitka spruce grew considerably more slowly in diameter than sample shipments originating in Oregon and Washington; in another Alaska area the trees grew at about the same rate in diameter as the slowest in Oregon and Washington.

Sitka spruce having 5 rings per inch or less averaged 0.31 in specific gravity; with 6 to 10 rings per inch it averaged 0.34; and with 11 to 16 and each additional 5 rings per inch, averages were 0.37, 0.39, and 0.41, the last average representing all specimens with 21 or more rings per inch (table 1).

The data show that the best Sitka spruce (in terms of strength) has a growth rate of 11 or more rings per inch. In order to achieve this objective in the management of second-growth stands, an initially high degree of stocking is necessary. Later the desired ring width can be maintained by suitable thinnings. Pruning is advisable in young stands to obtain clear wood by the time the growth has been regulated to a desired ring width.

Engelmann spruce grows mainly at high elevations in the Rocky Mountains and produces a fine, even-textured wood. Specimens with more than 20 rings per inch average 0.34. The published average specific gravity of the species is 0.32 (9). A growth rate of 10 rings per inch or less is uncommon in this species.

Engelmann spruce from two Wyoming sites over 9,000 feet in elevation averaged 0.34 and 0.35 in specific gravity with corresponding average growth rates of 30 and 46 rings per inch. Both stands were 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 rings per inch in the other (Site Quality I) (4).

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 in present stands to obtain trees of equal size and marketability. Also, removal of leaning trees -- particularly those bent by heavy snow loads when young -- would avoid formation of large amounts of compression wood, and early pruning would eliminate numerous small black knots.

Red Spruce and White Spruce

Relatively slow growth is characteristic of these species, particularly in dense, fully-stocked stands, and particularly among hardwoods. When released by thinnings or by poisoning of competing hardwood species, trees accelerate considerably in diameter sometimes attaining a rate of 6 to 10 rings per inch. Average density of 0.38 to 0.39 may occur in trees growing at the rate of 11 to 15 rings per inch or slower. In the stands tested, the samples most frequently had 16 to 20 or more rings per inch. In a pulpwood sample of white spruce in the Lake States, 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 variation among groups of different-sized trees.

Complete data for strictly second-growth stands are not available, but the present information indicates that growth rates of 10 or more rings per inch will provide wood of close to average specific gravity for these species.

Black spruce is known as a bog or swamp species, because it is able to persist under soil-water conditions that 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 produces wood of somewhat lower density; on better-drained sites, growth rate is close to that of red and white spruce.

Data from tests give an average growth rate for black spruce 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 averages of between 10 and 22 rings per inch for individual trees. These trees originated in a "highland" mixed stand of balsam fir, white spruce, white and yellow birch. The specific gravity averaged 0.335, compared to 0.36 for white spruce from the same forest. Under such similar conditions black and white spruce may be given the same silvicultural treatment.

Of two other samples of black spruce pulpwood, one averaged 25 rings per inch and 0.405 in specific gravity, and the other (growth rate not known) averaged 0.416 in specific gravity. It may be assumed that these shipments originated in a rather wet location as indicated by the slow growth of one and the relatively high density of both.

The Pines (*Pinus spp.*)

Among 18 commercially important species, 4 are classed as soft pines and 14 as hard pines.

Soft Pines

The soft pines are:

Eastern white pine (*P. strobus*)
Pinyon pine (*P. edulis*)
Sugar pine (*P. lambertiana*)
Western white pine (*P. monticola*)

Eastern white pine

Eastern white pine has relatively small variations in specific gravity with changes in growth rate. The average specific gravity for the species is 0.34; one old-growth stand averaged 0.36 and one second-growth stand 0.33 (9). Because of its general uniformity and because of the fact that high strength is not a requirement for many of its uses, fewer tests have been made on the wood of this species than on that of some other pines. In tests of old-growth timber, few specimens were found with less than 6 rings per radial inch, the average for the three shipments being 14. Specimens of second-growth eastern white pine averaged 10 rings per inch.

Specific gravity tests of wood from codominant trees in thinned and unthinned portions of a white pine plantation 30 years of age averaged 0.303 and 0.325. The thinning did not increase specific gravity greatly -- the value for a 12-year period after thinning was 0.317, compared with 0.303 before thinning. In the thinned plot slightly wider growth rings were maintained during the 12-year period; they averaged 14.5 rings per inch when the number of trees was reduced from 2,304 to 1,136 per acre, compared with 16.2 rings per inch and a specific gravity of 0.322 in the unthinned portion. The wood grown during the last 12 years in this 30-year stand was a little lower in specific gravity than the average of old-growth timber.

Western white pine

Wood of western white pine has properties so similar to those of eastern white pine that the two species are used interchangeably. In fact, the two cannot be separated on the basis of wood structure alone. Western white pine from Montana averages 0.39 and that from Idaho and Oregon 0.35 in specific gravity, all higher than the comparable value for white pine. Growth rate covers a wide range, averaging 28 rings per inch in Montana, 16 rings per inch in Idaho, and 20 rings per inch in Oregon. In all shipments the wood with 11 to 15 rings per inch averaged heaviest, 0.38. The wood averaged lighter in weight both near the center of trees, where growth was more rapid, and toward the circumference, where ring width was much slower.

There are no data at hand for properties of second-growth western white pine.

Sugar pine

Sugar pine 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. Specimens with more than 20 rings per inch averaged a little lower in specific gravity (table 1). No data are available for wood properties of second-growth sugar pine.

Pinyon pine

In tests from only one location pinyon pine averaged higher in specific gravity than any of the other soft pine species. Average specific gravity for the species is 0.50 for samples averaging 17 rings per inch. However, average strength in bending is lower than that of the other three soft pines, indicating an unusually high specific gravity in relation to the strength values obtained (9). Possibly the higher specific gravity may be due to high resin content of the samples. A confirmation of the relationship between specific gravity and strength is needed.

Eastern white, western white, and sugar pine appear to offer opportunities for high-quality products on fairly short rotations. The use of knotty pine finish has created a substantial market for lumber with numerous intergrown sound knots with normally come from top logs near the crown or from the central portion of butt logs. Without pruning, dead side branches in the white pines are persistent for a long time. Early pruning of side branches would permit both clear butt logs of high value for lumber or veneer and top logs for knotty finish on a 50-year rotation, if grown at about 8 rings per radial inch (25). Wood of this growth rate might be too wide ringed for match stock. Match sticks made from blocks having 12 to 16 rings per inch will break less readily because they have better distribution of summerwood (52).

Hard Pines (Yellow Pines)

Fourteen species of the hard pine group are here considered:

- Jack pine (*P. banksiana*)
- Jeffrey pine (*P. jeffreyi*)
- Loblolly pine (*P. taeda*)
- Lodgepole pine (*P. contorta*)
- Longleaf pine (*P. palustris*)
- Monterey pine (*P. radiata*)
- Pitch pine (*P. rigida*)
- Pond pine (*P. serotina*)
- Ponderosa pine (*P. ponderosa*)
- Red pine (*P. resinosa*)
- Sand pine (*P. clausa*)
- Shortleaf pine (*P. echinata*)
- Slash pine (*P. elliottii*)
- Virginia pine (*P. virginiana*)

There is a high degree of variability among species of the hard pine group among sites and stands and within individual stands. Many of these species are important in forest management because of their adaptability to a wide range of sites, their fairly rapid growth under favorable conditions, and their wood properties, which are suitable for a large number of uses.

Western species

The western species in the main have lower average specific gravity than the eastern ones. Data at hand give practically the same average specific gravity values for Jeffrey, lodgepole, and ponderosa pines (9). Data on native-grown Monterey pine are lacking.

Lodgepole pine shows only small average differences in specific gravity between locations in Colorado, Montana, and Wyoming; average values of data from seven locations range from 0.36 to 0.39 (4). The data indicate a nearly average specific gravity value when growth is 11 to 15 or more rings per inch. Samples with 6 to 10 rings per inch averaged only 0.31 in specific gravity. Since lodgepole generally occurs in very dense even-aged stands, growth in diameter soon decreases so much that thinnings are needed to keep it at a satisfactory level. Most of the sample shipments averaged 17 to 35 rings per inch. An average growth of 11 to 15 rings per inch is highly desirable from the standpoint of timber quality, size of trees, and a reasonable length of rotation.

Ponderosa pine, a species typically inhabiting areas of low summer rainfall, usually requires fairly long rotations of 100 to 150 years (including pruning) to obtain a high-grade product for either veneer or lumber. Sixty-five-year-old stands in the Southwest are of suitable size to supply pulpwood and small-to-medium-sized poles from thinnings. Stocking of ponderosa stands doubtless should be controlled with reference to soil moisture supplies.

Although average specific gravity values for ponderosa pine vary locally only slightly more than those for lodgepole, ponderosa inhabits a much wider total range. A sample shipment from Slivers County, Washington, averaged 0.42 in specific gravity and another from Coconino County, Arizona, 0.35; average values of seven other sample shipments were within that range (9).

Average ring width among the sample shipments ranged from 13 to 32 rings per inch. However, considerable variation may be found within one locality; more recent tests of released trees from the same Arizona county gave an average specific gravity of 0.415 for wood produced before release and 0.396 after release. In these trees, growth rate changed from an average of 54 rings per inch before release to 16 rings per inch after release (47).

