DIAMETER YIELD TABLES VERSUS SITE-INDEX YIELD TABLES FOR WESTERN HEMLOCK

by

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DIAMETER YIELD TABLES VERSUS SITE-INDEX YIELD TABLES FOR WESTERN HEMLOCK

I. INTRODUCTION

A. Background

In order to plan the management of a forest property for sustained yield, the forester must possess some means of estimating the future yield obtainable from present immature stands. Such estimates can not be made of course without some error, but the greater their precision, the more efficiently can the long-term management be planned. To serve this purpose yield tables in various forms have been compiled and are now available for practically all of the important timber species of North America. Knowing the present age of a stand and other pertinent variables, it is possible to predict its yield at any given future age.

The most conventional type of table to be employed has been the site-index yield table for normal or fully stocked stands. This type of table sets forth the yields in volume and other stand characteristics, expected at given ages, on land of a given site quality, when the ground is fully utilized by growing trees. A portion of the normal yield tables for western hemlock (Tsuga heterophylla (Raf.) Sarg.) are presented in the appendix. The yield of subnormal or supernormal stands may be estimated from the normal tables by determination of a density of stocking factor or percentage, and by adjusting the normal yields accordingly. The usual basis for determination of stocking is the relationship existing between the actual basal area as measured in a stand, and the normal basal area as recorded in the yield tables for the same age and site. An estimate of the present actual volume or yield of the stand is then made readily by discounting the normal yield by the percentage indicated. In order to estimate a future yield some recognition must be made of the well established fact that as time proceeds, stands understocked at the present tend to improve, and stands overstocked tend to regress in stocking. This concept is treated in more detail in part III of the thesis. At this point it is necessary merely to emphasize that the present stocking must be increased or decreased to obtain a reasonable stocking value for a future age. Having an adjusted value the future yield may be computed readily as before by discounting the normal yield as indicated by the adjusted stocking value.

It has been found that the site-index tables do not accurately define all stands, especially those which are abnormal. Understocked stands, for instance, have fewer but usually larger trees than is indicated by the density of stocking derived on the basis of basal area comparisons. The fewer but larger trees in turn mean a greater volume than that computed by the usual procedure described above. It also may be noted that stands which are fully stocked, and considered normal according to number of trees, are not necessarily normal on the basis of volume. This is usually due to the fact that the trees are not of normal average diameter for that site and age. Such conditions may exist in stands which have been overstocked or understocked and have just attained the normal condition in number of trees. For example, an overstocked stand whose trees are crowded and small may lose enough trees by competitional mortality to reduce it to normal on this basis, but on the basis of average diameter and stand volume it would be very subnormal.

Efforts to construct yield tables free of the faults mentioned above have resulted in another type of yield table based on average stand diameter as the independent variable. In 1931 Barnes (3,p.8) wrote that:

> "Since volume is a function of stem distribution, number of trees, and height, if the two latter factors should show more correlation with diameter than with age and site, it would seem that better results might be obtained by first estimating the future diameter and then basing both height and number of trees on this estimate."

At that time his study indicated that the correlation of height and number of trees with average diameter was much greater than with site and age. Further studies of this correlation were made by Bruce (7) in 1948 with respect to Douglas fir (Pseudotsuga taxifolia (Lamb.) Brit.), and a set of yield tables for this species was compiled on the average diameter basis. Barnes (2) has also prepared a similar set of tables for western hemlock. Extracts from these are presented in the appendix.

Diameter yield tables, as the name implies, are based on average stand diameter as the independent variable. The dependent variables are number of trees per acre, average height, and volume per acre. If, for any stand, the average diameter, average height, and number of trees per acre are known, the present volume may be estimated from the diameter yield tables. Listed in the table for a given average stand diameter, the normal number of trees per acre, normal average height, and normal volume per acre may be found. Adjustments then may be made in the normal volumes in accordance with the ratio of actual number to normal number of trees and with the ratio of actual average height to normal average height. Diameter tables may also be used to estimate probable future yields. This is done simply by estimating the future average diameter, number of trees, and average height, and applying the yield tables in the same procedure as for present yield.

B. Scope of study

Barnes (2) has compiled both conventional site index yield tables, and average diameter yield tables for western hemlock. The purpose of this thesis is to determine which type of table furnishes the best yield estimates and to evaluate the magnitude of the errors of estimate in each case. The statistical measure known as the standard error of estimate is used to indicate the accuracy of application of both types of tables. Comparisons of the errors are made in estimating both present and future stand yields.

In estimating probable future yields it is necessary to develop some means of determining changes in stocking as time proceeds. This is necessary for the application of both types of tables in predicting future yields. In order to facilitate this, a supplementary investigation of the trends in stand density had to be undertaken, although the necessary basic data for this was somewhat limited.

C. Basic data and sources

The necessary data for the investigation were already available. For construction of the original site yield tables, temporary sample plots had been established by the Pacific Northwest Forest and Range Experiment Station in even-aged stands distributed over all age classes from 10 to 300 years of age; and over all commercially productive site classes of the species in the coastal fog belt of Oregon and Washington. On each of the plots the following information was collected:

1. Area of the plot.
2. Age of 10 to 20 sample trees on the plot.
3. Total height of 20 to 30 sample trees for each of which the diameter breast high and crown class was recorded.
4. A tally of all the trees on the plot by diameter breast high classes.

From the above records it was possible to compile for each plot; and then express on an acre basis where pertinent, the information listed below:

1. Average age of the stand.
2. Average height of dominant and codominant trees of the stand, which defines site index.
3. Average height of all trees in the stand.
4. Average diameter breast high of all trees in the stand.
5. Number of trees per acre of 1.5 inches and over, or to any other minimum size limit that might be desired.
6. Basal area, volumes in cubic measure and board foot measure to any minimum tree size limit - all on an acre basis.

Both the site-index yield tables and the diameter yield tables were compiled from the above plot summaries. The former are based on correlations between age and site index as the independent variables and any one of the items mentioned in groups 5 and 6 as the dependent variable. The latter are based on correlations between average stand diameter as the independent variable and average height, number of trees per acre, and volumes in cubic foot measure and board foot measure as dependent variables. Data from the plots were also used in testing the accuracy of estimating present stand volumes by use of site-index and diameter yield tables.

