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Studies of Connecticut Hardwoods: The Form of Hardwoods and Volume Tables on a Form Quotient Basis

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STUDIES OF CONNECTICUT HARDWOODS

THE FORM OF HARDWOODS AND VOLUME TABLES ON A FORM QUOTIENT BASIS

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A Note to Readers
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INTRODUCTION

SATISFACTORY volume tables for Connecticut Hardwoods have been lacking. Considering the fact that the forestry movement within the state started a quarter of a century ago, this condition may seem strange. The scarcity of large bodies of timber, the diverse mixture of species in the average stand requiring several volume tables, and the fact that timber estimating as a business is of relatively lower importance here than in the more heavily timbered regions, account for the failure to develop volume tables. Foresters working within the region have been content to estimate timber by log unit methods or to adapt volume tables made for other localities to fit Connecticut conditions.

In 1912 the United States Forest Service published in a Bulletin[1] entitled *Second-Growth Hardwoods in Connecticut*, three sets of volume tables for (a) chestnut, (b) red, black, and scarlet oaks, and (c) white and chestnut oaks. These tables, while made for Connecticut and adjacent territory, have not proved entirely satisfactory for local conditions, particularly since the chestnut has lost permanently its place of first importance in the forest.

The oak volume tables do not contain values for trees of the larger diameter and taller height classes. Furthermore, the volume tables for lumber show contents in one-inch boards. This destroys the usefulness so far as the oaks are concerned, since these species, when cut for lumber, should be made into plank two inches or more thick. Other species than

[1] FROTHINGHAM, E. H.: *Second-Growth Flardwoods in Connecticut.* Bulletin No. 96, U.S. Forest Service, 1912, pp. 61 to 68.

chestnut or oaks are not covered by the volume tables in *Second-Growth Hardwoods in Connecticut.*

Suitable volume tables are becoming more a necessity each year, not only for timber estimates but also for use in silvicultural investigations. The senior author appreciated the situation some years ago and since 1919 has been gathering the necessary field data. During the academic year 1924-25 the junior author, while a graduate student at Yale University, devoted most of his time to a systematic study of the data. The results of his work are embodied in this report.

The authors are firm believers in the form quotient method as the basis for volume tables and have used it in constructing the volume tables in this study. It is deemed unnecessary to elaborate the details of this method, since the reader is assumed to be familiar with the general principles of the form quotient method as described in works on forest mensuration.[2] The authors also are impressed with the desirability of avoiding the use of a separate volume table for each species in a mixed hardwood stand. With this idea in view, volume tables were prepared which will apply to all the species in the stand.

Incident to the construction of volume tables on the form quotient basis there must be a study of tree form with the results expressed finally as definite diameters at selected intervals above the ground. The volume tables themselves may have local application. The figures expressing tree form should, when based on sufficient data, have wider application. Several studies of the form of conifers have been made; of which the most comprehensive in this country is the unpublished manuscript[3] by C. Edward Behre of the Northeastern Forest Experiment Station, Amherst, Mass. So far as the writers know there has been no similar study of the form of hardwood species undertaken.

Judging from the results of the present study, the form of hardwoods is not identical with the form of conifers. It is realized that the values here secured are likely to be modified when larger numbers of trees are measured and material is taken from other parts of the country. Hardwood form should be further investigated. Probably sufficient data already are existent, which, if assembled and compiled, would furnish more dependable figures than those derived from this preliminary study.

2 See CHAPMAN, H. H.: *Forest Mensuration.* Wiley, 1924, pp. 205 to 216.

3 BEHRE, C. E.,: "Form Class Taper Curves and Volume Tables and their Application."

In conclusion, the purpose of the authors in presenting this bulletin has been to (a) provide volume tables for immediate application to hardwood species in Southern Connecticut, and (b) furnish preliminary figures on the form of hardwood species with the hope of stimulating further investigation in the subject.

DESCRIPTION OF THE DATA

The data consist of measurements taken from 1919 to 1924 on 1229 felled trees of hardwood species. These trees were secured in the vicinity of New Haven, Connecticut, with the exception of 80 trees measured near White Plains, N. Y.,[4] and of the gray birch which were obtained at Milford, Pike County, Pennsylvania. Twenty-two species are represented. Two species have more than 200 trees apiece. Three others have between 100 and 200 representatives each. Ten of the remaining species have from 10 to 71 individuals each. The remaining seven species have less than 10 trees apiece. A wide range of growth conditions is represented in the material. The trees range from 2 to 28 inches in diameter breast-high, from 20 to 100 feet in height, and from 10 to 130 years in age at the stump. In Table I the species and the number of trees of each, as well as the range in height and diameter, are shown.

On a majority of the trees the measurements were taken at stump, breast-high, and at 8.1 or 8.5 foot intervals above stump for about 75 per cent of the total length of the stem. On a small number of trees the measurements were taken at stump, breast-high, and at each tenth of the stem above breast-high. In all cases the measurements comprised the customary lengths, diameters, and bark thicknesses usually secured preliminary to volume table construction, together with age at the stump and a few other special items.

THE FORM OF HARDWOODS

Plotting and Averaging the Measurements

The form quotient method of constructing volume tables necessitates averaging the forms of all the individual trees to secure average values. In so doing the trees are grouped into arbitrary form classes and average

[4] Measured by Edward Richards, who kindly allowed these data to be included in this study.

values obtained for each group separately. Form is expressed by obtaining diameters inside the bark at stated intervals above ground, which diameters are then turned into percentages of the normal[5] diameter inside bark at breast-high. The resulting figures are termed percentile

TABLE I

SHOWING THE CHARACTER AND DISTRIBUTION OF THE TREES USED IN THE INVESTIGATION

Species	*Number of Trees*	*Range in* *Diameter Inches*	*Range in* *Height Feet*	*Range in* *Age Years*
Red Oak	250	5 to 28	40 to 100	29 to 112
Black Oak	152	8 to 20	40 to 90	35 to 97
White Oak	145	7 to 19	30 to 80	40 to 129
Scarlet Oak	39	7 to 22	40 to 70	39 to 77
Chestnut Oak	28	8 to 15	40 to 80	60 to 115
Red Maple	202	4 to 16	40 to 80	45 to 96
Gray Birch	145	2 to 11	20 to 60	10 to 69
Black Birch	71	7 to 18	40 to 80	29 to 109
White Ash	45	7 to 16	50 to 80	39 to 114
Elm	37	4 to 14	40 to 80	38 to 127
Black Ash	19	7 to 11	50 to 60	46 to 88
Tulip Tree	18	8 to 16	60 to 70	33 to 67
Shagbark Hickory	15	8 to 17	50 to 80	66 to 125
Basswood	14	9 to 16	50 to 80	70 to 90
Pignut Hickory	10	8 to 10	50 to 70	56 to 80
Mockernut Hickory	8	11 to 23	70 to 90	69 to 130
Beech	7	8 to 15	60 to 70	58 to 108
Yellow Birch	7	9 to 14	60 to 80	55 to 91
Sugar Maple	7	6 to 12	50 to 60	52 to 70
Red Ash	6	12 to 17	70 to 80	81 to 91
Locust	2	9 to 10	60 to 70	42
Sycamore	2	11 to 13	70	56 to 70
Total	1229	2 to 28	20 to 100	10 to 130

[5] Normal diameter inside bark at breast-high is secured on individual trees by subtracting from the measured diameter at breast-high, double the thickness of bark actually measured and then an allowance (graphically secured) for root swell.

tapers. The intervals at which the percentile tapers are computed equal one-tenth of the distance from tip of tree to breast-high. The percentile taper at the middle interval (0.5 distance from tip to breast-high) is the form quotient of the tree.

In order to assign the trees to the proper form class the form quotient must be found for each individual tree. Since many of the trees were not actually measured at the middle point of the stem or at the other tenth intervals it became necessary to secure the diameters at all these points by interpolation. Furthermore, on every tree it was essential to eliminate root swell from the actually measured diameter inside the bark at breast-high.

To eliminate root swell and obtain by graphic interpolation the desired values, the diameters measured inside the bark were plotted on total height above ground. A separate graph was drawn for each tree by connecting the plotted points by straight lines. Wherever the position of the point at breast-high indicated a distortion due to root swell, the trend of the curve for the upper sections was continued down to breast-high to get the normal diameter inside the bark. The portion above breast-high was divided into tenths and marks placed on the graphs at the tenth intervals. In cases where the midpoint was obviously out of line with the rest of the measurements, an adjustment was made by drawing a smooth curve between the two points next above and below the middle point.

From the graph of each tree, diameters at the tenth intervals were read and later turned into percentages of the normal diameter inside bark at breast-high (termed percentile tapers hereafter). The trees were then grouped by species into form classes containing a range of five units. Eleven form classes in all were found, ranging from form class 0.40 to o.go.

The percentile tapers were averaged by form classes for each species and for all species combined. These averages were then plotted with form class as the abscissa and percentile taper as the ordinate. The plotted points were smoothed off and harmonized by a series of curves, one for each tenth interval with a separate series for each species and for all species combined. From the curves the final tables of percentile tapers were read. Tables II to VI show the percentile tapers for each of the five species best represented in number of trees, namely red oak, red maple, black oak, white oak, and gray birch. Table VII gives the percentile tapers resulting from the combination of all species.

