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THE APPLICATION OF SILVICULTURE IN CONTROLLING THE SPECIFIC GRAVITY...
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TECHNICAL BULLETIN No. 168 JANUARY, 1930

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.

# THE APPLICATION OF SILVICULTURE IN CONTROLLING THE SPECIFIC GRAVITY OF WOOD

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CONTENTS



Until recently it has been possible to secure easily, whenever needed, wood having the properties desired for a special use. The extent of the progressive exhaustion of our virgin forests, however, now emphasizes our ultimate dependence upon the younger, second-growth forest stands to fill all of our needs for lumber and other wood. When the time of that dependence comes, the difficulty of securing materials well suited for the more exacting wood uses will become infinitely greater, because the supply must then come both from fewer species and from trees of smaller size, that contain a lower relative amount of clear lumber. Learning what growth factors affect the quality of wood the most has consequently become a matter exceedingly important.

This bulletin gives the results of silvicultural studies which show that the specific gravity of the woods studied may be modified by controlling local factors which affect the growth either of forest stands or of individual forest trees, so that it becomes possible, within natural limits, to regulate the specific gravity of wood according to the particular use in view.

## HISTORICAL

The investigations upon which this bulletin are based are the first of their kind to be conducted on a comprehensive scale in the United States. In Europe, however, research on silvicultural con-

[1] Maintained at Madison, Wis., by the Forest Service, U. S. Department of Agriculture, in cooperation with the University of Wisconsin.

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trol of wood properties has been in progress for more than half a century.

The investigations of Hartig (*6–10*)[2] undoubtedly hold first place among such efforts abroad. Working with both broad-leaved and coniferous species, he sought to determine the influence of climate and of soil fertility upon the weight of dry wood. He also studied the relations between the rate of growth of trees in diameter and the resulting specific gravity of the wood produced by them.

After carrying on a great many experiments over a period of more than 20 years, he formulated his conclusions into a system which he termed the nourishment theory (Ernährungs Theorie) (*7*). In this theory he held that the specific gravity of wood is dependent upon the relationships of soil fertility, transpiration of water by the tree crown, and assimilation. He asserted that the anatomical structure of wood conforms to the needs of the tree as influenced by external conditions; that the quantity of growth depends upon the total amount of foliage and upon the assimilative energy of the leaves which is affected by the quality of the soil, the sunlight, and the temperature; while the specific gravity of wood is influenced by the proportional quantity of conducting tissue to supporting tissue. The greater the transpiration as compared with the production of wood substance the greater the amount of porous tissue formed and the lighter the wood. Therefore, heavier wood results when the most abundant assimilation possible accompanies a normal transpiration.

The large number of factors included in Hartig's nourishment theory make it difficult to state which factor or factors may be the more important in controlling wood quality. In discussing the weight and structure of wood, Busgen (*3*), probably on account of this uncertainty of factors, gives little credit to the results of research by Hartig (*6, 7, 8, 10*), Sanio (*15*), and Bertog (*1*). He summarizes the "present state of experimental research on the influence of external conditions upon wood structure" by saying: "In this direction but little has been done, although attention has for a long time been directed toward the dependence of anatomical relations upon environment."

The works of other early investigators had a much more restricted scope than the research of Hartig. Cieslar (*4*) found that spruce grown in the optimum of its natural habitat showed higher lignin content than when grown in locations outside its natural limits of distribution. Later (*5*) he investigated the properties of rapidly growing spruce in contrast with slow-growing spruce, basing his study upon a comparison of wood from two stands. A dominant, a codominant, and a suppressed tree were selected from each stand. In both stands he found that the more rapidly growing dominant spruce trees produced wood lower in specific gravity than did the codominant trees, but in one stand the suppressed tree produced wood of high specific gravity while in the other the wood was about the same weight as that of the dominant trees. He found that the higher specific gravity figures corresponded to the wood that contained a greater proportion of summer wood in the annual rings. The results of this work agree with Hartig's ideas that differences occur in the

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[2] Reference is made by italic numbers in parentheses to Literature Cited, p. 19.

quality of the wood in the same stand, and yet it can not be said that either the larger or the smaller trees produce the better wood.

Janka (*5*) made additional investigations upon the hardness of the wood in the same trees studied by Cieslar. His work showed that the spruce wood of rapid growth was softer than that of the slower or more normal growth. In investigating the quality of larch wood (*11, p. 51–55*) he could find no relation between the rate of growth and the specific gravity, but he was able to show that the weight depended upon the relative proportion of summer wood in the annual rings.

The work of Hartig, Cieslar, Janka, and other foreign investigators furnishes a background for silvicultural research now under way in this country. While the investigations thus far conducted here do not include all of the possible factors that influence the quality of wood, the results obtained on individual factors are well supported by the experiments of the earlier workers.

## FOREST PRODUCTS LABORATORY STUDIES

### SIGNIFICANCE OF SPECIFIC GRAVITY AS A BASIS FOR JUDGING WOOD QUALITY

Since 1922 the Forest Products Laboratory has been conducting investigations of the influence of growth conditions upon wood properties. In these investigations, except in a few cases, no mechanical tests of the strength of the wood have been made, since with species in which the relations of specific gravity to strength have been worked out, it is possible to use the specific gravity of wood as a basis for judging the strength when the original position of the specimens in the trees is known. Such specific gravity-strength relations for many of our native species including the species dealt with here have already been established from various tests (*13*), so that the specific gravity of the wood is used as a measure of the mechanical properties of the species in the present investigation.

To illustrate further the significance of the relation of specific gravity of wood to strength, examples, taken from the results of mechanical tests, are given in Table 1 for one of the broad-leaved and for one of the coniferous species included in the present investigation. The tests were made upon small clear pieces of wood tested while in a green condition.

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

| Species | Specific gravity (oven-dry), based on weight and volume when green | Kind of test | | | | |
|---|---|---|---|---|---|---|
| | | Static bending, modulus of rupture | Impact bending, height of drop causing complete failure with 50-pound hammer | Compression parallel to the grain, maximum crushing strength | Hardness, load required to imbed a 0.444-inch ball to one-half its diameter | |
| | | | | | End | Side |
| | | *Lbs. per sq. in.* | *Inches* | *Lbs. per sq. in.* | *Pounds* | *Pounds* |
| Pignut hickory (Hicoria glabra) | 0.50 | 8,200 | 54 | 3,600 | 850 | 780 |
| Do | .62 | 19,800 | 70 | 4,540 | 1,130 | 1,200 |
| Loblolly pine (Pinus taeda) | .41 | 6,870 | 24 | 3,950 | 390 | 400 |
| Do | .56 | 8,740 | 36 | 4,230 | 460 | 500 |

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

An attempt was first made to correlate the specific gravity of wood with geographic habitat. This attempt proved ineffectual except for Douglas fir, which grows over a wide area embracing distinct climatic conditions. Preliminary work with Douglas fir from the inland empire[3] showed that the average specific gravity of the wood was intermediate between that of Douglas fir from the Pacific coast and from the higher elevations of the Rocky Mountains. Other species investigated, with attention to specific gravity as related to local growth conditions as well as to general habitat, included white ash, pignut and shagbark hickory, rock elm, sugar maple, and four species of southern pine.

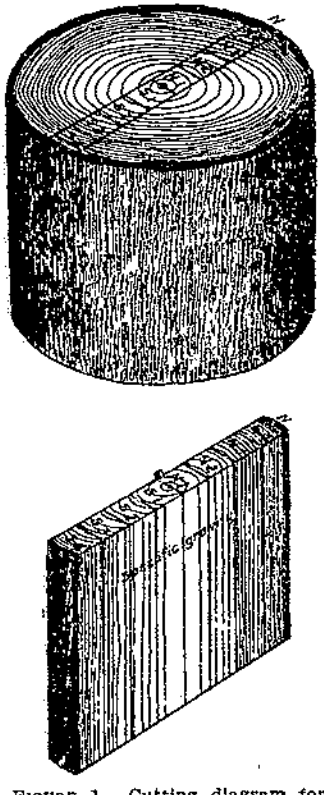


FIGURE 1.—Cutting diagram for specific gravity specimens

### METHODS USED IN THE INVESTIGATIONS

The wood collected for the investigations of the several species consisted of cross sections taken from the stems of trees at intervals of about 15 feet. The north-south direction of each section was marked. A description of each tree was made before felling, photographs were taken when possible, and the principal features of the site, soil type, topography, and forest were recorded.[4] Individual trees from which specimens were to be cut were designated by numbers, and each section taken was given its tree number and an identifying letter. The specimens used for specific gravity determinations were taken from flitches which extended in the north-south direction through the center of each tree. (Fig. 1.) The specimens were 6 inches long, about 2½ inches wide, and of varying radial thickness, since they were split off according to groups of annual rings. These groups of rings which occur in such a flitch in pairs, one group on each side of the pith, were matched carefully after

[3] The wooded area lying in northwestern Montana, Idaho north of the Salmon River, Washington east of the Cascade Mountains, and the northeastern tip of Oregon.

[4] The detailed silvical descriptions of the forest stands investigated, as well as the detailed results of the specific gravity determinations, are contained in unpublished reports on file at the Forest Products Laboratory, entitled "Influence of Growth Conditions on Wood Properties." Project 259

splitting the specimens off the individual flitches, and the first grouping of rings selected in a tree, as far as possible, was carried through all the sections taken from that tree; the result gave specimens representative of definite periods of growth, from different heights in the tree. The place of each specimen in the cross section was indicated by number, making it possible at any future time to locate accurately the original position of any individual test specimen.

The radial thickness of each specimen, the number of annual rings included, and the years of formation were recorded in full detail. In addition a carbon imprint of the annual growth rings of each cross section was made. The specimens were allowed to air dry for a period of several weeks and were then brought to constant weight by drying in an electric oven at a temperature of 100° C. Specific gravity determinations were then made upon the specimens by the immersion method.

## INVESTIGATIONS OF BROAD-LEAVED SPECIES

### WHITE ASH

The first of the broad-leaved species selected for investigation was white ash (*Fraxinus americana*).

In beginning this investigation it was considered advisable to determine, if possible, whether any noteworthy differences in the properties of the wood of this species could be found associated with the geographical location of the stand or with the characteristics of the site. Following the practice of foreign investigators and guided by the results of tests in this country (*12*, *13*) the specific gravity of the oven-dry wood was used as an index of its strength properties.

