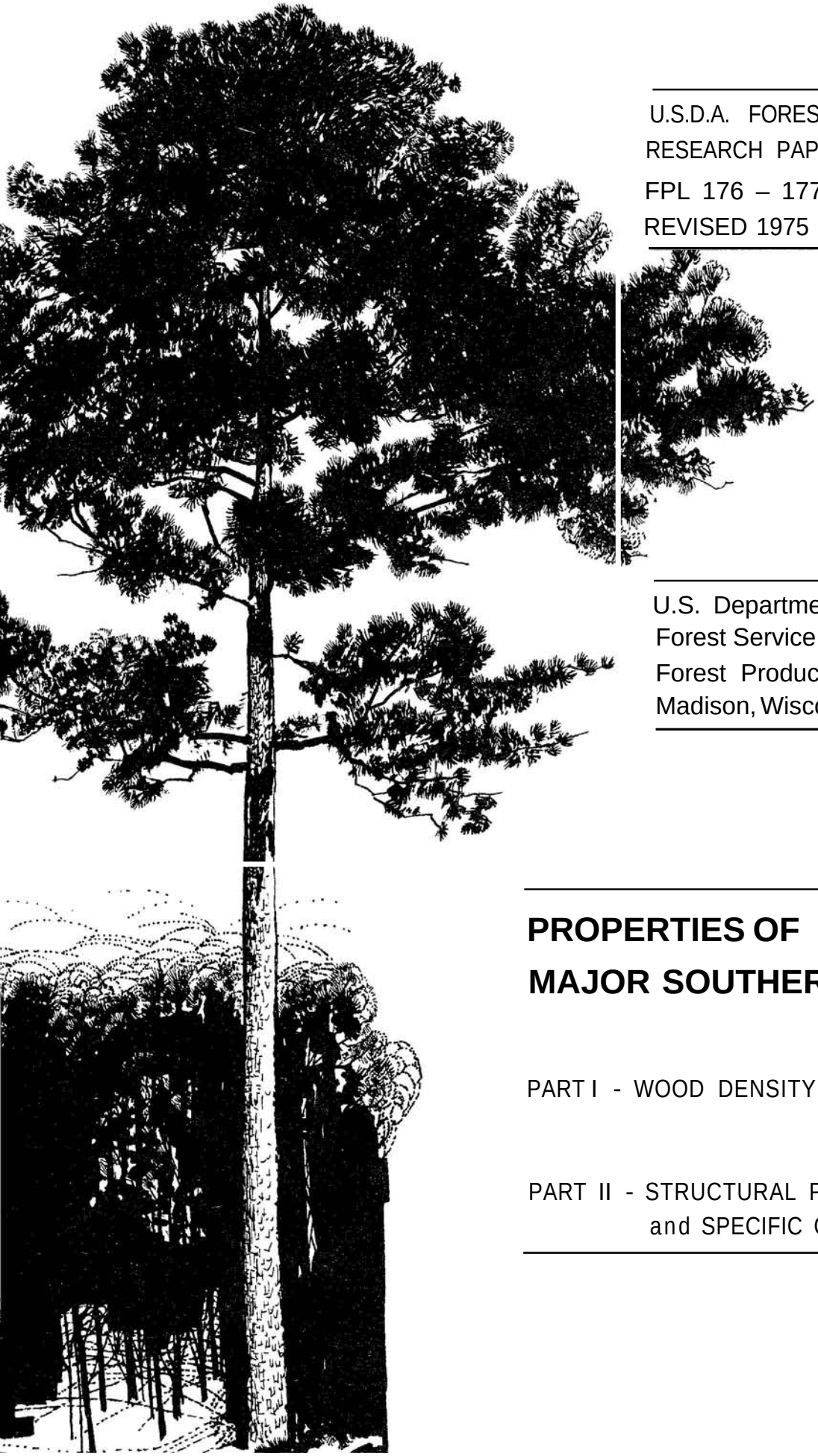

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Forest Products Laboratory
Madison, Wisconsin

PROPERTIES OF MAJOR SOUTHERN PINES:

PART I - WOOD DENSITY SURVEY

PART II - STRUCTURAL PROPERTIES and SPECIFIC GRAVITY

PROPERTIES OF MAJOR SOUTHERN PINES:

PART I - Wood Density Survey

USDA Forest Service Research Paper FPL 176

By H. E. Wahlgren & D. R. Schumann

Part II - Structural Properties and Specific Gravity

USDA Forest Service Research Paper FPL 177

By B.A. Bendtsen, R. L. Ethington, & W. L. Galligan

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Part I Wood Density Survey

USDA Forest Service Research Paper FPL 176

Abstract

In the survey of southern forest resources, information was collected on the specific gravity of the four major southern pines. This report presents mean increment core and predicted tree specific gravities by species, diameter class, and survey unit for 11 states. An analysis of geographical and environmental trends is included.

Using Specific Gravity Data

The specific gravity data in this report are presented as average values by species, diameter classes, and Forest Survey units. Readers unfamiliar with this type of data should note that differences between mean values must be interpreted with considerable caution. In addition to possible sampling errors in the means themselves, variations occur in specific gravity within individual trees, and between trees and locations within a survey unit. Nevertheless, the values do represent broad averages that are representative of the southern pine standing timber resource.

Acknowledgment

The accomplishment of a wood density survey of this proportion was made possible by the excellent cooperation of a large number of people. We acknowledge our appreciation to all members of the U.S. Forest Service, state agencies, and wood–using industries that cooperated in the 11 southern states surveyed––especially to Survey units of the Southern and Southeastern Forest Experiment Stations.

PROPERTIES OF MAJOR SOUTHERN PINES:

Part I Wood Density Survey

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Southern Wood Density Survey

The primary purpose of this publication is to provide interested state, private, and Federal agencies the most complete and up-to-date information ever assembled on the specific gravity of the four major southern pines--loblolly (Pinus taeda L.), shortleaf (P. echinata Mill.), longleaf (P. palustris Mill.), and slash (P. elliottii Engelm. var. elliottii) pine. In this report specific gravity is given for clear wood obtained on the basis of green volume and ovendry weight. The specific gravity data were summarized from extensive sampling in 11 southern states--extending from the Atlantic Coast westward to about the 96th meridian in Oklahoma and Texas.

Some of the data included herein were published in 1965 as a status report @).[2] The present publication combines those older data with information collected later, and thus updates and supersedes the 1965 report. The added data principally result from surveys since completed in Virginia, South Carolina, Oklahoma, and Texas, and from additional sampling in Arkansas and Florida to reinforce earlier sparse sampling.

A companion report, subtitled "Structural Properties and Specific Gravity," has been issued as Part II (2), of this report. Part II discusses application of the data contained herein to the development of information on the mechanical properties of the four species.

Background

Forest managers the world over rely on volume estimates of standing timber for development of working plans. From volume estimates they have predicted yield from their stands in terms of cords, cubic feet, board feet, and similar volume units. But as the forest industry has advanced technologically, the need for qualitative as well as quantitative information has become more evident.

The qualitative aspect is more appropriately referred to as timber quality, which by definition is considered to be that combination of physical and chemical characteristics of a tree or its parts that permit the best utilization of the wood for

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

[2] Underlined numbers in parentheses refer to literature cited, page 23.

its intended use. In other words, the intrinsic quality of wood is evaluated solely in terms of its suitability for various end uses. While such a definition may not be completely acceptable for all uses of wood, it does provide the framework for evaluating the quality of wood based on its physical, mechanical, anatomical, and chemical characteristics.

Because no single unit expresses the quality of clear, straight-grained wood directly for all end uses, quality is often described indirectly. That is, one or more properties of wood, indicative of its suitability for a particular end use, are measured or assessed.

Of all known indices, specific gravity, often used interchangeably with the term wood density, is the simplest and most useful, and is considered by many to be the most important criterion of clear wood quality. It is the single index most evaluated by researchers in wood science concerned with an assessment of wood quality (9,14,21,22,28,32,41,49,50,51) and has been the subject of symposia throughout the world (24 , 36).

Much of this interest in specific gravity stems from its relationship with strength and stiffness of clear wood. Because specific gravity is easier and less costly to determine than strength, it can be used as a strength predictor, and is thus of interest to producers of structural lumber, laminated beams, transmission poles, and pilings. The southern pine plywood industry has emphasized the importance of specific gravity to their product (12,25).

Perhaps the greatest support for the use of specific gravity as a quality indicator has come from the pulp and paper industry. This rapidly growing industry has long advocated the need for more specific gravity data, particularly for the southern pine species. This demand stems from the strong correlation between specific gravity and the yield of screened, kraft-type sulfate pulp per cubic foot of southern pine wood. For every 0.02 increase in specific gravity there is a corresponding increase of 50 pounds of dry processed pulp (18, 19).

Historically, Mitchell (17,18) was the first to recognize the feasibility of incorporating some simple qualitative evaluation along with the routine, periodic surveys of our standing timber resources. When the third forest survey commenced in the State of Mississippi in 1956, a standard increment boring was taken from every tree measured on forest survey plots. The cores were taken with standard increment borers that had been precisely calibrated for diameter. Core lengths were accurately measured in the fresh condition according to the method described by Mitchell (17, 18, 47) and forwarded to the Forest Products Laboratory for processing. This cooperative effort between the Forest Products Laboratory, the Southern Forest Experiment Station, the State of Mississippi, and various industries gave birth to the first wood density survey in this country.

Some 8,000 increment cores were evaluated in the Mississippi study and the results reported (16, 20); they stirred enough interest for their continuation into other States. Interest grew out of this study and led subsequently to the extension of wood density surveys throughout the South, the western United States (38), the State of Maine (42, 44), and recently to the Lake States (27). Similar wood density surveys have been reported from France (26), Sweden (22), and Finland (11).

All of the wood density surveys in the United States are part of a nationwide effort to determine the specific gravity and related quality characteristics of all commercially important timber species. The overall objective is to develop better information on the wood quality of the Nation's forest resources.

The study of southern pines was conducted cooperatively by Forest Survey personnel[3] of the Southern and Southeastern Forest Experiment Stations and the Forest Products Laboratory. The increment core sampling was carried on in conjunction with the regular Forest Survey activities and within the scheduled time frame for resurveying states.

The magnitude of this wood density study undertaken over the past 15 years precluded direct involvement on the remaining six minor species of southern pine--pitch (Pinus rigida Mill.), pond (P. serotina Michx.), sand (P. clausa (Chapm.) Vasey), spruce (P. glabra Walt.), table-mountain (P. pungens Lamb.), and Virginia (P. virginiana Mill.) pine. Wood density surveys of these minor species of southern pine became the responsibility of the Southeastern Forest Experiment Station. Results of those surveys have been published separately (5-8, 29, 33, 34).

Since initiation of the first wood density survey, improvements have been made in techniques of sampling and data analyses. Some of these improvements have been responsible for greatly reduced costs without sacrifice to the precision or reliability of the data (4, 31, 45).

Objectives

The objectives of the Southern Wood Density Survey were to:

(1) Obtain adequate data on the average specific gravity of each major species of southern pine, the magnitude of the differences between species, and the variation within species.

(2) Determine the extent specific gravity varies with tree age, tree volume, tree growth rate, climate, latitude, longitude, and other factors known to affect or suspected of affecting wood density. To also seek out individual trees that are superior in wood density as well as form, growth rate, and other desirable characteristics. Once located, such potentially "plus" trees could be examined by geneticists for possible use in breeding studies.

(3) Evaluate increment core/tree specific gravity relationships and develop regression equations for predicting tree specific gravity from increment core specific gravity.

(4) Provide mechanical property estimates of the four major southern pines.

Phases

The Southern Wood Density Survey divided logically into four phases, and completion of all four phases was necessary before data for the establishment of clear wood mechanical properties could be made available.

Phase I.--This phase was concerned with the planning and collection of increment cores and related data from sample plots distributed throughout the commercial forest area of the southern states.

Phase II.--Included in this phase were the laboratory processing of the sample cores, the statistical analysis, and interpretation of the results.

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[3] Joe P. McClure of the Southeastern Forest Experiment Station and Joe F. Christopher of the Southern Forest Experiment Station were responsible for developing the sampling plan and collecting the increment cores.

Phase III.--This phase consisted of studies to determine, for each of the four major species over its natural range, the relationship between increment core specific gravity at breast height and the average (tree) specific gravity for the merchantable volume of the whole tree, or various portions thereof.

Phase IV.--This phase was aimed at utilizing the wood density data derived from the earlier phases to obtain more reliable estimates of mechanical properties. The results, excluding the 1969 resurvey of Arkansas, are described in Part II (2).

Data Collection, Processing, and Estimation of Tree Specific Gravity

Phase I. Collection of Increment Cores and Related Data[3]

Collection of increment cores and related data for the Southern Wood Density Survey was begun in Mississippi in 1956.

The Forest Survey project at the Southeastern Forest Experiment Station completed Phase I of the survey in Georgia, Florida, North and South Carolina, and Virginia. The Forest Survey project at the Southern Forest Experiment Station completed this phase in Alabama, Mississippi, Louisiana, Texas, Oklahoma, and Arkansas. The work was conducted in conjunction with scheduled forest inventories.

Field data collected for the wood density survey included:

Trees	Increment Cores	Plots
Species	Length to 1/100 inch	State
Diameter at breast height to 1/10 inch	Diameter to 1/1,000 inch	Survey unit
		County
Merchantable length		Geographic coordinates

Maintenance of plot and tree identity permit recovery of other items measured or described for inventory purposes.

Sampling design.--In Florida, Georgia, North and South Carolina, and Virginia wood density was sampled at every fifth forest inventory plot. Initially the forest inventory plots were selected from a systematic grid printed on every third aerial photograph in alternate flight lines, using an interval which would provide sufficient plots to meet specific limits of error for volume estimates.

In Mississippi, the first state surveyed and the most intensively sampled, wood density was sampled at all forest inventory locations at the intersections of a 3- by 3-mile grid extending over the state.

In Alabama, Louisiana, Texas, Oklahoma, and Arkansas, wood density samples were taken at forest inventory locations positioned at the intersections of 12- by 12-mile grids extending over the states. In Arkansas and Mississippi two wood density plots were sampled at each wood density location. In terms of sampling intensity, the

Arkansas survey of 1959 as reported in FPL 26 (39) was quite weak. To supplement the data, additional wood density samples were taken in the 1969 forest resurvey of Arkansas. The additional samples were obtained from one-fourth of the total sample locations in the state.

The intensity of sampling is indicated in table 1, which shows the commercial forest area subdivided into a number of wood density sampling locations.

Sample tree selection.--Using point sampling procedures, sample trees were selected with probability proportional to basal area (table 2). The basal area factors, the number of points sampled per location, and the minimum tree d.b.h. (diameter at breast height) class included are shown.

Increment core sample.--In all states sampled, one core was extracted from each sample tree on the side of the tree facing plot center. In Alabama and Arkansas, a second core was taken at a position 90° clockwise from the first core.

Increment cores were obtained from a boring extending as nearly to the pith center at d.b.h. as permitted by the length of the borer and the size of the tree. The bark, pith, and the last growth increment, if incomplete, were removed by trimming. The length of the core was then carefully measured to the nearest 1/100 inch. The bore diameter of the increment borer, previously determined with a taper gage, was recorded as core diameter. Each core was placed in a paper straw or on corrugated paperboards and properly labeled. As the surveys progressed, accumulated cores were sent to the Forest Products Laboratory, where specific gravity determinations were made.

The sampling resulted in a total of 25,151 cores collected in the 11 states. A breakdown by species and states is given in table 3.

Phase II. Increment Core Processing

At the Forest Products Laboratory determinations were made of age and specific gravity. Use of individually calibrated increment borers of known diameter, and measurement of green core length in the field (and of the resoaked core again in the laboratory), permitted direct calculation of the green volume in cubic centimeters. Ovendrying and weighing the core to 0.001 gram was the final step to permit calculation of specific gravity on a green volume-ovendry weight basis. Cores were not extracted in order to maintain compatibility with mechanical property tests, which are always made on an unextracted basis.

Phase 111. Estimating Tree Specific Gravities from Breast Height Increment Core Specific Gravities

In southern pines, specific gravity tends to decrease with height in tree (23, 43) and to increase with distance from pith. Thus, an increment core specific gravity taken at breast height normally overestimates the average specific gravity of the merchantable portion of the tree. Studies of the relationships between tree specific gravity and breast height increment core specific gravities have been made for the four southern pines in Mississippi (43), for longleaf and slash pines in Georgia (35), and for loblolly and shortleaf pines in Arkansas (3). To further strengthen the increment core to tree specific gravity relationship additional sampling of loblolly and shortleaf pines was conducted in Texas. Because of this additional sampling, the regression equations in this report differ from those shown in FPL 26

Table 1.--Wood density sampling locations from commercial forest area

State	Unit	Commercial forest area represented by each sample location[1]
		Acres
Alabama	All	91,740
Arkansas	All	17,745
Florida	Northeast	20,885
	Northwest	33,480
	Central	15,355
	South	17,395
Georgia	Southeast	15,515
	Southwest	11,165
	Central	14,025
	North Central	14,730
	Northern	17,885
Louisiana	Excluding Delta units	89,691
Mississippi	All	5,340
North Carolina	South Coastal Plain	15,700
	North Coastal Plain	14,355
	Piedmont	17,525
	Mountain	12,985
Oklahoma	All	19,907
South Carolina	South Coastal Plain	28,580
	North Coastal Plain	23,180
	Piedmont	41,860
Texas	All	23,572
Virginia	Coastal Plain	29,385
	South Piedmont	37,795
	North Piedmont	35,235
	North Mountain	31,650
	South Mountain	37,765

[1] Includes wood density plots that did not yield any cores.

Table 2.--Selection of sample trees

State	Plots per location	Sampling points per plot	Basal area factor	Minimum d.b.h. class included
			Sq. ft.	In.
Alabama	1	10	37.5	5
Arkansas	2	1	10	3
Resurvey	1	1	10	5
Florida	1	1	10	4
Northwest unit	1	10	37.5	4
Georgia	1	1	10	4
Louisiana	1	10	37.5	5
Mississippi	2	1	10	3
North Carolina				
Coastal Plain	1	1	10	4
Piedmont	1	4	37.5	4
Oklahoma	1	10	37.5	5
South Carolina	1	10	37.5	4
Texas	1	10	37.5	3
Virginia	1	10	37.5	4

Table 3.--Number of trees sampled by species and states

State	Loblolly	Shortleaf	Longleaf	Slash	Total
Alabama	609	209	99	84	1,001
Arkansas	765	1,375	--	--	2,140
Florida	167	4	423	643	1,237
Georgia	1,247	599	337	760	2,943
Louisiana	500	138	45	36	719
Mississippi	3,752	2,815	992	576	8,135
North Carolina	1,327	469	109	--	1,905
Oklahoma	31	544	--	--	575
South Carolina	1,455	353	316	182	2,306
Texas	2,017	1,142	82	18	3,259
Virginia	583	348	--	--	931
Total.....	12,453	7,996	2,403	2,299	25,151

(39). These data were pooled with the material previously sampled. The total destructive sampling consisted of over 1,200 trees from 29 areas. Locations of the sampling areas are indicated in figure 1.

