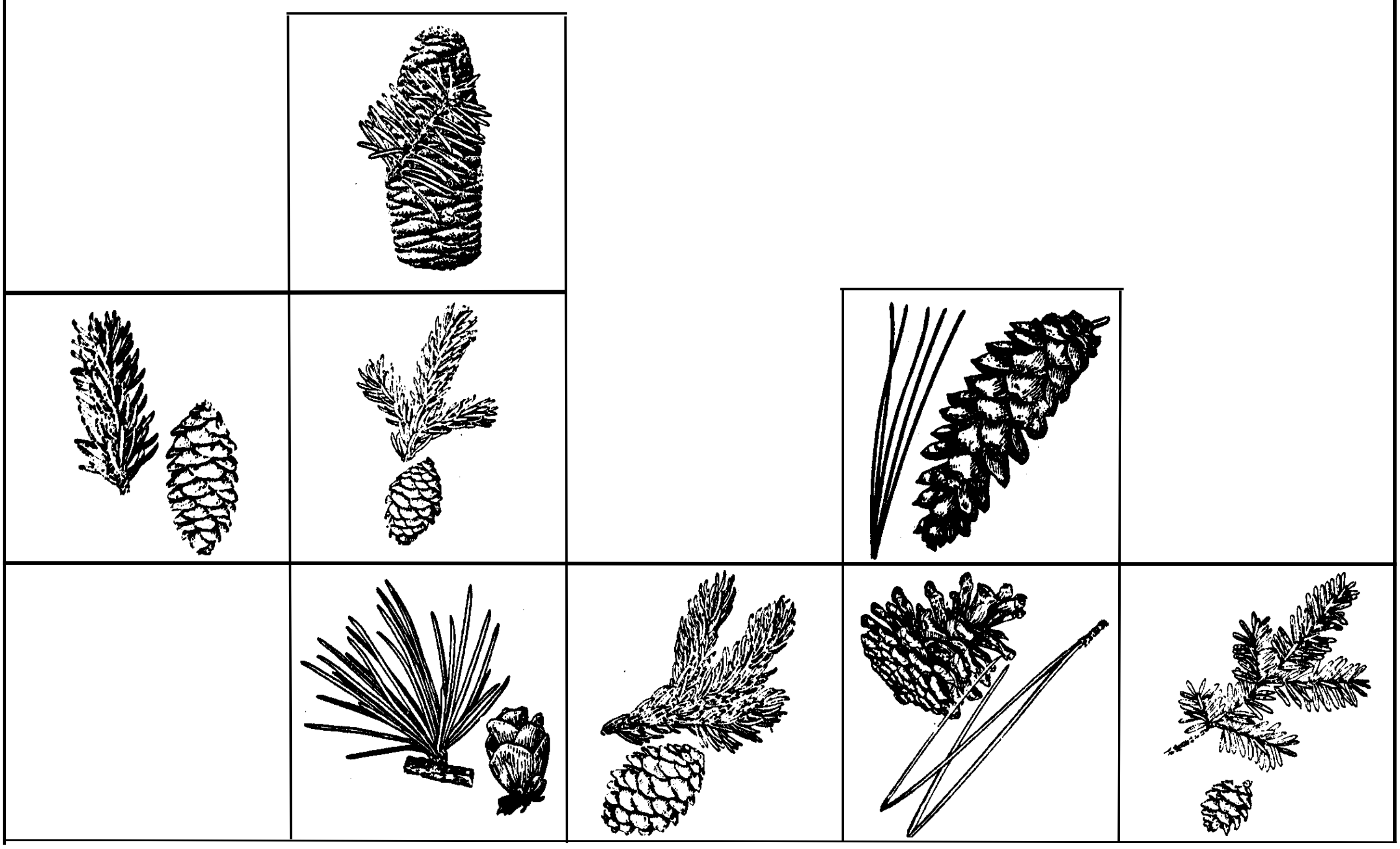
U.S.D.A. FOREST SERVICE
RESEARCH PAPER
FPL 95
JULY 1968

U.S. DEPARTMEMENT OF AGRICULTURE • FOREST SERVICE • FOREST PRODUCTS LABORATORY • MADISON, WIS.

SURVEY OF SPECIFIC GRAVITY OF EIGHT MAINE CONIFERS



Abstract

This analysis of a mass increment core sampling of eight coniferous species of Maine characterizes specific gravity for each of the species. No clear-cut relationships of specific gravity to forest type, stand-density class, height class, or tree diameter at breast height were found. Included in the data are the species average specific gravity and the range. These data can be used in the assembly of working equations for weight scaling, pulp yield estimation, and strength evaluation.

SURVEY OF SPECIFIC GRAVITY OF EIGHT MAINE CONIFERS

By
HAROLD E. WAHLGREN, [1] Forest Products Technologist
GREGORY BAKER, [2] Professor of Forestry
ROBERT R. MAEGLIN, [1] Forest Products Technologist
and
ARTHUR C. HART, [3] Silviculturist

Introduction

The significance of wood density to timber processors and manufacturers has often been acknowledged (4, 5, 6, 7, 8).[4] Wood density may be equated with wood volume, which is of importance to many industries. Knowing the characteristic density of a particular species is therefore important.