TABLE II

SHOWING PERCENTILE TAPERS FOR RED OAK
BASIS 250 TREES

Per cent of height from tip to breast-high	*0.40*	*0.45*	*0.50*	*0.55*	*0.60*	*0.65*	*0.70*	*0.75*	*0.80*	*0.85*
	Form Class									
	Per cent of Diameter inside Bark at Breast-high									
10	7.4	7.9	8.6	9.5	10.5	11.9	13.6	15.7	18.3	21.5
20	14.3	16.0	17.7	19.6	21.5	23.6	26.2	29.7	34.8	42.7
30	23.0	25.0	27.4	30.0	33.1	36.4	40.1	44.8	51.0	59.7
40	30.7	34.5	38.3	42.3	46.6	51.0	55.8	61.1	67.1	73.9
50	40.0	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0
60	56.1	60.4	64.5	68.5	72.3	75.7	79.0	82.3	85.5	89.1
70	74.0	76.0	77.8	79.2	81.0	82.5	84.3	86.5	89.0	91.8
80	84.6	85.6	86.6	87.5	88.4	89.4	90.6	91.9	93.1	94.9
90	92.3	93.0	93.6	94.1	94.8	95.1	95.6	96.0	96.3	97.0
Basis in number of trees	2	5	10	21	46	80	56	25	4	1

TABLE III

SHOWING PERCENTILE TAPERS FOR RED MAPLE
BASIS 202 TREES

Per cent of height from tip to breast-high	*0.45*	*0.50*	*0.55*	*0.60*	*0.65*	*0.70*	*0.75*	*0.80*	*0.85*
	Form Class								
	Per cent of Diameter inside Bark at Breast-high								
10	8.7	9.9	11.2	12.5	13.7	15.0	16.6	18.5	20.5
20	18.0	20.5	22.9	25.1	27.3	29.4	32.2	36.6	43.2
30	28.5	31.3	34.2	37.1	40.3	43.8	48.0	53.4	60.7
40	38.5	42.0	45.6	49.5	53.5	58.2	63.4	69.3	75.8
50	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0
60	60.8	64.0	67.1	70.3	73.7	77.4	81.1	84.9	88.7
70	72.1	74.4	76.5	78.8	81.2	83.5	86.0	88.7	91.4
80	82.2	83.6	85.0	86.2	87.4	88.8	90.3	92.2	94.2
90	89.7	90.8	92.0	93.3	94.3	95.2	96.1	96.9	97.7
Basis in number of trees	3	10	18	50	60	42	16	2	1

TABLE IV

SHOWING PERCENTILE TAPERS FOR BLACK OAK
BASIS 152 TREES

Per cent of height from tip to breast-high	Form Class							
	0.45	*0.50*	*0.55*	*0.60*	*0.65*	*0.70*	*0.75*	*0.80*
	Per cent of Diameter inside Bark at Breast-high							
10	10.3	10.7	11.2	11.9	12.8	14.3	16.6	20.0
20	18.0	19.7	21.5	23.6	26.0	29.0	32.5	37.0
30	31.1	31.8	33.2	35.3	38.6	43.5	49.8	57.4
40	37.1	40.4	44.0	48.0	52.5	58.0	64.0	70.5
50	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0
60	60.3	64.4	68.0	71.2	74.4	78.0	81.9	85.6
70	70.6	73.3	76.0	78.7	81.3	83.8	86.3	88.9
80	81.7	83.0	84.3	85.7	87.3	89.0	90.7	92.5
90	91.4	91.7	92.1	92.8	93.8	94.8	95.8	96.8
Basis in number of trees	2	4	19	29	42	37	16	3

TABLE V

SHOWING PERCENTILE TAPERS FOR WHITE OAK
BASIS 145 TREES

Per cent of height from tip to breast-high	Form Class								
	0.40	*0.45*	*0.50*	*0.55*	*0.60*	*0.65*	*0.70*	*0.75*	*0.80*
	Per cent of Diameter inside Bark at Breast-high								
10	8.6	8.9	9.4	10.0	11.0	12.1	13.4	14.8	16.2
20	20.0	20.3	20.8	21.5	22.7	24.5	27.0	30.6	36.0
30	26.9	28.0	29.3	31.0	33.5	37.2	42.3	49.2	57.2
40	32.8	36.1	39.6	43.2	47.2	51.8	57.3	63.3	70.0
50	40.0	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0
60	54.3	58.5	62.8	67.0	71.0	75.0	78.5	81.7	85.2
70	68.0	72.3	75.1	77.8	80.4	83.1	85.7	88.4	91.0
80	76.5	78.7	81.7	84.4	86.5	88.3	89.7	90.8	92.1
90	90.0	91.2	92.2	93.0	93.7	94.4	95.0	95.6	96.3
Basis in number of trees	1	3	4	16	29	47	31	11	3

FORM OF HARDWOODS

Variation in Form between Hardwood Species

Do all hardwood species have the same form? If not, are the different species similar enough in form to justify the use of one average percentile taper series? These questions required answers before the construction of volume tables on the form quotient basis could proceed. The percentile taper curves for the different species were compared, with the result that two groups appeared to exist.

One group possessed high percentile taper values in the tops, and low values in the sections below the middle point. In general, species with a single main stem belong to group one. Gray birch was representative of this group, which included black birch, elm, black ash, tulip tree, pignut hickory, locust, and sycamore.

TABLE VI

SHOWING PERCENTILE TAPERS FOR GRAY BIRCH
BASIS 145 TREES

Per cent of height from tip to breast-high	*Form Class* 0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80
	Per cent of Diameter inside Bark at Breast-high								
10	5.6	7.2	8.7	10.5	12.6	14.8	17.3	20.0	23.1
20	12.0	15.2	18.5	22.0	25.8	30.1	34.8	40.3	47.4
30	23.0	26.0	29.2	33.3	38.4	44.2	50.7	57.9	65.5
40	31.4	35.3	39.6	44.4	49.8	55.5	61.2	67.3	73.4
50	40.0	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0
60	51.0	55.5	60.1	64.5	69.0	73.2	77.3	81.2	85.0
70	63.0	67.1	71.0	74.5	77.5	80.3	83.2	86.1	89.0
80	74.9	77.8	80.6	83.1	85.3	87.4	89.3	91.2	93.2
90	87.8	89.5	90.5	91.3	92.3	93.3	94.4	95.5	96.6
Basis in number of trees	2	5	31	37	30	25	12	2	1

The other group had relatively low percentile taper in the tops, and high values in the portions below the middle point. These species approached a cylindrical form in the lower stem but had several heavy branches in the upper half of the stem. This group comprised the remaining species of which red oak was taken as typical. More thorough examination indicated that red oak and gray birch were extremes and that the other species were intermediate in form between these two trees. Figure 1 shows graphically the percentile taper series for red oak, for gray birch, and for all hardwoods combined.

Absolute form factors for the portion of the tree above breast-high were computed for red oak, gray birch, and all hardwoods combined. Using

TABLE VII

SHOWING PERCENTILE TAPERS FOR ALL HARDWOODS BASIS 1229 TREES

Per cent of height from tip to breast-high	*Form Class*										
	0.40	*0.45*	*0.50*	*0.55*	*0.60*	*0.65*	*0.70*	*0.75*	*0.80*	*0.85*	*0.90*
	Per cent of Diameter inside Bark at Breast-high										
10	7.3	8.4	9.7	10.7	11.9	13.0	14.0	15.7	17.7	20.4	
20	14.4	16.8	19.3	21.6	23.9	26.2	28.7	32.2	36.2	41.6	
30	22.0	25.6	29.1	32.6	36.0	39.5	43.7	48.6	54.4	62.2	
40	30.2	34.5	38.9	43.7	48.2	52.9	58.0	63.5	69.7	76.6	
50	40.0	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0	
60	52.5	57.8	62.4	66.9	71.1	74.7	77.9	81.6	85.1	89.0	
70	65.4	69.8	73.6	76.7	79.8	82.1	84.2	86.7	89.2	91.8	
80	77.9	80.8	83.2	85.1	86.8	88.2	89.6	91.3	92.8	94.7	
90	89.7	90.9	91.8	92.9	93.5	94.3	94.9	95.6	96.4	97.3	
100	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	
110	102.4	103.3	104.2	104.8	105.9	106.5	107.4	108.3	109.0	110.0	
120	105.1	106.6	108.3	109.8	111.6	113.3	114.9	116.6	118.2	120.0	
130	107.6	109.6	112.1	114.8	117.5	120.0	122.2	125.0	127.3	130.0	
Basis in number of trees	6	19	70	147	254	355	249	103	20	5	1

the absolute form factors to obtain the volumes, the per cent of variation in cubic foot volume of the red oak and of the gray birch from the average for all hardwoods combined was computed. These percentages, together with the absolute form factors, are given in Table VIII.

