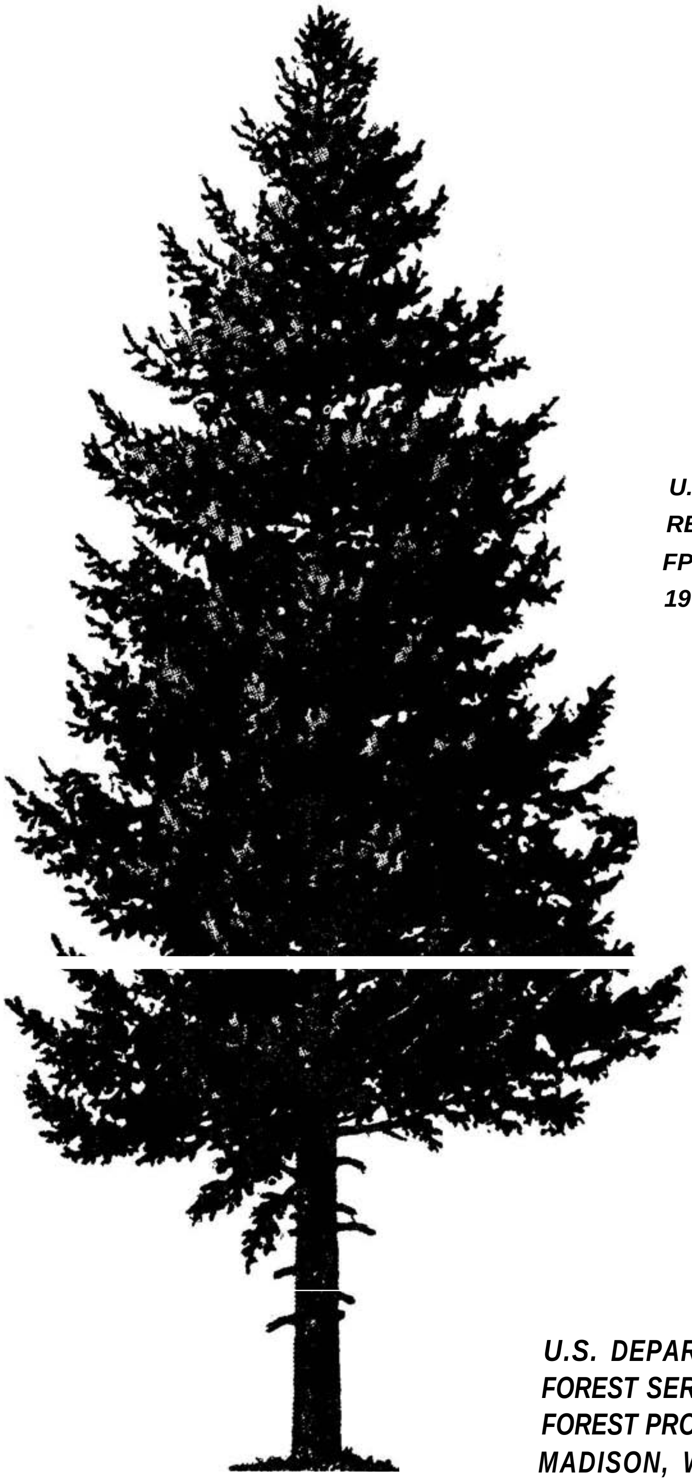
WESTERN WOOD DENSITY SURVEY

Report No. 2



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FOREST SERVICE
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MADISON, WISCONSIN

ABSTRACT

This report presents wood density data for 15 commercially important western timber species, with emphasis on six species not previously evaluated. Data are given for mean specific gravity and variability by states and survey units. Influence of environmental factors is discussed.

ACKNOWLEDGMENT

The assembly of a wood density survey is a task accomplished only by a large amount of cooperation among a wide variety of people. We therefore acknowledge our indebtedness to personnel of the U.S. Forest Service, Bureau of Land Management, State Foresters' offices, industry and logging employees that have assisted us in this study. A special thanks is given to E. Arnold Okkonen for processing materials and data, and to Frank Freese for help on statistical design and analysis.

WESTERN WOOD DENSITY SURVEY

Report No. 2

By

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INTRODUCTION

The Western Wood Density Survey is a long-term program to assess the wood quality, via wood density, for the major western timber species. The program, which was initiated in 1960, resulted in Western Wood Density Survey Report No. 1 (FPL 27) in 1965 (20).[2]

The first report brought together data on nine "priority"[3] species under an accelerated schedule. The report contained information on four phases of work:

Phase I - mass increment core collection by forest survey;
Phase II - increment core processing and data processing;
Phase III - regression equation development for predicting average tree specific gravity from mass sampled increment cores;
Phase IV - double sampling evaluation of mechanical properties.

Data for six additional species are presented in this report, bringing to 15 the total number of western species sampled and analyzed. The species included here, named according to Little (10), are: Ponderosa pine (Pinus ponderosa Laws.); sugar pine (P. lambertiana Dougl.); western white pine (P. monticola Dougl.); lodgepole pine (P. contorta Dougl.); Engelmann spruce (Picea engelmannii Parry); and western redcedar (Thuja plicata Donn) .

Information for these species includes only data for Phases I, II, and III. Data on mechanical properties are not presented because the double sampling procedure has, since Report No. 1, been replaced by direct random sampling methods (2, 3). Detailed data are presented in this report only for the six species noted above. To tie in with previous results, summary data are presented for all 15 species.

Since 1965, three related reports on intensive studies, derived from this work, have been published. These studies involved: (1) The relationships of environmental factors to wood density differences in Douglas-fir (8); (2) an evaluation of sapwood thickness for six species (9); and (3) an evaluation of height-specific gravity relationships for the 15 species thus far sampled (12).

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

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

[3] The species priorities were established by the Western Woods Technical Committee and the species included: Douglas-fir, white fir, grand fir, noble fir, Pacific silver fir, California red fir, western hemlock, western larch, and black cottonwood.

Table 1.--Field data collected

Trees	Cores	Plots
Species	Length (to 0.2 in.)	State
Diameter (to 0.1 in.)	Diameter[1] (to 0.001 in.)	County
		Latitude (to 15 min.)
Bark thickness (to 0.1 in.)	Radial growth, last 10 yr. in Washington, Oregon, and California (to 0.2 in.)	Longitude (to 15 min.)
Total height (or estimated cubic volume)		Elevation (to 100 or 200 ft.)
		Aspect
		Site index tree
		Topographic site
		Basal area per acre

[1]The bore diameter of all increment borers was calibrated to the nearest 0.001 in. and this value was recorded as the core diameter.

Table 2.--Number and location of sample plots and number of cores collected from the plots[1]

State	Sample locations		Sample cores	
	Phase I	Forrer	Phase I	Forrer
Arizona	184		1,254	
California	539		4,960	
Colorado	25		211	
		10		288
Idaho	711		5,114	
Montana	463		4,284	
New Mexico	109		672	
Oregon	849		5,622	
South Dakota	88		397	
Utah	172		1,152	
Washington	787		4,774	
Wyoming	298		1,886	
Subtotal	4,225	10	30,326	288
Total	4,235		30,614	

[1]All sample plots and cores collected during Phase I operations, except those by W. C. Forrer for the U.S. Forest Service.

In the years since the wood density surveys were begun, improvements have been made in methods of sampling and data analysis. Some of these improvements, noted elsewhere in this report, have been responsible for greatly reduced costs without any sacrifice in the reliability of the data.

Throughout this paper the terms density and specific gravity are used interchangeably. However, when figures are shown, density will be given in pounds per cubic foot (p.c.f.). Volume determinations are made on the fully water swollen (green) basis.

OBJECTIVES

The objectives of the Western Wood Density Survey are to:

1. Obtain, by systematic sampling, adequate data on average wood density and related wood quality characteristics for each of the sampled species, the magnitude of the differences between species, and the range of variation within each species.

2. Determine, if possible, the extent to which wood density varies with tree age, tree volume, tree growth rate, climate, longitude, latitude, altitude, aspect, and other growth factors.

3. Allow for the selection of superior trees from the systematic sampling, based on superior wood quality as well as form, growth rate, and other desirable characteristics, to be used for genetics studies and tree breeding programs.

PROCEDURES

Phase I--Systematic Mass Sampling of Increment Cores[4]

This phase consisted of collecting increment cores from sample trees and gathering related data concerning the trees and their environment. A complete description of sampling procedures can be found in Report No. 1 (20).

