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Growth-Quality Evaluation of Missouri-Grown Shortleaf Pine (*Pinus echinata,* Mill.)

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INTRODUCTION

Objectives—This study on the evaluation of several growth-quality relationships for Missouri-grown shortleaf pine *(Pinus echinata)* was undertaken for two main objectives. These are: (1) To obtain basic data on various parameters used as indices of wood quality, such as specific gravity, growth rate, percent summerwood, fiber dimensions, etc. that are used to predict the behavior of wood in use per se or as wood fiber in pulp products. (Such data were not currently available for shortleaf pine grown in Missouri), and (2) To relate such data with xylem growth for possible aid in preparation of forest management plans, tree breeding, or tree genetic research investigations.

Definition of growth-quality—Growth is defined as the xylem, and subdivisions thereof, as the annual ring, springwood zones, summerwood zones, tracheids, etc.; xylem samples were taken at breast height in this study. Quality is defined in terms of various parameters employed as indicators of how wood or wood fiber will behave in various end uses. Examples of different quality parameters are: specific gravity as a measure of wood strength or pulp yield; percent summerwood, fiber length, and fibril angle as measures of pulp strength and pulp sheet forming characteristics; and the uniformity and rate of annual growth as measures of performance in the machining, gluing and other procedures in the fabrication of furniture, millwork and related products.

Scope of investigation—Sample disks, some 2½-3 inches thick, removed at breast height for some 90, 40-year old shortleaf pine trees provided sample material for study. Parameters investigated were: specific gravity and growth rate for all samples, percent summerwood and selected chemical analyses for 19 samples, and fiber dimensions and fibril angle for one sample. Data illustrating within tree and between tree variation for some parameters investigated are presented in graphical form. Literature pertinent to methods and procedures employed, or providing data for comparative purposes, is included.

Brief literature review—Of all the indices of wood quality, specific gravity and growth rate are the two which have been studied most extensively as indicated by the number of published investigations. Two studies which point out relationships between specific gravity and wood strength are the extensive investigations of Markwardt and Wilson (11) and Newlin (15) on the majority of our commercial American woods. The direct relationship between specific gravity and Kraft pulp yield for several southern yellow pine species is shown in the work of Mitchell and Wheeler (12). Specific gravity and the rate of growth and their influence on machining and related characteristics of selected southern hardwoods are discussed in the investigation of Davis (2). In short, specific gravity, as a means of comparing wood within a species or between species, is firmly established as a quality parameter.

Numerous investigations have been undertaken to determine the influence of various aspects of xylem growth, such as growth rate, percent summerwood, etc., on the specific gravity of the southern yellow pines such as those of Pew (17), Schafer (20), Schrader (21), and Squillace (25). Percent summerwood has been found to be consistently related to specific gravity for southern yellow pines; the higher the percent summerwood the higher the specific gravity is the general trend noted. Growth rate classes for production of wood of high and average density for the majority of the commercial American species are presented in the work of Paul (16). Although growth rate has been found to be related to specific gravity for ring porous hardwoods, it is not strongly related to specific gravity or strength for the majority of softwood species (11).

As Missouri represents the Northwest boundary for the commercial range of shortleaf pine, mention should be made of investigations concerned with the influence of general location within the geographic range upon specific gravity for coniferous species. Among several studies on coniferous species by workers in foreign countries, those of Hale and Prince (4), Tiebe (26), and Trendelenburg (27), are briefly summarized—along with recent investigations in this field for the southern yellow pines by Larson (7), Goddard and Strickland (3), and Mitchell and Wheeler (12).

Hale and Prince, in studies on white spruce, black spruce and balsam fir grown in Canada, found no noticeable trend in specific gravity that could be attributed to latitude. However, they did find for black spruce that specific gravity increased in progressing geographically from East to West (Nova Scotia to Western Ontario). Tiebe found appreciable differences between the mean values for specific gravity of samples taken from each of eight geographic sources in Europe for *Pinus silvestris.* Trendelenburg noted, for European spruce and larch, that the average and extreme values for specific gravity increased for samples taken from the South to the North or in going from lower to higher altitudes.

Larson, and more recently Goddard and Strickland, presented data for slash pine indicating an increase in specific gravity when proceeding from West to East or from North to South within the species range. Mitchell and Wheeler, in an investigation of the southern pines in Mississippi, noted an increase in specific gravity for loblolly and shortleaf pine in proceeding from North to South within the state. For 40-year old shortleaf pine, specific gravity estimates for increment cores sampled at breast height were 0.546, 0.534, and 0.525 for the Southern, Central, and Northern portions, respectively, of Mississippi.

Although no data are available for determination of the influence of location over the entire geographic range on specific gravity of shortleaf pine, we may suspect, on the basis of findings reported above for other southern pines, that Missouri-grown shortleaf pine will be lighter than the species average. However, the final answer must wait on future research.

Within recent years there has been considerable work in the general areas of tree genetics and tree physiology for the purpose of growing superior (wood quality) strains of important species as the southern yellow pines. Several publications dealing with this general aspect of growth-quality for coniferous species are those of Dadswell (1), Kennedy (5), Richardson (18), Smith (23), Van Buijtenen (28, 20), and Zobel (35, 36, 37, 38, and 39). At the same time, progress has been made in obtaining considerable data from increment cores, for example the Kraft pulping studies of Van Buijtenen (29), following the concept of non-destructive wood-quality evaluation as mentioned by Mitchell (13). These investigations, the bulk published within the last two years, are indicative of a renewed and vigorous interest in wood-quality studies which it is hoped will lead to greater and improved wood utilization.

This presentation includes no extensive literature review on within tree variation of various quality parameters or on the subjects of environmental or hereditary influences on wood quality. Two recent literature surveys in these areas are those of Spurr (24) and Larson (9). An excellent starting point for a literature search and evaluation of growth-quality relationships is provided by the recent publication of an annotated bibliography on the influence of environment and genetics on pulpwood quality by Larson and his associates (8).

MATERIALS AND METHODS

Collection of Material—A description of the area sampled, for the growth-quality evaluation study, is taken directly from a work plan by Rogers and Liming (19), dealing with a study originated in 1950 on degrees of stocking and methods of thinning stands of shortleaf pine. "The study area is on the Bunker unit of the Sinkin Experimental Forest in Dent County, Missouri. The plots are located on 4 to 30 percent slopes on the tops and sides of two main ridges in the upper Red Hill branch of Sinkin Creek. The elevation ranges from 1230 to 1340 feet above sealevel. The soil is relatively thin, has an average amount of chert and rocks, and is classified as Clarksville stony loam soil.

"The 30-year old shortleaf pine stand was established by natural regeneration soon after an oak-pine stand was harvested in 1918, 1919, and 1920. Prior to 1933 the area was burned over periodically by uncontrolled fires. Since that time the area has been a part of the Clark National Forest and has not been burned over. In 1934 most of the overstory hardwood trees in these stands were cut or girdled. At that time the pine stands were thinned, mostly from below, to a stocking of approximately 600 pine trees per acre.

"The present, 1950, stands have an average stocking of approximately 570 pine trees per acre. The pine trees average about 6.6 inches in diameter breast high. Very few of the pine trees are less than 0.6 inches dbh and only an occasional tree is over 12 inches dbh. The basal area of the pine trees averages about 130 square feet per acre. The dominant and co-dominant pine trees average about 50 feet high, thus giving the area a site index of 70 for pine." This description applied at the year 1950, prior to the initiation of several silvicultural treatments. In 1950 a study on degree of stocking and methods of thinning stands of shortleaf pine was undertaken. Samples removed in 1960 for growth-quality evaluation were taken from areas that had been cut to the following degrees of stocking: 50, 70, 90, 110, 110±, and approximately 130 (check) square feet basal area of pine trees per acre in 1950. Several methods of thinning had been employed such as selective thinning, thinning from above and thinning from below. A more detailed description of this study is available in the work plan of Rogers and Liming mentioned above. Pictures of a representative area prior to and immediately after thinning in 1950 are presented in Figures 1 and 2.

Some 90 trees in all were sampled for this investigation according to the sampling scheme presented in Figure 3. The dbh classes for 5″, 7″, 9″, and 11″ trees are based on measurements made in 1952; however, the actual thinning operations were undertaken in 1950. Observation of disk samples in the field in-indicated that initial response to thinning had not been noticeable for the two-year period 1950-1952 and that diameter measurements in 1952 were valid, for practical purposes, for describing trees prior to the influence of thinning. It was impossible to obtain samples in the 11-inch dbh class of 1952 that had grown only ½ inch during the period 1951 to 1960. Each of the trees sectioned for study was randomly selected from IBM cards prior to going into the field at Sinkin. As may be observed from Figure 3, the only criteria for selection was a given dbh class, such as 5 inches, 7 inches, or 9 inches, in 1952—and a given dbh growth class as ½ inch, 1 inch, or 1½ inches, by 1960. Unless these trees, selected at random from individual data cards prior to going in the field, showed some visible defect at the time of their location on the sample plots, they were taken for growth quality analysis. A disk some 2½ inches thick at breast height was removed from each tree. Disks were placed in polyethylene bags and brought to Columbia and stored at −18°C. prior to analytical work. It was felt that storage at this low temperature would not affect any determinations made

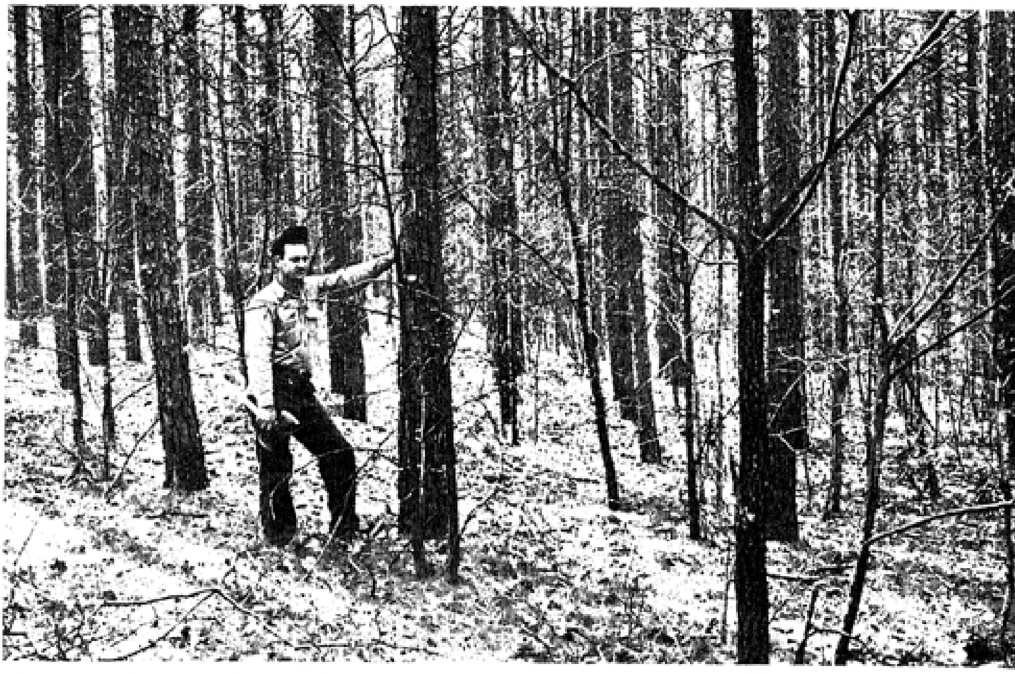


Figure 1—Picture of one of the pine stocking study plots prior to thinning operation in 1950. Photo courtesy of U. S. Forest Service.

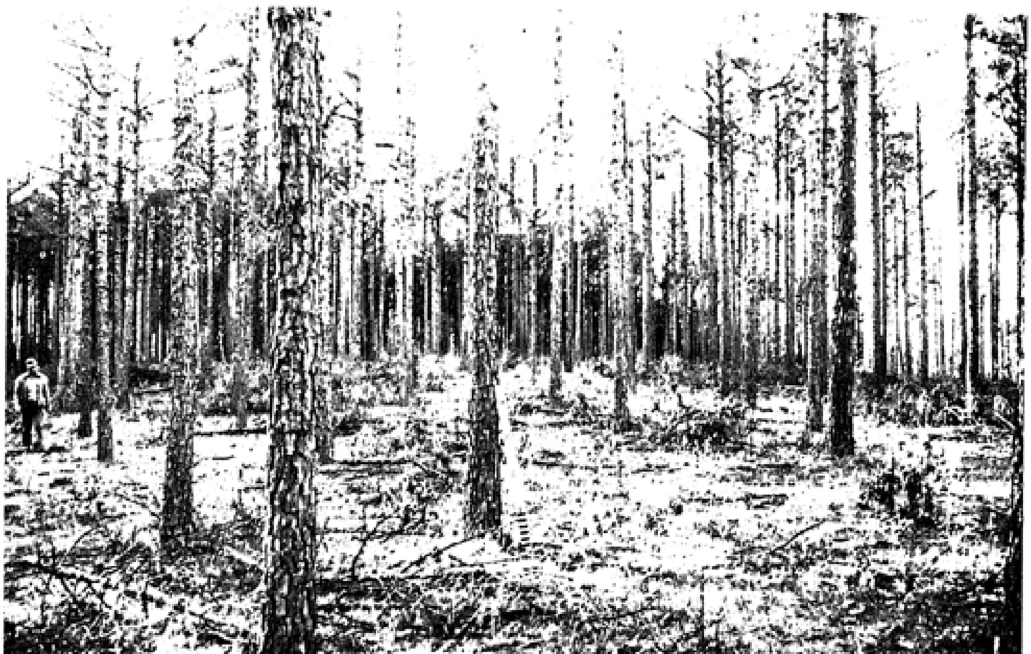


Figure 2—Picture of one of the pine stocking study plots immediately after thinning operation in 1950. Photo courtesy of U. S. Forest Service.

1952-60 DBH GROWTH (INCHES)	1952 DBH CLASS (INCHES)			
	5	7	9	11
0.4-0.6	6	6	7	—
0.9-1.1	6	6	6	4
1.4-1.6	6	5	6	4
1.9-2.1	7	6	6	1
2.4-2.6	1	6	2	1

Figure 3—Method of sampling for growth-quality analysis of shortleaf pine. Figure in each block indicates number of trees in the 40-year age group sampled.

as the felling and bucking operations and sample collections were done in midwinter of 1960. The samples appeared frozen at this time.

Laboratory preparation of material—A general description of disk breakdown is as follows. The disks were removed from cold storage and a strip some ⅜ to ½ inch thick (transverse plane of xylem) was cut along the average disk diameter on a band saw. These strips were then cut into several smaller strips each approximately ⅜ to ½ inch square and the length of the average disk diameter. Each strip was then cut into age periods representing the time of thinning operations as stated by Rogers and Liming (19). This sample breakdown is shown in Figure 4. The age periods are: the first 8 year's growth was taken as juvenile wood according to the definition used by Zobel (35, 37) and based on the work of Lodewick (10); the mature wood to and including the year 1935 (average age of these sections was 7 years); the mature wood from 1936 to 1950; and the mature wood from 1951 to 1960. This segregation was done using a wood chisel under a stereo microscope (30X magnification). It should be emphasized (Figure 4) that there are two samples per tree for each of the four age periods mentioned above: for example the period from 1951 to 1960 has two samples on opposite

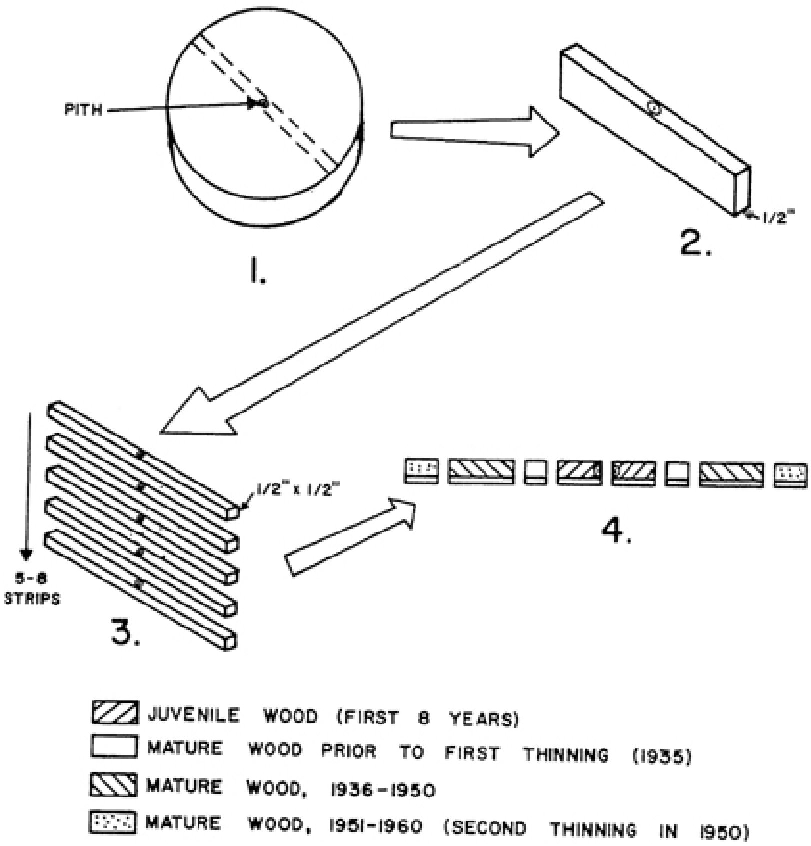


Figure 4—Breakdown of disks, approximately 2½ inches thick, of the sample trees. Disks were removed at breast height.

sides of the tree at the same height. With a maximum of 8 strips per tree, and with 8 samples per strip, the total number of sample sections taken from a tree ran to a maximum of 64. Each individual section was placed into a test tube and stored at -18°C. prior to further work.