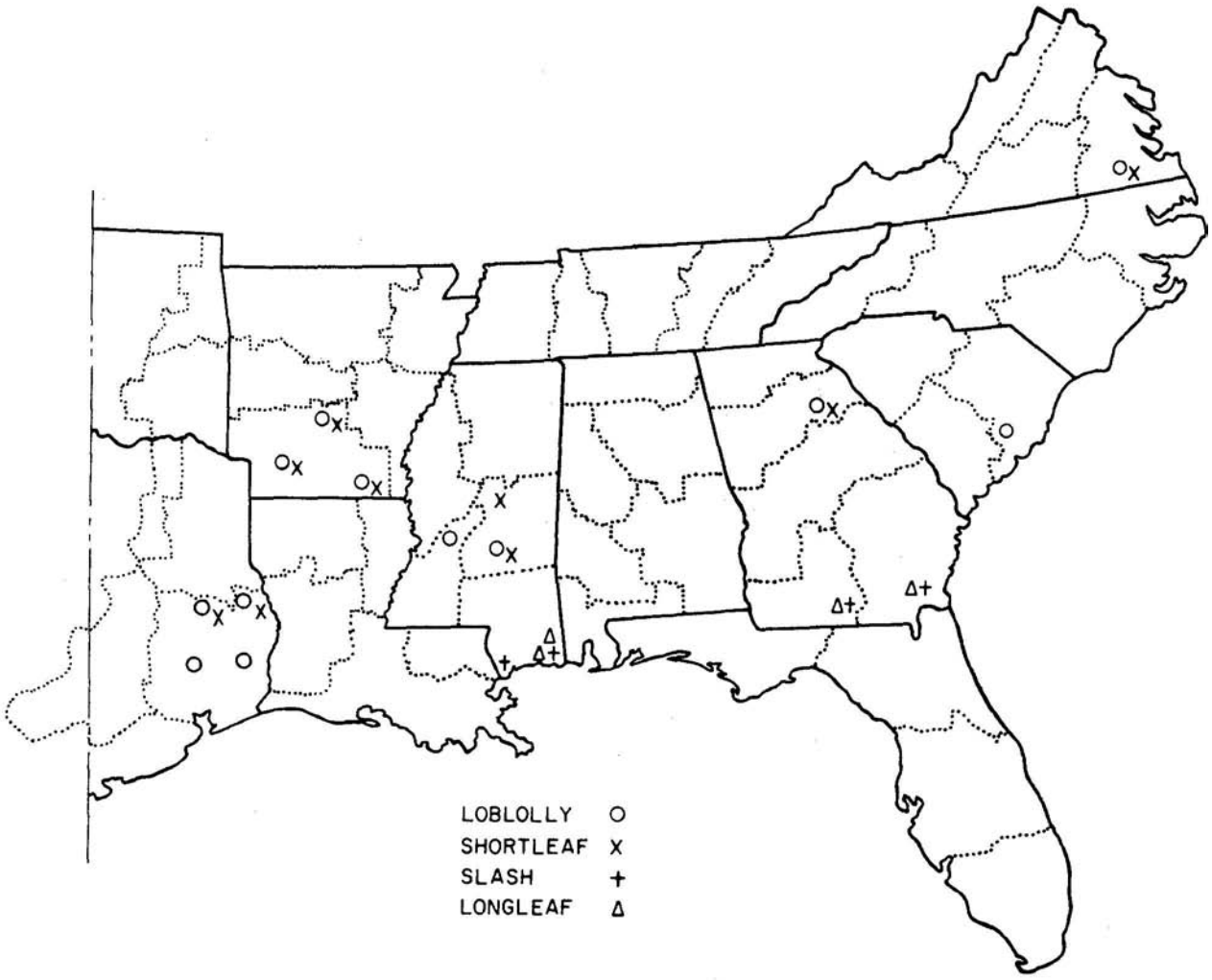

Figure 1.--Sampling areas for study of core-to-tree specific gravity relationships. M 140 229

Sampling procedures in each of the above studies involved extracting at least one increment core at a breast height position from each tree. After felling the tree, a disk was sawn at breast height and from the top end of each consecutive 5-foot bolt up to a merchantable top diameter of 3 inches d.i.b. (diameter inside bark). For sawtimber trees (at least 9 inches d.b.h.) disks were cut from the top end of each sawlog and from each pulpwood bolt in the upper bole. Specific gravity for trees was calculated as the average of component logs and bolts, each piece being weighted according to its volume.

To provide regression equations for converting increment core specific gravity to average weighted tree specific gravity, all available data for a species were pooled. For each species, a separate simple regression of the form,

$$\text{Tree specific gravity} = a + b\ (\text{increment core gravity})$$

was developed for each of four diameter classes, 3.0 to 4.9, 5.0 to 8.9, 9.0 to 14.9 and 15.0 inches plus.

Where data were insufficient, as in longleaf and slash pine, only two diameter classes were recognized, 3.0 to 8.9 and 9.0 inches plus. With these broader diameter classes a multiple regression equation of the form,

$$\text{Tree specific gravity} = a + b_1\ (\text{core gravity}) + b_2\ (\text{d.b.h.})$$

generally gave a significant improvement over a simple equation utilizing core gravity alone.

Another regression equation was developed for an "all classes" category for each species. As with the broader diameter classes, a multiple regression equation involving core gravity and d.b.h. also proved a significant improvement over a simple relationship.

In addition to the above equations, which are used to predict the average specific gravity of the wood in a tree up to a pulpwood top, separate equations were derived for predicting the average specific gravity of the sawtimber material in trees 9.0 inches d.b.h. and larger. The minimum top diameters used in defining the sawlog top depended on the tree d.b.h. (in line with standard Forest Survey practice). The specified limits were as follows:

D.b.h. (In.)	Minimum top d.i.b. (In.)
9 to 10	6
11 to 12	7
13 to 14	8
15 to 17	9
18 to 20	10
21 to 25	11
26 plus	12

Tree specific gravities for the "sawtimber" class, therefore, represent the average specific gravity of the material that can be converted to lumber, excluding the material between the sawlog top and a top d.i.b. of 3 inches. Tree specific gravities for all other diameter classification used in the report represent the average specific gravity of the total merchantable volume from a 1-foot stump to a 3-inch d.i.b. top.

The regression equations along with the coefficients of correlation and standard deviations from regression are shown in table 4.

Table 4.--Southern pine tree specific gravity estimating equations, all sampling areas combined.

Diameter class	Regression equations	Number of trees	Correlation coefficient	Standard deviation from regression
In.				
	LOBLOLLY PINE			
3.0- 4.9	Y=0.17430+0.63615(Core sp.gr.)	27	0.70	0.025
5.0- 8.9	Y=0.18094+0.58869(Core sp.gr.)	170	.74	.023
9.0-14.9	Y=0.14638+0.63907(Core sp.gr.)	203	.79	.022
15.0+	Y=0.12663+0.64951(Core sp.gr.)	97	.81	.020
All diam.	Y=0.17897-0.0025090(DBH)+0.63293(Core sp.gr.)	497	.78	.022
Sawtimber 9.0+	Y=0.16202-0.0027467(DBH)+0.68781(Core sp.gr.)	299	.83	.021
	SHORTLEAF PINE			
3.0- 4.9	Y=0.09621+0.79595(Core sp.gr.)	25	.75	.026
5.0- 8.9	Y=0.24988+0.44233(Core sp.gr.)	146	.68	.022
9.0-14.9	Y=0.16252+0.57943(Core sp.gr.)	152	.77	.023
15.0+	Y=0.20642+0.47140(Core sp.gr.)	51	.62	.024
All diam.	Y=0.22562-0.0032719(DBH)+0.53610(Core sp.gr.)	374	.74	.023
Sawtimber 9.0+	Y=0.19205-0.0027334(DBH)+0.60147(Core sp.gr.)	203	.76	.023
	LONGLEAF PINE			
3.0- 8.9	Y=0.30254-0.0075103(DBH)+0.52723(Core sp.gr.)	86	.79	.021
9.0+	Y=0.26018-0.0024827(DBH)+0.52982(Core sp.gr.)	96	.75	.022
All diam.	Y=0.27870-0.0038112(DBH)+0.52373(Core sp.gr.)	182	.76	.022
Sawtimber 9.0+	Y=0.28040-0.0034434(DBH)+0.53037(Core sp.gr.)	96	.75	.022
	SLASH PINE			
3.0- 8.9	Y=0.22893-0.0004820(DBH)+0.57700(Core sp.gr.)	104	.66	.027
9.0+	Y=0.31060-0.0043370(DBH)+0.47563(Core sp.gr.)	84	.67	.023
All diam.	Y=0.27322-0.0040380(DBH)+0.53806(Core sp.gr.)	188	.67	.025
Sawtimber 9.0+	Y=0.31198-0.0058519(DBH)+0.52878(Core sp.gr.)	84	.72	.024

Results and Analyses

The equations given in table 4 were used to calculate the average tree specific gravity values for each species, diameter class, and survey unit. Average tree specific gravity values are given in appendix A in tables 7 through 43. The reader should keep in mind that equations developed, except those for the "sawtimber" class, predict the average estimated tree specific gravity for all trees up to a 3-inch top diameter. The "sawtimber" equations predict the average estimated specific gravity by species and survey units for the sawtimber portion of trees 9.0 inches d.b.h. and greater to the variable top diameter shown in the previous tabulation.

Histograms of tree diameter, tree age, and increment core specific gravity for each of the four species are shown in figures 2 to 5. Frequency distribution of increment core specific gravity values shown in these figures indicate a relatively normal distribution pattern in each species. In terms of ranking, the highest average core specific gravity was found in longleaf pine followed by slash, shortleaf, and loblolly pine (table 6).

The voluminous specific gravity information obtained in this wood density survey is summarized in tables 5 and 6. In appendix A, each table presents the information for a single species and state. Within each table the data are arranged by diameter classes and Forest Survey units. (Figure 6 illustrates survey unit numbers.)

For each of these categories the following information is given:

1. Sample size.

a. Number of sample locations at which the particular species and size class was found during the density survey. Because more than one size class may be found at a single location within a survey unit, the total number of locations shown in the "all classes" category will not equal the sum of the locations of the individual diameter classes.

b. Number of trees from which increment cores were obtained. The size of sample provides a rough indication of the reliability of the sample data. In general, values based on a small number of trees or locations are not as reliable as those based on a large sample. Sample sizes may be small either because of a low sampling intensity or because of the scarcity of trees of a particular species and size class,

2. Mean diameter (outside bark at breast height) of sampled trees. Core specific gravity tends to increase with tree diameter so average diameter should be considered when comparing the average specific gravity values of two or more areas. Because the sampled trees were selected with probability proportional to their basal area, the average diameter of the core-sampled trees is not an estimate of the average diameter of all stems.

3. Increment core specific gravity.

a. For each species-diameter class-survey unit combination, the mean core specific gravity was computed as follows:

$$\text{Mean core specific gravity: } \bar{C} = \frac{\sum_i \sum_j C_{ij}}{\sum_i n_i}$$

where: C_{ij} = the core specific gravity of the jth tree at the ith location.
n_i = the number of trees sampled at the ith location.

b. The standard error of the mean core specific gravity was approximated by:

$$\text{Standard error} = \sqrt{\frac{k}{(\Sigma n_i)^2}\left[\frac{\Sigma S_i^2 + \bar{C}^2 \Sigma n_i^2 - 2\bar{C}\Sigma n_i S_i}{k-1}\right]}$$

where: k = the number of locations at which trees were bored for specific gravity.
S_i = the sum of the core specific gravities at the ith location $(= \sum_j C_{ij})$.

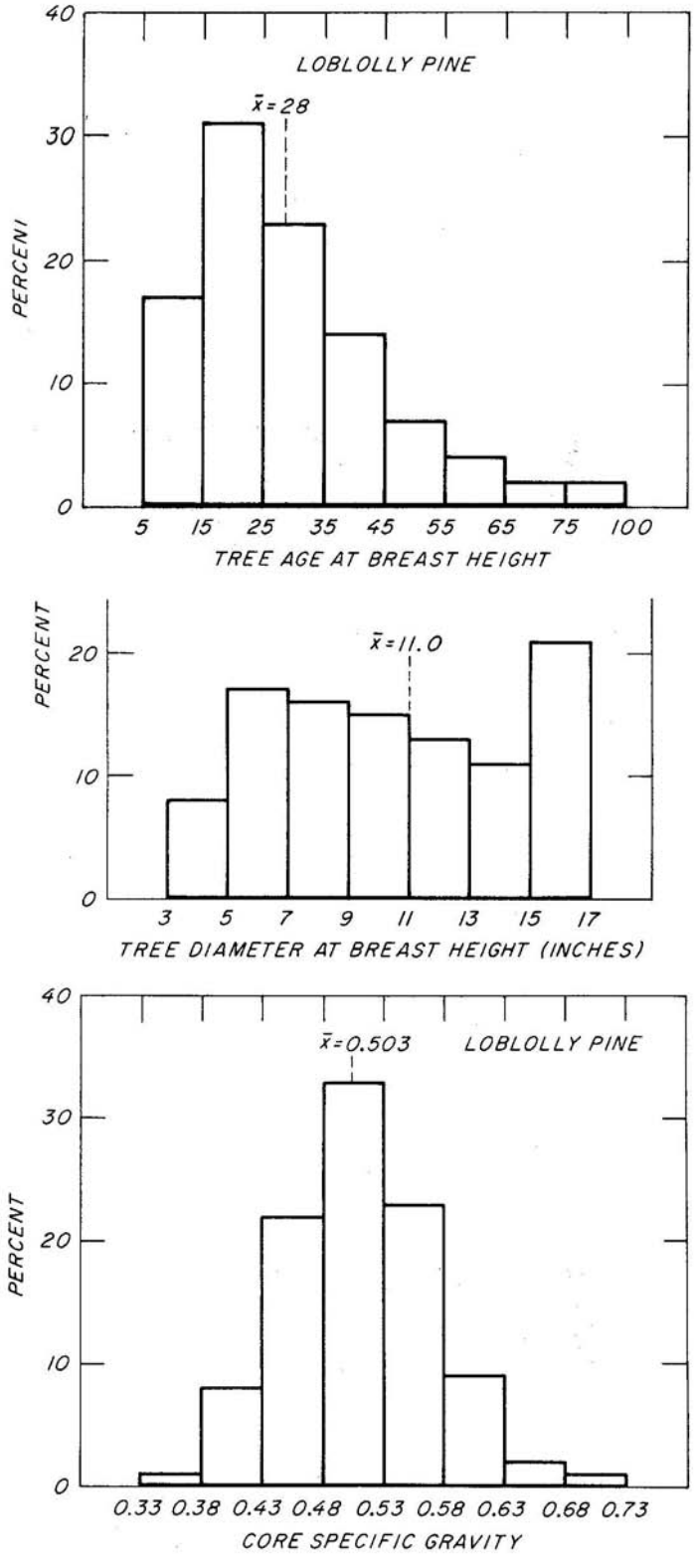

Figure 2.--Frequency distribution of tree age, tree diameter, and increment core specific gravity at breast height in loblolly pine (Pinus taeda). N = 12,453. (M 139 252, M 139 260, M 139 256)

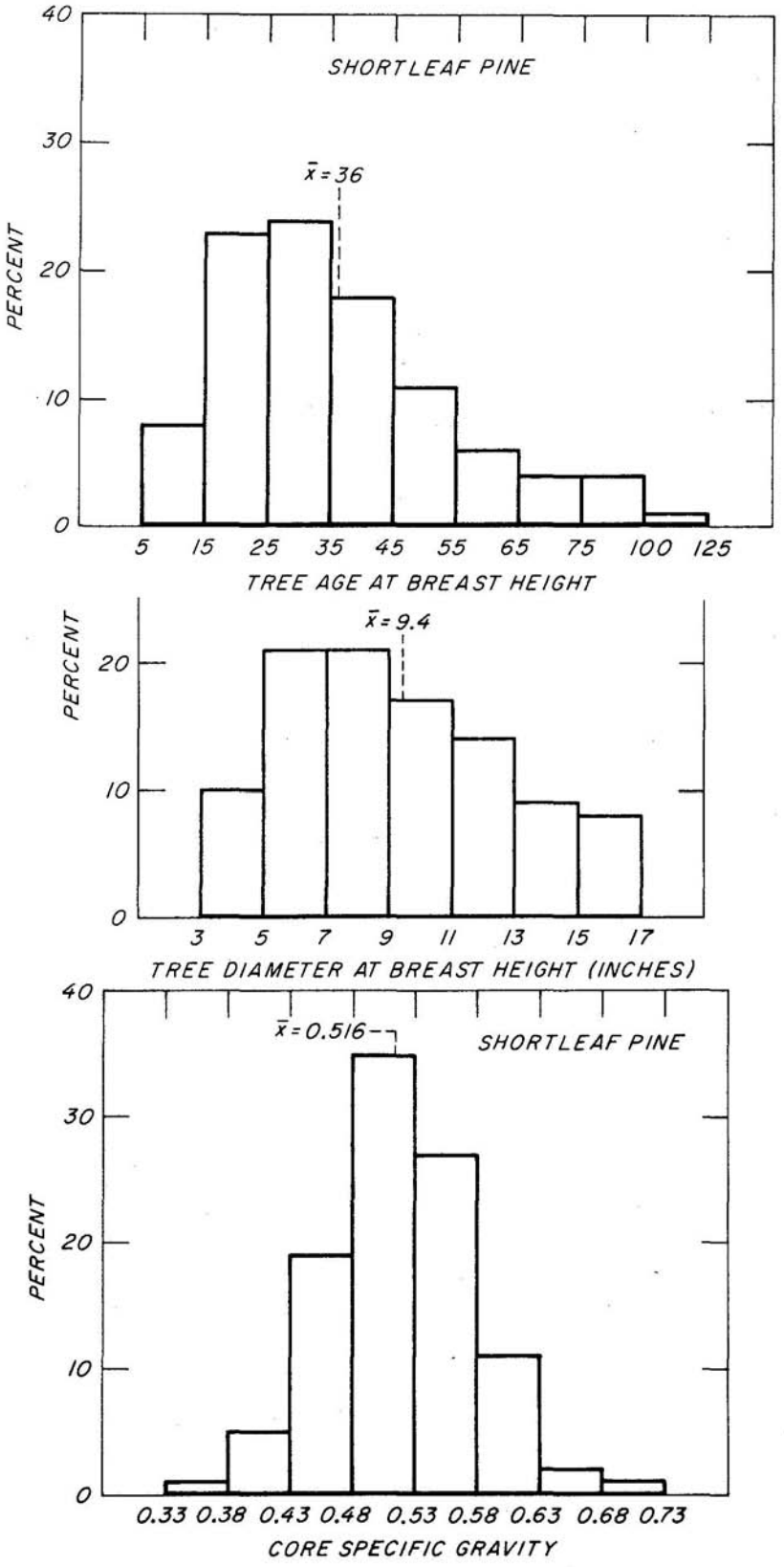

Figure 3.--Frequency distribution of tree age, tree diameter, and increment core specific gravity at breast height in shortleaf pine (Pinus echinata). N = 7,996. (M 139 251, M 139 250, M 139 249)

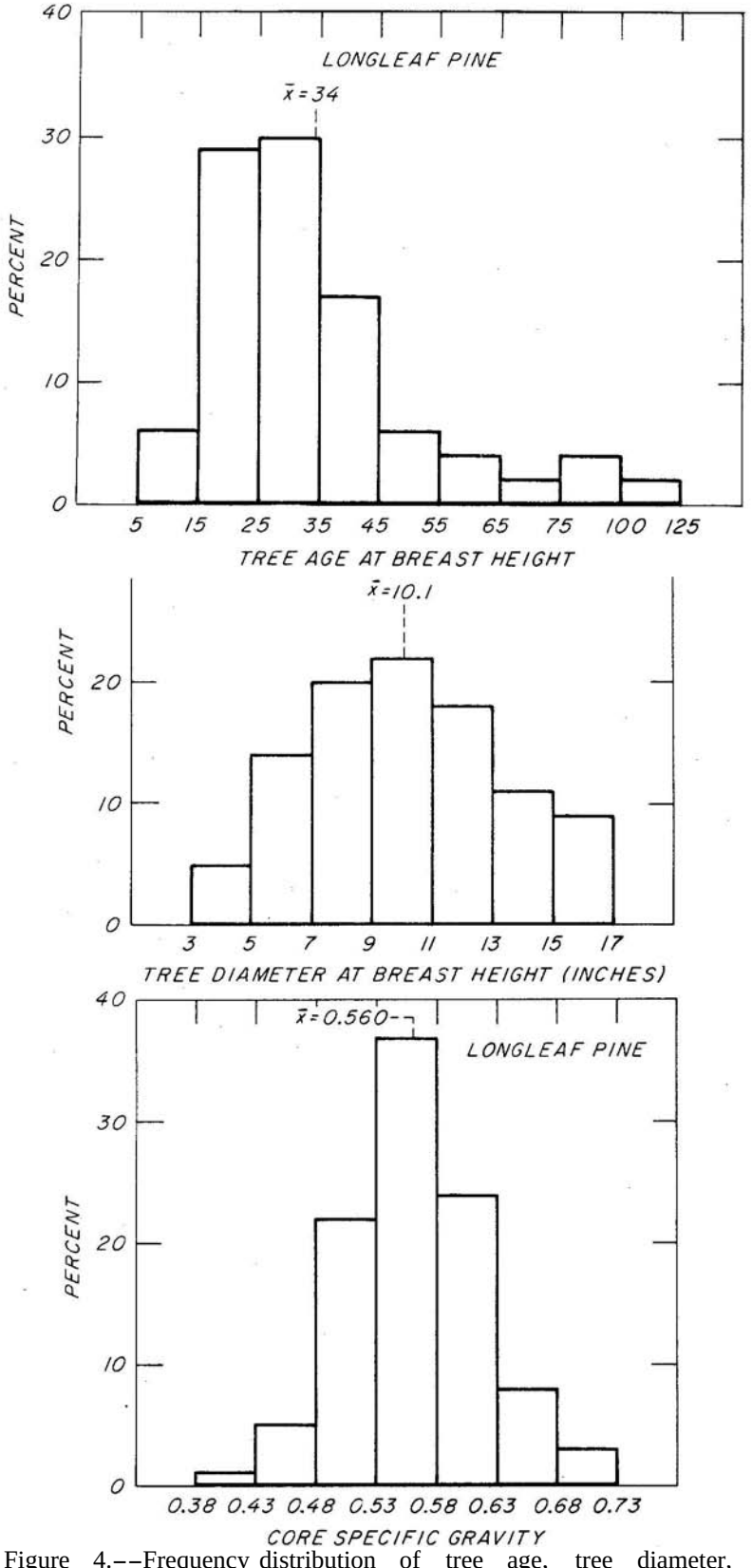

Figure 4.--Frequency distribution of tree age, tree diameter, and increment core specific gravity at breast height in longleaf pine (Pinus palustris). N = 2,403. (M 139 258, M 139 259, M 139 257)