The first collection of white ash for the investigation was made in the fall of 1922 from regions representing widely different conditions of topography and soil, ranging from the high slopes of the southern Appalachians to the bottom lands along the Mississippi River. Specimens were collected from two places in western North Carolina, from two places in western Tennessee, and from two places in northern Arkansas. Five or more trees were cut in each place.

Average specific gravity values for white ash from these different locations failed to show any striking differences. The only feature that could be attributed directly to the influence of locality was found in the wood from the lower portions of the trees which were cut from the overflow bottom lands along the Mississippi River. This wood was lower in specific gravity than wood from cross sections in the same trees 16 or more feet higher up, in contrast to the wood from all of the other places where the wood at the base of the white ash trees was heavier than that higher up in the trees.

Individual variations characterized the trees from nearly all locations. These variations were not only in the specific gravity of the wood among the trees in the same place but were also within the stems of the individual trees. The wood grown at different periods in the life of a tree sometimes exhibited widely different characteristics.

Specific gravity determinations for the wood produced at different stages of growth were obtained by separating the annual rings into groups including 10, 20, or more rings, representing the various periods of growth, and by splitting out specimens in such a way that the faster and the slower periods of growth would be contained in different specimens.

A general application of the specific gravity results, however, did not indicate any direct relation between the specific gravity of the wood and the width of the annual rings, but when individual specimens exhibiting low specific gravity were considered with respect to the whole life of the tree from which they were cut, they revealed a retardation of diameter growth in the tree. This suggested a relation between specific gravity and some factor that would retard the rate of growth in diameter of the trees. This retardation in growth was believed to be due to a lack of growing space, and, since a dense forest stand is usually associated with slow tree growth, it was considered advisable to determine whether crowding of the trees would influence the specific gravity of the wood and whether any beneficial effects would result from thinnings.

Plots previously established for silvical studies were sought for this investigation but a thinned plot of white ash was not found. The necessary combinations of growth conditions, therefore, were looked for in natural stands. Three suitable wood lots from soils of about equal quality as judged by the height and age of the trees were found in northeastern Ohio. Two of them consisted of even-aged crowded stands in which the trees had reached a stage of keen growth competition. In the third wood lot a heavy thinning had been made about 30 years previous to this investigation. In both of the crowded wood lots the rate of growth in diameter near the circumference of the trees was very slow and was accompanied by the production of wood of low specific gravity. In one of the crowded wood lots the average reduction from the specific gravity of the wood produced at a time when the tree had more growing space was 18 per cent and in the other crowded wood lot it was 11 per cent. In the thinned wood lot the average change in specific gravity since the thinning was only 1 per cent and during the same time the rate of growth of the trees in diameter had greatly increased.

Table 2 gives the results for the specific gravity determinations of white ash trees in the three wood lots.

TABLE 2.—*Comparison of rate of growth and average specific gravity of white ash for different periods of growth in unthinned and in thinned stands*

| No. | Description of stand: Kind | Average age | Average height | Average diameter (breast high) | Number of trees | Period of growth | Number of annual rings per inch | Specific gravity | Period of growth | Number of annual rings per inch | Specific gravity | Change in specific gravity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Years* | *Ft.* | *In.* | | | | | | | | *P. ct.* |
| 1 | Unthinned | 60 | 88 | 13 | 5 | Before crowding (first 30–35 years). | 8.4 | 0.695 | After crowding (last 15 years). | 21.3 | 0.571 | −17.9 |
| 2 | do | 50 | 81 | 12 | 6 | do | 8.5 | .674 | do | 14.0 | .599 | −11.1 |
| 3 | Thinned | 65 | 85 | 15 | 5 | Before thinning (first 35–40 years). | 11.0 | .661 | After thinning (last 30 years). | 8.3 | .654 | −1.0 |

The study of white ash emphasized the belief that the width of the annual rings or growth layers is not an index of the quality of the wood of this species unless considered with respect to the life history of the individual trees. The following deductions were drawn from the results of the specific gravity determinations:

During the early life of the white ash trees studied, the rate of growth did not seem to influence the specific gravity, since wood of high specific gravity was formed whether the growth was rapid or slow.

The white ash trees that maintained a nearly uniform rate of growth in diameter did not show any great differences in the specific gravity of the wood produced in different periods of their growth.

A retardation of the growth of the white ash trees studied, as exhibited by the formation of narrower annual rings, produced wood of low specific gravity.

An increase in the rate of growth of the white ash trees investigated, following a period of suppressed growth, produced wood of high specific gravity. (Pl. 1.)

When all growth conditions were favorable except space, thinnings in a dense stand of white ash apparently not only assisted in a continuation of the normal tree growth but also assisted in maintaining the wood uniformly high in specific gravity. Thus, wood having the most uniform mechanical properties and the greatest freedom from defects may be produced in white ash trees which are closely stocked in the stand during the early years of its formation, with subsequent thinnings of such degree that the rate of diameter growth of the trees is maintained or increased.

### PIGNUT HICKORY AND SHAGBARK HICKORY

To check the results of the investigation of white ash, a corresponding study was undertaken during the spring of 1923 upon hickory, a similar wood. Material for the investigation was collected from two places in the mountain forests of western North Carolina, from three places in the foothills of the Cumberland Mountains in Kentucky, from the north and the south slopes of Mount Logan in southern Ohio, and from two wood lots in southern Indiana. At least five trees were cut in each situation.

Two species of hickory were included in the investigation, pignut (*Hicoria glabra*) and shagbark (*H. ovata*). The specific gravity results conformed very closely to those obtained in the white ash. A sustained or an accelerated rate of diameter growth produced wood of uniform specific gravity and a retardation of the growth rate by crowding or by the deterioration of the site produced wood of nonuniform and lower specific gravity. The effect of unfavorable soil conditions in producing wood of lower specific gravity was revealed in a comparison of the wood of shagbark hickory trees from the north and the south slopes of Mount Logan. The trees from the southerly slope of this mountain were stunted in height growth, were of very poor form, and exhibited a slow rate of growth in diameter during recent years. Slow growth was not the result of crowding as the individual trees had plenty of growing space, but the very poor condition of the site was attributed in large measure to frequent forest fires during recent years, which had on such a southern slope no doubt lessened the moisture-holding capacity as well as the fertility of the soil. The hickory trees on the north side of the same mountain, however, were enjoying very favorable forest conditions although the stand was becoming slightly crowded. The specific gravity results for trees from these two sites appear in Table 3.

TABLE 3.—*Comparison of rate of growth and corresponding average specific gravity for different growth periods in shagbark hickory from the north and from the south slopes of Mount Logan, Ross County, Ohio*

| Situation | Trees | Average age | Total height | Initial growth period | | Final growth period | |
|---|---|---|---|---|---|---|---|
| | | | | Annual rings per inch | Specific gravity | Annual rings per inch | Specific gravity |
| | *Number* | *Years* | *Feet* | *Number* | | *Number* | |
| North slope | 6 | 90 | 80 | 12.5 | 0.833 | 19.4 | 0.792 |
| South slope | 5 | 70 | 45 | 15.8 | .803 | 25.4 | .728 |

The results of the investigation of the pignut and the shagbark hickories (pl. 2) corroborated the conclusions in the study of the specific gravity of white ash (p. 7) and were likewise in agreement with the results of tests of several species of commercial hickory (*2*).

### ROCK ELM

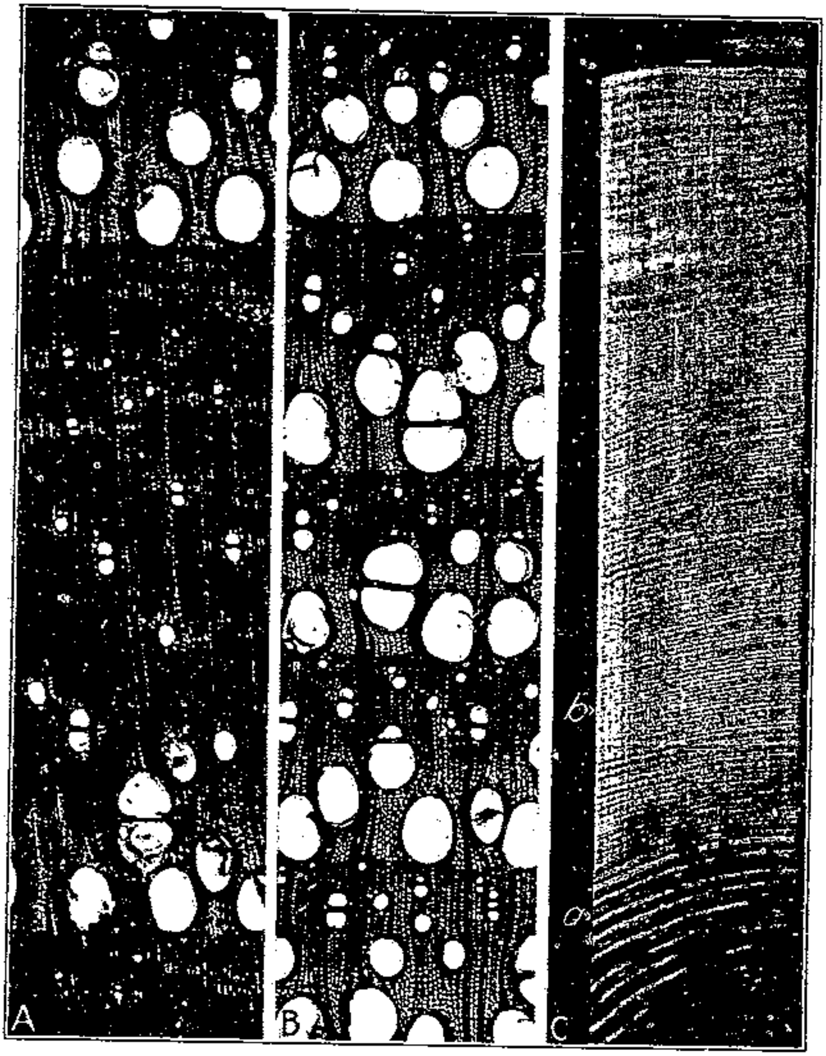
Rock elm (*Ulmus racemosa*) was chosen for further investigation because, being less conspicuously ring porous than ash and hickory, it is intermediate in structure between the typical ring-porous and the diffuse-porous woods. The material for this study was collected in southern Michigan in the fall of 1924. Specimens were taken from only two wood lots, but the results obtained conformed so closely to those for the white ash and the two species of hickory in regard to the relation between growing space and specific gravity that further study of this species was deemed unnecessary. The wood from the rock elm trees in one wood lot showed the effects of a long period of suppression which had been subsequently relieved by a thinning. In the other wood lot the conditions of growth had continued much more favorable.