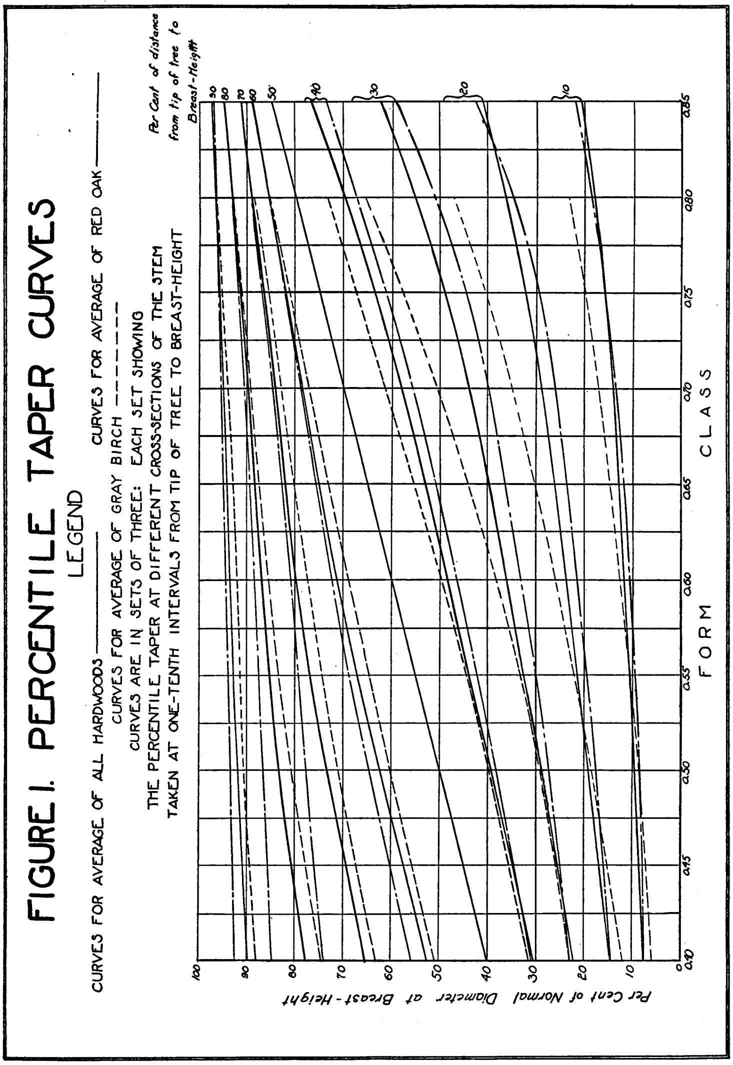


FIGURE I. PERCENTILE TAPER CURVES

It will be noted that the variations from the average are greater in the low and high form classes than in the middle classes. Fewer trees were measured in the low and high form classes than in the middle classes. Hence the results at the two extremes are less dependable than those for the middle classes. The form classes most likely to be used in practice are the 0.55, 0.60, 0.65, and 0.70, and particularly the two middle classes of this group. Within these two classes (0.60 and 0.65), the variation from the gray birch at one extreme to the red oak at the other is only 2.9 per cent.

While the absolute form factors for form class 0.65 of all hardwoods, red oak, and gray birch are identical, this does not mean that the percentile tapers for each of the three groups coincided. Inspection of Tables II, VI, and VII will show that the percentile tapers differ. The variations

TABLE VIII

SHOWING ABSOLUTE FORM FACTORS FOR ALL HARDWOODS, RED OAK, AND GRAY BIRCH, AND PER CENT OF VARIATION IN CUBIC FOOT VOLUME OF RED OAK AND GRAY BIRCH FROM ALL HARDWOODS

Form Class	*Absolute Form Factor*			*Per cent of variation in cubic foot volume from all hardwoods of:*	
	All Hardwoods	*Red Oak*	*Gray Birch*	*Red Oak*	*Gray Birch*
0.40	.300	.327	.282	+9.0	−6.0
0.45	.325	.345	.308	+6.2	−5.2
0.50	.351	.366	.337	+4.3	−4.0
0.55	.378	.387	.367	+2.4	−2.9
0.60	.405	.410	.398	+1.2	−1.7
0.65	.434	.434	.434	0	0
0.70	.466	.463	.473	−0.6	+1.5
0.75	.501	.495	.519	−1.2	+3.6
0.80	.540	.534	.570	−1.1	+5.6
0.85	.585	.584		−0.2	

in percentile tapers are so related in the 0.65 form class as to give the same absolute form factor and hence the same cubic contents. When volumes are computed in units other than the cubic foot, such, for example, as the board foot, the results in form class 0.65 may not be identical for all hardwoods, red oak, and gray birch.

The final decision was to use the percentile taper series for all hardwoods combined and make one set of volume tables for all species. Investigations based on more extensive data may later demonstrate that two and possibly more groups of hardwoods should be recognized on the basis of form. If this is done it seems probable that one group will consist of species having a continuous stem, such as gray birch; and another group will include species with a marked branching habit, of which red oak is a good example.

Comparison between the Form of Conifers and Hardwoods

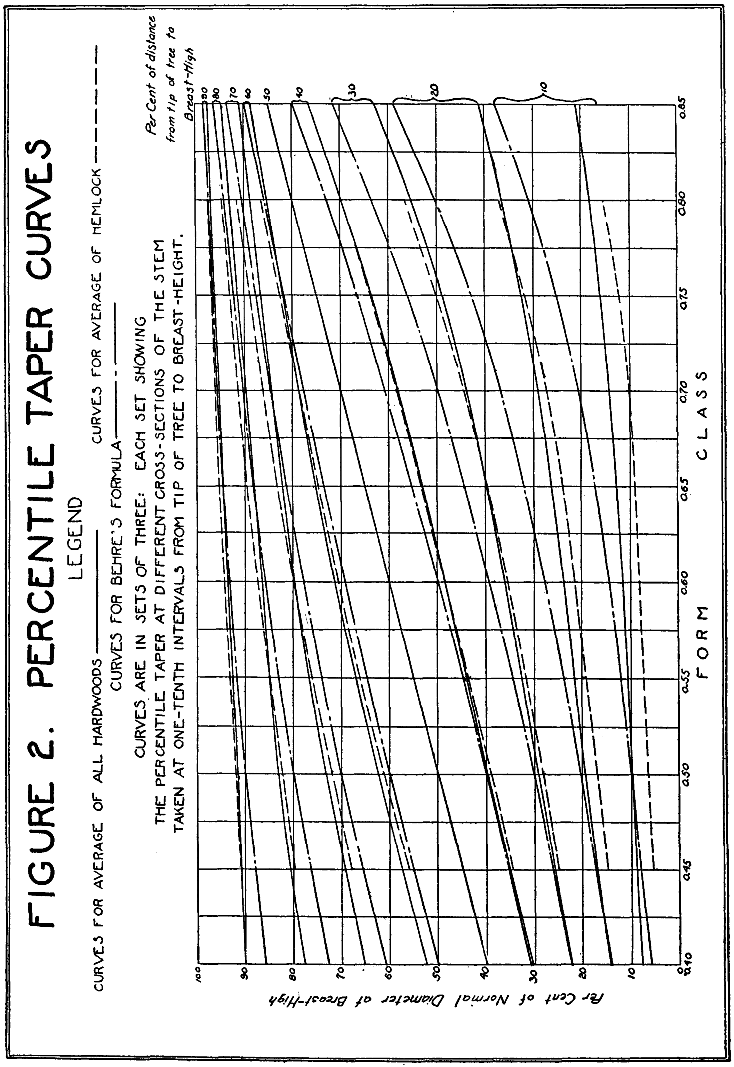
Behre[6] had already shown that the form of conifers may be expressed by the formula $y = \frac{x}{a + bx}$. y is the percentile taper and x is the per cent of height from tip to breast-high while a and b are constants. Behre's formula is taken as the best available expression of the average form of conifers. It furnishes an excellent basis for comparing the form of hardwoods with that of conifers. In Figure 2 graphs are shown comparing percentile tapers secured from Behre's formula with those for all hardwoods. For purposes of comparison, values for hemlock secured in the same region are given. It is evident that the hardwoods conform more closely than eastern hemlock[7] to the values derived from Behre's formula. Hemlock did not follow this formula so closely as did most other conifers tested. The greatest differences between Behre's formula and the hardwoods occur in the three top sections, where percentile tapers for all hardwoods are lower than those of the formula. Below the middle point the hardwoods are more cylindrical; in other words, have higher percentile taper values than those derived from the formula.

[6] Behre, C. E.: "Preliminary Notes on Studies of Tree Form." *Journal of Forestry,* Vol. 21, 1923, pp. 507 to 511.

[7] Merrill, P. H., and Hawley, R. C.: *Hemlock: Its Place in the Silviculture of the Southern New England Forest.* Bulletin No. 12, Yale University, School of Forestry, 1924, pp. 49 to 55.

Bark Thickness and Root Swell

As stated on page 9 root swell was eliminated before the percentile tapers were computed. However, it is essential in applying the form quotient method of constructing volume tables that values for root swell at



breast-high in trees of different diameters be obtained. Values for bark thicknes's at the same point also are needed. Both root swell and double bark thickness must be deducted in order to obtain normal diameter inside the bark for trees of each diameter breast-high class.