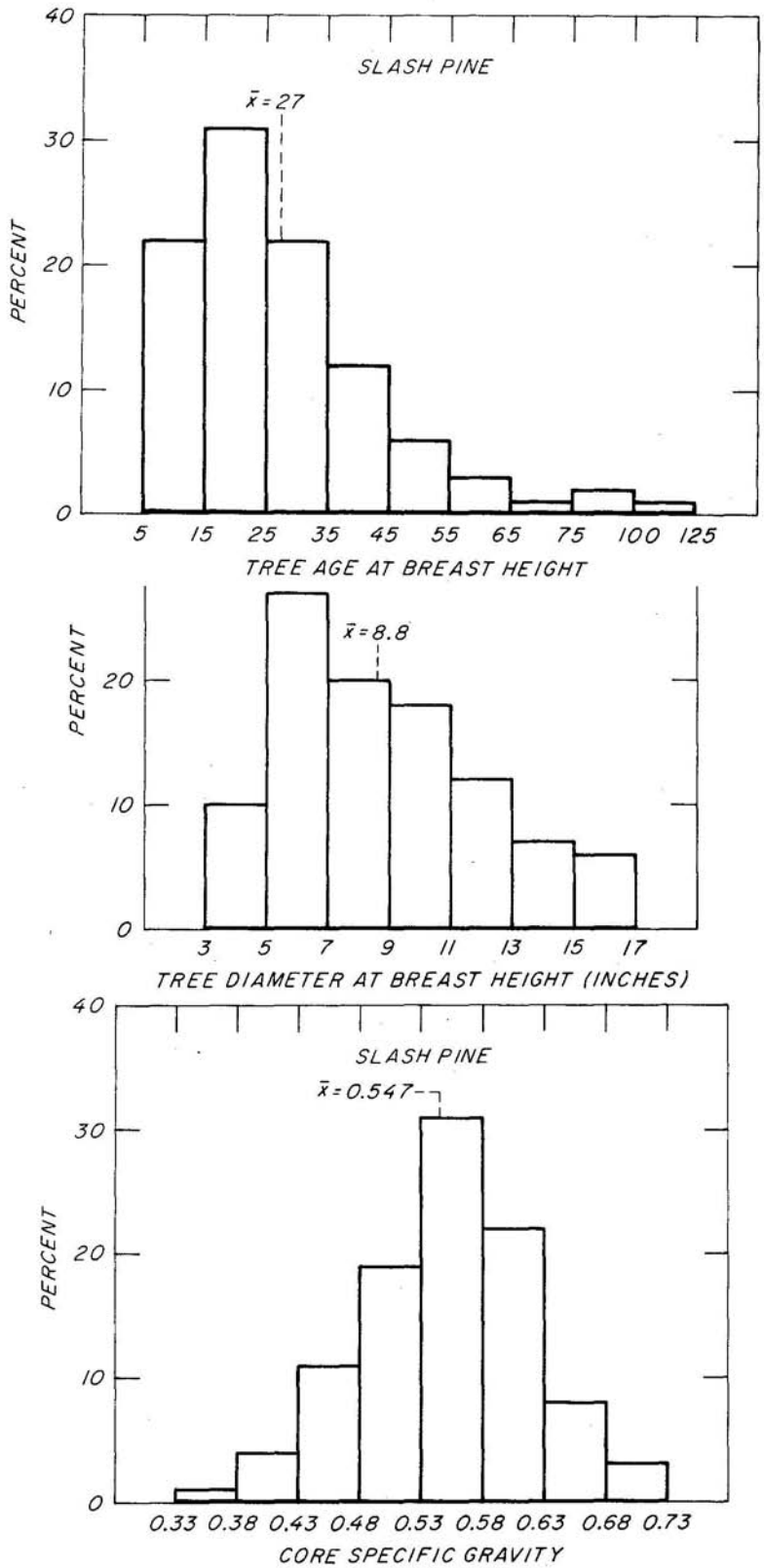

Figure 5.--Frequency distribution of tree age, tree diameter, and increment core specific gravity at breast height in slash pine (Pinus elliottii). N = 2,299. (M 139 253, M 139 254, M 139 255)

Table 5.--Specific gravity data by diameter classes for the four major species of southern pine

Diameter class	Number of trees	Mean diameter	Increment core specific gravity	Estimated tree specific gravity
In.		In.		
		LOBLOLLY		
3.0- 4.9	941	4.1	0.440	0.45
5.0- 8.9	4,008	6.9	.481	.46
9.0-14.9	4,826	11.7	.517	.48
15.0+	2,678	18.4	.532	.47
Sawtimber				
9.0+	7,504	14.1	.522	.48
		LONGLEAF		
3.0- 4.9	123	4.3	.518	.54
5.0- 8.9	828	7.2	.547	.54
9.0-14.9	1,232	11.4	.569	.53
15.0+	220	17.0	.580	.53
Sawtimber				
9.0+	1,452	12.3	.570	.54
		SHORTLEAF		
3.0- 4.9	762	4.1	.474	.47
5.0- 8.9	3,326	7.0	.509	.48
9.0-14.9	3,269	11.5	.528	.47
15.0+	639	17.0	.537	.46
Sawtimber				
9.0+	3,908	12.4	.529	.48
		SLASH		
3.0- 4.9	223	4.2	.503	.52
5.0- 8.9	1,087	6.7	.529	.53
9.0-14.9	848	11.3	.576	.54
15.0+	141	17.0	.583	.51
Sawtimber				
9.0+	989	12.1	.577	.55

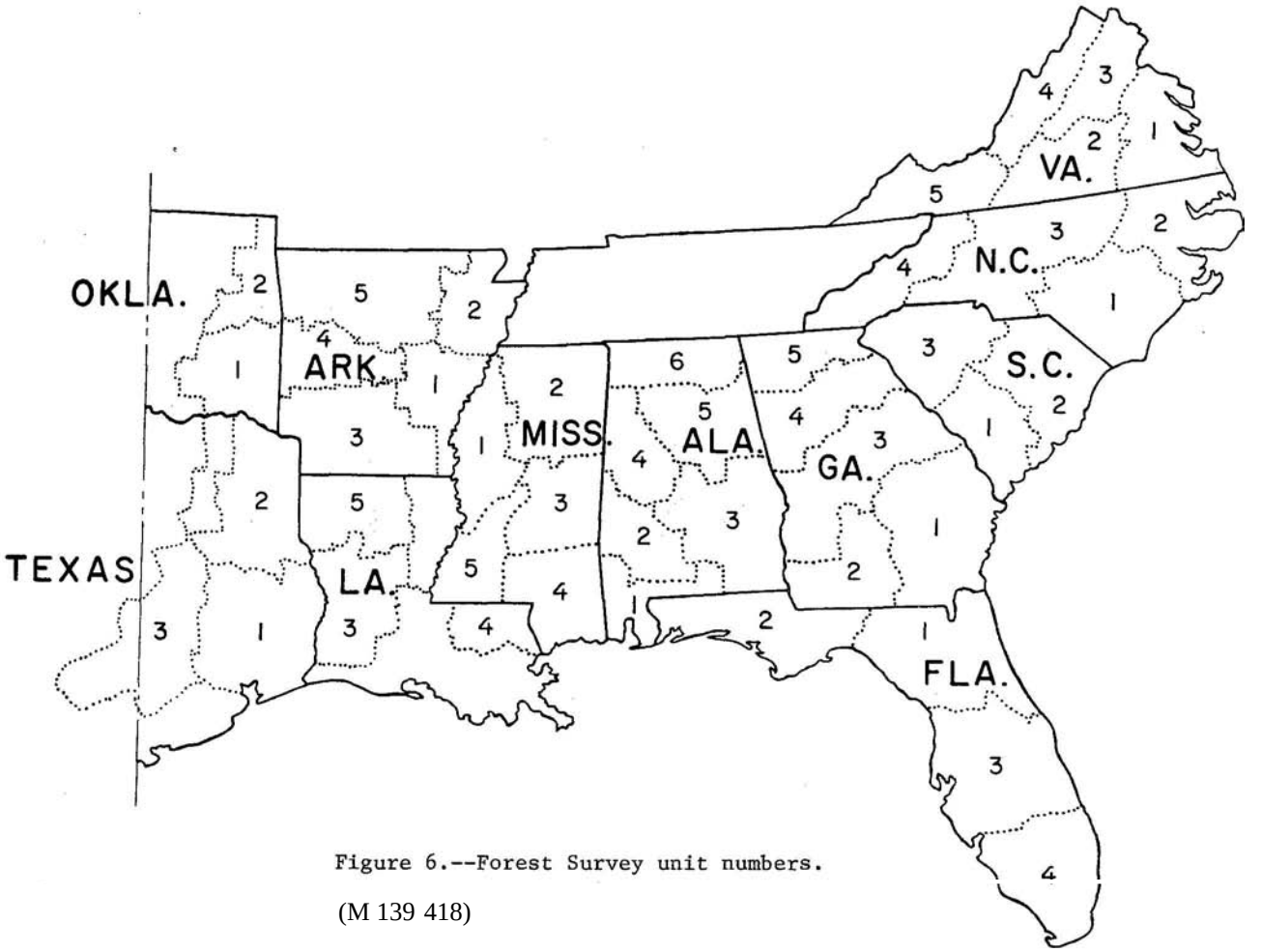

Figure 6.--Forest Survey unit numbers.

(M 139 418)

The standard error provides an indication of the precision with which the sample mean estimates the population mean. As a rough guide we can say that unless a one-in-twenty chance has occurred in sampling, the sample mean will be within two standard errors of the population mean. Standard errors could not be computed for the means that were based on samples from less than two locations.

c. The standard deviation of individuals is a measure of the variation among individuals in the population sampled. As an approximation we can say that about 95 percent of the individuals in the population will be within two standard deviations of the mean. This estimate of the standard deviation was obtained from the sample range of the core specific gravities (using tabular values of the ratio of the standard deviation to the range). In this report, standard deviations are not shown if there were less than two locations or five trees in the sample.

4. Estimated tree specific gravity.

a. The method of obtaining tree specific gravity was discussed in a previous section. Again, the tree specific gravities for the "sawtimber" class (9.0 in. d.b.h. and greater) represent the average specific gravity of the material up to a sawlog top diameter. For all other classes in the tables, the tree specific gravity is an estimated average for the material up to a pulpwood (3 in. d.i.b.) top.

b. The standard error of mean tree specific gravity provides a measure of the precision with which the true mean has been estimated. The standard error of the predicted mean tree specific gravity is estimated by:

$$\text{Standard error} = \sqrt{S^2_{y \cdot x}\left(\frac{1}{n_1} + \sum_{ij}^{kk}\sum c_{ij}(\bar{X}_{2i} - \bar{X}_{1i})(\bar{X}_{2j} - \bar{X}_{1j})\right) + \frac{S^2_y}{n_2}}$$

where: n_1 = the number of observations used to estimate the relationship between a Y-variable (tree specific gravity) and one or more X-variables.

n_2 = the number of observations used to estimate the population mean values of the X-variables.

$\bar{X}_{1i}$ = the mean value of the X_i from which the equation was developed.

$\bar{X}_{2i}$ = the mean value used in the equation to predict mean Y.

$S^2_{y \cdot x}$ = the residual mean square of the prediction equation:

$$Y = \beta_o + \sum_{i=1}^{k} \beta_i X_i$$

S^2_y = the variance of Y in the sample used in developing the prediction equation.

c_{ij} = the ij^{th} element of the inverse of the matrix of corrected sums of squares and products (of the X's) in the first sample.

c. Standard deviation of tree specific gravity of the species is estimated by:

$$\text{Standard deviation} = \sqrt{A_1^2\ \mathrm{Var}(X_1) + A_2^2\ \mathrm{Var}(X_2) + 2A_1A_2\ \mathrm{Cov}(X_1X_2) + \mathrm{Var}(E)}$$

where: X_1 = diameter at breast height of individual trees from Phase II.

X_2 = core specific gravity of individual trees from Phase II.

A_1 = regression coefficient of X_1 from prediction equation.

A_2 = regression coefficient of X_2 from prediction equation.

$\mathrm{Var}(X_1)$ = variance of X_1 from Phase II.

$\mathrm{Var}(X_2)$ = variance of X_2 from Phase II.

$\mathrm{Cov}(X_1X_2)$ = covariance of X_1X_2 from Phase II.

$\mathrm{Var}(E)$ = the residual mean square of the prediction equation.

5. Total cubic foot volume for species, diameter class, and survey unit as of the completion of the survey.

These volumes include a slight amount of cull material and are from the stump to a minimum 4.0-inch top outside bark or to the point where the central stem breaks into limbs. Volumes are shown for a given diameter class only if increment core data were available for that class. For this reason, in a given survey unit the diameter class volumes may not add up to the volume shown for "all classes."

Discussion of Results

For comparison of the average tree specific gravity values for the four species, the average increment core specific gravity and diameter breast height values shown in the histograms (figs. 2 to 5) were used in the "all diameter" regression equation (table 4) to arrive at a predicted tree specific gravity value for each species. The determination of the standard deviation of increment core specific gravity and estimated tree specific gravity were explained earlier. The corresponding values are as given in table 6.

Table 6.--Specific gravity values by species

Species	Number of cores	Mean d.b.h.	Increment core specific gravity		Estimated tree specific gravity	
			Mean	Standard deviation	Mean	Standard deviation
		In.				
Loblolly	12,453	11.0	0.503	0.053	0.47	0.042
Shortleaf	7,996	9.4	.516	.069	.47	.039
Longleaf	2,403	10.1	.560	.061	.53	.037
Slash	2,299	8.8	.547	.075	.53	.044

While the average increment core specific gravity values vary considerably between four species, the predicted tree specific gravity shows loblolly and shortleaf pine with values of 0.47 and longleaf and slash with 0.53. This represents essentially no change for loblolly and shortleaf, and a reduction of 0.01 for longleaf and slash (1). The reader should be reminded, however, that these predicted tree specific gravities are estimated values developed from the core-to-tree regression equations and apply to all trees 3 inches in diameter and above.

Following a similar procedure, an estimated average tree specific gravity value was calculated (using the appropriate regression equation from table 4) for each diameter class for each species and is shown in table 5.

Sources of Specific Gravity Variation

Differences in specific gravity between pieces of wood reflect differences in cell wall thickness, cell diameter, cell length, amount of extractives, and the like. While significant efforts have been directed toward defining relationships between the above factors and specific gravity, a far greater number of investigations have concentrated on evaluating the genetic and environmental components on observed variations in specific gravity (9, 10, 13-15, 32, 48-52).

Results of individual studies on environmental factors and their effect on specific gravity are often confusing and contradictory. Comparisons can seldom be made because of differences in sampling procedures, types of samples taken, and other design factors.

It is, of course, true that geographic location does not in itself affect specific gravity but rather it reflects the environmental factors that do have a more direct influence on wood specific gravity. That is to say site, soil type, precipitation, length of growing season, mean temperature, etc., all contribute to the specific gravity variations encountered.

In the first wood density survey in Mississippi, Mitchell (16, 20, 47) found the specific gravity of loblolly and shortleaf pine, the two most widely distributed Mississippi pines, to increase from northwest to southeast within the state. In this connection, Mitchell indicates in Mississippi the specific gravity variation follows quite closely the warm-season rainfall pattern, increasing from northwest to southeast.

In this wood density survey a number of environmental factors were investigated for their effects on tree specific gravity for the four species.

In each evaluation the all-diameter regression equation from table 4 was used to arrive at a predicted tree specific gravity value. This value calculated for each survey unit was then compared with an environmental factor also expressed on the survey unit level. Results (not tabulated) indicated the following variables had no noticeable effect on the variation of tree specific gravity in any of the four species :

(a) Mean annual evapo-transpiration.

(b) Mean annual water deficit.

(c) Mean annual total precipitation.

(d) Surface water and annual runoff.

(e) Principal soil types.

(f) Geological identification of rocks forming the surface classified according to their geologic ages.

(g) Tectonic classification of rocks subdivided according to their place in the evolution of the region of which they were a part along with a representation of the manner in which the rocks were warped into domes and basins, folded into anticlines and synclines, and broken by faults.

Longitude did not seem to appreciably influence specific gravity; however, latitude did in two species. Specific gravity of slash and longleaf pine generally increases from north to south. The same trend was also noted when the specific gravity of some of the slash pine increment cores were recalculated on an extractive-free basis (see appendix B).

The availability of water as represented by productive aquifers was correlated with specific gravity. Slash, longleaf, and loblolly pine growing on semiconsolidated aquifers consisting of coastal plain sand underlain by carbonate rocks have high specific gravity values.

Six physical subdivisions provided the most meaningful grouping of similar specific gravity values. These physiographic regions were developed by Hammond (40) from an empirical analysis of land surface defined in terms of a selected group of surface characteristics. These subdivisions are shown in figure 7.

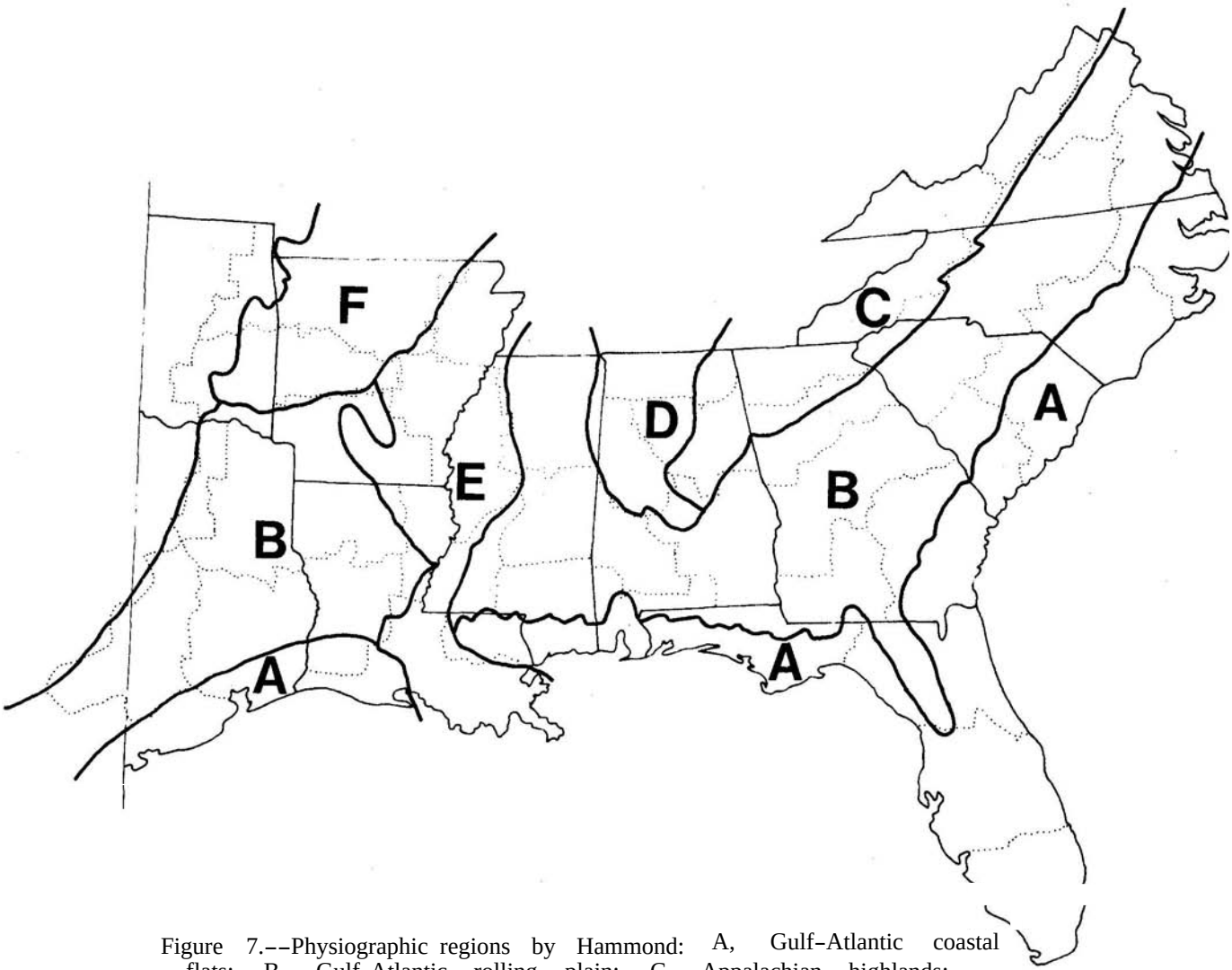

Figure 7.--Physiographic regions by Hammond: A, Gulf-Atlantic coastal flats; B, Gulf-Atlantic rolling plain; C, Appalachian highlands; D, Eastern Interior uplands and basin; E, Lower Mississippi alluvial plain; and F, Ozark-Ouachita highlands. (M 140 245)

Slash pine grows in only two of the subdivisions (coastal flats and rolling plain) and has predominantly higher specific gravities in the coastal flat. Longleaf pine also grows primarily in the coastal flat and rolling plain; however, it does extend into the Appalachian Highlands. The same relationship of higher coastal specific gravity found in slash pine was also true in longleaf with the addition of both the flat and plain having higher specific gravity values than the Appalachian Highlands.

