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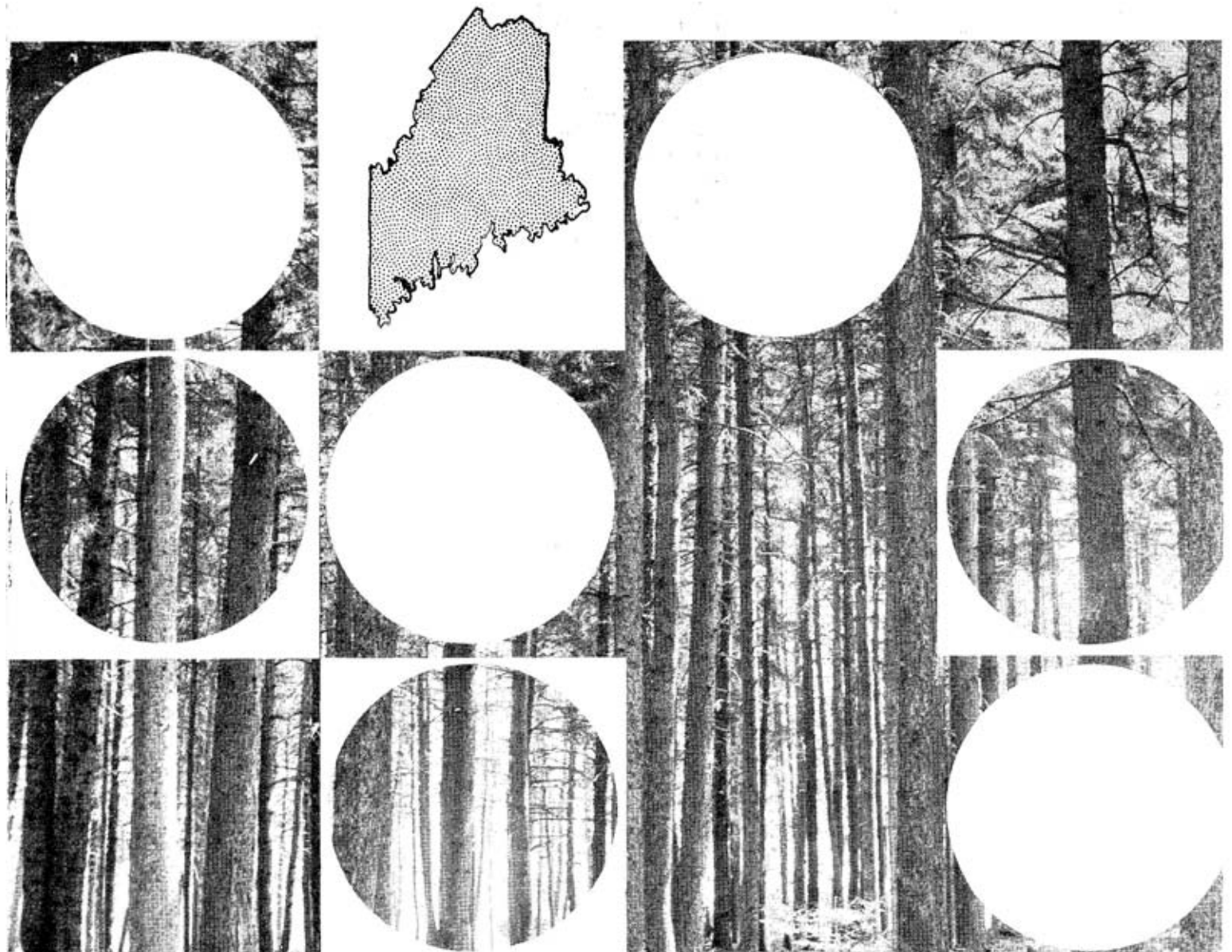
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# ESTIMATING TREE SPECIFIC GRAVITY OF MAINE CONIFERS



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## ABSTRACT

To use the specific gravity of a breast height increment core in estimating the average specific gravity of the merchantable portions of a tree, regression equations were developed for eight coniferous species in Maine. At slight additional cost, the precision of the estimates can be increased, markedly for some species, by including other measurable tree characteristics. The trend in specific gravity with height in stem is shown-- each species exhibiting a characteristic pattern.

## ACKNOWLEDGMENT

The work done in this study was part of the Maine Wood Density Survey, a cooperative effort of 18 timberland owners and wood users, the University of Maine, Northeastern Forest Experiment Station, and the U.S. Forest Products Laboratory. The primary objective of this survey was to determine the wood density of the eight principal softwood species in Maine. The companies involved were: Brown Co., Diamond-Gardner Co. (now Diamond-International Co.), Dead River Co., Eastern Pulp Wood Co. (now a subsidiary of Georgia Pacific Corp.), Great Northern Paper Co., Hudson Pulp and Paper Co., International Paper Co., James W. Sewall Co., Oxford Paper Co., Pejepscot Paper Co. (now a division of the Hearst Corp.), Penobscot Development Co., Prentiss and Carlisle Co., Scott Paper Co., St. Regis Paper Co., Standard Packaging Corp., S. D. Warren Co., T. L. Dickson Co., and U. S. Gypsum Co.

Grateful acknowledgment is hereby given to these participants.

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# ESTIMATING TREE SPECIFIC GRAVITY OF MAINE CONIFERS

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by

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and

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## INTRODUCTION

Specific gravity of wood is the simplest and most useful index to the suitability of wood for many important uses. It gives an estimate of the strength and some of the working properties of wood. It is a particularly important factor in the manufacture of pulp and paper, as specific gravity largely determines the pulp yield from a given volume of wood.

The U.S. Forest Service, in cooperation with private industry and the States, has been engaged in surveys to estimate the mean specific gravity of all commercially important species. The specific gravity data have been obtained by taking one or more breast height increment cores from each sampled tree. The specific gravity of each core is determined by the calibrated borer technique (1).<sup>3</sup> The results of two such surveys (on southern and western conifers) have already been reported in U.S. Forest Service publications (4, 5). An integral part of every wood density survey is development of a method to adjust specific gravity data from increment cores to reflect average values for the entire tree or parts of trees.

The objective of this study was to provide a

means of estimating the merchantable bole specific gravity of eight Maine conifers from increment core specific gravity and other tree measurements.

The eight coniferous species studied were: white pine (Pinus strobus L.), red pine (P. resinosa Ait.), balsam fir (Abies balsamea (L.) Mill.), white spruce (Picea glauca (Moench) Voss), black spruce (P. mariana (Mill.) B.S.P.), red spruce (P. rubens Sarg.), eastern hemlock (Tsuga canadensis (L.) Carr.), and tamarack (Larix laricina (Du Roi) K. Koch).

Other studies, principally those of Wahlgren and Fassnacht (6), Taras and Wahlgren (3), and the Southern and Western Wood Density Surveys (4, 5), have outlined predicting equations for 13 southern and western coniferous species. To this list are now added the eight species common to Maine and the northeastern United States.

The purpose of this study is to provide people involved in forest inventory a procedure by which they may more accurately assess the weight of dry fiber mass of trees and timber stands.

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<sup>1</sup>U.S. Forest Products Laboratory. The Laboratory is maintained at Madison, Wis., in cooperation with the University of Wisconsin.

<sup>2</sup>Northeastern Forest Experiment Station, Orono, Maine.

<sup>3</sup>Underlined numbers in parentheses refer to Literature Cited at the end of this report.

## FIELD PROCEDURES

Sample material was collected from 10 or more widely scattered areas selected to include a range of sites and age classes. Within these areas, sample trees were picked to obtain, insofar as possible, equal numbers in each combination of diameter class and species. No decayed trees or trees considerably above or below average form, vigor, or branchiness were taken. Trees were located, marked, and identified by number and species well in advance of felling and bucking.

Figures 1 to 4 show the location of sample areas by species, and table 1 summarizes the ranges in age, diameter, and height represented in the sample.

## DATA COLLECTION

Two increment cores were taken at breast height (4.5 feet): the first at a position facing the nearest road or trail, the second at 90° to the right. After extraction, each core was trimmed to exclude pith and bark. The trimmed length was measured to the nearest 0.01 inch and recorded on a special form, along with identifying information. Cores were placed in paper drinking straws and mailed with the data sheets to the Forest Products Laboratory for analysis.

Trees were felled, and a complete cross section 0.1 foot thick was sawed from each tree at approximately breast height. Similar cross sections were taken from the top of each consecutive 4-foot section up to a 4-inch top (d.i.b.) or for the entire merchantable length, whichever came first.

Cross sections were identified with tags showing species, tree number, and bolt number. For each section, diameter inside bark was measured and recorded to the nearest 0.1 inch. Bolt lengths, total merchantable length, and total tree height were measured and recorded to the nearest 0.1 foot for each tree. The sections were then bagged and shipped, and the data sheets mailed to the Forest Products Laboratory for further processing.

## LABORATORY PROCEDURES

When cross sections arrived at the Forest Products Laboratory, they were soaked in water to insure accurate green volume determinations. After the soaking period, the bark was removed from the cross sections; the age was determined from the breast height section only, and the green volume by water immersion. The sections were then dried at 105° C. in a forced draft oven and their weight determined. Specific gravity of each cross section was calculated as the ratio of oven-dry weight over green volume (when weights and volumes are expressed in the metric system).

The increment cores were handled differently than the cross sections. The green volume of each core was computed from the field measurement of its length and the calibrated diameter of its borer. The cores were then oven-dried to a constant weight and specific gravity computed as the ratio of oven-dry weight over calculated green volume (formula shown in the appendix).