The data were obtained from sample plots distributed throughout the commercial forest area of 12 western states. Although some features of the sampling design and plot design varied between areas, the same information concerning trees, cores, and tree environment was collected in all cases (table 1). All collections were made between 1960 and 1963 except for additional sampling in Colorado by Forrer (5).

The sampling resulted in a total of 30,614 cores collected at 4,235 sample locations distributed by states as shown in table 2.

As originally conducted, Phase I sampling was concentrated on the priority species reported earlier. Because of this emphasis, some species were not sampled as intensively as they could have been in all areas. For example, 38 percent of the total volume of Engelmann spruce is found in Colorado, yet only 15 cores were collected in Phase I from that state. A total of 1,501 cores were collected for the species in all states. Because of this imbalance, data collected by Forrer (5) have been added to achieve a better representation of Engelmann spruce in Colorado.

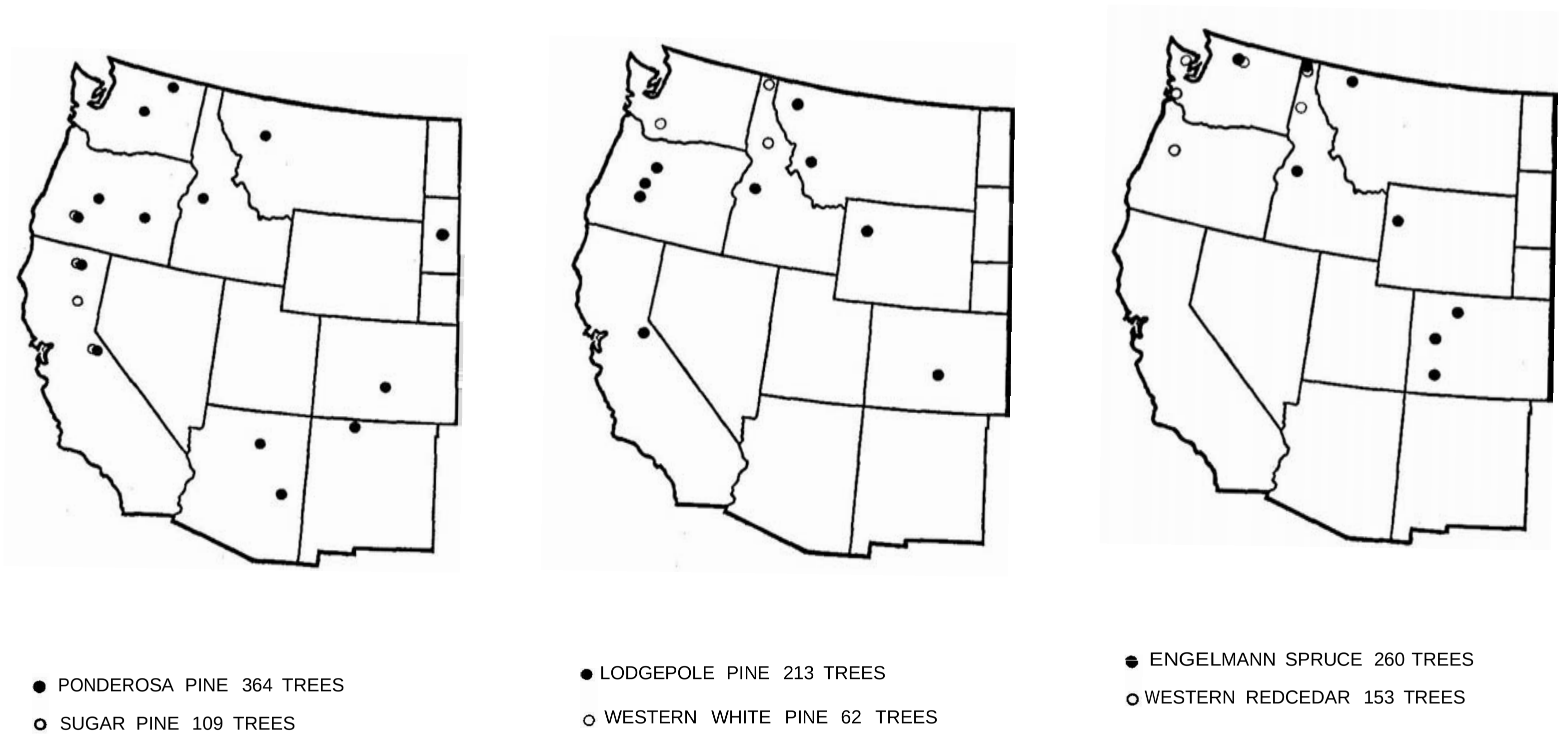

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Figure 1.--Phase III sample areas for the six species.

Phase II--Increment Core Processing and Data Processing

Increment cores and their accompanying field data were received at the Forest Products Laboratory from the Experiment Stations responsible for their collection. The data obtained from the cores at the Laboratory included sapwood thickness, specific gravity, and an estimate of age. These data were included with the field data for computer processing.

Age estimates were based on annual ring counts made on the cores. It should be pointed out that the ring count: estimates of age became less accurate with larger diameter, older trees. Cores were limited to a maximum length of 10 inches. Therefore, in trees exceeding 20 inches in diameter inside bark (d.i.b.), the number of rings, from the inner core end to pith center, had to be estimated. The average ring count for the 2 inches of core nearest the pith was used to extrapolate the ring count to pith.

The use of diameter-calibrated increment borers and green core length permitted the calculation of green core volume. Cores were ovendried and weighed to 0.001 gram. Cores were not extracted.

Data processing included: Conversion of increment core specific gravity to average tree specific gravity; calculation of standard errors of estimated average tree specific gravity; and development of specific gravity-environmental regressions.

Phase 111--Sampling to Estimate Tree Specific Gravity

To convert the increment core specific gravity data gathered in Phase II to average tree specific gravity, it was necessary to develop prediction equations. Basically the procedure consisted of selecting trees, extracting cores, felling trees and cutting cross sections, processing disks and cores for specific gravity data, and calculating the regression equations.

The techniques used are detailed in Report No. 1 (20) except for field procedure variations noted in the following discussion.

In the earlier work, a presampling system of double stratification by diameter at breast height (d.b.h.) and core specific gravity was used in selecting trees for analysis. Selection of trees for the six species included in this portion of the survey was based on a single d.b.h. stratification. This change reduced the number of man-hours required for field sampling. The precision of the regressions presented in this paper was as good as for those reported in Report No. 1 (20), as determined by coefficients of determination and standard deviations from regression.

Field Procedures

Plot selection.--Trees were selected on plots throughout the western United States to insure a representative sample of the natural distribution proportional to volume for each of the sampled species (fig. 1). All plots were in areas of active logging to facilitate sample collection.

Sample collection.--At each location a total of 40 to 70 trees was stratified by 5-inch diameter classes within the range of diameters available and cores were taken. Within each diameter class a random selection was made[5] until the desired number of cores was achieved. Final sample size by area ranged from 12 to 41 cores.

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[5] Cores containing branch knots, pitch pockets, compression wood, or other defects were eliminated prior to random selection.

After cores were selected, the trees from which the cores were taken were felled and logs[6] cut progressively, starting at a point 4.5 feet from the ground, to a merchantable top diameter.[7] Disks 1 to 2 inches thick were cut from the butt end of each log and from the top of the last log and debarked. Disk d.i.b. was measured and recorded to the nearest 0.1 inch. For large trees the disks were then reduced to wedges for ease of handling. Log lengths, live crown length, and unused length of top were recorded to the nearest 0.1 foot for each tree. Disks or wedges were then shipped to the Forest Products Laboratory for further processing.

Laboratory Procedure

At the Laboratory disks or wedges were water-saturated to insure green volume. After saturating, the volume was determined by the rapid water immersion method (6). The disks were then ovendried to a constant weight; specific gravity was computed on the green volume-ovendry weight basis.

The merchantable volume of each tree was calculated as the summation of log volumes, including disks. The average specific gravity for each log was estimated from the mean specific gravity of its terminal disks. (Computational details are shown in appendix A.) In estimating the average specific gravity of the tree, the specific gravity for each log was weighted in proportion to log volume. Specific gravity of increment cores was determined as detailed for Phase 11.