Bark thickness and root swell each were computed separately for the individual species and for all species combined. Bark thickness was secured from the actual measurements on each tree. Root swell was obtained by subtracting the normal diameter inside bark at breast-high as read from the plotted graph of each tree from the actual measured diameter at the same point. The resulting values for double bark thickness, for root swell, for the sum of the two factors, and for the normal diameter inside bark derived from curving the computed data are given for all species combined in Table IX.

Table X contains values for double bark thickness and root swell combined for each of the five best represented species. A column has been added for each species, showing for trees of each diameter class the difference expressed in per cent of cubic volume caused by the use of the average double bark thickness and root swell values (taken from Table IX) instead of the values for the individual species as given in Table X. Variations from -13 to +7 per cent are found between different species and up to 13 per cent between trees of different sizes within a given species. The method of constructing the average curve is responsible for the apparently great variation between small and large-sized trees of gray birch and red maple. These two were the only species represented in the 2, 3, and 4 inch classes. Consequently the average curve was based at the lower end upon gray birch and red maple. Red oak, the most abundant single species forming about 35 per cent of the stands in the hardwood type, shows only a small variation.

Evidently bark thickness and root swell are factors which combined may cause greater differences in volume between species than percentile taper. The five species represented in Table X illustrate nearly the total range to be expected in the region studied. Chestnut oak is the thickest barked species in the region. Indications from the 28 trees measured are that this species will only slightly exceed in bark thickness and root swell the values obtained for black oak. Gray birch shows the smallest values for bark thickness and root swell of any species examined.

The variations between species are great enough to warrant, ultimately, the use of independent bark thickness and root swell values and possibly as a consequence separate volume tables for each important species or at least for three groups of species. However, for the purpose of the present study it was decided to use average values (Table IX) for all species. In arriving at this decision the following facts had weight. The volume tables will be applied chiefly in mixed stands of such composition that plus and

TABLE IX

SHOWING DOUBLE BARK THICKNESS, ROOT SWELL, THE SUM OF THE TWO FACTORS, AND NORMAL DIAMETERS INSIDE THE BARK

Diameter Breast-high Inches	*Normal Diameter Inside the Bark Inches*	*Sum of Root Swell and Bark Thickness Inches*	*Double Bark Thickness Inches*	*Root Swell Inches*
2	1.9	0.1	0.1	0.0
3	2.8	0.2	0.2	0.0
4	3.6	0.4	0.3	0.1
5	4.5	0.5	0.4	0.1
6	5.4	0.6	0.5	0.1
7	6.2	0.8	0.6	0.2
8	7.0	1.0	0.8	0.2
9	7.9	1.1	0.8	0.3
10	8.7	1.3	1.0	0.3
11	9.6	1.4	1.0	0.4
12	10.4	1.6	1.1	0.5
13	11.3	1.7	1.1	0.6
14	12.2	1.8	1.2	0.6
15	13.1	1.9	1.2	0.7
16	14.0	2.0	1.3	0.7
17	14.9	2.1	1.3	0.8
18	15.8	2.2	1.3	0.9
19	16.7	2.3	1.4	0.9
20	17.6	2.4	1.4	1.0
21	18.5	2.5	1.5	1.0
22	19.4	2.6	1.5	1.1
23	20.4	2.6	1.5	1.1
24	21.3	2.7	1.6	1.1
25	22.2	2.8	1.6	1.2
26	23.1	2.9	1.6	1.3
27	24.0	3.0	1.7	1.3
28	24.9	3.1	1.7	1.4

TABLE X

SHOWING FOR INDIVIDUAL SPECIES THE DEDUCTION FOR BARK AND FOR ROOT SWELL TO BE MADE FROM DIAMETER BREAST-HIGH TO SECURE THE NORMAL DIAMETER INSIDE BARK AND ALSO THE DIFFERENCE (EXPRESSED IN PER CENT OF CUBIC VOLUME OF TREE), BETWEEN APPLYING AVERAGE VALUES FROM TABLE 9 AND VALUES FROM THIS TABLE

Diameter Breast-high Inches	*Red Oak Difference in per cent*	*Black Oak Difference in per cent*	*White Oak Difference in per cent*	*Red Maple Difference in per cent*	*Gray Birch Difference in per cent*
	Double Bark Thickness and Root Swell in Inches				
2					0.1 0
3					0.2 0
4				0.4 0	0.3 − 5
5	0.6 + 4			0.5 0	0.4 − 4
6	0.7 + 3			0.6 0	0.5 − 3
7	0.9 + 3		0.9 + 3	0.7 − 3	0.6 − 6
8	1.0 0	1.3 + 7	1.1 + 2.5	0.8 − 5	0.6 − 10
9	1.1 0	1.4 + 7	1.2 + 2	1.0 − 2	0.7 − 9
10	1.3 0	1.6 + 6	1.3 0	1.1 − 4	0.8 − 10
11	1.4 0	1.7 + 5	1.5 + 2	1.2 − 4	0.8 − 11
12	1.5 − 2	1.9 + 5	1.6 0	1.3 − 5	0.8 − 13
13	1.6 − 2	2.0 + 5	1.7 0	1.4 − 5	
14	1.7 − 1	2.1 + 4	1.8 0	1.4 − 6	
15	1.8 − 1	2.2 + 4	2.0 + 1	1.5 − 5	
16	1.9 − 1	2.3 + 4	2.1 + 1	1.6 − 5	
17	2.0 − 1	2.3 + 2	2.2 + 1	1.6 − 6	
18	2.1 − 1	2.4 + 2	2.3 + 1	1.7 − 5	
19	2.2 − 1	2.5 + 2	2.4 + 1		
20	2.2 − 2	2.5 + 1	2.5 + 1		
21	2.3 − 2				
22	2.4 − 2				
23	2.5 − 1				
24	2.5 − 2				
25	2.6 − 2				
26	2.7 − 2				
27	2.8 − 1				
28	2.8 − 2				
Basis Number of trees	250	152	145	202	145
Average Differences in per cent	−0.7	+4.2	+1.1	−3.7	−6.5

Plus signs indicate results too large when values in Table IX are used.
Minus signs indicate results too small when values in Table IX are used.

minus discrepancies of the individual species tend to balance one another. There is very little advantage under the local economic conditions of securing an estimate of high accuracy *by species-though* an accurate *total* estimate is wanted. Where exceptional cases occur, namely, in pure. stands or in those unusual in composition or in instances where an estimate accurate for the individual species is needed, the proper correction factor may be applied to the total contents of each species as taken from the average volume table. This correction factor would be secured from data such as shown in Table X and applied as a percentage of increase or decrease to the volumes either separately for each diameter class or as one average percentage for, all diameter classes encountered in that estimate.

In this way the necessity for constructing a set of volume tables for each species showing different bark thickness and root swell values could be avoided. The volume table based on average bark thickness and root swell values would be employed for all species, using correction factors for individual species where required.

THE VOLUME TABLES

The conclusion was reached in the preceding pages that average percentile tapers and average values for bark thickness and root swell may be accepted as applicable to all species of hardwoods for the purposes of this investigation. The problem then resolves itself into the construction of one s.et of volume tables. The percentile tapers for all species as given in Table VII furnish the basis by use of which all the volume tables have been constructed. The form quotient method as usually applied requires the construction of separate volume tables for each form class. Thus, if there were ten form classes ranging from 0.40 to 0.85 by 0.05 unit classes, there would be ten volume tables for each volume table unit, such as cubic feet, feet board measure, ties, etc. A single set of volume tables might then include thirty or more tables. In practice this would probably never be necessary as only two or three of the form classes would need to be considered.

In using such a set of tables, information must be obtained as to the form quotient of the trees or stands to which the tables are to be applied, in order that tables of the right form class may be selected and used in that particular estimate. Unfortunately, quick and accurate field methods of determining the form quotient of standing trees or stands have not yet been perfected. Doubtless this deficiency will be remedied within a few years. Meanwhile another way of applying the form quotient method, which does not require field determination of the form quotients of standing timber on each area estimated, is available where the volume tables are intended for a restricted region.

Within one locality and one forest type, such, for example, as the hardwood type in New Haven County, Connecticut, average form class values, when once determined for stands or for trees of different size classes, may prove generally applicable without the need of special field measurements at the time of making the estimate. If this proves to be the case, tables can be made up for that particular form class for each volume table unit desired, and thereby the number of tables in a single set appreciably reduced. The basic data, namely, the' percentile tapers for each form class (see Table VII), are available and enable the construction, quickly and easily, of volume tables for any other form classes that later developments may show are needed. Before starting the actual construction of volume tables, a study was made to determine which form classes were most applicable to local conditions.