The effect of the suppression of growth and of the release from crowding upon the specific gravity of rock elm is given in Table 4.

TABLE 4.—*Average specific gravity for successive growth periods in rock elm trees*

| Wood lot No. | Trees | Average age | Initial growth period | | Intermediate period of growth | | Final period of accelerated growth | |
|---|---|---|---|---|---|---|---|---|
| | | | Annual rings per inch | Specific gravity | Annual rings per inch | Specific gravity | Annual rings per inch | Specific gravity |
| | *Number* | *Years* | *Number* | | *Number* | | *Number* | |
| 1 | 5 | 240 | 28.7 | 0.712 | 34.1 | 0.624 | 20.7 | 0.660 |
| 2 | 5 | 235 | 31.8 | .708 | 25.3 | .706 | 15.5 | .716 |

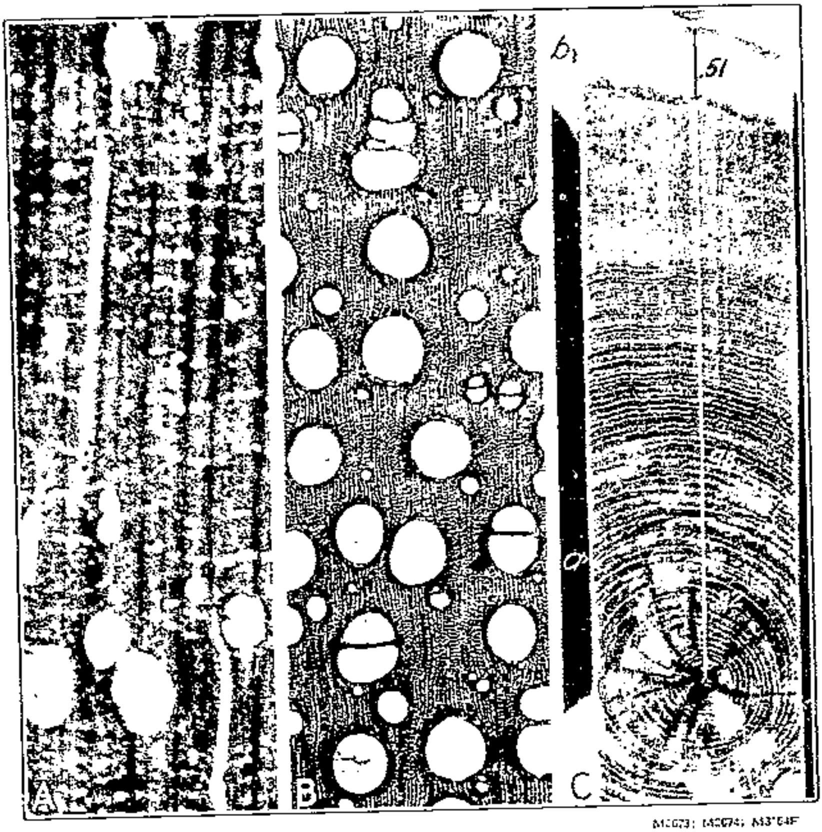
The table shows that the first group of rock elm trees produced heavy wood for a considerable period of time, followed by the production of wood of lower specific gravity during a subsequent period




COMPARISON OF WHITE ASH, SHOWING CHANGES IN RATE-OF-DIAMETER GROWTH AND STRUCTURE OF ANNUAL RINGS

A and B.—The structure of wide and narrow annual rings at points *a* and *b* in C. The specific gravity of the wood in A is 0.65; B is only 0.48.

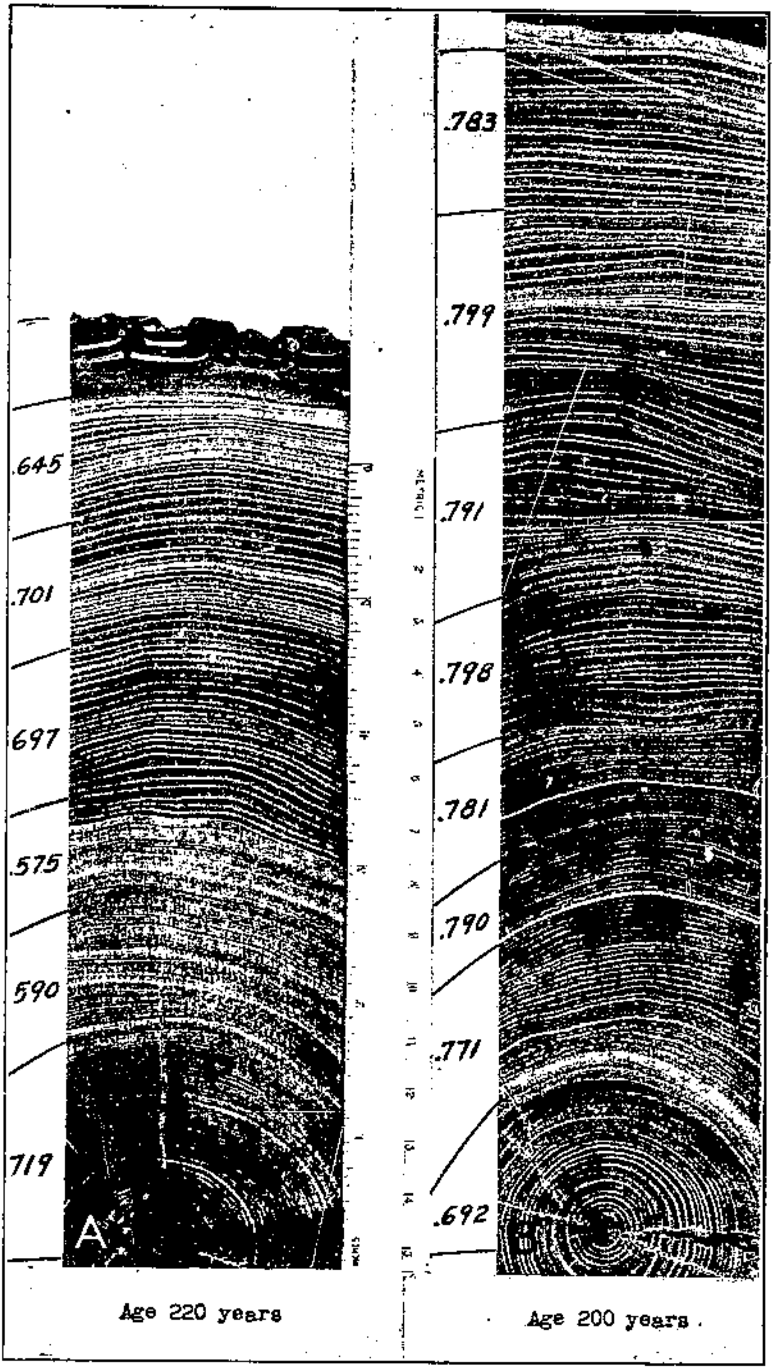
C.—Cross section of white ash. The wood near the center of the tree is of rapid growth and high specific gravity. Wood of slow growth and low specific gravity follows, caused by a long period of unfavorable growth conditions. A change to more favorable conditions is shown by renewed growth and wood of high specific gravity.




M3073; M3074; M3164F

COMPARISON OF PIGNUT HICKORY, SHOWING CHANGES IN RATE-OF-DIAMETER GROWTH, SPECIFIC GRAVITY, AND STRUCTURE OF ANNUAL RINGS

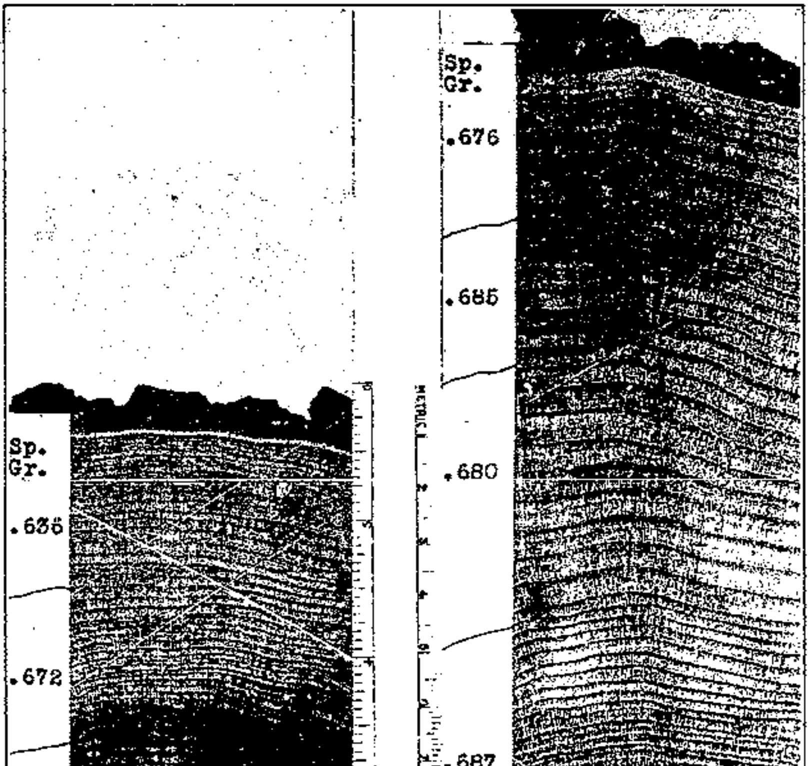
A and B. The structure of wide and narrow annual rings at points *a* and *b* in C. A has a specific gravity of 0.82, while that of B is only 0.51.
C. Cross section showing the gradual slowing down of the growth and decrease in specific gravity of the wood caused by lack of room for crown development.