Surveys of wood density have been under way since the late 1950's, and reports on two have been published (9, 10). This is a report of a density survey conducted in the State of Maine on eight coniferous species. It is the result of the combined efforts of 18 timberland owners and wood users in Maine, the University of Maine, the Northeastern Forest Experiment Station, and the U.S. Forest Products Laboratory (FPL).

The objective was to estimate the average and the range of specific gravity of eastern white pine (*Pinus strobus* L.), red pine (*P. resinosa* Ait.), red spruce (*Picea rubens* Sarg.), white spruce (*P. glauca* (Moench) Voss), black spruce (*P. mariana* (Mill.) B.S.P.), balsam fir (*Abies balsamea* (L.) Mill.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), and tamarack (*Larix laricina* (DuRoi) K. Koch).

Work for the survey was divided in two parts:

1. Relating the values for specific gravity of breast height increment cores to those for average tree specific gravity.
2. Analyzing increment core data from two types of growth study plots (mass sampling phase).

Part 1 was completed, and the results were presented in a research paper prepared by the Northeastern Forest Experiment Station and the FPL (11). This is a report on part 2; procedures for the survey are included as is an analysis of the data,

---

[1] Forest Products Laboratory, Forest Service, U.S. Department of Agriculture. The Laboratory is maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] University of Maine, Orono.

[3] Northeastern Forest Experiment Station, Orono, Maine.

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

Source of Data

The sampling scheme employed here differed from the systematic sampling employed in other wood density surveys (9, 10). Increment cores were collected from trees on permanent plots that had been established for earlier growth studies. The plots were samples of specific Sorest stand classes and were chosen for combinations of levels of three stand factors--type, density (crown closure), and height.

Two growth condition classes of sampling were used: they were determined by the rules of establishment for the growth study plots (1, 2). Using these conditions the plots were divided into spruce-fir region growth plots and southern region growth plots (fig. 1). The spruce-fir plots had three levels of each stand factor (3 by 3 by 3), whereas the southern plots had four levels of stand type, three of stand height, and two of stand density (4 by 3 by 2).

The spruce-fir growth study plots were established in 1950 with the cooperation of nine forest

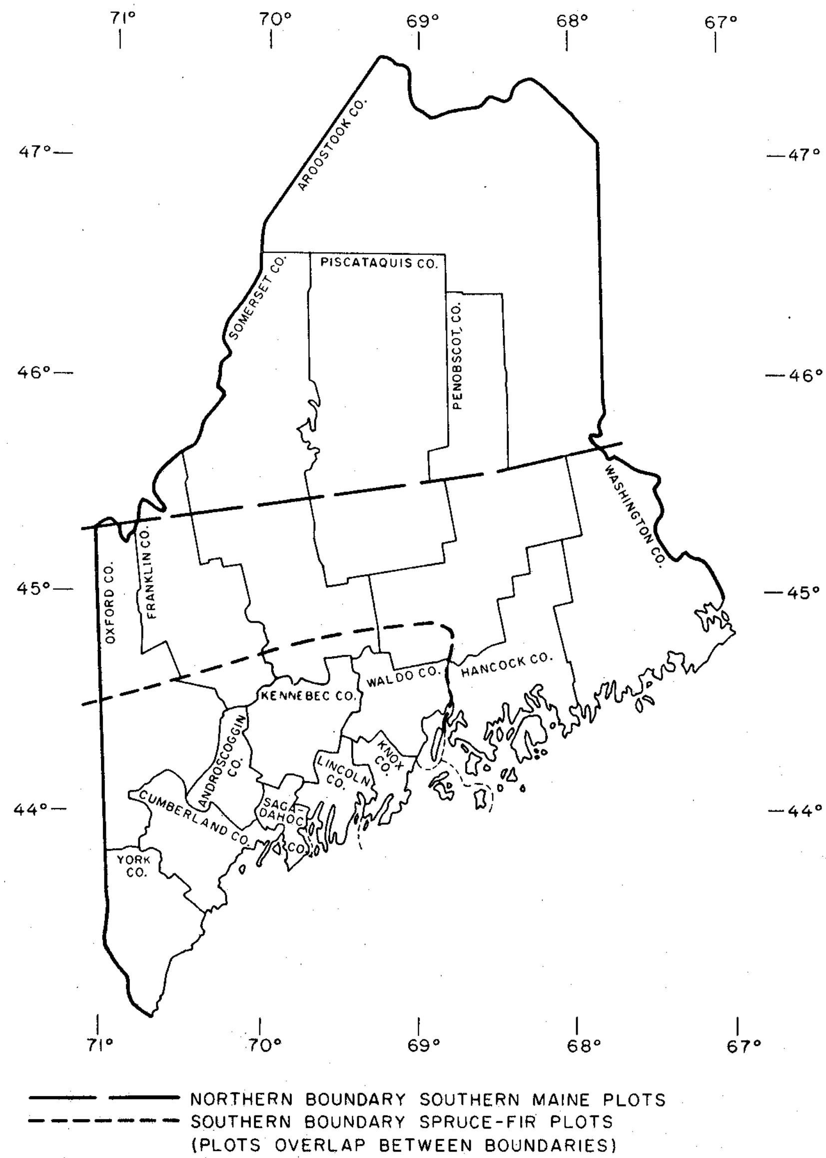


Figure I.--Map of Maine showing southern Maine plots in lower half of state and spruce-fir plots in upper two-thirds of state. M 134 718 industries of Maine; the southern growth study plots in 1958 with the cooperation of 14 forest industries of Maine; and the Wood Density Survey for Maine was begun in 1959 with 18 forest industries of the state cooperating. Increment cores were taken from trees on about 900 plots of the spruce–fir region and from trees on about 500 plots of the southern region, The differences in sampling criteria and number of cores had a bearing on the data analyses employed.