The specific gravity of each bolt was estimated as the average of its two terminal disks (except single disk observations for butt bolts). The specific gravity of the tree was then calculated as the weighted average of the bolt gravities, the weight being proportional to bolt volumes. The formula for this computation is shown in the appendix.

## DATA ANALYSIS

To provide regression equations for converting the specific gravity of a single increment core, or the average of two increment cores, to average weighted tree specific gravity, data from all sampling locations were pooled for each species. A separate regression of the form

$$\begin{aligned} \text{Tree specific gravity} = \\ a + b (\text{single core specific gravity}) \end{aligned}$$

or

$$\begin{aligned} \text{Tree specific gravity} = \\ a + b (\text{average specific gravity of two cores}) \end{aligned}$$

was fitted for each species.

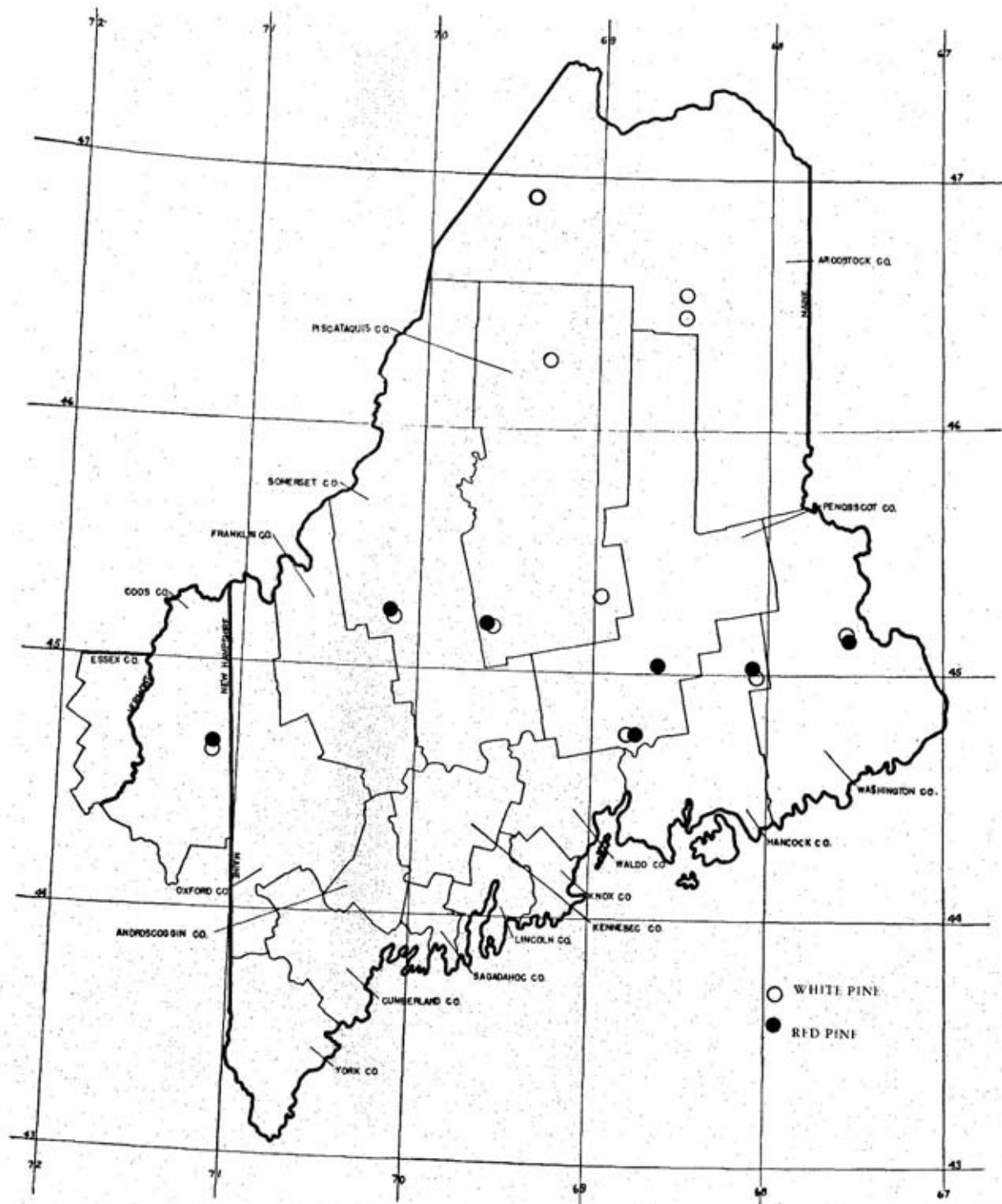


Figure 1.--Location of white pine and red pine sampling areas.

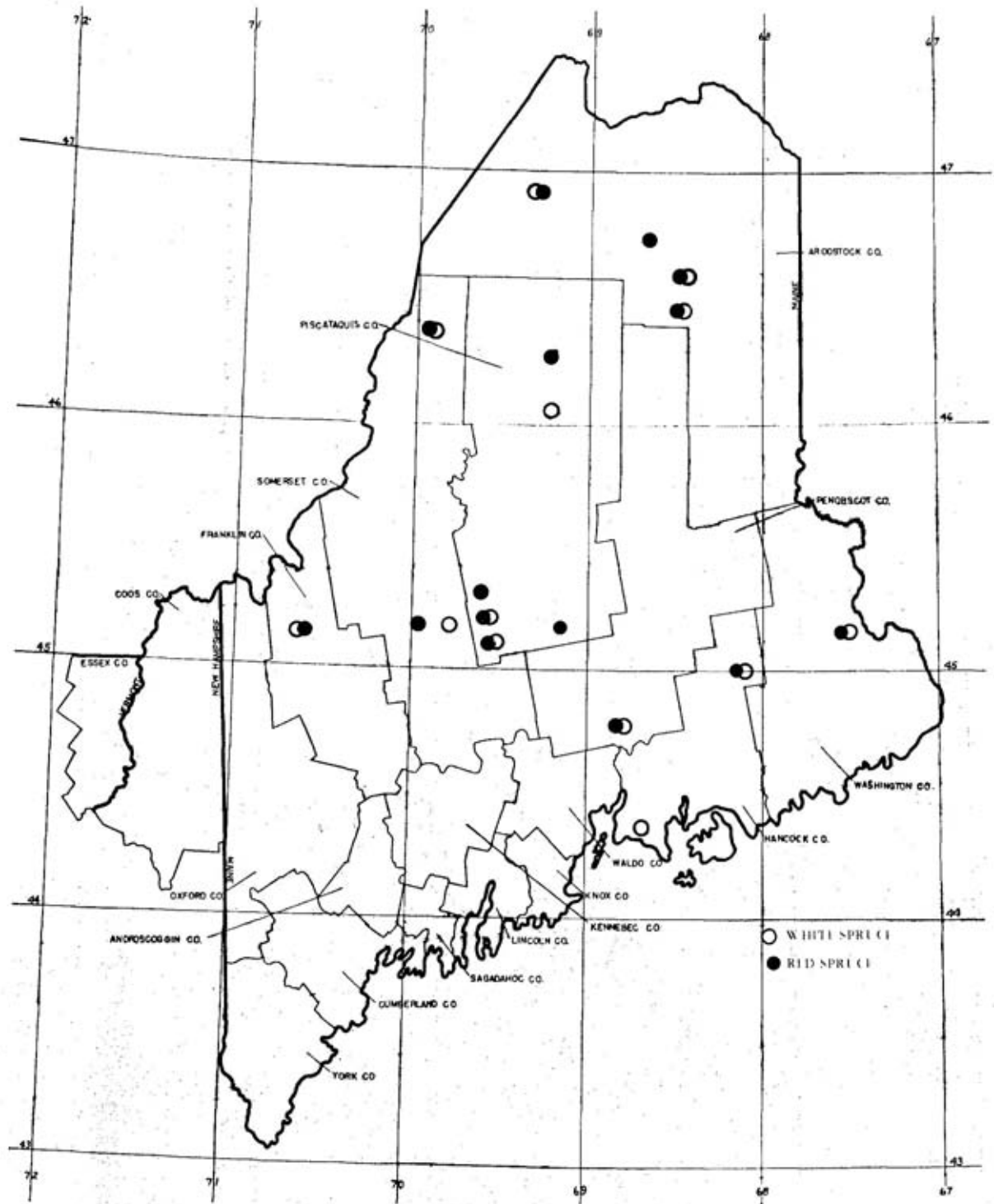


Figure 2.--Location of white spruce and red spruce sampling areas.