With loblolly pine, which grows in all subdivisions, specific gravity decreases from the flats to the plain and then to the interior. There is little variation in specific gravity between the Appalachian Highlands, Interior Uplands, and Alluvial Plain. The Ozark-Ouachita Highlands, however, do produce trees with specific gravity values comparable to those of the Coastal Flats.

Shortleaf pine also grows in all subdivisions and is the most widely distributed of the four species. No appreciable difference in tree specific gravity values was found in five of the subdivisions. The trees from the Ozark-Ouachita Highlands, however, have higher specific gravity values than the other subdivisions.

Considering the four species, shortleaf pine showed the least amount of variation in all of the environmental categories investigated. This agrees with the recent findings of Saucier and Taras (30).

Many factors account for variation in specific gravity, resulting in a highly complex relationship. No sophisticated attempt was made to isolate these variables or examine the confounding effect they have on one another. The observations made in this report, however, do provide some indication of the variation and insight into areas that require further investigation.

In any discussion of this nature, it is important to remember that patterns of specific gravity vary within and between trees of any species. Therefore, while differences in specific gravity do exist between geographical areas, they often are not as great as those within and between trees.

It is significant that the substantial amount of core specific gravity data independently collected by Zobel and Rhodes (52) in Texas; Larson (14) in Louisiana, Alabama, Georgia, and Florida; and by Saucier and Taras (30) throughout the south-eastern states show the same pattern of variation as observed in this Southern Wood Density Survey. Although these independent studies had other objectives, and employed different sampling designs that do not permit the pooling of all data, their results nevertheless tend to substantiate and confirm the trends observed in this density survey. No inconsistencies were noted among the various studies.

Summary and Conclusions

The average specific gravity, based on breast height increment cores, representing trees 3 inches in diameter and above was 0.560 for longleaf, 0.547 for slash, 0.516 for shortleaf, and 0.503 for loblolly pine. Using the "best" of the developed equations for predicting tree specific gravity, the average tree specific gravity values representing all trees 3 inches in diameter and above were estimated to be 0.53 for longleaf and slash pine and 0.47 for loblolly and shortleaf pine. Additional tree specific gravity values were estimated for various diameter classes for each species.

In terms of geographic variability, only slash pine and longleaf pine showed a general trend of specific gravity increasing from north to south. Of the four species, shortleaf pine showed the least amount of variation in all the environmental categories evaluated.

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Appendix A
Tables of Specific Gravity Data by Tree Species and State

Table 7.--Specific gravity data for loblolly pine in Alabama

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	Not Sampled							
5.0- 8.9	North (6)	2	3	6.6	0.462(.008)	---	0.45(.020)	20.2
	N. Central (5)	19	73	7.0	.470(.010)	0.044	.46(.004)	187.8
	W. Central (4)	16	60	7.0	.468(.007)	.043	.46(.005)	147.2
	Southeast (3)	22	54	6.7	.489(.007)	.038	.47(.005)	213.2
	Southwest-N (2)	15	40	7.1	.480(.012)	.042	.46(.006)	171.2
	Southwest-S (1)	1	1	5.8	.517(--)	---	.48(--)	31.9
9.0-14.9	North (6)	4	6	13.0	.490(.015)	.040	.46(.015)	46.6
	N. Central (5)	11	46	11.3	.486(.013)	.047	.46(.006)	349.4
	W. Central (4)	18	59	11.3	.486(.008)	.046	.46(.005)	326.1
	Southeast (3)	26	66	11.6	.527(.007)	.071	.48(.005)	540.4
	Southwest-N (2)	18	76	11.5	.522(.009)	.054	.48(.004)	519.1
	Southwest-S (1)	3	6	11.1	.539(.004)	.032	.49(.015)	86.0
15.0+	North (6)	1	7	21.8	.509(--)	---	.46(--)	44.8
	N. Central (5)	7	17	17.1	.513(.010)	.033	.46(.009)	177.9
	W. Central (4)	6	24	18.4	.491(.011)	.036	.45(.007)	198.9
	Southeast (3)	15	35	16.9	.537(.006)	.031	.48(.006)	299.5
	Southwest-N (2)	11	34	18.6	.522(.008)	.050	.47(.006)	335.6
	Southwest-S (1)	2	2	17.8	.567(.040)	---	.50(.002)	80.8
All classes	North (6)	4	16	15.6	.493(.008)	.034	.45(.009)	111.6
	N. Central (5)	26	136	9.7	.481(.008)	.049	.46(.003)	715.1
	W. Central (4)	19	143	10.7	.479(.005)	.042	.46(.003)	672.2
	Southeast (3)	38	155	11.1	.516(.006)	.061	.48(.003)	1053.1
	Southwest-N (2)	21	150	11.9	.511(.010)	.052	.47(.003)	1025.9
	Southwest-S (1)	5	9	12.0	.543(.009)	.040	.49(.012)	198.7
Sawtimber 9.0+	North (6)	4	13	17.7	.500(.010)	.036	.46(.010)	91.4
	N. Central (5)	13	63	12.9	.493(.011)	.045	.46(.005)	527.3
	W. Central (4)	19	83	13.3	.488(.008)	.042	.46(.004)	525.0
	Southeast (3)	27	101	13.5	.530(.005)	.065	.49(.004)	839.9
	Southwest-N (2)	19	110	13.7	.522(.007)	.051	.48(.004)	854.7
	Southwest-S (1)	4	8	12.8	.546(.010)	.042	.50(.013)	166.8

Table 8.--Specific gravity data for loblolly pine in Arkansas

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	Ouachita (4)	1	3	4.3	0.472(--)	---	0.48(--)	--
	Southwest (3)	11	25	4.1	.453(.012)	0.056	.46(.008)	--
5.0- 8.9	Ouachita (4)	3	12	6.6	.488(.018)	.042	.47(.010)	19.0
	South Delta (1)	3	5	7.9	.529(.033)	.058	.49(.016)	16.9
	Southwest (3)	82	187	6.9	.495(.008)	.058	.47(.003)	500.2
9.0-14.9	Ouachita (4)	2	4	11.8	.524(.033)	---	.48(--)	41.9
	South Delta (1)	5	13	11.4	.527(.009)	.034	.48(.010)	16.1
	Southwest (3)	108	258	11.9	.520(.004)	.044	.48(.003)	1,080.3
15.0+	Ouachita (4)	1	2	17.6	.579(--)	---	.50(--)	9.2
	South Delta (1)	3	6	18.4	.522(.010)	.038	.47(.014)	16.5
	Southwest (3)	95	250	18.6	.528(.003)	.037	.47(.003)	918.9
All classes	Ouachita (4)	4	21	8.3	.509(.018)	.061	.48(.008)	70.1
	South Delta (1)	6	24	12.4	.526(.008)	.039	.48(.007)	49.5
	Southwest (3)	171	720	12.7	.514(.004)	.051	.47(.002)	2,499.4
Sawtimber 9.0+	Ouachita (4)	3	6	13.7	.552(.027)	.059	.50(.015)	51.1
	South Delta (1)	6	19	13.3	.526(.006)	.031	.49(.009)	32.6
	Southwest (3)	144	508	15.3	.523(.003)	.038	.48(.002)	1,999.2

Table 9.--Specific gravity data for loblolly pine in Florida

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	Northeast (1)	1	1	4.3	0.490(--)	---	0.49(--)	--
	Northwest (2)	1	1	4.9	.370(--)	---	.41(--)	--
5.0- 8.9	Northeast (1)	6	11	6.0	.507(.015)	0.038	.48(.011)	42.0
	Northwest (2)	12	40	6.9	.463(.030)	.071	.45(.006)	48.8
	Central (3)	1	1	5.3	.576(--)	---	.52(--)	1.7
9.0-14.9	Northeast (1)	9	16	11.9	.558(.013)	.045	.50(.009)	120.4
	Northwest (2)	25	55	11.7	.537(.011)	.060	.49(.005)	111.0
	Central (3)	1	1	11.9	.566(--)	---	.51(--)	5.3
15.0+	Northeast (1)	2	5	17.6	.567(.011)	.034	.50(.016)	82.9
	Northwest (2)	11	36	17.5	.542(.008)	.042	.48(.006)	72.6
All classes	Northeast (1)	12	33	10.6	.540(.010)	.041	.49(.006)	245.3
	Northwest (2)	32	132	11.8	.515(.018)	.063	.48(.003)	232.4
	Central (3)	2	2	8.6	.571(.005)	---	.52(.025)	11.9
Sawtimber 9.0+	Northeast (1)	10	21	13.2	.560(.010)	.042	.51(.008)	203.3
	Northwest (2)	30	91	14.0	.539(.006)	.058	.49(.004)	183.6
	Central (3)	1	1	11.9	.566(--)	---	.52(--)	10.2

Table 10.--Specific gravity data for loblolly pine in Georgia

Diameter class	Survey unit area and number		Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.			Number	Number	In.				Million cu.ft.
3.0- 4.9	Northern	(5)	6	7	4.4	0.436(.020)	0.052	0.45(.014)	--
	N. Central	(4)	16	25	4.5	.426(.008)	.041	.44(.009)	--
	Central	(3)	41	56	4.4	.445(.010)	.046	.46(.007)	--
	Southwest	(2)	2	2	4.2	.443(.014)	---	.46(.024)	--
	Southeast	(1)	4	6	4.5	.515(.039)	.099	.50(.016)	--
5.0- 8.9	Northern	(5)	15	37	6.9	.449(.009)	.052	.44(.006)	103.6
	N. Central	(4)	47	113	6.9	.461(.006)	.053	.45(.004)	288.5
	Central	(3)	105	243	6.7	.462(.005)	.083	.45(.003)	597.0
	Southwest	(2)	14	27	7.1	.479(.013)	.050	.46(.006)	22.3
	Southeast	(1)	20	38	7.0	.505(.020)	.082	.48(.006)	115.5
9.0-14.9	Northern	(5)	10	36	11.4	.510(.012)	.079	.47(.006)	99.5
	N. Central	(4)	52	105	11.0	.481(.006)	.051	.45(.004)	368.9
	Central	(3)	140	324	11.4	.490(.004)	.067	.46(.003)	1059.3
	Southwest	(2)	17	23	11.4	.512(.015)	.068	.47(.008)	82.1
	Southeast	(1)	31	57	12.0	.542(.011)	.057	.49(.005)	243.2
15.0+	Northern	(5)	4	5	20.2	.472(.015)	.034	.43(.016)	34.0
	N. Central	(4)	7	10	17.7	.517(.025)	.075	.46(.011)	71.3
	Central	(3)	53	87	17.0	.500(.004)	.076	.45(.004)	353.9
	Southwest	(2)	8	19	20.4	.560(.005)	.038	.49(.009)	82.5
	Southeast	(1)	17	27	18.0	.544(.012)	.060	.48(.007)	134.8
All classes	Northern	(5)	20	85	9.3	.475(.011)	.078	.46(.004)	237.1
	N. Central	(4)	87	253	8.8	.468(.005)	.054	.45(.002)	728.7
	Central	(3)	210	710	10.0	.478(.003)	.071	.46(.002)	2010.2
	Southwest	(2)	30	71	12.0	.510(.012)	.058	.47(.004)	186.9
	Southeast	(1)	49	128	11.4	.530(.009)	.066	.49(.003)	493.5
Sawtimber 9.0+	Northern	(5)	11	41	12.5	.505(.011)	.076	.48(.006)	133.5
	N. Central	(4)	56	115	11.6	.484(.006)	.055	.46(.004)	440.2
	Central	(3)	158	411	12.6	.492(.003)	.063	.47(.002)	1413.2
	Southwest	(2)	24	42	15.4	.534(.010)	.060	.49(.006)	164.6
	Southeast	(1)	38	84	13.9	.542(.010)	.056	.50(.004)	378.0

Table 11.--Specific gravity data for loblolly pine in Louisiana

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	Not Sampled							
5.0- 8.9	Northwest (5)	21	78	6.9	0.471(.007)	0.042	0.46(.004)	271.6
	Southwest (3)	21	53	6.8	.511(.014)	.075	.48(.005)	229.2
	Southeast (4)	8	23	6.8	.477(.012)	.044	.46(.007)	63.2
9.0-14.9	Northwest (5)	26	91	11.5	.510(.008)	.058	.47(.004)	580.0
	Southwest (3)	20	74	12.0	.550(.013)	.060	.50(.005)	601.4
	Southeast (4)	11	39	12.0	.556(.015)	.056	.50(.006)	251.3
15.0+	Northwest (5)	18	50	19.1	.530(.008)	.044	.47(.005)	618.6
	Southwest (3)	15	60	18.3	.564(.011)	.054	.49(.006)	674.2
	Southeast (4)	7	32	17.3	.557(.012)	.044	.49(.007)	308.7
All classes	Northwest (5)	33	219	11.6	.500(.008)	.053	.47(.003)	1,470.2
	Southwest (3)	29	187	12.5	.543(.009)	.061	.49(.003)	1,504.8
	Southeast (4)	15	94	12.5	.537(.015)	.060	.49(.004)	623.2
Sawtimber 9.0+	Northwest (5)	30	141	14.2	.517(.007)	.053	.48(.003)	1,198.6
	Southwest (3)	23	134	14.8	.556(.011)	.057	.50(.004)	1,275.6
	Southeast (4)	12	71	14.4	.556(.012)	.048	.50(.005)	560.0

Table 12--Specific gravity data for loblolly pine in Mississippi

Diameter class	Survey unit area and number		Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.			Number	Number	In.				Million cu.ft.
3.0- 4.9	North	(2)	29	63	3.9	0.426(.006)	0.054	0.44(.008)	--
	Central	(3)	137	284	4.0	.433(.004)	.054	.45(.006)	--
	South	(4)	75	139	4.0	.446(.005)	.048	.46(.006)	--
	Southwest	(5)	79	193	4.1	.436(.006)	.065	.45(.006)	--
5.0- 8.9	Delta	(1)	3	5	6.5	.484(.003)	.009	.47(.015)	2.1
	North	(2)	66	145	6.8	.470(.007)	.059	.46(.003)	105.9
	Central	(3)	204	478	6.7	.464(.004)	.090	.45(.002)	346.9
	South	(4)	119	260	6.9	.481(.006)	.068	.46(.002)	167.9
	Southwest	(5)	120	315	6.9	.464(.005)	.072	.45(.003)	193.0
9.0-14.9	Delta	(1)	2	2	11.5	.472(.007)	---	.45(.026)	2.2
	North	(2)	48	91	11.2	.491(.006)	.060	.46(.004)	120.3
	Central	(3)	197	469	11.6	.511(.004)	.048	.47(.002)	556.7
	South	(4)	123	297	11.8	.526(.005)	.078	.48(.003)	331.6
	Southwest	(5)	127	346	11.9	.511(.004)	.054	.47(.003)	415.1
15.0+	Delta	(1)	4	6	25.7	.496(.029)	.055	.45(.014)	3.6
	North	(2)	22	47	18.5	.512(.007)	.050	.46(.005)	47.6
	Central	(3)	109	204	17.9	.522(.005)	.048	.47(.003)	343.7
	South	(4)	76	153	18.5	.541(.004)	.050	.48(.004)	297.8
	Southwest	(5)	98	255	18.8	.535(.005)	.058	.47(.003)	398.9
All classes	Delta	(1)	7	13	16.1	.488(.013)	.042	.45(.010)	7.9
	North	(2)	110	346	9.0	.473(.005)	.054	.46(.002)	273.8
	Central	(3)	343	1,435	9.4	.481(.003)	.084	.46(.001)	1,247.3
	South	(4)	225	849	10.2	.502(.004)	.080	.47(.002)	797.3
	Southwest	(5)	216	1,109	10.7	.490(.004)	.063	.46(.001)	1,007.0
Sawtimber 9.0+	Delta	(1)	5	8	22.2	.490(.021)	.049	.44(.013)	5.8
	North	(2)	60	138	13.7	.498(.005)	.057	.47(.003)	167.9
	Central	(3)	233	673	13.5	.514(.003)	.046	.48(.002)	900.4
	South	(4)	152	450	14.0	.531(.004)	.069	.49(.002)	629.4
	Southwest	(5)	156	601	14.8	.521(.004)	.058	.48(.002)	814.0

Table 13.--Specific gravity data for loblolly pine in North Carolina

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	Mountain	(4)	--Not Sampled--					
	Piedmont	(3)	11	23	4.5	0.460(.008)	0.042	0.47(.008)	--
	N. Coast. Plain	(2)	17	29	4.3	.452(.010)	.037	.46(.008)	--
	S. Coast. Plain	(1)	18	24	4.4	.471(.009)	.052	.47(.009)	--
5.0- 8.9	Mountain	(4)	1	1	8.6	.394(--)	---	.41(--)	--
	Piedmont	(3)	40	109	6.8	.461(.006)	.036	.45(.004)	176.6
	N. Coast Plain	(2)	45	116	6.8	.475(.008)	.049	.46(.004)	296.4
	S. Coast Plain	(1)	63	179	7.0	.502(.005)	.054	.48(.003)	313.4
9.0-14.9	Mountain	(4)	1	7	12.1	.391(--)	---	.40(--)	--
	Piedmont	(3)	33	86	11.5	.487(.005)	.036	.46(.004)	339.5
	N. Coast Plain	(2)	87	256	12.1	.527(.006)	.056	.48(.003)	1,023.4
	S. Coast Plain	(1)	86	211	11.4	.538(.004)	.053	.49(.003)	801.5
15.0+	Mountain	(4)	1	8	17.6	.377(--)	---	.37(--)	--
	Piedmont	(3)	8	15	18.0	.487(.016)	.046	.44(.009)	112.9
	N. Coast Plain	(2)	67	181	18.2	.529(.005)	.061	.47(.003)	680.6
	S. Coast Plain	(1)	43	82	18.2	.544(.007)	.056	.48(.005)	385.6
All classes	Mountain	(4)	1	16	14.7	.384(--)	---	.38(--)	--
	Piedmont	(3)	50	233	9.0	.472(.004)	.036	.46(.003)	629.0
	N. Coast Plain	(2)	121	582	12.5	.523(.004)	.057	.48(.002)	2,000.4
	S. Coast Plain	(1)	130	496	10.6	.513(.005)	.054	.48(.002)	1,500.5
Sawtimber 9.0+	Mountain	(4)	1	15	15.1	.384(--)	---	.38(--)	--
	Piedmont	(3)	35	101	12.5	.487(.005)	.034	.46(.004)	452.4
	N. Coast Plain	(2)	110	437	14.6	.528(.005)	.058	.48(.002)	1,704.0
	S. Coast Plain	(1)	104	294	13.3	.539(.004)	.053	.50(.003)	1,187.1

Table 14.--Specific gravity data for loblolly pine in Oklahoma

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	Not Sampled							
5.0- 8.9	South (1)	1	14	7.0	0.527(--)	---	0.49(--)	7.5
9.0-14.9	South (1)	2	6	12.3	.533(.031)	0.091	.49(.015)	16.1
15.0+	South (1)	4	11	19.4	.531(.012)	.028	.47(.011)	34.9
All classes	South (1)	4	31	12.4	.530(.006)	.056	.48(.006)	58.5
Sawtimber 9.0+	South (1)	4	17	16.9	.532(.014)	.064	.48(.009)	51.0