Primarily for the purpose of obtaining growth data for a check on the site-index yield tables, the Pacific Northwest Forest and Range Experiment Station has established a number of permanent sample plots in the spruce-hemlock type. There are 4 plots in Clatsop county near Young's River Falls and 11 plots at Cascade Head. Detailed measurements of all trees have been made on these plots and among the data the following, pertinent to this study, were recorded.

1. Date and age at time of measurement.
2. Number of trees by species and in total in the stand at minimum diameter limits of 2.6 inches, 6.6 inches and 11.6 inches.

3. Site index and average height of the total stand of trees 2.6 inches and over.

4. Total basal area for trees above the minimum diameter limits mentioned in item 2.

5. Volume in cubic foot measure in trees 2.6 inches and over and in Scribner board foot measure in trees 11.6 inches and over.

Where necessary the above data were also expressed on a horizontal acre basis. Measurements of plots at Cascade Head were available for the Spring of 1935 and the Fall of 1945 and thereby provided data for an 11-year growth period. Plots 1 and 2 in Clatsop county were measured first in 1928 and all the Clatsop county plots were measured in 1933, 1938, and 1944. These provided growth periods of 10,11, and 12 years.

The data from these plots were used in testing the accuracy of estimating probable future stand conditions by both diameter and site-index yield tables. For uniformity all the growth values for periods of 11 and 12 years given in the plot data were adjusted so as to be representative of 10-year periods. The 10-year change in stand density on these plots was also used in establishing the trend toward normality.

The remaining data made available were permanent line plots on Elk Bay and Thurlow Island in British Columbia established by the British Columbia Forest Service. The plots were one fortieth of an acre in size and furnished the following stand data as of 1930 and 1942.

1. Age of stand.

2. The number of trees 1.5 inches and over by 1 inch diameter classes for each species and in total.

From the above stand measurements it was possible to calculate the average diameter and average number of trees per acre for each of the dates of measurement. This information was the major basis of establishing the rate of change in stand density. These data were also adjusted to represent a 10-year period of growth by interpolation.

II. ESTIMATES OF PRESENT YIELD

Yield tables are primarily for the purpose of predicting future yields of stands. To do this effectively it is evident that they should also portray the present conditions of the plots from which they were compiled. One test of the accuracy of the tables may be made then by estimating the present volume of the plots, and comparing the estimated with the actual plot volumes. Statistical analysis of the differences between estimated and actual values results in the standard error of estimate, a conventional statistical measure. Consequently, estimates were made of the present plot volumes by means of the diameter tables and the conventional tables separately.

A. Volume estimates by diameter tables

Of the temporary sample plots used in compilation of the base tables, 226 plots averaged 5.5 inches or more in stand diameter and 169 plots averaged 11.5 inches or more. The plot measurements provided the average stand diameter, number of trees per acre, average stand height and the following standard volume measurements:

1. Volume in cubic feet of trees 1.5 inches and over.
2. Volume in cubic feet of trees 6.5 inches and over.

3. Volume in board feet by International rule in trees 6.5 inches and over.

4. Volume in board feet by International rule in trees 11.5 inches and over.

5. Volume in board feet by Scribner rule in trees 11.5 inches and over.

These measurements made it possible to estimate present yields for each plot and to compare these estimates with the actual volumes in all the standards mentioned above.

<u>Computation of present volumes.</u> The procedure employed in deriving an estimate of present volume by means of the diameter tables is described below for plot number 102, entered as the first line of table 1. For an average stand diameter of 5.9 inches the normal volume in cubic feet is interpolated from table 12 of the appendix as 6,160 cubic feet in trees 1.5 inches and over. This value must be adjusted now for the difference in average height of the stand from the normal height, and for density of stocking. The adjustment for height is made by multiplying the normal volume by the ratio of actual average height to normal average height. The ratio in this instance is the actual height of 58 feet to the normal height of 60 feet interpolated from the tables opposite 5.9 inches in diameter. The volume adjusted for height is then (58/60) x 6,160 or 5,960 cubic feet. The adjustment for stocking is made next by multiplying this

TABLE 1. Sample of computation of percent deviations of estimated from the actual cubic volumes per acre for diameter tables

Plot no.	Average DBH*	Average no. trees per a.*		Average height*		Height ratio	Stocking percent	Volume in cubic ft.*		Percent	d
		actual	normal	actual	normal			actual	est'd		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
102	5.9	1107	1237	58	60	.97	90	5387	5365	100	0
5	6.0	1205	1200	52	61	.85	101	5594	5420	97	-3
298	6.1	976	1170	61	62	.98	83	5498	5260	96	-4
276	6.4	1245	1083	67	64	1.05	115	8190	8180	100	0

Columns 1, 2, 3, 5, and 9 are taken from plot measurements.
Columns 4 and 6 are from the diameter yield table in the appendix.
Column 7 is column 5 divided by column 6.
Column 8 is column 3 divided by column 4.
Column 10 is the normal volume multiplied by columns 7 and 8.
Column 11 is column 10 divided by column 9, and multiplied by 100.
Column 12 is column 11 minus 100 percent.

* For all trees 1.5 inches and over

volume by the stocking percent based on number of trees. The measure of stocking used is a ratio of the actual to the normal number of trees and in this case is 1107/1237 or .90. The present volume of this stand is therefore .90 x 5,960 or 5,360 cubic feet. This procedure was used in tabulating the volumes for all of the plots as illustrated partially in table 1. A similar procedure was followed in estimating the respective volumes in board feet.

Deviations and standard errors. The standard errors of estimate were computed in the following manner. The estimated volumes were expressed as a percent of the actual volumes for each plot. These percentages are also shown in part in table 1. The deviation of each percentage from 100 percent was squared. The squared deviations were subtotaled by diameter classes and then totaled for all plots 5.5 inches and over and for all plots 11.5 inches and over. This was done in order to facilitate the computation of the standard error of estimate for any diameter class or range of diameter classes. The standard error of estimate in percent of volume is then the square root of the quotient of the sum of all the squared plot deviations divided by one less than the number of plots involved or, expressed algebraically, $S.E. = \sqrt{\frac{S(d^2)}{n - 1}}$

The results of the computations for each diameter class, for the two ranges of diameter classes, and for the several standards of volume measurement are given in table 2.