Procedures

For this wood density survey, two breast height (4.5 ft.) increment cores were extracted with a calibrated increment borer from each of the five conifers closest to the plot center. All trees were 4.6 inches or larger in diameter at breast height. On growth plots with less than five trees, all conifers were sampled,

Specific gravity (green volume, ovendry weight basis) was computed for each increment core at the University of Maine, These data were then forwarded to the FPL for analysis.

Data Analyses

For the first of three stages employed in the analysis, average and range of unweighted increment core and tree specific gravity were calculated by diameter classes for each species. All data (spruce–fir and southern regions) were pooled for analysis.

Mean increment core and tree specific gravity were determined for each diameter class as follows:

$$\frac{\Sigma G}{N}$$

where G = Core or tree specific gravity, and
N = Number of trees.

The second stage involved plotting the distribution of diameters and specific gravity and the relationships of diameter at breast height to specific gravity for each species.

The third stage was to develop weighted averages and their standard errors for both core and tree specific gravity. This was by species in each of 27 stand factor combinations (3 forest types by 3 density classes by 3 height classes) for the spruce–fir region plots. Because of the difference in levels for the various factors in the spruce–fir and southern regions, the data could not be combined. More plots and more trees were available for the spruce–fir region; therefore the analysis was first made on them, Because the analysis showed a lack of sufficient data in many stand factor combinations and no clear–cut relationship between specific gravity and stand factor combinations where sufficient data were present, no analysis was run on the southern region data,

The following stand condition classes were recognized for the spruce–fir region growth plots:

- Forest Stand Types––
  - Softwood (66 to 100 percent coniferous)
  - Mixed wood (21 to 65 percent coniferous)
  - Hardwood (0 to 20 percent coniferous)
- Stand Density Classes (Percent crown closure)––
  - 11 to 40 percent
  - 41 to 70 percent
  - 71 to 100 percent
- Stand Height Classes––
  - 0 to 30 feet
  - 31 to 64 feet
  - More than 64 feet

Of the approximately 900 plots from the spruce–fir region, about 560 contained the necessary stand condition-class information for analysis. Weighted core and tree specific gravity averages, standard errors of the means, and ranges were calculated by species for each stand condition class as follows:

Let G_{ij} = Specific gravity (core or tree) of j^{th} tree in i^{th} plot.

D_{ij} = Diameter of j^{th} tree on i^{th} plot.

$Z_i = \Sigma_j D^2_{ij} G_{ij}$ = Plot sum of weighted specific gravity values,

$W_i = \Sigma_j D^2_{ij}$ = Sum of weights for plot i.

Then $\bar{Z}$ = Weighted mean specific gravity (core or tree).

$$\bar{Z} = \frac{\sum_{i=1}^{k} Z_i}{\sum_{i=1}^{k} W_i}$$

where k. = Number of plots.

The standard error of $\bar{Z}$ is estimated by the following equation (this underestimates the standard error of mean - specific gravity because it ignores the sampling error in the equations used to convert core specific gravity to tree specific gravity):

$$SE_{\bar{Z}} = \bar{Z}\sqrt{\frac{k}{k-1}\left[\frac{\Sigma Z_i^2}{(\Sigma Z_i)^2} + \frac{\Sigma W_i^2}{(\Sigma W_i)^2} - \frac{2\Sigma Z_i W_i}{(\Sigma Z_i)(\Sigma W_i)}\right]}$$

The standard error indicates the precision with which the sample mean estimates the population mean. As a rough guide we can say that unless a 1-in-20 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 plots.

Discussion

The regression equations developed to predict tree specific gravity from increment core specific gravity are shown in table 1. The equations are from those recommended by Wahlgren, et al. (11) and from unpublished data at the Forest Products Laboratory.

Stage 1 Analysis

To summarize specific gravity values for a species, data from the spruce-fir growth plots and from the southern growth plots were combined. These data were grouped by diameter class, giving number of trees and specific gravity averages and ranges (table 2).

No marked trends either in core or in tree specific gravity were found with changes in dia-

Table l.--Regression equations for converting values for increment core specific gravity to values for tree specific gravity

Species	Regression equation	Standard deviation	r^2 or R^2 [1, 2]
Eastern white pine			
n[3] = 202	$Y = 0.12996 + 0.57025_{(2\ \text{core av.})}$	0.017	[4]0.5493
Red spruce			
n = 106	$Y = 0.18771 + 0.48015_{(2\ \text{core av.})}$	.018	.4098
White spruce			
n = 119	$Y = 0.14365 + 0.58537_{(2\ \text{core av.})}$	.017	.5676
Black spruce			
n = 105	$Y = 0.15333 + 0.60494_{(2\ \text{core av.})}$	.022	.5354
Balsam fir			
n = 206	$Y = 0.10542 + 0.67227_{(2\ \text{core av.})}$	.017	.5678
Eastern hemlock			
n = 98	$Y = 0.21975 + 0.47005_{(2\ \text{core av.})} - 0.00311_{\text{dbh}}$[5]	.018	.5858
Red pine			
n = 65	$Y = 0.34595 + 0.20814_{(2\ \text{core av.})} - 0.22914_{\text{dbh/age}}$	.016	.6871
Tamarack			
n = 84	$Y = 0.25042 + 0.50845_{(2\ \text{core av.})} - 0.00325_{\text{dbh}}$	.018	.6666

[1] r^2 is the coefficient of determination for simple regressions; R^2 is the coefficient of determination for multiple regressions.