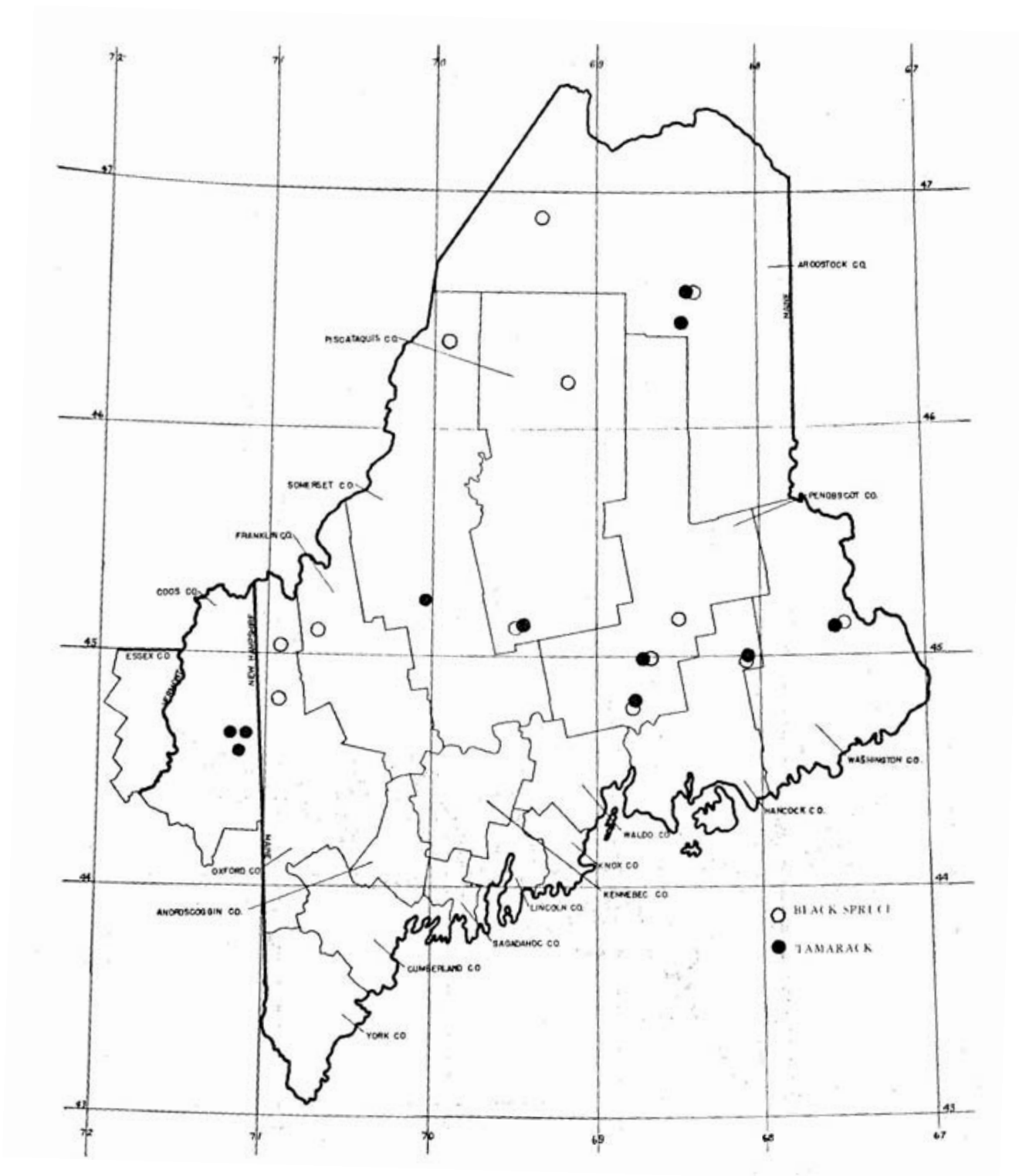


Figure 3.--Location of black spruce and tamarack sampling areas

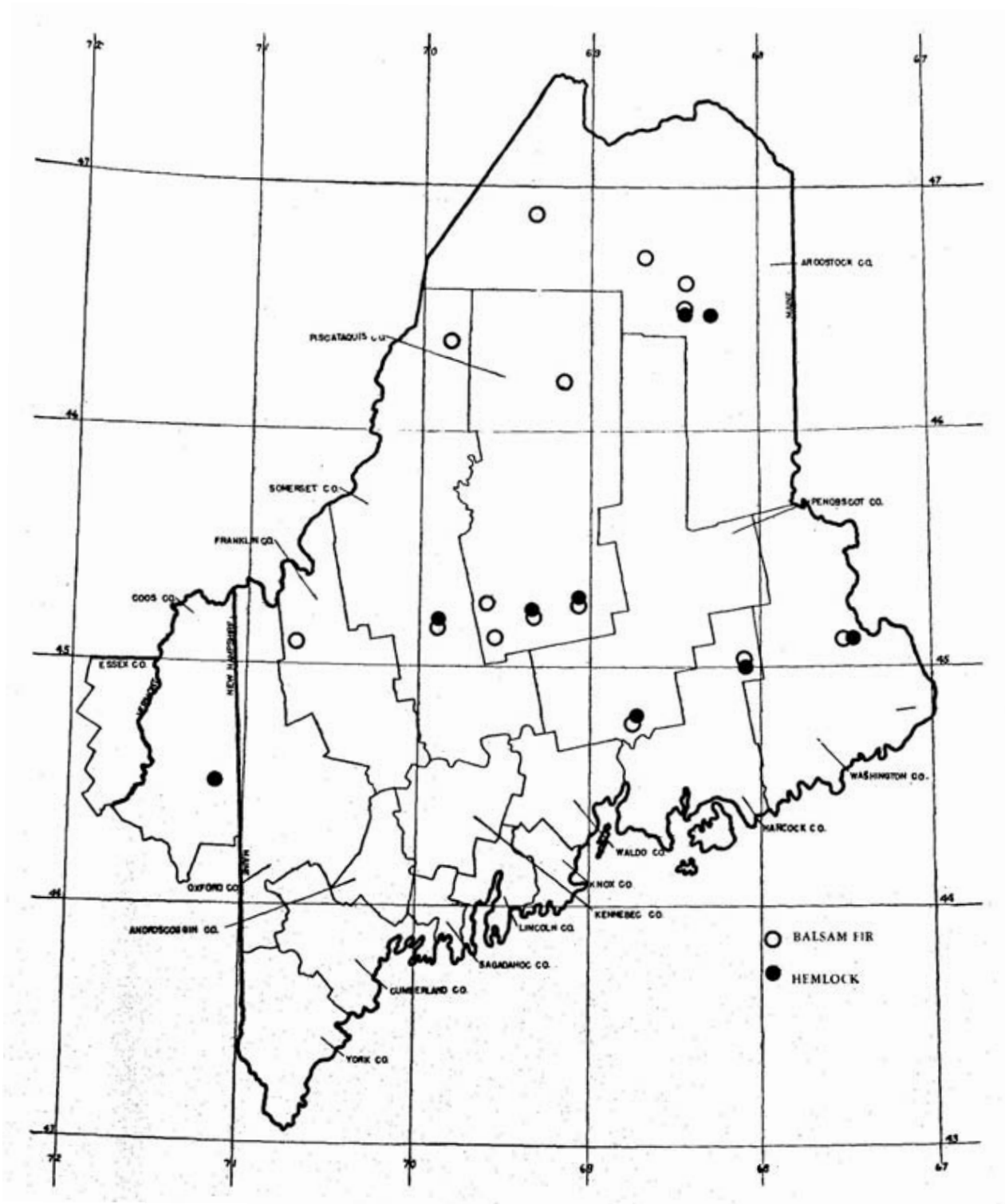


Figure 4.--Location of balsam fir and hemlock sampling areas.

Table 1.--Data on sample trees from Maine

Species	Number of trees	Range in age	Diameter breast height		Merchantable tree specific gravity	
			Mean	Range	Mean	Range
		Yr.	In.	In.		
White pine	202	23 - 174	12.0	4.5 - 22.9	0.331	0.268-0.405
Red pine	65	22 - 167	12.7	4.8 - 20.7	.391	.324- .424
Tamarack	84	28 - 201	9.3	4.6 - 17.0	.484	.413- .554
Red spruce	106	22 - 227	10.6	4.6 - 18.0	.381	.339- .449
White spruce	119	16 - 159	10.6	4.5 - 19.3	.358	.290- .452
Black spruce	105	24 - 222	9.4	4.8 - 16.1	.412	.336- .497
Balsam fir	206	34 - 126	8.7	4.6 - 16.1	.339	.281- .424
Eastern hemlock	98	29 - 227	11.9	4.9 - 20.6	.376	.333- .483

In addition, other measurable tree characteristics were used with one- and two-core specific gravities in developing a multiple regression of the form

$$\text{Tree specific gravity} = a + b_1 X_1 + b_2 X_2 + \dots + b_n X_n$$

for each species where

$X_1$  = single-core specific gravity or average specific gravity of two cores.

$X_2 \dots X_n$  = other measurable tree characteristics (dbh, total height, merchantable height, age,  $(\text{dbh})^2$ , dbh/age, total height/ $(\text{dbh})^2$ , and merchantable volume).

## DISCUSSION OF RESULTS

### Simple Regression Analysis

Pertinent regression statistics for each species are presented in table 2. In the data for the single

core equations, coefficients of determination ( $r^2$ ) range from 27 percent in eastern hemlock to 56 percent in tamarack. Use of two increment cores resulted in varying degrees of improvement. In hemlock, the  $r^2$  value increased from 27 to 36 percent while in tamarack it increased only slightly, from 56 to 58 percent. In balsam fir 47 percent of the variation was associated with the single-core regression: going to two cores raised this to 57 percent.

To evaluate the merits of single- versus two-core sampling, it is necessary to consider the amount of increased precision possible for the increased time, effort, and money that two-core sampling requires. To warrant justification it was felt that two-core sampling should reduce the standard deviation from regression to at least 0.002 below that achieved in one-core sampling. As seen in table 2, only balsam fir meets this requirement. For the other species, one-core sampling appears more efficient.