Trees of an 80-year Plumas County, California, stand grew more rapidly in diameter than those of other regions tested. In this west Sierra site initial ring width was about 3 rings per inch near the pith but slowed to 20 or more toward the periphery of the cross sections of the trees. The initially rapid growth indicated a moderately wide spacing of trees at first, although at 80 years the stand density ranged from full to sparse stocking. In the trees tested from this locality, the wood varied only moderately in specific gravity; the average for the sample shipment was 0.366, excluding some resin-soaked specimens. Individual specimens ranged upward from 0.29.

Jeffrey pine from one location, Plumas County, California, averaged 0.37 in specific gravity for samples having an average of 18.3 rings per inch (9).

With the exception of such favorable sites as the west slope Sierra region, ring width for these western hard pine species probably will not often be more than 0.1 inch (10 rings per inch), and will average much slower in most stands unless intensive silvicultural measures are taken. Even then growth may be expected to average about 15 rings per inch, as was the case with released trees in the Coconino National Forest of Arizona. Ten to 15 rings per inch will supply wood of satisfactory quality for either lumber or veneer. Slower growth will not affect quality unfavorably, but it will extend the rotation length required to produce trees of desired merchantable sizes.

Pruning.--Pruning is helpful in improving lumber grades of these species (10). Many ponderosa stands are sparsely or irregularly stocked and natural pruning is slow. Second-growth lodgepole stands favor natural pruning, but this advantage is offset by the dense stocking that retards growth. The stands should be thinned to encourage production of larger sized trees containing proportionally more high-grade lumber on the clear stems. If pruning can be done either before lateral branches die or soon after, no loose knots will occur in the pruned stems. Intergrown knots in lumber are suitable for knotty pine finish and thus less objectionable than loose knots.

Eastern species

Hard pines in the eastern United States include 10 species, all of which will grow rapidly when young if trees are given plenty of growing space on medium or good sites. Most of these species will produce wood of higher density than that of the western species of the hard pine group, although species of the northern States are only a little heavier. Jack pine in northern New England, New York, and the Lake States averages only a little heavier than lodgepole and ponderosa (9, 57). It occurs mostly on the drier sites and sandy soils 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 cannot compete successfully with hardwoods on the better soils. In plantations, however, red pine grows well on heavier soils; as a rule, early growth rings are wide and the wood of which they are formed is of very low density for the species. On the other hand, tests of virgin-growth red pine averaging 22 rings per inch averaged 0.44 in specific gravity (9). Only 5 percent of the old-growth specimens had fewer than 5 rings per inch, and most had 21 or more. In plantations up to 30 years old, wood with progressively slowing growth averaged 0.35 in specific gravity. In a plantation more than 40 years old, in which the crowns were restricted to the upper one-third of the trees, wood density increased first in the lower part of the stems, nearly equaling that of old-growth timber (40). Full stocking appears to hasten specific gravity increase outward for a time, but thinnings are required to maintain both density and growth rate, which are likely to fall off when crowns are greatly reduced in size by too much competition among the individual trees.

The influence of an extremely dry site on wood structure of jack pine was shown in the Nebraska sand hill plantations, where trees were lacking in normal summerwood development in the annual growth rings. Fence posts from thinnings lacked sufficient strength for satisfactory use.

Pitch pine typically occupies dry, sandy areas, where it reproduces itself abundantly and grows slowly in crowded stands. Tests of old growth and second growth revealed small differences in the density of the wood. Most of the second-growth samples had 11 to 15 rings per inch. In this ring-width class old growth averaged 0.47 specific gravity and second growth 0.45 (9). A growth rate of 6 to 10 rings per inch appears to produce wood of good quality for this species.

Longleaf, slash, shortleaf, and loblolly are commercially the most important of the pines of the southern and southeastern States (50). In early tests, old-growth longleaf and slash were rated as having exceptionally high mechanical properties (9). In the case of slash pine, this is ascribed to inclusion of some of the very dense South Florida variety. Although some second-growth stands of slash and longleaf are of lower specific gravity than the old growth tested, many cases have been found where average specific gravity of second-growth slash and longleaf equaled the average density of individual shipments of old growth (12, 16). For example, a shipment of second-growth longleaf from just north of Lake Pontchartrain in Louisiana averaged 0.56 in specific gravity as compared with old-growth shipments of 0.550 and 0.574. Second-growth slash pine from Louisiana averaged 0.526 as compared with 0.580 for shipments from north Florida and 0.696 for south Florida (var. densa). Second-growth shipments of slash pine from northern Florida and southern Georgia averaged 0.55, 0.52, and 0.45 in stands ranging from close to sparse stocking (20). Similar differences in specific gravity were found in longleaf (2), shortleaf (3), loblolly, and slash (20) pines when trees from adjacent closely stocked and sparsely stocked areas were compared (16).

In general, wood of average or higher density is produced in closely stocked young southern pine stands with an initial growth of six or more rings per inch. Growth maintained at 8 to 10 rings per inch throughout a 50- to 75-year rotation will give rise to a product of highly uniform density (22, 38). Second-growth loblolly growing on moist sites among hardwoods developed more uniformity in ring width as well as heavier wood than that growing on typical old-field sites (19, 21).

Wood of released growth in thinned southern pine stands is sometimes heavier and sometimes lighter than that produced in the same trees just before release (16). In Louisiana, longleaf pine trees showing 20 years of released growth at an average of 11 rings per inch contained wood that averaged 2.3 percent lighter after release than before release while growing at 33 rings per inch. In the same stand 16 years later the released growth averaged 7 percent lighter (29). In Florida, release of longleaf produced wood that averaged 6.2 percent heavier at 13 rings per inch after release than at 43 rings per inch before release. Similar differences are recorded for released shortleaf and loblolly pine. In such cases the density of released growth is related to a combination of such factors as crown development and soil moisture, which influence the proportions of springwood and summerwood in the growth rings.

Removal of competition both in old fields and on better sites will permit these southern pine species to grow initially at 3 to 4 rings per inch or even faster. However, such rapid growth is undesirable in many cases because of low specific gravity, low strength, and frequently high longitudinal shrinkage in the wide growth rings near the center of the trees (26, 6).

Except under extreme conditions of dryness, site quality is manifested more in the size of trees than in its influence on specific gravity of wood. Extremely dry sites produce wood of very slow growth and low specific gravity. For example, shortleaf pine from the the sandy areas of New Jersey averaged only 0.405 in specific gravity; the same species from tops of ridges in the Ozarks averaged 0.442, while trees from flat land 500 feet lower than the ridges averaged 0.492. Irrigation of longleaf pine on an area of deep sand in Florida greatly increased the proportion of summerwood in the growth rings (45).

The less important pines of the South occupy typical sites for each of the species. Pond pine grows slowly on the pocosins of the coastal plain where the tight soils are subject to shallow flooding during part of the year. In this species the highest average specific gravity was attained by wood with 11 to 15 rings per inch; values were slightly higher than for shortleaf and loblolly.

Sand pine is typically found on flat, sandy areas where growth rate is moderate and specific gravity a little below the shortleaf and loblolly averages for the same growth rate. A large amount of spiral grain was found in the sand pine studied (23). Virginia pine occupies steep stony and rocky hillsides of the southern Appalachians and some poorer areas of the upper Piedmont; the wood also averages a little below shortleaf and loblolly. Because of poor site conditions, many trees are scrubby, limby, and generally poor in form.

An increase in the value of lumber from southern pine stands may be obtained by pruning, particularly when the trees are young. This will greatly increase the proportion of lumber in the higher grades under conditions unfavorable to natural pruning (21, 17).

Baldcypress and Pond Cypress

The genus Taxodium is represented by:

Baldcypress (*Taxodium distichum*)
Pond cypress (*Taxodium distichum* var. *nutans*)

These species grow in swamplands of the Atlantic and Gulf coastal plains and in the Mississippi Delta. Trees are of slow growth, and virgin stands of baldcypress attained great age; the heartwood is durable and highly variable in color. The slowly grown, more deeply colored timber of tidewater areas is reputed to be the most durable of the species. Younger trees grown farther from the coast are of somewhat more rapid growth and contain lighter colored heartwood and wider sapwood.

The specific gravity of baldcypress averages 0.42, somewhat below that of the southern pines. Available data indicate an increase in density, with slower growth averaging 0.40 for 6 to 10 rings per inch and 0.43 for 16 or more rings per inch (table 1). Since cypress is used for many purposes where both strength and durability are important, a growth rate no faster than 10 rings per inch appears desirable. Probably this faster growth rate would be attainable only on the less deeply or less frequently flooded sites.