The first (top) strip prepared from the sample disk, as shown in Figure 4, was used in estimating specific gravity, and ring-width for 90 trees. This same top strip was also used, for some 19 trees, in estimation of percent summerwood, fiber dimensions, and fibril angle. The two strips immediately under the first strip were kept in reserve in event of experimental mishap. The other strips (maximum number of 5) after being segregated into the indicated age periods, were used for chemical analysis.

Description of analytical techniques—This section includes procedures employed for the determination of specific gravity, growth rate, percent summerwood, and various chemical analysis, such as alcohol-benzene extractables, water resistant carbohydrate content, and lignin content. It also includes techniques employed for estimations of the various fiber dimensions such as width, wall thickness, length, and determination of fibril angle.

Specific gravity determination—A maximum moisture content procedure was adapted for determination of all specific gravities mentioned in this report, as it was found to be the fastest and most accurate procedure. The works of Smith (22) and Keylwedth (6) were used as a basis for development of the technique used in this investigation. The procedure used for specific gravity estimation was evaluated against water immersion techniques; the influence of alcohol-benzene extractable material upon specific gravity determinations was investigated and found to be significant.

Briefly the two foregoing methods (immersion and maximum moisture content) for estimation of specific gravity of wood are based on the following principles: the standard immersion procedure is based on liquid (usually water) displacement to estimate sample volume; whereas the maximum moisture content method is based on ***completely*** filling the void volume of wood with a liquid (water in this instance) of known density, assuming a value (1.53 when measured using water) for the density of the fiber cell wall material itself, and then making estimates of wood weight when the sample is completely saturated (hence the term maximum moisture content) with water and when the sample is oven-dry.

Maximum moisture content methods give specific gravity estimates expressed on a green (wet) volume, oven-dry weight basis. Immersion techniques may be used to provide specific gravity estimates similarly expressed or on an oven-dry volume, oven-dry weight basis.

It is generally recognized that the extractable content in the inner (heartwood) zone of most coniferous species tends to, at least for some time, increase with tree age. The influence of these extractables on the estimation of specific gravity of 40-year old shortleaf pine was unknown and hence explored.

On material which had been alcohol-benzene extracted in a standard Soxhlet apparatus for a minimum time of 18 hours, no significant differences for either the outer zone of mature wood i.e., 1951-1960, ***or*** the inner core of juvenile wood, first 8 years' growth, was found between the maximum-moisture content procedure or the standard water immersion procedure. Data to support this statement are shown in Table 1. For samples which ***had not*** been previously extracted in alcohol-benzene, higher specific gravities were obtained by the maximum moisture content method. Supporting data for the age period 1951 to 1960 (last formed mature wood) are presented in Table 2. This difference between the two procedures, for unextracted material, is greatly emphasized when data for the core or juvenile wood zone are compared as shown in Table 3. It is in juvenile wood region where the bulk of the extractives were found to be concentrated. Specific gravity estimates, obtained by maximum moisture content method, for extracted versus unextracted juvenile wood sections are shown in Table 4. Although no tests were devised to determine the cause of discrepancy in specific gravity estimates between the two procedures on unextracted material, the data presented in Table 1 to 4 permits the following theory. As the green

TABLE 1 - COMPARISON OF ESTIMATES OF SPECIFIC GRAVITY FOR OUTER 10 YEARS (1951-1960) GROWTH AND INNER (1921-1928) GROWTH OF SHORTLEAF PINE, AS OBTAINED ON EXTRACTED MATERIAL BY THE MAXIMUM MOISTURE CONTENT AND WATER IMMERSION PROCEDURES.

Growth Zone and Sample Number		Specific Gravity: Maximum Moisture Content Procedure	Specific Gravity: Water Immersion Procedure	Difference
1951-1960	1	.405	.408	+.003
	2	.447	.447	.000
	3	.443	.431	-.002
	4	.453	.459	+.006
	5	.507	.500	-.007
	6	.459	.458	+.001
	7	.408	.409	-.001
	8	.410	.407	+.003
	9	.472	.480	-.008
	10	.461	.461	.000
	11	.438	.437	+.001
	12	.472	.470	+.002
	13	.415	.418	-.003
	14	.420	.422	-.002
	15	.446	.445	-.001
1921-1928	1	.372	.375	+.003
	2	.351	.351	+.005
	3	.366	.366	.000
	4	.400	.408	+.008
	5	.352	.356	+.004
	6	.395	.392	-.003
	7	.405	.401	-.004
	8	.372	.373	+.001
	9	.335	.339	+.004
	10	.361	.367	+.006
	11	.351	.350	-.001
	12	.372	.368	-.004
	13	.379	.374	-.005
	14	.395	.398	+.003
	15	.356	.354	-.002
			Sum of Differences	.093
			Mean Difference	.003

volume of wood remains, as far as was determined by immersion techniques, the same prior to or after alcohol-benzene extraction, it is the oven-dry weight that should be assumed to be significantly influenced by the presence of the extractable material. The extractables are not removed by oven-drying either at 105°C. in a standard forced draft oven or under reduced pressure at 65°C. Therefore, a slightly higher oven-dry weight results, causing a slightly higher specific gravity estimate, when unextracted and extracted material are compared using immersion procedures.

TABLE 2 – COMPARISON OF ESTIMATES OF SPECIFIC GRAVITY FOR OUTER 10 YEARS (1951-1960) GROWTH OF SHORTLEAF PINE AS OBTAINED ON UNEXTRACTED SAMPLES OF MAXIMUM MOISTURE CONTENT AND WATER IMMERSION PROCEDURES

	Specific Gravity		
Sample Number	Maximum Moisture Content Procedure	Water Immersion Procedure	Difference
1	.451	.456	+.005
2	.423	.413	-.010
3	.544	.536	-.008
4	.526	.514	-.012
5	.502	.500	-.002
6	.488	.474	-.014
7	.532	.524	-.008
8	.468	.460	-.008
9	.522	.513	-.009
10	.552	.541	-.011
11	.543	.539	-.004
12	.560	.556	-.004
		Sum of Differences	.095
		Mean Difference	.008 (.0079)

TABLE 3 – ESTIMATES OF SPECIFIC GRAVITY, FOR COMPARISON OF FIRST 8 YEAR'S GROWTH OF SHORTLEAF PINE OBTAINED ON UNEXTRACTED SAMPLES BY WATER IMMERSION AND MAXIMUM MOISTURE CONTENT PROCEDURES

	Specific Gravity		
Sample Number	Water Immersion Procedure	Maximum Moisture Content Procedure	Difference
1	.438	.509	+.071
2	.459	.533	+.074
3	.449	.545	+.096
4	.448	.532	+.084
5	.508	.573	+.065
6	.478	.538	+.060
7	.566	.689	+.123
8	.490	.500	+.010
9	.669	.824	+.155
10	.664	.810	+.146
11	.666	.758	+.092
12	.700	.892	+.192
		Sum of Differences	1.168
		Mean Difference	.097

TABLE 4 - ESTIMATES OF SPECIFIC GRAVITY FOR COMPARISON OF FIRST 8 YEAR'S GROWTH OF SHORTLEAF PINE OBTAINED ON UNEXTRACTED AND EXTRACTED SAMPLES BY THE MAXIMUM MOISTURE CONTENT PROCEDURE

Sample Number	Specific Gravity Unextracted	Extracted	Difference
1	.509	.405	-.104
2	.533	.477	-.086
3	.545	.433	-.112
4	.532	.453	-.079
5	.573	.507	-.066
6	.538	.459	-.079
7	.689	.408	-.281
8	.500	.410	-.090
9	.824	.382	-.442
10	.810	.433	-.377
11	.758	.407	-.351
12	.892	.407	-.485
		Sum of Differences	2.552
		Mean Difference	.213

In maximum moisture content procedures, the extractable content may influence the final determination in two ways. These are:

1. A natural increase in oven-dry weight by their mere presence, as for immersion techniques.

2. It is possible that extractables inhibit the diffusion of water both into and out of the void volume of wood itself, therefore giving an abnormally low maximum moisture content value. This situation is indicated by evaluation of data presented in Tables 2 and 3 where mature and juvenile wood zones are compared. For all specific gravity estimates presented in this study, material was previously extracted in alcohol-benzene (ratio 2:1).

The procedure used is as follows. Samples were removed from storage, still in original "green" condition, and extracted for minimum of 18 hours in a conventional Soxhlet apparatus. After this extraction, samples were soaked in alcohol (ethanol) for a minimum of 18 hours to remove residual benzene. Two or more changes of ethanol were needed for this step. Samples were then soaked some 18 hours in water (several changes) to minimize residual alcohol content. This was followed by intermittent evacuation (29″ Hg) and release of vacuum treatments for three days, to assure "maximum-moisture content" conditions. Weights, "wet" and "oven-dry" (18 hours, 65°C., 29″ Hg) were obtained on a Mettler semi-micro balance. Density of cell wall material was assumed to be 1.53 (as water was void—filling media). Specific gravity was calculated using formula of Smith (22).

To establish a reliable estimate of reproducibility in determination of specific gravity, the following program was initiated. Twenty samples representative of juvenile and mature wood zones, each sample pre-extracted in alcohol-benzene, were used for estimation of specific gravity by the maximum-moisture content method by three investigators, on each of three separate days, resulting in an average deviation in specific gravity estimates of ±.003.

Growth rate—Growth rate was determined on green samples, on their cross sections, under 30X magnification using a stereo microscope, for all ninety trees. For 19 selected trees, used for summerwood measurements, growth rate was measured on microtome sections of the radial plane of the wood. Reproducibility of results between three investigators, under a system similar to that employed for specific gravity, indicated an average deviation in growth rate estimates of ±0.09 mm. No significant difference was established between growth rate measurements made on radial and cross-sections for these 19 trees.

Percent summerwood—In view of the more precise but time consuming analytical technique of Mork (14) and the subsequent modification of his techniques by Wiksten (33), a subjective procedure was used to differentiate between spring- and summerwood zones of the annual increments in shortleaf pine. By *subjective* is meant that the boundary between springwood and summerwood is left to the discretion of the investigator as opposed to the following of a prescribed formula. Radial sections, 45 to 60 microns in thickness, were prepared on a sliding microtome. No difference was established in cross and radial sections for the same wood sample in determination of percent summerwood estimates as is indicated in Table 5. No marked reduction in accuracy of estimation, or reproducibility of results was encountered using this subjective procedure as opposed to the more precise analytical technique of Wiksten (33). Data in Table 6 present the basis for this statement and also point out the possibility that subjective methods for summerwood determination tend to exclude transition zone material from the summerwood zone of annual increments, at least in shortleaf pine, with the possible exception of the very early formed years.

It should be emphasized that analytical techniques, Wiksten's, for example, when used by the same investigator, and where duplicate measurements are made at the same time, give excellent reproducibility. It is when several investigators make estimates at a number of different times on the same sample, that the reproducibility of this technique is reduced near that of faster, subjective, methods. At least this is the situation borne out here in work on shortleaf pine. It may be further pointed out, that at present no data in the literature propose or indicate a sharp boundary (one cell difference) actually existing between the springwood and summerwood zones of annual increments either anatomically or physiologically speaking. The main tests of techniques for defining these zones are reproducibility of results and reasonable rapidity of measurement.

The added advantages of using radial sections in preference to cross sections are:

TABLE 5 – COMPARISON OF ESTIMATES OF PERCENT SUMMERWOOD BETWEEN RADIAL AND CROSS SECTIONS OF SHORTLEAF PINE SAMPLES AT BOTH 50X AND 125X MAGNIFICATION

Wood Classification	Ring Age from Pith (years)	Percent Summerwood* Radial 50X	Section 125X	Cross 50X	Section 125X	Differences 50X	Differences 125X
Juvenile	2	29.4	----	33.0	----	-3.6	----
		28.2	----	31.2	----	-3.6	----
		30.1	----	31.5	----	-1.4	----
	3	14.3	----	13.6	----	+0.3	----
		13.7	----	13.0	----	+0.7	----
		14.0	----	14.0	----	0.0	----
	4	31.0	----	30.8	----	+0.2	----
		29.6	----	30.2	----	-0.6	----
		31.5	----	29.8	----	+1.7	----
	5	42.6	----	41.8	----	+0.8	----
		41.8	----	41.0	----	+0.8	----
		42.0	----	42.4	----	-0.4	----
Mature	30	62.4	65.5	63.5	66.0	-1.1	-0.5
		64.2	66.9	62.0	65.0	+2.2	+1.9
		63.0	64.0	63.2	63.2	-0.2	+0.8
	31	55.5	57.4	53.5	54.5	+2.0	+2.9
		55.8	56.0	54.2	55.5	+1.6	+0.5
		56.2	55.8	54.0	54.0	+2.2	-0.2
	32	55.5	61.2	59.0	57.7	-3.5	+3.5
		57.2	58.2	58.0	58.2	-0.8	0.0
		56.2	59.2	59.6	58.9	-3.4	+0.3
	33	53.2	59.8	51.0	51.5	+2.2	+8.3
		52.6	57.6	52.2	52.6	+0.4	+5.0
		55.4	52.8	53.5	52.0	+1.9	+0.8
				Sum of Differences	=	35.0	24.7
				Mean Differences	=	1.4 (1.45)	2.0 (2.05)

*Each entry obtained from same section but on one of three different days and by one of three different technicians.

1. Dimensions of fiber width and fiber wall thickness and also fibril angle can be obtained directly upon the same material for which percent summerwood has been estimated.

2. The demarkation between the spring and summerwood zones of the annual increments was found to be more accentuated, particularly in the juvenile wood zone.

Chemical analyses—As mentioned previously, the first three ½ x ½ inch strips prepared from the sample disk were allocated for specific gravity and

TABLE 6 - COMPARISON OF ESTIMATES OF PERCENT SUMMERWOOD BETWEEN WIKSTEN'S (33) ANALYTICAL AND THE SUBJECTIVE PROCEDURE FOR SHORTLEAF PINE SAMPLES ON THE CROSS-SECTION

Wood Classification	Ring Age from Pith (years)	Percent Summerwood* Analytical (125X)	Percent Summerwood* Subjective (50X)	Difference
	2	30.21	33.0	-2.79
		27.43	31.2	-3.77
		28.62	31.5	-2.88
	3	14.20	13.6	+0.60
		17.62	13.0	+4.62
		15.35	14.0	+1.35
	4	36.95	30.8	+6.15
		35.93	30.2	+5.73
		32.37	29.8	+2.57
	5	42.79	41.8	+0.99
		43.53	41.0	+2.53
		44.25	42.4	+1.85
Mature	30	66.21	63.5	+2.71
		64.13	62.0	+2.13
		64.75	63.2	+1.55
	31	55.73	53.5	+2.23
		58.21	54.2	+4.01
		56.05	54.0	+2.05
	32	62.15	59.0	+3.15
		63.17	58.0	+5.17
		61.81	59.6	+2.21
	33	52.25	51.0	+1.25
		54.06	52.2	+1.86
		53.55	53.5	+0.05
			Sum of Differences =	64.20
			Mean Difference =	2.67

*Each entry obtained from same section but on one of three different days and by one of three different technicians.

anatomical analyses. One tree, in each of the 20 sampling unit cells (for example 7 inch dbh class—1 inch dbh growth class) shown in Figure 3 was randomly picked for chemical analyses. It soon became apparent that not enough sample material was available in the mature wood zone from 1929 to 1935 to perform all analyses desired. Therefore, *all* of the mature wood from the year 1929 to 1950 was treated as one sample. This sample was used for analyses of alcohol-benzene extractables, water resistant carbohydrate content, and lignin content. This means that for each tree analyzed (19 in all as no 11-inch tree that grew ½ inch during the period 1959-1960 was available), there were six separate sampling points. These are: Two each, for the juvenile wood zone, the mature wood to 1950, and the period 1951 to 1960. Chemical analyses were done in triplicate whenever possible and at least in duplicate for each age period.

In order to conserve the amount of material necessary, a procedure was designed for the determination of extractables, water resistant carbohydrate content, and lignin content on the same sample without having to resort to numerous samples for separate determinations of oven-dry conditions after a particular chemical analysis. The success of this procedure depended upon a substitution of drying under vacuum (between 55 and 65°C) for the more usual drying conditions in a forced draft oven at 105°C. It is generally assumed that drying under the latter condition renders the sample less reactive for subsequent determination of some chemical constituents or else possibly alters some of the complex chemical make-up of wood itself. After numerous trial runs, the following procedure was employed for determination of chemical analyses.

1. Samples were ground in a laboratory Wiley mill to pass a 40- and be retained on a 60-mesh screen.

2. Samples were then dried under vacuum at 60°C for a minimum of 24 hours and the sample weight recorded to four decimal places, forming the oven-dry conditions for future reference.

3. The amount of extractable material (alcohol-benzene; ⅔ 95% ethanol—⅓ benzene) was determined in a Goldfisch fat extraction apparatus. This equipment permits a more rapid determination of extractables than the conventional Soxhlet apparatus as the extraction takes place under a continuous rather than a batch-wise system.

4. Samples were then washed on a coarse porosity fritted glass filter with alcohol and then water.

5. Samples redried under vacuum and the extractive-free weight determined

6. Percent alcohol-benzene extractables expressed as the ratio of the loss in weight over the original oven-dry weight.

For determination of the water-resistant carbohydrate content, as reported by Zobel (37), correspondence with Mr. Zobel and Mr. R. W. Kennedy[1] were utilized for the following procedure.

7. 0.70 grams (±0.05 grams) of vacuum-dried samples previously extracted in alcohol-benzene was placed into a tared Erlenmeyer flask.

8. Ten mls. of stock solution *A* were added and one ml. of stock solution *B* was added. The flask was stoppered with a weighted glass stopper. Stock solution *A:* 60 mls. of glacial acetic acid and 20 grams of sodium hydroxide per liter of distilled water. Stock solution *B:* 200 grams of sodium chlorite per liter of distilled water.