M1740F

COMPARISON OF GROWTH AND OF SPECIFIC GRAVITY IN CROSS SECTIONS OF ROCK ELM

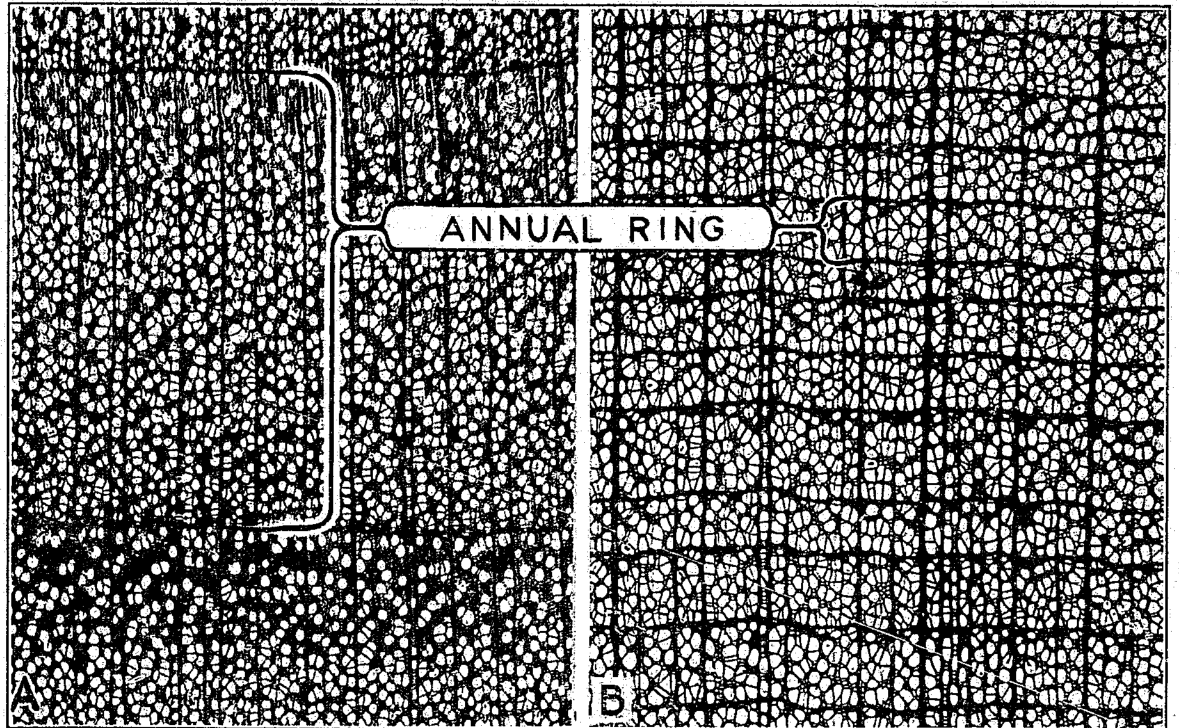
A.—Experienced a long period of crowding, which decreased the specific gravity of the wood, and was followed by a rapid growth period as a result of thinning.
B.—Maintained a dominant position in the stand throughout its life and at 200 years of age was growing rapidly and producing wood of high specific gravity.




M1902F

COMPARISON OF GROWTH AND OF SPECIFIC GRAVITY IN CROSS SECTIONS OF SUGAR MAPLE

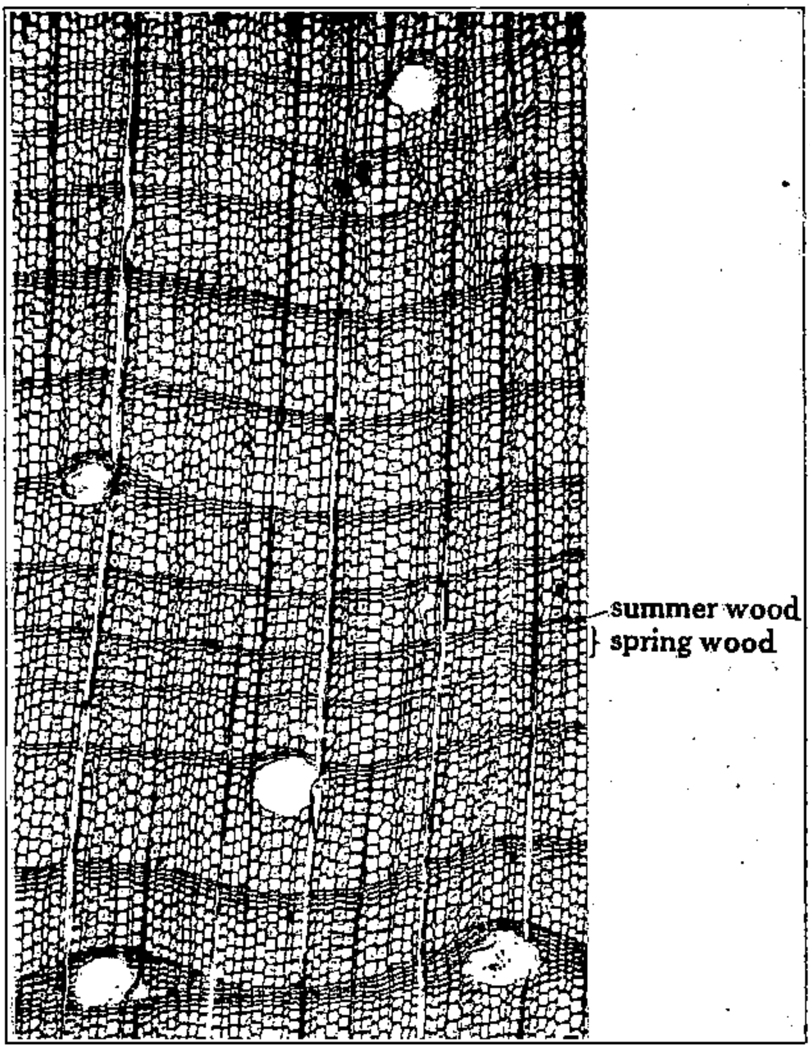
A.—Produced wood of high specific gravity until the period of maximum rate-of-diameter growth was reached. Afterwards, as the result of crowding and the reduction of the crown size, the specific gravity decreased.
B.—Enjoyed more growing space, developed a larger crown, maintained rapid diameter growth, and produced wood of uniformly high specific gravity.




M2676; M2677

COMPARISON OF THE STRUCTURE OF WOOD PRODUCED DURING THE PERIODS OF RAPID AND OF SLOW GROWTH IN A YELLOW POPLAR TREE

A.—Has a specific gravity of 0.41 and was produced during the early life of the tree, while it enjoyed sufficient growing space.
B.—Was produced after the tree had suffered reduction of crown as a result of many years' crowding in the virgin forest; this wood has a specific gravity of only 0.31.




M6184F

PHOTOMICROGRAPH OF A SECTION OF LONGLEAF PINE THAT GREW IN DRY SANDY SOIL

The annual growth rings contain little summer wood.

conforming to the time during which the growth of the trees was suppressed. The last period of growth in these trees showed a renewed activity in the rate of diameter growth resulting from the removal of some of the surrounding trees and a definite average increase in the specific gravity of the wood. (Pl. 3, A.) The specific gravity determinations for the wood from the second wood lot gave uniform results throughout the lives of the trees. These trees were grown under continued favorable conditions of soil and growing space in a wood lot in southern Michigan. As a result of selective cutting in this stand the trees continued to make rapid growth in diameter and at 200 years of age were producing wood practically as heavy as at any previous time. (Pl. 3, B.)

### SUGAR MAPLE

Samples of sugar maple (*Acer saccharum*) were collected from wood lots in southern Michigan, in northern Ohio, and in the Adirondack region of New York. Specimens from 44 trees were selected from eight localities. The trees were divided into two groups, those showing a decreasing rate of diameter growth with advancing age and those maintaining the initial rate of this growth.

The reaction of the wood of sugar maple to crowding in the stand is shown in the specific gravity results recorded in the first group of Table 5.

TABLE 5.—*Average specific gravity values for successive growth periods in sugar maple trees*

| Wood lot No. | Trees | Average age | Initial growth period | | Final growth period | |
|---|---|---|---|---|---|---|
| | | | Annual rings per inch | Specific gravity | Annual rings per inch | Specific gravity |
| Group 1: | *Number* | *Years* | *Number* | | *Number* | |
| 1 | 3 | 180 | 24 | 0.692 | 26 | 0.623 |
| 2 | 4 | 95 | 15 | .703 | 20 | .660 |
| 4 | 7 | 133 | 18 | .685 | 24 | .630 |
| 5 and 6 | 4 | 145 | 18 | .691 | 26 | .644 |
| Average | | | 19 | .693 | 24 | .634 |
| Group 2: | | | | | | |
| 1 | 2 | 105 | 25 | .701 | 18 | .688 |
| 2 | 2 | 84 | 14 | .727 | 17 | .702 |
| 3 | 6 | 152 | 27 | .708 | 17 | .688 |
| 5 and 6 | 6 | 130 | 17 | .731 | 12 | .704 |
| 7 | 5 | 82 | 11 | .690 | 14 | .675 |
| 8 | 5 | 56 | 12 | .693 | | |
| Average | | | 18 | .708 | 16 | .691 |

While the results of the specific gravity determinations show that the wood of the sugar maple trees investigated is affected by crowding in the same manner as the ash, hickory, and rock elm trees studied, the changes take place less abruptly. This may be due to the fact that the sugar maple trees usually occupied the better soils and also that sugar maple is especially tolerant of shade. A comparison of the specific gravity of the wood formed up to and including the time of most rapid growth in diameter with that of the wood formed during periods of subsequent retardation of diameter growth shows a lower specific gravity of the wood for the periods of retardation in trees from all of the wood lots investigated.

The wood produced during the initial growth periods, even though of slow growth, and the wood produced during periods of maintained or of accelerated rate of growth in diameter were the heaviest, while the wood produced during the periods of decreasing growth always had a somewhat lower specific gravity than that in the preceding period. (Pl. 4.)

No sugar maple that exhibited the results of thinning a crowded stand was collected but it is believed that this species would not be different in this respect from the species already discussed or from the yellow poplar which is considered later. Sugar maple trees with sufficient growing space continued to maintain a fairly rapid rate of growth in diameter and to produce wood layers of uniformly high specific gravity.