RESULTS AND DISCUSSION

Multiple Regression Analysis (Phase 111)

The relationships of average tree specific gravity (Y) to average core specific gravity and other tree characteristics were examined by multiple regression analysis, using the following 10 independent variables:

X_1 = Diameter at breast height

X_2 = Total height of tree

X_3 = Age of tree

X_4 = Merchantable volume

$X_5 = (X_1)^2$

X_6 = Core specific gravity

$X_7 = X_4$ divided by X_3

X_8 = Reciprocal of age

$X_9 = X_1$ divided by X_3

X_{10} = Reciprocal of core specific gravity

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[6] Log lengths of 16 ft. were used when possible.

[7] Merchantable top diameters varied from 3-10 in. with locale, species, and tree diameter.

Table 3.--Best and next best variables for predicting tree specific gravity from core specific gravity in simple regressions

Species	Variable	r^2	Significance[1]	n
Ponderosa pine	[2]X_6	0.5798	**	364
	X_1	.0155	*	364
Sugar pine	X_6	.7081	**	109
	X_4	.0101	NS	109
Western white pine	X_6	.4919	**	62
	X_1	.0201	NS	62
Lodgepole pine	X_6	.7491	**	213
	X_2	.1644	**	213
Engelmann spruce	X_6	.6898	**	260
	X_{10}	.3632	**	260
Western redcedar	X_{10}	.4400	**	153
	X_6	.4227	**	153

[1]* = Significant at 0.05 level of probability.
** = Significant at 0.01 level of probability.
NS = Not significant.

[2]X_1 = D.b.h., X_2 = total height, X_4 = merchantable volume, X_6 = core specific gravity, X_{10} = reciprocal of core specific gravity.

Table 4.--Regression equations for predicting tree specific gravity from core specific gravity

Species	Equations	[1]r^2 or R^2	Standard deviation from regression
Ponderosa pine	$Y = 0.10843 + 0.61391X_6$	[2]0.5798	0.020
	[3]$Y = 0.11597 + 0.62973X_6 - 0.00078X_1$	.6198	.020
Sugar pine	$Y = 0.11803 + 0.58201X_6$	.7081	.013
	[3]$Y = 0.11332 + 0.58762X_6 + 0.00011X_1$	.7104	.013
Western white pine	$Y - 0.19593 + 0.40548X_6$	.4919	.015
	[3]$Y = 0.19006 + 0.46851X_6 - 0.00109X_1$	.6217	.013
Lodgepole pine	$Y = 0.06464 + 0.76173X_6$	.7491	.025
	[3]$Y = 0.05586 + 0.76467X_6 + 0.00068X_1$	.7527	.025
Engelmann spruce	$Y = 0.08639 + 0.72896X_6$	.6898	.021
	[3]$Y = 0.10297 + 0.69920X_6 - 0.00035X_1$	.6935	.021
Western redcedar	$Y = 0.19012 + 0.39013X_6$	.4227	.023
	[3]$Y = 0.20616 + 0.36160X_6 - 0.00034X_1$	.4310	.023

[1]r^2 = coefficient of determination for simple regression; R^2 = coefficient of determination for multiple regression.

[2]All regressions significant at 0.01 level of probability.

[3]Equations used to convert Phase II core data; X_1 = d.b.h., X_6 = core specific gravity.

Of the simple regressions developed for the six species, core specific gravity was the best variable, based on r^2, for five of the species and reciprocal of core specific gravity was best for the other one (table 3). The simple regressions with core specific gravity as the independent variable are shown in figure 2.

The inclusion of a second variable, in addition to core specific gravity, did not significantly improve the regressions for ponderosa pine, sugar pine, lodgepole pine, Engelmann spruce, or western redcedar. A significant improvement was made, though, in the regression for western white pine, where the addition of d.b.h. reduced the residual sum of squares and subsequently the standard deviation from regression significantly (P = 0.01), table 4.

The inclusion of three or more variables in multiple regression resulted in a significant improvement only for lodgepole pine and only with three variables. The addition of total height to d.b.h. and core specific gravity yielded an R^2 of 0.8083 and a standard deviation from regression of 0.022 ($Y = 0.05826 + 0.68012X_6 - 0.00209X_1 + 0.00096X_2$).

The multiple regressions used to convert Phase II core data (table 4) arbitrarily use core specific gravity and d.b.h. as independent variables, to conform with equations found in Report No. 1.

Although there is not much improvement with the multiple regressions over the simple, the use of the equations with core specific gravity and d.b.h. are recommended because d.b.h. is so easily obtained and some precision is gained.

Regression equations for the original nine species of the Survey may be found in appendix A.

Analysis of Increment Core Sample Data (Phase 11)

The Western Wood Density Survey (Phase 11) was designed to establish the mean and range of estimated tree specific gravity by species. It was also designed to permit the investigation of other factors (tree and environmental) that might affect wood specific gravity.

Estimated specific gravity means and ranges by species.--Histograms of estimated tree specific gravity, along with sampling area maps, are shown in figures 3 to 5. Where sampling locations were within 15 minutes of longitude or latitude of each other they are shown as solid areas on the maps.

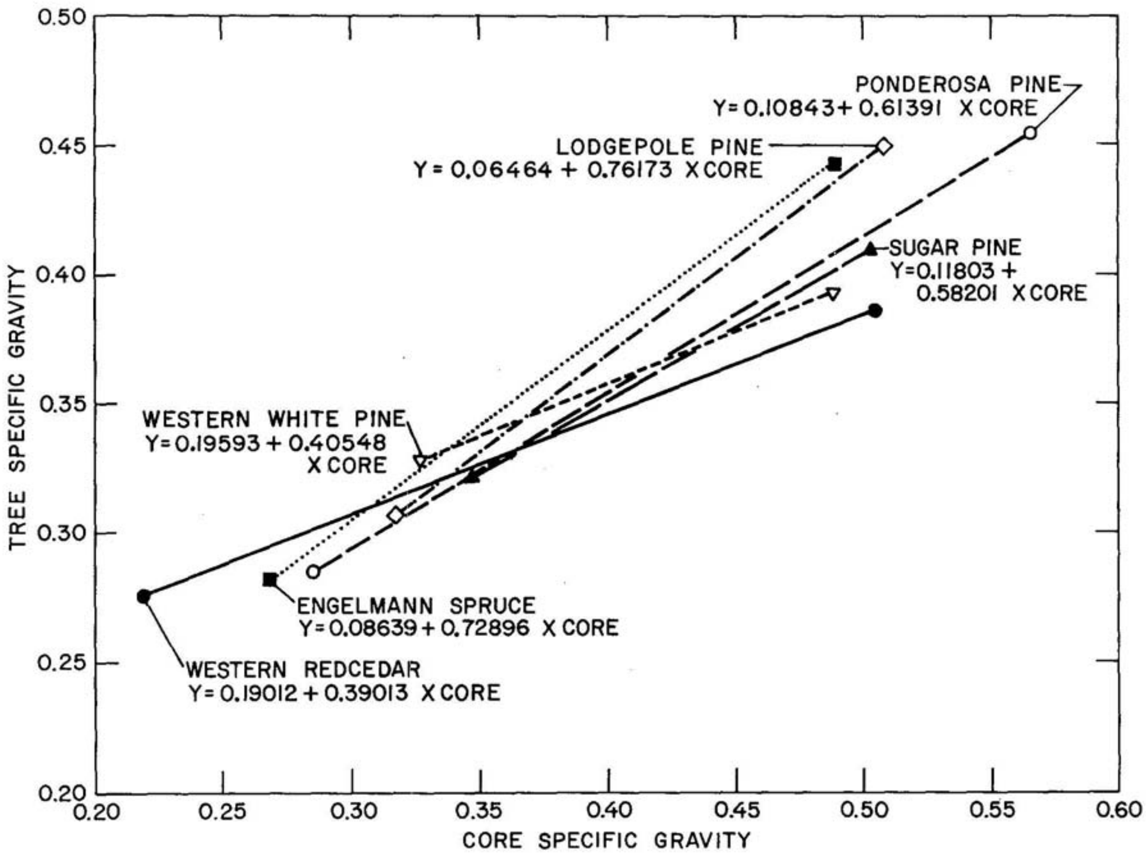

Figure 2.--The relationships of increment core specific gravity and average tree specific gravity for ponderosa pine, sugar pine, western white pine, lodgepole pine, Engelmann spruce, and western redcedar.