If one desires information on tree specific gravity only of balsam fir, then two-core sampling is recommended. If, however, tree specific gravity estimates are sought for all eight species, for example in a large State-wide survey, then standardization of one core for all species would seem logical. The resulting gain in precision to only one species would not be worth the ad-

Table 2.--Simple linear regression equations and best multiple regression equations for estimating tree specific gravity of eight Maine softwoods

Regression equations	Correlation coefficient: r	Coefficient of determination: r <sup>2</sup>	Standard deviation from regression
WHITE PINE			
Y = 0.15274 + 0.50445 (Sp. gr., 1 core)	: 0.7244	: 0.5249	: 0.017
Y = 0.12996 + 0.57025 (Sp. gr., 2 cores)	: .7411	: .5493	: .017
Y = 0.18294 + 0.46703 (Sp. gr., 1 core) - 0.095821 ( $\frac{Dbh}{Age}$ )	: .7603	: .5782	: .016
Y = 0.18826 + 0.41131 (Sp. gr., 1 core) + 0.000268 (total ht.) - 0.10771 ( $\frac{Dbh}{Age}$ )	: .7745	: .5999	: .016
Y = 0.16024 + 0.42437 (Sp. gr., 1 core) - 0.002515 (Dbh) + 0.000607 (total ht.) + 0.000185 (age)	: .7832	: .6135	: .015
RED PINE			
Y = 0.23672 + 0.36266 (Sp. gr. 1 core)	: .5509	: .3035	: .024
Y = 0.20517 + 0.43648 (Sp. gr., 2 cores)	: .6148	: .3780	: .023
Y = 0.36128 + 0.17776 (Sp. gr., 1 core) - 0.24154 ( $\frac{Dbh}{Age}$ )	: .8264	: .6831	: .016
Y = 0.35537 + 0.15563 (Sp. gr., 1 core) + 0.000297 (total ht.) - 0.25122 ( $\frac{Dbh}{Age}$ )	: .8395	: .7049	: .016
Y = 0.35674 + 0.16130 (Sp. gr., 1 core) + 0.000360 (total ht.) - 0.000055 (age) - 0.226780 ( $\frac{Dbh}{Age}$ )	: .8404	: .7063	: .016
TAMARACK			
Y = 0.18505 + 0.57361 (Sp. gr., 1 core)	: .7502	: .5629	: .020
Y = 0.17742 + 0.59112 (Sp. gr., 2 cores)	: .7607	: .5787	: .020
Y = 0.25854 + 0.49165 (Sp. gr., 1 core) - 0.003324 (Dbh)	: .8092	: .6549	: .018
Y = 0.27793 + 0.50362 (Sp. gr., 1 core) - 0.000363 (age) - 0.21254 ( $\frac{Dbh}{Age}$ )	: .8309	: .6904	: .017
Y = 0.25732 + 0.50258 (Sp. gr., 1 core) - 0.000259 (age) - 0.16284 ( $\frac{Dbh}{Age}$ ) + 0.007997 ( $\frac{Total\ ht.}{(Dbh)^2}$ )	: .8336	: .6950	: .017
RED SPRUCE			
Y = 0.21065 + 0.42461 (Sp. gr., 1 core)	: .6094	: .3714	: .018
Y = 0.18771 + 0.48015 (Sp. gr., 2 cores)	: .6401	: .4098	: .018
Y = 0.22517 + 0.40180 (Sp. gr., 1 core) - 0.038426 ( $\frac{Dbh}{Age}$ )	: .6185	: .3826	: .018
Y = 0.16330 + 0.41842 (Sp. gr., 1 core) + 0.002778 (Dbh) + 0.033234 ( $\frac{Total\ ht.}{(Dbh)^2}$ )	: .6479	: .4199	: .018
Y = 0.17507 + 0.40507 (Sp. gr., 1 core) + 0.002597 (Dbh) - 0.023504 ( $\frac{Dbh}{Age}$ ) + 0.031262 ( $\frac{Total\ ht.}{(Dbh)^2}$ )	: .6511	: .4240	: .018

WHITE SPRUCE

Y = 0.16022 + 0.54053 (Sp. gr., 1 core)	:	.7172	:	.5145	:	.018
Y = 0.14365 + 0.53537 (Sp. gr., 2 cores)	:	.7533	:	.5676	:	.017
Y = 0.20300 + 0.46826 (Sp. gr., 1 core) - 0.084388 $\left(\frac{Dbh}{Age}\right)$	:	.7500	:	.5626	:	.018
Y = 0.21224 + 0.47496 (Sp. gr., 1 core) - 0.000118 (Age) - 0.10781 $\left(\frac{Dbh}{Age}\right)$	:	.7567	:	.5726	:	.018
Y = 0.21033 + 0.47727 (Sp. gr., 1 core) + 0.000120 (total ht.) - 0.000178 (age) - 0.11975 $\left(\frac{Dbh}{Age}\right)$	:	.7580	:	.5747	:	.017

BLACK SPRUCE

Y = 0.17933 + 0.55017 (Sp. gr., 1 core)	:	.7227	:	.5224	:	.022
Y = 0.15333 + 0.60494 (Sp. gr., 2 cores)	:	.7317	:	.5354	:	.022
Y = 0.21893 + 0.50482 (Sp. gr., 1 core) - 0.002261 (Dbh)	:	.7519	:	.5654	:	.021
Y = 0.18210 + 0.52132 (Sp. gr., 1 core) - 0.006047 (Dbh) + 0.001267 (total ht.)	:	.7805	:	.6093	:	.020
Y = 0.15543 + 0.51670 (Sp. gr., 1 core) - 0.003372 (Dbh) + 0.001068 (total ht.) + 0.019239 $\left[\frac{Total\ ht.}{(Dbh)^2}\right]$	:	.7862	:	.6182	:	.020

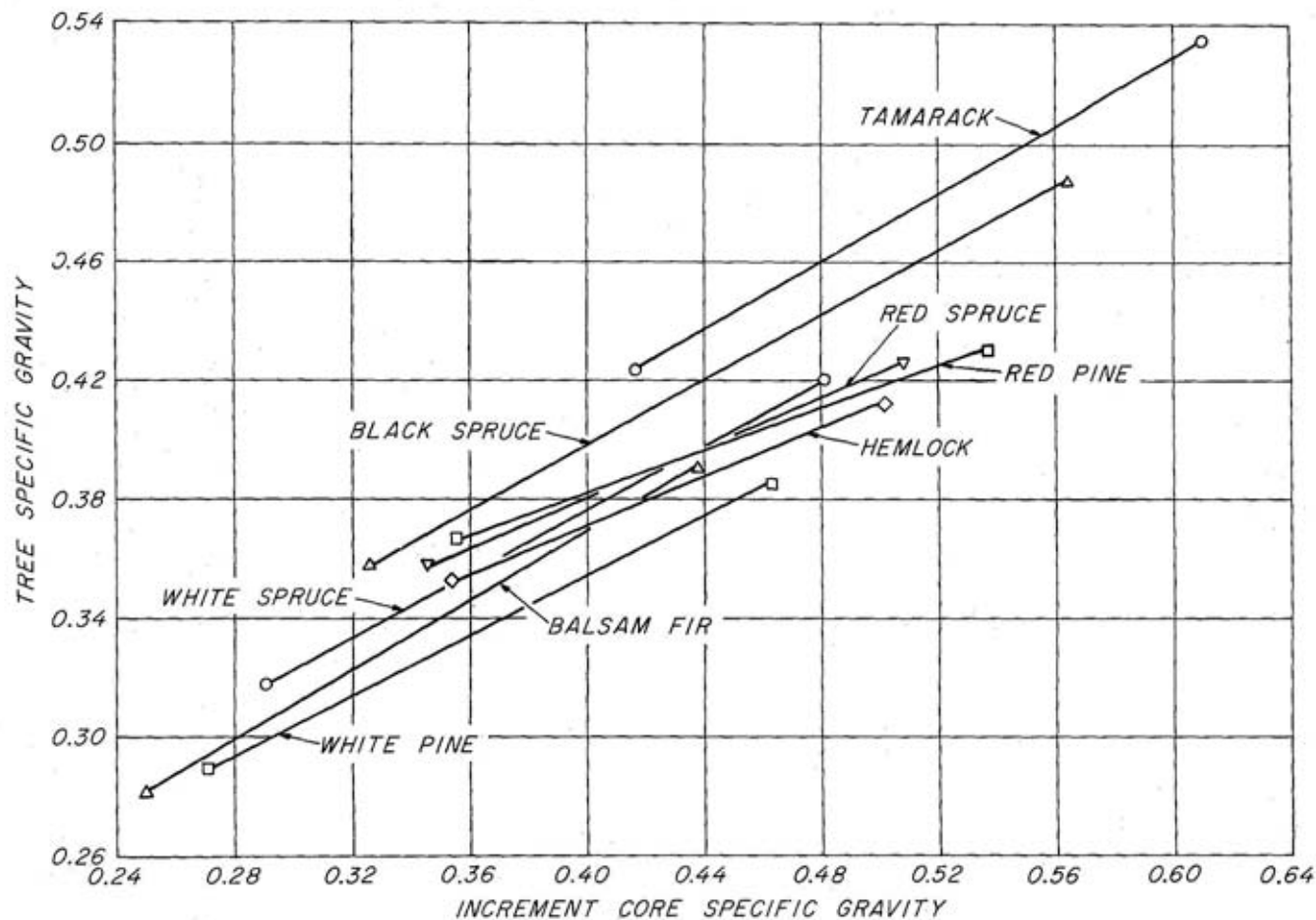
BALSAM FIR

Y = 0.13598 + 0.58429 (Sp. gr., 1 core)	:	.6873	:	.4725	:	.019
Y = 0.10542 + 0.67227 (Sp. gr., 2 cores)	:	.7535	:	.5678	:	.017
Y = 0.10742 + 0.69187 (Sp. gr., 2 cores) - 0.000155 (age)	:	.7598	:	.5774	:	.017
Y = 0.07825 + 0.70190 (Sp. gr., 2 cores) + 0.072555 $\left(\frac{Dbh}{Age}\right)$ + 0.006319 $\left[\frac{Total\ Ht.}{(Dbh)^2}\right]$	:	.7627	:	.5818	:	.017
Y = 0.08092 + 0.70235 (Sp. gr., 2 cores) - 0.000041 (total ht.) + 0.071839 $\left(\frac{Dbh}{Age}\right)$ + 0.0056436 $\left[\frac{Total\ ht.}{(Dbh)^2}\right]$	:	.7628	:	.5819	:	.017