Recognizing the algebraic sign, the deviations were totaled for each diameter class and for all plots above the specified minimum limits. These totals were divided then by the pertinent number of plots to obtain an average of the deviations for each of the mentioned groups of plots. It should be noted that these average deviations differ from the average deviation as commonly known among statisticians since the latter disregards the algebraic sign. The average deviation as used here merely serves as a test of the correct placement of the original curves from which the normal tables were derived. Table 3 is a list of these "deviation averages", as they shall be named herein to avoid confusion. It may be noted that the deviation averages are very close to zero both for individual diameter classes, and over the data as a whole for all standards of measurement. This would imply that the total of the estimated volumes of the plots, compares closely with the total of the actual volumes by diameter classes and over all the data, and indicates that the original curves were well placed with respect to the basic data.

TABLE 2. Standard errors of estimate by diameter classes for diameter yield tables

DBH class	No. of plots	Standard errors of estimate*				
		Cubic feet		Internat'l bd.ft.		Scrib. b.f.
		1.5"plus	6.5"plus	6.5"plus	11.5"plus	11.5"plus
6	8	4.6	3.2	12.6	115.0	115.0
7	16	4.2	5.4	8.1	28.4	30.3
8	14	3.4	4.3	5.4	39.1	38.0
9	6	2.6	2.7	8.9	12.3	14.6
10	10	3.9	4.0	8.2	10.6	11.5
11	3	7.0	8.0	15.5	16.8	14.7
12	4	3.2	4.1	5.7	4.8	8.7
13	14	6.2	7.6	3.1	3.5	4.3
14	14	4.5	4.9	4.9	4.4	7.0
15	19	4.1	4.5	4.1	4.3	5.4
16	29	2.3	2.8	3.8	3.4	3.5
17	24	2.8	2.9	3.9	3.7	4.7
18	18	3.0	3.3	4.4	4.5	4.0
19	13	2.3	2.3	1.9	2.5	2.9
20	11	1.7	1.7	2.1	2.7	2.0
21	7	4.1	4.1	5.3	5.7	5.6
22	6	1.8	1.8	4.4	4.6	4.5
23	2	5.1	5.1	8.0	8.0	7.1
24-40	8	4.1	4.1	4.7	4.8	5.5
All plots	226	3.2	4.3	5.4	24.0	24.2
12" & over	169	3.0	3.8	3.8	3.8	4.5

* Percent of volume (all values are plus or minus)

TABLE 3. Average percentage deviations by diameter classes for diameter yield tables

DBH class	No. of plots	Deviation averages *				
		Cubic feet		Internat'l b.f.		Scrib.b.f.
		1.5"plus	6.5"plus	6.5"plus	11.5"plus	11.5"plus
6	8	-0.5	+4.0	+5.0	+67.0	+68.0
7	16	-0.9	0.0	-4.0	+3.0	+6.0
8	14	0.0	-1.0	-3.0	+13.0	+13.0
9	6	+0.5	-2.0	-7.0	+3.0	+5.0
10	10	+2.0	0.0	-6.0	-1.0	0.0
11	3	+2.0	-1.0	-4.0	-5.0	-3.0
12	4	-1.0	-3.0	-4.0	-2.0	-2.0
13	14	0.0	0.0	-2.0	0.0	+1.0
14	14	+2.0	+1.0	+1.0	+1.0	+2.0
15	19	0.0	0.0	+2.0	+1.0	+1.0
16	29	0.0	-1.0	+2.0	0.0	+1.0
17	24	0.0	-1.0	+1.0	-1.0	0.0
18	18	0.0	+1.0	+1.0	-1.0	0.0
19	13	-1.0	-1.0	0.0	-2.0	-1.0
20	11	+0.5	0.0	0.0	-1.0	-1.0
21	7	0.0	0.0	-1.0	-2.0	-2.0
22	6	-1.0	-1.0	-2.0	-2.0	-4.0
23	2	-2.0	-2.0	-4.0	-4.0	-4.0
24-40	8	+1.0	+1.0	-3.0	-3.0	-2.0
All plots	226	0.0	0.0	-1.0	+3.0	+4.0
12" & over	169	0.0	0.0	0.0	-1.0	0.0

* Percent of volume

The entries in table 2 indicate the probable result of any attempt to estimate board foot volume in stands of small average diameter. The standard errors of estimate in Scribner board foot measure are excessively high in the small average diameter classes. The summary of all the plots at the bottom of table 2 indicates a standard error of estimate of ±24.2 percent while, for those plots in the 12-inch class and larger, the standard error is only ±4.5 percent.

Reference is made to table 37 in the yield bulletin by Meyer (18, p.54) for an explanation of the above mentioned discrepancy. For a normal stand whose average diameter is 6 inches there are only 4 percent of the total number of trees in size classes above the 11-12 inch class. An actual stand whose average diameter is 6 inches admittedly may have, for example, an additional 4 percent or 8 percent of its trees in classes above the 11-12 inch class. An estimate of the volume of trees over 11.5 inches in such a stand obviously would result in 100 percent error. Stands in which approximately 50 percent or more of the total number of trees are over 12 inches in diameter are much less liable to the occurrence of such an exaggerated error. As a further example, a normal stand is indicated to have 50 percent of its trees in this upper range of sizes. An actual stand of corresponding average diameter may have 4 more percent of its trees in this range than the normal tables indicate. This means that the actual stand has 54 percent of its trees in this larger class of diameters, but the error in assuming that there are 50 percent is only 8 percent. Volume is a direct multiple of number of trees therefore the 8 percent error is reflected in the same degree to the volume estimate.

B. Volume estimates by site-index tables

Volume estimates for the same standards as used previously were made for the temporary sample plots by use of the site-index tables. Only those plots whose average diameter fell into even one inch diameter classes, that is, in the 6, 8, 10 inch classes etc., were used. This provided a total of 131 plots in the classes over 6 inches which was considered to be an adequate sample. The age of the stand, site index, and basal area in trees 1.5 inches and over, all of which are necessary in volume estimation by site-index tables, were available in the temporary sample plot data.

Computation of volumes. As an illustration of the procedure followed in estimating volumes by means of the site-index tables, the successive computations are outlined again for plot number 102. The age of the plot

TABLE 4. Sample of computation of percent deviations of estimated from actual cubic volumes per acre for site-index tables

Plot no.	Average age	Site index	Basal area* per a. sq.ft. actual	Basal area* per a. sq.ft. normal	Stocking percent	Volume in cubic ft.* est'd	Volume in cubic ft.* actual	Percent of actual	Percent deviation d
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
102	30	165	211.0	215.5	98	5680	5387	105	5
5	34	133	236.6	224.0	106	5760	5594	103	3
298	36	148	200.6	238.0	87	6060	5498	110	10
276	40	137	274.4	249.0	110	8460	8190	103	3

Columns 1, 2, 3, 4, and 8 are taken from plot measurements.
Column 5 is taken from the site-index yield tables.
Column 6 is column 4 divided by column 5.
Column 7 is the normal site-index table volume multiplied by column 6.
Column 9 is column 7 divided by column 8 and multiplied by 100.
Column 10 is column 9 minus 100 percent.