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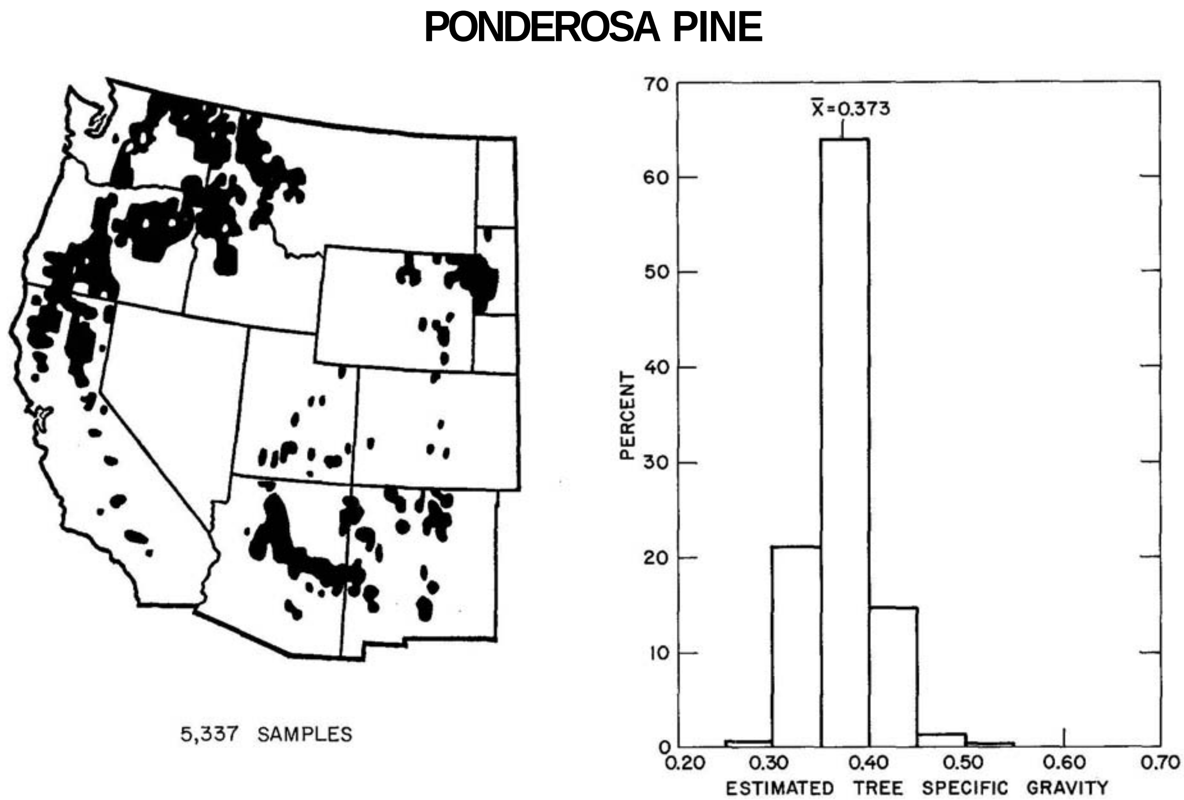

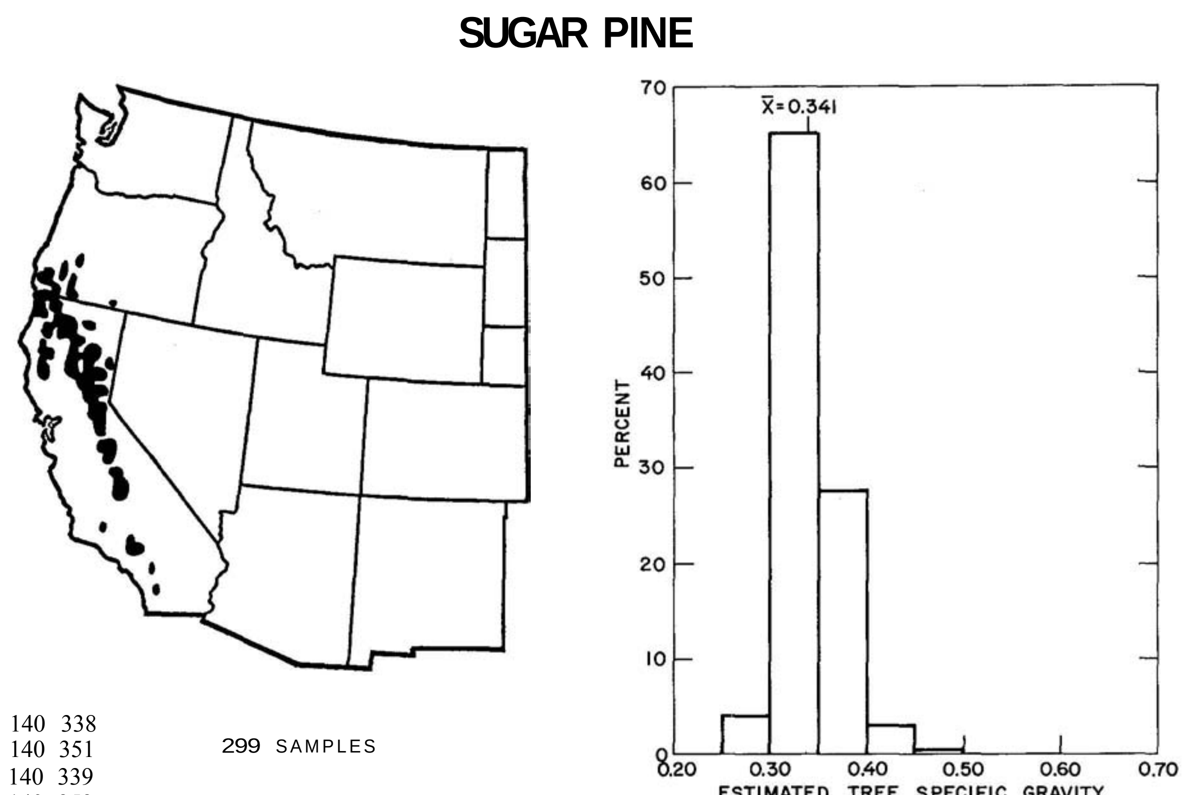

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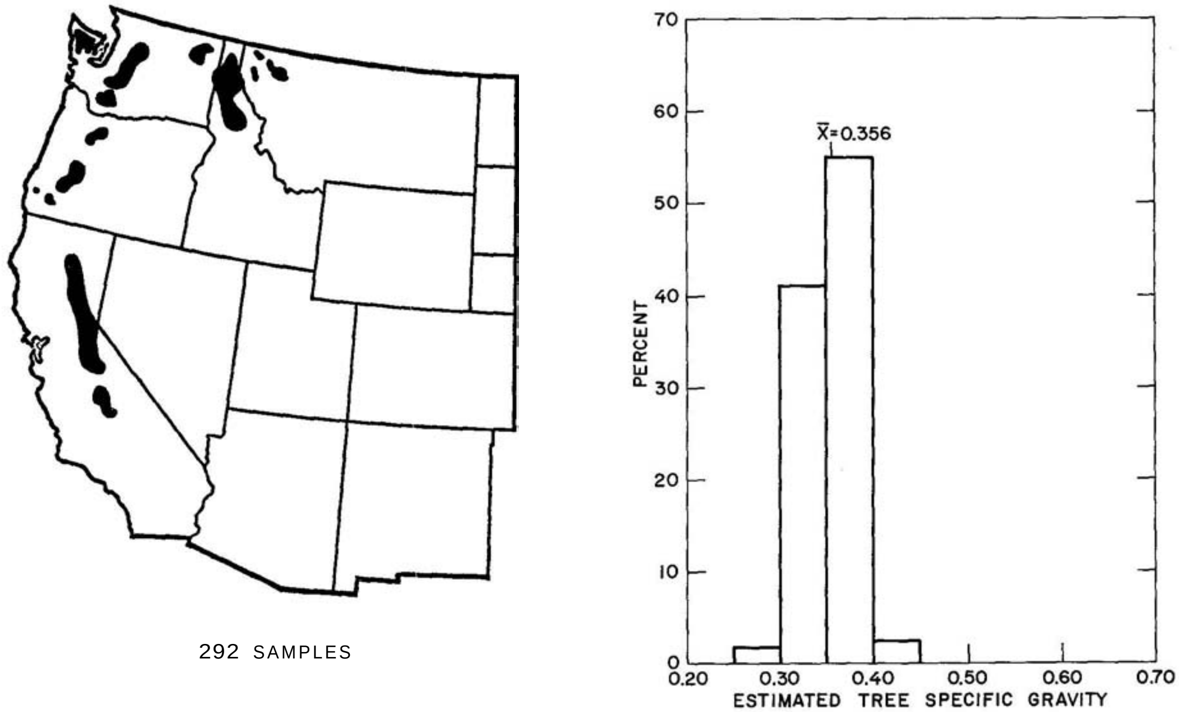
Figure 3.--Sample areas and estimated tree specific gravity for ponderosa and sugar pine.