DETERMINATION OF THE AVERAGE FORM QUOTIENT

The 1229 trees measured during the investigation were used to determine average form quotient values. At first the trees were grouped into ten-foot height and one-inch diameter classes and the average form quotient of each group computed. The species were treated separately. It developed that neither height, diameter, nor species was significant in affecting the average form quotient of the groups. The average form quotient of the material fell within the 0.65 form class. While a slight falling off in average form quotient appeared with increase in diameter, this was not sufficiently pronounced to justify a change in form class. The extent of the decrease is shown in Table XI.

There was one exception to the foregoing statements. Gray birch differed so markedly from the other species that it was taken out of the general average. In this connection it should be noted that the gray birch material was secured at Milford, Pike County, Pa., and furthermore largely in pure stands of the old field type rather than in the hardwood type. All other species are representative of the hardwood type. It is believed that the difference in type here is a more important factor than the difference in regional location on the average form quotient of the trees. For purposes of comparison, Table XI gives the average form quotients for each diameter class (represented by ten or more trees) for all species other than gray birch and for gray birch separately. It is evident that the gray birch falls between the 0.55 and 0.60 form classes, being closer to the latter.

TABLE XI

SHOWING AVERAGE FORM QUOTIENT FOR TREES OF VARIOUS DIAMETER CLASSES

Diameter Breast-high	*All Species except Gray Birch*		*Gray Birch*	
Inches	*Average Form Quotient*	*Basis Number of Trees*	*Average Form Quotient*	*Basis Number of Trees*
3			0.568	17
4			0.596	14
5			0.568	35
6			0.587	32
7	0.661	57	0.603	24
8	0.653	159	0.572	12
9	0.652	177		
10	0.654	157		
11	0.650	130		
12	0.630	104		
13	0.631	85		
14	0.609	56		
15	0.645	41		
16	0.650	38		
17	0.615	20		
18	0.610	12		
19	0.639	15		

In order to learn whether relative position in the stand had influence on the form quotient the material was classified into the four crown classes, dominant, codominant, intermediate, and overtopped. When averaged on this basis, results as shown below were obtained. In every crown class the values for all species except gray birch fall in the 0.65 form class.

	Crown Class							
	Dominant		*Codominant*		*Intermediate*		*Overtopped*	
	Average Form Quotient	*Basis No. of Trees*	*Average Form Quotient*	*Basis No. of Trees*	*Average Form Quotient*	*Basis No. of Trees*	*Average Form Quotient*	*Basis No. of Trees*
All species except Gray Birch	0.637	231	0.643	370	0.648	325	0.629	46
Gray Birch	0.549	56	0.602	72	0.569	14	0.646	3

A classification of the trees by stands, with computation of the average form quotient of each stand, furnished an even better indication that the 0.65 form class is the one most commonly found. The 1229 trees measured were taken from eighteen stands. These are listed in Table XII and the average form quotient is given for each stand. The stands are arranged in two groups—"All species except gray birch" and "gray birch." It will be seen that in the former group the average form quotient ranges from 55.2 to 78.1 but that nine out of the thirteen stands in the group fall into the 0.65 form class.

Stand No. 1, with an average form quotient of 55.2, was distinctly different in density and forest form from stands ordinarily encountered. Stand No. 2, which fell in the 0.60 form class, has a high standard deviation. Portions of this stand contained merchantable trees grown in a two-storied form.

Stands Nos. 12 and 13 are based on too few trees to have much weight.

The stands in the gray birch group all fall into the 0.55 and 0.60 form classes. As previously stated, most of the gray birch measured was growing in the old field type, which usually has a lower density than found in the hardwood type. Stands Nos. 17 and 18 approach the density conditions prevailing in the hardwood type. It will be noted that the average form quotient of each of these stands is nearly up to the 0.65 form class. The authors believe that gray birch when found in mixed stands of the hardwood type will fall into the 0.65 form class along with the other species.

Volume Table Units

The cubic foot, the cord, the board foot, and the crosstie are the units in which the volume tables show contents of different-sized trees. Seven volume tables in all are presented, four of them, numbers XVIII, XIX,

TABLE XII

SHOWING AVERAGE FORM CLASS BY STANDS

	Average Age	*Number of Trees*	*Average Form Quotient*	*Standard Deviation for trees in each stand*
All Species except Gray Birch				
1. Open Two Storied Forest above Bethany Gorge	76	8	55.2	±6.4
2. Compartment 8, Sub-Compartment 10, West River	77	79	61.4	±9.8
3. Ford's job summit Totoket Ridge	68	28	62.7	±5.4
4. Compartment 4, Sub-Compartment 11, Maltby	40	4	63.3	±1.3
5. Northerly slope Totoket Ridge, North Branford	63	344	63.3	±2.0
6. Goshen Pond Swamp, North Branford	76	249	64.4	±2.1
7. North of Waite St., Lake Whitney	64	57	65.2	±5.9
8. Compartment 2, Sub-Compartment 37, Maltby	60	7	65.9	±6.5
9. Dense Forest, Bethany Gorge	92	74	66.3	±7.8
10. Prescott Place, Lake Whitney	68	143	67.0	±6.7
11. Saxton's Woods, White Plains, N. Y.	88	85	67.3	±7.0
12. Compartment 8, Sub-Compartment 4, West River, Dense Forest	60	5	68.6	±13.2
13. Laurel Hill Farm, Branford, Dense Forest		1	78.1	
Gray Birch				
14. In Pine Plantations, Milford, Pa.	24	45	53.5	±5.6
15. Open Forest, Milford, Pa.	38	10	54.1	±4.1
16. Medium Density, Milford, Pa.	42	29	57.7	±5.2
17. Edgar Pinchot Woodlot, Milford, Pa.	53	9	61.9	±5.9
18. Dense Forest, Milford, Pa.	45	52	62.0	±7.7

XXII, and XXIII, being intended for local use, the other three, numbers XIV, XV, and XXI, being inserted for purposes of comparison.

Contents are given in the following products.

Tables XIV and XV	Cubic feet of whole stem without bark and excluding a stump equal in height to one per cent of the total height of the tree.

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Table XVIII	Cubic feet with bark to a minimum top diameter of two inches outside bark and excluding a stump equal in height to one per cent of the total height of the tree.
Table XIX	Cords to a minimum top diameter of two inches outside bark and excluding a stump equal in height to one per cent of the total height of the tree.
Tables XXI and XXII	Feet board measure of two-inch plank plus additional one-inch boards to a minimum top diameter inside bark of six inches.
Table XXIII	Ties and additional feet board measure.

THE CUBIC FEET VOLUME TABLES (WITHOUT BARK)

In preparing these volume tables the form factor method was employed in much the same way as described in Chapman's *Forest Mensuration*,[8] except that the normal stump diameters were secured through extension of the percentile taper series (Table VII) and not by use of Höjer's

TABLE XIII

SHOWING FORM-HEIGHT PRODUCTS FOR TREES OF DIFFERENT HEIGHT AND FORM CLASSES

(For Volume in cubic feet of stem, without bark, and excluding a stump one per cent of the total height.)

Height Class Feet	*Form Class* 0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85
	Form-Height Products									
20	10.6	10.8	11.1	11.3	11.6	11.8	12.1	12.5	12.9	13.4
30	13.0	13.6	14.1	14.7	15.2	15.8	16.5	17.2	18.1	19.0
40	15.9	16.7	17.5	18.4	19.3	20.2	21.2	22.2	23.3	24.9
50	18.4	19.6	20.7	21.9	23.2	24.4	25.8	27.2	28.8	30.7
60	21.2	22.6	24.0	25.4	27.1	28.7	30.3	32.1	34.1	36.4
70	24.1	25.7	27.4	29.0	30.9	32.8	34.9	37.0	39.4	42.2
80	27.0	28.9	30.8	32.8	35.0	37.1	39.4	41.9	44.7	48.0
90	29.9	31.9	34.0	36.4	38.8	41.3	44.0	46.9	50.1	53.9
100	32.6	35.0	37.5	40.1	42.7	45.6	48.6	51.9	55.6	59.9

[8] CHAPMAN, H. H.: *Forest Mensuration.* Wiley and Sons, 1924, pp. 213 to 214.