[2] Values of r^2 or R^2 are significant at the 1 percent level of probability.

[3] n values are from destructive sample used to establish prediction equations (Wahlgren et al., 1966. U.S. Forest Serv. Res. Pap. FPL 61, Forest Prod. Lab., Madison, Wis.).

[4] The significance noted in footnote 2 for simple regressions is that of correlation; for multiple regression it indicates improvement over the simple regression.

[5] Diameter at breast height.

meter at breast height. Where data are sufficient (at least 10 samples), some suggestion of trends exists (table 2). For instance, eastern white pine specific gravity increases up to a diameter at breast height of 16.9 inches. The other species with sufficient data show a drop in specific gravity with increased diameter at breast height,

Stage 2 Analysis

For balsam fir and red spruce, although slightly skewed, the tendency of distribution for average tree specific gravity is generally normal. This holds for other species, too. Normality is definitely not the case for the distribution of

Table 2.--Core and tree specific gravity values by diameter classes for combined growth plots

Diameter class	Number of trees	Specific gravity of-- Average core	Range of core	Average tree	Range of tree
Inch					
EASTERN WHITE PINE					
4.6- 8.9	82	0.322	0.242-0.428	0.314	0.268-0.374
9.0-12.9	55	.354	.248- .548	.332	.271- .442
13.0-16.9	27	.356	.267- .418	.333	.282- .368
17.0-20.9	8	.349	.298- .420	.329	.300- .369
21.0- UP	4	.366	.348- .395	.339	.328- .355
RED PINE					
4.6- 8.9	3	.431	.329- .491	.392	.335- .425
9.0-12.9	4	.428	.394- .451	.401	.373- .416
13.0-16.9	2	.422	.411- .433	.384	.376- .391
TAMARACK					
4.6- 8.9	11	.498	.402- .613	.484	.436- .546
9.0-12.9	2	.528	.487- .568	.487	.465- .509
13.0-16.9	1	.495	.495	.464	.464
RED SPRUCE					
4.6- 8.9	1,873	.405	.287- .603	.382	.326- .477
9.0-12.9	478	.401	.304- .542	.380	.334- .448
13.0-16.9	83	.397	.309- .476	.378	.336- .416
17.0-20.9	10	.399	.366- .433	.379	.363- .396
WHITE SPRUCE					
4.6- 8.9	154	.384	.278- .494	.368	.306- .433
9.0-12.9	48	.368	.300- .483	.359	.319- .426
13.0-16.9	12	.354	.301- .414	.351	.320- .386
17.0-20.9	2	.370	.334- .407	.360	.339- .382
BLACK SPRUCE					
4.6- 8.9	52	.444	.355- .572	.422	.368- .499
9.0-12.9	7	.420	.356- .480	.407	.369- .444
BALSAM FIR					
4.6- 8.9	2,480	.341	.244- .567	.335	.269- .487
9.0-12.9	323	.340	.253- .483	.334	.276- .430
13.0-16.9	18	.331	.275- .391	.328	.290- .368
17.0-20.9	1	.279	.279	.293	.293
21.0- UP	1	.399	.399	.374	.374
EASTERN HEMLOCK					
4.6- 8.9	452	.419	.330- .558	.397	.352- .460
9.0-12.9	146	.411	.342- .526	.380	.345- .428
13.0-16.9	26	.369	.346- .466	.361	.335- .393
17.0-20.9	4	.423	.407- .445	.359	.341- .383
21.0- UP	1	.435	.435	.359	.359

diameter at breast height; this distribution is extremely imbalanced in all species.

Because of this extreme imbalance, lumping data by diameter without due consideration for age does not present a complete analysis. Hale (3) has suggested, in these situations, grouping by age class first might give a more complete analysis. This was done for balsam fir and red spruce (figs, 2 through 7).

A fairly consistent pattern of decreasing specific gravity with increasing diameter at breast height is established for red spruce (figs. 5 through 7). This holds for red spruce whether the data are combined for the spruce-fir and the southern growth plots or whether they are used separately. The results are not as consistent for balsam fir, however. The pattern of change in the spruce-fir growth plots data is similar to the red spruce (fig. 2), but confusion arises from the data of the southern growth plots and the combined growth plots (figs. 3 and 4). In the lowest age class (10 to 30 years) specific gravity has a positive relationship to diameter at breast height, but the older classes have inconsistent and negative relationships.

In both species one can generalize that the older and the smaller the material, the higher the specific gravity will be, For red spruce this trend disappears as diameter increases, and the curves converge. The average tree specific gravity is approximately the same at the larger diameters; therefore a short rotation aimed at large volume with lower specific gravity will be most advantageous. The larger volume will more than offset the reduction in specific gravity and result in a larger weight yield. Balsam fir, however, maintains a considerable spread in average tree specific gravity at all diameters. Because of the differences, an optimum age-volume-density combination should be determined to establish a maximum yield point.