WESTERN WHITE PINE



LODGEPOLE PINE

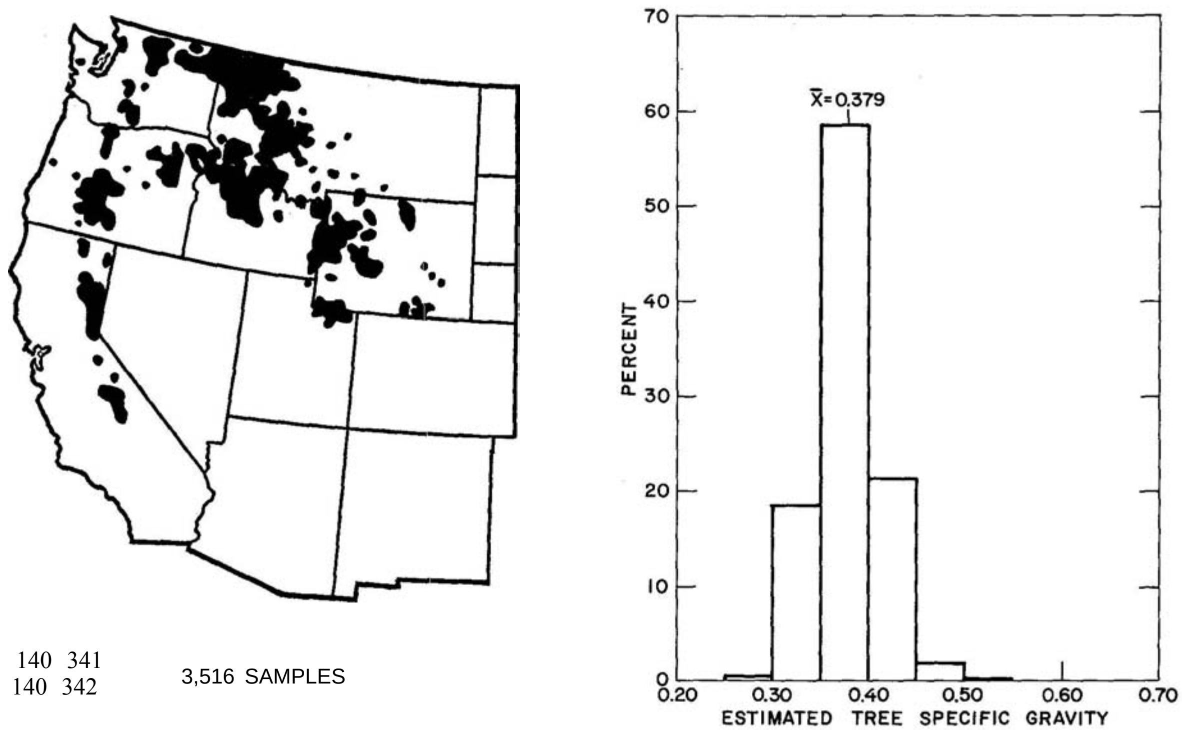


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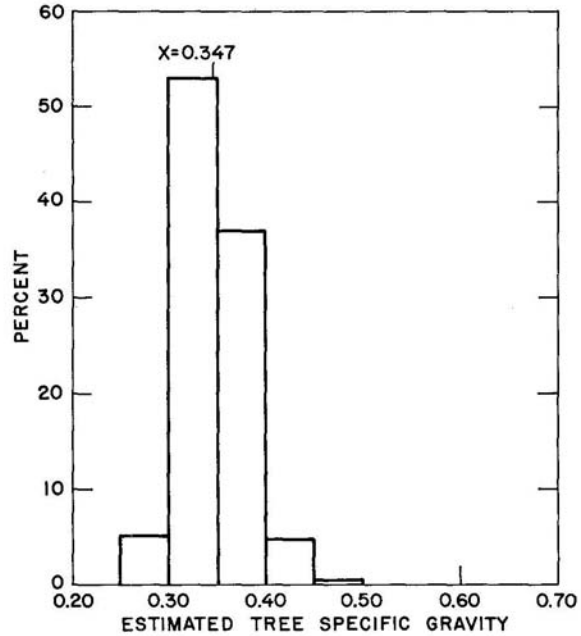
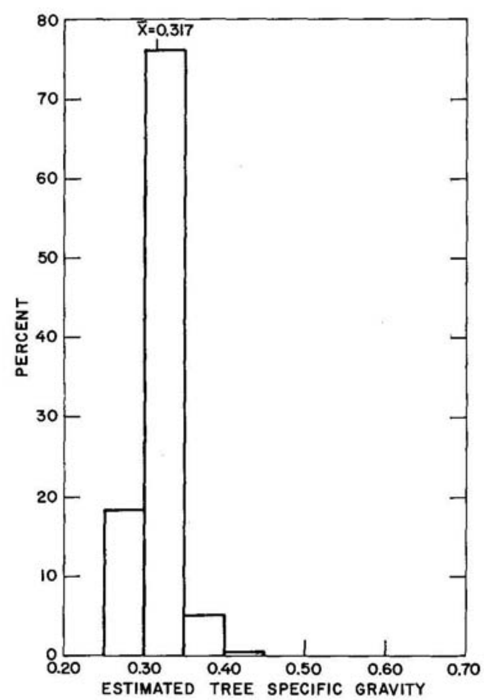
Figure 4.--Sample areas and estimated tree specific gravity for western white, and lodgepole pines.

ENGELMANN SPRUCE



1789 SAMPLES

WESTERN REDCEDAR



504 SAMPLES

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M 140 336
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Figure 5.--Sample areas and estimated tree specific gravities for Engelmann spruce and western redcedar.

Table 5 presents the average estimated tree specific gravity and its standard error, range of estimated tree specific gravity, average core specific gravity, average diameter, and the standing volume weighting factor[8] by the Forest Survey units outlined in figure 6. In table 5, the standard errors indicate the precision with which the sample means estimate the population means for estimated tree specific gravity. Roughly, unless a 1-in-20 chance has occurred in the sampling, the sample mean will be within two standard errors of the population mean. Computational details for obtaining average tree specific gravity and standard error are given in appendix A.

A summary of mean estimated tree specific gravity and related data is shown for all 15 species in table 6. The values for mean estimated tree specific gravity are weighted by the volume weighting factors found in table 5. Mean core specific gravities are simple, unweighted values.

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[8] The standing volume weighting factor is the percent volume present in the Forest Survey unit, e.g., the Arizona unit contains 12.17 pct. of the volume of ponderosa pine in the U.S.

Figure 6.--Forest Survey units.