TABLE XIV

SHOWING VOLUME IN CUBIC FEET OF STEM, WITHOUT BARK, AND EXCLUDING A STUMP ONE PER CENT OF THE TOTAL HEIGHT OF THE TREE

Form Class 0.60

Diameter Breast-high Inches	*Total Height in Feet*								
	20	*30*	*40*	*50*	*60*	*70*	*80*	*90*	*100*
	Volume in Cubic Feet								
2	0.3	0.3							
3	0.5	0.7	0.8						
4	.	1.1	1.3	1.6					
5	.	1.6	2.1	2.5					
6	.	2.4	3.1	3.7	4.3				
7	.	.	4.0	4.8	5.7	6.4			
8	.	.	5.1	6.1	7.2	8.2			
9	.	.	6.6	8.0	9.2	10.6	11.9		
10	.	.	8.0	9.7	11.2	12.8	14.4		
11	.	.	9.7	11.7	13.6	15.6	17.6		
12	.	.	11.4	13.7	16.0	18.2	20.6		
13	.	.	.	16.1	18.9	21.6	24.3	27.1	
14	.	.	.	18.8	22.0	25.2	28.4	31.7	
15	.	.	.	21.7	25.3	29.1	32.7	36.5	
16	.	.	.	24.7	28.9	33.3	37.4	41.7	
17	.	.	.	.	32.8	37.6	42.3	48.1	
18	.	.	.	.	36.9	42.4	47.6	52.9	
19	.	.	.	.	41.2	47.2	53.2	59.2	
20	.	.	.	.	45.7	52.3	59.0	65.7	
21	.	.	.	.	50.5	57.8	65.3	72.6	
22	.	.	.	.	.	63.6	71.8	80.0	
23	.	.	.	.	.	70.3	79.4	88.6	
24	.	.	.	.	.	76.6	86.5	96.3	
25	.	.	.	.	.	.	94.0	104.6	115.2
26	.	.	.	.	.	.	101.7	113.1	124.7
27	.	.	.	.	.	.	.	122.2	134.9
28	.	.	.	.	.	.	.	131.5	144.9

TABLE XV

SHOWING VOLUME IN CUBIC FEET OF STEM, WITHOUT BARK, AND EXCLUDING A STUMP ONE PER CENT OF THE TOTAL HEIGHT OF THE TREE

Form Class 0.65

Diameter Breast-high Inches	*Total Height in Feet*								
	20	*30*	*40*	*50*	*60*	*70*	*80*	*90*	*100*
	Volume in Cubic Feet								
2	0.3	0.3							
3	0.6	0.8	0.9						
4	.	1.2	1.5	1.8					
5	.	1.8	2.2	2.7					
6	.	2.5	3.2	3.9	4.6				
7	.	.	4.2	5.1	6.0	6.9			
8	.	.	5.4	6.5	7.7	8.8			
9	.	.	6.9	8.3	9.7	11.1	12.5		
10	.	.	8.3	10.0	11.7	13.5	15.2		
11	.	.	10.2	12.3	14.4	16.6	18.7		
12	.	.	12.0	14.4	17.0	19.4	21.9		
13	.	.	.	17.0	20.0	22.9	25.9	28.8	
14	.	.	.	19.7	23.2	26.6	30.1	33.5	
15	.	.	.	22.8	26.7	30.7	34.6	38.6	
16	.	.	.	26.2	30.7	35.3	39.7	44.3	
17	.	.	.	.	34.7	39.9	45.0	50.1	
18	.	.	.	.	39.1	44.9	50.7	56.6	
19	.	.	.	.	43.5	50.0	56.6	63.0	
20	.	.	.	.	48.3	55.5	62.7	69.8	
21	.	.	.	.	53.4	61.3	69.3	77.0	
22	.	.	.	.	.	67.6	76.3	84.8	
23	.	.	.	.	.	74.7	84.3	94.0	
24	.	.	.	.	.	81.4	91.8	102.3	
25	.	.	.	.	.	.	99.8	111.3	122.7
26	.	.	.	.	.	.	108.1	120.3	132.7
27	.	.	.	.	.	.	.	130.1	143.3
28	.	.	.	.	.	.	.	139.8	154.1

formula. As one step in the work a table showing form-height products was computed. This is given here (see Table XIII) on account of its usefulness for purposes of quickly computing the total cubic contents (above stump) of trees of any size and form quotient. In applying this table, values for the well-known formula V = B H F[9] are computed, taking the product of H X F directly from Table XIII.

Volume Tables XIV and XV giving contents for form classes 0.60 and 0.65, respectively, were made in this way. Table XV is advised for local use except in open grown or two-storied stands.

Check on the Accuracy of the Cubic Feet Tables.

The cubic foot volume of each individual tree of the 1229 measured was computed in order that tests might be made of the accuracy of the volume tables. These computations were conducted in such manner as to minimize differences in method of obtaining volumes, as between the table values and the individual tree computations. Particular care was taken to use the normal diameters at the base of each tree, reading these from graph of each tree as plotted to eliminate root swell. The results of the tests indicated that Table XV was more accurate than Table XIV. The latter gave too low values. Table XV when used to estimate the contents of the 1229 measured trees gave a plus difference over the actual computed values of 0.43 per cent. The average deviation of the individual tree, computed without interpolation for its variation either in height, diameter, or form quotient from the class values, proved to be 11 per cent. In view of the fact that twenty-two species are represented in the material this result is considered satisfactory.

When the species are scaled individually the volume table is not likely to give such a high degree of accuracy. The results of the check by species and by all species combined are presented in Table XVI. It will be noted that even some of the species which are represented by the largest number of trees show relatively wide discrepancies when scaled by the volume table. This is not surprising, since the table is based on average values for all species combined, while each species may differ from the average

[9] V = Volume of stem without bark and excluding stump.
B = Basal area of the normal diameter inside bark for each diameter breast-high class.
H = Total height.
F = Breast-high form factor.
H X F = Form-height products.

in percentile taper, in bark thickness and root swell, and in the average form quotients for the different diameter classes. The number of trees representing each species influences the extent of the divergence which may be expected. This effect may be expressed inversely in terms of the ratio existing between the square roots of the two numbers involved. For example, it is reasonable to anticipate that red oak, represented by 250 trees, will show a divergence 2.2 times greater than that found for all species combined, represented by 1229 trees, since the ratio of the square root of 250 to that of 1229 is 1 to 2.2.

The probable errors of the different groups listed in Table XVI furnish an acceptable basis for expressing this ratio and also for estimating the extent to which other causes besides the fluctuations of sampling have influenced the results. In the last column of Table XVI are given the probable errors for each species sampled. The probable error for the material as a whole (1229 trees) is ± 0.27, and for red oak, with 250 trees, ± 0.59. Locust and sycamore, with only two trees apiece, show the largest probable error, amounting to ± 6.60. Of the twenty-two species, eight have actual differences smaller than the probable error, four have differences greater than but less than twice the probable error, while ten have differences more than twice the probable error. In the latter class only one species, yellow birch, has a difference less than three times the probable error. The arrangement of the species on this basis is shown below.

Actual difference as compared to probable error		
Less than probable error	*Larger but less than twice probable error*	*More than twice probable error*
Black Ash	White Ash	Beech
Basswood	Red Ash	Black Birch / Yellow Birch
Gray Birch	Red Oak	Mockernut Hickory
Elm	Sycamore	Shagbark Hickory
Pignut Hickory		Locust
Hard Maple		Red Maple
Scarlet Oak		Black Oak
Chestnut Oak		White Oak / Tulip Tree

Several species show differences greater than can be attributed reasonably to sampling. It is probable that bark thickness is the factor chiefly responsible. Certain thin-barked species, such as beech, black birch, yellow birch,

TABLE XVI

SHOWING RESULTS OF A CHECK AGAINST VOLUME TABLE XV

Species	*Number of trees*	*Measured and Computed Volume Cubic feet*	*Table Volume Cubic feet*	*Difference in Cubic feet*	*Difference in Per cent*	*Probable error per cent*
White Ash	45	585.038	598.7	+ 13.662	+ 2.34	±1.39
Black Ash	19	195.055	193.0	− 2.055	− 1.05	±2.14
Red Ash	6	191.970	204.3	+ 12.330	+ 6.42	±3.81
Basswood	14	296.693	292.4	− 4.293	− 1.45	±2.50
Beech	7	129.713	107.7	− 22.013	−16.97	±3.52
Gray Birch	145	474.824	477.0	+ 2.176	+ 0.46	±0.78
Black Birch	71	1222.353	1104.0	−118.353	− 9.68	±1.11
Yellow Birch	7	127.429	118.2	− 9.229	− 7.24	±3.52
Elm	37	431.267	434.0	+ 2.733	+ 0.63	±1.54
Mockernut Hickory	8	240.582	264.7	+ 24.118	+10.02	±3.30
Pignut Hickory	10	101.659	100.9	− 0.759	− 0.75	±2.95
Shagbark Hickory	15	252.140	286.2	+ 34.060	+13.51	±2.41
Locust	2	17.097	23.2	+ 6.103	+35.70	±6.60
Red Maple	202	2166.110	2098.4	− 67.710	− 3.13	±0.66
Hard Maple	7	73.082	70.9	− 2.182	− 2.99	±3.52
Black Oak	152	2878.274	3049.1	+170.826	+ 5.94	±0.76
Red Oak	250	5798.722	5733.6	− 65.122	− 1.12	±0.59
Scarlet Oak	39	685.592	695.7	+ 10.108	+ 1.47	±1.50
Chestnut Oak	28	386.619	393.4	+ 6.781	+ 1.75	±1.76
White Oak	145	1833.721	1901.6	+ 67.879	+ 3.70	±0.78
Sycamore	2	43.708	39.5	− 4.208	− 9.63	±6.60
Tulip Tree	18	301.818	325.9	+ 24.082	+ 7.98	±2.20
All Species Combined	1229	18,433.5	18,512.4	+ 78.9	+ 0.43	±0.27

Plus differences in cubic feet and per cent indicate volume table values higher than those of the trees actually measured.