The data in table 2 provide a good summary of characteristic specific gravity values and ranges for the eight species in Maine. This information should be valuable for working equations for weight scaling, estimating of pulp yields, and other related purposes.

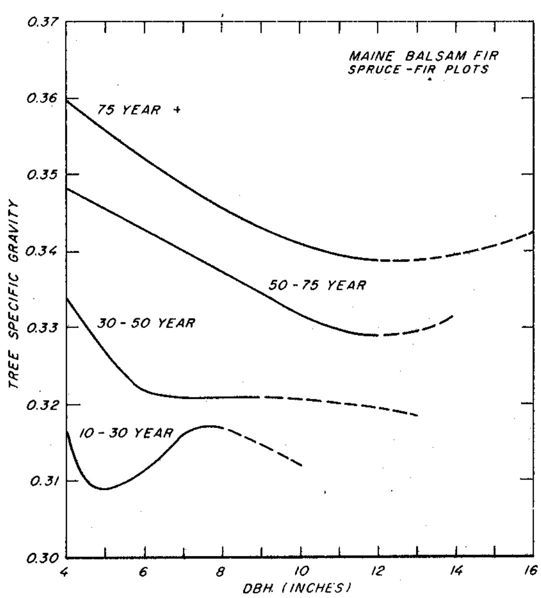


Figure 2.--Relation of average tree specific gravity to diameter at breast height and tree age for balsam fir from spruce-fir plots of Maine. Dashed lines indicate areas with less than 10 data points.

M 134 024

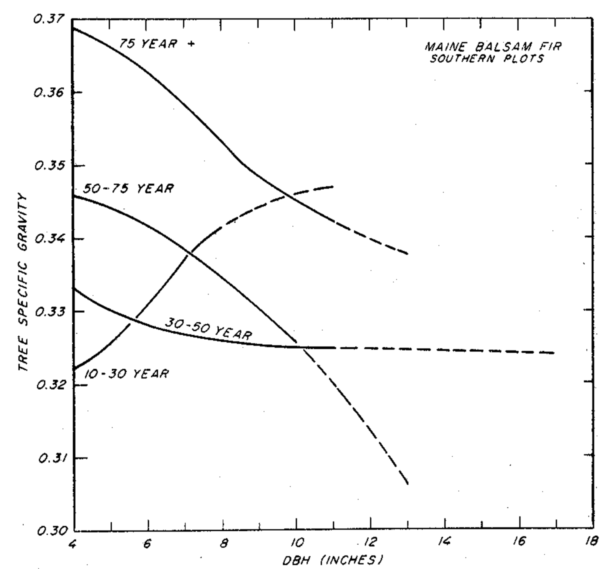


Figure 3.--Relation of average tree specific gravity to diameter at breast height and tree age for balsam fir from southern plots of Maine. Dashed lines indicate areas with less than 10 data points.

M 134 023

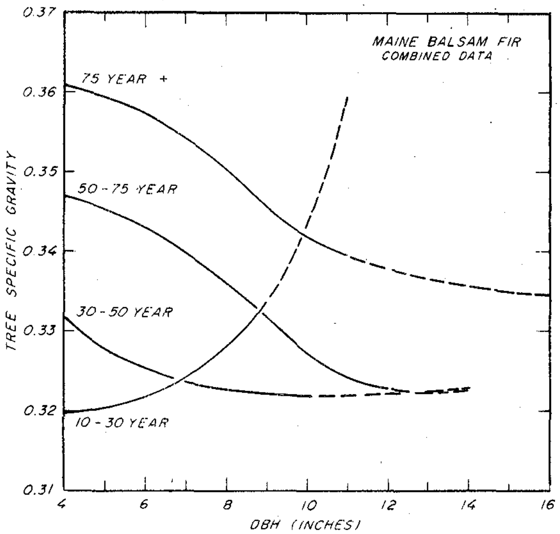


Figure 4.--Relation of average tree specific gravity to diameter at breast height and tree age for combined data from balsam fir of Maine. Dashed lines indicate areas with less than 10 data points.

M 134 022

Stage 3 Analysis

Average core and average tree specific gravity values and their respective standard errors for the stand type, density, and height classes for six of the eight species are listed in table 3. Red pine and tamarack did not have sufficient data, and there were no data for any of the species in the hardwood stand type.

Lack of data prevents valid assessment of the stand type-density-height combinations in four of the six species listed in table 3. Even where data are sufficient, as for red spruce and balsam fir, there is no evidence that specific gravity is associated in any consistent manner with any of the stand classes examined.