Cedar and Juniper

The more important species of cedar and juniper are:

Alaska cedar (*Chamaecyparis nootkatensis*)
Port-Orford-cedar (*Chamaecyparis lawsoniana*)
Eastern redcedar (*Juniperus virginiana*)
Rocky Mountain juniper (*Juniperus scopulorum*)
Western juniper (*Juniperus occidentalis*)
Incense-cedar (*Libocedrus decurrens*)
Atlantic white-cedar (*Chamaecyparis thyoides*)
Northern white-cedar (*Thuja occidentalis*)
Western redcedar (*Thuja plicata*)

The western cedars -- Alaska cedar, Port-Orford-cedar, incense-cedar, and western redcedar -- commonly have highly durable heartwood. Data on diameter growth rate of the trees indicate medium to slow growth in old-growth stands where they have grown in competition with other species (9). In the tests made, the higher specific gravity values usually accompanied the slower growth rates, although variability in specific gravity is rather small. Alaska cedar with a specific gravity of 0.42 and Port-Orford-cedar with a specific gravity of 0.40 average higher than the other cedars, with growth rates generally more than 10 and mostly around 20 rings per inch. This slow growth is desirable for certain specialty uses requiring uniformity of structure.

In managed forests it is likely that growth rate will conform closely to that of associated species and could be planned for 10 rings per inch without important loss of density or quality. Incense-cedar with an average specific gravity of 0.35 produced somewhat heavier wood, 0.36, with 16 or more rings per inch, which is suitable for pencil stock. For other uses a more rapid growth rate is satisfactory, and management could plan for 6 to 10 rings per inch.

A similar growth rate apparently would give a near average product for western redcedar that averages only 0.32 in specific gravity. Rocky Mountain juniper is typically a tree of poor sites and slow growth with a highly decay-resistant heartwood. Its wood has an average specific gravity of 0.41, which places it near the top among cedars and junipers. Western juniper is not represented by tests at the Laboratory.

Eastern species of cedar and juniper are eastern redcedar, Atlantic white-cedar, and northern white-cedar. Eastern redcedar prefers limestone areas. Young trees grow at a fairly rapid rate of 6 to 10 rings per inch; at 11 to 15 rings per inch the wood averages 0.45 in specific gravity, which is also the average value for the species. There is little change upward in density with slower growth. Eastern redcedar has been used so extensively for pencils that lumber of pencil-stock quality is now relatively scarce and long rotations of slow-growth material would be required to renew it. For posts, development of a high proportion of naturally durable heartwood is desirable. This type of tree can be developed if the stand is allowed to grow rapidly at first and then to slow down during the later years to reduce the width of the sapwood zone.

Northern white-cedar and Atlantic white-cedar produce lumber of similar characteristics and quality. They frequently form pure, densely stocked stands where diameter growth of trees is very slow. The density of the wood varies little with changes in growth rate, so that thinnings to increase growth rate will not influence wood quality adversely. As in other durable species, however, a thin sapwood is desirable for decay resistance of untreated posts and poles. Ten rings per inch may be considered a satisfactory growth objective.

Redwood (*Sequoia sempervirens*)

Most old-growth redwood trees have grown slowly in diameter, many from their earliest years. Growth rate among specific gravity specimens was commonly 20 to 50 rings per inch; only 8 percent had fewer than 10 rings per inch (7). In closely stocked second-growth stands, growth rate ranged mainly between 2 and 20 rings per inch. Open-grown, second-growth redwood generally had less than 5 rings per inch (37).

Specific gravity of wood in old-growth trees varied over a wide range, between 0.21 and 0.62, and averaged 0.38. Average differences of wood in old-growth stands from different site qualities were relatively unimportant. Lowest density occurred in wood of exceedingly slow growth. In second-growth trees, however, lowest density was in the wood of most rapid growth, averaging 0.31 for samples from openly grown trees and 0.36 for trees from a closely stocked stand.

From the forest management standpoint, the slowest initial growth possible appears desirable in securing uniformly dense wood (44). Such wood may be difficult to obtain in sprout stands, in which old stumps may be quite widely separated. Thinning of sprout clumps will help maintain a more uniform growth rate and will somewhat reduce the tendency of trees to lean outward from the center of the group, a frequent cause of compression wood. Seedling and planted stands may be managed in a manner similar to that used for other rapidly growing conifers, with a growth objective of 8 to 10 rings per inch.

Because of its limited distribution and large size, big tree (*Sequoia gigantea*) has been considered more as a curiosity than as a tree suited to silvicultural management. The wood has not been tested at the Forest Products Laboratory but is reported to be lighter in weight than redwood.

Hardwoods

The quality factor looms large in hardwood forestry. Premium prices are paid for logs that will yield high-quality face veneer or furniture stock, and the price differential between such material and run-of-the-woods logs is considerable. In hardwoods, soft texture is sought for ease of machining, low shrinkage and warping tendencies, and freedom from splitting in nailing. However, hard or tough-textured material is as eagerly sought for uses demanding high bending or crushing strength and resistance to impact, abrasion, or wear.

Sustained or accelerated diameter increment in both ring-porous and diffuse-porous hardwoods normally results in uniformly high specific gravity and excellent mechanical properties (11). Continued retardation of growth, either slowly or abruptly, results in lowered specific gravity, in contrast to the usual relationship of growth rate to specific gravity in conifers (16). Exceptions to this general rule, are some soft-textured hardwoods and the fast-growing hybrid poplars that tend to have a lower specific gravity than the average for native species of the genus Populus (39).

Although high specific gravity values accompany rapid growth in many broad-leaved species, rapidly grown material is not always the best. Although high in density, wood of rapid growth in species like ash and hickory may be low in stiffness (50).

Old-growth oak and yellow-poplar are lower in specific gravity and hardness than the more rapidly grown second growth. Nevertheless, they are preferred for furniture and certain other uses because they shrink and warp less (27), are easier to machine, and because their ring pattern is generally more attractive when given a natural finish. On the other hand, in uses where strength is an important factor, the wood from the faster-growing, stronger hardwoods is preferred.

Many hardwoods -- such as oaks, maple, birch, and hickory -- grow considerably more slowly on the average than conifers. Production of high-quality veneer logs of these species will require a 80- to 100-year rotation on favorable sites where management practices maintain a uniform growth of 10 or more rings per inch.

For some species that can be used in small sizes, such as hickory and ash for handles, picker sticks, and the like, trees 10 to 12 inches in diameter at breast height are merchantable and might be produced in 50 years. Some soft-textured hardwoods, such as soft maple, gum, and Populus species (including hybrids), can be grown to a veneer-bolt size of 16 to 20 inches in 30 to 40 years.

Among hardwood species the weight of the wood may be influenced within quite wide limits by such environmental conditions of growth as site quality and closeness or openness of the trees in a stand, particularly as the development of the crowns of the trees is affected (16). To obtain a slow growth rate that will favor production of wood with certain characteristics, good sites where the trees will develop well must be selected. Silvicultural measures to control quality will be most effective when species and suitability of the site are properly correlated.

Another important lumber characteristic, the proportion of heartwood, also may vary with stand conditions that influence the growth rate of trees; the younger, more thrifty, larger crowned trees of a species have wider sapwood zones (15).

From the silvicultural standpoint, the production of hardwood high in mechanical properties -- including hardness -- requires an initial period of close stocking to encourage natural pruning and to develop trees of suitable form with long clear trunks, followed by the maintenance of thrifty growth by suitable thinnings. A well-sustained or accelerated growth rate throughout the rotation will produce wood of uniformly high weight and strength characteristics (11). Lighter wood can be produced only by a carefully controlled growth rate, in which trees experience early competition and are developed uniformly during a relatively long rotation. In other words, even and close stocking to control crown development is necessary.

In second-growth stands, uniformity of growth is highly important because the small size of the trees does not permit easy segregation of the wood of different growth rates and varying characteristics during manufacture.

Two main efforts at wood quality control are open to progress in forest management: control of wood density by regulation of diameter growth of trees in silvicultural practices (crown control) and improvement of lumber grades at least in butt logs by early pruning of side branches. For understocked stands and widely spaced plantations pruning may have some beneficial effect in promoting crown control, particularly if done in the early life of a stand (38).

In the past, high-quality and high-grade lumber products have come from old-growth trees, often centuries old, as in the case of yellow-poplar (49). This is because nature has been exceedingly wasteful of time in producing the highest grade of lumber. It now appears feasible in forest management practice to obtain essential high-quality products more quickly than is possible in virgin forests. Some of the uses for natural forest products are being met practically by fiber products, chipboards, overlays, and lamination which will tend to reduce the size of trees required.

Certain classes of products still require trees of fairly large size -- for example, veneers and large-sized piling and poles. The latter, like some large-size structural timbers, at present cannot be successfully laminated.

It is well known that every forest has always had a surplus of low-quality material and waste in addition to high-quality products. An important problem is to channel the low-quality material to an appropriate use. For example, low-grade hardwood trees, logs, and logging waste are gaining use in the fiberboard and particle board industries.

Structure of Hardwoods

The wood of hardwoods or broadleaved species, unlike that of conifers, contains large pores or vessels with open ends set one above another. Hardwoods are classified by three different structural arrangements of the pores: ring-porous, diffuse-porous, and semiring-porous. While it cannot be said that the typical structure is significantly affected by environmental relationships, the response to changed conditions during the life of a tree appears to be reflected in the density of the wood. For example, in the ring-porous species, a decrease in ring width is accompanied by an immediate decrease in wood density, whereas in diffuse-porous woods the response is slower.