The European red beech, also a diffuse-porous species like sugar maple, has been found by Hartig to respond by faster growth and heavier wood to thinning in the stand. In his work on this beech (*Fagus sylvatica*) (*10*), Hartig includes specific gravity results for different periods in the life of two trees taken from a 150-year-old stand that had been heavily thinned seven years previously. The average specific gravity of the wood formed in these trees during a 23-year period just before the thinning was 0.60, whereas that of the wood formed in the same trees during the 7-year period following the thinning had an average value of 0.70, and although the rate of volume growth of these trees had been falling off before the thinning, it increased fourfold as a result of giving the trees more growing space.

### YELLOW POPLAR

The wood of yellow poplar (*Liriodendron tulipifera*) was investigated as a second example of a species with diffuse-porous structure. The material used was obtained from forests in northern Georgia, in western North Carolina, and in West Virginia. Twenty-five trees, including both virgin growth and second growth, were cut.

The yellow poplar trees studied gave wider variations in specific gravity than the sugar maple trees, but like the latter, they showed less abrupt changes in specific gravity with the first retardation of the growth rate than the typical ring-porous species investigated. But whenever prolonged suppression of growth occurred, the severity of the suppression was reflected in a lowering of the specific gravity of the wood. (Pl. 5.) Similarly, old virgin-growth trees responded readily to improved conditions of growth effected by a thinning of the original forest stand.

The wood of the second-growth yellow poplar trees was heavier than that of the old virgin-growth trees, which had struggled for many years under the crowded conditions of the original forest. In the second growth the wood of 14 trees under 150 years of age had an average specific gravity of 0.460 while that of 11 older virgin-growth trees averaged only 0.426.

The influence of improved growth conditions upon the rate of growth and upon the specific gravity of the wood of virgin-growth yellow poplar trees in the mountains of West Virginia is shown in Table 6.

TABLE 6.—*Average specific gravity for successive periods in the growth of yellow poplar trees*

| Trees | Average | Period of initial growth | | Intermediate period of suppression | | Final period of accelerated growth | |
|---|---|---|---|---|---|---|---|
| | | Annual rings per inch | Specific gravity | Annual rings per inch | Specific gravity | Annual rings per inch | Specific gravity |
| *Number* 4 | *Years* 260 | *Number* 18.2 | 0.403 | *Number* 34.1 | 0.379 | *Number* 19.8 | 0.402 |

## RELATION OF SPECIFIC GRAVITY TO THE STRUCTURE OF THE ANNUAL RING IN HARDWOODS

In the ring-porous species studied, a retardation of the rate of growth in diameter brought the rows of large open pores in successive annual rings, as seen in cross section, closer together by a reduction in the development of the portion of the ring containing the thicker-walled summer-wood cells. This reduction resulted from unfavorable growth conditions during the summer and consequently affected the summer wood more than the spring wood. The net result was wood with a greater than normal proportion of the porous spring wood, which caused a lower specific gravity.

In the diffuse-porous woods studied, less contrast existed in the portion of the annual rings formed during the early and during the later parts of the growing season, so that the first gradual retardation of radial growth may not be reflected in the specific gravity of the wood. A continuation of adverse growth conditions, however, resulted not only in the formation of narrower rings but also in the formation of rings more porous, so that the wood became correspondingly lighter. In the ring-porous ash and hickory and in the diffuse-porous sugar maple and yellow poplar, the result was essentially the same and doubtless depends upon the same principles of growth.

## CONCLUSIONS

From the preceding investigations of broad-leaved species it is apparent that wood having the most uniform properties and the highest quality with respect to both strength properties and freedom from defects is produced, in the hardwoods, when the trees are grown sufficiently close together while young to cause removal of lateral branches, and are subsequently thinned sufficiently to maintain or increase the rate of diameter growth of the trees. Where dry sites or soils low in fertility are involved, the silvicultural treatment should also aim to benefit the water-holding capacity and the fertility of the soil.

Forest management may not anticipate a maintained or increased rate of diameter growth throughout the entire rotation, a maintained volume increment being all that is desired. However, with species such as hickory and ash, where the strength of the wood is of paramount importance, the additional effort required to maintain the rate of diameter growth up to a practical rotation period should be well worth while.

### INVESTIGATIONS OF CONIFEROUS SPECIES

There is much confusion of opinion in regard to the relation between growth factors and the properties of wood in broad-leaved species and in conifers. This is perhaps due primarily to the differences in structural arrangement of the elements in the annual growth rings in the two classes.

The coniferous annual ring, typified by species like the hard pines, redwood, and Douglas fir, consists of two distinct parts, the spring wood and the summer wood. These parts are somewhat comparable to the parts of the ring of the ring-porous hardwoods except that they are more variable in width. The spring wood consists of thin-walled cells, whereas the summer wood cells are thick walled. As in the ring-porous hardwoods, the total weight of the wood is influenced by the relative proportion of the two kinds of wood layers present. Both very wide and very narrow annual rings in conifers usually contain a larger proportion of the spring-wood layer, so that in these species wood representing either extreme of growth may be low in specific gravity. The wood of intermediate growth rate is usually the heavier.

The fact that conifers usually grow on lighter soils than the hardwoods may somewhat influence the relation between the width of the annual rings and the specific gravity, but there seems to be no doubt that the relationship between rate of growth and specific gravity differs in the conifers and hardwoods. This is shown by the generally recognized superiority in strength of the rapidly grown second-growth hickory as compared to virgin-growth hickory and the inferiority in strength of the rapidly grown second-growth southern pine as compared to virgin-growth southern pine.

#### THE SOUTHERN PINES

In the study of the southern pines that was begun in 1925, specimens were obtained from 380 trees collected from 55 stands, representing the region from New Jersey to Texas. The species included are longleaf (*Pinus palustris*), shortleaf (*P. echinata*), loblolly (*P. taeda*), and slash pine (*P. caribaea*).

The principal phases of the southern pine study were: (1) A comparison of the specific gravity of the wood from virgin-growth and from second-growth trees; (2) an investigation of the influence of closeness of stocking of the stand and of thinnings upon the specific gravity; and (3) to some degree, the effect of the moisture conditions and the fertility of the site upon the specific gravity of the wood.

##### COMPARISON OF VIRGIN-GROWTH AND SECOND-GROWTH SOUTHERN PINE

The specific gravity of the wood of some second-growth stands equaled that of virgin-growth stands while in others it was lower. In both kinds of stands, variations in specific gravity were found that reflected the influence of the environmental conditions on the trees in the stand at different periods in the lives of the trees.

As a rule, the virgin-growth southern pines contained wood of low specific gravity in the very narrow slow-growth annual rings in the outer portions of the boles and wood of comparatively high specific gravity in the central portions representing an intermediate rate of growth. Exceptions were found in the trees that had made very rapid growth in early life and as a result possessed wide rings of low specific gravity near the center.

In the second-growth trees, however, the wood of low specific gravity was contained in the wide growth rings usually occupying the central portion of the trees. This was especially true in stands where the trees started with plenty of growing space and then crowded each other as they increased in size. The smallest variation in specific gravity in the cross section of second-growth southern pine was found in trees from fairly open stands. A fair comparison of virgin-growth and second-growth southern pine must therefore be made on the basis of the character of the stand. The wood of a medium-growth rate in well-stocked second-growth stands was as heavy as the best wood from virgin-growth trees, as may be seen in Table 7.

TABLE 7.—*Comparison of rate of growth and of average specific gravity for successive growth periods in virgin-growth and in second-growth stands of longleaf pine*

| Locality | Growth | Trees | Range in age | Initial growth period | | Intermediate growth period | | Final growth period | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Annual rings per inch | Specific gravity | Annual rings per inch | Specific gravity | Annual rings per inch | Specific gravity |
| | | *Number* | *Years* | *Number* | | *Number* | | *Number* | |
| Walton County, Fla | Virgin | 6 | 100-220 | 19 | 0.680 | 31 | 0.592 | 42 | 0.481 |
| Smith County, Miss | do | 10 | 125-350 | 16 | .670 | 19 | .617 | 30 | .508 |
| Vernon Parish, La | do | 5 | 130-200 | 14 | .644 | 33 | .620 | 49 | .490 |
| Richland County, S. C | do | 4 | 100-140 | 16 | .628 | 24 | .535 | 21 | .521 |
| Berkley County, S. C | do | 5 | 120-150 | 25 | .609 | 42 | .531 | 27 | .533 |
| Do | do | 5 | 60-140 | 20 | .638 | 11 | .589 | 15 | .581 |
| St. Tammany Parish, La | Second | 5 | 90 | 11 | .674 | 14 | .643 | 18 | .652 |
| Columbia County, Fla | do | 5 | 35 | 4 | .505 | | | 8 | .561 |
| Charleston County, S. C | do | 10 | 45 | 5 | .545 | 6 | .556 | 12 | .581 |
| Clay County, Fla | do | 5 | 25 | 3 | .545 | | | 5 | .529 |
| Do | do | 5 | 30 | 6 | .546 | | | 14 | .694 |
| Do | do | 5 | 30 | 5 | .539 | | | 9 | .590 |

THE INFLUENCE OF CLOSENESS OF STOCKING AND THINNINGS

The trees from open second-growth southern pine stands developed very large and spreading crowns which often covered a considerable portion of the length of the bole. An examination of the wood from such trees usually reveals very wide growth rings containing a large proportion of spring wood that merges into summer wood so gradually that no definite point of change can be determined in the ring. Wood of this type is, as a rule, light in weight, the weight depending upon the proportionate amount of summer wood present.

In contrast with the wood from sparsely stocked stands, small-crowned trees from fully stocked areas in the same forest, often only a few rods distant, contained wood that was much heavier. In these areas the rate of growth of the individual trees was slower; the proportion of spring wood in the annual growth rings was less; there was an abrupt line of demarcation between the spring-wood portion and the summer-wood portion of the annual growth ring; and the total proportion of summer wood, as measured on a radial line in cross section, was greater. Contrasts of this type were found in second-growth stands of the four species of southern pine studied. The results of the specific gravity determinations are given in Table 8.