9. The flask was placed in a water bath which was regulated to 75°C ± 2 degrees. The flask was swirled vigorously for one minute, every half hour. A drop or two of wetting agent was added after the initial addition of stock solution *B* to aid in initial delignification.

[1] R. W. Kennedy, member of Faculty of Forestry, University of British Columbia, Vancouver, B. C., Canada.

10. After ¾ of an hour, one and one-half hours, and two and one half hours, additional one ml. aliquots of solution ***B*** were added. Not more then one minute elapsed between an addition of (solution ***B***) and a thorough mixing by hand swirling.

11. After four hours in the water bath, the flask was placed in an ice-water bath. 15 mls. of iced distilled water was added to the content of the flask. Contents of the flask were quantitatively transferred to a tared, coarse-porosity fritted-glass filter. The flask was washed down with 100 mls. of a one-percent acetic acid solution utilizing a glass rod to initiate complete transfer of material from flask to filter. The sample was then washed with 5 mls. portions of acetone (drained by gravity in this instance) and then suction was applied for 5 minutes.

12. Samples were dried under vacuum again and the water resistant carbohydrate content calculated on an extractive free basis.

13. The residual lignin content of the water resistant carbohyrdate material was analyzed using a 72 percent sulfuric acid lignin procedure (TAPPI-standard). Residual lignin (sulfuric acid lignin) content of water resistant carbohydrate material ranged from 9-14 percent on several samples of juvenile and mature wood so analyzed. In addition, the 72 percent sulfuric acid lignin content of extractive free wood was determined in some instances as is mentioned subsequently in this report.

Fiber dimensions and fibril angle—Longitudinal tracheid width and common tangential wall thickness were determined on radial wood sections which had been previously used for percent summerwood determinations. Three distinct zones of annual increment were characterized. These are: the initial one or two tracheids of the springwood zone within a given annual increment; a zone referred to as a transition zone, which were the two fibers, one immediately before, and the other immediately after, the subjective demarkation between spring- and summerwood; and finally the last two or three longitudinal tracheids in the outermost portion of the annual increment in the summerwood zone. Measurements of fiber width, common tangential wall thickness and fibril angle were determined under 500X magnification on a Leitz polarizing research microscope. With reference to the determination of fibril angle, independent observations were also made utilizing the presence of cell wall checks which are thought to be oriented in the same way as the macrofibrils in the secondary wall. Comparison of estimates of fibril angle by the polarizing microscope technique and the cell wall check technique are presented in Table 7.

Briefly, the method employed for determination of fibril angle orientation on the radial walls of longitudenal tracheids is as follows. The equipment involved consists of a polarizing microscope equipped with a rotating stage, a first order red retardation plate positioned at 45 degrees to the direction of vibration, and an eyepiece with a reference line parallel to the direction of the light vibration of the polarizer. After experimentation, a magnification of 500 diameters was found to be quite satisfactory for conducting the analyses.

TABLE 7 - COMPARISON OF ESTIMATES OF FIBRIL ANGLE DETERMINATION ON RADIAL WALLS OF LONGITUDINAL TRACHEIDS OF SHORTLEAF PINE BY THE USE OF THE POLARIZED LIGHT AND CELL WALL CHECK TECHNIQUES

	Fibril Angle (Degrees)*		
Fiber Number	Polarized Light	Cell Wall Check	Difference
1	42.6	41.0	+1.6
2	32.5	32.7	-0.2
3	45.2	43.6	+1.6
4	19.1	18.2	+0.9
5	7.2	7.0	+0.2
6	5.8	6.6	-0.8
7	29.6	30.1	-0.5
8	28.4	27.6	+0.8
9	33.2	35.4	-2.2
10	7.6	9.2	-1.6
11	11.2	10.0	+1.2
12	15.8	14.7	+1.1
13	52.3	51.0	+1.3
14	49.1	49.0	-0.5
15	40.6	41.4	-0.8
		Sum of differences =	15.3
		Mean difference =	1.0 (1.02)

*Each entry is average of two estimates for each technique.

After selection of tracheids to be measured, care was taken to insure that no measurements were made in the vicinity of either bordered pits, or at the tracheid ends.

The method consisted of locating the major extinction position of a single cell wall. At this major extinction position, the fibrillar structure of the wall lies in the direction of the vibration of the polarizer and will thus be the same color as the background, i.e., a reddish purple. This condition also exists at the minor extinction position which is 90 degrees to the major position. Thus in rotating the wood section, there will be four extinction positions in a 360 degree rotation. To determine the major extinction position, it is necessary to note the color change of the tracheid wall as it is rotated. If the color changes to blue or green upon a slight *clockwise* rotation, the extinction position is major. A yellow or orange color with a similar clockwise rotation indicates the minor extinction position. After the major extinction position had been determined, a reading of the angular position of the stage was made. The stage was then so rotated that the lengthwise axis of the tracheid was parallel to the hairline in the eyepiece. At this point a second angular reading of the stage was taken. The difference between these two angular readings was taken as the fibril angle of the tracheid.

Fiber length was not obtained on the radial sections for two reasons:

1. the actual interlocking of fiber ends in the radial plane of the spring and summerwood zones made a measurement of fiber length not only tedious but also inaccurate, and

2. by the use of the chlorite holocellulose procedure of Wise and associates (34), fibers could be isolated and length measurements determined quite accurately on individual fibers by projection of the microscope image onto a suitable screen. Macerating (pulping) techniques, as mild as most holocellulose procedures, are not felt to influence fiber length measurements.

Statistical analyses—Various data obtained from this investigation were selected for statistical analyses to establish correlation and/or regressions between various parameters. The bulk of the measurement data obtained, however, are presented in a graphical form which attempts to illustrate within and between tree variation.

RESULTS AND ANALYSES

Results of this investigation are presented in three separate parts. Part one deals with estimates of growth rate and specific gravity determined on some 90, 40-year old shortleaf pine trees. This section deals with presentation of mean data for the various age periods outlined in the Materials and Methods section along with comparisons between the various tree-size classes; that is 5-inch, seven-inch, nine-inch and eleven-inch trees, and between the various diameter growth-classes for the ten-year period from 1951 to 1960. These diameter growth-classes are the ½, 1, 1½, 2 and 2½-inch groups.

The second part of this section is concerned with analyses of specific gravity, growth rate, percent summerwood, and various chemical analyses for 19, 40-year old shortleaf pine trees. These trees represent one from each of the twenty sampling units wherever possible, as shown in Figure 3. As indicated earlier, no eleven-inch that grew ½-inch in diameter over the ten year period 1951-1960 was available. Mean data for the various quality parameters are presented in Figures and Tables along with statistical correlations whereever appropriate.

The third part of this section deals with determinations made on 2 individual trees. In one instance, data for one tree at breast height for three standard parameters of quality—specific gravity, growth rate, and percent summerwood—are given. This tree was in the eleven-inch dbh—1½ dbh growth class. Data for the other tree (eleven-inch dbh—2½ dbh growth) are shown for fiber width, fiber wall thickness, fiber length, fibril angle, and estimates of specific gravity for isolated springwood and summerwood zones of the juvenile portion and the mature wood portion from 1951 to 1960.

All specific gravity data for this section are also expressed on an alcohol-benzene extractive free, green volume, and oven-dry basis.

Growth Rate and Specific Gravity Data for 90, 40-year old trees. Mean data for the specific gravity of the complete mature wood zone, from the year 1929 through 1960, versus the specific gravity data for the juvenile sections of all 90 trees for both sides (termed "North" and "South") of the trees are shown in Figure 5. The terms "North" and "South" do not imply true north and south orientation but indicate opposite sides of the tree only. Data illustrated in Figure 5, are arranged according to increasing specific gravity of the mature wood on one side ("North") of the tree. The array illustrates the within variation pres-

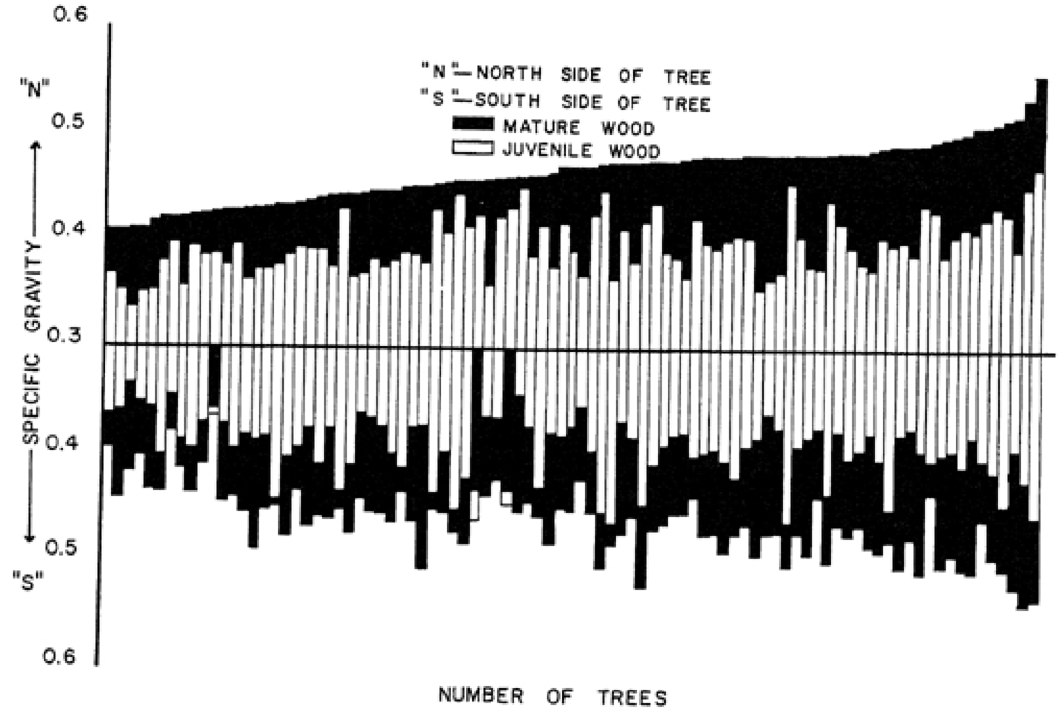


Figure 5—Specific gravity estimates (green volume, oven-dry weight) for juvenile and mature wood zones of 90 shortleaf pine trees averaging 40 years old at breast height. Values arranged according to increasing specific gravity of all mature wood (1929-1960) on one side "North" of the tree. The terms "North" and "South" refer to opposite sides of the trees only, and do not infer true north and south orientation.

ent in the tree as far as the two opposite sampling points are concerned. This difference between specific gravity estimates for opposite sides of the trees, for both mature and juvenile wood sections, is shown more clearly in Figure 6. Some statistics and comments associated with data illustrated in Figures 5 and 6 are given in Table 8. It should be noted that for the 180 comparisons of core and mature wood shown in Figure 5, that the core wood was heavier in only three instances. Re-examination of these three core sections indicated the possible presence of compression wood zones which may attribute to the departure

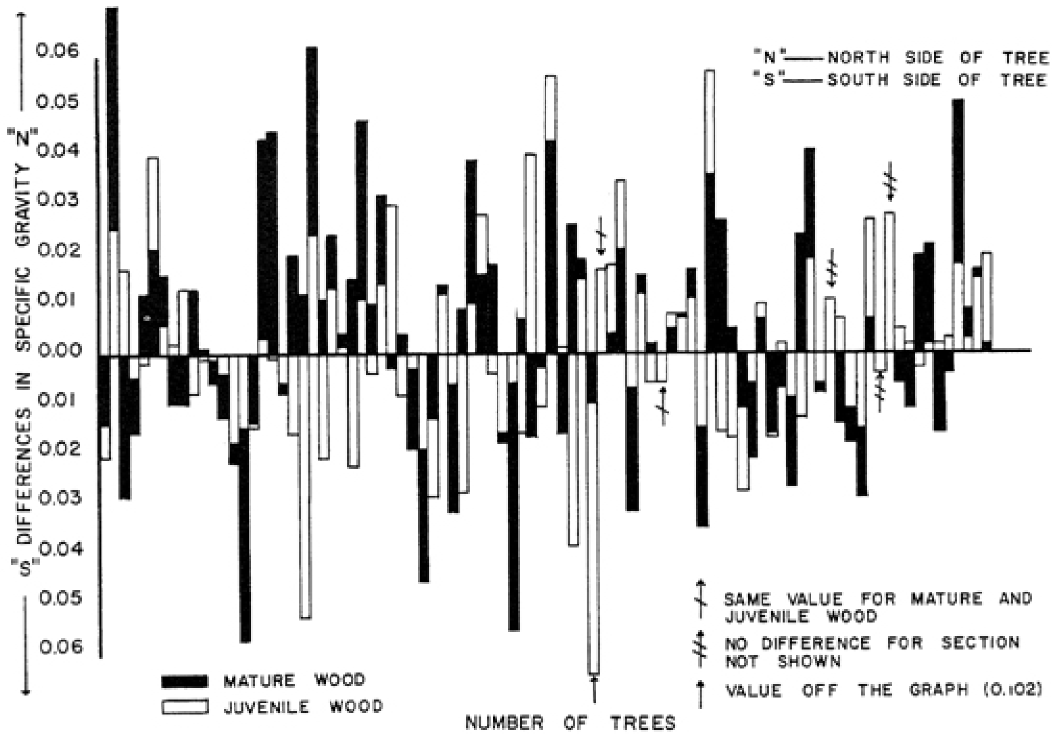


Figure 6—Differences in specific gravity estimates between opposite sides of the trees for mature and juvenile wood zones for the same array presented in Figure 5. The terms "North" and "South" refer to opposite sides of the tree only and do not infer true north and south orientation.

in core and mature wood specific gravity relationships shown for the other 177 observations. Comparison between the specific gravity estimates for the mature wood formed between the periods 1951 to 1960 and the period 1935 to 1950, for opposite sides of the tree are illustrated in Figure 7; again differences between estimates for opposite sides of the tree are shown in Figure 8. Some associated statistics and comments are given in Table 9. Variation *within* trees, as measured by specific gravity data for opposite sides termed ("North") and ("South") in the bar graph diagrams of Figures 5 to 8, appears randomly distributed throughout both mature and juvenile wood zones and independent of tree size or dbh growth class.The juvenile wood zones showed as much variation as their mature counterparts. Further it was noted that within tree variation was independent of tree size in 1950 or of diameter growth class from 1951 to 1960. One way to indicate the magnitude of within tree variation, shown most clearly in Figures 6 and 8, is to state that the average deviation in reproducibility of the maximum moisture content procedure for estimation of specific

TABLE 8 - SOME STATISTICS AND COMMENTS ASSOCIATED WITH SPECIFIC GRAVITY ESTIMATES FOR 90 40-YEAR OLD SHORTLEAF PINES PRESENTED IN FIGURES 5 AND 6.

Figure Number	Statistic
5	1. Mean specific gravity for entire (1929-1960) mature wood on "North" side* of trees ---- .466 2. As above but for "South" side of trees------ .463 overall average------ .464(5) 3. Mean specific gravity for juvenile (1921-1928) wood on "North" side of trees ------------ .394 4. As above but for "South" side of trees------ .394 overall average------ .395 5. Correlation between specific gravity of mature and juvenile wood on "North" side of trees ----------------------------- r = +.461 6. As above but for "South" side of trees r = +.438
6	1. The average difference in estimating specific gravity between opposite sides of the same tree, for either mature or core wood zones, is far in excess of the established reproducibility of the method found to be ± 0.003. 2. Variation between juvenile estimates is as great as between mature wood estimates within trees.

*The "North" and "South" designation refer to opposite sides for the same tree and do not infer true North and South orientation.

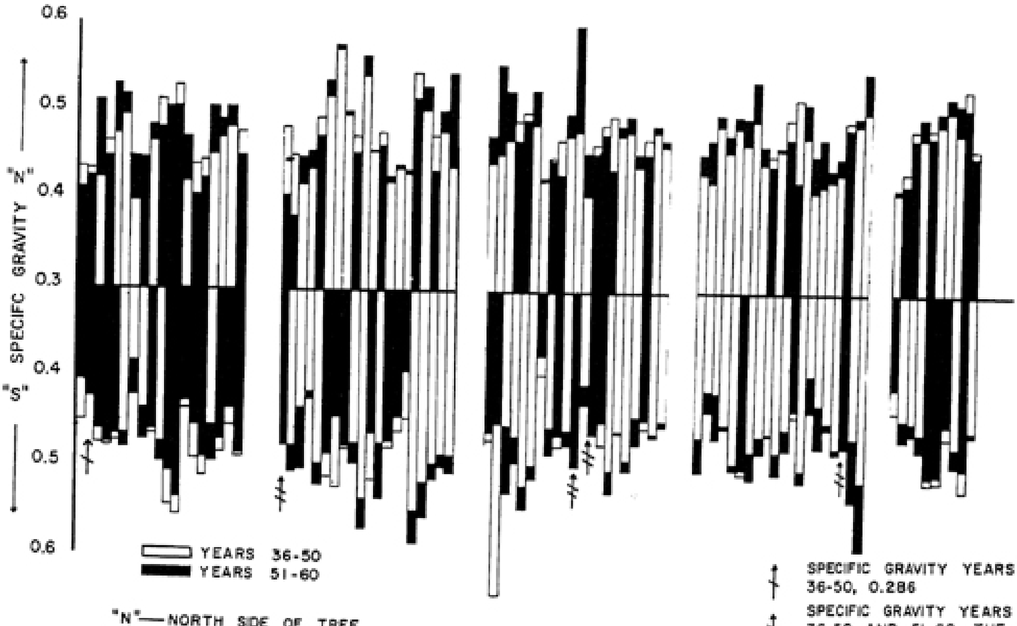


Figure 7—Comparison of specific gravity estimates between the five DBH-growth classes, ½″, 1″, 1½″, 2″, and 2½″ (reading from left to right), for the mature wood zones 1936-50, and 1951-60. Data presented for opposite sides of the trees. Within each DBH-growth class, data are presented first for all the 5″ trees, then the 7″ trees, and finally the 11″ trees, (according to 1952 measurements).