* For all trees 1.5 inches and over.

has been determined to be 30 years and the site index is 165. By interpolation in the normal table of cubic volumes by site index and age the normal volume of 5,800 cubic feet was determined. It was necessary to adjust this value for degree of stocking or percent of normality. The ratio of actual to normal basal area per acre is the usual indicator of the departure of a stand from the normal condition. The ratio in this case is 211.0/215.5 or .98. The product of .98 and 5,800 results in an estimate of 5,680 cubic feet. Table 4 is an example of the tabulation form used in computing the estimated volumes and the deviations which are discussed in the following paragraphs.

Deviations and standard errors. The standard errors of estimate were computed by the same procedure as followed for the estimates by the diameter yield tables and are shown in table 5. Similarly the deviation averages are recorded in table 6. In board foot expressions the standard error of estimate was again higher for plots having average diameters of 5.6 inches and over than for plots of 11.5 inches and over. This is for the same reason as previously described in the case of diameter tables. The deviation averages were once more used to indicate the accuracy attained in fitting the original curves to the plot data.

TABLE 5. Standard errors of estimate by diameter classes for site-index yield tables

DBH class	No. of plots	Standard error of estimate *				
		Cubic feet		Internat'l b.f.		Scrib. b.f.
		1.5"plus	6.5"plus	6.5"plus	11.5"plus	11.5"plus
6	8	7.2	22.6	28.0		
8	14	6.3	11.2	16.3	67.4	104.5
10	10	5.8	7.7	12.7	16.7	21.8
12	4	4.9	3.1	10.9	28.4	26.4
14	14	5.3	4.7	5.0	7.4	10.0
16	29	3.9	4.4	4.0	7.8	8.8
18	18	3.7	4.3	4.9	5.6	6.0
20 & over	34	4.6	4.2	3.9	5.0	6.2
All plots	131	4.8	7.6	9.8	17.7	22.1
12" & over	99	4.3	4.2	4.5	7.9	8.7

* Percent of volume(all values are plus or minus)

TABLE 6. Average percentage deviations by diameter classes for site-index yield tables

DBH class	No. of plots	Deviation averages *				
		Cubic feet		Internat'l b.f.		Scrib. b.f.
		1.5"plus	6.5"plus	6.5"plus	11.5"plus	11.5"plus
6	8	+6.0	+16.0	+16.0		
8	14	+4.0	+2.0	+2.0	+55.0	+86.0
10	10	+5.0	0.0	-5.0	+8.0	+15.0
12	4	+3.0	-1.0	-5.0	-11.0	-10.0
14	14	+3.0	+2.0	+3.0	+3.0	+4.0
16	29	-1.0	-2.0	-1.0	-3.0	-1.0
18	18	-1.0	-1.0	-1.0	-3.0	-1.0
20 & over	34	+1.0	+1.0	-1.0	-4.0	-5.0
All plots	131	+2.0	+1.0	+1.0	+1.0	+3.0
12" & over	99	+1.0	0.0	0.0	-3.0	-2.0

* Percent of volume

C. Comparison of results

Table 7 is a summary of the standard errors of estimate for diameter yield tables and site-index yield tables. A comparison can be made of the errors of estimates for stands having average diameters of 6 inches and over and of 12 inches and over. It is significant that in almost all cases the diameter yield tables provide a better estimate. This indicates that the stand volume may be defined more accurately by use of the diameter yield tables than by the conventional site-index yield tables. It may be noted also that the standard error of estimate for plots averaging 11.5 inches and more is nearly the same for all standards of measurement by the diameter tables, the range being from ±3.0 percent to ±4.5 percent. On the other hand, the standard error of estimate, on the same basis by site-index yield tables, varies from ±4.2 percent to ±8.7 percent, and is therefore approximately twice the error as by the diameter tables.

TABLE 7. Summary of standard errors and deviation averages of present volume estimated by two types of yield tables

Method of volume estimation	Cubic feet				International bd.ft.				Scribner bd.ft.	
	1.5"plus		6.5"plus		6.5"plus		11.5"plus		11.5"plus	
	S.E.*	D.A.**	S.E.	D.A.	S.E.	D.A.	S.E.	D.A.	S.E.	D.A.
(For plots in the 6-inch class and over)										
Diameter tables	3.2	0.0	4.3	0.0	5.4	-1.0	24.0	+3.0	24.2	+4.0
Site-index tables	4.8	+1.5	7.6	+1.1	9.8	+1.0	17.7	+1.5	22.1	+3.0
(For plots in the 12-inch class and over)										
Diameter tables	3.0	0.0	3.8	0.0	3.8	0.0	3.8	-1.0	4.5	0.0
Site-index tables	4.3	+1.0	4.2	0.0	4.5	0.0	7.9	+3.0	8.7	+2.0

* Standard error of estimate in percent (all values are plus or minus).

** Deviation averages in percent of volume.

III. DETERMINATION OF FUTURE VOLUME IN TEN YEAR PERIODS

The estimation of future yields by use of the diameter yield tables is based upon estimation of the future diameter, future height ratio, and future stand density. The basic data needed is average diameter, average number of trees per acre, average age, and average height of those trees in the stand having diameters of 1.5 inches or more. Such data are available for 15 permanent sample plots established and remeasured at periodic intervals by the Pacific Northwest Forest and Range Experiment Station. These plots were used in checking the accuracy of predicted yields.

Any error of estimate in predicting future volume yield must be composed of the separate errors due to estimating the future diameter, stand density, and height ratio in addition to the standard error of estimate computed previously for the present yields. An attempt has been made here to determine the error contributed by each component. These should indicate which of the stand characteristics is most difficult to estimate either inherently or due to method.

A. Predicting future average stand diameter

The probable average diameter of a stand at any year in the future may be estimated with the aid of a graph or a table showing the correlation of average stand diameter with age. Such a graph was available from Barnes' work previously mentioned. Table 8 was compiled then from the values of stand diameter for every 10 years of stand age read from the graph.