Ring-porous Hardwoods

The ring-porous genera include true and pecan hickories, ashes, oaks, locusts, elms, and hackberry. In terms of growth and quality the ashes and hickories may be considered together because of similarity of requirements for such special uses as handles for striking tools. Important species of hickory and ash are:

Hickory (*Carya*)

Bitternut hickory (*C. cordiformis*)
Mockernut hickory (*C. tomentosa*)
Nutmeg hickory (*C. myristicaeformis*)
Pecan hickory (*C. illinoensis*)
Pignut hickory (*C. glabra*)
Shagbark hickory (*C. ovata*)
Shellbark hickory (*C. laciniosa*)

Ash (*Fraxinus*)

Black ash (*F. nigra*)
Green ash (*F. pennsylvanica*)
White ash (*F. americana*)

In these species, studies of annual ring width in relation to their chronological development and to the quality of the wood revealed a uniformly high trend in the specific gravity of the wood where ring width was either maintained or increased from its initial starting point. However, either abrupt or gradual narrowing of ring width resulted in a corresponding decrease in the specific gravity of the wood (11).

In other words, as long as favorable conditions for growth of the trees were maintained, little change in specific gravity took place, whether growth at the beginning was rapid or slow (16). In ash and hickory, therefore, slow initial growth followed by increasing ring width has produced uniformly high specific gravity, but in the same tree a change to less favorable conditions later on, as shown by decreasing ring width, produced wood of lower specific gravity.

Investigations of virgin-growth southern Appalachian hickories revealed patterns similar to those just described (14). The wood of slow growth toward the bark, which sometimes represented 200 years or more of radial growth and that consisted of both outer heartwood and the sapwood, was of progressively lower density toward the periphery of the cross section of a tree (33).

A poor site will influence tree size and form of hickories more unfavorably than it will the specific gravity of the wood, although the latter is also somewhat lower. Dry ridges and southern exposure produce short, rough limby trees of less merchantable value than trees grown in coves and on moist, shady slopes. In southern Ohio, specific gravity of Hickory on a north slope averaged 9 percent higher than that from a steep south slope of the same mountain (16).

Crowding of white ash in second-growth stands 60 years old reduced both ring width and specific gravity, the latter as much as 18 percent in one stand and 11 percent in another. In a third stand where crowding was relieved by cutting, specific gravity decreased only 1 percent when the wood of the last 30 years was compared with that of the initial 35 to 40 years of the life of the trees in the stand (16).

Sites in the Mississippi delta and other locations that are subjected to periodic flooding had an important influence on the wood of white and green ash (17). On these sites the trees developed pronounced flaring buttresses containing weak, brash wood of unusually low density. In this buttressed portion of the trees, width of growth rings was no indication of wood quality; in fact the rings varied greatly from year to year, apparently in response to the length of the flooding period. Contrary to expectations, diameter growth was least in the portions of trees that were submerged during the growing season of the years of prolonged flooding (13). In such years, the ring width above the high water level greatly exceeded that of the same ring near the base of a tree; in years of low water the reverse was true (46). In the buttressed trees, density of the wood increased from below upward, becoming practically normal at 20 feet above the ground.

A less spectacular site influence occurred where only limited flooding took place or where soil had abundant moisture, as in creek bottoms. There the ash trees produce a type of wood known as "rubber ash." Such wood has average or higher density but lacks stiffness, and is unsuitable for handles (51).

The ring width of hickories and ash may vary widely in individual trees and between old-growth and second-growth stands. Growth rates between 6 and 15 rings per inch usually accompany the wood of above-average specific gravity, although there may be exceptions in both directions. Handle specifications for both ash and hickory restrict the growth rate to not more than 17 rings per inch for the highest grade handles (54, 55). In the case of ash a minimum of 5 rings per inch may also be specified. In forest management, a growth objective of 8 to 10 rings per inch is suggested to produce ash and hickory of high strength, stiffness, and resilience.

The Red Oak Group

Among the red oaks the following 12 species are of commercial importance:

- Black oak (*Quercus velutina*)
- California black oak (*Q. kelloggii*)
- Cherry bark oak (*Q. falcata* var. *pagodaefolia*)
- Laurel oak (*Q. laurifolia*)
- Northern red oak (*Q. rubra*)
- Nuttal oak (*Q. nuttallii*)
- Pin oak (*Q. palustris*)
- Scarlet oak (*Q. coccinea*)
- Shumard oak (*Q. schumardii*)
- Southern red oak (*Q. falcata*)
- Water oak (*Q. nigra*)
- Willow oak (*Q. phellos*)

These species have few characteristics that serve to differentiate important environmental influences among them. In general, wood of second-growth red oaks is on the average heavier than that of old-growth trees of the same species, probably because of a greater proportion of narrow-ringed (lower density) wood in the older trees. Old-growth red oak in Tennessee averaged 0.53 in specific gravity in comparison with 0.56 for second growth in the same State, 0.57 in North Carolina, and 0.58 in West Virginia (24, 28). In the past, the slowly grown Appalachian oaks have been highly prized because of soft texture, which affords ease of working and has low shrinkage and fine appearance coupled with sufficient hardness and strength for flooring, interior trim, and furniture.

Southern red oaks growing in stream bottomlands are considered to be less satisfactory in some respects, particularly warping, than upland oaks. The lowland oaks, however, generally are not of the same species as the upland oaks, so it is difficult to determine whether the differences are due mainly to species or environment. Average difference in specific gravity between second-growth upland and lowland oaks is slight (24). In the cases investigated, growth rate -- specific gravity relationships were similar in the lowland oaks to those in upland oaks.

While a few specimens of most species of second-growth red oak had 5 or fewer rings per inch, more frequently they had 6 to 10 or 11 to 15 rings (table 1). For the red oaks, about 6 to 10 rings per inch appears to be a maximum growth rate that could be uniformly maintained during a rotation of 75 to 100 years. Wood near the center of trees, whether narrow or wide ringed, had average or better specific gravity; trees that maintained uniform growth also had fairly uniform specific gravity. Those in which the growth rate declined progressively showed a corresponding specific gravity decrease (32).

The White Oak Group

Ten important species of the white oak group are:

Bur oak (*Quercus macrocarpa*)
Chestnut oak (*Q. prinus*)
Chinkapin oak (*Q. muehlenbergii*)
Live oak (*Q. virginiana*)
Oregon white oak (*Q. garryana*)
Overcup oak (*Q. lyrata*)
Post oak (*Q. stellata*)
Swamp chestnut oak (*Q. michauxii*)
Swamp white oak (*Q. bicolor*)
White oak (*Q. alba*)

White oak species usually are of slower growth than the red oaks. In chestnut oak, overcup oak, and white oak, specimens were more frequently in the 11 to 16 rings-per-inch class than in any other 5-ring group. Samples having greater ring width averaged a little heavier. In a comparison of second-growth white oak with old growth, the second-growth white oak (*Q. alba*) from West Virginia, Kentucky, and North Carolina averaged 0.63 in specific gravity, while old growth from West Virginia, Virginia, Tennessee, and Indiana averaged 0.55. The second growth averaged 12 rings per inch and the old growth 19 (28). A growth objective for second-growth species of the white oak group may be set at 8 to 12 rings per inch, which should be fairly easy to maintain under forest management on medium or good sites.

Allowing stands to become closely stocked during the final stage of a rotation may result in a thinner sapwood layer, an advantage for the production of staves for use in tight cooperage. Tyloses that plug the pores of white oak do not develop abundantly in sapwood, which must be removed from tight cooperage staves.

Other Ring-Porous Woods

Honeylocust (*Gleditsia triacanthis*) and black locust (*Robinia pseudoacacia*) possess naturally decay-resistant heartwood. They are best adapted to non-acid soils, but grow under a variety of conditions. When grown rapidly, the wood is heavy and strong (9). These species may be grown in plantations on short rotations for posts, crossarms, poles, and treenails. Growth of 4 to 6 rings per inch will supply material of excellent quality.

Elms, Hackberries, and Sassafras

The genera include the following commercial species:

Hackberry (*Celtis occidentalis*)
Sugarberry (*C. laevigata*)
Sassafras (*Sassafras albidum*)
American elm (*Ulmus americana*)
Cedar elm (*U. crassifolia*)
Rock elm (*U. thomasii*)
Slippery elm (*U. rubra*)
Winged elm (*U. alata*)

Elm species are classified as hard elms (rock elm, winged elm, and cedar elm) and soft elms (American elm and slippery elm) (1). The elms usually inhabit moist, well-drained sites of good quality, such as valley bottoms and the better farm woodlots.

The wood of rock elm is heavy and strong, averaging 0.57 in specific gravity, and is often preferred for bent wood products (16). Decreasing ring width is reflected in a somewhat lower specific gravity. However, in the same trees renewed growth activity that again produced wider growth rings likewise produced heavier wood.

Winged elm grew more slowly on a hardpan soil in Louisiana than on well-drained sites in Arkansas and Texas. In the first location, growth averaged 26 rings per inch and specific gravity 0.56; in the other two locations growth averaged 17 rings per inch and specific gravity 0.59 and 0.60.

Cedar elm occupies a limited range in Louisiana and adjoining States but produces wood that averages 0.60 in specific gravity. It is one of the species that inhabit the low Delta areas. In an analysis of a number of hardwood species in a periodically flooded area, cedar elm produced the heaviest wood near the stump, while the reverse was true of other species of the area (46).