TABLE 9 - SOME STATISTICS AND COMMENTS ASSOCIATED WITH SPECIFIC GRAVITY ESTIMATES FOR 90, 40-YEAR OLD SHORTLEAF PINES, PRESENTED IN FIVE GROUPS OF INCREASING DBH GROWTH (0.5", 1.0", 1.5", 2.0", AND 2.5") FROM 1951-1960, IN FIGURES 7 AND 8.

Figure Number	Age period and tree side*		Statistic	dbh (1951-1960) Growth Class 0.5"	1.0"	1.5"	2.0"	2.5"
7	1951-60	North side	Mean	.476	.485	.483	.479	.482
		South side	Specific	.467	.476	.473	.485	.472
			Gravity					
		Combined		.472	.481	.478	.482	.477
	1938-50	North side	Mean	.458	.485	.468	.457	.478
		South side	Specific	.456	.477	.472	.461	.472
			Gravity					
		Combined		.457	.481	.470	.459	.475
			Number of trees	19	20	21	20	10
Correlation between 1938-1950 and 1951-1960 age periods			(r)	+.594	+.643	+.322	+.532	+.849
			(r)	all 90 trees ---- +.525				
8	1. Variation within trees, well in excess of average reproducibility of method which is ± .003 units, prohibits establishment of significant differences between dbh growth classes of 10-year period of 1951-1960.							
	2. Although the 2.0"dbh growth class shows the greatest increase in specific gravity, .023 units (.482 and .459), over mature wood formed during the period 1938-1950; data do not infer the establishment of a 2.0" growth rate (10-year period) as optimum for production of wood with high specific gravity.							

*The "North" and "South" designation refer to opposite sides for the same tree and do not infer true north and south orientation.

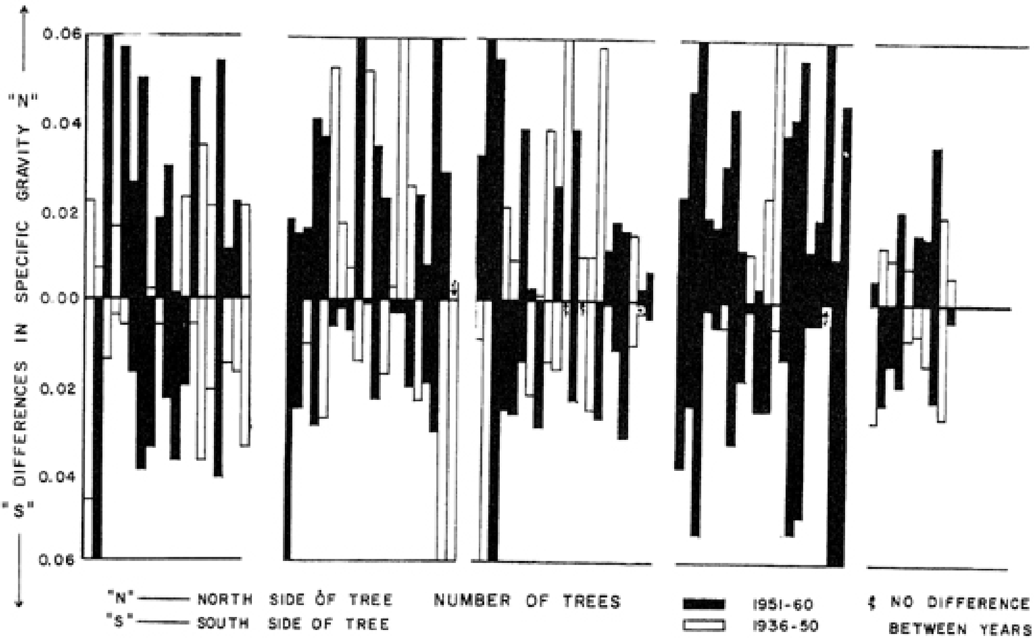


Figure 8—Differences in specific gravity estimates between opposite sides of the trees for the two mature wood zones (1936-50, and 1951-60) for the same array presented in Figure 7. Again "North" and "South" indicate opposite sides of the tree only and do not infer true north and south orientation.

gravity as used in this study was .003 units; whereas the average deviation between opposite sides of the tree for juvenile and mature wood zones is seven times this amount (.021) as is indicated in the Figures.

Specific gravity and growth rate data translated from the metric system into expressions of density as pounds per cubic foot and volume as cubic inches respectively for given sample disks occupied by the 4 age periods studied are presented for the various dbh-growth classes in Figures 9 to 13. Density is measured on a green volume extractive-free, oven-dry basis. Volume is measured on a green, extractive-free basis. Data in the same form for tree size classes are shown in Figures 14 to 17. Summary data for information shown in Figures 9 to 17 are given in Tables 10 and 11.

Presentation of data in this form illustrates two main thoughts or points, to be considered in growth-quality evaluation studies, more firmly then by either the expression of growth rate in a lineal fashion as so many mm. or inches per ring.

1. Density by age periods increased from pith to bark regardless of classification system used i.e., either tree size or dbh growth (except the 11-inch tree group where it was constant for the last two divisions of the mature wood). This increase is ***significant*** averaging some 20 to 25 percent of juvenile wood density.

Figure 9—Reconstructed disk, one inch thick, of shortleaf pine wood 40-years old at breast height. Composite volume (green) and density (green volume, oven-dry weight) data shown are based on analyses of 19 trees in the ½″ diameter growth class for the period 1951-60.

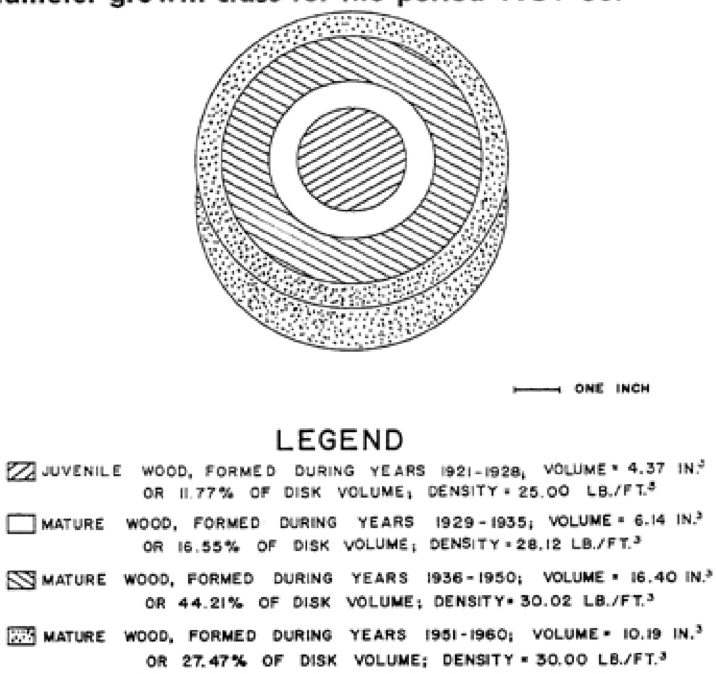
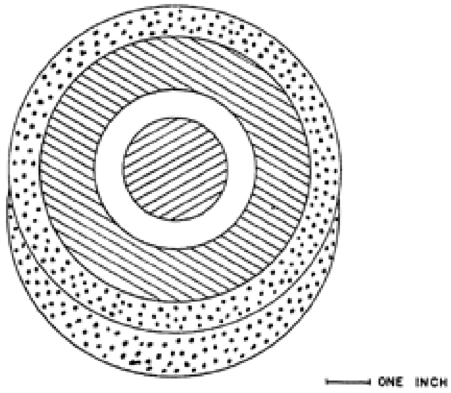


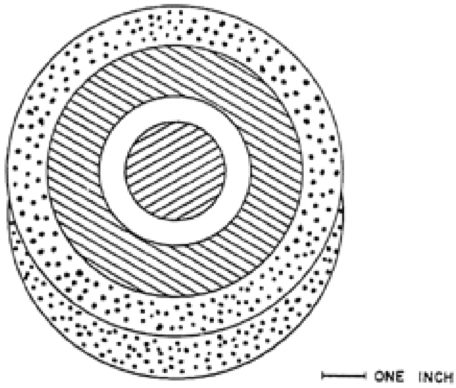
Figure 10—Reconstructed disk, one inch thick, of shortleaf pine wood 40-years old at breast height. Composite volume (green) and density (green volume, oven-dry weight) data shown are based on analyses of 20 trees in the 1″ diameter growth class for the period 1951-60.



LEGEND

- JUVENILE WOOD, FORMED DURING YEARS 1921-1928; VOLUME = 4.49 $IN.^3$ OR 9.90% OF DISK VOLUME; DENSITY = 24.63 $LB./FT.^3$
- MATURE WOOD, FORMED DURING YEARS 1929-1935; VOLUME = 5.90 $IN.^3$ OR 13.00% OF DISK VOLUME; DENSITY = 27.53 $LB./FT.^3$
- MATURE WOOD, FORMED DURING YEARS 1936-1950; VOLUME = 18.31 $IN.^3$ OR 40.37% OF DISK VOLUME; DENSITY = 29.34 $LB./FT.^3$
- MATURE WOOD, FORMED DURING YEARS 1951-1960; VOLUME = 16.66 $IN.^3$ OR 36.73% OF DISK VOLUME; DENSITY = 29.84 $LB./FT.^3$

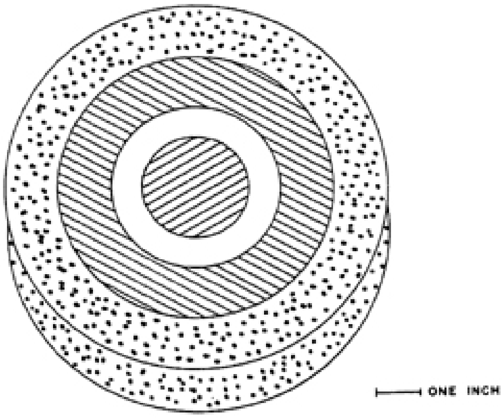
Figure 11—Reconstructed disk, one inch thick, of shortleaf pine wood 40-years old at breast height. Composite volume (green) and density (green volume, oven-dry weight) data shown are based on analyses of 21 trees in the 1½″ diameter growth class for the period 1951-60.



LEGEND

- JUVENILE WOOD, FORMED DURING YEARS 1921-1928; VOLUME = 3.97 $IN.^3$ OR 8.67% OF DISK VOLUME; DENSITY = 24.78 $LB./FT.^3$
- MATURE WOOD, FORMED DURING YEARS 1929-1935; VOLUME = 5.32 $IN.^3$ OR 11.62% OF DISK VOLUME; DENSITY = 27.47 $LB./FT.^3$
- MATURE WOOD, FORMED DURING YEARS 1936-1950; VOLUME = 16.44 $IN.^3$ OR 35.89% OF DISK VOLUME; DENSITY = 28.65 $LB./FT.^3$
- MATURE WOOD, FORMED DURING YEARS 1951-1960; VOLUME = 20.07 $IN.^3$ OR 43.82% OF DISK VOLUME; DENSITY = 30.09 $LB./FT.^3$

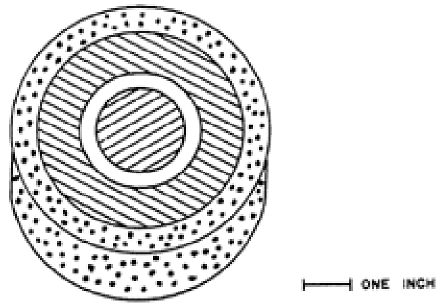
Figure 12—Reconstructed disk, one inch thick, of shortleaf pine wood 40-years old at breast height. Composite volume (green) and density (green volume, oven-dry weight) data shown are based on analyses of 20 trees in the 2″ diameter growth class for the period 1951-1960.



LEGEND

- JUVENILE WOOD, FORMED DURING YEARS 1921-1928; VOLUME = 4.36 $IN.^3$ OR 7.40% OF DISK VOLUME; DENSITY = 24.50 $LB./FT.^3$
- MATURE WOOD, FORMED DURING YEARS 1929-1935; VOLUME = 6.35 $IN.^3$ OR 10.77% OF DISK VOLUME; DENSITY = 27.94 $LB./FT.^3$
- MATURE WOOD, FORMED DURING YEARS 1936-1950; VOLUME = 19.39 $IN.^3$ OR 32.90% OF DISK VOLUME; DENSITY = 29.65 $LB./FT.^3$
- MATURE WOOD, FORMED DURING YEARS 1951-1960; VOLUME = 28.83 $IN.^3$ OR 48.93% OF DISK VOLUME; DENSITY = 29.78 $LB./FT.^3$

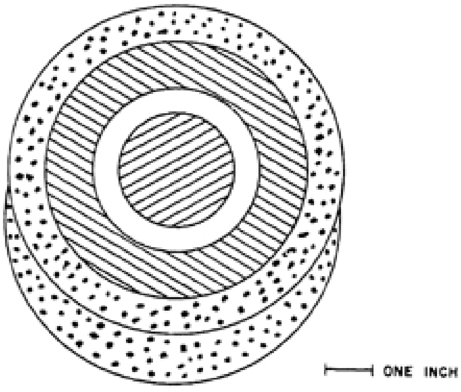
Figure 13—Reconstructed disk, one inch thick, of shortleaf pine wood 40-years old at breast height. Composite volume (green) and density (green volume, oven-dry weight) data shown are based on analyses of 10 trees in the 2½″ diameter growth class for the period 1951-1960.



LEGEND

- JUVENILE WOOD, FORMED DURING YEARS 1921-1928; VOLUME = 2.27 $IN.^3$ OR 9.25% OF DISK VOLUME; DENSITY = 26.39 $LB./FT.^3$
- MATURE WOOD, FORMED DURING YEARS 1929-1935; VOLUME = 2.87 $IN.^3$ OR 11.70% OF DISK VOLUME; DENSITY = 28.08 $LB./FT.^3$
- MATURE WOOD, FORMED DURING YEARS 1936-1950; VOLUME = 9.24 $IN.^3$ OR 37.67% OF DISK VOLUME; DENSITY = 29.14 $LB./FT.^3$
- MATURE WOOD, FORMED DURING YEARS 1951-1960; VOLUME = 10.15 $IN.^3$ OR 41.38% OF DISK VOLUME; DENSITY = 30.26 $LB./FT.^3$

Figure 14—Reconstructed disk, one inch thick, of shortleaf pine wood 40-years old at breast height. Composite volume (green) and density (green volume, oven-dry weight) data shown are based on analyses of 25 trees in the 5″ dbh class in 1952.



LEGEND

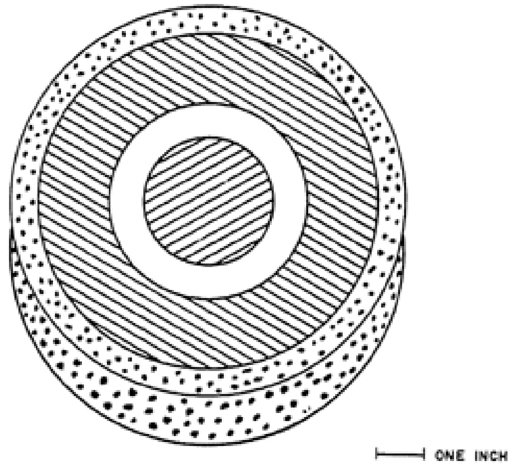
JUVENILE WOOD, FORMED DURING YEARS 1921–1928; VOLUME = 3.87 IN.^{3}, OR 9.72% OF DISK VOLUME; DENSITY = 24.68 LB./FT.^{3}

MATURE WOOD, FORMED DURING YEARS 1929–1935; VOLUME = 5.42 IN.^{3}, OR 13.61% OF DISK VOLUME; DENSITY = 27.58 LB./FT.^{3}

MATURE WOOD, FORMED DURING YEARS 1936–1950; VOLUME = 15.25 IN.^{3}, OR 38.31% OF DISK VOLUME; DENSITY = 29.33 LB./FT.^{3}

MATURE WOOD, FORMED DURING YEARS 1951–1960; VOLUME = 15.27 IN.^{3}, OR 38.36% OF DISK VOLUME; DENSITY = 29.70 LB./FT.^{3}

Figure 15—Reconstructed disk, one inch thick, of shortleaf pine wood 40-years old at breast height. Composite volume (green) and density (green volume, oven-dry weight) data shown are based on analyses of 29 trees in the 7″ dbh class in 1952.