Table 15--Specific gravity data for loblolly pine in South Carolina

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled error	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0-4.9	Piedmont (3)	8	10	4.2	0.449(.016)	0.046	0.46(.012)	--
	N. Coastal Plain (2)	16	24	4.4	.437(.012)	.040	.45(.009)	--
	S. Coastal Plain (1)	6	12	4.4	.457(.015)	.037	.46(.011)	--
5.0-8.9	Piedmont (3)	38	170	6.8	.483(.010)	.057	.46(.003)	311.3
	N. Coastal Plain (2)	70	218	7.1	.480(.005)	.054	.46(.003)	278.2
	S. Coastal Plain (1)	25	107	6.8	.485(.009)	.049	.47(.004)	145.0
9.0-14.9	Piedmont (3)	31	110	11.4	.506(.006)	.050	.47(.004)	584.0
	N. Coastal Plain (2)	86	343	11.8	.511(.004)	.044	.47(.003)	696.0
	S. Coastal Plain (1)	28	101	11.6	.518(.010)	.045	.48(.004)	290.2
15.0+	Piedmont (3)	14	45	18.5	.509(.013)	.046	.46(.006)	245.8
	N. Coastal Plain (2)	63	277	19.3	.532(.004)	.051	.47(.003)	654.3
	S. Coastal Plain (1)	14	38	17.8	.551(.008)	.045	.48(.006)	256.1
All classes	Piedmont (3)	50	335	9.8	.493(.007)	.052	.47(.002)	1,141.1
	N. Coastal Plain (2)	111	862	12.8	.508(.004)	.051	.47(.002)	1,628.5
	S. Coastal Plain (1)	40	258	10.2	.507(.009)	.046	.47(.002)	691.3
Sawtimber 9.0+	Piedmont (3)	35	155	13.5	.507(.006)	.047	.47(.003)	829.8
	N. Coastal Plain (2)	99	620	15.1	.521(.004)	.043	.48(.002)	1,350.3
	S. Coastal Plain (1)	35	139	13.3	.527(.008)	.045	.49(.003)	546.3

Table 16.--Specific gravity data for loblolly pine in Texas

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	Southeast (1)	2	2	2.9	0.495(.030)	---	0.49(.025)	--
5.0- 8.9	Southeast (1)	141	450	7.1	.522(.004)	0.039	.49(.003)	590.5
	Northeast (2)	45	112	7.0	.495(.007)	.037	.47(.004)	123.8
	Post Oak (3)	4	21	7.3	.487(.018)	.041	.47(.008)	--
9.0-14.9	Southeast (1)	180	719	11.8	.536(.004)	.040	.49(.002)	1,528.4
	Northeast (2)	57	157	11.6	.516(.006)	.044	.48(.003)	231.0
	Post Oak (3)	5	13	10.8	.503(.009)	.028	.47(.010)	--
15.0+	Southeast (1)	137	469	18.3	.549(.004)	.044	.48(.003)	1,250.5
	Northeast (2)	36	72	19.3	.529(.007)	.045	.47(.005)	143.0
	Post Oak (3)	2	2	15.4	.467(.020)	---	.43(.024)	--
All classes	Southeast (1)	209	1,640	12.4	.536(.003)	.037	.49(.002)	3,369.4
	Northeast (2)	79	341	11.7	.512(.005)	.046	.47(.002)	497.8
	Post Oak (3)	7	36	9.0	.492(.013)	.038	.47(.006)	--
Sawtimber 9.0+	Southeast (1)	198	1,188	14.4	.541(.003)	.037	.50(.002)	2,778.9
	Northeast (2)	68	229	14.0	.520(.005)	.041	.48(.003)	374.0
	Post Oak (3)	6	15	11.4	.498(.010)	.030	.47(.010)	--

Table 17.--Specific gravity data for loblolly pine in Virginia

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	Coastal Plain (1)	9	12	4.3	0.449(.021)	0.049	0.46(.011)	--
5.0- 8.9	Coastal Plain (1)	56	201	6.9	.478(.007)	.065	.46(.003)	372.8
	S. Piedmont (2)	2	6	7.9	.515(.016)	.043	.48(.014)	30.1
	S. Mountain (5)	1	2	5.6	.354(--)	---	.39(--)	.3
9.0-14.9	Coastal Plain (1)	62	250	11.7	.512(.006)	.042	.47(.003)	932.6
	S. Piedmont (2)	3	7	12.5	.478(.040)	.057	.45(.014)	44.6
15.0+	Coastal Plain (1)	37	98	18.0	.509(.010)	.047	.46(.004)	454.0
	S. Piedmont (2)	3	7	16.7	.518(.024)	.041	.46(.013)	20.2
All classes	Coastal Plain (1)	82	561	10.9	.498(.006)	.054	.47(.002)	1,759.4
	S. Piedmont (2)	6	20	12.6	.503(.021)	.048	.47(.008)	94.9
	S. Mountain (5)	1	2	5.6	.354(--)	---	.39(--)	1.3
Sawtimber 9.0+	Coastal Plain (1)	71	348	13.5	.511(.006)	.040	.48(.002)	1,386.6
	S. Piedmont (2)	5	14	14.6	.498(.028)	.048	.46(.010)	64.8

Table 18.--Specific gravity data for shortleaf pine in Alabama

Diameter class	Survey unit area and number		Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.			Number	Number	In.				Million cu.ft.
3.0- 4.9	Not Sampled								
5.0- 8.9	North	(6)	2	8	6.6	0.480(.009)	0.025	0.46(.011)	49.5
	N. Central	(5)	15	30	6.8	.511(.010)	.054	.48(.006)	181.9
	W. Central	(4)	6	13	6.2	.479(.025)	.066	.46(.008)	118.3
	Southeast	(3)	12	44	6.8	.519(.009)	.057	.48(.005)	169.8
	Southwest-N	(2)	7	14	6.4	.528(.016)	.041	.48(.008)	122.6
	Southwest-S	(1)	2	3	6.6	.473(.004)	---	.46(.007)	16.2
9.0-14.9	North	(6)	5	5	10.0	.562(.044)	.090	.49(.016)	30.2
	N. Central	(5)	9	15	11.4	.532(.019)	.066	.47(.009)	170.3
	W. Central	(4)	8	9	11.1	.534(.022)	.061	.47(.012)	153.7
	Southeast	(3)	13	33	10.2	.544(.009)	.053	.48(.007)	228.5
	Southwest-N	(2)	7	22	12.5	.535(.008)	.058	.47(.008)	293.9
	Southwest-S	(1)	1	3	9.7	.532(--)	---	.47(--)	24.2
15.0+	N. Central	(5)	3	3	17.1	.519(.018)	---	.45(.018)	27.0
	W. Central	(4)	1	1	21.5	.522(--)	---	.45(--)	15.1
	Southeast	(3)	2	3	15.8	.564(.019)	---	.47(.018)	43.8
	Southwest-N	(2)	1	1	17.1	.594(--)	---	.49(--)	73.8
	Southwest-S	(1)	1	2	16.8	.503(--)	---	.44(--)	2.2
All classes	North	(6)	4	13	8.0	.512(.016)	.072	.47(.009)	84.6
	N. Central	(5)	20	48	8.9	.518(.010)	.056	.47(.005)	379.2
	W. Central	(4)	12	23	8.8	.502(.020)	.081	.47(.007)	287.1
	Southeast	(3)	18	80	8.8	.531(.007)	.056	.48(.004)	442.1
	Southwest-N	(2)	10	37	10.3	.534(.006)	.051	.48(.006)	490.3
	Southwest-S	(1)	2	8	10.3	.502(.008)	.039	.46(.012)	42.6
Sawtimber 9.0+	North	(6)	5	5	10.0	.562(.044)	.090	.53(.016)	35.1
	N. Central	(5)	10	18	12.4	.530(.017)	.063	.48(.009)	197.3
	W. Central	(4)	9	10	12.1	.533(.020)	.058	.48(.011)	168.8
	Southeast	(3)	14	36	11.2	.546(.009)	.052	.49(.006)	272.3
	Southwest-N	(2)	7	23	12.7	.538(.006)	.057	.48(.008)	367.7
	Southwest-S	(1)	1	5	12.5	.520(--)	---	.47(--)	26.4

Table 19.--Specific gravity data for shortleaf pine in Arkansas

Diameter class	Survey unit area and number	Sample unit: Locations	Sample unit: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.9- 4.9	Ozark (5)	3	11	4.0	0.483(.005)	0.038	0.48(.013)	--
	Ouachita (4)	13	38	4.0	.500(.008)	.047	.49(.009)	--
	Southwest (3)	6	9	4.5	.523(.040)	.088	.51(.016)	--
5.0- 8.9	Ozark (5)	32	58	6.9	.531(.008)	.061	.48(.004)	149.5
	Ouachita (4)	84	280	7.1	.529(.003)	.045	.45(.003)	547.3
	South Delta (1)	2	2	7.4	.456(.068)	---	.45(--)	5.5
	Southwest (3)	55	105	7.0	.519(.006)	.058	.48(.003)	241.7
9.0-14.9	Ozark (5)	34	74	11.2	.539(.007)	.045	.46(.005)	272.4
	Ouachita (4)	97	395	11.7	.528(.003)	.048	.47(.003)	1,050.0
	South Delta (1)	3	5	13.0	.541(.042)	.036	.48(.016)	13.5
	Southwest (3)	87	213	11.8	.535(.004)	.042	.47(.003)	706.2
15.0+	Ozark (5)	9	15	16.1	.499(.024)	.054	.44(.009)	70.4
	Ouachita (4)	52	102	17.0	.532(.005)	.043	.46(.005)	251.8
	South Delta (1)	2	2	17.2	.507(.020)	---	.44(--)	5.4
	Southwest (3)	44	66	17.5	.546(.006)	.059	.46(.005)	288.1
All classes	Ozark (5)	49	158	9.6	.532(.006)	.051	.48(.003)	492.3
	Ouachita (4)	122	815	11.0	.527(.003)	.043	.47(.002)	1,849.1
	South Delta (1)	4	9	12.7	.520(.015)	.066	.46(.011)	24.4
	Southwest (3)	116	393	11.3	.533(.004)	.051	.47(.002)	1,236.0
Sawtimber 9.0+	Ozark (5)	35	89	12.0	.534(.006)	.026	.48(.004)	342.8
	Ouachita (4)	108	497	12.7	.530(.003)	.045	.48(.002)	1,301.8
	South Delta (1)	3	7	14.2	.523(.016)	.072	.47(.013)	18.9
	Southwest (3)	101	279	13.2	.538(.004)	.050	.48(.003)	994.3

Table 20.--Specific gravity data for shortleaf pine in Florida

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	Northwest (2)	1	1	4.6	0.467(--)	--	0.47(--)	--
5.0- 8.9	Northwest (2)	2	2	8.3	.506(.085)	--	.47(.021)	8.7
9.0-14.9	Northwest (2)	1	1	10.2	.486(--)	--	.44(--)	13.0
15.0+	Not sampled							
All classes	Northwest (2)	3	4	7.8	.491(.032)	0.083	.46(.017)	28.5
Sawtimber 9.0+	Northwest (2)	1	1	10.2	.486(--)	--	.46(--)	19.8

Table 21.--Specific gravity data for shortleaf pine in Georgia

Diameter class	Survey unit area and number		Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.			Number	Number	In.				Million cu.ft.
3.0- 4.9	Northern	(5)	13	23	4.4	0.469(.013)	0.063	0.47(.001)	--
	N. Central	(4)	13	17	4.4	.464(.013)	.056	.47(.011)	--
	Central	(3)	19	22	4.4	.470(.017)	.061	.47(.001)	--
	Southwest	(2)	1	4	4.4	.457(--)	---	.46(.020)	--
5.0- 8.9	Northern	(5)	41	64	6.7	.504(.010)	.067	.47(.004)	186.3
	N. Central	(4)	57	114	7.0	.496(.007)	.044	.47(.003)	272.5
	Central	(3)	57	116	6.7	.489(.008)	.063	.47(.003)	258.5
	Southwest	(2)	2	2	5.5	.486(.010)	---	.46(.021)	6.7
9.0-14.9	Northern	(5)	18	28	11.1	.521(.010)	.050	.46(.007)	165.5
	N. Central	(4)	43	84	10.9	.511(.007)	.072	.46(.004)	245.4
	Central	(3)	59	100	11.3	.508(.005)	.048	.46(.004)	351.6
	Southwest	(2)	3	4	13.2	.565(.025)	---	.49(.018)	19.4
	Southeast	(1)	2	2	12.0	.495(.020)	---	.45(.025)	2.2
15.0+	Northern	(5)	3	4	17.3	.521(.029)	---	.45(.015)	26.9
	N. Central	(4)	1	1	16.0	.560(--)	---	.47(--)	22.8
	Central	(3)	8	13	16.3	.523(.019)	.063	.45(.009)	44.9
	Southeast	(1)	1	1	16.2	.433(--)	---	.41(--)	2.4
All classes	Northern	(5)	52	119	7.7	.502(.009)	.059	.47(.003)	378.7
	N. Central	(4)	77	216	8.3	.500(.006)	.068	.47(.003)	540.7
	Central	(3)	106	251	8.8	.497(.005)	.056	.46(.002)	655.0
	Southwest	(2)	5	10	8.2	.506(.033)	.078	.47(.011)	31.7
	Southeast	(1)	2	3	13.4	.474(--)	---	.44(--)	5.0
Sawtimber 9.0+	Northern	(5)	19	32	11.9	.521(.009)	.048	.47(.006)	192.4
	N. Central	(4)	43	85	11.0	.512(.007)	.072	.47(.004)	268.2
	Central	(3)	62	113	11.9	.510(.005)	.053	.47(.004)	396.5
	Southwest	(2)	3	4	13.2	.565(.025)	---	.50(.018)	25.0
	Southeast	(1)	2	3	13.4	.474(--)	---	.44(--)	4.6

Table 22.--Specific gravity data for shortleaf pine in Louisiana

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	Not Sampled							
5.0- 8.9	Northwest (5)	5	32	7.0	0.477(.011)	0.043	0.46(.006)	176.6
	Southwest (3)	6	23	6.8	.523(.021)	.078	.48(.006)	58.2
	Southeast (4)	1	7	5.6	.464(--)	---	.46(--)	16.0
9.0-14.9	Northwest (5)	10	29	11.4	.522(.013)	.040	.46(.007)	358.4
	Southwest (3)	12	20	12.4	.552(.012)	.059	.48(.008)	135.4
	Southeast (4)	1	5	11.3	.514(--)	---	.46(--)	33.2
15.0+	Northwest (5)	5	6	16.0	.566(.026)	.071	.47(.013)	163.6
	Southwest (3)	7	16	17.3	.585(.011)	.062	.48(.010)	66.2
All classes	Northwest (5)	20	67	9.7	.505(.012)	.052	.46(.004)	698.6
	Southwest (3)	13	59	11.6	.550(.015)	.081	.48(.005)	259.8
	Southeast (4)	1	12	8.0	.485(--)	---	.46(--)	54.2
Sawtimber 9.0+	Northwest (5)	2	35	12.2	.530(.014)	.052	.48(.006)	522.0
	Southwest (3)	14	36	14.6	.567(.011)	.088	.49(.006)	201.6
	Southeast (4)	1	5	11.3	.514(--)	---	.47(--)	38.2

Table 23.--Specific gravity data for shortleaf pine in Mississippi

Diameter class	Survey unit area and number		Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.			Number	Number	In.				Million cu.ft.
3.0- 4.9	Delta	(1)	6	10	3.9	0.433(.013)	0.039	0.44(.014)	--
	North	(2)	129	214	4.0	.472(.005)	.042	.47(.006)	--
	Central	(3)	112	196	4.1	.484(.006)	.092	.48(.006)	--
	South	(4)	35	58	4.0	.482(.011)	.092	.48(.007)	--
	Southwest	(5)	38	80	3.9	.444(.010)	.054	.45(.008)	--
5.0- 8.9	Delta	(1)	9	18	7.7	.494(.014)	.041	.47(.007)	7.7
	North	(2)	211	507	6.9	.506(.003)	.067	.47(.002)	215.6
	Central	(3)	176	428	6.9	.516(.004)	.054	.48(.002)	238.9
	South	(4)	54	105	6.8	.520(.006)	.044	.48(.003)	71.6
	Southwest	(5)	73	146	6.7	.494(.008)	.070	.47(.003)	99.7
9.0-14.9	Delta	(1)	7	27	11.4	.483(.006)	.043	.44(.007)	12.3
	North	(2)	135	304	11.2	.535(.005)	.075	.47(.003)	306.7
	Central	(3)	147	344	11.3	.541(.004)	.078	.48(.003)	371.6
	South	(4)	50	102	11.7	.548(.007)	.053	.48(.004)	132.9
	Southwest	(5)	52	113	11.8	.534(.007)	.061	.47(.004)	116.1
15.0+	Delta	(1)	3	3	17.6	.498(.056)	---	.44(.018)	1.7
	North	(2)	24	41	17.0	.537(.009)	.041	.46(.006)	71.2
	Central	(3)	30	44	16.6	.551(.012)	.073	.47(.006)	59.4
	South	(4)	14	18	16.9	.547(.013)	.044	.46(.008)	30.5
	Southwest	(5)	28	57	17.7	.543(.008)	.051	.46(.006)	61.2
All classes	Delta	(1)	13	58	9.3	.474(.006)	.048	.45(.005)	21.7
	North	(2)	308	1,066	7.9	.509(.003)	.067	.47(.002)	593.5
	Central	(3)	267	1,012	8.3	.520(.003)	.092	.48(.002)	669.9
	South	(4)	93	283	8.6	.524(.006)	.071	.48(.002)	235.0
	Southwest	(5)	118	396	9.2	.502(.006)	.064	.47(.002)	277.0
Sawtimber 9.0+	Delta	(1)	7	30	12.0	.484(.010)	.047	.45(.007)	14.0
	North	(2)	143	345	11.9	.533(.005)	.075	.48(.003)	377.9
	Central	(3)	155	388	11.9	.542(.004)	.077	.49(.003)	431.0
	South	(4)	54	120	12.5	.548(.006)	.053	.49(.004)	163.4
	Southwest	(5)	66	170	13.8	.537(.006)	.058	.48(.003)	177.3

Table 24.--Specific gravity data for shortleaf pine in North Carolina

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	Mountain (4)	6	9	4.5	0.477(.018)	0.040	0.48(.014)	--
	Piedmont (3)	19	25	4.5	.455(.007)	.036	.46(.010)	--
	S. Coast. Plain (1)	3	3	4.5	.560(.004)	---	.54(.026)	--
5.0- 8.9	Mountain (4)	10	28	6.7	.493(.014)	.061	.47(.006)	56.9
	Piedmont (3)	78	190	7.1	.495(.005)	.054	.47(.003)	464.9
	S. Coast. Plain (1)	7	10	6.7	.517(.013)	.042	.48(.009)	24.6
9.0-14.9	Mountain (4)	10	21	11.1	.500(.011)	.054	.45(.008)	111.9
	Piedmont (3)	60	152	11.4	.503(.005)	.049	.45(.003)	581.4
	N. Coast. Plain (2)	3	3	10.8	.554(.023)	---	.48(.021)	26.5
	S. Coast. Plain (1)	3	6	12.0	.571(.007)	.032	.49(.015)	26.4
15.0+	Mountain (4)	3	4	15.9	.554(.009)	---	.47(.016)	19.7
	Piedmont (3)	10	16	16.2	.502(.010)	.034	.44(.008)	81.6
	N. Coast. Plain (2)	2	2	17.8	.480(.050)	---	.43(.022)	8.4
All classes	Mountain (4)	21	62	8.5	.497(.009)	.053	.46(.004)	188.5
	Piedmont (3)	108	383	9.0	.496(.004)	.048	.46(.002)	1,127.9
	N. Coast. Plain (2)	5	5	13.6	.524(.027)	.069	.46(.015)	47.1
	S. Coast. Plain (1)	11	19	8.1	.541(.010)	.043	.49(.008)	55.5
Sawtimber 9.0+	Mountain (4)	11	25	11.9	.508(.010)	.052	.46(.007)	131.6
	Piedmont (3)	61	168	11.8	.503(.005)	.049	.46(.003)	663.0
	N. Coast. Plain (2)	5	5	13.6	.524(.027)	.069	.47(.016)	34.9
	S. Coast. Plain (1)	3	6	19.9	.571(.007)	.032	.48(.015)	30.9