M 140 350

Table 5.--Specific gravity and related data by species and Forest Survey units

Forest Survey unit	Average estimated tree density	Average estimated tree specific gravity	Range of estimated tree specific gravity	Standard error of average estimated tree specific gravity	Number of trees sampled	Average core specific gravity	Average d.b.h. for sample trees	Volume weighting factor for species means
	P.c.f.						In.	Pct.
PONDEROSA PINE								
Arizona	22.91	0.367	0.275-0.539	0.0012	1,067	0.423	18.2	12.17
California (1)	22.54	.361	.286- .454	.0034	195	.409	22.0	5.87
(2)	22.72	.364	.284- .451	.0036	165	.431	23.5	10.00
(3)	23.54	.377	.271- .468	.0036	152	.433	19.0	4.97
(4)	23.22	.372	.302- .408	.0134	14	.421	15.5	.82
(5)	22.72	.364	.305- .443	.0069	35	.429	30.5	.51
Colorado	22.29	.357	.337- .390	.0036	10	.401	13.9	2.36
Idaho (N)	23.41	.375	.314- .485	.0033	160	.434	18.0	2.83
(S)	22.91	.367	.270- .458	.0023	355	.422	18.3	4.68
Montana (W)	23.54	.377	.290- .489	.0032	353	.429	14.9	4.53
New Mexico	22.97	.368	.305- .505	.0018	439	.418	16.7	9.31
Oregon (W)	23.91	.383	.336- .507	.0069	61	.470	20.9	1.67
(E)	23.16	.371	.289- .467	.0012	1,111	.427	20.1	24.14
South Dakota	24.78	.397	.332- .515	.0020	388	.458	11.9	2.19
Utah	22.66	.363	.320- .423	.0034	99	.415	18.9	1.01
Washington (W)	24.16	.387	.352- .434	only one location	7	.443	9.9	.05
(E)	23.78	.381	.310- .479	.0018	541	.441	17.2	9.75
Wyoming	24.60	.394	.327- .502	.0037	185	.460	12.7	1.62
SUGAR PINE								
California (1)	20.91	.335	.298- .405	.0068	25	.370	28.5	4.08
(2)	20.91	.335	.291- .425	.0022	140	.378	30.2	44.93
(3)	21.23	.340	.286- .415	.0051	46	.376	31.4	19.32
(4)	21.54	.345	.307- .392	.0055	23	.395	28.9	15.24
(5)	22.16	.355	.306- .453	.0053	33	.408	30.0	.13
Oregon (W)	20.66	.331	.282- .432	.0051	29	.383	33.8	15.63
(E)	21.79	.349	.320- .377	.0140	3	.391	23.4	.66
WESTERN WHITE PINE								
California (1)	21.91	.351	.295- .410	.0094	22	.400	24.6	2.09
(2)	21.23	.340	.288- .376	.0051	20	.385	28.6	4.48
Idaho (N)	22.16	.355	.300- .433	.0029	149	.385	15.1	51.96
Montana (W)	22.60	.362	.310- .416	.0039	35	.404	14.3	6.96
Oregon (W)	22.41	.359	.316- .448	.0088	17	.413	18.8	13.16
(E)	21.66	.347	.324- .376	.0080	7	.403	21.2	2.96
Washington (W)	22.29	.357	.316- .391	.0086	17	.391	19.2	8.75
(E)	23.10	.370	.335- .434	.0076	25	.412	14.1	8.28
LODGEPOLE PINE								
California (1)	25.03	.401	.292- .505	.0088	52	.425	16.1	2.94
(2)	23.29	.373	.328- .430	.0047	23	.398	22.5	1.75
Colorado	21.66	.347	.264- .401	.0084	8	.371	7.9	14.26
Idaho (N)	23.91	.383	.303- .512	.0045	166	.415	9.7	5.42
(S)	23.54	.377	.285- .498	.0022	811	.409	9.0	10.61
Montana (W)	24.22	.388	.305- .509	.0019	1,015	.425	8.3	18.61
(E)	22.66	.363	.319- .405	.0051	39	.394	9.8	13.37
Oregon (W)	26.34	.422	.328- .554	.0137	61	.464	9.9	1.75
(E)	24.10	.386	.319- .493	.0026	415	.420	9.7	8.34
Utah	22.79	.365	.284- .425	.0025	200	.394	9.1	4.21
Washington (W)	26.97	.432	.388- .512	.0393	4	.472	9.6	.32
(E)	24.28	.389	.319- .499	.0040	179	.417	8.1	6.12
Wyoming	23.16	.371	.298- .482	.0023	542	.398	10.4	12.01
ENGELMANN SPRUCE								
Arizona	20.54	.329	.285- .384	.0041	33	.333	16.6	1.41
Colorado	21.04	.337	.258- .507	.0022	303	.343	13.7	37.84
Idaho (N)	21.98	.352	.278- .433	.0055	85	.363	16.0	5.25
(S)	21.85	.350	.285- .447	.0040	169	.362	16.0	5.68
Montana (W)	22.60	.362	.292- .507	.0035	248	.374	15.3	13.80
(E)	21.79	.349	.280- .436	.0059	52	.361	12.4	3.45
New Mexico	21.04	.337	.307- .424	.0035	26	.346	12.6	4.31
Oregon	22.10	.354	.317- .397	.0041	29	.370	14.7	4.63
Utah	21.35	.342	.263- .499	.0017	291	.352	15.6	7.42
Washington	22.79	.365	.293- .444	.0046	56	.383	15.9	5.91
Wyoming	21.54	.345	.261- .503	.0014	497	.357	16.6	10.30
WESTERN REDCEDAR								
Idaho (N)	20.04	.321	.273- .393	.0029	144	.322	15.6	11.64
Montana (W)	20.29	.325	.288- .407	.0043	71	.357	14.5	6.48
Oregon (W)	19.60	.314	.279- .372	.0021	67	.326	31.5	23.08
Washington (W)	19.42	.311	.269- .421	.0017	171	.318	26.1	55.21
(E)	19.98	.320	.296- .382	.0033	51	.338	15.5	3.59

Sources of specific gravity variation.--The items involved in wood specific gravity variation are seemingly innumerable. Environmental factors such as moisture availability, temperature, wind, and sunlight play important roles in affecting wood specific gravity. These factors are in turn affected by longitude, latitude, elevation, aspect, slope, slope position, soil type, stocking density, stand composition, etc. All of these elements affect cell diameter, cell length, cell wall thickness, packing density, and amount of extractives (4, 13, 14, 16, 17).

Specific gravity patterns with height, diameter, and age have also been reported by many authors (1, 11, 15, 17, 18, 19, 21, 22, 23).

At best, in areas of little climatic and topographic variation, relationships between wood specific gravity and environmental factors have only been fair. Lassen (8) studying Douglas-fir of a fixed age class in an area of limited climatic variation and on sites of specified elevation and rainfall could account for only 53 percent of the specific gravity variation with precipitation and a function of elevation. Knigge (7) in the same region and again with Douglas-fir accounted for only 34 percent of the specific gravity variation with seven variables.

Table 6.--Specific gravity data for 15 western species

Species	Mean estimated tree density	Mean estimated tree specific gravity	Range of estimated tree specific gravity	Mean core specific gravity	Number of trees sampled	Wood Handbook average specific gravity[1]
	P.c.f.					
Douglas-fir	28.0	0.45	0.33-0.59	0.47	9,133	[2]0.45
White fir	23.0	.37	.26- .54	.39	2,150	.35
California red fir	22.5	.36	.31- .46	.41	840	.37
Grand fir	21.8	.35	.24- .55	.39	862	.37
Pacific silver fir	25.0	.40	.28- .55	.41	330	.35
Noble fir	23.0	.37	.26- .44	.42	158	.35
Western hemlock	26.2	.42	.30- .52	.45	1,040	.38
Western larch	30.0	.48	.38- .54	.54	678	.51
Black cottonwood	19.4	.31	.28- .40	.35	120	.32
Ponderosa pine	23.0	.37	.27- .54	.43	5,337	.38
Sugar pine	21.2	.34	.28- .45	.38	299	.35
Western white pine	22.5	.36	.29- .45	.39	292	.36
Lodgepole pine	23.7	.38	.26- .55	.41	3,516	.38
Engelmann spruce	21.8	.35	.23- .58	.36	1,789	.32
Western redcedar	20.0	.32	.27- .42	.33	504	.31

[1] Wood Handbook values are developed from small clear wood specimens. U.S. Forest Products Laboratory, Wood Handbook. U.S.D.A. Agr. Handb. 72. 1955.

[2] Value for Coast type; Intermediate type 0.41, Rocky Mountain type 0.40.

In a survey such as the one reported here, correlations are even poorer because of the broad range of sites included. Table 7 shows coefficients of determination for the four variables: Latitude, longitude, elevation, and aspect. The best relationship involving these variables and estimated tree specific gravity, in simple regression, occurred between specific gravity and longitude for lodgepole pine in the West Coast survey units (r^2 = 0.1334). This relationship accounts for only 13 percent of the variation in specific gravity. In multiple regression all four variables account for only 29 percent of the variation in specific gravity (R^2 = 0.2896).

For the other species, results range downward from those noted above.

Figures showing the variation and relative distribution of core specific gravity and diameter at breast height are shown in appendix B. The sample of increment core specific gravities for this study approach normal distributions while the distribution of diameter is weighted toward the small diameters, as would be expected of natural forest stands.

It is important to realize that because wood specific gravity varies widely within trees, between trees, and between areas, results such as presented here apply only to the populations specified.