LEGEND

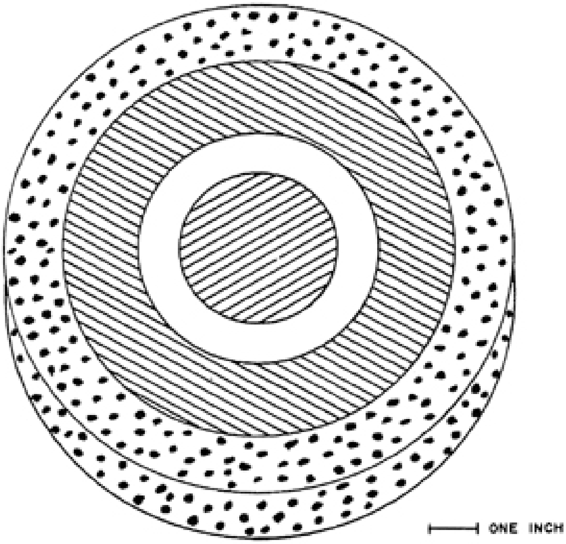
JUVENILE WOOD, FORMED DURING YEARS 1921–1928; VOLUME = 5.85 IN.^{3}, OR 10.58% OF DISK VOLUME; DENSITY = 24.33 LB./FT.^{3}

MATURE WOOD, FORMED DURING YEARS 1929–1935; VOLUME = 8.27 IN.^{3}, OR 14.95% OF DISK VOLUME; DENSITY = 27.64 LB./FT.^{3}

MATURE WOOD, FORMED DURING YEARS 1936–1950; VOLUME = 23.49 IN.^{3}, OR 42.47% OF DISK VOLUME; DENSITY = 29.33 LB./FT.^{3}

MATURE WOOD, FORMED DURING YEARS 1951–1960; VOLUME = 17.70 IN.^{3}, OR 32.00% OF DISK VOLUME; DENSITY = 29.95 LB./FT.^{3}

Figure 16—Reconstructed disk, one inch thick, of shortleaf pine wood 40-years old at breast height. Composite volume (green) and density (green volume, oven-dry weight) data shown are based on analyses of 27 trees in the 9″ dbh class in 1952.



LEGEND

JUVENILE WOOD, FORMED DURING YEARS 1921–1928; VOLUME = 8.71 IN.^{3}, OR 9.61% OF DISK VOLUME; DENSITY = 24.40 LB./FT.^{3}

MATURE WOOD, FORMED DURING YEARS 1929–1935; VOLUME = 12.45 IN.^{3}, OR 13.74% OF DISK VOLUME; DENSITY = 26.89 LB./FT.^{3}

MATURE WOOD, FORMED DURING YEARS 1936–1950; VOLUME = 31.39 IN.^{3}, OR 34.65% OF DISK VOLUME; DENSITY = 28.70 LB./FT.^{3}

MATURE WOOD, FORMED DURING YEARS 1951–1960; VOLUME = 38.04 IN.^{3}, OR 42.00% OF DISK VOLUME; DENSITY = 28.70 LB./FT.^{3}

Figure 17—Reconstructed disk, one inch thick, of shortleaf pine wood 40-years old at breast height. Composite volume (green) and density (green volume, oven-dry weight) data shown are based on analyses of 9 trees in the 11″ DBH class in 1952.

Cumulative disk density increased with age regardless of classification system.

2. We are concerned not only with the relative weights of the wood but also the *quantity* of wood produced.

Five-inch trees (1950) laid down wood, from 1951 to 1960, averaging 30.26 pounds per cubic foot as opposed to 11-inch trees (1950) putting on wood estimated at 28.70 pounds per cubic foot for this same ten-year period. However, the 5-inch trees laid down *only* 10.15 cubic inches of wood over this period while the 11-inch trees put on 38.04 cubic inches of wood, which is more then 1½ times the total volume (24.53) cubic inches) of the 5-inch trees for the entire 40-year period.

Specific gravity and growth rate expressed as mm. per ring, data are given in Table 12. Data for opposite ("North and "South") sides are combined within an indicated age period. Data are presented for the five dbh growth-classes as well as for all 90 trees. Correlation, as expressed by the correlation coefficient (r), between specific gravity and growth rate is poor ranging from +.043 to -.476. A trend of going from a negative to a positive relationship between specific gravity and growth rate with increasing age is shown in comparing data within each dbh class, except the 2½ class where only 10 trees were available, and for all 90 trees regardless of classification. Explanation of this condition is deferred to a subsequent portion of this discussion.

TABLE 10 - SUMMARY OF VOLUME (CUBIC INCHES) AND DENSITY (POUNDS/CUBIC FOOT) ESTIMATES PRESENTED BY DBH GROWTH CLASSES IN FIGURES 9-13, AND BY TREE SIZE (1952) CLASSES IN FIGURES 14-17, FOR RECONSTRUCTED ONE-INCH DISKS, AT DBH, OF SHORTLEAF PINE

Figure Number	Number of Trees	Classification	Statistic	Age Period 1921-28	1929-35	1936-50	1951-60
9	19	0.5" dbh Growth ('51-'60)	Volume Density	4.11 24.31	6.08 27.44	14.93 28.53	7.35 29.43
10	20	1.0" dbh Growth ('51-'60)	Volume Density	4.37 25.00	6.14 28.12	16.40 30.02	10.19 30.00
11	21	1.5" dbh Growth ('51-'60)	Volume Density	4.49 24.63	5.90 27.53	18.31 29.34	16.66 29.84
12	20	2.0" dbh Growth ('51-'60)	Volume Density	3.97 24.78	5.32 27.47	16.44 28.65	20.07 30.09
13	10	2.5" dbh Growth ('51-'60)	Volume Density	4.36 24.50	6.35 27.94	19.39 29.65	28.83 29.78
14	25	5" dbh 1950	Volume Density	2.27 26.39	2.87 28.08	9.24 29.14	10.15 30.26
15	29	7" dbh 1950	Volume Density	3.87 24.60	5.42 27.58	15.25 29.33	15.27 29.70
16	27	9" dbh 1950	Volume Density	5.85 24.33	8.27 27.64	23.49 29.33	17.70 29.95
17	9	11" dbh 1950	Volume Density	8.71 24.40	12.45 26.89	31.39 28.70	38.04 28.70

TABLE 11 - CUMULATIVE VOLUME (CUBIC INCHES) AND DENSITY (POUNDS/ CUBIC FOOT) ESTIMATES PRESENTED BY DBH GROWTH CLASSES, AND BY TREE SIZE (1952) CLASSES, FOR RECONSTRUCTED ONE-INCH DISKS, AT DBH, OF SHORTLEAF PINE AT AGES 8, 15, 30 AND 40 YEARS.

Classification	Statistic	Increasing Age of Tree 8 years	15 years	30 years	40 years
0.5" dbh	Volume	4.11	10.19	25.12	32.47
Growth ('51-'60)	Density	24.31	26.17	27.57	27.98
1.0" dbh	Volume	4.37	10.51	26.91	37.10
Growth ('51-'60)	Density	25.00	26.82	28.76	29.10
1.5" dbh	Volume	4.49	10.39	28.70	45.36
Growth ('51-'60)	Density	24.63	26.27	28.33	28.88
2.0" dbh	Volume	3.97	9.29	25.73	45.80
Growth ('51-'60)	Density	24.78	26.32	27.80	28.80
2.5" dbh	Volume	4.36	10.72	30.11	58.94
Growth ('51-'60)	Density	24.50	26.51	28.53	29.14
5" dbh	Volume	2.27	5.14	14.38	24.53
1950	Density	26.39	27.33	28.49	29.22
7" dbh	Volume	3.87	9.29	24.54	39.81
1950	Density	24.60	26.34	28.20	29.47
9" dbh	Volume	5.85	14.12	37.61	55.31
1950	Density	24.33	26.26	28.18	28.74
11" dbh	Volume	8.71	21.16	52.55	90.59
1950	Density	24.40	25.86	27.55	28.03

Briefly, from data presented in Figures 5 to 17 and Tables 8 to 12, the following statements may be made:

1. The specific gravity for the mature wood (1929-1960) of 40-year old shortleaf pines was found to be .465. Translated into density on an alcohol-benzene extractive-free basis this may be expressed as 29.45 pounds per cubic foot.

2. Correlation between specific gravity of the entire mature wood zone (the years 1929 to 1960) with that of the juvenile wood (first eight years' growth) is rather low, as expressed by a correlation coefficient (r) of +.453. It may be added that the correlation between specific gravity of the juvenile wood zone with that of the mature wood zones from 1929-1935, 1936-1950, and 1951-1960, consistently decreases as expressed by (r's) of +.525, +.356, and +.283 respectively.

3. Based on a range in specific gravity data from .472 to .482, or only .010 units, there is no reason to suspect a significant difference in wood quality of the five dbh growth classes as far as employing the use of specific gravity as an

TABLE 12 - ESTIMATES OF SPECIFIC GRAVITY AND GROWTH RATE (MM/RING) FOR 90 40-YEAR OLD SHORTLEAF PINES BY AGE PERIODS, WITH CORRELATION COEFFICIENT (r) BETWEEN SPECIFIC GRAVITY AND GROWTH RATE

dbh Growth Class (51-60)	Number of Trees	Statistic	Age Periods 1921-28	1929-35	1936-50	1951-60
		Specific Gravity	.390	.440	.457	.472
0.5"	19	Growth Rate	3.74	2.39	1.74	.98
		Correlation (r)	-.476	-.227	+.197	+.062
		Specific Gravity	.401	.451	.481	.481
1.0"	20	Growth Rate	3.75	2.37	1.87	1.30
		Correlation (r)	-.132	-.163	+.081	+.095
		Specific Gravity	.395	.441	.470	.478
1.5"	21	Growth Rate	3.80	2.27	2.05	1.98
		Correlation (r)	-.170	-.250	-.151	+.175
		Specific Gravity	.397	.440	.459	.482
2.0"	20	Growth Rate	3.58	2.17	1.94	2.47
		Correlation (r)	-.365	-.205	+.066	+.147
		Specific Gravity	.393	.448	.475	.477
2.5"	10	Growth Rate	3.74	2.43	2.12	3.14
		Correlation (r)	+.148	+.043	+.221	-.122
	all	Specific Gravity	.395	.443	.468	.478
---	90	Growth Rate	3.71	2.31	1.92	1.85
	trees	Correlation (r)	-.212	-.152	+.068	+.070

index of wood strength or of wood pulp yield.

4. Correlations within any particular age period between growth rate and specific gravity may be considered non-significant for mature wood zones. A trend is noted indicating that the correlation between specific gravity and growth rate is strongest in the juvenile wood zone and that this correlation changes from a negative to a weakly positive relationship with increasing age of the tree.

5. By use of growth rate data for the purpose of reconstructing a disk of wood sampled at breast height, it is rather strikingly pointed out how the volume of wood laid down during the last 10 years of growth (¼ the total tree age) comprises from 22 to 48 percent of the disk volume for the dbh growth classes of ½ to 2½ inches. The amount of wood formed by the 2½ inch dbh class is some 3.8 times that formed by trees in the ½-inch growth class, and is for many practical purposes of equivalent specific gravity.

Specific gravity, ring width, percent summerwood, and chemical analyses of 19 selected trees—Mean data for specific gravity, ring width and percent summerwood, with associated correlation coefficients are presented in Table 13. The average annual ring width and summerwood width by calendar year from 1922 to 1959 for all 19 trees studied in this phase of the investigation are shown in Figure 18. The correlation coefficients for ***between trees*** for ring width and summerwood width by calendar year and by particular age periods are shown in

TABLE 13 - ESTIMATES OF SPECIFIC GRAVITY, PERCENT SUMMERWOOD, AND GROWTH RATE (MM/RING) FOR 19 SHORTLEAF PINE TREES, ONE FROM EACH SAMPLE UNIT, AS SHOWN IN FIGURE 3.

dbh Growth class (1951-1960) number of trees	Statistic mean data and correlations ("r")	Age Period*			
		1921-28	1929-35	1936-50	1951-60
0.5" - 3	1. Specific Gravity	.402	.445	.458	.486
	2. Percent Summerwood	13.46	32.06	36.36	41.19
	3. Growth Rate	3.44	2.15	1.71	0.93
1.0" - 4	1. Specific Gravity	.376	.439	.464	.456
	2. Percent Summerwood	18.57	36.83	37.20	37.12
	3. Growth Rate	4.22	2.09	2.00	1.23
1.5" - 4	1. Specific Gravity	.396	.438	.467	.471
	2. Percent Summerwood	16.58	34.58	37.73	40.97
	3. Growth Rate	4.21	2.39	2.03	1.89
2.0" - 4	1. Specific Gravity	.397	.431	.459	.492
	2. Percent Summerwood	20.90	38.88	40.74	46.41
	3. Growth Rate	3.72	2.86	2.37	2.58
2.5" - 4	1. Specific Gravity	.370	.428	.457	.466
	2. Percent Summerwood	17.02	36.90	39.58	44.16
	3. Growth Rate	4.30	2.47	2.11	3.23
all - 19	1. Specific Gravity	.387	.436	.461	.474
	2. Percent Summerwood	17.57	36.06	37.88	42.00
	3. Growth Rate	4.00	2.40	2.06	2.03
	4. "r" 1 x 2	+.348	+.458	+.545	+.752
	5. "r" 1 x 3	-.312	-.122	-.049	+.028
	6. "r" 2 x 3	-.260	+.004	+.075	+.351

*Opposite ("North" and "South") sides combined.

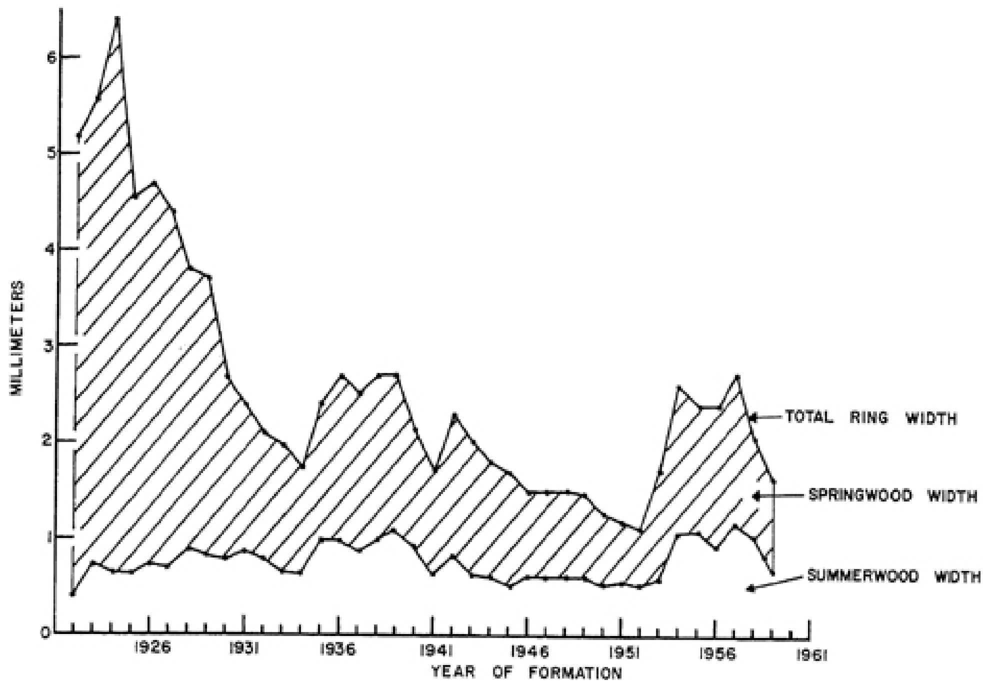


Figure 18—Average ring width and summerwood width, in millimeters, by calendar year for 19 shortleaf pine trees. Two estimates (opposite sides of the tree) were made for each year for each tree. Samples taken at breast height where the average tree age was 40 years in 1960.

Figure 19. Alcohol-benzene extractable data for opposite sides of the 19 trees are given in Figure 20; the differences between "North" and "South" sides of the trees for these data are accentuated in Figure 21. Water resistant carbohydrate data, corrected for residual lignin content and based on extractive free wood, for the trees are similarly shown in Figures 22 and 23. Mean data for alcohol-benzene extractable material water resistant carbohydrate content, and lignin content for the five dbh growth classes are summarized for all 19 trees in Table 14. Review of data shown in Figures 18 to 23 and Tables 13 and 14 permits the following summary statements:

1. There is a positive correlation between percent summerwood and specific gravity for all age periods from the juvenile wood through mature wood. This correlation becomes progressively stronger as the tree ages over the 40-year period as shown in Table 13.

2. Correlation between growth rate and specific gravity data for these 19 trees follow the trend previously noted for all 90 trees in that these parameters are negatively correlated in the juvenile wood and become weakly positively correlated in the age period 1951-1960.

3. Growth rate and percent summerwood show a correlation trend similar to that of growth rate and specific gravity; however, the relationship becomes positive much earlier in the 40-year period. This condition may be explained in

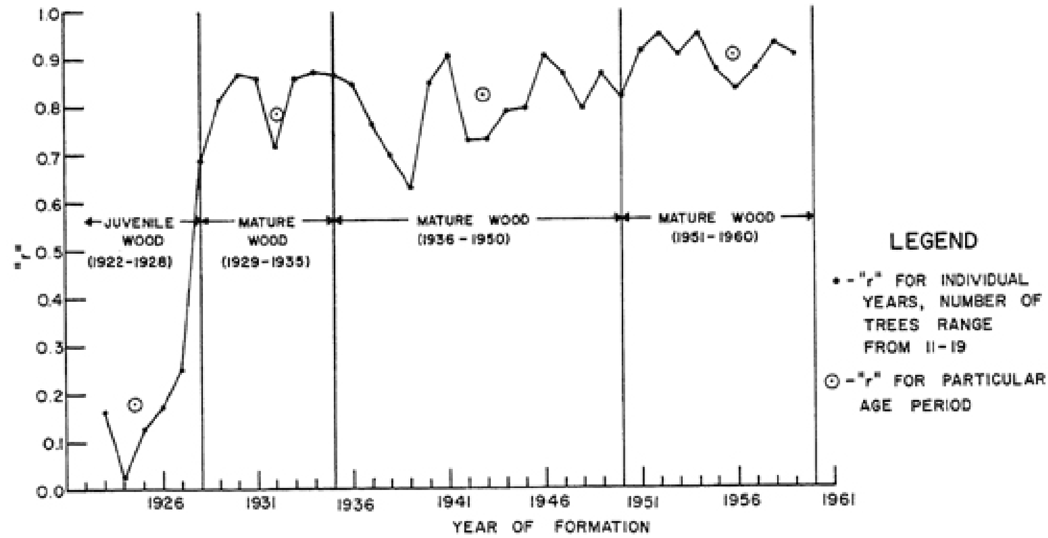


Figure 19—Correlation coefficients ("r") between trees for ring width and summerwood width data plotted against calendar year for 19 shortleaf pine trees. Two estimates (opposite sides of the tree) were made for each year for each tree. Samples taken at breast height where the average tree age was 40 years in 1960.