HEMLOCK

Y = 0.20501 + 0.41557 (Sp. gr., 1 core)	:	.5206	:	.2711	:	.024
Y = 0.17094 + 0.49833 (Sp. gr., 2 cores)	:	.5963	:	.3556	:	.023
Y = 0.19880 + 0.37610 (Sp. gr., 1 core) + 0.045528 $\left[\frac{Total\ ht.}{(Dbh)^2}\right]$	:	.7387	:	.5457	:	.019
Y = 0.26486 + 0.26469 (Sp. gr., 1 core) - 0.15145 $\left(\frac{Dbh}{Age}\right)$ + 0.041939 $\left[\frac{Total\ ht.}{(Dbh)^2}\right]$	:	.7709	:	.5943	:	.018
Y = 0.27713 + 0.26299 (Sp. gr., 1 core) - 0.000038 (Dbh) <sup>2</sup> - 0.15499 $\left(\frac{Dbh}{Age}\right)$ + 0.031915 $\left[\frac{Total\ ht.}{(Dbh)^2}\right]$	:	.7765	:	.6030	:	.018

<sup>1</sup>Indicates the proportion of the variation in 1 that is associated with the regression.



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Figure 5.--The relationship between single core specific gravity at breast height and tree (average for merchantable volume) specific gravity for eight Maine conifers.

ditional expense, and certainly one-core sampling would be less confusing to fieldpersonnel collecting the increment cores,

Graphic representations of the simple linear relations for the eight species, with specific gravity of one increment core as the independent variable, are shown in figure 5. Averages and ranges in tree specific gravity by species are presented in table 1.

#### Multiple Regression Analysis

The multiple regression analysis in this study was made to see whether tree characteristics such as dbh, total and merchantable height, age,  $(dbh)^2$ ,  $dbh/age$ , merchantable volume, and total height/ $(dbh)^2$ , made a significant improvement over the simple relationships of tree specific gravity to core specific gravity, Regression

analysis was made using a computer program which fits all possible linear combinations of one or more independent variables. The multiple correlation coefficients, coefficients of determination, standard deviations from regression, and regression equations for the "best" (smallest standard deviation from regression) two, three, and four-variable regressions are shown in table 2.

As indicated in table 2, the variable  $(dbh/age)$  appeared in the "best" two-variable regression for four species. In three other species, dbh or a function involving dbh appeared in the "best" two-variable regression. In the remaining species, balsam fir, age was the "best" second variable.

The amount of improvement realized in going from the simple core-to-tree relationship to a two-variable multiple regression varied considerably among the eight species under investi-

gation. For red spruce and balsamfir, the amount of variation accounted for remained the same, 41 percent and 57 percent, respectively. This is more evident in terms of the precision achieved, where the standard deviation from regression in red spruce is the same, 0.018, for both the simple and two-variable regression equations. Similarly, in balsam fir the standard deviation from regression remained at 0.017.

At the other end of the scale is the great improvement in red pine and eastern hemlock. In red pine a simple regression involving only core specific gravity accounts for 30 percent of the variation while a multiple regression involving the variables of core specific gravity and dbh/age accounts for 68 percent of the variation. The standard deviation from regression was reduced from 0.024 to 0.016--representing a sizable gain in precision. Similarly, in hemlock the amount of accounted variation increased from 27 percent in the simple regression to 56 percent in the two-variable regression. The standard deviation from regression was reduced from 0.024 to 0.019.

Following the arbitrary system used to evaluate gain in precision of two-core versus single-core sampling, table 2 shows that a multiple regression involving two independent variables is justified for red pine, tamarack, and hemlock. For these four species the standard deviation from regression was reduced by at least 0.002 below that achieved in the simple regression analysis. In white pine, red spruce, white spruce, and black spruce, the gain in precision does not justify using a two-variable regression equation.

The "best" three- and four-variable regression equations are also shown in table 2. Following the arbitrary rule that the addition of each independent variable must reduce the standard deviation from regression by at least 0.002, no three- or four-variable regression is justified in any of the species investigated.

### Specific Gravity Variation with Height

The within-tree trend of specific gravity is very important, particularly when dealing with individual units within a tree. It has long been known that, for many conifers, specific gravity

decreases with height in the tree. According to Spurr and Hsiung (2), this has been demonstrated for the pines, eastern hemlock, Douglas-fir, jack pine, and European larch, to mention but a few.

To investigate it here, graphic plottings were made of disk specific gravity at intervals up the stem for each of three tree height classes within each species. The height class restriction was made to insure equal numbers of disks at all heights.

Figures 6 through 13 illustrate the average specific gravity and range of specific gravity at intervals up the stem to a merchantable top for the eight species under investigation. While an average line can be drawn up the stem, it is readily apparent that tremendous between-tree variation does exist in specific gravity at all heights for each species.

A quick glance at these figures suggests that the trend of specific gravity up the stem may differ by species. Of the eight species, only red pine shows the clear-cut pattern of decreasing specific gravity with height. This strongly exhibited pattern is consistent in each of the height classes shown in figure 7.

For white pine (fig. 6) the relationship is less striking. There is some decrease in specific gravity with height in the lower segments of the tree, but in the upper segments a leveling off or even a slight increase in gravity with height is detectable.

Perhaps the most inconsistent trend of specific gravity with height occurs in tamarack (fig. 8). In the 28-foot height class group, a regular decline in gravity occurs to a height of 24 feet and then increases up to the merchantable top of 28 feet. The 52-foot height class group shows somewhat an opposite pattern. A rapid decrease occurs from 4 to 8 feet, followed by a general leveling off and then increases above 40 feet.

The exception to the general rule of specific gravity decreasing with height was evidenced in red spruce, black spruce, and hemlock (figs. 9, 10, and 13). The average specific gravity line in these three species exhibits well-defined concave curves and with specific gravities at the upper height levels exceeding that recorded at the lower levels.

There are a number of possible explanations why this occurs in the spruces: Lack of a pronounced decrease in percentage of latewood

with height in tree (low percentage of latewood tending to be constant at all heights); low specific gravity of the latewood itself; significantly higher specific gravity of the earlywood of the juvenile core as compared to mature wood; and little clear wood between branch nodes in the

crown in older spruce trees that are falling off in height growth.

While attempts were made to exclude knots from the sample disks, proximity to branch nodes will tend to increase the specific gravity of the cross sections in the upper crown.

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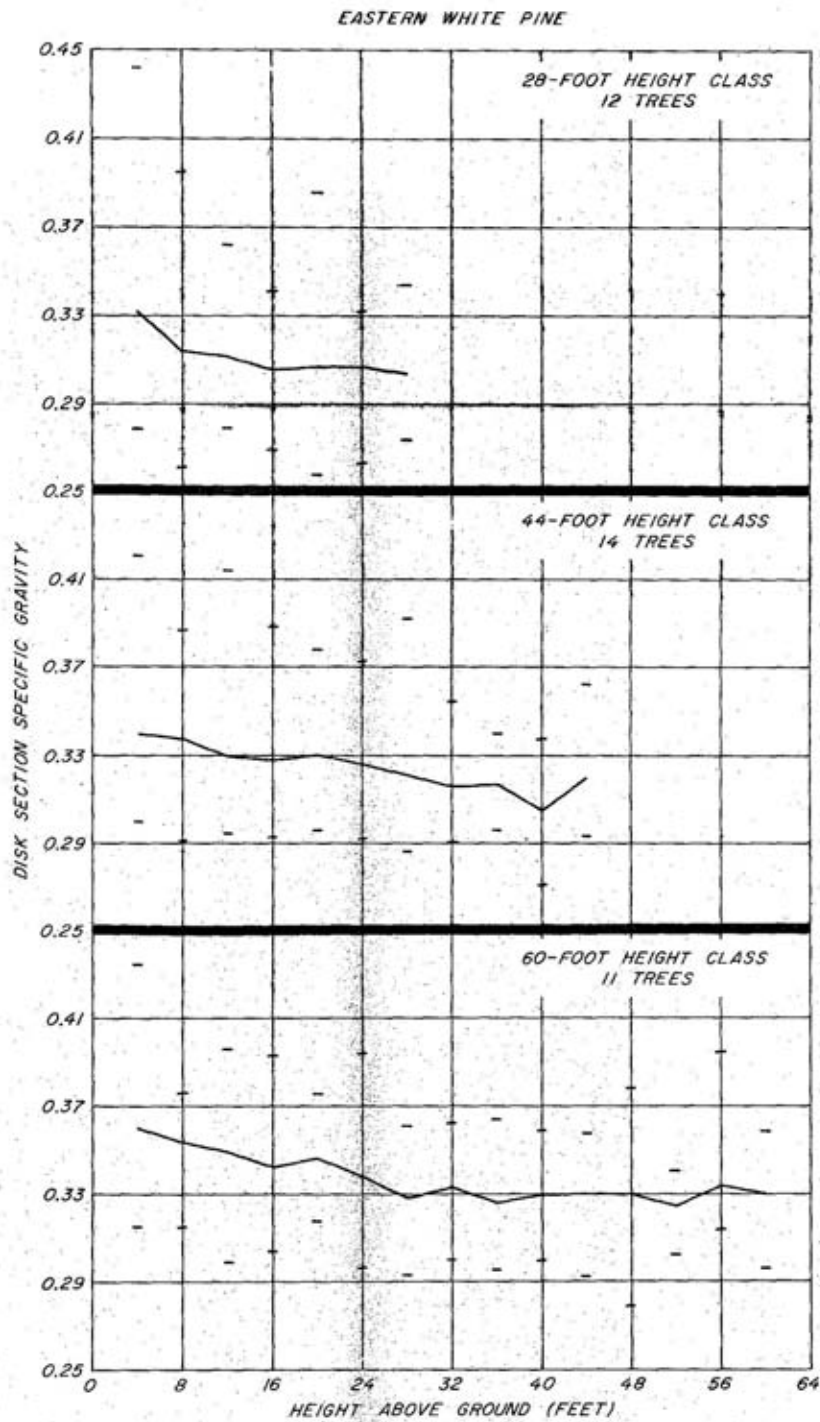
## SUMMARY and CONCLUSIONS