TABLE 8.—*Comparison of crown size and of average specific gravity of the wood of second-growth southern pine trees in stands of different density on the same forest area*

| Species | Locality | Trees | Character of stand | Rate of growth (annual rings per inch) | Average specific gravity of trees with— | |
|---|---|---|---|---|---|---|
| | | | | | Large crowns | Small crowns |
| | | *Number* | | *Number* | | |
| Loblolly pine | Louisiana | 5 | Fully stocked | 9 | | 0.496 |
| Do | do | 10 | Open stand | 2 | 0.388 | |
| Do | South Carolina | 5 | Dense stand mixed with hardwoods. | 6 | | .472 |
| Do | do | 10 | Open stand | 3 | .423 | |
| Shortleaf pine | Arkansas | 5 | Fully stocked | 11 | | .502 |
| Do | do | 5 | Open stand | 7 | .457 | |
| Do | Texas | 5 | Fully stocked | 11 | | .566 |
| Do | do | 5 | Medium open | 6 | .496 | |
| Slash pine | Florida | 5 | Dense stand mixed with hardwoods. | 11 | | .598 |
| Do | do | 5 | Very open | 3 | .507 | |
| Longleaf pine | Texas | 5 | Fully stocked | 11 | | .580 |
| Do | do | 5 | Medium open | 5 | .537 | |
| Do | Florida | 5 | Fully stocked | 9 | | .620 |
| Do | do | 5 | Medium open | 4 | .538 | |

It is evident from this phase of the study that the proportionate amount of spring wood in the annual ring is influenced largely by the crown size. The development of the summer wood portion, however, appears to depend more upon favorable conditions for continued growth throughout the season.

Investigations of thinned stands of southern pine and of trees left in logging revealed a great increase in the rate of growth in diameter after such thinnings. The wood of faster-growth rate produced after the thinning was sometimes heavier but more often the production of spring wood was proportionally so much greater than summer wood that lighter wood resulted. Some comparisons of the specific gravity of wood in the same trees, representing the wood before and subsequent to thinning, are given in Table 9.

TABLE 9.—*Comparison of rate of growth and average specific gravity of the wood of southern pine before and after thinning*

| Species | Locality | Trees | Average age | Initial growth period | | Intermediate growth period | | Final growth period, after thinning | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Annual rings per inch | Specific gravity | Annual rings per inch | Specific gravity | Annual rings per inch | Specific gravity |
| | | *Number* | *Years* | *Number* | | *Number* | | *Number* | |
| Longleaf | LaSalle Parish, La. | 7 | 125 | 20 | 0.669 | 33 | 0.626 | 11 | 0.612 |
| Do | Walton County, Fla. | 5 | 100 | 28 | .636 | 43 | .600 | 13 | .637 |
| Shortleaf | Moore County, N. C. | 5 | 55 | 10 | .521 | 37 | .507 | 16 | .551 |

## THE EFFECT OF MOISTURE CONDITIONS AND THE FERTILITY OF THE SITE UPON THE SPECIFIC GRAVITY OF THE WOOD OF SOUTHERN PINES

The reason for the formation near the perimeter of the old virgin-growth trees of narrow annual rings, containing relatively light wood, has not yet been positively determined. Several factors may be involved. An examination of these extremely narrow annual rings showed that they are greatly lacking in summer-wood development. (Pl. 6.) Perhaps an insufficient water supply during the summer accounts for the lack of summer wood. During years of extreme drought, the development of the summer-wood portion of an annual ring is very much below that formed in a season of usual rainfall, even though the spring-wood development for the same years is practically normal. But these virgin-growth trees were also lacking in spring-wood development, which indicates some other factor. Possibly the site had become deficient in one or more of the plant-food elements required for tree growth. Frequent forest fires may have decreased the soil fertility and lowered the moisture-holding capacity of the soil, thus causing an almost complete cessation of growth.

Further evidence of the importance of water and of soil fertility in the production of summer wood in the annual ring was found in a comparison of the wood of shortleaf pine trees grown on dry sandy land with that grown on clay loam soils. The wood of the shortleaf pine trees from the sandy site averaged 15 per cent lower in specific gravity than the wood of the same species growing on heavier and more moist soils. (Pl. 7 and Table 10.) Wood of slower growth and lower specific gravity directly attributable to surface burning of the site was found in shortleaf pine formed during a 17-year period in which the area about the trees was burned annually, and as compared to wood produced in the same trees previous to the burning, and also as compared to wood produced during the same years in near-by trees of the same species growing on an adjacent unburned area. (Pl. 8.) During the period of burning there was a considerable decrease in the rate of the growth of the trees, and the wood produced was 6 per cent lower in specific gravity than that produced during the same years in trees on the unburned site.

TABLE 10.—*Comparison of average specific gravity for second-growth shortleaf pine from different types of soil*

| Type of soil | Trees | Age class | Average height | Initial growth period | | Intermediate growth period | | Final growth period | | Average specific gravity for site |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Annual rings per inch | Specific gravity | Annual rings per inch | Specific gravity | Annual rings per inch | Specific gravity | |
| | *Number* | *Years* | *Feet* | *Number* | | *Number* | | *Number* | | |
| Light gravelly sand | 10 | 60–70 | 50 | 8 | 0.459 | 15 | 0.446 | 36 | 0.458 | 0.454 |
| Red clay loam | 10 | 60–70 | 75 | 5 | .489 | 11 | .536 | 17 | .566 | .530 |
| Do | 10 | {50–60<br>60–70 | 65<br>70} | 8 | .514 | | | 13 | .560 | .537 |

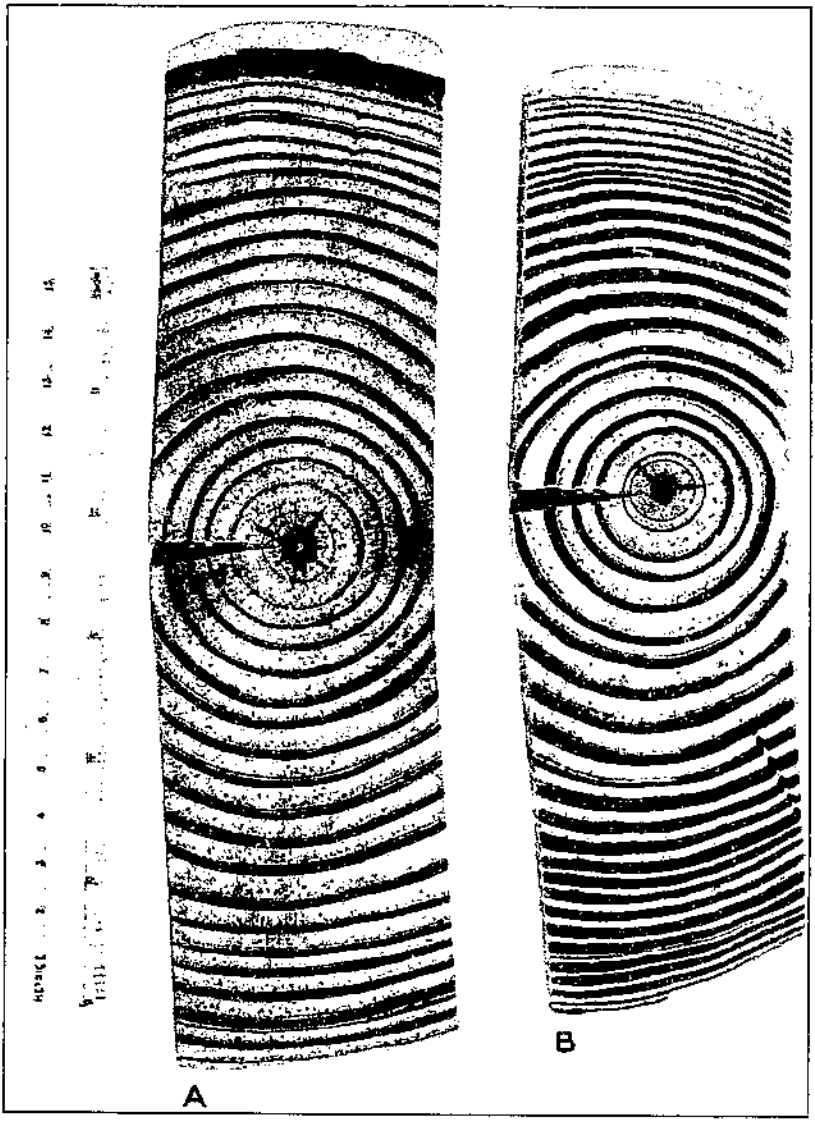
It has been pointed out that the specific gravity of the wood of the southern pines depends to a great extent upon the relative amount of spring wood and summer wood present in the annual rings. Since the strength of southern pine, as in the hardwoods, is closely related to its specific gravity, the question of controlling the proportion of the heavier summer wood by silvicultural methods becomes of interest.

#### FACTORS INFLUENCING SPRING WOOD AND SUMMER WOOD DEVELOPMENT IN THE SOUTHERN PINES

As already pointed out, the wide annual rings (Table 8) from second-growth trees having relatively large crowns contained very broad bands of spring wood and rather narrow bands of summer wood. Also in the wider rings there is usually a very gradual change from one type of wood into the other, a change far more gradual than that in narrow rings. On the other hand, in the trees that originated in very dense stands, where the crown development of the individual trees was restricted, comparatively narrow spring wood bands and proportionately broader summer wood bands were formed in the annual rings. It appears from the rate of growth near the center of the trees that most of the virgin-growth southern pine stands originated under fairly crowded forest conditions; this may be one explanation of the differences in the specific gravity of the wood in virgin-growth and in second-growth southern pine stands.