Minus differences indicate the reverse.

and red maple, show large minus differences, while several thick-barked species, including black oak, white oak, mockernut hickory, shagbark hickory, tulip tree, and locust, have large plus differences. The thin-barked gray birch and the thick-barked chestnut oak are both accurately scaled by the volume table. This is a surprising result and is due to the character of the material used for the two species. In the case of gray birch the effect of thin bark was offset by form quotients below the average. (See Table XVII.) Chestnut oak, which has approximately the same root swell and bark thickness as black oak, should show a plus difference in per cent as high as the latter species. That it does not do so may be due to the fact that the few (28) trees measured had form quotients above the average of the material.

Since there is so much variation between species it may be argued that the volume table is accurate only where the mixture of species is the same as in the measured group of 1229 trees. If the mixture is radically different the changed proportion of the species must be noted and the effect on the applicability of the volume table determined. It is believed that the table can be applied with reasonable accuracy in the forests of New Haven

TABLE XVII

SHOWING VARIATIONS IN PER CENT BETWEEN INDIVIDUAL SPECIES AND THE VOLUME TABLE VALUES DUE TO ROOT SWELL AND BARK THICKNESS, PERCENTILE TAPER, AND AVERAGE FORM QUOTIENT

	Per cent of variation due to:			
Species	*Root Swell and Bark Thickness*	*Percentile Taper*	*Average Form Quotient*	*Sum of all three Factors*
Black Oak	+4.2	+1.4	−0.1	+5.5
Red Oak	−0.7	0	−0.6	−1.3
White Oak	+1.1	+0.7	−0.7	+1.1
Gray Birch	−6.5	0	+7.4	+0.9
Red Maple	−3.7	+0.7	+2.7	−0.3

Plus variations indicate that the volume table gives too high values.
Minus variations indicate the reverse.

County, Connecticut. This conclusion is based not alone on general observation but also on data secured on 86 yield table plots[10] located in the county. The proportion between species on these plots was similar to that existing among the 1229 trees forming the basis for the volume tables.

A check on another basis was made for each of the five best represented species, namely, black, red, and white oaks, gray birch, and red maple. The discrepancies in volume between the different species may be traced to three primary sources:

(1) Form itself as expressed in percentile taper. This is a factor characteristic of the species.
(2) Root swell and bark thickness which also are inherent with the species, and
(3) Average form quotient as determined for the trees actually measured in this study.

An attempt was made to isolate the effect of each factor in causing variation in volume. The results are given in Table XVII.

The per cent of variation due to root swell and bark thickness already has been shown in Table X. From this table the average difference in per cent of all the diameter classes represented for each species is taken and entered in the second column of Table XVII. The per cent of variation between species ranges from -6.5 to +4.2.

The effect of percentile taper was' determined by comparing volumes derived by use of the average percentile taper series, Table VII, with volumes derived by use of the percentile taper series applicable to each species. The per cent of variation from this source ranged from 0 to +1.4 per cent. The effect of average form quotient of the material used was isolated by comparing volumes based on average form quotients of all species with those based on average form quotients of the individual species. Variation in per cent ran from -0.7 to +7.4. In demonstrating the effect of percentile taper and of average form quotient, separate values were worked out for trees of each height class in the 5, 10, 20, and 25 inch diameter classes.

It is evident that differences in cubic volume due to varying percentile taper are small. Average form quotient and root swell and bark thickness are all important in causing variation in cubic volume. The variation due to form quotient must in practice be allowed for by using volume tables of the form class suited to the material. Root swell and bark thickness are so

10 Measured by R. H. Westveld in 1924 in connection with a study of hardwood yield, soon to be published.

variable between species that they require special consideration. Further study is needed with the purpose in view of obtaining for each species the proper allowances to be made. Eventually it should be possible to express such allowances as percentages to be applied to the volume tables for all species combined.

The values in the last column of Table XVII, showing the average per cent of variation for the sum of all three factors, are approximately the same as the figures given in the next to the last column of Table XVI. In this respect white oak and red maple show more variation than the other three species. Two factors cause 'considerable variation in volume of gray birch, namely, thin bark and low average form quotient, but the two nearly balance one another. When used for gray birch of form class 0.65, Table XV may be expected to give results approximately six per 'cent too low.

Until more information is secured the use of Table XV for scaling pure stands or for scaling the volumes separately of individual species in mixed stands should be supplemented by the employment of the following correction factors:

for black oak deduct	5 per cent
for chestnut oak deduct	5 per cent
for white oak deduct	2 per cent
for red oak use without change	
for scarlet oak use without change	
for gray birch add	6 per cent
for black and yellow birch add	6 per cent
for red maple add	3 per cent

'THE CORDWOOD VOLUME TABLE

A volume table was needed to give contents in cords of stacked firewood, as this is one of the principal forest products in the region. Instead of constructing a table directly in the cord unit, one was first computed in cubic feet outside bark and then converted into a table reading directly in cords. To the percentile tapers (all species combined, Table VII) were added at regular intervals up the stem average bark thicknesses secured from the 1229 measured trees. Then the cubic contents outside bark of trees of various sizes were computed. The computed volumes included the stem up to a point two inches in diameter outside bark and excluded a stump equal in ,height to one per cent of the total height of the tree. (See Table XVIII.)

TABLE XVIII

SHOWING VOLUME IN CUBIC FEET OF STEM INCLUDING BARK AND ROOT SWELL TO TOP DIAMETER OF 2 INCHES OUTSIDE BARK AND EXCLUDING A STUMP 1 PER CENT OF THE TOTAL HEIGHT OF THE TREE

Form Class 0.65

Diameter Breast-high Inches	*Total Height in Feet* 20	30	40	50	60	70	80	90	100
	Volume in Cubic Feet								
2	0.1	0.1							
3	0.5	0.6	0.7						
4	.	1.2	1.5	1.7					
5	.	1.9	2.3	2.9					
6	.	2.8	3.6	4.5	5.2				
7	.	.	4.9	5.9	7.0	8.0			
8	.	.	6.4	7.7	9.1	10.4			
9	.	.	8.3	10.0	11.6	13.3	15.0		
10	.	.	10.0	12.0	14.0	16.2	18.2		
11	.	.	12.2	14.8	17.3	19.9	22.4		
12	.	.	14.3	17.2	20.3	23.2	26.2		
13	.	.	.	20.2	23.8	27.3	30.8	34.3	
14	.	.	.	23.2	27.4	31.4	35.5	39.5	
15	.	.	.	26.8	31.4	36.1	40.7	45.4	
16	.	.	.	30.6	35.9	41.3	46.4	51.8	
17	.	.	.	.	40.6	46.7	52.6	58.7	
18	.	.	.	.	45.6	52.3	59.1	65.9	
19	.	.	.	.	50.4	58.0	65.6	73.0	
20	.	.	.	.	56.0	64.4	72.7	81.0	
21	.	.	.	.	62.0	71.2	80.4	89.4	
22	.	.	.	.	.	78.4	88.5	98.4	
23	.	.	.	.	.	86.6	97.8	109.0	
24	.	.	.	.	.	94.0	106.0	118.2	
25	.	.	.	.	.	.	115.3	128.6	141.7
26	.	.	.	.	.	.	124.9	139.0	153.3
27	.	.	.	.	.	.	.	150.3	165.5
28	.	.	.	.	.	.	.	161.5	178.0

TABLE XIX

SHOWING VOLUME IN CORDS OF STEM INCLUDING BARK AND ROOT SWELL TO TOP DIAMETER OF 2 INCHES OUTSIDE BARK AND EXCLUDING A STUMP 1 PER CENT OF THE TOTAL HEIGHT OF THE TREE

Form Class 0.65

Diameter Breast-high Inches	*Total Height in Feet* 20	30	40	50	60	70	80	90	100
	Volume in Cords								
2	0.002	0.002							
3	0.007	0.008	0.01						
4	.	0.02	0.02	0.02					
5	.	0.02	0.03	0.03					
6	.	0.03	0.04	0.05	0.06				
7	.	.	0.05	0.06	0.08	0.09			
8	.	.	0.07	0.08	0.10	0.11			
9	.	.	0.09	0.10	0.12	0.14	0.16		
10	.	.	0.10	0.12	0.14	0.17	0.19		
11	.	.	0.12	0.15	0.18	0.20	0.23		
12	.	.	0.14	0.17	0.21	0.24	0.27		
13	.	.	.	0.20	0.25	0.28	0.31	0.34	
14	.	.	.	0.23	0.27	0.31	0.36	0.40	
15	.	.	.	0.27	0.31	0.36	0.41	0.45	
16	.	.	.	0.31	0.36	0.41	0.46	0.52	
17	.	.	.	.	0.40	0.46	0.52	0.58	
18	.	.	.	.	0.45	0.52	0.59	0.65	
19	.	.	.	.	0.50	0.57	0.65	0.72	
20	.	.	.	.	0.55	0.64	0.72	0.80	
21	.	.	.	.	0.61	0.70	0.80	0.89	
22	.	.	.	.	.	0.78	0.88	0.97	
23	.	.	.	.	.	0.86	0.97	1.08	
24	.	.	.	.	.	0.93	1.05	1.17	
25	.	.	.	.	.	.	1.14	1.27	1.40
26	.	.	.	.	.	.	1.24	1.38	1.52
27	.	.	.	.	.	.	.	1.49	1.64
28	.	.	.	.	.	.	.	1.60	1.76