American elm from Wisconsin and Pennsylvania averaged 19 rings per inch and New Hampshire second growth 7.5 rings per inch. The New Hampshire wood was about 10 percent heavier than the other two samples. Slippery elm from Wisconsin, with 17 rings per inch, was more than 10 percent lighter in weight than that from Indiana with 8.4 rings per inch (9).

Hackberry averaged 8.3 rings per inch and 0.50 in specific gravity in Indiana and 13.4 rings per inch and 0.482 in Wisconsin. Sugarberry from Missouri averaged 17.2 rings per inch and 0.473 in specific gravity. The density of wood having the wider growth rings was a little higher.

Since the elms and hackberry are frequently used for purposes requiring some mechanical strength, it appears desirable to promote a more rapid growth rate than has usually occurred in unmanaged stands. Since these species frequently grow in mixture with oaks and other hardwoods, a similar growth rate of 8 to 10 rings per inch should be encouraged.

Sassafras occurs as an occasional tree in the forest, but more frequently in small thickets of root-sprout origin along the margins of woodlots. The wood is of medium growth rate and similar in density to hackberry (0.47) (9). The wood is highly durable and useful for posts and poles. Growth rate can be increased and the density and the strength of the wood improved by thinnings. The data indicate that the heaviest wood has grown at about 11 to 15 rings per inch.

Semiring-porous Woods

Four species are designated as semiring porous:

Water hickory (*Carya aquatica*)
Persimmon (*Diospyros virginiana*)
Black walnut (*Juglans nigra*)
Butternut (*Juglans cinera*)

Water hickory grows mainly in southern river bottoms that are frequently inundated for considerable periods. Diameter growth of test trees was relatively slow, averaging 17 rings per inch. The wood had an average specific gravity of 0.56, considerably below that of the true hickories (0.64). Like some other trees in the inundated regions, the wood near the base of the trees was considerably lower in density than that above the high water level in the same trees. In individual trees this difference was as much as 10 percent (46).

Persimmon is a tree of medium to slow growth, normally producing wood of high specific gravity. It is close grained, wears smoothly, and is thus suitable for such uses as textile shuttles. Growth rate of trees from Missouri averaged 13.8 rings per inch and that of trees from the Mississippi delta 20 rings per inch. In a flooded area the wood toward the base of the trees was lighter than that above flood-water levels in the same trees (46). Since hardwoods generally produce wood of high density with increasing growth rate, it would probably be advantageous in silvicultural practices to favor persimmon by giving individual trees more growing space.

Black walnut is the most important of the semiring-porous species. The wood is moderately heavy (average specific gravity is 0.52) and hard, but varies greatly in specific gravity depending upon growth conditions (31). The lightest wood occurred in slowly grown old-growth trees of the southern Appalachian Mountains, averaging 17 rings per inch and 0.46 in specific gravity. Young trees in the same forest contained much heavier wood, however; their growth averaged 12 rings per inch and their specific gravity was 0.50. The black walnut stand with the heaviest wood tested consisted of open-grown trees on a moist slope in the Ozarks. These trees averaged 13 rings per inch and 0.58 in specific gravity.

Wood close to the stump in black walnut trees was always heavier than wood higher in the trees, and there was often a marked decrease in density of sapwood compared to adjacent heartwood. Walnut can be grown rapidly in open stands, in margins of woodlots, and along fences. Although pruning will help develop clear trunks, cross grain from tapering logs or from swellings near branches can be utilized as sliced veneers for matched figure or other desirable patterns. Growth rate of material studied ranged from 5 to 23 rings per inch, the wider rings being in the open-grown trees. A growth objective of 8 rings per inch will provide highly uniform wood with above-average strength properties.

Butternut has much the same growth habits as black walnut, yet the wood is of much lower weight, averaging 0.36 in specific gravity (9). The heaviest wood was produced at growth rate of less than 10 rings per inch.

Diffuse-porous Woods

Diffuse-porous woods of commercial importance include 34 species, of which 6 occur in the Pacific Northwest. They present a wide range in physical and mechanical properties; flowering dogwood has about twice the density of willow. Many of them have a wide range of natural distribution.

Eastern Species

Diffuse-porous species of the eastern United States may well be divided into three general groups on a density basis. Those averaging 0.50 or more in specific gravity are:

Beech (*Fagus grandifolia*)
Black maple (*Acer nigrum*)
Sugar maple (*Acer saccharum*)
Sweet birch (*Betula lenta*)
Yellow birch (*Betula alleghaniensis*)
Flowering dogwood (*Cornus florida*)

Because of the extensive latitudinal range of these species, the comparative quality of wood from widely separated regions -- for example, between Lake States and south Appalachian maple -- is frequently called in question. Studies have shown no great differences based on origin of wood from northern and southern locations when similar stands were compared; that is, wood of old-growth stands in the south generally was quite similar to that of old-growth stands in the north. The same was true when second-growth stands were compared. However, rather large differences occurred between second-growth stands and old-growth stands in a given locality, either north or south. These differences could be related to the immediate growth conditions of individual stands. In general, the second-growth stands had the advantage of greater thrift due to less competition. The usual result was that the second-growth trees produced heavier and harder wood than old-growth trees, particularly during the latter, slower decades of old growth (28).

Old-growth sugar maple averaged 0.55 in Indiana, 0.56 in Wisconsin and North Carolina, and 0.58 in Michigan (9). Second-growth values were 0.58 for Kentucky, Vermont, and New York and 0.59 for Michigan. The heaviest wood of sugar maple was obtained from short trunks of open-grown trees in Vermont, which averaged 0.65 (41). In hardness tests, second-growth sugar maple averaged 13 percent heavier than old growth. Black maple is in the density range of sugar maple.

Ring width is a good criterion for judging quality in maple, birch, and beech only if the origin of the sample is known in relation to the life history of the tree or stand. Narrow-ringed wood near the center of trees usually is as high in specific gravity as wide-ringed wood at the same relative position. However, as diameter growth of trees declines, specific gravity almost always decreases. Thus wood of slow growth near the bark is of lower specific gravity than that of equal ring width near the pith, particularly if a zone of wider ring width has intervened (48).

In beech, sweet and yellow birch, and black and sugar maple, test specimens most frequently had 6 to 10 and 11 to 15 rings per inch. An average of 10 rings per inch appears to be about the best attainable in well-stocked, second-growth stands. If wood of very high density is desired, the trees will need plenty of growing space, probably at a sacrifice of the clear length of the boles.

The wood of flowering dogwood is heavy, hard, and close grained. This tree generally occupies a subordinate position in the forest, and slow growth may be largely due to competition and shading of surrounding trees. It appears advisable to favor flowering dogwood in forest management and thus increase the growth rate, because this species is in great demand, particularly for shuttles in the textile industry.

Diffuse-porous woods of intermediate density range in specific gravity mostly from 0.41 to 0.50. The species in this group are:

Paper birch (Betula papyrifera)
Black cherry (Prunus serotina)
Red maple (Acer rubrum)
Silver maple (Acer saccharinum)
Southern magnolia (Magnolia grandiflora)
Black tupelo (Nyssa sylvatica)
Water tupelo (Nyssa aquatica)
Ogeechee tupelo (Nyssa ogeche)
Sweetgum (Liquidambar styraciflua)
Sycamore (Platanus occidentalis)

These species represent a great variety of forest types and stand conditions, yet average differences in density of wood among species are not striking.

Paper birch, an associate of other birches in the northern States and Canada, grows more rapidly than sweet and yellow birches yet produces wood with an average specific gravity of only 0.50. Growth rates of test specimens were mostly at 6 to 10 rings per inch, wider-ringed specimens had slightly higher density and narrow-ringed specimens slightly lower (table 1).

Black cherry, usually occurring in mixed stands, maintains its dominance by rapid growth. In the Middle Atlantic States it has become an important element in second-growth stands, where trees have attained sizes of 15 to 20 inches in diameter at breast height in 50 to 75 years. Nearly one-fourth of the second-growth test specimens had 5 growth rings or less per inch, averaging 0.50 in specific gravity; about one-half had 6 to 10 rings per inch with an average of 0.48 in specific gravity. Old growth averaged 0.47 and second growth 0.49. Specific gravity was reduced gradually from the wider to narrower ring width. For first-quality cabinet wood and for gunstocks, growth of 6 to 10 rings per inch doubtless is very satisfactory (30).

Red maple is intermediate in specific gravity between silver maple and sugar maple. Red maple and silver maple are sold as soft maple. Soft maple lumber grown in the northern states is likely to be red maple, and that grown in the south, silver maple. The difference in density of red maple, (0.49) and silver maple (0.44) is sufficient to be of importance in many uses, particularly in furniture parts requiring a fair degree of strength (9). No important differences in specific gravity of red maple appeared to correspond with changes in ring width. Red maple is found frequently in marshy areas but in such locations the trees are of poor form and are not suitable for lumber. The heaviest wood of silver maple was in the first rings-per-inch class; specific gravity dropped noticeably in the 6 to 10 rings-per-inch class (table 1).

While all but one of the specific gravity specimens of southern magnolia had 11 to 15 rings per inch, these data are insufficient for an assessment of factors influencing quality. The average specific gravity was 0.46 (9).