The data have shown varying degrees of precision in the single core-to-tree specific gravity relations for eight Maine conifers. The proportion of variation in tree specific gravity associated with the regression on single core specific gravity ranged from 27 percent in eastern hemlock to 56 percent in tamarack. Based on the assumption that a reduction of 0.002 in the standard deviation from regression represents a worthwhile gain in precision, the following conclusions were reached:

1. Comparisons of single-core sampling with two-core sampling favors single-core for seven of the eight species investigated. The one exception was balsam fir,
2. Multiple regression equations involving two independent variables result in added precision for red pine, tamarack, and hemlock
3. No added improvement was indicated in any three- or four-variable regression.

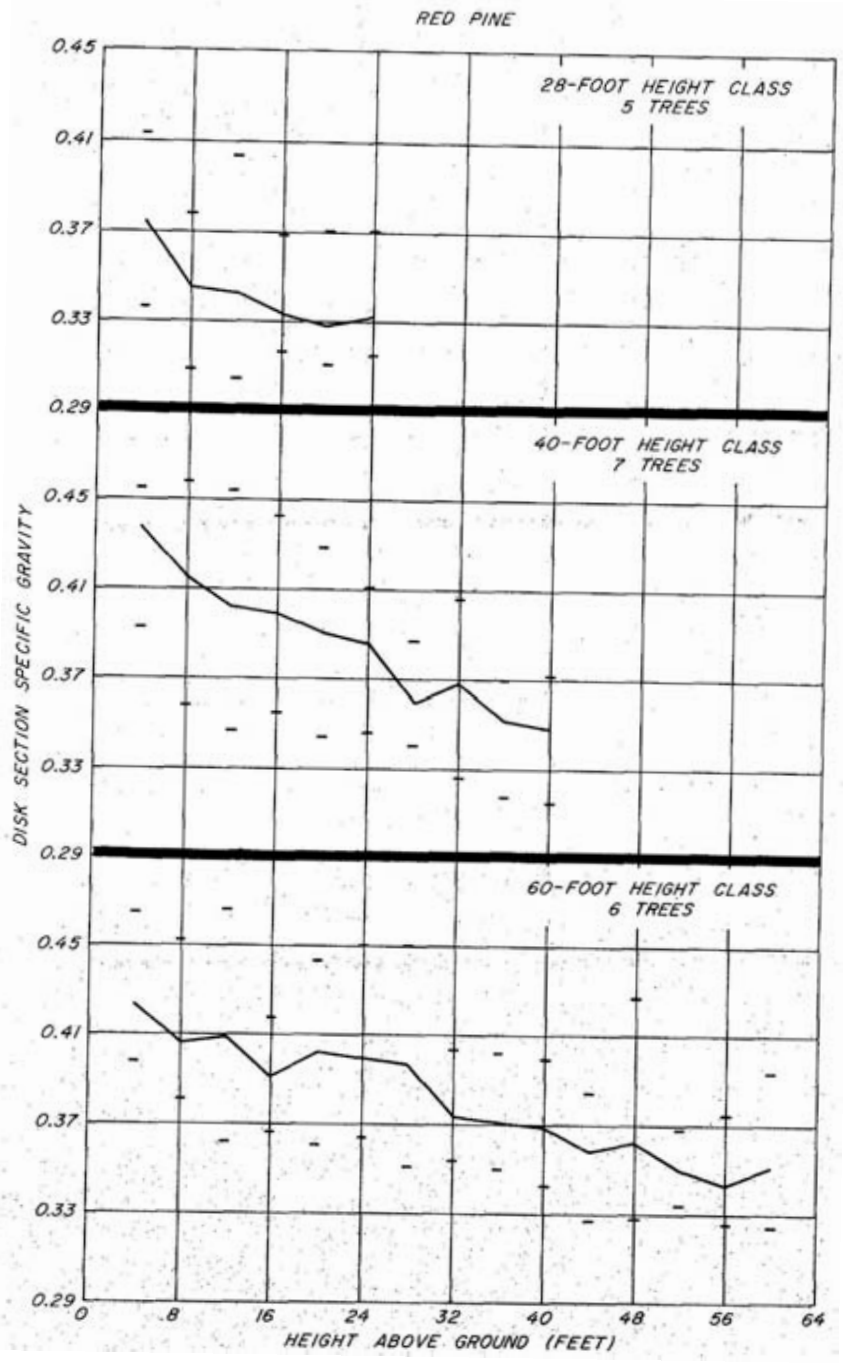
Plottings of cross section specific gravities at various heights showed patterns that appear to be characteristic of the species. The large between-tree variation in specific gravity at all heights in the stem indicates why predicting tree specific gravity with a high degree of precision may be difficult.

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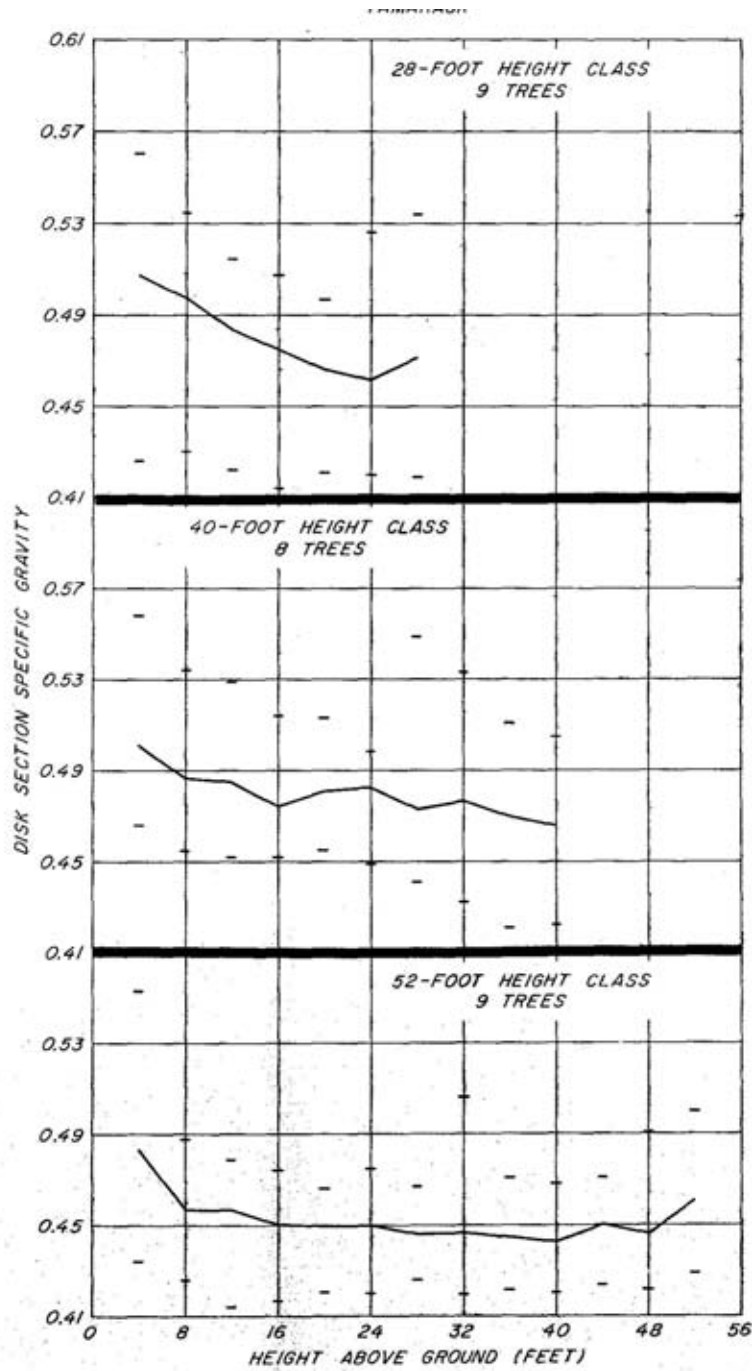
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Figure 6.--Eastern white pine: average specific gravity (solid lines) at successive intervals up the stem for three height classes of trees. The dashed points indicate the range of specific gravity values.