Table 25.--Specific gravity data for shortleaf pine in Oklahoma

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	Not Sampled							
5.0- 8.9	North (2)	3	4	8.1	0.580(.035)	---	0.51 (.015)	7.6
	South (1)	62	194	7.1	.513(.006)	0.055	.48 (.003)	212.2
9.0-14.9	North (2)	2	7	11.2	.548(.030)	.040	.48 (.014)	16.3
	South (1)	64	293	11.7	.522(.004)	.062	.46 (.003)	369.5
15.0+	South (1)	25	46	16.9	.538(.010)	.053	.46 (.006)	84.4
All classes	North (2)	3	11	10.1	.559(.014)	.055	.49 (.010)	24.8
	South (1)	78	533	10.5	.520(.004)	.054	.47 (.002)	666.1
Sawtimber 9.0+	North (2)	2	7	11.2	.548(.030)	.040	.49 (.014)	17.2
	South (1)	67	339	12.4	.524(.004)	.060	.47 (.003)	453.0

Table 26.--Specific gravity data for shortleaf pine in South Carolina

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled error	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0-4.9	Piedmont (3)	13	23	4.4	0.502(.010)	0.054	0.50(.011)	--
	N. Coastal Plain (2)	2	2	4.6	.481(.052)	---	.48(.028)	--
5.0-8.9	Piedmont (3)	50	162	7.0	.506(.008)	.058	.47(.003)	327.2
	N. Coastal Plain (2)	10	19	7.1	.488(.011)	.029	.47(.007)	22.9
9.0-14.9	Piedmont (3)	40	102	11.1	.520(.009)	.051	.46(.004)	323.4
	N. Coastal Plain (2)	9	25	12.0	.522(.010)	.045	.46(.007)	33.9
	S. Coastal Plain (1)	1	2	13.4	.468(--)	---	.43(--)	29.4
15.0+	Piedmont (3)	5	8	16.7	.534(.013)	.034	.46(.011)	50.1
	N. Coastal Plain (2)	6	10	16.9	.567(.017)	.046	.47(.011)	11.7
All classes	Piedmont (3)	63	295	8.5	.511(.006)	.055	.47(.002)	700.7
	N. Coastal Plain (2)	15	56	10.9	.517(.011)	.049	.47(.005)	68.5
	S. Coastal Plain (1)	1	2	13.4	.468(--)	---	.43(--)	45.8
Sawtimber 9.0+	Piedmont (3)	40	110	11.5	.521(.008)	.051	.47(.004)	373.5
	N. Coastal Plain (2)	10	35	13.4	.535(.011)	.050	.48(.006)	45.6
	S. Coastal Plain (1)	1	2	13.4	.468(--)	---	.44(--)	33.9

Table 27.--Specific gravity data for shortleaf pine in Texas

Diameter class	Survey unit area and number		Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.			Number	Number	In.				Million cu.ft.
3.0- 4.9	Southeast	(1)	1	1	4.8	0.558(--)	---	0.54(--)	--
5.0- 8.9	Southeast	(1)	66	157	7.2	.521(.005)	0.037	.48(.003)	277.0
	Northeast	(2)	78	242	7.1	.520(.005)	.048	.48(.003)	313.6
	Post Oak	(3)	4	7	6.9	.536(.007)	.025	.49(.011)	--
9.0-14.9	Southeast	(1)	93	301	11.9	.536(.005)	.056	.47(.003)	689.7
	Northeast	(2)	76	288	11.7	.528(.005)	.044	.47(.003)	527.2
	Post Oak	(3)	1	6	12.4	.487(--)	---	.44(.015)	--
15.0+	Southeast	(1)	39	83	16.8	.541(.007)	.050	.46(.005)	224.9
	Northeast	(2)	28	56	16.9	.523(.013)	.053	.45(.005)	130.1
	Post Oak	(3)	1	1	15.0	.581(--)	---	.48(--)	--
All classes	Southeast	(1)	113	542	11.3	.532(.004)	.042	.47(.002)	1,191.6
	Northeast	(2)	103	586	10.3	.524(.004)	.038	.47(.002)	970.9
	Post Oak	(3)	4	14	9.8	.518(.008)	.042	.47(.009)	--
Sawtimber 9.0+	Southeast	(1)	98	384	13.0	.537(.004)	.052	.48(.003)	914.6
	Northeast	(2)	81	344	12.5	.527(.005)	.044	.48(.003)	657.3
	Post Oak	(3)	1	7	12.8	.500(--)	---	.46(.013)	--

Table 28.--Specific gravity data for shortleaf pine in Virginia

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	S. Piedmont (2)	8	13	4.4	0.442(.017)	0.046	0.45(.012)	--
	N. Piedmont (3)	2	3	4.8	.432(.002)	---	.44(.023)	--
5.0- 8.9	Coastal Plain (1)	8	10	7.5	.491(.012)	.038	.47(.009)	38.9
	S. Piedmont (2)	34	132	7.0	.488(.006)	.050	.47(.003)	223.2
	N. Piedmont (3)	15	47	7.1	.477(.012)	.051	.46(.005)	55.9
	N. Mountain (4)	2	2	8.4	.559(.022)	---	.50(.021)	3.3
	S. Mountain (5)	1	1	5.4	.421(--)	---	.44(--)	6.4
9.0-14.9	Coastal Plain (1)	9	14	11.6	.524(.012)	.048	.47(.010)	73.6
	S. Piedmont (2)	26	77	10.8	.486(.006)	.035	.44(.004)	251.9
	N. Piedmont (3)	11	26	11.3	.467(.015)	.058	.43(.007)	49.8
	N. Mountain (4)	5	7	11.4	.509(.016)	.049	.46(.014)	10.9
	S. Mountain (5)	2	2	11.2	.481(.018)	---	.44(.025)	8.4
15.0+	Coastal Plain (1)	3	5	16.4	.490(.029)	.061	.44(.014)	11.9
	S. Piedmont (2)	5	7	17.9	.491(.018)	.049	.44(.012)	26.7
	N. Piedmont (3)	2	2	17.2	.509(.002)	---	.45(.021)	4.3
All classes	Coastal Plain (1)	13	29	11.0	.507(.012)	.042	.46(.006)	124.4
	S. Piedmont (2)	41	229	8.5	.485(.005)	.045	.46(.003)	501.8
	N. Piedmont (3)	19	78	8.7	.473(.010)	.050	.45(.004)	109.9
	N. Mountain (4)	6	9	10.7	.520(.014)	.044	.47(.011)	17.3
	S. Mountain (5)	2	3	9.2	.461(.026)	---	.44(.020)	17.1
Sawtimber 9.0+	Coastal Plain (1)	9	19	12.9	.515(.014)	.048	.47(.008)	85.5
	S. Piedmont (2)	27	84	11.4	.487(.005)	.035	.45(.004)	278.6
	N. Piedmont (3)	12	28	11.7	.470(.015)	.056	.44(.007)	54.1
	N. Piedmont (4)	5	7	11.4	.509(.016)	.049	.47(.013)	14.0
	S. Mountain (5)	2	2	11.2	.481(.018)	---	.45(.025)	10.8

Table 29.--Specific gravity data for longleaf pine in Alabama

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	Not Sampled							
5.0- 8.9	N. Central (5)	2	6	7.5	0.570(.038)	0.087	0.55(.014)	44.9
	Southeast (3)	7	10	7.1	.536(.016)	.029	.53(.011)	37.1
	Southwest-N (2)	2	2	8.6	.596(.018)	---	.55(.024)	21.8
	Southwest-S (1)	8	19	7.8	.576(.011)	.054	.55(.008)	150.0
9.0-14.9	N. Central (5)	3	6	11.3	.598(.006)	.040	.55(.014)	93.7
	W. Central (4)	1	2	11.0	.529(--)	---	.51(--)	40.0
	Southeast (3)	7	12	12.6	.584(.013)	.034	.54(.010)	95.9
	Southwest-N (2)	4	4	11.4	.566(.019)	---	.53(.017)	52.1
	Southwest-S (1)	8	32	11.3	.582(.010)	.055	.54(.006)	440.0
15.0+	N. Central (5)	2	4	17.2	.517(.029)	---	.49(.018)	33.1
	W. Central (4)	1	1	17.5	.607(--)	---	.54(--)	16.3
	Southeast (3)	1	1	15.1	.632(--)	---	.56(--)	25.1
All classes	N. Central (5)	5	16	11.4	.567(.021)	.062	.53(.009)	171.7
	W. Central (4)	1	3	13.2	.555(--)	---	.52(--)	80.3
	Southeast (3)	12	23	10.3	.565(.014)	.042	.54(.007)	158.1
	Southwest-N (2)	5	6	10.4	.576(.010)	.032	.54(.014)	85.8
	Southwest-S (1)	10	51	10.0	.580(.010)	.053	.54(.005)	654.6
Sawtimber 9.0+	N. Central (5)	4	10	13.7	.566(.022)	.065	.53(.011)	126.8
	W. Central (4)	1	3	13.2	.555(--)	---	.53(--)	56.3
	Southeast (3)	7	13	12.7	.588(.014)	.033	.55(.001)	121.0
	Southwest-N (2)	4	4	11.4	.566(.019)	---	.54(.017)	64.0
	Southwest-S (1)	8	32	11.3	.582(.010)	.056	.55(.006)	504.6

Table 30.--Specific gravity data for longleaf pine in Florida

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	Northeast (1)	2	2	4.8	0.558(--)	---	0.56(--)	--
	Northwest (2)	6	7	4.4	.598(.008)	0.026	.58(.014)	--
	Central (3)	1	1	4.9	.565(--)	---	.56(--)	--
5.0- 8.9	Northeast (1)	27	37	7.3	.577(.011)	.044	.55(.006)	117.2
	Northwest (2)	36	116	7.1	.560(.008)	.041	.54(.004)	255.2
	Central (3)	14	20	7.1	.571(.017)	.070	.55(.008)	26.1
9.0-14.9	Northeast (1)	36	73	11.2	.613(.010)	.082	.56(.005)	362.1
	Northwest (2)	44	121	11.1	.568(.005)	.046	.53(.004)	468.5
	Central (3)	20	26	11.4	.589(.011)	.053	.54(.007)	85.1
	South (4)	1	1	9.0	.646(--)	---	.58(--)	2.4
15.0+	Northeast (1)	1	1	15.0	.609(--)	---	.55(--)	32.6
	Northwest (2)	7	12	17.6	.562(.017)	.060	.51(.012)	34.4
	Central (3)	6	6	16.4	.611(.016)	.036	.54(.015)	16.6
All classes	Northeast (1)	51	113	9.8	.600(.008)	.078	.56(.004)	511.9
	Northwest (2)	57	256	9.4	.565(.005)	.042	.54(.003)	758.1
	Central (3)	33	53	10.2	.584(.009)	.062	.55(.005)	127.8
	South (4)	1	1	9.0	.646(--)	---	.58(--)	3.5
Sawtimber 9.0+	Northeast (1)	36	74	11.2	.613(.010)	.082	.57(.005)	394.7
	Northwest (2)	46	133	11.7	.568(.005)	.046	.54(.004)	502.9
	Central (3)	23	32	12.3	.593(.011)	.051	.55(.006)	101.7
	South (4)	1	1	9.0	.646(--)	---	.59(--)	2.4

Table 31.--Specific gravity data for longleaf pine in Georgia

Diameter class	Survey unit area and number		Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.			Number	Number	In.				Million cu.ft.
3.0- 4.9	Central	(3)	1	1	4.1	0.370(--)	---	0.47(--)	--
	Southwest	(2)	3	4	4.5	.487(.071)	---	.53(.018)	--
	Southeast	(1)	5	5	4.3	.524(.014)	0.034	.55(.016)	--
5.0- 8.9	Northern	(5)	1	1	6.5	.480(--)	---	.51(--)	0.5
	N. Central	(4)	1	1	8.7	.479(--)	---	.49(--)	3.3
	Central	(3)	11	21	7.5	.551(.017)	.080	.54(.008)	42.2
	Southwest	(2)	17	37	7.0	.532(.010)	.040	.53(.006)	71.3
	Southeast	(1)	32	75	7.3	.557(.009)	.068	.54(.005)	202.6
9.0-14.9	Northern	(5)	1	4	12.2	.520(--)	---	.50(--)	3.9
	N. Central	(4)	2	5	11.4	.507(.034)	.060	.50(.016)	9.7
	Central	(3)	18	31	11.4	.559(.011)	.051	.53(.006)	97.3
	Southwest	(2)	25	50	11.9	.571(.008)	.056	.53(.005)	191.6
	Southeast	(1)	38	75	11.0	.564(.010)	.060	.53(.004)	449.4
15.0+	Central	(3)	7	12	18.4	.571(.012)	.055	.52(.013)	23.3
	Southwest	(2)	5	6	15.3	.575(.016)	.036	.53(.014)	46.5
	Southeast	(1)	9	9	16.3	.607(.027)	.091	.54(.013)	43.0
All classes	Northern	(5)	1	5	11.1	.512(--)	---	.50(--)	4.4
	N. Central	(4)	2	6	10.9	.502(.033)	.055	.50(.014)	14.0
	Central	(3)	26	65	11.3	.556(.009)	.071	.53(.005)	162.8
	Southwest	(2)	36	97	9.9	.553(.008)	.064	.53(.004)	309.4
	Southeast	(1)	60	164	9.4	.562(.007)	.061	.54(.003)	695.0
Sawtimber 9.0+	Northern	(5)	1	4	12.2	.520(--)	---	.51(--)	3.9
	N. Central	(4)	2	5	11.4	.507(.035)	.060	.51(.015)	10.7
	Central	(3)	21	43	13.4	.562(.009)	.048	.53(.006)	120.6
	Southwest	(2)	28	56	12.3	.571(.008)	.055	.54(.005)	238.1
	Southeast	(1)	41	84	11.6	.569(.010)	.064	.54(.004)	492.4

Table 32.--Specific gravity data for longleaf pine in Louisiana

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	Not Sampled							
5.0- 8.9	Southwest (4)	1	3	6.6	0.538(--)	---	0.54(--)	35.6
9.0-14.9	Northwest (5)	1	2	13.0	.638(--)	---	.57(--)	14.8
	Southwest (3)	5	5	11.3	.566(.071)	0.172	.53(.015)	132.7
	Southeast (4)	3	13	11.4	.581(.016)	.045	.54(.009)	62.5
15.0+	Northwest (5)	3	3	17.9	.556(.036)	---	.51(.021)	16.5
	Southwest (3)	6	16	18.3	.617(.029)	.059	.54(.012)	78.5
	Southeast (4)	2	3	16.7	.608(.051)	---	.54(.020)	8.4
All classes	Northwest (5)	4	5	16.0	.589(.033)	.082	.53(.015)	34.1
	Southwest (3)	9	21	16.6	.605(.033)	.106	.53(.009)	246.8
	Southeast (4)	4	19	11.5	.578(.009)	.046	.54(.008)	93.1
Sawtimber 9.0+	Northwest (5)	4	5	16.0	.589(.033)	.082	.54(.016)	31.3
	Southwest (3)	9	21	16.6	.605(.033)	.106	.54(.010)	211.2
	Southeast (4)	4	16	12.4	.586(.012)	.034	.55(.009)	70.9

Table 33..--Specific gravity data for longleaf pine in Mississippi

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	Central (3)	2	3	3.8	0.511(.017)	---	0.54(.020)	--
	South (4)	58	90	4.2	.515(.009)	0.056	.54(.007)	--
5.0- 8.9	Central (3)	17	21	7.0	.536(.007)	.034	.53(.008)	9.1
	South (4)	139	311	7.2	.541(.003)	.051	.53(.003)	138.8
	Southwest (5)	5	5	7.6	.489(.028)	.064	.50(.015)	2.9
9.0-14.9	Central (3)	11	15	11.8	.556(.018)	.063	.52(.009)	27.5
	South (4)	186	442	11.3	.566(.004)	.058	.53(.003)	393.0
	Southwest (5)	11	29	11.5	.564(.012)	.057	.53(.007)	14.6
15.0+	Central (3)	5	5	17.2	.589(.028)	.064	.53(.016)	10.9
	South (4)	47	60	16.5	.584(.009)	.058	.53(.008)	70.9
	Southwest (5)	7	11	17.1	.571(.007)	.038	.52(.012)	11.4
All classes	Central (3)	27	44	9.6	.547(.008)	.052	.53(.005)	47.5
	South (4)	276	903	9.5	.553(.003)	.057	.53(.002)	602.7
	Southwest (5)	16	45	12.4	.557(.009)	.079	.52(.006)	28.9
Sawtimber 9.0+	Central (3)	15	20	13.1	.564(.015)	.062	.53(.008)	38.4
	South (4)	208	502	12.0	.568(.004)	.057	.54(.003)	463.9
	Southwest (5)	15	40	13.0	.566(.009)	.055	.54(.006)	26.0

Table 34.--Specific gravity data for longleaf pine in North Carolina

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	N.Coast. Plain (2)	1	1	4.9	0.438(--)	---	0.50(--)	--
	S.Coast. Plain (1)	5	5	4.5	.525(.034)	0.077	.55(.016)	--
5.0- 8.9	Piedmont (3)	1	1	8.9	.469(--)	---	.48(--)	0.9
	N.Coast. Plain (2)	1	4	6.4	.441(--)	---	.49(--)	7.6
	S.Coast. Plain (1)	21	45	7.0	.557(.012)	.075	.54(.006)	136.3
9.0-14.9	Piedmont (3)	1	1	9.1	.439(--)	---	.47(--)	2.8
	N.Coast. Plain (2)	5	12	12.3	.513(.019)	.037	.50(.010)	18.4
	S.Coast. Plain (1)	17	36	11.2	.568(.009)	.057	.53(.006)	154.0
15.0+	N.Coast. Plain (2)	1	1	15.7	.491(--)	---	.48(--)	3.5
	S.Coast. Plain (1)	3	3	16.8	.572(.024)	---	.52(.020)	24.0
All classes	Piedmont (3)	2	2	9.0	.454(.015)	---	.48(.024)	4.2
	N.Coast. Plain (2)	5	18	10.8	.492(.024)	.047	.50(.008)	29.5
	S.Coast. Plain (1)	31	89	8.9	.560(.009)	.066	.54(.004)	314.3
Sawtimber 9.0+	Piedmont (3)	1	1	9.1	.439(--)	---	.48(--)	3.3
	N.Coast. Plain (2)	5	13	12.5	.512(.018)	.036	.51(.010)	21.9
	S.Coast. Plain (1)	18	39	11.6	.568(.008)	.056	.54(.006)	178.0

Table 35—Specificgravity data for longleaf pine in South Carolina

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled error	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0-4.9	S. Coastal Plain (1)	2	4	4.4	0.504(.030)	---	0.54(.018)	--
5.0-8.9	N. Coastal Plain (2)	21	49	7.2	.536(.008)	.050	.53(.005)	80.4
	S. Coastal Plain (1)	14	30	7.4	.533(.011)	.061	.53(.007)	65.5
9.0-14.9	Piedmont (3)	1	2	14.4	.654(--)	---	.57(--)	3.8
	N. Coastal Plain (2)	26	124	11.9	.561(.006)	.063	.53(.004)	233.4
	S. Coastal Plain (1)	18	66	11.2	.557(.010)	.066	.53(.005)	173.0
15.0+	N. Coastal Plain (2)	13	32	17.1	.571(.008)	.033	.52(.009)	60.2
	S. Coastal Plain (1)	7	9	16.9	.555(.015)	.045	.51(.013)	40.2
All classes	Piedmont (3)	1	2	14.4	.654(--)	---	.57(--)	6.2
	N. Coastal Plain (2)	34	205	11.6	.556(.005)	.058	.53(.003)	374.0
	S. Coastal Plain (1)	25	109	10.4	.548(.008)	.060	.53(.004)	278.7
Sawtimber 9.0+	Piedmont (3)	1	2	14.4	.654(--)	---	.58(--)	5.1
	N. Coastal Plain (2)	28	156	13.0	.563(.005)	.061	.53(.004)	293.6
	S. Coastal Plain (1)	20	75	11.9	.557(.008)	.064	.54(.004)	213.2

Table 36.--Specific gravity data for longleaf pine in Texas

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	Not sampled							
5.0- 8.9	Southeast (1)	7	14	7.3	0.541(.022)	0.073	0.53(.009)	24.0
9.0-14.9	Southeast (1)	15	43	12.8	.574(.013)	.048	.53(.006)	111.7
15.0+	Southeast (1)	11	25	16.8	.578(.012)	.044	.52(.010)	57.4
All classes	Southeast (1)	22	82	13.1	.570(.012)	.051	.53(.005)	193.1
Sawtimber 9.0+	Southeast (1)	21	68	14.3	.576(.010)	.044	.54(.006)	169.1