Table 7.--Coefficient of determination (r^2), by Forest Survey Units for the regression of physical factors on estimated tree specific gravity

Survey Units(s)	Latitude	Longitude	Elevation	Aspect
PONDEROSA PINE				
West Coast	0.0654	0.0021	0.1102	0.0703
California Sierra	.0132	.0023	.0836	.0003
Interior South	.0061	.0002	.0129	.0009
Interior North	.0082	.0223	.0147	.0000
South Dakota	.0237	.0005	.0009	.0026
SUGAR PINE				
California-Oregon	.0152	.0052	.0130	.0085
WESTERN WHITE PINE				
Combined Units	.0458	.0067	.0803	.0263
LODGEPOLE PINE				
Interior South	.0058	.0125	.0030	.0131
Interior North	.0095	.0069	.0033	.0016
West Coast	.0098	.1334	.0127	.0106
California Sierra	.0723	.0000	.0098	.0033
ENGELMANN SPRUCE				
Interior South	.0379	.0041	.0023	.0000
Interior North and West Coast combined	.0239	.0146	.0192	.0001
WESTERN REDCEDAR				
West Coast	.0012	.0053	.0001	.0006
Interior North	.0658	.0057	.0051	.0002

SUMMARY AND CONCLUSIONS

This report presents data on six additional timber species evaluated in the Western Wood Density Survey. Statistics shown for wood density are means, ranges, and standard errors by species within survey units, and means and range for species as a whole.

Mean tree specific gravity values are: Ponderosa pine, 0.37; sugar pine, 0.34; western white pine, 0.36; lodgepole pine, 0.38; Engelmann spruce, 0.35; and western redcedar, 0.32. These data, except for Engelmann spruce, are within 0.01 of the established Wood Handbook values. The Engelmann spruce value exceeds the older value by 0.03. While general agreement exists between the two sources, the reliability of these new data are far greater than those of the Wood Handbook, which were based on a very limited sample size.

Because of the broad geographic range and the great variety of sites encountered in this study, correlations between specific gravity and latitude, longitude, elevation, and aspect yielded no trends. Studies on limited areas where variations in environmental factors could be monitored might yield information on the causes of density variation.

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APPENDIX A

Computational Details and Prediction Equations
for Nine Priority Species from FPL 27

1. Log volume was computed by the following formula:

$$V = (\text{d.i.b.})^2 \times 0.0054542 \times \text{length in feet}$$

2. Specific gravity of each disk was computed by the following formula:

$$\text{Disk specific gravity} = \frac{\text{ovendry weight of disk}}{\text{displaced volume of disk}}$$

3. Increment core specific gravity was computed with the following formula:

$$\text{Increment core specific gravity} = \text{ovendry weight (grams)} \div 12.8754\ (\text{core diameter})^2\ (\text{core length})^{1}$$

4. Specific gravity means and standard errors for Forest Survey Units were computed as follows:

(a) Specific gravity means.

Given: k = number of locations from which density samples were obtained.
n_i = number of trees (of a given species) sampled at location i ($i = 1 \ldots k$).
G_{ij} = specific gravity of the jth sampled tree at the ith location ($j = 1 \ldots n_i$).
B_i = basal area per acre observed at the ith sample location.

$$G_i = \frac{\sum_{j=1}^{n_i} G_{ij}}{n_i} = \text{average specific gravity for location } i$$

$$W_i = B_i G_i = \text{weighted specific gravity for location } i$$

$$\text{then, } \bar{G} = \frac{\sum_{i=1}^{k} B_i G_i}{\sum_{i=1}^{k} B_i} = \frac{\sum_{i=1}^{k} W_i}{\sum_{i=1}^{k} B_i} = \text{average specific gravity for a Survey Unit.}$$

(b) Standard error.

$$\text{Standard error of } \bar{G} = \sqrt{\frac{k}{(\Sigma B_i)^2}\left[\frac{\Sigma W_i^2 + \bar{G}^2(\Sigma B_i{}^2) - 2\bar{G}\Sigma B_i W_i}{k-1}\right]}$$

[1] Both core diameter and core length are measured in inches.

Multiple Regressions Predicting Tree Specific Gravity Using Core Specific Gravity and D.b.h.

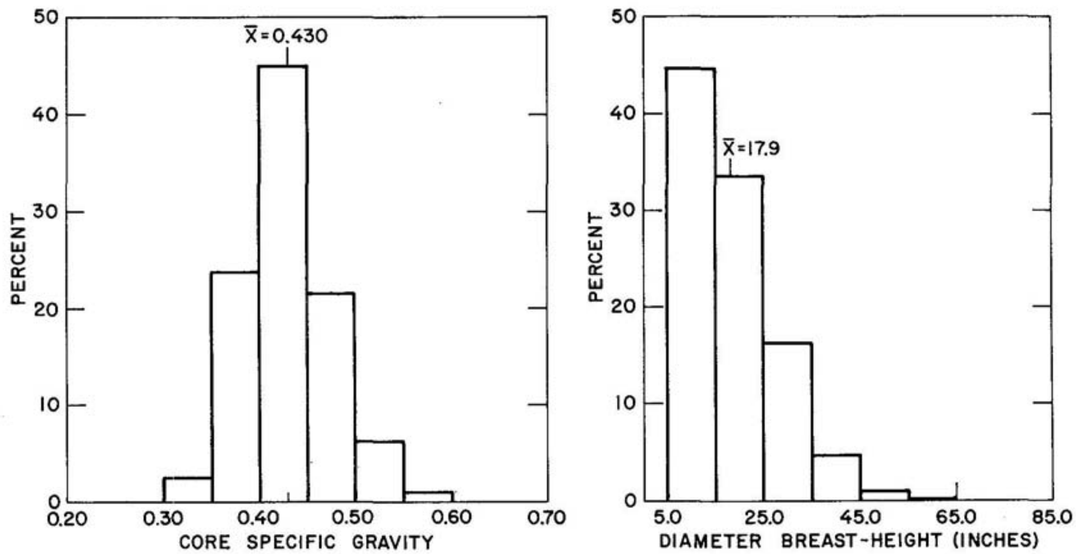
Species	Equation	R^2 [1]	Standard deviation from regression
Douglas-fir	$Y = 0.17219 + 0.63623X_6 - 0.00107X_1$	0.6100	0.023
White fir	$Y = 0.13559 + 0.63528X_6 - 0.00062X_1$	.6095	.019
California red fir	$Y = 0.18053 + 0.47318X_6 - 0.00045X_1$	.4859	.023
Grand fir	$Y = 0.01876 + 0.80654X_6 - 0.00054X_1$	.6681	.024
Pacific silver fir	$Y = 0.14388 + 0.64930X_6 - 0.00096X_1$	.6492	.026
Noble fir	$Y = 0.29638 + 0.28141X_6 - 0.00161X_1$	.5887	.016
Western hemlock	$Y = 0.25630 + 0.47233X_6 - 0.00220X_1$	.7022	.023
Western larch	$Y = 0.27429 + 0.43400X_6 - 0.00199X_1$	.4394	.023
Black cottonwood	$Y = 0.14364 + 0.54095X_6 - 0.00055X_1$	.4828	.019

[1] The "coefficient of determination" (R^2) indicates the proportion of the variation in Y that is associated with the regression.