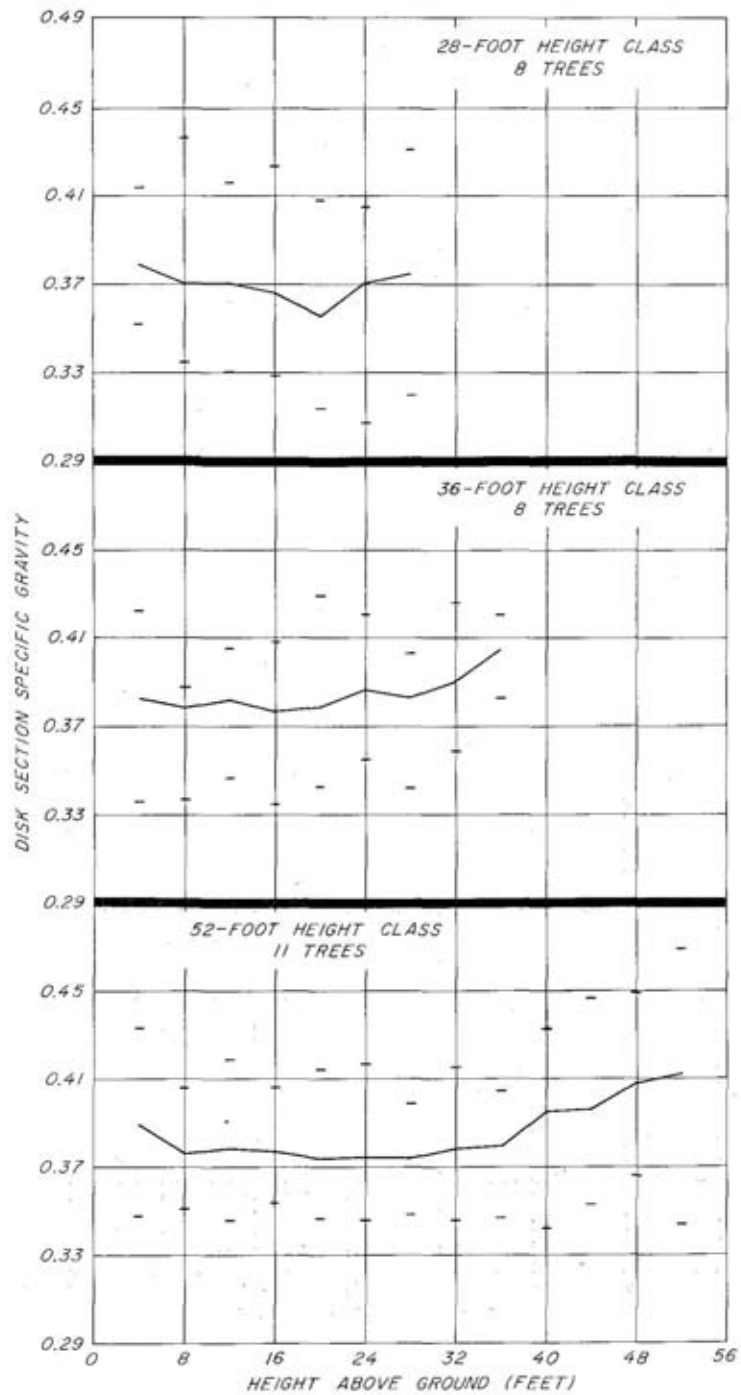
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Figure 7.--Red pine: average specific gravity (solid lines) and range in specific gravity (dashes) at successive intervals up the stem for three height classes



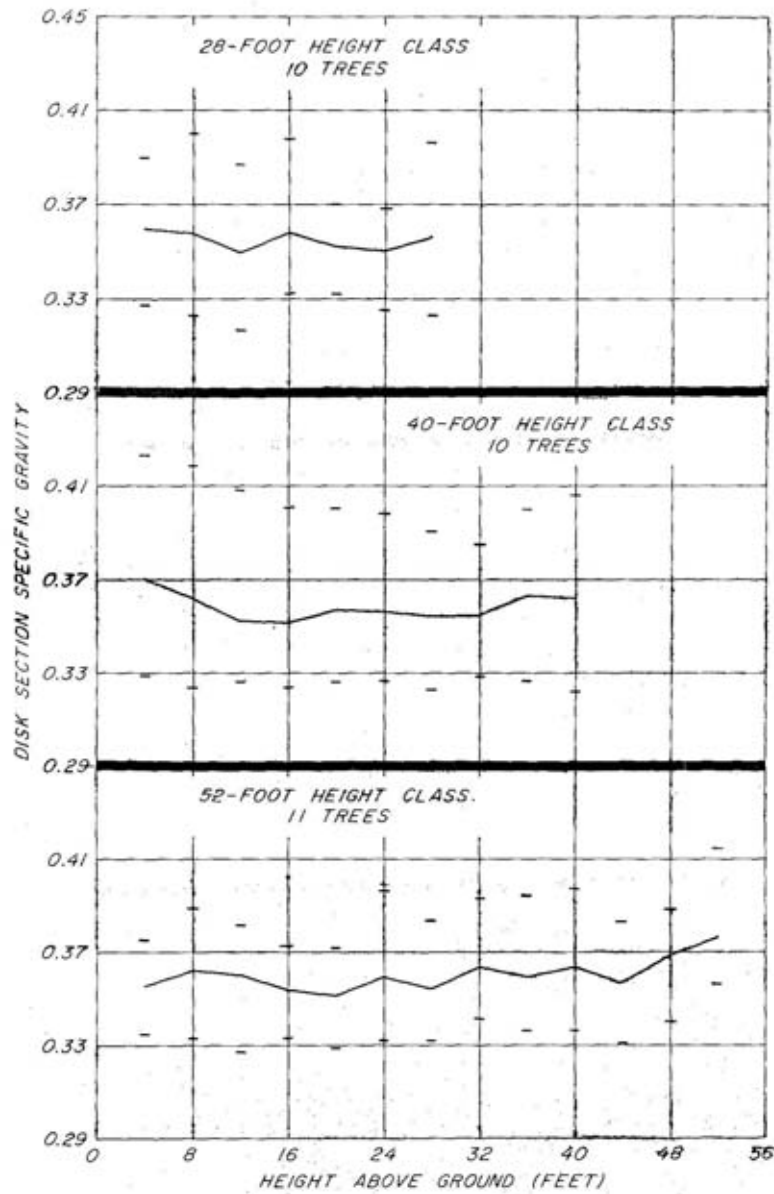
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Figure 8.--Tamarack: average specific gravity (solid lines) and range in specific gravity (dashes) at successive intervals up the stem for three height classes.



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Figure 9.--Red spruce: average specific gravity (solid lines) and range in specific gravity (dashes) at successive intervals up the stem for three height classes.



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Figure 10.--White spruce: average specific gravity (solid lines) and range in specific gravity (dashes) at successive intervals up the stem for three height classes.