Table 37.--Specific gravity data for slash pine in Alabama

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	Not Sampled							
5.0- 8.9	Southeast (3)	1	1	8.9	0.551(--)	---	0.54(--)	13.7
	Southwest-N (2)	1	3	5.9	.447(--)	---	.48(--)	16.4
	Southwest-S (1)	10	24	6.7	.546(.006)	0.028	.54(.008)	112.4
9.0-14.9	Southeast (3)	2	8	10.7	.551(.009)	.028	.53(.011)	16.0
	Southwest-N (2)	1	2	13.0	.606(--)	---	.54(--)	15.3
	Southwest-S (1)	10	34	11.7	.570(.007)	.052	.53(.006)	254.6
15.0+	Southeast (3)	1	1	15.3	.572(--)	---	.52(--)	10.3
	Southwest-S (1)	4	11	16.6	.576(.008)	.028	.51(.012)	110.3
All classes	Southeast (3)	2	10	11.0	.553(.008)	.026	.53(.011)	40.0
	Southwest-N (2)	2	5	8.7	.511(.076)	.073	.51(.015)	33.7
	Southwest-S (1)	13	69	10.7	.563(.004)	.046	.53(.005)	477.3
Sawtimber 9.0+	Southeast (3)	2	9	11.2	.553(.008)	.027	.54(.012)	26.3
	Southwest-N (2)	1	2	12.9	.606(--)	---	.56(--)	17.3
	Southwest-S (1)	10	45	12.9	.571(.005)	.050	.54(.006)	364.9

Table 38.--Specific gravity data for slash pine in Florida

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	Northeast (1)	15	24	4.4	0.533(.019)	0.060	0.53(.009)	--
	Northwest (2)	8	13	4.4	.517(.029)	.054	.52(.012)	--
	Central (3)	5	6	4.4	.548(.032)	.083	.54(.016)	--
	South (4)	3	4	4.6	.612(.029)	---	.58(.019)	--
5.0- 8.9	Northeast (1)	41	106	6.5	.563(.016)	.066	.55(.005)	768.8
	Northwest (2)	49	166	6.8	.535(.014)	.053	.53(.004)	290.3
	Central (3)	11	22	6.6	.584(.018)	.061	.56(.008)	67.1
	South (4)	9	23	6.8	.635(.033)	.070	.59(.010)	49.4
9.0-14.9	Northeast (1)	32	66	11.0	.603(.012)	.078	.55(.005)	695.9
	Northwest (2)	39	137	11.5	.575(.006)	.051	.53(.004)	340.1
	Central (3)	13	33	11.1	.649(.012)	.060	.57(.008)	126.9
	South (4)	8	11	11.2	.701(.032)	.098	.60(.013)	56.9
15.0+	Northeast (1)	4	6	16.9	.599(.021)	.083	.52(.015)	123.5
	Northwest (2)	16	20	16.3	.578(.010)	.039	.52(.010)	89.8
	Central (3)	3	3	19.3	.644(.057)	---	.53(.022)	37.2
	South (4)	3	3	17.0	.776(.042)	---	.61(.024)	10.4
All classes	Northeast (1)	64	202	8.1	.574(.012)	.068	.55(.003)	1,588.2
	Northwest (2)	64	336	9.2	.553(.010)	.048	.53(.003)	720.2
	Central (3)	23	64	9.3	.617(.013)	.067	.57(.006)	231.2
	South (4)	17	41	8.5	.661(.028)	.082	.59(.008)	116.7
Sawtimber 9.0+	Northeast (1)	35	73	11.5	.606(.012)	.074	.57(.006)	819.4
	Northwest (2)	42	157	12.1	.575(.006)	.051	.54(.004)	429.9
	Central (3)	15	36	11.8	.649(.012)	.062	.59(.009)	164.1
	South (4)	9	14	12.4	.717(.028)	.091	.62(.014)	67.3

Table 39.--Specific gravity data for slash pine in Georgia

Diameter class	Survey unit area and number		Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.			Number	Number	In.				Million cu.ft.
3.0- 4.9	N. Central	(4)	1	1	4.7	0.476(--)	---	0.50(--)	--
	Central	(3)	3	5	4.7	.462(.016)	0.060	.49(.017)	--
	Southwest	(2)	10	15	4.3	.442(.017)	.060	.48(.012)	--
	Southeast	(1)	31	43	4.5	.517(.013)	.095	.53(.008)	--
5.0- 8.9	N. Central	(4)	1	4	7.8	.536(--)	---	.53(--)	6.8
	Central	(3)	6	18	6.4	.447(.016)	.052	.48(.011)	20.3
	Southwest	(2)	34	100	6.8	.484(.013)	.055	.50(.006)	132.4
	Southeast	(1)	105	262	6.8	.542(.006)	.076	.54(.003)	644.3
9.0-14.9	N. Central	(4)	1	4	11.6	.460(--)	---	.48(--)	2.2
	Central	(3)	2	3	11.6	.615(.038)	---	.55(.019)	5.9
	Southwest	(2)	36	71	11.5	.544(.011)	.084	.52(.005)	266.2
	Southeast	(I)	89	197	10.9	.565(.005)	.067	.53(.004)	1,074.0
15.0+	Central	(3)	1	1	16.0	.560(--)	---	.51(--)	1.0
	Southwest	(2)	9	19	17.6	.558(.016)	.051	.50(.011)	74.4
	Southeast	(1)	13	17	16.8	.574(.021)	.109	.51(.010)	192.5
All classes	N. Central	(4)	2	9	9.2	.495(.032)	.054	.50(.012)	9.0
	Central	(3)	7	27	7.0	.473(.024)	.078	.50(.008)	27.2
	Southwest	(2)	56	205	9.2	.509(.012)	.082	.51(.004)	473.0
	Southeast	(1)	153	519	8.5	.549(.004)	.068	.53(.002)	1,910.8
Sawtimber 9.0+	N. Central	(4)	1	4	11.6	.460(--)	---	.49(--)	2.2
	Central	(3)	2	4	12.7	.605(.039)	---	.56(.017)	6.9
	Southwest	(2)	39	90	12.8	.547(.010)	.084	.53(.005)	340.6
	Southeast	(1)	92	214	11.3	.565(.005)	.073	.54(.003)	1,266.5

Table 40.--Specific gravity data for slash pine in Louisiana

Diameter class	Survey unit area and number		Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.			Number	Number	In.				Million cu.ft.
3.0- 4.9	Not Sampled								
5.0- 8.9	Southwest	(3)	1	5	5.8	0.481(--)	---	0.50(--)	37.6
	Southeast	(4)	1	10	7.0	.521(--)	---	.53(--)	29.6
9.0-14.9	Northwest	(5)	1	6	12.2	.573(--)	---	.53(--)	7.9
	Southeast	(4)	2	11	10.6	.570(.016)	0.047	.54(.010)	33.8
15.0+	Northwest	(5)	1	1	15.3	.561(--)	---	.51(--)	1.1
	Southeast	(4)	1	3	17.1	.590(--)	---	.52(--)	14.6
All classes	Northwest	(5)	1	7	12.6	.571(--)	---	.53(--)	24.0
	Southwest	(3)	1	5	5.8	.481(--)	---	.51(--)	96.7
	Southeast	(4)	2	24	9.9	.552(.010)	.052	.53(.007)	78.0
Sawtimber 9.0+	Northwest	(5)	1	7	12.6	.571(--)	---	.54(--)	9.0
	Southeast	(4)	2	14	17.0	.574(.011)	.044	.52(.012)	48.4

Table 41.--Specific gravity data for slash pine in Mississippi

Diameter class	Survey unit area and number		Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.			Number	Number	In.				Million cu.ft.
3.0- 4.9	South	(4)	42	91	3.9	0.510(.007)	0.042	0.52(.008)	--
5.0- 8.9	South	(4)	78	196	7.0	.554(.004)	.065	.55(.004)	153.5
9.0-14.9	South	(4)	87	241	11.4	.580(.006)	.075	.54(.003)	261.0
15.0+	South	(4)	34	48	17.2	.583(.007)	.035	.51(.009)	70.2
All classes	South	(4)	137	576	9.2	.560(.004)	.064	.54(.002)	484.7
Sawtimber 9.0+	South	(4)	98	289	12.4	.580(.005)	.075	.55(.004)	331.2

Table 42 — Specific gravity data for slash pine in South Carolina.

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0-4.9	N. Coastal Plain (2)	2	4	4.4	0.431(.012)	---	0.48(.020)	--
	S. Coastal Plain (1)	8	17	4.6	.426(.011)	.054	.47(.012)	--
5.0-8.9	N. Coastal Plain (2)	4	46	6.3	.462(.024)	.051	.49(.008)	30.6
	S. Coastal Plain (1)	9	83	6.4	.453(.010)	.052	.49(.008)	87.0
9.0-14.9	N. Coastal Plain (2)	1	13	13.2	.548(--)	---	.51(--)	14.1
	S. Coastal Plain (1)	6	11	11.7	.528(.023)	.064	.51(.010)	69.8
15.0+	N. Coastal Plain (2)	1	3	17.0	.538(--)	---	.49(--)	1.7
	S. Coastal Plain (1)	2	5	15.6	.602(.000)	.038	.53(.015)	19.5
All classes	N. Coastal Plain (2)	5	66	8.0	.480(.024)	.053	.50(.006)	46.4
	S. Coastal Plain (1)	14	116	7.0	.463(.012)	.059	.49(.005)	176.3
Sawtimber 9.0+	N. Coastal Plain (2)	1	16	13.9	.546(--)	---	.52(--)	15.8
	S. Coastal Plain (1)	6	16	12.9	.551(.027)	.059	.53(.008)	89.3

Table 43.--Specific gravity data for slash pine in Texas

Diameter class	Survey unit area and number	Sample size: Locations	Sample size: Trees	Mean diameter of sampled trees	Increment core specific gravity: Mean and standard error	Increment core specific gravity: Standard deviation	Estimated tree specific gravity, mean and standard error	Approximate timber volume
In.		Number	Number	In.				Million cu.ft.
3.0- 4.9	Not sampled							
5.0- 8.9	Southeast (1)	2	17	7.0	0.462 (.001)	0.036	0.49 (.010)	25.1
	Northeast (2)	1	1	6.9	.476 (--)	---	.50 (--)	4.4
9.0-14.9	Not sampled							
15.0+	Not sampled							
All classes	Southeast (1)	2	17	7.0	.462 (.001)	.001	.49 (.009)	31.9
	Northeast (2)	1	1	6.9	.476 (--)	---	.50 (--)	7.6
Sawtimber 9.0+	Not Sampled							

Appendix B

Effect of Extractives on Specific Gravity of Slash Pine

The average specific gravities for slash pine show a rather pronounced increase from north to south, particularly in the Florida survey units. It has been suggested that this may be, in part, attributable to differences in extractive content. To explore this possibility, 307 slash pine cores from Florida were extracted for 3 days with alcohol benzene in a Lloyd extractor. The results are given in table 44. Although extraction did reduce the magnitude of the differences between units, the observed trend remains the same.

However, this trend should be regarded with considerable caution. In sampling slash pine, no attempt was made to distinguish between the typical variety (Pinus elliottii Engelm. var. elliottii) and the south Florida variety (Pinus elliottii Engelm. var. densa Little and Dorman). The wood of south Florida slash pine is generally heavier than that of the typical variety. It is, therefore, possible that the observed trend of increasing specific gravity from north to south reflects an increasing proportion of south Florida slash pine in the sample.

Table 44.--Specific gravity of slash pine as affected by extractives

Survey unit	Specific gravity before extraction		Specific gravity after extraction	
	Mean and standard error	Range	Mean and standard error	Range
1-Northeast	0.574 (0.012)	0.40-0.80	0.532 (0.011)	0.35-0.70
3-Central	.617 (.013)	.48- .79	.566 (.010)	.45- .68
4-South	.661 (.028)	.52- .88	.590 (.019)	.47- .70

PART II--STRUCTURAL PROPERTIES AND SPECIFIC GRAVITY

USDA Forest Service Research Paper
FPL 177

Abstract

Reliable estimates of the mechanical properties of clear wood of a timber species are required if this resource is to be used efficiently. The average mechanical properties of the four major southern pines were estimated using a double–sampling technique which combines information from the very intensive Southern Wood Density Survey and mechanical property and specific gravity data from the files of the U.S. Forest Products Laboratory.

Analyses were made using all available property data, and using a traditional subset from wood between 8 and 16 feet above stump. Very small changes in average mechanical properties were found, using either set of data. Most changes were less than 4 percent, and none exceeded 10 percent.

Significance of This Work

The results of clear wood property studies are used to establish allowable properties for stress–graded lumber, plywood, and round timbers. In 1970, softwood lumber production in the South was estimated ai more than 7 billion board feet, yet clear wood properties of the southern pines had not been comprehensively studied for many years. Thus, it is in the public interest to reassess this heavily used resource and confirm that safe, efficient structural application prevails.

More specific information on the detailed surveys of southern pine density are contained in Pari I, Wood Density Survey.

PROPERTIES OF MAJOR SOUTHERN PINES:

Part II STRUCTURAL PROPERTIES AND SPECIFIC GRAVITY

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Introduction

Allowable properties for visual stress grades of lumber (3)[2] and plywood (1) are calculated from mechanical properties of small clear, straight–grained specimens of green wood. Estimates of the mean modulus of elasticity and the mean proportional limit in compression perpendicular to grain are used as bases for computation. For strength properties, the 5 percent exclusion limit is estimated from the average and standard deviation of a sample. Accurate and reliable estimates of mechanical properties of small clear, straight–grained specimens of green wood are an essential part of developing appropriate ratings.

It is, from time to time, necessary to review the strength property data to insure that it is as up to date, accurate, and reliable as possible. The most recent activities in this regard are reported in four publications (5, 6, 8, 12) and include 15 species. Two techniques of sampling and evaluation have been employed. In the present study, the "double–sampling" technique was used.

This report provides (by the double–sampling technique) new estimates of the averages and standard deviations of the important clear wood properties of four principal southern pine species––loblolly, longleaf, shortleaf, and slash pine. A variability index for each property and species is also given as a measure of comparison between small geographic areas and the entire species.

Methods

General

Three methods for sampling properties of clear, straight–grained wood from the forests are compared in a recent paper (7). The double–sampling method was chosen for this study because much of the sampling and data processing required had already been completed or was in process for other studies.

The principles of double sampling are discussed by Freese (9). Basically, they involve estimating one variable by carefully measuring a well–correlated auxiliary

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.
[2] Underlined numbers in parentheses refer to literature cited on p. 67.

variable. The application of double sampling to obtain estimates of the mechanical properties of a timber species is covered in detail in Phase IV of the Western Wood Density Survey (12).

The methods used in this study are essentially the same as those in (12). Four sequential steps lead to the final property estimates: (1) Development of specific gravity–mechanical property relationships; (2) subdivision of the geographic growth range of each species into smaller parts called unit areas; (3) development of estimates of average mechanical properties for each unit area; and (4) combination of unit areas to estimate average mechanical properties and variability indices for each species. Application of these steps is discussed in the following sections. Where these steps differ significantly from those used in (12) the differences are acknowledged in the text and details are presented in the appendix, One of the major differences occurs because early standardized procedures for collection of mechanical property data (4) did not deal with methods of analysis. Thus, a variety of procedures and data combinations are possible. Those employed in this study are discussed in step 1. Other differences between the studies, which are discussed in the appendix, involve the methods of sampling for slash pine regressions and for the formation of unit areas.

Step 1––Specific Gravity–Mechanical Property Relationships

Regression procedures .––Mechanical property estimates are obtained using specific gravity as the independent variable in a linear regression (fig. 1). Regressions of modulus of rupture, modulus of elasticity in bending, maximum crushing strength parallel to grain, maximum shearing strength, and proportional limit strength in compression perpendicular to grain versus specific gravity were computed for each species. It was assumed that a single property–gravity regression applied to all parts of the growth range of each species. Except for slash pine, Forest Products Laboratory data available from earlier research (10) were used for this purpose (both specific gravity and the mechanical property were usually measured on each specimen).

New data were collected for slash pine regressions, except in compression perpendicular to grain, because correlation coefficients based on study (=) ranged as low as 0.2. Section 4.1.4.2 of ASTM D 2555 (2) suggests that a correlation coefficient of at least 0.50 is desirable to provide satisfactory property estimates by double sampling.

The consideration of correlation coefficients was waived for compression perpendicular to grain in longleaf, shortleaf, and slash pines because this property was judged less important structurally.

Shear strength parallel to grain was regressed on the specific gravity value of specimens for compression parallel to grain because specific gravity had not been determined on the shear specimen.

Historical data segregation.––Although not recorded in a published reference , the records of this Laboratory demonstrate that property estimates have historically been based on data from c–d or equivalent bolts only.[3] This is true, for example, for property averages listed in reference (10), and for most of those in table 2 of reference (2). Equivalent bolts have no known definition, but were probably bolts that, in the judgment of the scientist, could be incorporated with c–d samples. In practice, they probably were the only bolts available at the Laboratory for some species, and were then judged equivalent on the basis that some data are preferable to no data. In some instances, specimens taken from lumber of unknown position in the tree were judged equivalent.

[3] "c–d" bolts constitute the portion of the tree bole from approximately 8 to 16 ft above ground line (4).

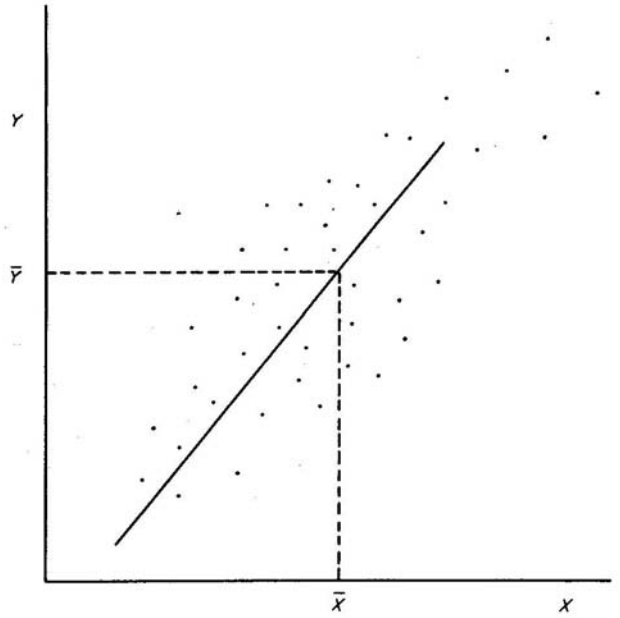

Figure 1.--Schematic representation of the use of the double sampling method to obtain a best estimate of $\bar{y}$, the mean of the dependent variable. The regression is reliably obtained from a relatively small joint sample of x and y; in this application the mean of x is obtained from a separate sample.

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In the Western Wood Density Survey (12), inclusion of data from bolts other than c-d was considered. However, for Douglas-fir in that study, of 62 non-c-d bolts sampled, 26 had been taken from a single tree. It was felt that one tree should not so dominate the sample, and non-c-d bolt data from Forest Products Laboratory files were not used in the study. But in an effort to increase sample size, data from non-c-d bolts reported in an independent study were combined with Forest Products Laboratory data from c-d or equivalent bolts.[4]

In an objectively collected sample from a well-defined population, the quality of a regression is improved by increasing sample size. Early data (10), of course, do not fully meet the present concepts of the objective sampling desired in statistical treatments. Nevertheless, the addition of non-c-d bolts in the Western Wood Density Survey (12) was an effort to improve regression quality.

Current data segregation.--Two data segregations have been employed here, and all tables summarizing results appear in pairs. One of the segregations was simply the use of all available data (except for slash pine as noted earlier); the other segregation was the use of data from c-d or equivalent bolts only. The quality of regressions from the two data sets can be compared by observing the relative size of standard errors (standard deviation from regression divided by square root of sample size). In table 1 the standard error is shown for each species and four properties. The smaller the value, the better the data are grouped around the regression line. Small improvements in regression quality are evident in most cases as a consequence of using data from bolts other than c-d.

Step 1 results.--Table 2 gives the regression coefficients, coefficients of correlation, number of specimens, and the standard deviations from regressions for the four species and five mechanical properties, based on data from all available bolts. Table 3 gives analogous values from c-d or equivalent bolts only. Table 3 contains no information on slash pine because no c-d bolts were studied in the resampling for slash pine regressions (see appendix, p. 74).

[4]See reference (12), p. 67.

Compression perpendicular regression data are included in table 2 only. This is for consistency with the Western Wood Density Survey, where proportional limit in compression perpendicular to grain was not studied. Thus, where tables in this study are based on c–d bolts only, compression perpendicular property estimates are as obtained by direct calculation from compression perpendicular measurements on specimens from the c–d bolts and shown in previous literature (10).