Black tupelo grows slowly on a variety of soils. It is considered more of an upland species than the other Nyssas, which largely inhabit low ground, stream courses, or swamps. A majority of the test specimens showed 20 or more rings per radial inch, and average specific gravity was 0.46. There is a slight indication that more rapid growth would produce somewhat heavier wood. A more rapid growth rate appears desirable from the standpoint of volume yields.

Water tupelo occupies very low areas that are often under water for long periods each year. As a result of excessive water conditions, the trees develop large buttresses often extending to heights of 10 feet or more.

The wood of water tupelo varies considerably in specific gravity from the base of the trees upward. Wood in the large buttresses may be weak, brash, and exceptionally low in density. The total specific gravity range in a backwater area of the Mississippi delta was 0.19 to 0.52. In the same location average variations up the tree at progressive heights were: at 2 to 3 feet, 0.25; 8 to 10 feet, 0.33; 12 to 16 feet, 0.42; and at 24 to 30 feet, 0.44 (46). In this case, variation up the tree was greater than horizontal variation, and the direct reverse of what is normally the case with upland species. As in the case of delta ash, many uses require a classification of the lumber on a basis of density and strength. Other Nyssa species growing under similar conditions may be expected to react to water conditions in the same way. The depth and duration of flooding appear to influence the extent of buttress development.

Sweetgum grows to large size on moist soils of good quality, Diameter growth of trees is relatively slow but quite uniform. Specimens averaged about 15 rings per radial inch, the majority having 11 to 15 rings per inch. There was no great difference in specific gravity according to growth rate, and no specimens had less than 5 rings per inch. One second-growth shipment from South Carolina averaged 0.49 in specific gravity compared to 0.44 for old-growth shipments. Specific gravity of another second-growth shipment from Mississippi averaged only slightly above the old growth. Young sweetgum trees have wide sapwood, which is known as sap gum on the lumber market and the heartwood from old-growth trees is known as red gum. Uniform growth of about 10 rings per inch should supply high-quality lumber of near-average density. As trees near maturity, slower diameter growth will tend to narrow the sapwood zone, thus providing more of the darker heartwood preferred for natural finishes.

Sycamore is typically a tree of rapid growth occupying moist sites along streams and rivers. About half of the test specimens had fewer than 10 rings per inch. Specific gravity values, averaging 0.45, were rather uniform and showed no consistent variation with ring width. Specimens with 5 or fewer rings per inch averaged 0.43; those with 6 to 10 averaged 0.46, which was slightly above that of the narrower ring-width classes (table 1).

Diffuse-porous woods having a density range generally between 0.31 and 0.40 are:

American basswood (*Tilia americana*)
White basswood (*Tilia heterophylla*)
Ohio buckeye (*Aesculus glabra*)
Yellow buckeye (*Aesculus octandra*)
Yellow-poplar (*Liriodendron tulipifera*)
Balsam poplar (*Populus balsamifera*)
Bigtooth aspen (*Populus grandidentata*)
Black cottonwood (*P. trichocarpa*)
Eastern cottonwood (*P. deltoides*)
Plains cottonwood (*P. sargentii*)
Quaking aspen (*P. tremuloides*)
Swamp cottonwood (*P. heterophylla*)
Black willow (*Salix nigra*)

Although most of these species have a widely distributed natural range, the data available do not indicate any large differences in properties due to geographic location. For a number of the species, data on trees from only one or two locations are at hand.

In these woods, differences in ring width have a less marked relationship to density than in many other species. The widest growth rings, particularly near the pith, do not produce the heaviest wood (table 1) (39). Slow growth near the pith may be heavy, while very slow growth near the bark is lighter than wood of intermediate growth rate formed previously.

Rings-per-inch and specific-gravity data for American basswood reveal a fairly uniform ring width in the two lots tested, one from Wisconsin and the other from Pennsylvania. The Wisconsin shipment, with 22 rings per inch and a specific gravity of 0.316, was a little lower in specific gravity than the Pennsylvania shipment, which averaged 17 rings per inch and 0.33 in specific gravity (9). Second-growth basswood (especially that of sprout origin) grows much more rapidly, but data on second growth of this species are lacking, as also is the case with the southern Appalachian white basswood.

Yellow buckeye from one location contained specimens that had mostly 10 or more rings per inch (9). Specific gravity increased slightly with slower growth from the central portions of the trees outward. No tests have been made on Ohio buckeye.

Yellow-poplar is the most important species of this group, and for that reason it has been given considerable study. Specific gravity determinations reveal great variability. In old-growth trees the lightest wood is in the slowly grown outer portions that have 30 to 50 or more growth rings per radial inch. Such wood ranges between 0.30 and 0.33 in specific gravity. Wood of old-growth trees with between 10 and 30 rings per inch averaged about 0.37 in specific gravity. With 5 to 10 rings per inch the specific gravity was slightly lower, about 0.35 (49); no old-growth specimens had fewer than 5 rings per inch (table 1). For comparable ring-width classes in younger trees and in second-growth stands, the specific gravity values averaged somewhat higher than in the old-growth trees, about 0.40 in the 11 to 15 rings-per-inch group. However, the wood with 5 rings or less near the center of young trees likewise was a little lighter, but near the species average of 0.38. From the data it appears that yellow-poplar wood having 11 to 15 rings per inch is likely to be heaviest. For carving and for easily worked pattern stock the lower density old growth with about 20 rings per inch is preferred.

As a matter of fact, much of the second-growth yellow-poplar is less satisfactory for traditional uses than that from old, slowly grown trees. It has been observed that released growth in yellow-poplar trees left after logging produced wood in the outer portion of the bole closely approaching the characteristics of second-growth timber. Management of second-growth yellow-poplar and other species of this group can be planned at 5 to 10 rings per inch, a growth rate that will doubtless produce wood somewhat heavier than that of old-growth timber.

The aspens, including quaking aspen, bigtooth aspen, and balsam poplar, are among the most widespread species on the North American continent. This extensive geographical distribution, however, is not reflected in highly variable wood density, although some important differences are evident among stands. Variations of growth appeared important only in extreme cases.

Balsam poplar of 5 rings per inch in Vermont averaged the same in specific gravity as at 10 rings per inch in Alaska -- 0.30 in both cases (9). Still slower growth in Alaska produced a specific gravity of 0.35. With bigtooth and quaking aspen it appeared that the heaviest wood was produced on sites of intermediate quality, and somewhat lighter wood on both the poorer and the better soils (56).

An average growth rate of 10-13 rings per inch on medium and good sites produced wood averaging about 0.40 in specific gravity. Other stands of 6 to 8 rings per inch produced wood with density of 0.34 to 0.36. Cottonwood with 6 to 7 rings per inch in Missouri produced wood in the aspen range, while poplar hybrids from Maine, Massachusetts, and Iowa produced wood averaging downward from 0.37 to 0.29 with increases of nearly 1 inch in ring width (39).

Black willow produced a light, soft wood averaging 0.34 in specific gravity for material of 5 rings per inch grown in Missouri. In southwestern Mississippi, along the Mississippi River, trees grew in diameter at a rate of 2 to 16 rings per inch and attained heights of 100 feet in 30 to 40 years. There appeared to be no relationship between width of rings and specific gravity in this sample, however; the trees showed specific gravity variations typical of trees from inundated areas, with lighter wood near the stump and a slight increase in specific gravity at successive heights. The average value below 4 feet was 0.35 and above 40 feet 0.37. The average for the stand was 0.36 and the specific gravity range was 0.30 to 0.42.

Western Species

A few species of diffuse-porous woods occur in the west and are of considerable local importance. They are:

Black cottonwood (*Populus trichocarpa*)
Red alder (*Alnus rubra*)
Bigleaf maple (*Acer macrophyllum*)
Oregon myrtle (*Umbellularia californica*)
Pacific madrone (*Arbutus menziesii*)
Tanoak (*Lithocarpus densiflorus*)

Black cottonwood inhabits stream bottoms and moist soils at low elevations in the Pacific coastal region, where it grows rapidly. Test specimens averaged 5.6 rings per inch and 0.32 in specific gravity. While variability of wood was not great, that with widest growth rings was lowest in specific gravity.

Red alder occurs in commercial quantities along the coast of Oregon and Washington, where it grows well on moist lowlands and lower slopes. The wood is of medium weight, having about the same specific gravity, 0.38, as old-growth yellow-poplar (9). Specific gravity data show moderate variability for growth rates up to 20 rings per inch. The most frequent ring width is 11 to 16 (table 1). Natural stands have supplied large quantities of lumber that is used mainly in the manufacture of furniture. A growth rate of 6 to 15 rings per inch appears suitable for production of timber to meet the needs of current uses.

The wood of bigleaf maple averages a little higher in specific gravity than that of silver maple; comparative values of the two species are 0.45 and 0.44 (9). Ring width varies between 6 and 20 rings per inch, the density increasing slightly for material having relatively wider growth rings. Certain growth conditions will improve the tree form; well-stocked stands will yield smoother, more cylindrical, and straighter-grained logs, and are important in improving grade, although density may decrease somewhat if stands are too crowded.