THE VOLUME TABLES

The values in cubic feet outside bark were converted into cords. For this purpose the average diameter outside the bark at the point midway between the stump and the point where the diameter outside the bark was two inches was found for trees of each diameter and height class. This was recorded as the average diameter of the cordwood sticks from a tree of such size. Frothingham's[11] values for solid cubic feet per cord in sticks

TABLE XX

SHOWING CONTENTS OF 12 FOOT LOGS IN 2 INCH PLANK AND ADDITIONAL 1 INCH BOARDS, BASED ON DIAGRAMS WITH NO ALLOWANCE FOR TAPER

Diameter inside Bark at top of Log Inches	*Contents in Feet Board Measure*
6	17
7	23
8	30
9	39
10	50
11	63
12	77
13	93
14	110
15	129
16	148
17	169
18	191
19	214
20	238
21	265
22	292
23	321
24	350
25	380
26	411

[11] FROTHINGHAM, E. H.: *Second-Growth Hardwoods in Connecticut.* Bulletin No. 96, United States Forest Service, 1912, p. 64.

of various sizes were plotted on diameter of stick and a curve drawn. This made it possible to read for a stick of any diameter its equivalent in solid cubic feet per cord. The figures in Table XVIII then were each divided by the converting factor appropriate to a tree of that size. The results were the desired contents in cords for trees of each diameter and height class. Table XIX is the completed volume table giving contents in cords.

TABLE XXI

SHOWING CONTENTS IN LUMBER OF TREES OF DIFFERENT SIZES

Form Class 0.60

Diameter Breast-high Inches	*Total Height in Feet*						
	40	*50*	*60*	*70*	*80*	*90*	*100*
	Feet Board Measure						
8	15	20	25	30			
9	25	30	40	45	50		
10	35	45	55	60	70		
11	45	55	65	80	90		
12	50	65	85	95	110		
13	.	80	100	120	140	160	
14	.	100	125	145	170	190	
15	.	115	145	170	200	225	
16	.	140	170	200	235	265	
17	.	.	195	235	270	305	
18	.	.	225	270	310	350	
19	.	.	225	305	355	405	
20	.	.	290	345	400	450	
21	.	.	325	385	445	505	
22	.	.	.	435	500	565	
23	.	.	.	480	555	625	
24	.	.	.	525	610	695	
25	.	.	.	.	655	770	875
26	.	.	.	.	725	830	940
27	.	.	.	.	.	895	1010
28	.	.	.	.	.	970	1090

THE VOLUME TABLES

Volume Tables giving Contents in Lumber

Logs cut for lumber usually are put into lengths ranging from 8 to 16 feet with the average around 12 feet. Hence 12 feet was taken as the log length in computing the volumes in feet board measure of trees of different sizes. A minimum top diameter limit of 6 inches was set. The height of stump was taken as one foot for trees of all sizes.

TABLE XXII

SHOWING CONTENTS IN LUMBER OF TREES OF DIFFERENT SIZES

Form Class 0.65

Diameter Breast-high Inches	*Total Height in Feet*						
	40	*50*	*60*	*70*	*80*	*90*	*100*
	Feet Board Measure						
8	20	20	25	30			
9	25	35	40	45	55		
10	35	45	55	65	75		
11	45	60	75	85	100		
12	55	70	90	105	120		
13	.	90	110	130	150	170	
14	.	105	130	155	180	205	
15	.	125	155	185	215	245	
16	.	145	180	215	250	285	
17	.	.	210	250	290	335	
18	.	.	240	290	335	380	
19	.	.	275	325	380	435	
20	.	.	305	365	430	490	
21	.	.	340	410	480	550	
22	.	.	.	460	535	605	
23	.	.	.	505	590	675	
24	.	.	.	555	650	745	
25	.	.	.	.	710	815	920
26	.	.	.	.	770	885	1005
27	.	.	.	.	.	965	1090
28	.	.	.	.	.	1040	1175

Hardwood lumber in this region should be put into plank, two inches or thicker, for best utilization, rather than into one-inch boards. For this reason a log rule showing contents in two-inch plank and additional one-inch boards was needed. Such a log rule was devised by increasing the values in Merrill's[12] log rule proportionately to the increase in length of log from 8½ to 12 feet. No pieces shorter than 12 feet are considered, so the values derived are considered conservative. The log rule is given in Table XX. Tables XXI and XXII showing volumes in feet board measure for form classes 0.60 and 0.65 were derived by transforming the percentile taper series into absolute diameters for trees of different sizes and then scaling the contents of these trees by means of the log rule for 12 foot logs.

VOLUME TABLE GIVING CONTENTS IN TIES AND ADDIT'IONAL LUMBER

Hardwoods in New Haven County, Connecticut, often are utilized for crossties. All species commonly found are taken for this purpose and used either treated or untreated. Three grades of ties are recognized by the New York, New Haven, and Hartford Railroad, which is the largest consumer of ties in this territory. All three grades are 8½ feet long. The grades vary in thickness and width from No. 1, 7 x 9 inches in size, to No. 2, 6 x 8 inches, and down to NO.3, 6 x 7 inches in size. In sawing logs for ties some lumber is secured. as a by-product.

Table XXIII has been constructed to show for trees of different sizes the contents in the various grades of ties and the additional feet board measure of lumber. Merrill's[13] log rule for ties and additional lumber was used in connection with the percentile taper series for all hardwoods as the basis for constructing the table.

12 This log rule was constructed from diagrams for 8½ foot logs. MERRILL, PERRY H., and HAWLEY, RALPH C.: *Hemlock: Its Place in the Silviculture of the Southern New England Forest.* Bulletin No. 12, Yale School of Forestry, 1924, pp. 18 to 24.

13 MERRILL, PERRY H., and HAWLEY, RALPH C.: *Hemlock: Its Place in the Silviculture of the Southern New England Forest.* Bulletin No. 12, Yale School of Forestry, 1924, pp. 16 to 17.

TABLE 23

SHOWING CONTENTS IN TIES AND ADDITIONAL FEET BOARD MEASURE

BASED ON FORM CLASS 0.65

ALL TIES 8½ FEET LONG

Nº1 7×9 INCHES, Nº2 6×8 INCHES, Nº3 6×7 INCHES

Diameter Breast-High in inches	Total Height in Feet: 40			50			60			70			80			90			100		
	Ties No	Ties Grade	Additional Feet B.M.	Ties No	Ties Grade	Additional Feet B.M.	Ties No	Ties Grade	Additional Feet B.M.	Ties No	Ties Grade	Additional Feet B.M.	Ties No	Ties Grade	Additional Feet B.M.	Ties No	Ties Grade	Additional Feet B.M.	Ties No	Ties Grade	Additional Feet B.M.
9													1	3	29						
10	1	3	14	1	3	17	1	3	32	2	3	16	2	3	30						
11	1	2	18	1 1	2 3	12	1 1	2 3	17	1 2	2 3	20	1 2	2 3	27						
12	1 1	2 3		1 1	1 3	17	1 1 1	1 2 3	2	1 1 1	1 2 3	19	1 1 2	1 2 3	15						
13				1 1	1 2	21	2 1	1 3	21	2 1 1	1 2 3	17	2 1 1	1 2 3	24	2 2 1	1 2 3	20			
14				2 1	1 3	7	2 1	1 2	34	3 1	1 3	35	3 1 1	1 2 3	32	3 1 1	1 2 3	39			
15				2 1	1 2	20	3 1	1 3	22	3 1	1 2	38	3 2 1	1 2 3	47	3 3 1	1 2 3	34			
16				1 3	1 2	27	2 2 1	1 2 3	29	2 3	1 2	51	3 3	1 2	49	3 4 1	1 2 3	58			
17							1 5	1 2	36	2 4 1	1 2 3	48	2 5	1 2	69	3 5	1 2	67			
18							2 4	1 2	37	3 3 1	1 2 3	58	3 5 1	1 2 3	67	3 6	1 2	87			
19							4 2	1 2	80	3 5	1 2	77	4 4 1	1 2 3	86	4 6 1	1 2 3	88			
20							2 6	1 2	73	2 7	1 2	90	2 9	1 2	92	4 7 1	1 2 3	111			
21							2 6 1	1 2 3	80	4 6	1 2	97	3 8 1	1 2 3	111	2 12 1	1 2 3	96			
22										2 10 1	1 2 3	74	2 11	1 2	129	3 12	1 2	129			
23										2 11 1	1 2 3	97	2 14	1 2	126	2 13	1 2	155			
24										1 13 1	1 2 3	111	2 14 1	1 2 3	132	4 14	1 2	159			
25										4 13 1	1 2 3	141	4 16 1	1 2 3	154	4 18	1 2	192			
26													4 11 6	1 2 3	129	5 13 6	1 2 3	141	5 16 6	1 2 3	174
27																3 11 13	1 2 3	162	5 13 13	1 2 3	166
28																8 12 6	1 2 3	174	8 14 8	1 2 3	204

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