Table 8. Average stand diameter for any stand age

Present age of stand	Average diameter of trees 1.5 inches or more
20	3.2
30	5.1
40	8.2
50	11.5
60	14.0
70	15.9
80	17.6
90	19.2
100	20.5
110	21.8
120	23.1

The use of this table now may be shown by example. A sample plot is now 94 years old and has an average stand diameter of 17.7 inches. Interpolating in table 8, for 94 years a value of 19.7 inches is obtained. The ratio of the actual diameter of 17.7 inches to the tabular diameter of 19.7 inches is .90. Ten years later at age 104 years the average stand diameter should be nine tenths of the tabular diameter of 21.0 inches or 18.9 inches. The average stand diameter was estimated in this way for each of the 15 permanent sample plots at hand.

The standard error of estimate is needed in terms of percent of volume for comparisons to be made in this study. In order to do this, the volumes corresponding to the estimated probable future diameter and the measured permanent plot diameter were read from the normal table 12 in the appendix. The volume based on estimated average stand diameter was divided by the volume based on actual average stand diameter and the ratio stated as a percentage. The deviations were then the differences of these percentages from 100 percent. The standard error of estimate in volume in this case is the square root of the sum of the deviations squared and divided by one less than the number of samples. The result is shown for both cubic foot volume, 1.5 inches and over, and Scribner board foot volume, 11.5 inches and over, in table 11. Although the same diameter was estimated for both types of volume, the conversion of this diameter into the two types of volume results in differences in error.

B. Predicting future height ratio

In regard to future height ratios in Douglas fir stands, Bruce (7, p.7) wrote the following:

> "A careful search of all available permanent sample plot information failed to discover any definite tendency for the ratios of actual to standard heights either to increase or decrease. The present height ratios may, therefore, be used for future stands without change."

From limited tests the same rule seems to apply to western hemlock stands. Therefore the present height ratios of the plots were considered applicable to future stands. Since the estimated volume yield is a multiple of the height ratio, any percent of error in the estimate of height ratio is directly reflected as a percent of error in volume. The present and future height ratio of each plot was determined and for one permanent plot the results were .90 and .94 respectively. If the future height ratio could have been known in predicting future yield, .94 would have been used. Since the estimated .90 was used, the percent difference of actual from estimated value is $100 - \left(\frac{.90}{.94} \times 100\right)$ or 4 percent. These differences so obtained for each plot were squared and the standard error of estimate computed by the same procedure as previously described. As shown in table 11 this error is the same for both cubic foot and Scribner board foot volumes. This is due to the fact that all the estimated volume yields are multiples of the height ratio when diameter yield tables are used.

C. Predicting Future Stand Density

General observations. It has been the practice in using the conventional site-index yield tables to consider that the future yields will be the same percent of normal as the present volume is to the normal. This practice disregards any acceleration or deceleration of growth rate that may occur in the stand and can lead to rather high error in growth and yield predictions. Under this practice it was understood that the result obtained would necessarily be a conservative one, particularly in the case of understocked stands.

Observations by foresters have indicated that many forest stands tend to approach the normal stocking either by means of an increasing or a decreasing growth rate. Stands of the spruce-hemlock type in question should conform with this general rule.

Previous findings. From intensive study as well as from general observation Carter (9) and Haig (15) have shown that stands tend to approach normal stocking as they grow older. Gerhardt (12) investigated this trend and developed formulas for use in estimating the approach of understocked stands toward normal stocking. This investigation was made in Europe and remained unknown in this country until Gevorkiantz (13) (14) presented a discussion of it in 1934 and in 1937 considered the application of the formulas to uneven-aged stands of northern hardwoods. Duerr (11) also considered the application of Gehrhardt's formulas to various species in the Lake States. Both

Gevorkiantz and Duerr were able to apply Gehrhardt's formulas successfully. As early as 1928 McArdle and Meyer (16, p.33) recognized the tendency of understocked stands of Douglas fir to approach normal stocking. At that time they stated that limited data gave evidence that the rate of increase was about 4 percent per decade for this species. In 1933 with additional data Meyer (17) was able to compute regression equations of the five-year change in normality percentages based on number of trees, basal area, cubic foot measure, International board foot measure, and Scribner board foot measure. The results indicated that understocked stands of Douglas fir tend to improve at a rate dependent on the degree of understocking. Overstocked stands on the other hand tend to regress toward a normal condition. The rate of change in both cases diminished as the stands approached the normal. Based on remeasurements of the same permanent plots, Briegleb (5) was able to test the correlation of change in stocking with respect to age, site, and original stocking. His findings indicated a definite correlation with both age and stocking but not with site.

Similar investigations of the tendency of abnormally stocked stands of other species to approach normality have been made. Chaiken (10) used temporary plot averages in determining an expression of the change in the density of stocking in loblolly pine (*Pinus taeda* L.) and Virginia pine (*Pinus virginiana* Mill.) stands with increase in age. He compiled a series of regressions based on age and stocking. Wellwood (20) used the same plot data for loblolly pine and computed a regression of the percent of normal after a five-year period with respect to site, age, and present normality class.

In 1943 Briegleb and Girard (6) compiled sawtimber growth correction factors for Douglas fir based on age and two broad classes of stocking, medium and good. The factors reflected the average accelerated and decelerated growth rates of stands of different age and density. These correction factors have been applied satisfactorily in constructing empirical yield tables for that timber type by Weyerhaeuser Timber Company (21) which allow in themselves for changes. Bruce (7, p.7) was able to use the growth correction factors in compiling a table of estimated increase in normality by number of trees in a 10-year period for use with his diameter yield tables for Douglas fir. Bruce based his normality figures on the ratio of actual to normal number of trees as defined by average stand diameter.

D. <u>Investigation of the approach of western hemlock stands toward normality</u>

There is nothing available at present for estimating the change in density in hemlock stands but general observations indicate that they react like other species. Barnes suggested that Bruce's table for Douglas fir be used for hemlock until sufficient data for the latter could be collected and analyzed. The only sources of such data are permanent sample plots. Since hemlock is a tolerant species, it was suspected that the rate of change would be greater than for the less tolerant Douglas fir. At present the only permanent plots available are the 15 plots established by the Pacific Northwest Forest and Range Experiment Station and 80 permanent line plots in British Columbia. These were considered sufficient to warrant a preliminary investigation. An interval of 10-years for all the plots mentioned was attained by interpolation. Of these plots 83 were approximately 40 years old and 12 plots were approximately 80 years old at the time of the first measurement.