Oregon myrtle, Pacific madrone, and tanoak represent a class of fairly hard and heavy woods. Oregon myrtle averages 0.52 in specific gravity, with a slightly higher average for material grown at 6 to 10 rings per inch than at less than 5 rings per inch. Since Oregon myrtle is highly suitable as a cabinet wood, the closer grained, harder material doubtless is preferable. Material of very slow growth has not been tested. A growth rate of 6 to 10 rings per inch may be considered a suitable objective.

Pacific madrone grows in diameter at a medium rate up to 15 rings per inch, Most of the specimens had 6 to 10 rings per inch. The wood averaged a little heavier than that of slower growth specimens; the average specific gravity of the species is 0.57, a value close to that of birch and maple.

Although tanoak belongs to a different genus than oak, it has properties similar to those of many species of _Quercus_. Its average specific gravity is 0.59, compared to 0.60 for white oak. Average rings per inch for all test specimens was 14.1. Samples from next to the pith had wider rings than those near the bark, but differences in specific gravity throughout the cross sections of the trees were unimportant. Some specimens had high longitudinal shrinkage and were characterized by tension wood, such as frequently occurs in leaning broadleaved trees (42).

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Table 1.--Average specific gravity values, percentage distribution by rings-per-inch classes, and recommended ring widths for second-growth stands

Species	Total number of tests	Average specific gravity	0-5 Average specific gravity	0-5 Percent of total	6-10 Average specific gravity	6-10 Percent of total	11-15 Average specific gravity	11-15 Percent of total	16-20 Average specific gravity	16-20 Percent of total	21+ Average specific gravity	21+ Percent of total	Recommended rings per inch for second growth: High density	Recommended rings per inch for second growth: Average density
SOFTWOODS														
Baldcypress (Taxodium distichum)	83	0.42	0.38	2	0.40	19	0.42	22	0.43	23	0.43	34		10
Cedar:														
Alaska (Chamaecyparis nootkatensis)	23	.43							.43	26	.43	74		12
Atlantic white (C. thyoides)	23	.32	.32	5	.31	30	.35	22	.32	30	.32	13		10
Eastern redcedar (Juniperus virginiana)	14	.45	.52	7	.44	29	.45	43	.45	14	.47	7		8
Incense (Libocedrus decurrens)	16	.34			.31	19	.33	37	.36	19	.35	25		12
Northern white (Thuja occidentalis)	18	.29			.25	6			.30	11	.30	83		12
Port-Orford (Chamaecyparis lawsoniana)	57	.40					.39	21	.39	47	.41	32		12
Western redcedar (Thuja plicata)	71	.32			.29	4	.31	28	.32	33	.32	35		12
Douglas-fir (old growth):														
Coast type (Pseudotsuga menziesii)	1,087	.42	.38	3	.41	24	.43	22	.44	20	.43	31		
Intermediate type (P. menziesii glauca)	534	.42	.38	1	.40	19	.42	26	.43	20	.43	34		
Rocky Mountain type (P. menziesii var. glauca)	531	.39	.41	0	.39	17	.39	24	.40	17	.40	42		
Douglas-fir (second growth):														
Coast type (Pseudotsuga menziesii)	1,192	.43	.40	26	.44	31	.45	13	.45	11	.45	19	10	6-8
Intermediate (P. menziesii glauca)	53	.42	.40	6	.40	45	.44	25	.48	13	.45	11	10	8
Fir:														
Balsam (Abies balsamea)	17	.35			.34	47	.36	35	.36	12	.32	6		8
California red (A. magnifica)	114	.36	.32	1	.35	42	.38	35	.36	16	.36	6		8
Grand (A. grandis)	40	.37	.39	10	.36	35	.37	5	.36	8	.39	42		8
Noble (A. procera)	96	.37	.33	9	.33	23	.36	24	.36	4	.40	40		8
Pacific silver (A. amabilis)	96	.37			.35	17	.35	39	.38	21	.41	23		10
Subalpine (A. lasiocarpa)	20	.29			.28	5	.29	55	.29	35	.31	5		10
White (A. concolor)	39	.34	.34	15	.34	41	.34	26	.35	10	.32	8		8
Hemlock:														
Eastern, old growth (Tsuga canadensis)	57	.39			.38	9	.41	21	.39	33	.37	37		
Eastern, second growth (T. canadensis)	19	.39			.38	58	.41	26	.40	11	.38	5		8
Mountain (T. mertensiana)	41	.46					.46	12	.43	24	.47	64		10
Western (T. heterophylla)	88	.39	.36	9	.39	17	.38	22	.40	18	.40	34		8
Juniper:														
Rocky Mountain (Juniperus scopulorum)	46	.41							.48	2	.40	98		20
Western (J. occidentalis)														

Table 1.--Average specific gravity values, percentage distribution by rings-per-inch classes, and recommended ring widths for second-growth stands--continued

Species	Total number of tests	Average specific gravity	0-5 Average specific gravity	0-5 Percent of total	6-10 Average specific gravity	6-10 Percent of total	11-15 Average specific gravity	11-15 Percent of total	16-20 Average specific gravity	16-20 Percent of total	21+ Average specific gravity	21+ Percent of total	Recommended rings per inch for second growth: High density	Recommended rings per inch for second growth: Average density
Larch:														
Tamarack (Larix laricina)	13	.49			.51	15	.48	31	.48	23	.49	31		12
Western, old growth (L. occidentalis)	90	.51			.48	7	.51	12	.52	14	.51	67		
Western, second growth (L. occidentalis)	45	.51			.50	29	.51	38	.53	24	.50	9		12
Pine (soft):														
Eastern white, old growth (Pinus strobus)	35	0.35	0.26	3	0.34	37	0.34	29	0.37	14	0.38	17		
Eastern white, second growth (P. strobus)	75	.35	.32	12	.35	55	.36	24	.35	4	.35	5		10
Pinyon (P. edulis)	44	.49					.50	2	.51	9	.48	89		15
Sugar (P. lambertiana)	31	.35			.35	39	.35	42	.35	13	.32	6		10
Western white (P. monticola)	79	.36			.33	13	.36	20	.38	19	.37	48		10
Pine (hard):														
Jack (P. banksiana)	93	.40	.40	4	.40	42	.40	31	.42	13	.40	10		6
Loblolly, second growth (P. taeda)	859	.42	.37	46	.45	37	.49	14	.47	2	.52	1	12	6
Longleaf, old growth (P. palustris)	545	.55	.57	1	.56	19	.57	25	.56	21	.52	34		
Longleaf, second growth (P. palustris)	589	.52	.47	14	.51	26	.56	18	.55	11	.53	31	12	6
Pitch, old growth (P. rigida)	20	.48			.48	50	.47	25	.45	15	.50	10		
Pitch, second growth (P. rigida)	17	.45			.44	18	.45	41	.46	29	.43	12	15	10
Pond (P. serotina)	20	.50			.50	35	.52	40	.51	5	.49	20	15	6
Red, old growth (P. resinosa)	20	.45			.36	5	.41	5	.46	35	.45	55		
Red, second growth (P. resinosa)	44	.39	.33	2	.35	32	.40	43	.41	18	.43	5	12	8
Sand (P. clausa)	7	.44	.38	14	.45	86								8
Shortleaf, old growth (P. echinata)	109	.47	.41	7	.49	7	.50	16	.49	20	.47	50		
Shortleaf, second growth (P. echinata)	1,013	.45	.40	14	.44	39	.46	25	.47	10	.47	12	15	6
Slash, old growth (P. elliottii)	26	.62	.57	4	.64	39	.61	15	.69	15	.56	27		
Slash, second growth (P. elliottii)	349	.51	.46	41	.54	46	.55	12	.54	1			10	6
Virginia (P. virginiana)	63	.45	.44	22	.44	46	.48	24	.47	8				8
Jeffrey (P. jeffreyi)	20	.38			.37	15	.37	30	.40	20	.39	35	15	8
Lodgepole (P. contorta)	108	.37			.31	6	.38	17	.36	21	.38	56	20	12
Ponderosa, old growth (P. ponderosa)	162	.39	.36	3	.38	13	.38	24	.38	14	.40	46		
Ponderosa, second growth (P. ponderosa)	234	.37	.37	26	.37	41	.38	24	.38	6	.36	3		10
Redwood, old growth (Sequoia sempervirens)	941	.40	.36	4	.41	9	.41	14	.40	15	.39	58		
Redwood, second growth (S. sempervirens)	442	.33	.32	52	.34	34	.33	11	.34	3	.38	0	20	6
Spruce:														
Black (Picea mariana)	5	.38					.35	20	.37	40	.41	40		10
Englemann (P. engelmannii)	213	.33	.28	1	.30	6	.31	12	.33	19	.34	62		15
Red (P. rubens)	96	.37			.35	36	.37	39	.39	15	.41	10		10
Sitka (P. sitchensis)	139	.37	.31	9	.34	12	.37	35	.37	30	.40	14	20	10
White (P. glauca)	39	.39			.38	10	.40	18	.38	26	.40	46		10

Table 1.--Average specific gravity values, percentage distribution by rings-per-inch classes, and recommended ring widths for second-growth stands--continued