Step 2––Subdivision of Growth Range

The growth range of each of the four southern pines was subdivided into "unit areas" by combining adjacent counties. In developing the rules for combining, it was assumed that the geographic distribution of the mechanical properties of the four species was similar to the specific gravity distribution of loblolly pine. Mitchell (11) published isograms showing a trend of increasing specific gravity from northwest to southeast for loblolly pine from Mississippi through Florida. The rules were written to objectively combine counties in bands that generally parallel the specific gravity isograms, the intent being to combine counties having trees with similar mechanical properties.

The maps in figure 2 delineate the boundaries of the growth ranges in each species. For slash and longleaf pine this includes all counties reported containing live growing stock volume by the U.S. Forest Service Forest Survey. In loblolly and shortleaf pines, peripheral or fringe areas were excluded because the recent Southern Wood Density Survey had not yet been completed in these outlying areas. However, the counties covered by this report contain about 98 percent of the total reported growing stock volume for loblolly and 92 percent for shortleaf.

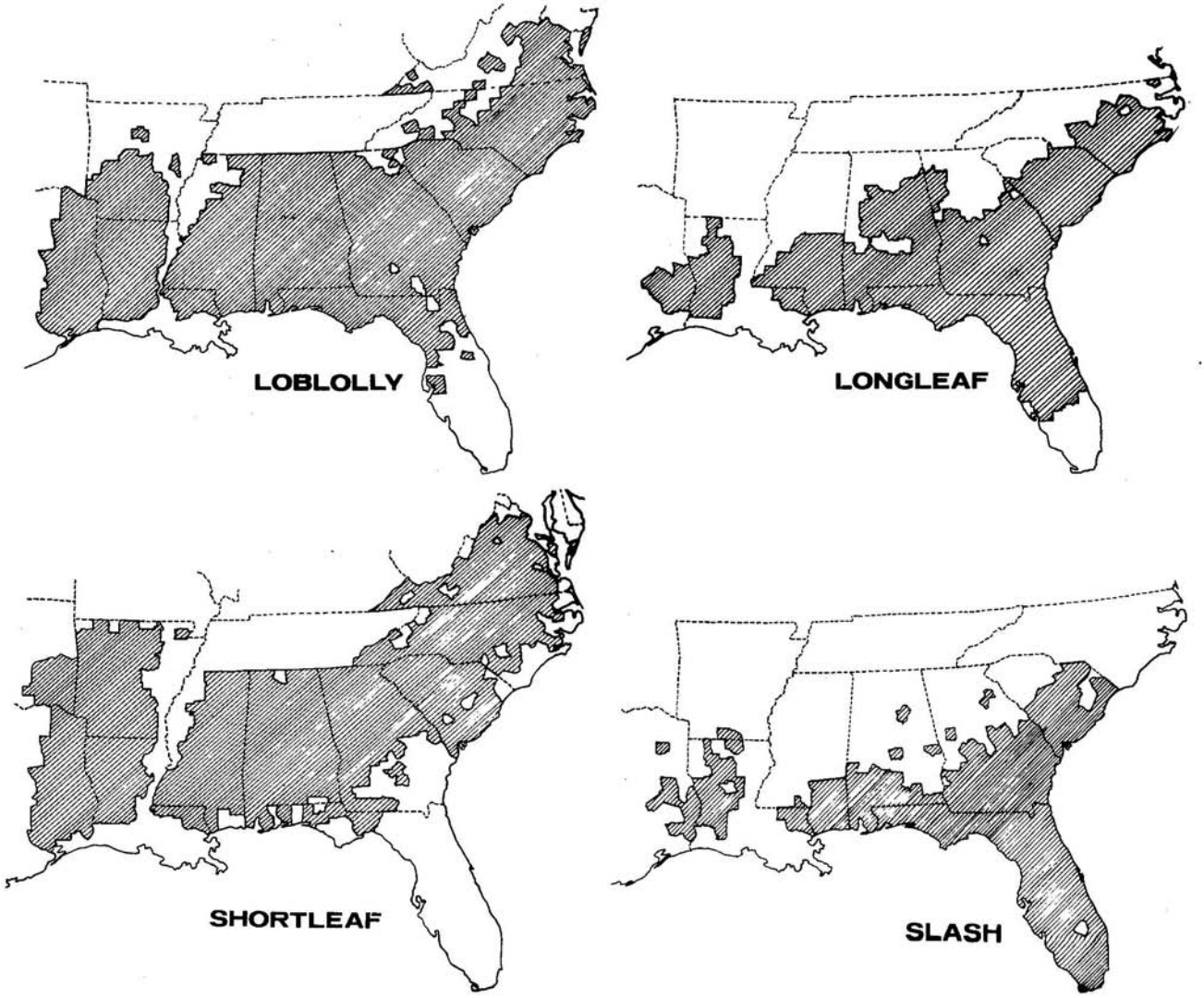

Figure 2.––Boundaries of growth ranges considered in the development of mechanical properties.

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The number of unit areas formed for each species was:

Species	Number of unit areas
Loblolly	81
Longleaf	53
Short 1 ea f	71
Slash	53

The number of counties in a unit area is a function of the volume of timber reported in the counties by the Forest Survey and the intensity of sampling by the wood density survey. In forming the unit areas, counties were combined until at least 1 percent of the total volume of the species was contained in the combination, and until at least 20 trees had been sampled by the density survey in the group of counties.

Step 3--Mechanical Properties for Each Unit Area

A sample estimate of the mean specific gravity of each unit area for each species was determined from the Southern Wood Density Survey data (13). These average specific gravity values were then applied to the specific gravity-property regressions using the regression parameters in tables 2 and 3 to determine average mechanical properties for each unit area. These unit area properties are numerous and were used only for further computations so they are not tabulated here.

Step 4--Estimating Average Mechanical Properties and Variability Indices for Each Species

It is possible to calculate a volume-weighted average mechanical property for any group of unit areas desired. The group average is given by

$$\frac{\Sigma \bar{y}_i V_i}{\Sigma V_i}$$

where $\bar{y}_i$ is the mean of the property for the ith unit area and V_i is the growing stock volume of the species for the ith unit area.

Table 4 gives statistics calculated using specimens from all positions in the tree; table 5 gives statistics based on c-d or equivalent bolts only. For each property a volume-weighted average for all unit areas combined was calculated. These values estimate the mean mechanical properties for each species. Standard deviations were obtained by the regression method described in appendix E of the Western Wood Density Survey (12). Variability indices are also included. The variability index is the ratio of average for the species to the average for the lowest unit area. It measures how small, presumably more homogeneous, unit areas compare with the species as a whole, and is sometimes used in the development of allowable properties.

Since table 5 is based on c–d or equivalent bolts only, the compression perpendicular to grain averages are the same as shown in previous literature (10). Furthermore, since in the traditional literature standard deviations and variability indices for compression perpendicular to grain were not calculated or reported based on c–d bolt data, none are reported in table 5. Table 5 contains no information on slash pine because, as noted previously, no c–d bolts were studied.

The average mechanical property values obtained by both methods of data segregation and computation, and average specific gravity values calculated from data obtained in the Wood Density Survey are compared to estimates currently in use (2) in table 6. For the analysis using data from all bolts, in eight instances these new estimates of mechanical properties exceed the existing estimates, and in 12 instances the new estimates are smaller. For the analysis from c–d bolts only, in seven instances the estimates of mechanical properties exceed the existing estimates, and in five the new estimates are smaller; values for compression perpendicular to grain and specific gravity remain essentially unchanged.

Although a valid statistical comparison cannot be made, it is apparent that the differences obtained in this reevaluation of mechanical properties are small. By either data segregation, in only a few instances does the difference exceed 4 percent above or below the presently used values; none exceed 10 percent.

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Table 1.--standard error for the two alternative data sets

Species and property	c-d or equivalent bolts	All bolts
Loblolly		
Modulus of rupture (p.s.i.)	36.8	35.5
Modulus of elasticity (1,000 p.s.i.)	13.3	13.3
Maximum crushing strength (p.s.i.)	13.0	13.3
Shear strength (p.s.i.)	6.4	6.0
Longleaf		
Modulus of rupture (p.s.i.)	35.9	31.3
Modulus of elasticity (1,000 p.s.i.)	9.6	8.5
Maximum crushing strength (p.s.i.)	15.9	13.7
Shear strength (p.s.i.)	6.3	5.5
Shortleaf		
Modulus of rupture (p.s.i.)	39.8	37.2
Modulus of elasticity (1,000 p.s.i.)	11.1	10.6
Maximum crushing strength (p.s.i.)	15.0	13.4
Shear strength (p.s.i.)	7.3	6.6

Table 2.--Regression results based on data from all bolts

Property	A[1,2]	B[1,2]	Coefficient of correlation	Number of specimens	Standard deviation from regression[3]
			LOBLOLLY		
Modulus of rupture	-418	16,189	0.72	498	793
Modulus of elasticity	1	2,905	.44	494	295
Maximum crushing strength, parallel	-448	8,207	.70	989	419
Shear strength	229	1,311	.56	240	93
Compression perpendicular to grain	-150	1,191	.53	256	98
			LONGLEAF		
Modulus of rupture	-500	16,441	.83	776	872
Modulus of elasticity	20	2,821	.68	774	237
Maximum crushing strength, parallel	-356	8,447	.79	1,452	522
Shear strength	174	1,591	.77	293	95
Compression perpendicular to grain	-135	1,124	.53	483	133
			SHORTLEAF		
Modulus of rupture	88	15,665	.75	508	839
Modulus of elasticity	158	2,654	.56	508	238
Maximum crushing strength, parallel	-261	8,066	.79	750	368
Shear strength	63	1,765	.80	123	73
Compression perpendicular to grain	11	694	.38	400	105
			SLASH		
Modulus of rupture	47	16,152	.87	199	551
Modulus of elasticity	198	2,492	.52	199	252
Maximum crushing strength, parallel	778	5,690	.68	198	423
Shear strength	391	1,070	.56	189	110
Compression perpendicular to grain	-12	998	.38	108	142

[1] Coefficients in the relation Y = A + BX where Y is the mechanical property (in 1,000 p.s.i. for MOE; in p.s.i. for all others) and X is specific gravity.

[2] All digits retained through the unit's position to permit further computations with minimum round-off error. Original data contained 3 significant digits.

[3] The standard deviation from regression is a measure of dispersion about the regression. It is assumed that it represents the standard deviation of property about the line at any choice of specific gravity. This parameter is often called the standard error of estimate. Units are in p.s.i. except MOE, which is in 1,000 p.s.i.

Table 3.--Regression results based on data from c-d or equivalent bolts

Property	A[1,2]	B[1,2]	Coefficient of correlation	Number of specimens	Standard deviation from regression[3]
		LOBLOLLY			
Modulus of rupture	-1,318	18,287	0.77	380	717
Modulus of elasticity	-317	3,648	.56	376	258
Maximum crushing strength, parallel	-967	9,501	.79	747	354
Shear strength	224	1,359	.58	181	86
		LONGLEAF			
Modulus of rupture	-986	17,609	.81	509	811
Modulus of elasticity	-281	3,453	.71	509	216
Maximum crushing strength, parallel	-466	8,851	.77	927	485
Shear strength	298	1,365	.66	210	91
		SHORTLEAF			
Modulus of rupture	67	15,682	.75	457	851
Modulus of elasticity	227	2,472	.54	457	237
Maximum crushing strength, parallel	-300	8,141	.78	649	383
Shear strength	-34	1,999	.82	100	73

[1]Coefficients in the relation Y = A + BX where Y is the mechanical property (in 1,000 p.s.i. for MOE; in p.s.i. for all others) and X is specific gravity.

[2]All digits retained through the unit's position to permit further computations with minimum round-off error. Original data contained 3 significant digits.

[3]The standard deviation from regression is a measure of dispersion about the regression. It is assumed that it represents the standard deviation of property about the line at any choice of specific gravity. This parameter is often called the standard error of estimate. Units are in p.s.i. except MOE, which is in 1,000 p.s.i.

Table 4.--Average, standard deviation, and variability index for mechanical properties of clear, green wood, based on data from all bolts[1]

Modulus of rupture			Modulus of elasticity			Maximum crushing strength parallel to grain			Shear strength			Compression perpendicular to grain: Fiber stress at proportional limit		
Average	Standard deviation[2]	Variability index	Average	Standard deviation[2]	Variability index	Average	Standard deviation[2]	Variability index	Average	Standard deviation[2]	Variability index	Average	Standard deviation[2]	Variability index
P.s.i.	P.s.i.		1,000 p.s.i.	1,000 p.s.i.		P.s.i.	P.s.i.		P.s.i.	P.s.i.		P.s.i.	P.s.i.	
LOBLOLLY														
7,208	1,217	1.07	1,370	338	1.07	3,419	628	1.08	846	119	1.05	412	120	1.09
LONGLEAF														
8,396	1,424	1.06	1,547	306	1.06	4,213	779	1.07	1,038	145	1.05	472	154	1.08
SHORTLEAF														
7,449	1,173	1.04	1,404	276	1.04	3,531	560	1.05	892	118	1.04	337	111	1.04
SLASH														
8,692	1,144	1.09	1,532	296	1.08	3,823	551	1.07	964	128	1.05	523	155	1.09

[1] All digits retained in the average and standard deviation through the unit's position to permit further computation with minimum round-off error, original data contained 3 significant digits.

[2] Estimated by the regression method (12).

Table 5.--Average, standard deviation, and variability index for mechanical properties of clear, green wood, based on data from c-d or equivalent bolts[1]

Modulus of rupture			Modulus of elasticity			Maximum crushing strength parallel to grain			Shear strength			Compression perpendicular to grain: Fiber stress at proportional limit[2]
Average	Standard deviation[3]	Variability index	Average	Standard deviation[3]	Variability index	Average	Standard deviation[3]	Variability index	Average	Standard deviation[3]	Variability index	Average
P.s.i.	P.s.i.		1,000 p.s.i.	1,000 p.s.i.		P.s.i.	P.s.i.		P.s.i.	P.s.i.		P.s.i.
						LOBLOLLY						
7,300	1,199	1.08	1,402	321	1.08	3,511	612	1.09	863	112	1.05	389
						LONGLEAF						
8,538	1,305	1.07	1,586	295	1.07	4,321	707	1.07	1,041	120	1.05	479
						SHORTLEAF						
7,435	1,167	1.04	1,388	268	1.04	3,527	564	1.05	905	125	1.05	353

[1]For mechanical properties, all digits retained in average and standard deviation through unit's position to permit further computation with minimum round-off error. Original data contained 3 significant digits.

[2]Compression perpendicular values are a direct computation from c-d or equivalent bolt data. As traditionally, standard deviations and variability indices are not calculated from the c-d or equivalent bolt data.

[3]Estimated by regression method (12).

Table 6.--Average properties of clear, green wood compared to those currently in use[1]

Modulus of rupture			Modulus of elasticity			Maximum crushing strength parallel to grain			Shear strength			Compression perpendicular to grain: Fiber stress at proportional limit			Specific gravity[2]	
Current values	New values		Current values	New values		Current values	New values		Current values	New values		Current values	New values		Current values	New values[3]
	All bolts	c-d bolts		All bolts	c-d bolts		All bolts	c-d bolts		All bolts	c-d bolts		All bolts	c-d bolts[4]		
P.s.i.	P.s.i.	P.s.i.	1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.		
LOBLOLLY																
7,340	7,208	7,300	1,406	1,370	1,402	3,490	3,419	3,511	850	846	863	389	412	389	0.47	0.47
LONGLEAF																
8,670	8,396	8,538	1,598	1,547	1,586	4,300	4,213	4,321	1,037	1,038	1,041	479	472	479	.54	.54
SHORTLEAF																
7,300	7,449	7,435	1,391	1,404	1,388	3,430	3,531	3,527	851	892	905	353	337	353	.46	.47
SLASH																
8,570	8,692	--	1,588	1,532	--	4,210	3,823	--	958	964	--	529	523	--	.54	.54

[1] Values currently in use taken from ASTM D 2555-73.

[2] Based on green volume and ovendry weight.

[3] Calculated from Southern Wood Density Survey data (Part I) by ASTM D 2555 unit area volume weighting procedure.

[4] Same as current values. See page 64 for explanation.

APPENDIX

Introduction

The methods of data acquisition and analysis in this study of southern pine differ in several ways from methods employed in an earlier study on western species (12). These differences include (a) the procedure for formation of unit areas, (b) the method of clear wood sampling for slash pine, (c) the choice of clear wood specimens to use in establishing property versus specific gravity regressions for loblolly, longleaf, and shortleaf pines, and (d) the use of the regression technique to estimate proportional limit in compression perpendicular to grain. The following paragraphs briefly discuss (a) and (b). Differences (c) and (d) are discussed in the text.

Formation of Unit Areas

Major geographical site features provide natural regional boundaries for some western species, particularly Douglas–fir. This condition does not exist within the growth ranges of the southern pines; as a consequence, the rules for forming unit areas in reference (12) were not applicable to this study. Furthermore, the rules in (12) were cumbersome and somewhat difficult to use. The rules below are greatly simplified. Use of these rules for other species could require slight modification.

In this study, a unit area is defined as a county or group of counties that contain at least 1 percent of the volume of the growing stock of a species existing in the United States. A county is the smallest unit area for which the U.S. Forest Service Survey has reported volume information. An additional requirement for a unit area is that it contain specific gravity measurements from at least 20 trees. Specific gravity was obtained from increment core borings in the Southern Wood Density Survey.

Unit area selection begins by selecting a base county. If the base county does not meet the criteria for volume (1 pct) and density survey (20 cores), adjacent counties are combined with the base county until these criteria are satisfied. Specific procedures for doing so are outlined below. Definitions of terminology used in these procedures are given after the last rule.

Rules

1. Base county.––Select the northwesternmost county (that has reported growth stock volume) of a species growth range as the initial base county. For subsequent base counties, select the northwesternmost "unused" county. Proceed to step 2.

2. Check unit area criteria.––If the base county contains 1 percent or more of the species volume and at least 20 trees were bored in the wood density survey, the county constitutes a unit area; proceed to step 1 to select another base county. If the unit criteria are not satisfied, go to step 3.

3. Combining rule.––Combine with the base county the adjacent unused county that is closest to the reference point. Check for the unit area criteria after the combination. Repeat the combination until the criteria are satisfied, then proceed to step 1. Repeat steps 1, 2, and 3 until all counties containing reported volume are used.

Special combining rules. --

3.1 When the closest county is isolated or with a group of counties that cannot stand alone, it (they) takes precedence over the closest adjacent county.

3.2 If two or more counties are equally close, take the northernmost.

3.3 If two or more counties are equally close and equally northernmost, take the westernmost.

3.4 If an adjacent county or group of counties are isolated in the process of combining and the isolated county or counties cannot stand alone, combine (takes precedence over the closest adjacent) into the unit area being formed even if the volume and core requirements have been satisfied.

Definitions

1. Northwesternmost, northernmost, etc.––A Cleartype county outline map No. 6242 (E 127) made by the American Map Company, Inc., was used in this study. A different map using the rules above could provide a different set of unit areas. The north declination on the map was used as a basis for reference. For instance, a 45° draftsman's triangle slid along a straightedge laying parallel to the north declination defined northwest everywhere on the map. The last point of a county or species growth range remaining uncovered as the triangle is slid northward is the northwesternmost point of the county or growth range. Similar techniques were used to establish northernmost and westernmost.

2. Unused county.––A county which has a reported growing stock volume but which has not been previously used as a base county or combined with a base county.

3. Adjacent county.––Any county that has a common boundary with the base county or any county previously combined with base county. (Point or corner contact does not constitute common boundary.)

4. Reference point.––The northwesternmost point within the boundary lines of the base county. If two or more points are equally northwest, the northernmost point is used for reference.

5. Closest county.––A county, any part of which (inside the boundary line) is closer to the reference point than any part of any other county.

6. Isolated county or counties.––A county or group of counties surrounded by water, by counties for which no volume or cores were reported, by counties that are a part of other unit areas previously formed or the unit area being formed, or by any combination thereof.

7. Cannot stand alone.––Does not have sufficient volume and cores to satisfy the unit area criteria.

Methods of Clear Wood Sampling for Slash Pine

Slash pine was resampled in 1966 because correlation coefficients of the regressions of clear wood properties on specific gravity, based on data reported in reference (10), were judged too low for the purposes of ASTM D 2555. The objective of the resampling was specifically to develop adequate regressions expressing the property–gravity relationships. To establish these relationships, four specimens for each mechanical property test were cut from each of 50 slash pine trees. Two specimens were taken from the a bolt, and two from the highest useful bolt in the tree. Ten trees were obtained from each of five Forest Service Survey units selected because they are reported to contain 75 percent of the total volume of the species. Increment core sampling was used to select trees to obtain a stratified specific gravity sample (and therefore a stratified mechanical properties sample). This resulted in a more uniform distribution of properties over a broad range and an improvement in property–gravity regressions.