#### REDWOOD (SECOND GROWTH)

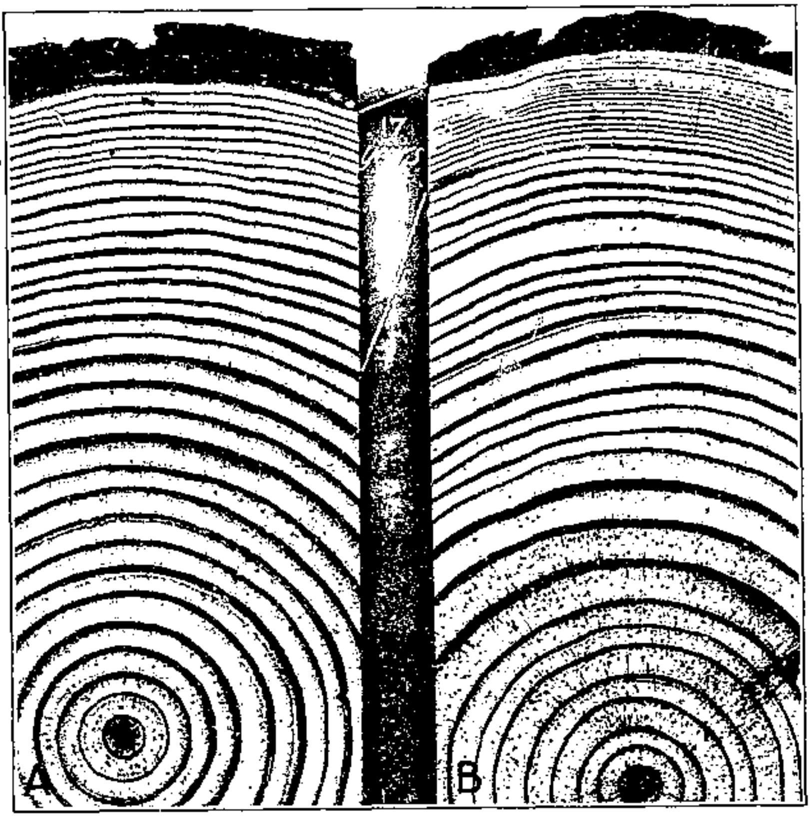
Investigations of the influence of growing space in second-growth redwood *(Sequoia sempervirens) (14)* show that the relations found in respect to trees with large crowns and small crowns in the southern pines hold also in redwood. Wood was taken from large-crowned trees in a sparsely stocked area and from small-crowned trees in a densely stocked area of the same second-growth forest near Eureka, Humboldt County, Calif. Compressive strength tests (parallel to the grain) were made on the same sticks that were used for the specific gravity determinations. The specific gravity and compressive strength values of both types of second-growth redwood trees are presented in Table 11. The wood from trees in the more dense stands has a higher specific gravity and is stronger in compression than the wood from trees in open stands.



M7305F

CROSS SECTIONS OF TWO LONGLEAF PINE TREES

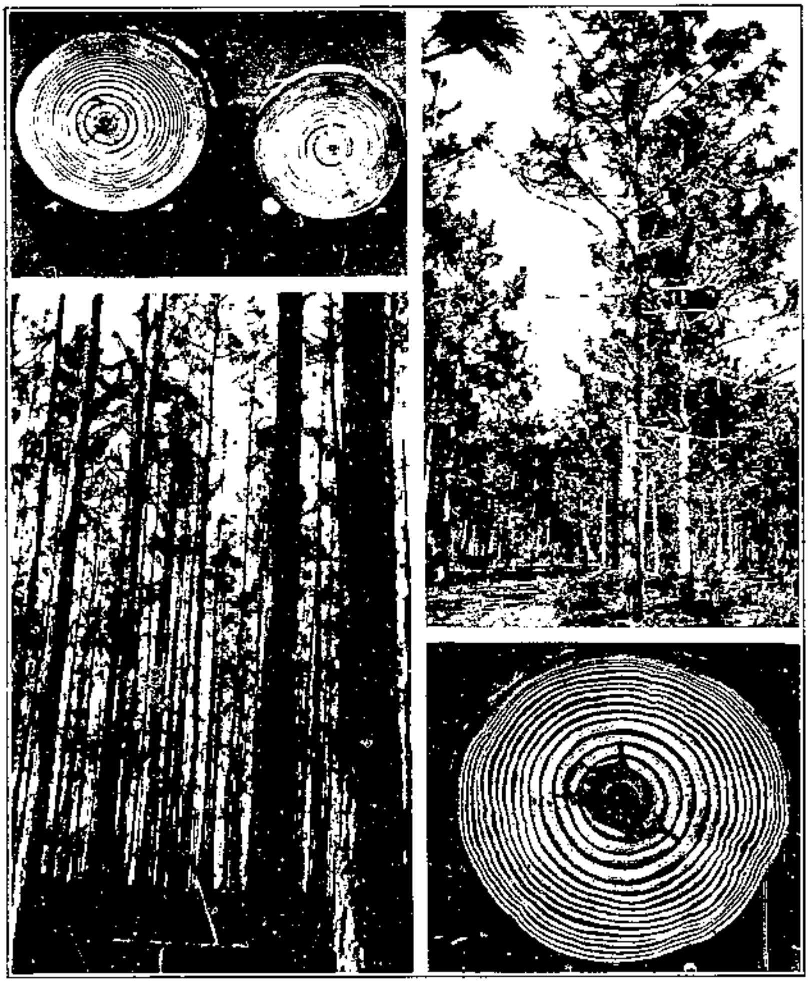
A.—From high ground.
B.—From a low, moist situation. The tree from the moist situation produced wider summer-wood bands in individual annual rings and wood of greater density.




M3016F

THE DISASTROUS EFFECT OF FIRE ON TREE GROWTH

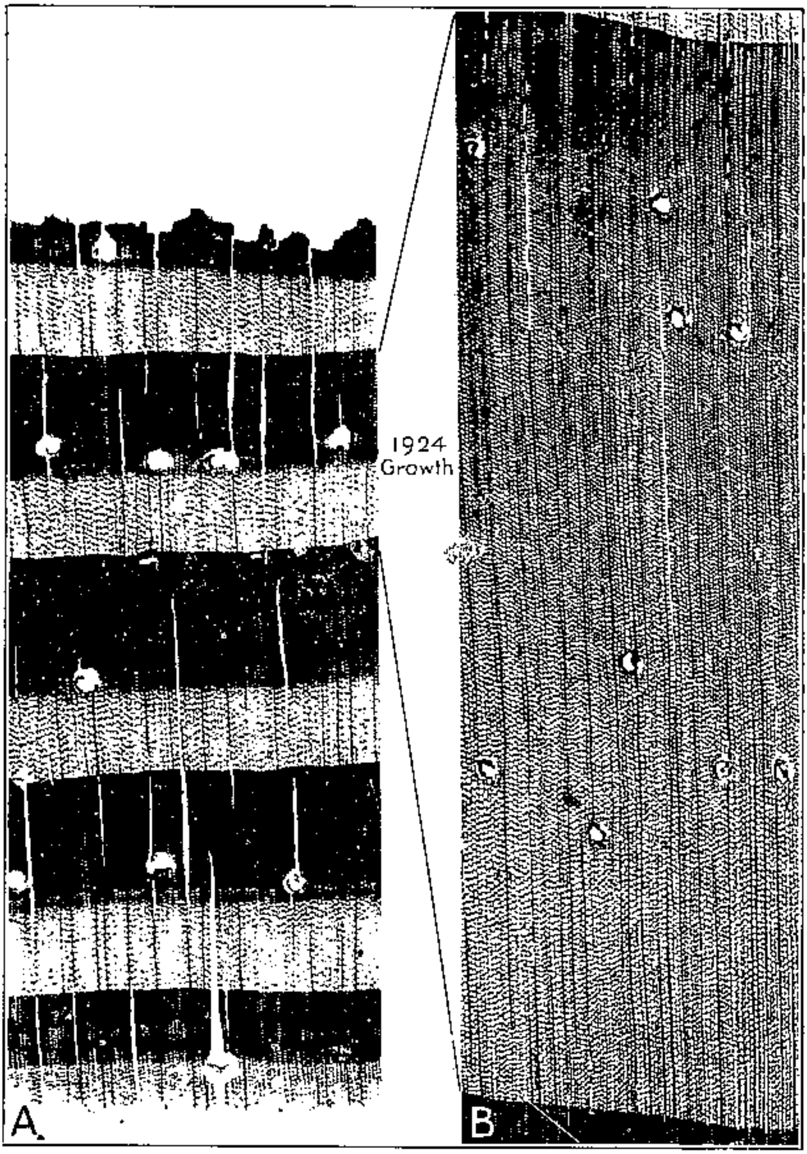
A.—Was not in burned area and grew faster with more summer wood.
B.—Was located on an area burned over annually during a 17-year period prior to cutting. The two trees grew only a few yards apart.



M 304F

ADJACENT LONGLEAF PINE STANDS THAT WILL PRODUCE, RESPECTIVELY, DENSE AND NONDENSE WOOD

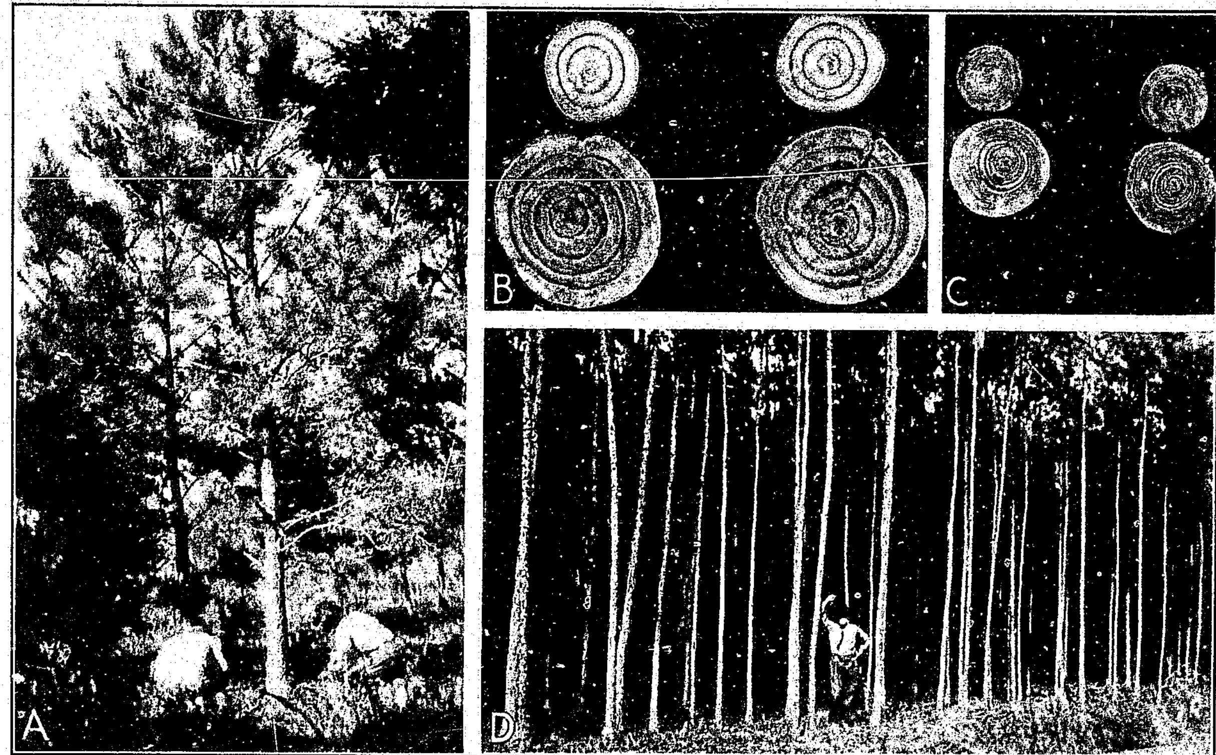
A, Cross sections of trees from stand B, showing denser wood in the outer rings, formed during the period of restricted crown development.
D, Cross section from large-crowned tree from stand C; this wood is of relatively low density.