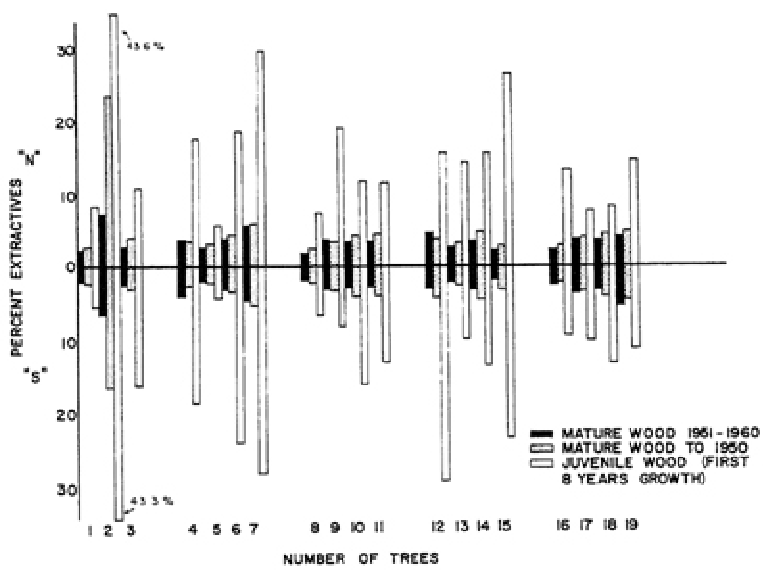


Figure 20—Alcohol-benzene extractable content estimates between 19 randomly sampled trees for the five dbh growth classes; ½″, 1″, 1½″, 2″, and 2½″ (reading from left to right) for the age period from 1951-1960. Data presented for opposite ("N" and "S") side of the trees. Within each dbh growth class, data are shown first for the 5″, then the 7″, 9″, and 11″ tree (1952 dbh classification). There was no 11″ tree in the ½″ dbh growth class.

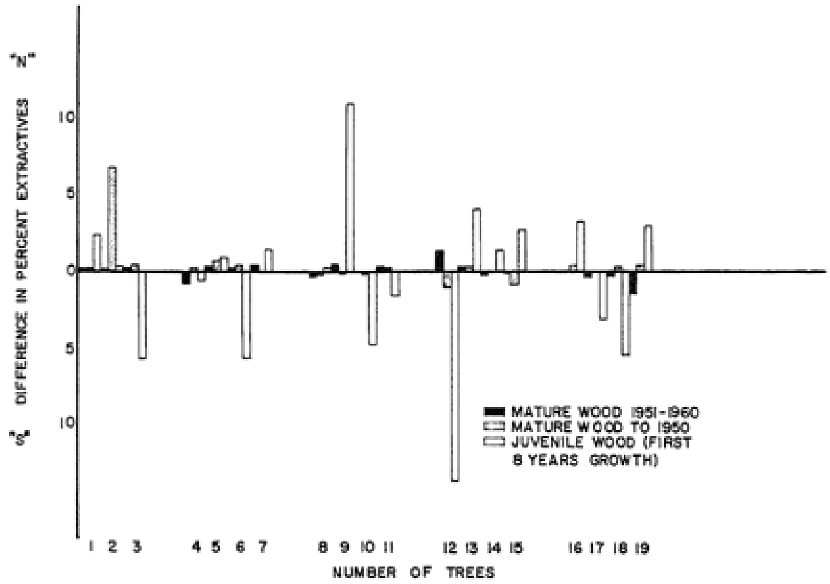


Figure 21—Differences in alcohol-benzene extractable content between opposite sides of the trees for the array of data presented in Figure 20. The terms "North" and "South" do not infer true north and south orientation.

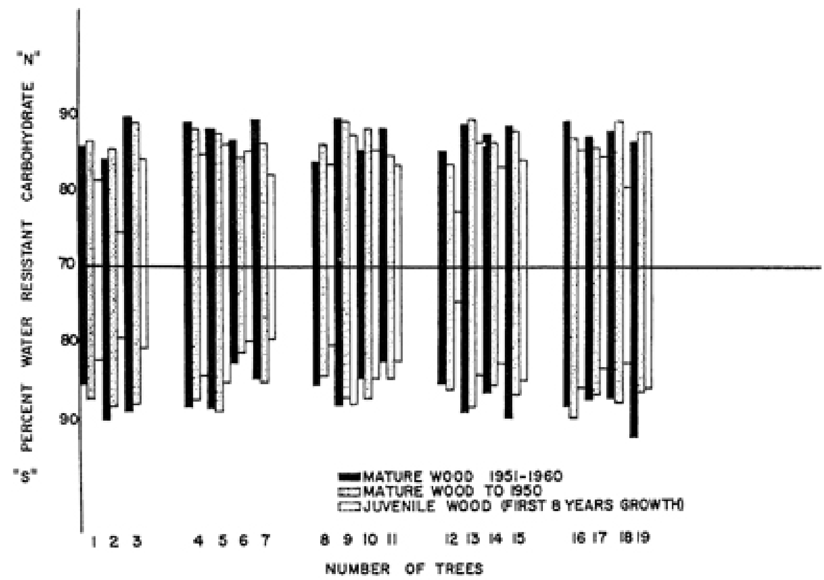


Figure 22—Water resistant carbohydrate content estimates between 19 randomly sampled trees for the five dbh growth classes; ½", 1", 1½", 2" and 2½" (reading from left to right) for the age period from 1951-1960. Data presented for opposite ("N" and "S") sides of the trees. Within each dbh growth class, data are shown first for the 5", then the 7", 9" and finally the 11" tree (1952 dbh classification). There was no 11" tree in the ½" dbh growth class. All data uncorrected for residual sulfuric acid lignin content

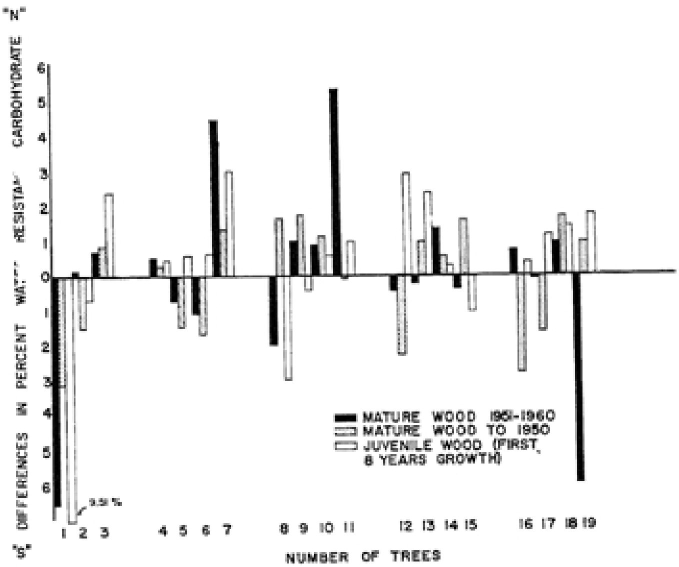


Figure 23—Differences in water resistant carbohydrate content between opposite sides of the trees for the array of data presented in Figure 22. The terms "N" and "S" do not infer true north and south orientation.

part, by reference to Figure 18. Here it is shown that, in general, the actual summerwood width in successive annual increments remains fairly constant. However, in the juvenile wood zone there is a trend toward slightly increasing summerwood width with age from 1922 to 1928 while the total ring width decreases markedly; whereas, in the mature wood zone, particularly from 1952 on, an increase in total ring width is accompanied by a similar response in total summerwood width. This situation allows an explanation, in part, for the trend in correlation between ring width (or growth rate) and specific gravity in going from a negative to a slightly positive relationship. In the juvenile wood zone, rapid increases in ring width are accompanied by slightly decreased summerwood width hence a decrease in specific gravity. However, in the mature wood, noteably that formed during the last 10 years, an increase in ring width is accompanied by a similar increase in summerwood width, hence a slight increase in specific gravity. The specific gravity of the summerwood zone was found to be .746 while that of the springwood counterpart was found to be .309 for isolated sections of this last 10-year period in the one tree so dissected and analyzed (see Figure 25). This difference in specific gravity, a factor of 2+, illustrates dependence of specific gravity upon summerwood content. The difference between springwood and summerwood specific gravity is not as great in the juvenile wood zone. Values for isolated sections were found to be .380 and .668 respectively for the same tree studied above. This condition explains, in part, the increasing dependence of specific gravity upon summerwood content as the tree

TABLE 14 - ESTIMATES OF ALCOHOL-BENZENE EXTRACTABLES CONTENT, "WATER RESISTANT CARBOHYDRATES"* CONTENT AND LIGNIN CONTENT FOR 19 SHORTLEAF PINE TREES, ONE FROM EACH SAMPLE UNIT, AS SHOWN IN FIGURE 3.

dbh Growth Class (1951-1960) and Number of Trees	Statistic (Mean Data all Values in Percent)	Age Period**		
		1921-1928	1929-1950	1951-1960
0.5" - 3	Alcohol-Benzene Ext.	21.34	7.75	4.08
	"Water Resistant Carbohydrate"*	68.45	74.40	74.39
1.0" - 4	Alcohol-Benzene Ext.	18.43	3.82	3.72
	"Water Resistant Carbohydrate"*	71.03	73.75	74.69
1.5" - 4	Alcohol-Benzene Ext.	11.84	3.63	2.86
	"Water Resistant Carbohydrate"*	71.54	73.97	73.05
2.0" - 4	Alcohol-Benzene Ext.	15.06	2.50	2.10
	"Water Resistant Carbohydrate"*	68.44	72.31	72.89
2.5" - 4	Alcohol-Benzene Ext.	11.00	3.79	3.55
	"Water Resistant Carbohydrate"*	61.76	74.68	75.21
all - 19	Alcohol-Benzene Ext.	15.23	4.27	3.22
	"Water Resistant Carbohydrate"*	70.24	73.82	74.04
	Lignin***	30.64	27.93	27.49

* Corrected for residual sulfuric acid lignin
**See footnote, Table XIII
***Not determined for individual dbh growth classes, only for combined age periods as shown.

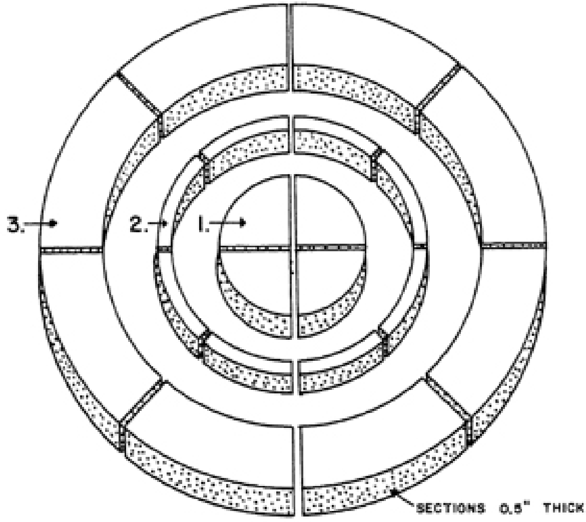


Figure 24—Disk breakdown for study of within tree variation, at breast height, for specific gravity, percent summerwood, and growth rate. Four successive ½ inch thick disks were broken down as the one indicated above.

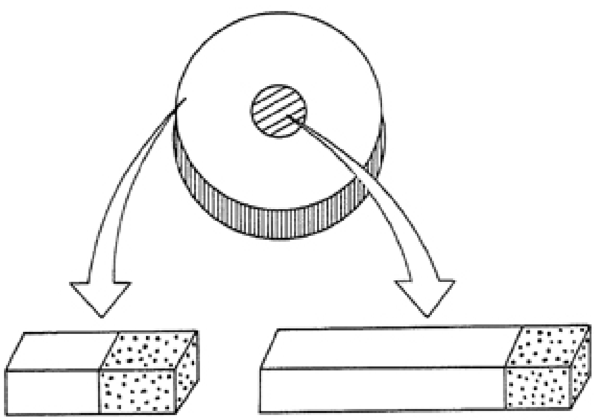


Figure 25—Mean springwood and summerwood widths, with associated mean specific gravities for these zones of annual growth, for the mature wood portion (1951-1960) and the juvenile wood portion (first eight years of growth) of one shortleaf pine sampled at breast height.

ages. In other words, the specific gravity gradient between springwood and summerwood zones of annual increments becomes greater as the tree grows older; the springwood zone becoming lighter and the summerwood zone, not only occupying an increase in proportion of the annual ring, but also becoming heavier.

4. Figure 19 shows an increasingly stronger correlation for summerwood width and ring width ***between*** trees with age. Although no complete explanation is possible for this condition at present, it may be suggested that, for a given tree, the annual ring components of springwood and summerwood, at breast height, become less dependent on the influence of individual crown-root system characteristics and more dependent on general environmental site influences—such as available rainfall for example—as the tree ages.

5. Data for chemical analyses, for opposite sides of the tree, by age periods shown in Figures 20 to 23 illustrate the magnitude of within tree variations as well as indicating no significant differences between dbh growth classes. Differences observed between opposite sides of the tree for these data, shown best in Figures 21 to 23, are several times the reproducibility of the methods established on that sample and hence may be considered significant.

6. From Table 14, it is obvious that the juvenile wood zone (1921-1928) contains more extractives, more lignin, and less water resistant carbohydrate material than the mature wood zone of the xylem at breast height. It may further be noted that with increasing age the extractive content decreases, the lignin content decreases, and the water resistant carbohydrate content increases. Differences between the juvenile wood zone and the complete 32-year mature wood zone are significant for all chemical parameters.

Within tree variation—Estimation of specific gravity, growth rate, and percent summerwood differences within one sample disk was undertaken as is shown in Figure 18. Only one ½ inch a disk is shown in the Figure. Four such disks were prepared from successive ½-inch slices of the original disk. This condition allowed parameters to be determined in quadruplicate. Results are presented in Table 15. The first value for specific gravity in the Table, .403, is the estimate made on the sample of the juvenile wood zone designated by the number 1. The following three values .419, .426, and .420 are estimates of specific gravity of the three remaining segments of the core wood zone proceeding clockwise from the number 1. This same sequence is followed for the 8 portions of the annual increment formed in 1931 starting with piece number 2, and for the 8 portions for the outer 10 years of growth from 1951 to 1960 starting with the number 3. The tree selected for this analysis was in the 11-inch, 1½ dbh growth class. It should be mentioned that one portion of the annual increment for 1931 might possibly contain compression wood. Specific gravity and percent summerwood data are included, however, because no visible defect was observed in the tree prior to sample collection, nor was the presence of compression wood macroscopically visible. Microscopic examination did not confirm pronounced compression wood formation in this zone although some compression wood was evident.

TABLE 15 – ESTIMATES OF SPECIFIC GRAVITY PERCENT SUMMERWOOD AND GROWTH RATE (MM/RING) FOR ONE SHORTLEAF PINE, IN THE 11-INCH - 1½ INCH DBH GROWTH CLASS, SHOWING MAGNITUDE OF WITHIN VARIATION AT DBH. SAMPLE BREAK DOWN IN FIGURE 24.

Growth Zone (Figure 24)	Statistic	Mean Value* (clockwise from number shown in Figure 24)				Range (clockwise)
1. (juvenile wood)	Specific Gravity	.403	.419	.426	.420	.023
	Percent Summerwood	14.7	16.3	14.9	16.7	2.0
	Growth Rate	4.17	4.38	4.78	4.82	.65
2. (1 year's growth) 1931	Specific Gravity	.432 .427	.444 .442	.440 .445	.495** .435	.068 (.018)
	Percent Summerwood	35.2 30.1	35.1 37.6	35.4 30.7	45.3** 32.3	15.2 (6.5)
	Growth Rate	4.43 4.68	4.98 4.60	4.91 6.08	7.97 5.06	3.54
3. (mature wood 1951-1960)	Specific Gravity	.417 .437	.438 .437	.426 .443	.414 .417	.026
	Percent Summerwood	35.2 39.8	39.7 39.5	37.2 42.6	36.8 36.6	7.4
	Growth Rate	2.42 2.21	2.39 2.44	2.71 2.53	2.54 2.24	.50
Range (radial from juvenile wood)	Specific Gravity	.034	.025	.019	.081(.021)	
	Percent Summerwood	25.1	33.4	27.7	28.6 (20.1)	
	Growth Rate	2.47	2.54	3.54	5.37	

* Each value represents mean of 4 estimates made on successive 0.5" disks; average deviation between these estimates for: Specific Gravity = 0.004, Percent Summerwood = 1.50, and Growth Rate = 0.09.
**Possible compression wood zone, values shown in parentheses for clockwise and radial ranges delete estimates of specific gravity and percent summerwood.

From Table 15, it is apparent that variation (clockwise, or tangential) in specific gravity within any age class is of the same magnitude as in proceeding radially from the juvenile wood zone to the mature zone laid down in the same quarter of the disk. Comparative tangential or clockwise within age zone variation is .023, .018, and .026. Variation proceeding radially from juvenile to mature wood is .034, .025, .019, and .021.