Table 3.--Specific gravity values and their respective standard errors for six species from spruce-fir plots in Maine

Stand	Number of plots	Number of trees	Stand density (crown closure)	Stand height	Specific gravity: Core average and standard error	Specific gravity: Tree average and standard error
			Percent	Feet		
			EASTERN WHITE PINE			
Softwood[1]	3	12	41- 70	65+	0.377 (0.0144)	0.345 (0.0090)
	7	8	41- 70	35-64	.330 (.0195)	.318 (.0115)
	8	9	71-100	35-64	.389 (.0222)	.352 (.0140)
Mixed wood[2]	9	13	41- 70	35-64	.358 (.0180)	.334 (.0110)
	2	3	71-100	35-64	.384 (.0391)	.349 (.0246)
			RED SPRUCE			
Softwood[1]	22	62	11- 40	35-64	.421 (.0212)	.390 (.0110)
	106	272	41- 70	35-64	.402 (.0077)	.380 (.0039)
	6	14	41- 70	<35	.401 (.0136)	.380 (.0069)
	4	12	71-100	65+	.402 (.0125)	.381 (.0063)
	92	243	71-100	35-64	.400 (.0071)	.380 (.0036)
	29	112	71-100	<35	.421 (.0196)	.390 (.0101)
Mixed wood[2]	15	38	11- 40	35-64	.416 (.0116)	.387 (.0060)
	2	3	41- 70	35-64	.425 (.1018)	.392 (.0530)
	107	258	41- 70	<35	.400 (.0080)	.380 (.0040)
	6	13	71-100	65+	.374 (.0282)	.367 (.0138)
	45	112	71-100	35-64	.389 (.0105)	.374 (.0052)
	2	6	71-100	<35	.402 (.0106)	.380 (.0054)

Table 3.--Specific gravity values and their respective standard errors for six species from spruce-fir plots in Maine (Continued)

Stand	Number of plots	Number of trees	Stand density (crown closure)	Stand height	Specific gravity: Core average and standard error	Specific gravity: Tree average and standard error
			Percent	Feet		
			BALSAM FIR			
Softwood[1]	19	46	11- 40	35-64	.340 (.0185)	.334 (.0126)
	108	314	41- 70	35-64	.342 (.0113)	.335 (.0078)
	5	18	41- 70	<35	.339 (.0878)	.334 (.0601)
	4	9	71-100	65+	.354 (.0215)	.343 (.0150)
	89	256	71-100	35-64	.338 (.0093)	.333 (.0064)
	23	62	71-100	<35	.352 (.0211)	.342 (.0146)
			BALSAM FIR			
Mixed wood[2]	8	21	11- 40	35-64	0.353 (0.0351)	0.343 (0.0243)
	2	6	41- 70	65+	.319 (.0208)	.320 (.0140)
	113	353	41- 70	35-64	.341 (.0094)	.334 (.0064)
	6	19	71-100	65+	.336 (.0296)	.331 (.0202)
	45	137	71-100	35-64	.340 (.0107)	.334 (.0073)
	2	4	71-100	<35	.341 (.0050)	.335 (.0034)
			EASTERN HEMLOCK			
Softwood[1]	13	31	11- 40	35-64	.417 (.0196)	.387 (.0096)
	18	35	41- 70	35-64	.410 (.0247)	.381 (.0177)
	15	38	71-100	35-64	.418 (.0166)	.383 (.0111)
Mixed wood[2]	14	42	11- 40	35-64	.413 (.0110)	.386 (.0086)
	33	72	41- 70	35-64	.417 (.0128)	.387 (.0069)
	9	14	71-100	35-64	.400 (.0173)	.376 (.0127)
			WHITE SPRUCE			
Softwood[1]	17	24	41- 70	35-64	.372 (.0411)	.362 (.0248)
	11	16	71-100	35-64	.346 (.0227)	.346 (.0133)
Mixed wood[2]	2	3	11- 40	35-64	.365 (.0039)	.358 (.0025)
	14	23	41- 70	35-64	.375 (.0294)	.363 (.0177)
	3	3	71-100	35-64	.321 (.0705)	.331 (.0399)
			BLACK SPRUCE			
Softwood[1]	2	10	11- 40	35-64	.486 (.0136)	.447 (.0089)
	2	6	71-100	35-64	.404 (.0288)	.398 (.0177)
	2	10	71-100	<35	.457 (.0769)	.430 (.0494)

[1] 66-100 percent coniferous.

[2] 25-65 percent coniferous.