M7303F

A PHOTOMICROGRAPHIC COMPARISON OF THE STRUCTURE OF THE 1924 ANNUAL RINGS IN TREES REPRESENTING THE TWO TYPES OF GROWTH CONDITIONS IN PLATE 9

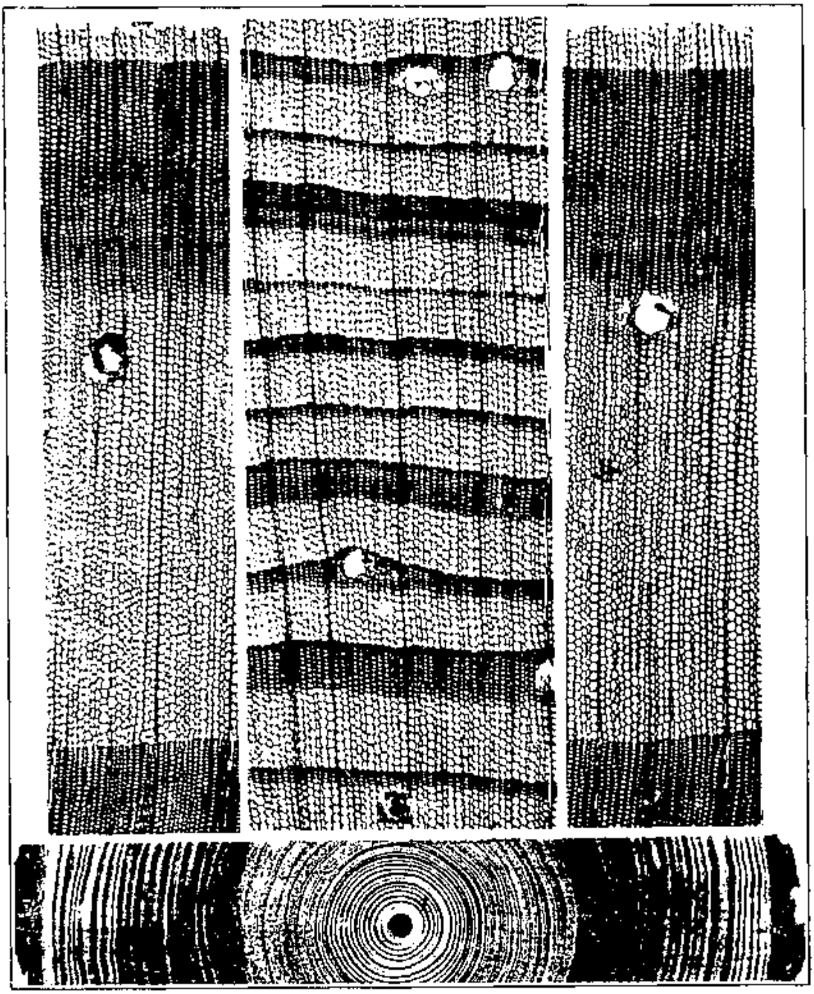
A.—Cut from the fully stocked stand and shows relatively small spring wood.
B.—Was taken from the open stand, and spring wood is abundant, but it merges into summer wood so gradually that no definite point of change can be determined in the ring. The trees from which these sections were cut grew within a few rods of each other.




M7301F

TYPES OF GROWTH AND THE RESULTING WOOD OF LOBLOLLY PINE CONTRASTED

B.—Rapid-growth wood from the large-crowned trees of A.
C.—Slower growth and more dense wood from the stand shown in D. Stand A is 7 years old; stand D, 18. The two grew very close to each other and all conditions, excepting the growing space of the individual trees, are nearly equal.



M7302F

THE THREE PHOTOMICROGRAPHS ARE FROM THE CROSS SECTION OF THE PINE TRUNK DIRECTLY BELOW

The middle photomicrograph shows slow growth, due to thick stands; the outer photomicrographs show fast and suitable growth, made possible by thinning.

TABLE 11.—*Relation of growing space and of crown development to the specific gravity and the compressive strength parallel to the grain of second-growth redwood*

| Trees | Crown development and growing space | Anual rings per inch | Average specific gravity (oven-dry) based on weight and volume when green | Average compressive strength parallel to grain— | |
|---|---|---|---|---|---|
| | | | | In green condition | In air-dry condition (5.5 per cent moisture content) |
| *Number* | | *Number* | | *Lbs. per sq. in.* | *Lbs. per sq. in.* |
| 8 | Trees with large crowns in open portion of stand | 2.9 | 0.30 | 2,490 | 5,420 |
| 10 | Trees with smaller crowns from more densely stocked portions of stand | 8.4 | .35 | 3,430 | 7,110 |

The difference in specific gravity presented in Table 11, caused by difference in growing space on the same area, is greater than the average difference in the specific gravity of close-grown second-growth redwood trees from the best and the poorest sites on which the species grows. The quality of the respective sites was determined on the basis of age and of height growth of the stand. While fertility of the site apparently has an important relation to the rate of height growth of the trees, the rate of diameter growth in the early decades of the life of a tree is more closely related to its crown development. Thus the open-growth second-growth redwood trees have increased in diameter nearly three times as fast as the more closely grown trees.

A comparison of the structure of the wide and the narrow annual rings in the sections reveals the fact that in the large-crowned open-grown trees a much greater proportion of the annual ring is occupied by spring wood—the lighter-weight and weaker part of the wood—than in the more narrow annual rings from the trees with the smaller crowns.

## CONCLUSIONS

From the investigations of the southern pines and second-growth redwood it may be concluded that:

During the early years of the coniferous stands studied the size of the individual tree crown appears to be the principal factor in determining the specific gravity of the wood.

The young southern pine and redwood trees with large crowns growing in fairly open stands produced greater amounts of spring wood than summer wood in the annual rings, while trees of similar age with small crowns growing in fairly dense stands produced more nearly equal amounts of spring wood and of summer wood. (Pls. 9, 10, and 11.)

Where crowding in a southern pine stand had resulted in a decline in the specific gravity of the wood, a thinning either caused a subsequent increase in rate of growth in diameter accompanied by a remarkable increase in specific gravity when all of the growth conditions in the stand were especially favorable, or such a thinning caused a decrease in the specific gravity of the wood when the growth conditions were apparently more favorable to the production of spring wood than summer wood. (Pl. 12 and Table 9.)

The closely crowded trees on the good sites continued to produce wood of high specific gravity under conditions of crowding that greatly reduced the growth rate. In such trees the proportion of summer wood was relatively high.

Heavy wood in the open stands of southern pine was produced when the conditions of soil moisture and of soil fertility were such that the trees continued to grow throughout the vegetative season sufficiently to maintain a high proportion of summer wood in the annual growth rings.

The second-growth shortleaf pine growing on a very dry site produced wood of much lower specific gravity than that of the other second-growth shortleaf pine stands investigated.

## THE APPLICATION OF THE RESULTS

The results of the foregoing investigations show that the regulation of growing space is the silvicultural tool which the forester can use most easily in controlling the specific gravity of wood. The species studied show a ready response to changes in the condition of the stand, whether it be crowding or thinning. This response, therefore, can be used to advantage in silvicultural management.

In all of the broad-leaved species investigated severe crowding in the stands resulted in a decrease in the specific gravity of the wood, while relief from crowding was always accompanied by an increase in specific gravity. In addition, the production of wood of uniformly high specific gravity was concurrent with a well-sustained, usually a fairly rapid, growth rate, so that in future crops of species, such as ash and hickory, the trees may be brought to merchantable maturity in a comparatively short rotation—one of perhaps 50 to 60 years.

In coniferous species, such as the southern pines and redwood, the control of specific gravity by the influence of growing space must be dealt with somewhat differently than with the broad-leaved species. In these species the specific gravity of the wood depends principally upon the relative proportions of spring wood and summer wood in the individual annual growth rings. In the second-growth stands of southern pine and redwood, the spacing of the trees had a distinct influence upon the width of the spring-wood portion of the growth ring; this portion being much narrower in the small-crowned trees of crowded stands. In trees growing under this condition the amount of summer wood was proportionately greater, and the wood accordingly heavier, but the growth rate was slower than in the trees of the more open stands. Thus, in these species the production of timber having very high strength properties requires a longer rotation than the production of timber having lower strength. For the best results, however, the stands should not be allowed to become too dense, since in that event the production of summer wood will be curtailed. In order to produce timber of high strength in the shortest possible time it will be necessary to thin the stands carefully, to prevent forest fires, and to maintain as good soil conditions as possible during the life of the stand. Thus, quantity and quality production are apparently combined on the more fertile sites.

Improvement of the soil is suggested as a means of improving wood quality. The prevention of forest fires in the southern pines should increase the organic content of the soil, furnish nitrogen in the process of decomposition, and increase the retention of soil moisture. Improvement of conditions in regard to these factors should increase the production of summer wood in the annual growth ring.

To produce light wood in second-growth southern pines and redwood, relatively wide spacing of the trees throughout the entire period of growth is required. The individual trees will then have larger crowns, more knots, shorter clear boles, and a higher percentage of sapwood, but to offset these disadvantages it will be possible to grow a tree of a specified diameter in a much shorter time.

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## ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE

**January 10, 1930**

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U. S. GOVERNMENT PRINTING OFFICE: 1930

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