<u>Gehrhardt's formula.</u> An attempt was made first to fit Gehrhardt's type formula to the data. There was definitely no relationship which the Gehrhardt formula defined even though several constants were tried. The

gains indicated for understocked stands were considerably in excess of the actual gains recorded.

Linear regression. The next step was to analyze the available data to determine whether a regression of the change in density with respect to time could be defined. The stand density of each plot was determined by computing the ratio of actual number of trees on the plot to the normal number as defined by the average stand diameter. This ratio was computed for each plot at the time of original establishment and at 10-year intervals thereafter. By multiplying by 100 the ratios were converted to percent of stand density. The 10-year chages that occurred in the plot densities were then computed. These were recorded as being plus or minus according to whether they were increases or decreases from the original stand density. The plots were grouped in classes of 40 percent, 50 percent, etc. of original stand density and the average 10-year change computed for each class. The average change was then plotted over the class midpoint as shown on the graph in figure 1. A linear regression of the change was determined by the abbreviated method of least squares as described by Bruce and Schumacher (8, p.188). This calculation is shown in table 9. The regression is $C = 27 - .27N$, where C is the 10-year change in stand density and N is the percent of stand density at the

TABLE 9. Determination of linear regression by method of least squares

Original density N	10-year change C	No. of plots f	fC	fN	fN^2	fC^2	fNC
40	16	2	32	80	3,200	512	1,280
50	20	4	80	200	10,000	1,600	4,000
60	8	6	48	360	21,600	384	2,880
70	12	6	72	420	29,400	864	5,040
80	3	17	51	1,360	108,800	153	4,080
90	0	10	0	900	81,000	0	0
100	-1	14	-14	1,400	140,000	14	-1,400
110	-7	13	-91	1,430	157,300	637	-10,010
120	-4	12	-48	1,440	172,800	192	-5,760
130	-4	5	-20	650	84,500	80	-2,600
140	-1	3	-3	420	58,800	3	-420
150	-22	3	-66	450	67,500	1,452	-9,900
Totals		95	41	9,110	934,900	5,891	-12,810

General form of linear equation:

$$C = a + bN$$

Normal equations:

$$a(\Sigma f) + b\Sigma(fN) = \Sigma(fC)$$

$$a\Sigma(fN) + b\Sigma(fN^2) = \Sigma(fNC)$$

By substituting and solving simultaneously:

$$a = 27$$

$$b = -.27$$

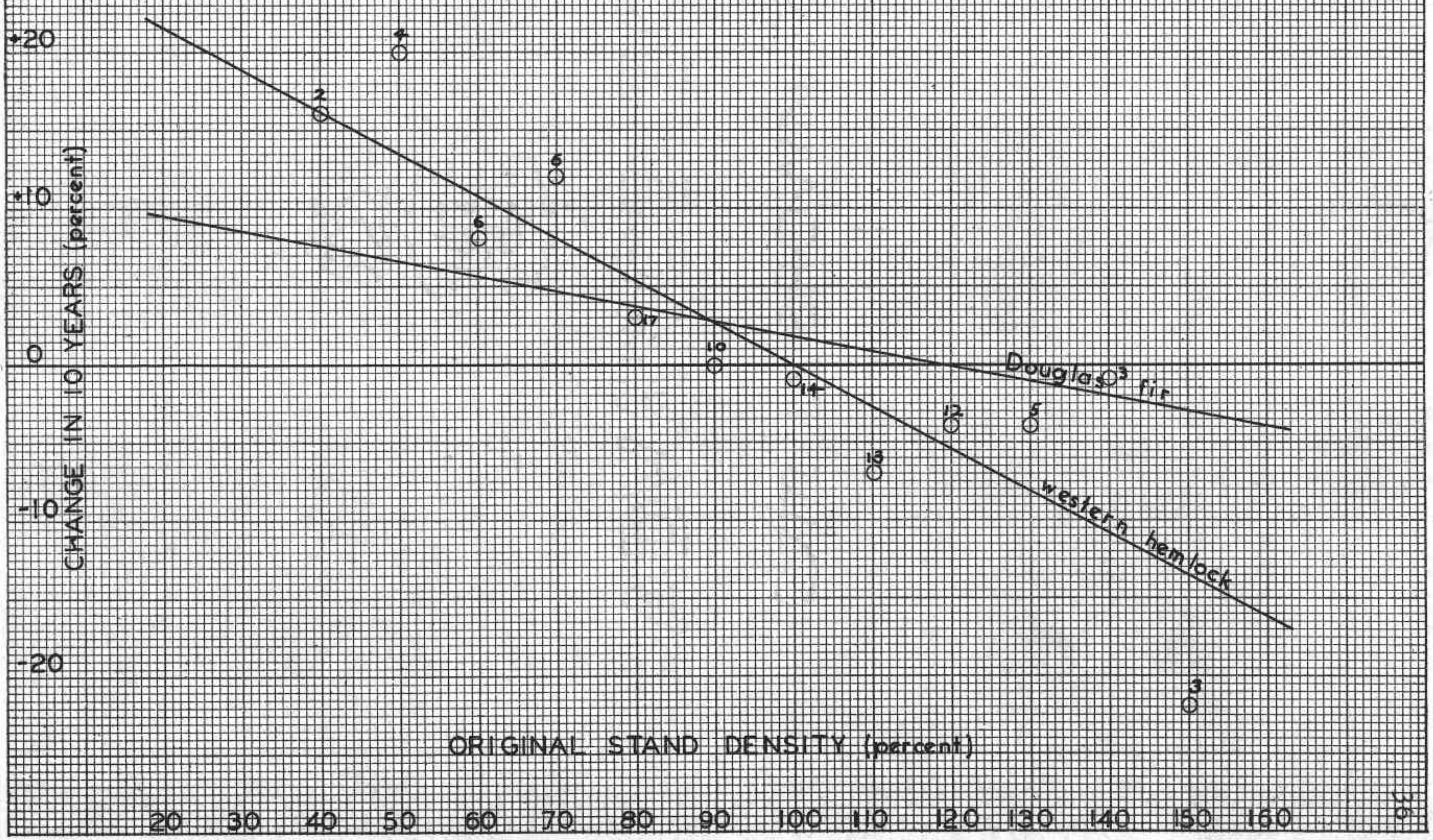
Substituting in the general form:

$$C = 27 - .27N$$

beginning of the 10-year period.