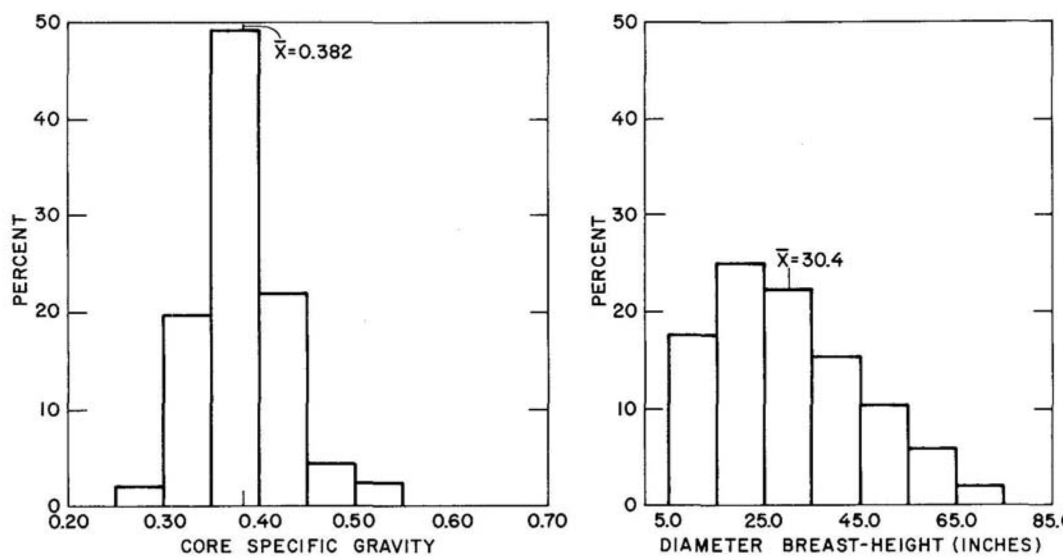
APPENDIX B

Variation and Relative Distribution of
Core Specific Gravity and Diameter

PONDEROSA PINE



SUGAR PINE



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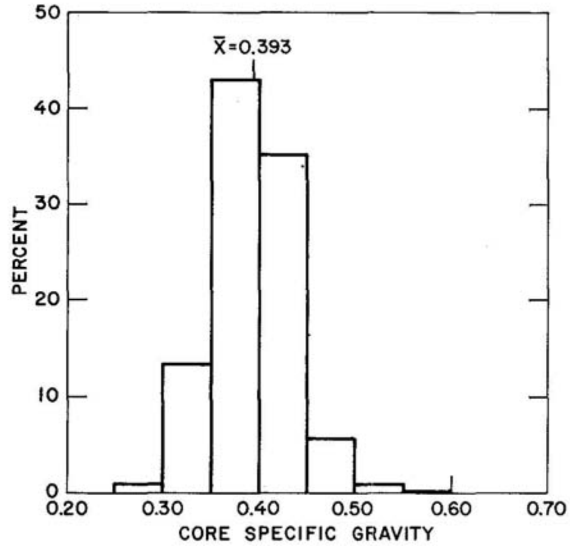
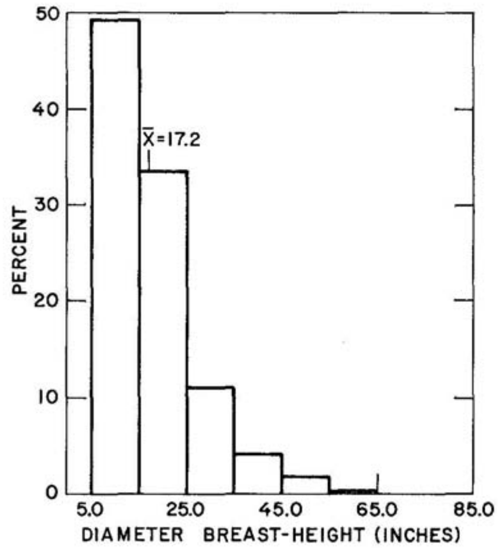
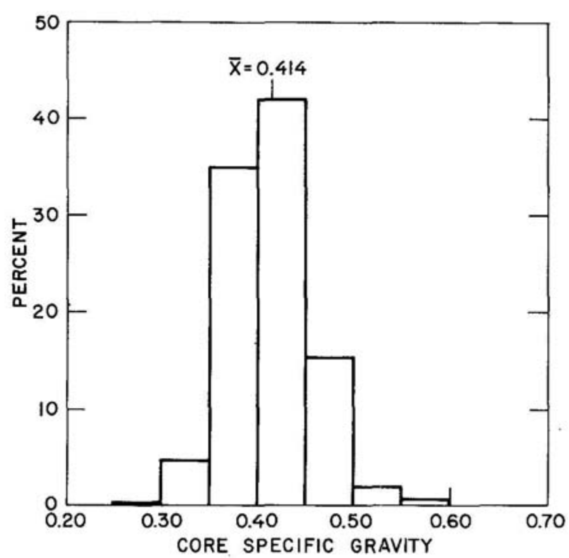
M 140 344

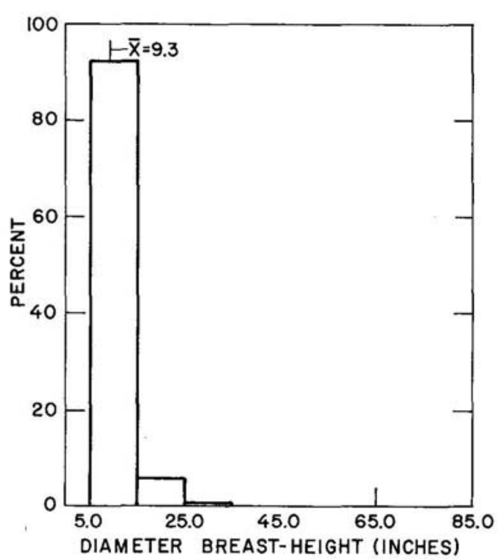
WESTERN WHITE PINE





LODGEPOLE PINE





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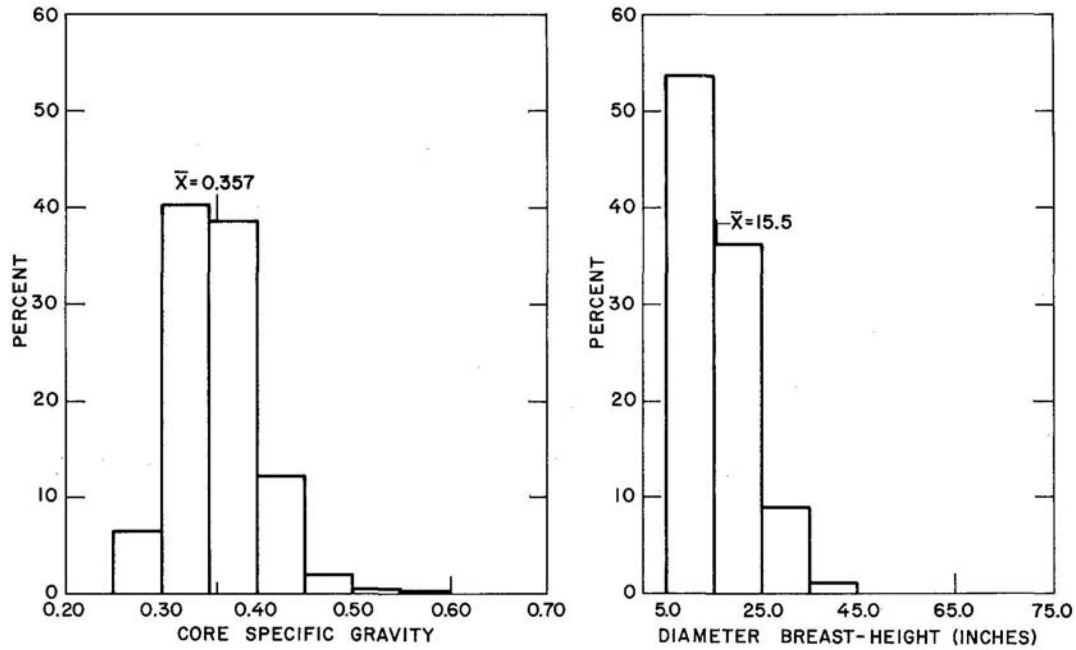
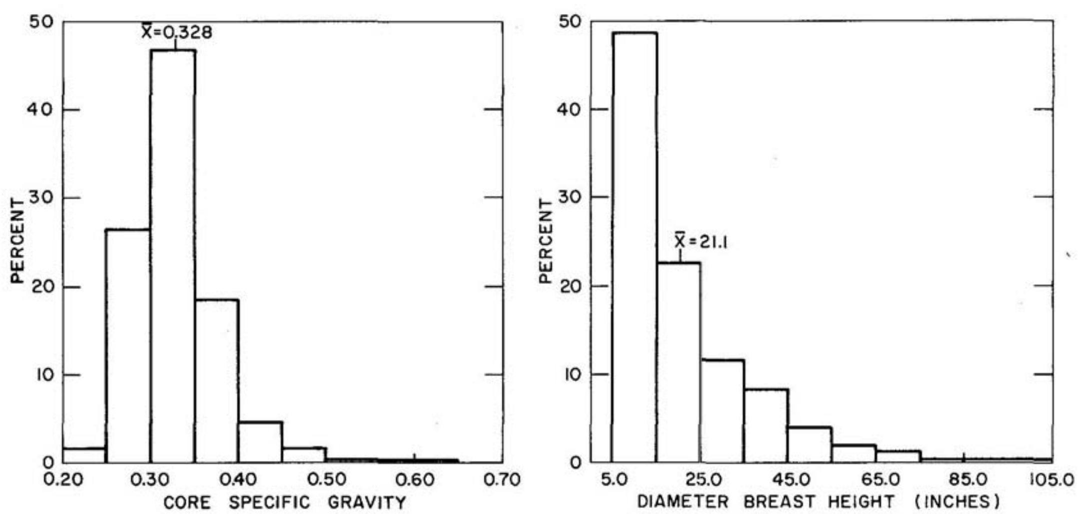
M 140 348

ENGELMANN SPRUCE



WESTERN REDCEDAR



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