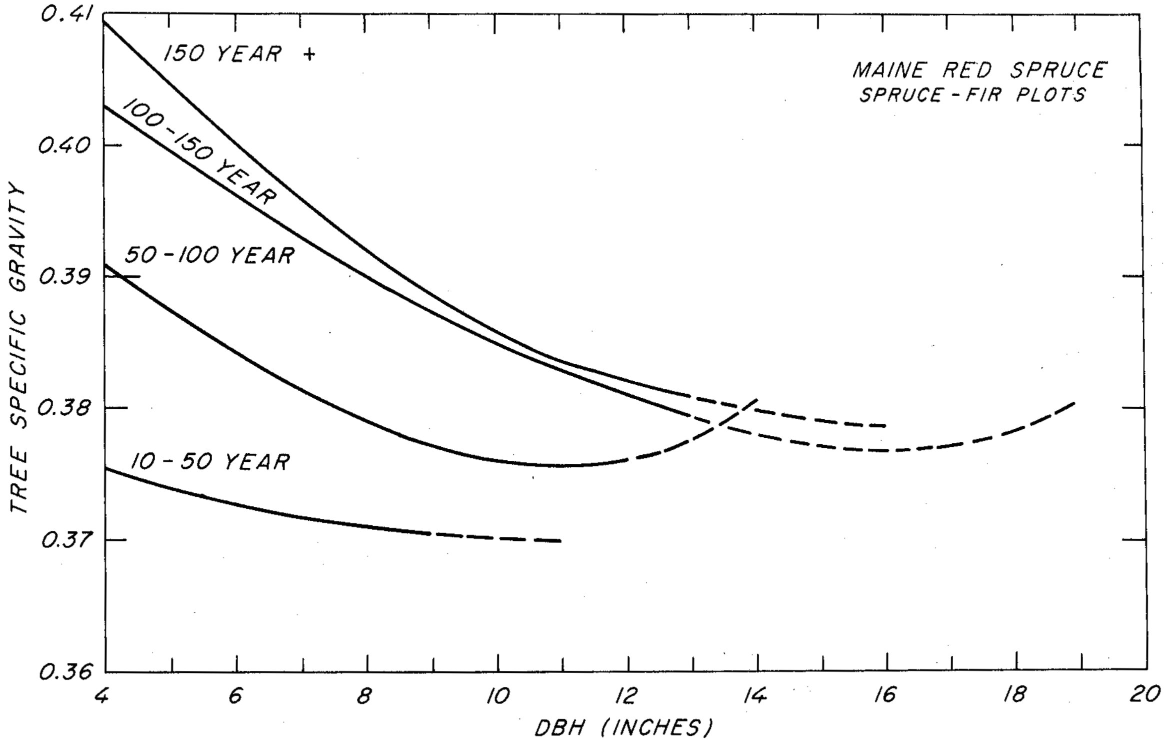


Figure 5.--Relation of tree specific gravity to diameter at breast height and tree age for red spruce from spruce-fir plots of Maine. Dashed lines indicate areas with less than 10 data points.
M 134 021

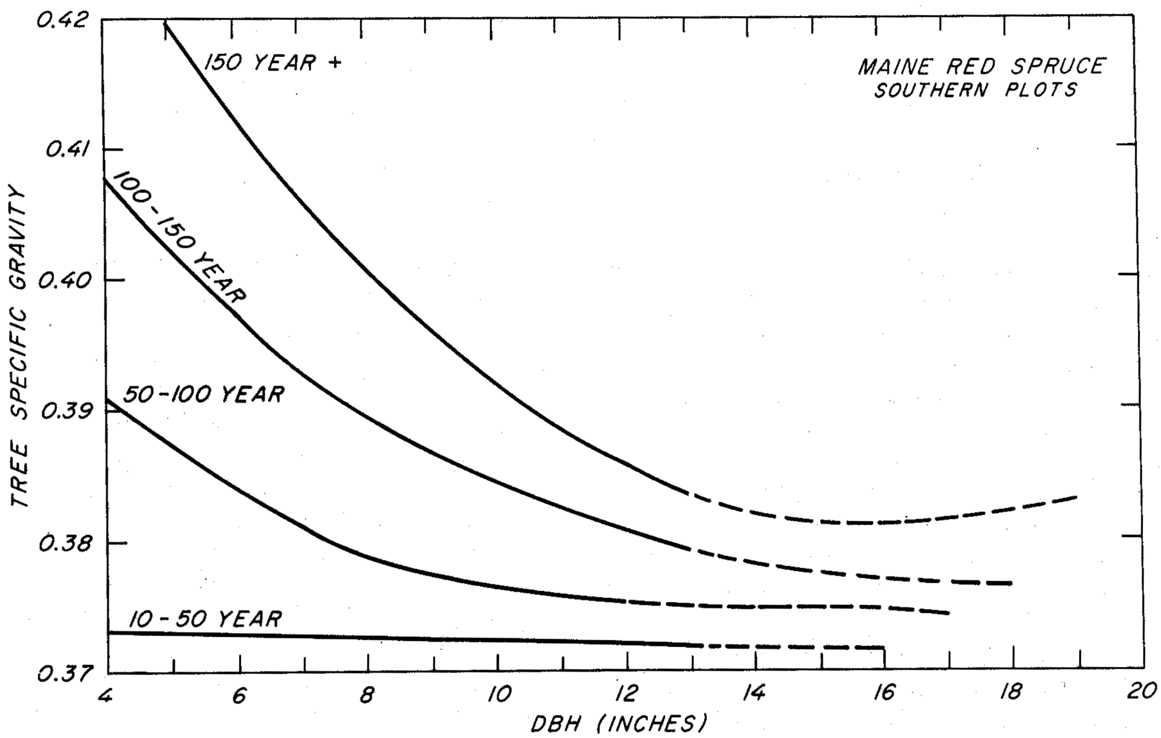


Figure 6.--Relation of tree specific gravity to diameter at breast height and tree age for red spruce from southern plots of Maine. Dashed lines indicate areas with less than 10 data points.
M 134 019