The regression line is plotted on the graph in figure 1. Also on this graph is the regression of the change in density for Douglas fir determined by Bruce (7, p.16). The hemlock regression has a greater slope than the Douglas fir. This indicates that abnormally stocked stands of hemlock tend to approach normality faster than abnormally stocked stands of Douglas fir, and conforms with accepted theory. The comparison may not be entirely reliable since the data used in determining the hemlock regression were limited to two age classes. In addition to the lack of age distribution it should be pointed out also that the 13 plots of the 80-year age class were originally selected because they appeared to be nearly normal in stand density. Plots of the 40-year age class are rather evenly distributed over a range of 38 to 148 percent of normal. The regression then may be considered satisfactory for stands near 40 years of age. Nothing definite can be said about the regression of the change in density in regard to older stands. It is generally believed that older stands are less capable of approaching normality as they advance in age. For this reason it seems reasonable to assume that older stands would determine a regression with less slope. Whether or not a hemlock regression with all ages and densities represented

FIGURE 1. A graph of the 10-year change in stand density for western hemlock and Douglas fir



would approximate the regression determined herein is not known. It might be well to point out that the regression, $C = 27 - .27N$, does bear a relationship to the Douglas fir regression in accord with the characteristics of the two species. Western hemlock and its associate Sitka spruce are both more tolerant than Douglas fir according to Baker (1, p.234). It is generally recognized that tolerant species respond more quickly to the favorable condition of low density, thereby filling openings and improving in stocking at a greater rate. This is supported by the relative positions of the regression lines in figure 1.

Despite the shortcomings indicated, the regression as given is used for predicting future densities of stands in all age classes. The regression, $C = 27 - .27N$, expresses the improvement for periods of 10 years. Estimates of improvement for periods exceeding 10 years may be made by repeated application of the equation to the estimated stocking obtained at the end of successive decades. In order to eliminate this step-by-step procedure, table 10 has been compiled, by means of which the final stocking may be determined directly at the end of specified periods of growth.

Application of the trend. The stand density of each of the 15 permanent sample plots at the beginning and

TABLE 10. Estimated normality in 10-year periods for western hemlock

Present normality percent	Estimated future normality* 10 yrs later	20 yrs later	30 yrs later	40 yrs later	50 yrs later	60 yrs later
20	42	58	69	77	83	87
25	45	60	71	79	84	88
30	49	63	73	80	85	89
35	53	66	75	82	86	90
40	56	68	77	83	87	90
45	60	71	79	84	88	91
50	63	73	80	85	89	92
55	67	76	82	87	90	93
60	71	79	84	88	91	93
65	74	81	86	90	92	94
70	78	84	88	91	93	95
75	82	87	90	93	94	95
80	85	89	92	94	95	96
85	89	92	94	95	96	97
90	93	95	96	97	98	99
95	96	97	98	99	99	100
100	100	100	100	100	100	100
105	104	103	102	101	101	100
110	107	105	104	103	102	101
115	111	108	106	104	103	102
120	115	111	108	106	104	103
125	118	113	110	107	105	104
130	122	116	112	109	106	104
135	126	119	114	110	107	105
140	129	121	116	112	109	106
145	133	124	118	113	110	107
150	137	127	120	114	110	107
155	140	129	121	115	111	108
160	144	132	123	117	112	109

* Percentages based on normal number of trees per acre 1.5 inches and over in breast high diameter.

at the end of each 10-year growth period was computed. Knowing the beginning stand density it was possible to predict the probable stand density 10 years hence by making use of table 10. The standard error of estimate of stand density was computed in the following manner. The differences of the estimated from the actual stand density were squared and then totaled. The total was divided by one less than the number of plots and the square root taken of this quotient. The result is the standard error of estimate of stand density and is given in table 11. Since stand density applies directly to all normal volumes, the same standard error is shown for both cubic foot measure and Scribner board foot measure.

Although the result of ±10.4 percent is rather high, it is within reason. The permanent sample plots used in the test were mostly of the 80-year age class which was not well represented in the data used to compute the regression of trend. Also the plots were overstocked. The actual change in density for most of the overstocked plots was positive while the regression indicated a decrease. As was pointed out previously, the regression applies more specifically to 40 year old stands. Even then the standard error of estimate is large because of the innumerable variables which effect density and yet can not be removed from the regression of the trend.

E. Standard errors of estimating volumes 10 years hence.

Diameter tables. The standard error of estimating a volume 10 years hence is a combination of the standard errors of estimating average stand diameter, height ratio and stand density 10 years hence and the standard error of estimate of the normal diameter yield table. If there is no intercorrelation between these errors then theoretically the standard error of such an estimate would be the square root of the sum of the squares of these errors. As shown in table 11 this calculation for cubic volume would be

$$\sqrt{1.7^2 + 10.4^2 + 3.4^2 + 3.2^2} = \pm 11.5 \text{ percent.}$$

The cubic volume 10 years hence for each of the 15 permanent plots was also estimated directly. This consisted of using the estimated future diameter, actual height ratio, and a future density from table 10 in the method described for present volume calculations in table 1. The standard error of estimate by this direct calculation was ±7.9 percent. There is a discrepancy of 3.6 percent between the two values. The difference may well be due to an intercorrelation of the errors. For instance, the first three standard errors of estimate are based on the normal table values and the last standard error is by definition the standard error of the normal

TABLE 11. Standard errors of estimating stand variables 10 years hence by the diameter tables and the site-index tables *

Cubic foot volume 1.5 inches and over

Error of estimating:	Percent error**	
	Diameter	Site index
Future average stand diameter	1.7	
Future stand density	10.4	10.4
Future height ratio	3.4	
Present yield	3.2	4.3
Total error of estimate		
by theoretical calculation	11.5	
by direct calculation	7.9	16.7

Scribner board foot volume 11.5 inches and over

Error of estimating:	Percent error**	
	Diameter	Site index
Future average stand diameter	4.2	
Future stand density	10.4	10.4
Future height ratio	3.4	
Present yield	4.5	8.7
Total error of estimate		
by theoretical calculation	12.6	
by direct calculation	9.9	22.4

* Based on 15 permanent sample plot estimates.

** All values are plus or minus.

table itself. This may have resulted in some intercorrelation among the separate errors which can not be removed from the theoretical calculation.