Species	Total number of tests	Average specific gravity	0-5 Average specific gravity	0-5 Percent of total	6-10 Average specific gravity	6-10 Percent of total	11-15 Average specific gravity	11-15 Percent of total	16-20 Average specific gravity	16-20 Percent of total	21+ Average specific gravity	21+ Percent of total	Recommended rings per inch for second growth: High density	Recommended rings per inch for second growth: Average density
HARDWOODS														
Alder, red (Alnus rubra)	24	0.38	0.33	12	0.36	46	0.40	17	0.38	17	0.41	8		8
Ash:														
Black (Fraxinus nigra)	24	.44			.47	4	.42	12	.47	17	.44	67		10
Green (F. pennsylvanica)	235	.53	.55	4	.55	27	.54	25	.53	16	.51	28		
White, old growth (F. americana)	212	.56	.60	1	.59	26	.56	35	.54	24	.53	14		
White, second growth (F. americana)	409	.56	.58	4	.57	46	.56	27	.54	14	.50	9		8
Aspen:														
Bigtooth (Populus grandidentata)	31	.37	.38	10	.36	77	.37	13						10
Quaking (P. tremuloides)	85	.38	.32	1	.36	62	.40	33	.41	4				10
Basswood, American (Tilia americana)	31	.34			.30	16	.34	16	.36	23	.33	45		10
Beech, American (Fagus grandifolia)	227	.58	.66	1	.61	27	.57	29	.56	23	.58	20		8
Birch:														
Paper, (Betula papyrifera)	23	.50	.51	35	.50	56	.49	9						6
Sweet, (B. lenta)	53	.59	.57	2	.57	21	.59	28	.58	23	.61	26		8
Yellow, (B. alleghaniensis)	99	.55	.54	8	.55	27	.56	35	.56	9	.55	21		8
Buckeye:														
Ohio (Aesculus glabra)														
Yellow (A. octandra)	20	.34			.32	25	.32	25	.35	40	.37	10		6
Butternut (Juglans cinerea)	40	.36	.37	18	.37	52	.34	20	.35	10				8
California laurel (Umbellularia californica)	20	.52	.505	30	.52	70								
Cherry, black (Prunus serotina)	103	.48	.50	21	.48	52	.45	20	.47	7				6
Cottonwood:														
Black (Populus trichocarpa)	20	.32	.31	50	.34	50								6
Eastern (P. deltoides)	18	.37	.38	61	.37	39								6
Plains (P. sargentii)														
Swamp (P. heterophylla)														
Dogwood, Flowering (Cornus florida)	9	.64							.55	11	.64	89		10
Elm:														
American (Ulmus americana)	35	.47	.57	3	.51	20	.47	37	.46	20	.43	20		8
Cedar (U. crassifolia)	90	.56			.62	2	.59	8	.58	17	.55	73		10
Rock (U. thomasii)	20	.56			.67	5			.60	10	.55	85		8
Slippery (U. rubra)	22	.49	.58	4	.55	18	.50	23	.48	23	.43	32		8
Winged (U. alata)	95	.58	.54	6	.61	14	.58	25	.57	18	.55	37		8
Hackberry (Celtis occidentalis)	24	.48	.48	4	.50	29	.47	42	.48	17	.46	8		8
Hickory, pecan:														
Bitternut (Carya cordiformis)	6	.59					.59	100						6
Nutmeg (C. myristicaeformis)														
Pecan (C. illinoensis)	13	.60			.63	31	.59	31	.59	38				6
Water (C. aquatica)	13	.59					.60	23	.58	54	.59	23		10
Hickory, true:														
Mockernut (C. tomentosa)	18	.66					.67	17	.67	55	.64	28		8
Pignut (C. glabra)	213	.66	.72	0	.70	9	.67	21	.66	21	.64	48		8
Shagbark (C. ovata)	80	.63			.69	9	.65	15	.64	17	.61	59		8
Shellbark (C. laciniosa)														
Honeylocust (Gleditsia triacanthos)	19	0.58	0.54	10	0.60	53	0.52	21	0.55	16				6
Locust, black (Robinia pseudoacacia)	12	.65			.66	42	.64	42	.64	16				6

Table 1.--Average specific gravity values, percentage distribution by rings-per-inch classes, and recommended ring widths for second-growth stands--continued

Species	Total number of tests	Average specific gravity	0-5: Average specific gravity	0-5: Percent of total	6-10: Average specific gravity	6-10: Percent of total	11-15: Average specific gravity	11-15: Percent of total	16-20: Average specific gravity	16-20: Percent of total	21+: Average specific gravity	21+: Percent of total	Recommended rings per inch for second growth: High density	Recommended rings per inch for second growth: Average density
Madrone, Pacific (Arbutus menziesii)	24	.57			.58	79	.56	17	.50	4				8
Magnolia, southern (Magnolia grandiflora)	8	.46					.47	88	.43	12				8
Maple:														
Bigleaf (Acer macrophyllum)	20	.45			.46	45	.45	35	.44	20				8
Black (A. nigrum)	4	.53			.55	25	.56	25	.51	50				10
Red (A. rubrum)	107	.50	.44	1	.49	27	.49	38	.52	23	0.50	11		8
Silver (A. saccharinum)	20	.44	.47	40	.42	40	.44	20						6
Sugar, old growth (A. saccharum)	40	.56			.56	2	.57	25	.56	23	.56	50		
Sugar, second growth (A. saccharum)	451	.58	.59	2	.58	31	.57	34	.58	17	.58	16		8
Oaks, red:														
Black (Quercus velutina)	309	.59	.62	3	.60	45	.59	33	.58	11	.54	8		8
California black (Q. kelloggii)	38	.51			.56	34	.52	21	.49	21	.44	24		8
Cherrybark (Q. falcata var. pagodafolia)	107	.61	.62	37	.61	47	.60	14	.59	2				8
Laurel (Q. laurifolia)	20	.57			.57	60	.56	30	.58	10				8
Northern red, old growth (Q. rubra)	138	.56	.61	3	.57	50	.54	41	.53	6				
Northern red, second growth, (Q. rubra)	136	.58	.59	10	.58	71	.56	16	.58	3				8
Nuttall (Q. nuttallii)	83	.56	.56	24	.56	65	.56	10	.53	1				8
Pin (Q. palustris)	20	.58	.56	5	.59	75	.57	10	.52	10				8
Scarlet (Q. coccinea)	245	.58	.61	3	.59	53	.58	37	.58	7	.61	0		8
Shumard (Q. shumardii)														
Southern red (Q. falcata)	269	.57	.61	7	.59	29	.57	26	.56	21	.53	17		8
Water (Q. nigra)	113	.59	.61	24	.59	61	.56	12	.54	3				8
Willow (Q. phellos)	73	.59	.65	6	.59	71	.57	19	.58	3	.55	1		8
Oaks, white:														
Bur (Q. macrocarpa)	19	.59	.63	11	.60	47	.56	26	.54	5	.57	11		8
Chestnut (Q. prinus)	187	.63			.67	20	.65	32	.62	22	.58	26		8
Chinkopin (Q. muehlenbergii)														
Live (Q. virginiana)														
Oregon white (Q. garryana)	40	.65			.66	15	.68	32	.63	35	.61	18		10
Overcup (Q. lyrata)	239	.56	.56	0	.57	32	.57	38	.54	21	.53	9		8
Post (Q. stellata)	36	.62					.68	17	.62	39	.60	44		10
Swamp chestnut (Q. michauxii)	16	.61	.66	6	.61	44	.58	38	.62	12				8
Swamp white (Q. bicolor)	4	.65			.65	25	.68	50			.60	25		8
White, old growth (Q. alba)	236	.59			.62	16	.60	26	.59	27	.58	31		
White, second growth (Q. alba)	444	.63	.63	0	.64	29	.63	43	.62	21	.60	7		10
Persimmon (Diospyros virginiana)	13	.62					.65	46	.54	31	.66	23		10
Poplar balsam (Populus balsamifera)	20	.31	.31	40	[illegible]	60								6
Sassafras (Sassafras albidum)	20	.47					.53	15	.46	35	.46	50		10
Sugarberry (Celtis laerigata)	41	.44	.43	5	.44	34	.44	15	.44	24	.43	22		6
Sweetgum (Liquidambar styraciflua)	218	.46			.46	29	.46	40	.47	24	.46	7		8
Sycamor, American (Plantanus occidentalis)	82	.45	.43	17	.46	34	.44	26	.45	13	.45	10		8
Tanoak (Lithocarpus densiplorus)	29	.59			.58	34	.58	24	.60	21	.59	21		10
Tupelo:														
Black (Nyssa sylvatica)	102	.46	.47	1					.47	11	.46	88		10
Ogeechee (N. ogeche)														
Water (N. aquatica)	21	.42			.39	5	.47	5	.42	47	.42	43		10
Walnut, black (Juglans nigra)	379	.51	.52	12	.52	45	.51	26	.48	12	.47	5		8
Willow, black (Salix nigra)	89	.36	.37	80	.35	19	.37	1						6
Yellow-poplar, old growth (Liriodendron tulipifera)	193	.39	.39	9	.40	26	.41	21	.38	18	.37	26		
Yellow-poplar, second growth (L. tulipifera)	433	.43	.40	18	.43	36	.44	25	.44	12	.43	26		8

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(Sheet 4 of 4)