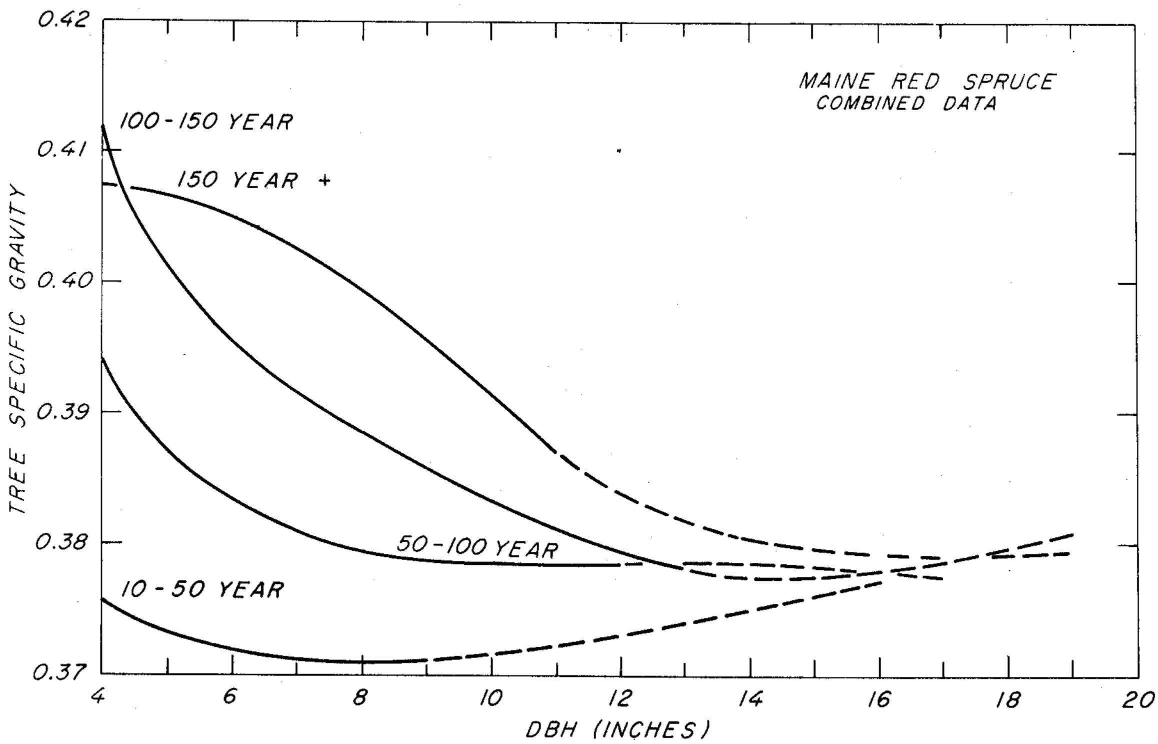


Figure 7.--Relation of tree specific gravity to diameter at breast height and tree age for combined data of red spruce of Maine. Dashed lines indicate areas with less than 10 data points. M 134 020

Summary

The Maine Wood Density Survey was undertaken to evaluate the specific gravity of eight coniferous species in Maine. The survey was divided into two parts:

1. To develop equations for estimating tree specific gravity from increment core specific gravity. This was completed and published as Forest Service Research Paper FPL 61.
2. To evaluate the specific gravity of the resource by mass sampling established growth plots in Maine. The results are reported in this paper.

Summarization of specific gravity by diameter classes within species showed no trends but has characterized average core and tree specific gravity and their respective ranges for the eight coniferous species. This compilation of specific gravity data should be of help to those using and studying the species involved.

Plottings of the distribution of tree specific gravity indicate a normal distribution, whereas similar treatment of data for diameter at breast height shows extremely skewed results,

Balsam fir and red spruce data were separated by age class, and tree specific gravity was plotted over diameter at breast height. The result for red spruce was a clear family of curves with age. However, for balsam fir, only the spruce-fir region data responded similarly. The southern and combined data were highly inconsistent.

Analysis of groupings by stand type, height, and density (crown cover) within species suggested no relationships with specific gravity.

Literature Cited

1. Bickford, C. Allen, Longwood, Franklin R., and Bain, Robert
   1961. Average growth rates in the spruce-fir region of New England. U.S.D.A. Forest Serv. Northeastern Forest Exp. Sta. Pap. 140, Upper Darby, Pa., 23 pp.
2. Frayer, Warren E., and Barnard, Joseph E.
   1966. Aver age growth rates in southern Maine. U.S.D.A. Forest Serv. Res. Note NE-47, Northeastern Forest Exp. Sta., Upper Darby, Pa., 8 pp.
3. Hale, J. D.
   1962. Minimum requirements for defining species norms for quality of variable woods. Tappi 45:538-542.
4. Markwardt, L. J., and Wilson, T. R C.
   1935. Strength and related properties of woods grown in the United States. U.S. Dep. of Agr. Tech. Bull. No. 479, 99 PP.
5. Mitchell, H. L.
   1958. Wood quality evaluation from increment cores. Tappi 41:150-156.
6. _______
   1960. Development of an adequate concept of wood quality for the guidance of geneticists and forest managers. Fifth World Forestry Congress Proc., Vol. 3, pp. 1341-1348.
7. _______, and Wheeler, P. R.
   1959. Highlights of Mississippi Survey. The search for wood quality. Forest Farmer 18(4):4-6.
8. _______, and Wheeler, P. R
   1959. The search for wood quality. Pt. II. Forest Farmer 18(5):10-12.
9. U.S. Forest Service
   1965. Southern wood density survey. 1965 Status Report. U.S.D.A. Forest Serv. Res. Pap. FPL 26. Forest Prod. Lab., Madison, Wis., 38 pp.
10. _______
    1965. Western wood density survey, Rep. No. 1. U.S.D.A. Forest Serv. Res. Pap. FPL 27. Forest Prod. Lab., Madison, Wis., 58 pp.
11. Wahlgren, H. E., Hart, A. C., and Maeglin, R R
    1966. Estimating tree specific gravity of Maine conifers. U.S.D.A. Forest Serv. Res. Pap. FPL 61. Forest Prod, Lab., Madison, Wis., 22 pp.