A similar calculation of the standard error of estimate was made for Scribner board foot measure as follows:

$$\sqrt{4.2^2 + 10.4^2 + 3.4^2 + 4.5^2} = \pm 12.6 \text{ percent}$$

The result is shown in table 11. Here again the standard error of estimate by direct calculation is less than the theoretical. The same intercorrelations may be responsible for the discrepancy.

Errors of the site index tables. As a test of the site-index yield tables, estimates of volumes 10 years hence were made for the same 15 permanent sample plots by means of this set of tables. The stand density attained at the end of the period was estimated by table 10 in the same manner as outlined previously. The standard error of estimate now was ±16.7 percent for cubic foot volume and ±22.4 percent for Scribner board foot volume. These values are shown for comparison with others in table 11. The individual errors for each variable used were not computed and therefore a theoretical calculation was not made. The standard error of estimate of ±10.4 percent for stand density is the only portion of the total error which can be defined separately.

IV. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

1. In the determination of the present volume in stands whose average diameter is 5.5 inches or more, the use of the normal table based on average stand diameter results in a better estimate than does the use of the normal tables based on site index and age when the following standards of measurement are considered:

   a. Volume in cubic feet of trees 1.5 inches and over.

   b. Volume in cubic feet of trees 6.5 inches and over.

   c. Volume in board feet by International Rule of trees 6.5 inches and over.

The standard errors of present yield estimates by both types of tables are high when the following standards of measurement are considered:

   a. Volume in board feet by International Rule of trees 11.5 inches and over.

   b. Volume in board feet by Scribner Rule of trees 11.5 inches and over.

On the other hand in stands whose average diameters are 11.5 inches or more, the tables based on average stand diameter are superior to those based on site index and age when any of the above standards of measurement are considered.

2. Abnormally stocked stands of western hemlock show a definite trend in stand density toward the normal condition with an increase in age. This trend in stands of the 40-year age class has been defined by a linear equation of the regression.

3. The standard error of estimate in predicting stand density for 10-year periods, using the regression mentioned above, is ±10.4 percent. This is rather high and tentative reasons are given. First, any prediction of stand density may result in a high error because of the erratic occurrence of mortality and accidental damage. Secondly, the plots used in determining the above standard error of estimate were of a different age class than that for which the trend regression was developed.

4. The accuracy of estimating probable future yields is decidedly better by use of the diameter tables than by use of the site-index tables on the basis of the limited amount of permanent sample plot data available.

5. The writer considers that the one normal table based on average stand diameter is more easily used than the several normal tables based on site and age.

B. Recommendations

The establishment of more permanent sample plots in understocked stands and collection of additional data for use in determining the trends of stand density toward normal for a wide variety of age classes is recommended. Such data would facilitate predictions based on any type of yield table in existence now.

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APPENDIX

TABLE 12. Normal yields of western hemlock with respect to average stand diameter of trees 1.5 inches and over.

Av. DBH of stand 1.5" -	No. of trees per a. 1.5" -	Av. ht. of trees 1.5" -	Volume per acre			
			Thousands of: cubic feet		Thousands of bd.ft.	
					Internat'l	Scribner
			1.5"-	6.5"-	6.5"- 11.5"-	11.5"-
3	3,130	38	1.8				
4	2,060	45	3.6	1.0	6		
5	1,550	54	4.9	2.7	9	1	1
6	1,200	61	6.3	4.4	22	5	4
7	905	69	7.5	5.8	30	11	8
8	723	76	8.5	7.2	38	18	13
9	595	82	9.5	8.5	47	27	20
10	498	89	10.6	9.8	56	37	28
11	425	95	11.6	11.0	66	49	38
12	368	101	12.6	12.1	77	63	48
13	325	107	13.5	13.2	88	76	59
14	284	112	14.4	14.2	99	88	68
15	255	117	15.3	15.0	109	98	76
16	228	122	16.1	15.9	117	108	85
17	207	127	16.8	16.7	123	116	91
18	187	132	17.4	17.4	129	123	97
19	172	136	18.1	18.1	134	130	103
20	157	140	18.8	18.8	139	135	109
21	143	144	19.4	19.4	143	141	114
22	133	148	20.0	20.0	147	146	119
23	123	151	20.5	20.5	152	151	123
24	114	154	21.0	21.0	156	156	128
25	107	158	21.5	21.5	161	161	132
26	100	161	22.1	22.1	165	165	137
27	94	164	22.6	22.6	169	169	141
28	89	167	23.1	23.1	174	174	145
29	83	170	23.6	23.6	178	178	149
30	79	173	24.1	24.1	182	182	153
32	71	180	25.1	25.1	191	191	161
34	64	186	26.0	26.0	199	199	169
36	59	192	27.0	27.0	208	208	177
38	54	199	28.0	28.0	216	216	184
40	49	206	28.8	28.8	225	225	192

TABLE 13. Normal yields of western hemlock with respect to age for site index 150.

Age (years)	Aver. height 1.5"-	Av. ht. of dom. & codom.	No. of trees* 1.5"-	Aver. DBH 1.5"-	Basal area* 1.5"-	Volume in thousands of feet*				
						Cubic feet		Internat'l		Scribner
						1.5"-	6.5"-	6.5"-	11.5"-	11.5"-
30	53	57	1520	5.1	212	5.2	2.98	14		
40	73	78	710	8.1	254	8.5	7.3	39	19	14
50	91	96	400	11.4	285	11.9	11.3	69	53	42
60	107	112	290	13.8	304	14.2	13.8	96	85	65
70	117	123	240	15.7	316	15.8	15.5	113	103	81
80	127	133	200	17.4	327	17.0	16.7	124	116	93
90	136	142	172	18.9	336	17.8	17.8	132	126	102
100	144	150	150	20.2	343	18.8	18.8	139	135	109
110	149	157	138	21.5	348	19.6	19.6	144	142	116
120	154	161	125	22.8	355	20.2	20.2	150	149	121
140	161	168	108	24.8	364	21.2	21.2	159	159	131
160	166	173	95	26.7	372	22.2	22.2	167	167	139
180	170	177	87	28.3	379	23.0	23.0	173	173	145
200	173	180	81	29.5	384	23.6	23.6	178	178	150
250	175	182	70	32.1	393	25.0	25.0	189	189	160
300	177	184	66	33.2	402	25.4	25.4	194	194	165

* Values are for one horizontal acre.