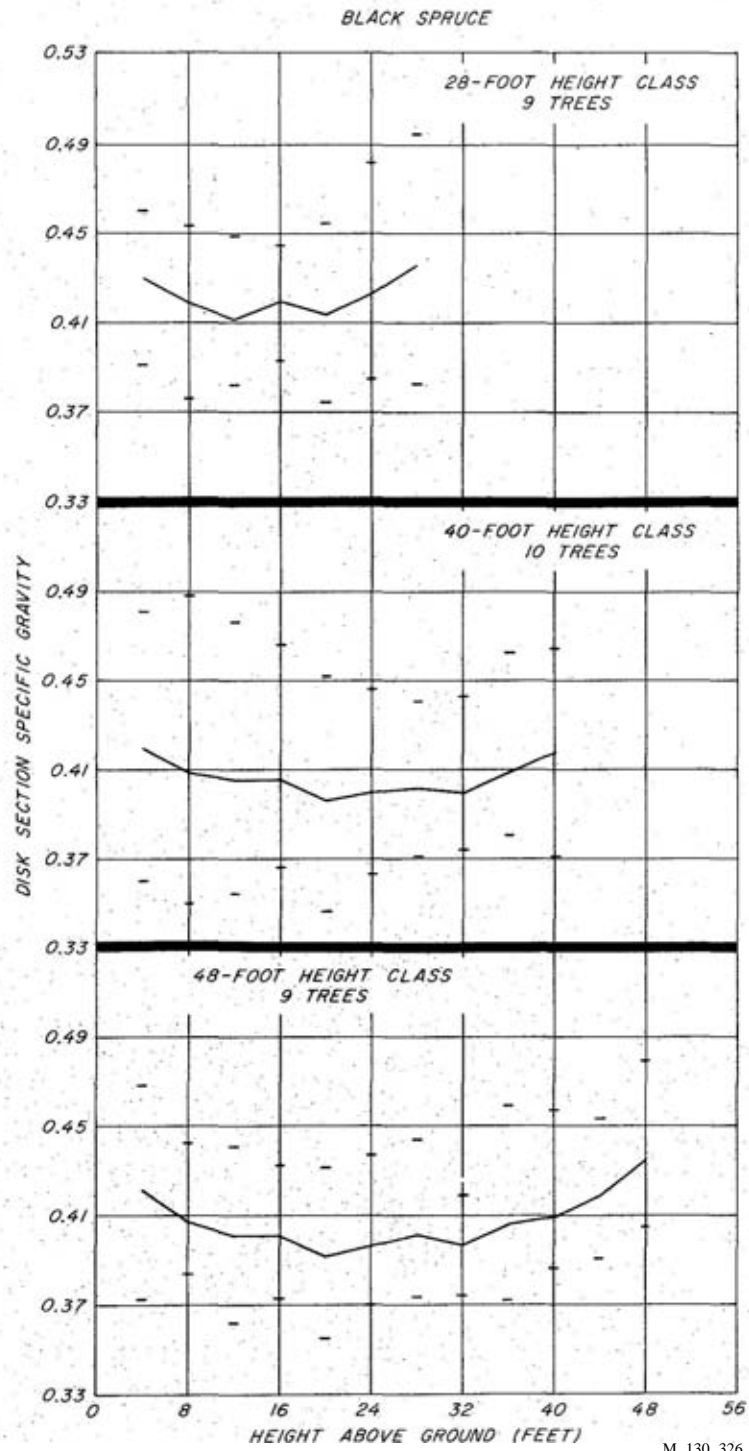
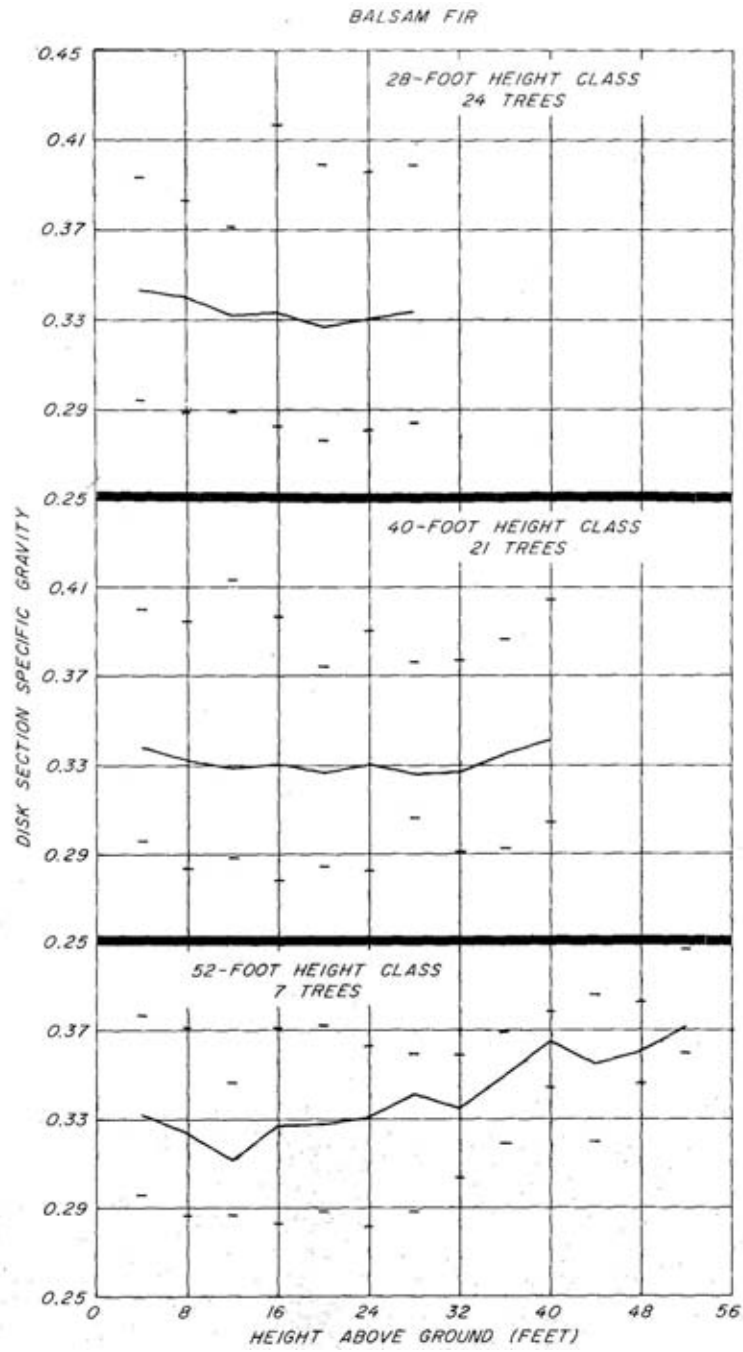
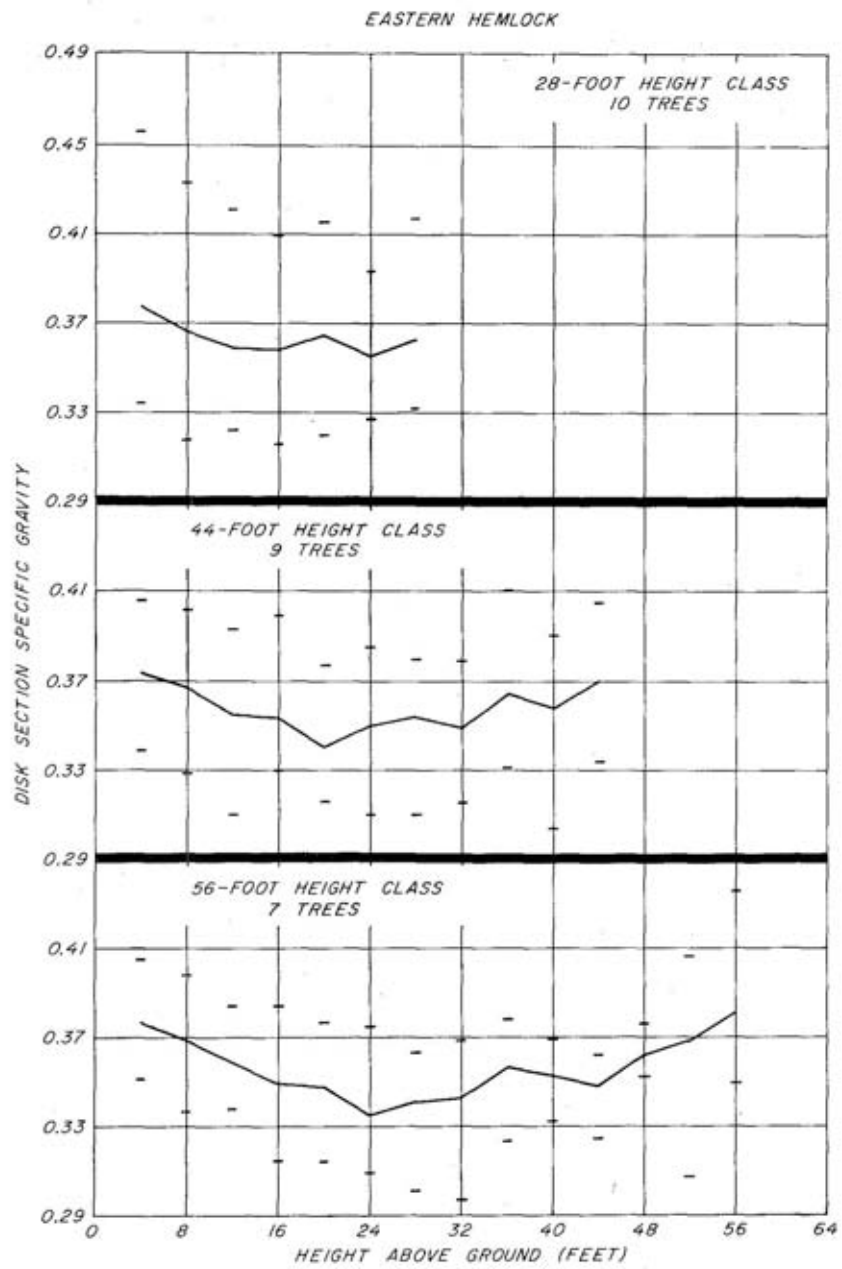


Figure 11.--Black spruce: average specific gravity (solid lines) and range in specific gravity (dashes) at successive intervals up the stem for three height classes.



M 130 324

Figure 12.--Balsamfir: average specific gravity (solid lines) and range in specific gravity (dashes) at successive intervals up the stem for three height classes.



M 130 328

Figure 13.--Eastern hemlock: average specific gravity (solid lines) and range in specific gravity (dashes) at successive intervals up the stem for three height classes.

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# APPENDIX

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

$$\text{Specific gravity} = 0.077697 \text{ SV/D}^2\text{L}$$

where

W = oven-dry weight (grams)

D = diameter of increment borer (inches)

L = length of core (inches)

2. =Weighted merchantable tree specific gravity was computed as:

$$V = 1/2 \frac{L_1 (D_0^2 + D_1^2)(2G_1^*) + L_2 (D_1^2 + D_2^2)(G_1 + G_2) + \dots + L_n (D_{n-1}^2 + D_n^2)(G_{n-1} + G_n)}{L_1 (D_0^2 + D_1^2) + \dots + L_n (D_{n-1}^2 + D_n^2)}$$

V = weighted specific gravity for merchantable portion of tree.

$L_i$  = length of  $i$ th bolt in feet.

$D_i$  = top diameter of  $i$ th bolt in inches.

$D_{n-i}$  = bottom diameter of  $i$ th bolt in inches.

$G_i$  = specific gravity top disk of  $i$ th bolt.

$G_{n-i}$  = specific gravity bottom of  $j$ th bolt.

\*In the butt bolt a single cross section was used to estimate the specific gravity.