Another tree, in the 11-inch 2½-inch dbh growth class was used for determination of specific gravity, of isolated springwood and summerwood zones, growth rate, fiber dimensions, and fibril angle. This tree was the youngest in the study, 36 years old, and the only sample obtainable in the 11-inch—2½-inch dbh growth class. Estimates of springwood and summerwood specific gravities for juvenile and mature wood zones are presented in Figure 25. Fiber width, fiber wall thickness and fibril angle data for tracheids in the springwood, transition wood, and summerwood zones of the annual ring are given for the juvenile wood section, the mature wood from 1933 to 1950, and the mature wood from 1951 to 1960 as shown in Figure 26. Fiber length data are presented in Figure 27. Fiber wall

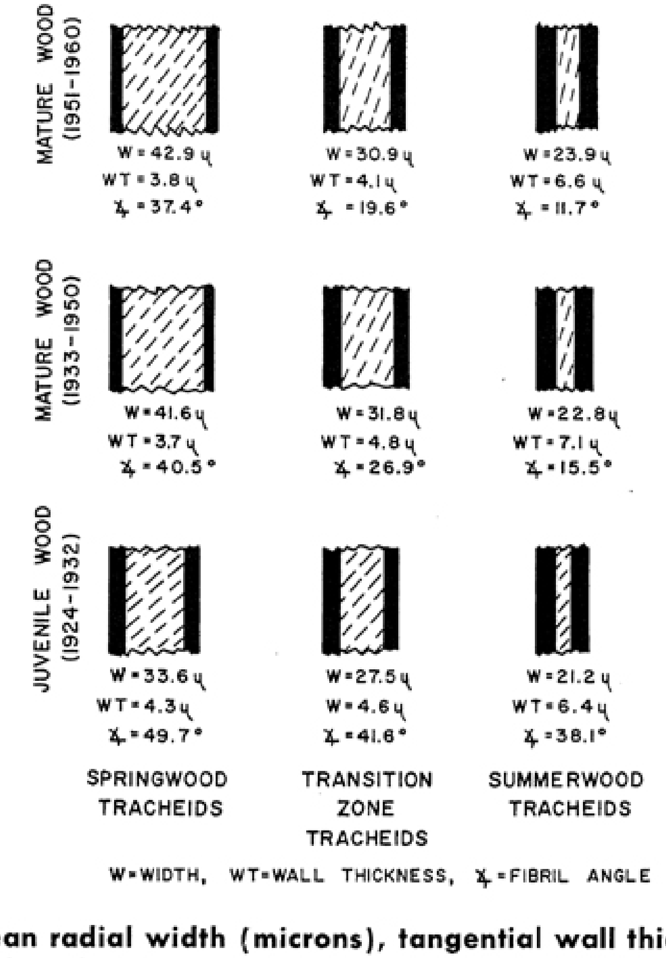


Figure 26—Mean radial width (microns), tangential wall thickness (microns), and fibril angle (degrees, as measured on the radial wall) for tracheid types and age periods indicated for one sample of shortleaf pine 36 years old at breast height.

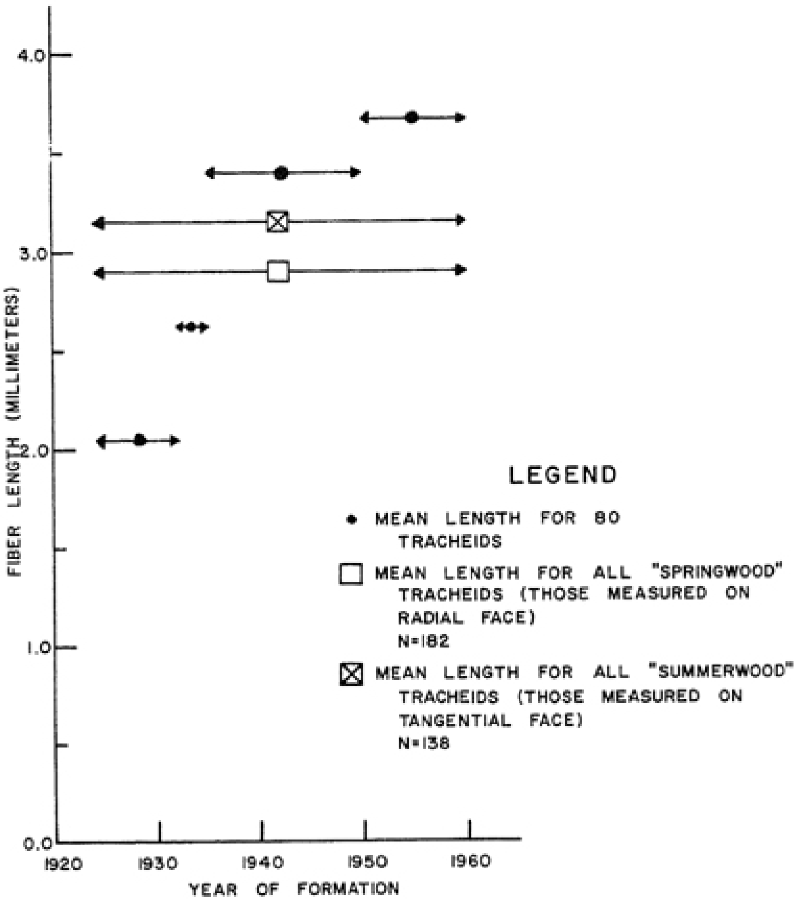


Figure 27—Mean complete longitudinal tracheid length (millimeters) for age period indicated. Values obtained on chlorite prepared holocelluloses from one sample of shortleaf pine 36 years old at breast height.

thickness versus year of formation are shown in Figure 28. Correlation between year of formation and fibril angle is shown in Figure 29, and the relationship between fibril angle and fiber wall thickness for various zones of the annual increments is given in Figure 30.

From analyses of information presented in Figure 25-30 certain conclusions are apparent as follows:

1. Differences in the specific gravity of isolated springwood zones from mature and juvenile wood zones are significant. The two estimates .309 and .380 respectively, support the idea that the springwood zone in annual increment tends to become lighter as the tree ages; the reverse relationship was found for summerwood regions of annual increments studied in the mature and juvenile wood zones. Here the two estimates are .746 and .668 respectively.

2. Fibril angle, assumed to indicate the orientation of the macro-fibril cellulose structure within the cell wall, for the juvenile wood section is much greater

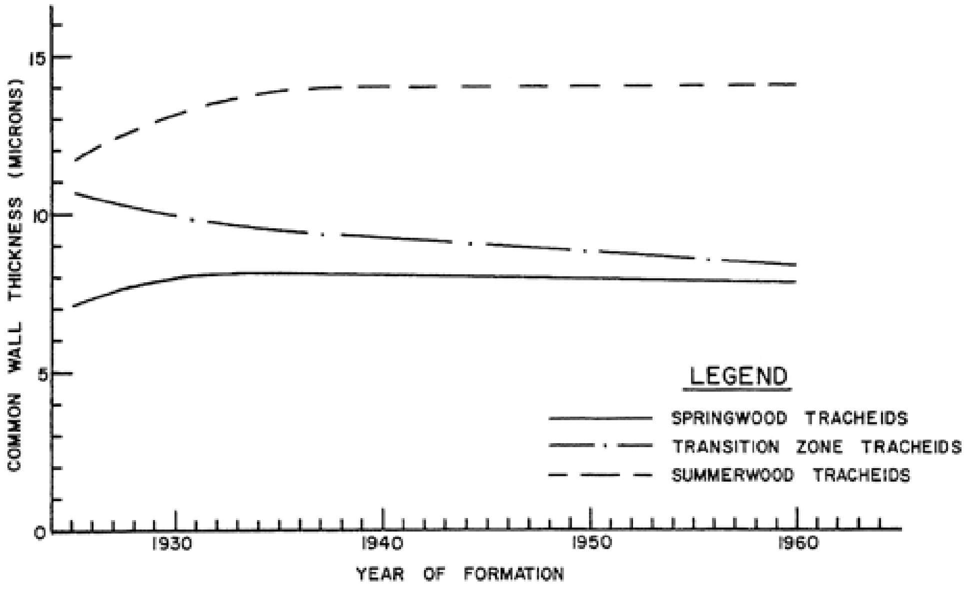


Figure 28—Common tangential wall thickness (microns) vs. year of annual ring formation, at breast height, for one 36-year old shortleaf pine. Measurements made from lumen to lumen on tangential walls of tracheids.

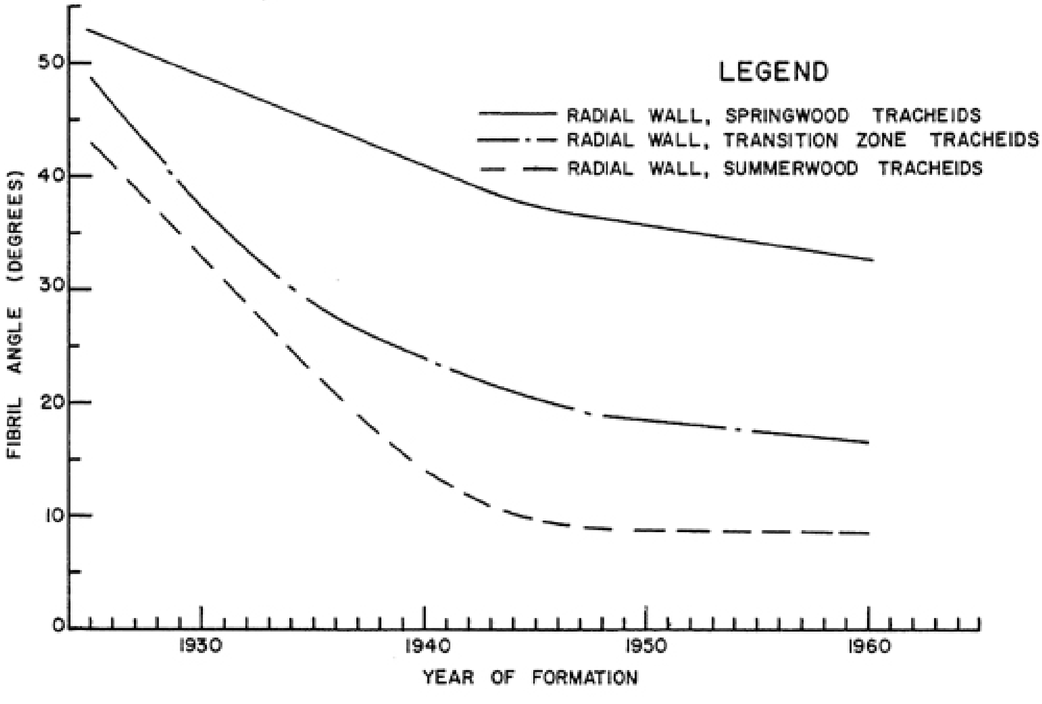


Figure 29—Fibril angle (degrees) vs. year of annual ring formation, at breast height, for one 36-year old shortleaf pine. Fibril angle measured in degrees from the longitudinal axis of tracheid.

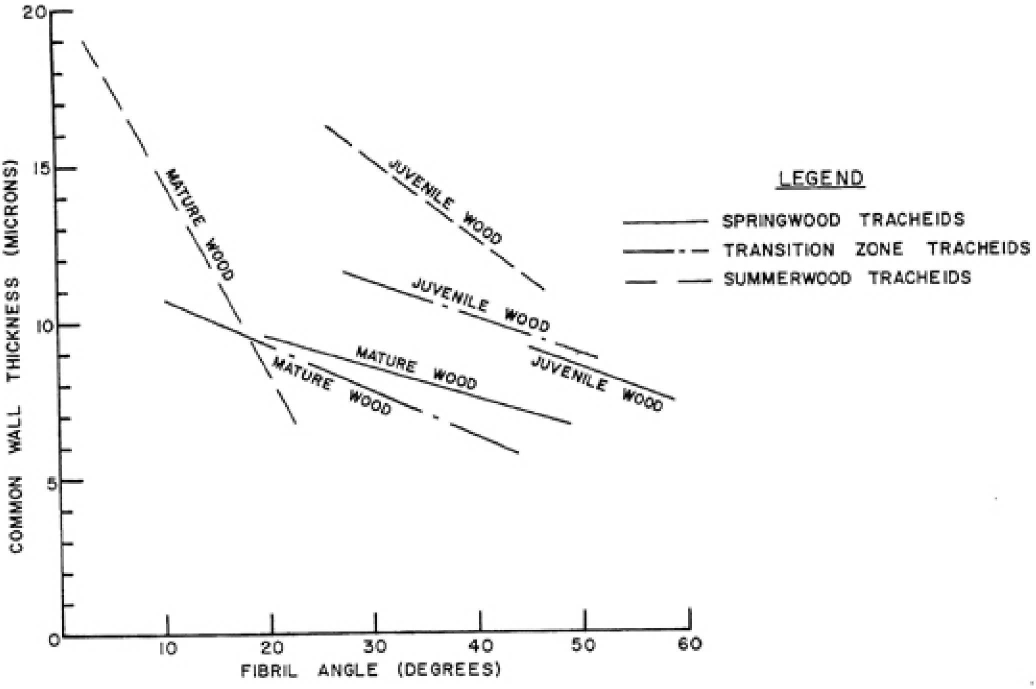


Figure 30—Common tangential wall thickness (microns) vs. fibril angle (degrees), at breast height, for one 36-year old shortleaf pine. Juvenile wood zone is the first eight years growth. All remaining wood (the last 28 years of growth) is classified as mature.

than that for comparable fiber types found in the mature wood. This is most noticeable in summerwood tracheids where the fibril angle decreases from 38.1 degrees in the juvenile wood to 11.7 degrees in the older mature wood.

3. Fiber length data, shown in Figure 27, followed the expected trend for coniferous species; i.e., indicating an increase in length with age. The difference between fiber length in the core or juvenile wood (2.04 mm) and all the mature wood (3.26 mm) is significant. Data given for average length of "springwood" fibers and "summerwood" fibers are not based on measurement of fibers from macerated springwood and summerwood zones but is rather a classification of fiber types based on naming those that are observed on their radial face of possible springwood origin, and fibers that are observed on their tangential face of possible summerwood origin *when* the macerated stock is prepared on a microscope slide for examination. This procedure is frequently used by those having to analyse fiber distributions in commercial pulp stock where it is no longer possible to confirm fibers being of springwood and summerwood origin. When one recalls the fact that the summerwood tracheids of coniferous species are roughly rectangular in cross section as viewed on transverse sections of wood, with the tangential diameter of the tracheids longer than the radial diameter, it is not surprising to note that, in macerated stock, summerwood tracheids tend to lie on their tangential face. Springwood tracheids, on the other hand,

particularly those first formed in the springwood zone, tend to have as large or larger radial diameter than tangential diameters. These tracheids have a tendency to lie on their radial face in macerated stock. It is interesting to note that the average wall thickness of the "springwood" and "summerwood" tracheids (so classified in Figure 27) was 3.5 and 7.0 microns respectively; these values are in fair agreement with measurements made on microtome sections of wood shown in Figure 26.

4. The changes in common tangential wall thickness for springwood, transition zone wood, and summerwood tracheids with increasing age of the tree are presented in Figure 28. Data are interpreted to mean that the transition between spring- and summerwood zones of annual increments becomes more abrupt with increasing age of the tree. Such was the conclusion of Vikhrov (31) in a study of European Larch. This situation may account for, at least in part, the higher specific gravity found for springwood zones in the juvenile portion of the tree as compared with the springwood zone in the outer mature wood as shown in Figure 25. It should also be noted that the wall thickness of summerwood tracheids in the juvenile wood zone (Figure 28) is less than that for summerwood tracheids in the mature wood. This situation may also contribute to differences in specific gravity of isolated springwood and summerwood zones of core and mature wood samples presented in Figure 25.

5. The relationship between fibril angle versus year of formation, for tracheids in the three zones of annual growth, shown in Figure 29, indicate a greater range between similar tracheid types (springwood, transition zone, summerwood) for the mature wood zone than the core wood zone of the sampled tree.

6. Data in Figure 30 also indicate that for a given wall thickness, the fibril angle is less for comparable tracheid types in the mature wood than in the juvenile wood. It is important to bare in mind that fibril angle has been shown to be clearly related to strength properties of wood Mitchell (13).

7. In general, data presented in this section, indicate a sharper change in fiber properties measured, and in the isolated springwood and summerwood specific gravities, in progressing through an annual increment of the mature wood as opposed to an annual increment of juvenile wood.

Composite summary of results—A comparison of various wood quality parameters for juvenile and mature wood zones, presented in the various sections of this Chapter, is given in Table 16.

As mentioned previously, under the material and methods chapter, specific gravity estimates on this study of shortleaf pine were found to be strongly influenced by presence of alcohol-benzene extractables. The alcohol-benzene content of the 40-year old shortleaf pines studied, was appreciably higher than had been anticipated. The maximum value obtained was 43 percent for the juvenile wood zone of one 7-inch tree that had grown ½ inch in diameter for the ten-year period 1951 to 1960.

TABLE 16 - COMPARISON OF VARIOUS QUALITY PARAMETERS FOR JUVENILE AND MATURE WOOD ZONES OF SHORTLEAF PINE. ALL DATA OBTAINED BY MEASUREMENTS AT DBH.

			Wood Zone			
			Mature			
Number of trees	Parameter	Juvenile (1921-1928)	1929-1935	1936-1950	1951-1960	all mature
90	Specific Gravity	.395	.443	.468	.478	.464
	Growth Rate (mm/ring)	3.71	2.31	1.92	1.85	2.04
19	Summerwood (%)	17.57	36.06	37.88	42.00	38.64
	Alcohol-Benzene Ext. (%)	15.23	4.27		3.22	3.74
	Water Resistant Carbohydrate (%)*	70.24	73.82		74.04	73.93
	Lignin (%)	30.64	27.93		27.49	27.71
1	Specific Gravity					
	Springwood	.380	-- --		.309	- --
	Summerwood	.668	-- --		.746	- --
	Fiber Dimensions					
	Width (microns)					
	Springwood	33.6	41.6		42.9	42.2
	Transition Zone	27.5	31.8		30.9	31.3
	Summerwood	21.2	22.8		23.9	23.3
	Wall thickness (microns)					
	Springwood	4.3	3.7		3.8	3.7
	Transition Zone	4.6	4.8		4.1	4.5
	Summerwood	6.4	7.1		6.6	6.9
	Length (mm)	2.04	2.64	3.40	3.69	3.26
	Fibril Angle (degrees)					
	Springwood	49.7	40.5		37.4	38.9
	Transition Zone	41.6	26.9		19.6	23.2
	Summerwood	38.1	15.5		11.7	13.6

*Corrected for residual sulfuric acid lignin content.

A concept of breaking the xylem down into mature and juvenile wood zones, as opposed to the more conventional sapwood and hardwood regions, is in order when data presented show that it is after the first 8 years of growth that the changes in the majority of parameters measured become less drastic. These two sections; i.e., core and mature wood reflect differences not only in extractable contents but also for fiber length, fibril angle, specific gravity, quality of summerwood thereof (as reflected by specific gravity determinations of isolated spring- and summerwood zones), water resistant carbohydrate content, and lignin content.

Within tree variation (both in tangential and radial planes of the wood) in some parameters investigated more extensively (specific gravity, growth rate, and percent summerwood) was found to be significant. Within tree variation (radial plane of the wood) for the chemical analyses undertaken was also found to be significant. By "significant" is meant that the difference for alcohol-benzene extractables and water-resistant carbohydrate contents within trees as illustrated in Figure 21 and 23 exceeds some 5-fold the reproducibility of the methods established for these analyses. It is interesting to note that the circumferential within-tree variation in specific gravity and percent summerwood for the one disk analyzed was as great within any one age period, as the difference between age periods going from juvenile wood to the mature wood in any given quadrant.

The magnitude of within-tree variation presented in this investigation suggests a need for more comprehensive analyses of individual stems. The work of Smith (23) which illustrates the responce of xylem sections to soil-water deficiencies, is an example of such needed research.

In Table 17, a comparison of estimates of specific gravity for shortleaf pine from various literature sources is presented. It should be noted that the first three sets of specific gravity estimates were not measured on increment cores extracted from living trees. The values range from 0.45-0.51. The 0.51 figure is indicated as being of heartwood origin and ***may*** be abnormally high due to presence of extractives. The next two sets of data are based on increment core samples, extracted at breast height, where it is noted that specific gravity estimates range from 0.450 (for trees 10 years old) to 0.561. The two average values presented are 0.509 and 0.512. As compared to the previously mentioned data, and also, to data obtained in this study, the values obtained for increment cores are high. Two possible explanations for this condition are as follows:

1. Comparison of specific gravity estimates between increment core samples and larger wood samples (½-inch cores) obtained from slash pine trees by Larson (7) indicated that the specific gravity values of the larger samples were consistently lower than those of the increment cores. Larson attributed this difference (3.90%) to compression of the wood during extraction with the conventional size increment borer.

2. The presence of extractives, concentrated mainly in the juvenile wood zone, was found to have a significant effect on specific gravity estimates, by

TABLE 17 - COMPARISON OF ESTIMATES OF SPECIFIC GRAVITY FOR SHORTLEAF PINE FROM VARIOUS LITERATURE REFERENCES

Number of Samples	Geographic Location	Location within tree	Specific Gravity (green volume-ovendry basis)	Literature Reference
36 (trees)	Arkansas Louisiana N. Carolina New Jersey Georgia	top 4' of 16' butt log	0.46	(11.)
4357	sawmills throughout species range	mill run boards	0.46-sapwood 0.51-heartwood 0.47-combined heartwood and sapwood	(11.)
1013 109	not stated	second growth old growth	0.45 0.47	(16.)
100 (trees)	central Mississippi	increment cores dbh tree ages 27-48 years	0.509	(32.)
2815 (trees) by tree age; 359-10 years 777-20 years 687-30 years 454-40 years 229-50 years 309-60+ years	Mississippi (entire state)	increment cores @ dbh	0.512-all trees 0.450 0.492 0.521 0.533 0.542 0.561	(12.)
90 (trees)	Dent County; Missouri	dbh	0.464* mature wood zone 0.395* juvenile wood zone	this study

*Alcohol-benzene extractive-free basis; for other literature values, no indication of prior extraction is presented. Juvenile wood defined as first 8-year growth.

both the standard emersion and maximum-moisture content techniques, in this study. Extractives increased specific gravity estimates, in the standard emersion procedure, presumably through contribution to an increase in the oven-dry sample weight. The combined effect of the two points mentioned above; i.e., a compressed volume, and an abnormal high oven-dry weight may be one cause for descrepency of specific gravity estimates, between values obtained for increment cores and for larger wood samples, compared in Table 17. It should be further emphasized that in increment core samples, the contribution of the juvenile wood zone to the total increment core volume and mass is quite large (60+% based on growth rate data obtained in this study). Under this situation, the influences of extractables become fairly pronounced in estimation of specific gravity for *entire* increment cores.

SUMMARY AND CONCLUSIONS

The main points of this investigation may be summarized as follows: The sampling scheme was so designed that the mature wood, for the 10 years from 1951-1961, had a range in dbh. growth from ½ to 2½ inches. This range in dbh. growth was distributed over trees that were in the five-inch, seven-inch, nine-inch, and 11-inch dbh. classes based on 1952 measurements. This scheme provided a rigorous test to ascertain the influence of rate of growth upon one main parameter of wood quality—specific gravity. Specific gravity data presented in the first section of the results for this investigation confirm current thinking in wood technology that growth rate has a negligible influence on the specific gravity of mature wood for some coniferous species as the southern yellow pines. On the other hand, data (Table 12) indicate a gradual change in the influence of growth rate upon specific gravity in progressing from the juvenile wood zone through the mature wood zone. In the juvenile wood (the first 8 years' growth), rate of growth does have a statistically "significant" influence on specific gravity. Correlation coefficients (r), for the juvenile wood zone and the subsequent first 7-year zone of mature wood of -0.212 and -0.152, are significant at the 1% and 5% levels, respectively. The range in specific gravity for the last ten-year period of mature wood, laid down from 1951 through 1960, was from 0.472 to 0.482 or 0.010 units. This range may be considered non significant for many of the practical applications to which specific gravity is used as an index of wood quality.

The status of tree-size, i.e., a member of the 5,7,9, or 11-inch dbh. growth class in 1952, appears to have no striking influence on specific gravity of wood formed during the last 10-year period (1951-1960). Data presented in Figures 9-17 indicate that the increased quantity of wood produced by larger tree sizes, as a result of different thinning operations is ceratinly an important factor to bear in mind in future management plans aimed at optimum utilization of shortleaf pine.

Perhaps one of the most important concepts to grasp as a result of this investigation, is the marked influence of age (first 40 years), not only on the specific gravity of the wood formed, but also upon all the other quality parameters investigated in somewhat less extensive detail. The chemical analyses, for example, show a significant dependence upon age. The water resistant carbohydrate content, an analysis designed to be indicative of pulp yield, increases significantly from pith to bark within all trees investigated regardless of dbh or dbh growth classification. On the other hand, the quantity of alcohol-benzene extractables, and the quantity of 72 percent sulfuric acid lignin, each significantly drops with age in progressing from the pith to the bark for all trees investigated. These three parameters of the chemical quality of wood are certainly of interest for those in the manufacture of pulp and pulp products. It should be remembered that during the cooking processes, in most of the standard chemical procedures used for pulp manufacture, the alcohol-benzene extractables and lignin content of the wood become soluable during the cooking stage and hence are lost as a part of the final pulp product. Of equal importance in the manufacture of pulp products, as well as in those uses of wood *per se* as structural members where strength is the prime prerequisite, are changes in fiber dimensions and noticeably fibril angle with increasing age from the pith which are also significant. The fibril angle decreases markedly, the fiber length increases markedly, whereas measurements of wall thickness in the radial plane remained somewhat the same. The radial width of tracheid types increased slightly in proceeding from pith to bark; the greatest increase was noticed for the first-formed springwood tracheids. There is a marked change in the composition of the annual ring in juvenile wood as compared to that of the mature wood as follows:

1. Within the annual ring of the juvenile wood the transition zone occupies a greater proportion of the annual ring than it does in a mature wood annual increment of equivalent width.

2. There is a greater difference between the specific gravity of isolated summerwood zones for mature wood when compared with similar sections from juvenile wood.

It should also be borne in mind that changes for various quality parameters, proceeding from pith to bark (represented by a *maximum* radius of only 5+ inches of wood in this study) are as great, or greater, as was encountered between trees for either the five dbh growth classes or for the four tree-size classes, sampled in this investigation. Within tree variation, illustrated for specific gravity and the various chemical analyses in this study, indicates that increment core sampling to obtain data for the general over-all picture for large numbers of trees is quite sufficient. However, this technique may not be adequate in describing within tree variation satisfactorily for investigations concerned with the isolation of superior (growth-quality) individuals. Until attention is focused upon more detailed analyses of individual stems, and crown-stem relationships, we will gain no real insight into the problem of isolation and possible effects of heredity and environment upon various parameters of wood quality in use today.

With reference to the use of the data in this investigation for the preparation of management plans for the production of shortleaf pine in Missouri, one is able to evaluate several different existing management practices. These will be briefly discussed, in view of the findings of this study.

There is today a general philosophy in silvicultural practice to capitalize on the work of recent investigations which indicate a lack of significant correlation between specific gravity and growth rate in mature wood of some coniferous species. As a result, the suggestion is frequently implied to grow the trees as fast as possible without recognizing the importance of age. This situation suggests that it is possible to harvest a 10, 15 or 20 year old tree, with the same *quantity* of wood of equal specific gravity for a tree had been grown at a slower growth rate for a greater number of years. The point that may be overlooked is that the first 8-years growth in *all* trees examined in this study contained wood not only with low specific gravity but with other quality parameters "inferior" to those found in the mature wood zones examined. Therefore the philosophy dedicated to growing trees as fast as possible and ignoring the benefits of increasing age is misleading because although the quantity of wood produced will be high, the quality of wood produced will be low (based on parameters measured in this study).

On the other hand, the conservative viewpoint suggests that the tree should be grown slowly during the early years so as to minimize the quantity and thus the percentage of juvenile wood formed, and then after 10, 15 or 20 years of age or more the trees should be released to produce wood at some *optimum* growth rate. This concept is also to be discouraged. First, on examination of the data for juvenile wood volumes presented in this study the percentages of core wood as related to total disk volume in either the 5, 7, 9, or 11-inch trees in 1952, range only from 9.2% to 10.6%. Comparable values for the five dbh growth classes range from 7.4% (for the 2½" class) to 12.7% for the ½" class. Therefore the juvenile wood zone occupies about the same volume regardless of classification. Second, over the range of growth rates studied for the outer mature wood zone (1951-1960), no optimum growth rate for the production of specific gravity was established. It may well be true that some exceedingly fast growth rate, say less than 6 rings per inch, may produce mature wood of relatively low specific gravity; however, data to substantiate this point are lacking at present for Missouri-grown shortleaf pine. Another point to keep in mind is that specific gravity is not the only quality parameter that is beneficially influenced by age. Certainly the data obtained on fiber length, indicating an increase in one-third of the length of fibers (juvenile wood compared to mature wood) is significant. Fibril angle data are also significant. The influence of fibril angle upon various wood uses as wood per se or as fiber is not presently fully understood. But it is assumed that fibers with a high fibril angle, characteristics of the juvenile wood zone regardless of fiber type (springwood or summerwood), are fibers that have a tendency to shrink more, exhibit a lower stiffness, and possibly a lower degree of cellulose crystallinity than fibers with a very small fibril angle as are characterized by those found in the outer mature wood. It should be reemphasized that fiber properties significantly changed with age over the 40-year period studied.

From these two philosophies of silvicultural practice, i.e., very fast growth from the start, or a controlled slow growth in youth followed by a production of wood at some optimum growth rate figure, emerges a "compromise" silvicultural practice used for growing shortleaf pine in Missouri.

1. There would be no suppression in youth. The core or juvenile portion of the xylem should be allowed to developed at as fast a rate as practical. There is no need to control the amount of this wood. The faster it grows the larger will be the amount of mature wood formed subsequently for trees of equivalent age. The "quality" of fiber properties of juvenile wood is approximately the same, regardless of growth rate although it is true that the specific gravity of slower grown juvenile wood will be higher than that of faster grown juvenile wood. It should be noted that juvenile wood with an average density of say 26+ pounds per cubic foot is not equivalent in "quality" to wood of comparable density in the mature wood zone. Here specific gravity alone, is a false indicator; although the two values for juvenile and mature wood may be identical, fiber composition and chemical composition of these two wood zones may be quite different (Table 16).

2. The concept of growing wood as fast as possible should also include the beneficial influence of age. The trees should be grown as fast as possible with a reservation that for specific uses, a "harvest-age" would be applied and the trees would be allowed to grow at least this long in order to insure not only an adequate specific gravity but also the development of other desirable indices (fiber length, fibril angle, etc.) of wood quality as well.

These two concepts:

1. a fast rate of growth throughout the life span of the tree.

2. allowing for the influence of age upon the various wood parameters should form the basis for silvicultural practices recognized to insure shortleaf pine wood quality.*

We are aware that the quality indices of today may or may not share the same relative importance in predicting uses of wood in the future. However, it has been shown that there is a definite difference in wood properties along the radius of the tree for the various age zones studied. With reference to the influence of this fact on future wood utilization and to those interested in the general area of tree genetics and tree breeding, data suggest future avenues of ex-

*in Missouri. It is to be remembered that Missouri represents the northwest boundry of the commercial range of shortleaf pines. This situation may indicate that extremely fast growth rates for this species are not likely to be encountered in Missouri.

ploration. A big contribution could be made through tree improvement research by possibly changing the genetic make-up of trees to reduce within tree variation in the various quality parameters important as of now. This implies a means to minimize differences between juvenile wood and mature wood characteristics and hence grow more uniform wood. Naturally any "breakthrough" leading to substantial improvement in one or more important quality parameters would also be appreciated by wood-using industries.

With reference to the relation between the specific gravity of core wood and mature wood within trees, the correlations obtained in this study were not as high as previously reported by Zobel (35). This difference probably is due to the type of correlation analysis applied to the data. A statistical evaluation similar to that used by Zobel, when employed on the data reported in this investigation, gave similar results. In this study shortleaf pine juvenile wood specific gravity was correlated with specific gravity of the mature wood formed subsequently, as opposed to comparisons between juvenile wood specific gravity and specific gravity of the entire xylem section as made by Zobel.

In summary, data and analyses are presented on the influence of diameter growth rate upon specific gravity for the mature wood zone of some ninety 40-year old shortleaf pines. This influence was found to be insignificant. However, growth rate was found to have a statistically significant influence on specific gravity for the juvenile wood zone. Age was significantly correlated with several parameters investigated including specific gravity, percent summerwood, fiber length, fibril angle, and certain chemical properties. Data in this investigation are interpreted in the light of existing silvicultural philosophies to suggest that a rapid rate of growth throughout the age of the tree is not detrimental to the parameters measured; however, the beneficial influence of age on all quality parameters measured should be taken into consideration for the growing of high quality wood.

Alcohol-benzene extractables were found to have a significant influence on determination of specific gravity by either the immersion or maximum moisture content procedures; the within tree variation for alcohol-benzene extractable content of juvenile wood zones was found to be significant. In future studies designed to make slight differences in specific gravity assume significance, the possible influence of extractables should not be overlooked.

Specific gravity data on the extractive-free shortleaf pine samples in this study indicate that Missouri-grown shortleaf pine is of comparable quality to samples obtained by others for the species elsewhere in its range. However, it should be pointed out that no extensive study, along the lines of Larson's (7) or Goddard and Strickland's (3) of the influence of location within the geographic range for specific gravity of shortleaf pine has been reported to date.

ABSTRACT

Ninety 40-year-old shortleaf pine trees were sampled for growth-quality evaluation. The sampling scheme was designed so that the wood formed during the last 10 years of growth (1951-1960) ranged (d.b.h.) from ½ to 2-½ inches. This range in diameter growth was distributed over trees that were in 5-inch, 7-inch, 9-inch, and 11-inch d.b.h. classes based on 1952 measurements. Trees were sampled (some 3,000 trees available) from a stand which had been established by natural regeneration after harvest of an oak-pine stand from 1918-1920.

Disks, 2-½ inches in thickness, removed at breast height, were used for analyses. Parameters (indices) of wood quality measured were: specific gravity and growth rate (all 90 trees); specific gravity, growth rate, percent summerwood. alcohol-benzene extractables, and water-resistant-carbohydrate content (19 trees); fibril angle, fiber width, fiber wall thickness, and fiber length (1 tree); and specific gravity of isolated springwood and summerwood zones (1 tree). All specific gravity measurements were made on alcohol-benzene extracted material.

Pertinent conclusions are:

1. Alcohol-benzene extractables were found to have a significant influence on determination of specific gravity, using either maximum-moisture content or immersion techniques.
2. Rate of growth had no significant influence on specific gravity of wood formed during the 10-year period from 1951-1960. This was the case regardless of tree size in 1952 or d.b.h. growth from 1951-1960.
3. Core or juvenile wood, defined as the first 8 years of growth, was lower in specific gravity, contained more extractables, more lignin, less water-resistant-carbohydrate material, and had shorter fibers than the mature wood (last 32 years of growth) in trees so investigated.
4. Correlation between specific gravity of core wood and mature wood is low ($r = +.453$) although significant.
5. Fibril angle of both spring- and summerwood fibers in juvenile wood was larger than in fibers in mature wood for one tree so studied.
6. Springwood zones of juvenile wood were denser than their counterparts in the last 10 years of growth in the tree so investigated. The opposite was true for summerwood zones.

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