AN ABSTRACT OF THE THESIS OF

ROGER DEAN STUCK II for the MASTER OF SCIENCE
(Name) (Degree)

in FOREST MANAGEMENT presented on July 31, 1973
(Major) (Date)

Title: PREDICTING DIAMETER INSIDE BARK AT VARIOUS UPPER STEM HEIGHTS FOR SEVERAL CONIFEROUS SPECIES ALONG THE WESTERN SLOPE OF THE CASCADE MOUNTAINS

Abstract approved: Signature redacted for privacy.

David P. Paine

The purpose of this thesis was to develop regression equations for predicting diameter inside bark at various heights up the stem for four tree species, noble fir (Abies procera Rehd.), Pacific silver fir (Abies amabilies (Doug.) Forbes), Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), and western hemlock (Tsuga heterophylla (Raf.) Sarg.). Data from scattered plots on the upper slopes of the Cascade Mountain range in Oregon and Washington were analysed in a stepwise regression computer program.

A significant difference was found between observations in Oregon and Washington for three species, noble fir, Pacific silver fir, and Douglas-fir. In addition to the equations for the combined Oregon Washington data, separate equations were developed for each state.

Diameter outside bark always entered the stepwise equation first. Regression equations were also developed using this single independent variable to predict diameter inside bark.

Predicting Diameter Inside Bark at Various Upper Stem Heights for Several Coniferous Species Along the Western Slope of the Cascade Mountains

by

Roger Dean Stuck II

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Commencement June 1974

APPROVED:

Signature redacted for privacy.

Professor of Forest Management
In Charge of Major

Signature redacted for privacy.

Head of Department of Forest Management

Signature redacted for privacy.

Dean of Graduate School

Date thesis is presented July 31, 1973

Typed by Melodee Lynne Haynes for ROGER DEAN STUCK II

ACKNOWLEDGEMENTS

The author wishes to thank Francis Herman for permission to use his data and for the suggestion and help he provided during the course of this study. Thanks are also expressed to the Computer Science Department at Oregon State University for supplying computer time.

The author is grateful to Dr. David Paine for reviewing and making valuable suggestions about this thesis.

TABLE OF CONTENTS

LIST OF TABLES

PREDICTING DIAMETER INSIDE BARK AT VARIOUS UPPER STEM HEIGHTS FOR SEVERAL CONIFEROUS SPECIES ALONG THE WESTERN SLOPE OF THE CASCADE MOUNTAINS

I. INTRODUCTION

A. Need For Diameter Inside Bark Predictions

A sampling scheme introduced by Grosenbaugh (8) involves the use of optical dendrometers to get away from the use of volume tables to predict volume of standing trees. This sampling method is known as probability proportional to prediction (3P sampling). When a tree is selected for measurement, an optical dendrometer is used to obtain diameter outside bark at various heights on the stem. For the volume computation, diameter outside bark must be converted to diameter inside bark to obtain either board or cubic-foot volumes. The calculation can be done by computer using a Fortran IV program written by Grosenbaugh (8). This program uses a bark ratio of diameter inside bark to diameter outside bark to express diameter inside bark. Three options are provided the user based on assumptions about the changes in bark ratio as the distance up the tree increased. The assumptions are:

1. The ratio remains constant as the distance up the stem of the tree increases.

2. The ratio decreases as the distance up the stem of the tree increases.

3. The ratio increases as the distance up the stem of the tree increases.

According to Brickell (3) not all tree species hold to one of the above assumptions but may use a combination of the assumptions.

To predict diameter inside bark directly would be one way of avoiding the use of the ratio. A study by Khan (18) found that the direct estimates of diameter inside bark at various stem heights produced more accurate results than using the bark ratio.

However, most of the work to predict diameter inside bark has been concerned only with the prediction at breast height. According to Maezaua (19) the equations to predict diameter inside bark at breast height are not accurate for other stem heights.

Therefore, there is a definite need for equations to accurately predict diameter inside bark at various points along the stem, and should be compatible with slight modification to Grosenbaugh's (8) computer program.

B. Purpose and Scope

The purpose of this study was to develop equations for predicting diameter inside bark for four tree species, noble fir (*Abies procera* Rehd.), Pacific silver fir (*Abies amabilis* (Dougl.) Forbes), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco.), and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), in the Cascade Mountain Range of Oregon and Washington. The equations must be capable of being incorporated into Grosenbaugh's (8) program, with minimum modification, to convert diameter outside bark to diameter inside bark.

II. REVIEW OF LITERATURE

Meyer (21, 22) found a need to predict diameter inside bark at breast height in his studies of growth. He considered the relationship between diameter inside bark at breast height (d.b.h.i.b.) and diameter outside bark at breast height (d.b.h.o.b.) to be linear. The equation he used was in the form, d.b.h.o.b. = K(d.b.h.i.b.).

In 1948, Finch (7) used the same relationship as Meyer but in the form of a linear equation with a non-zero intercept, d.b.h.o.b. = $b_0 + b_1$ (d.b.h.i.b.).

McCormack (20) derived a linear relationship by plotting average values for diameter outside bark over those for diameter inside bark in two inch diameter classes. He found linear relationships for 55 species of conifers and hardwoods in the southeastern United States.

Honor and Alendag (17) established a linear relationship between d.b.h.i.b. and d.b.h.o.b. for 11 tree species in eastern and central Canada. By determining past diameter inside bark with the help of an increment borer, the linear relationship they established can be used to predict past diameter outside bark. The coefficients of determination (R^2 value) of the 11 equations, one for each species, varied between 0.990 and 0.999.

Minor (23) added age of the tree to his equation to predict d.b.h.i.b. Age had little effect on the equation, increasing R by only 0.01 and decreasing the standard error by 0.01 inches.

In 1954, Hamf (14) working with white pine in the northeastern United States established multiple regression equations to predict d.b.h.o.b. from variables determined by the stump of the tree. The equation was in the form, d.b.h.o.b. = $b_0 + b_1$ (stump d.i.b.) + b_2 (stump height). The conversion was necessary so that existing volume tables could be used in areas where the timber had been removed to estimate volumes. Similar equations have been developed for a variety of species (1, 2, 4, 5, 9, 10, 11, 12, 13, 15, 16, 24).

Khan (18) developed equations to predict diameter inside bark at various stem heights for young growth Douglas-fir on plots in Oregon and Washington. Location was determined to have an effect on the results; therefore, the equation for the Oregon plots was in the form:

$$Y = b_0 + b_1x_1 + b_2x_3 + b_3 (x_2)^2 + b_4 (x_2x_3)$$

The equation for the plots in Washington was in the form:

$$Y = b_0 + b_1x_1 + + b_2x_3 + b_3 (x_2x_3)$$

where:

Y = diameter inside bark at the point of interest on the stem

x_1 = bark ratio at breast height (d.b.h.i.b./d.b.h.o.b.)

x_2 = length up the stem from the ground

x_3 = diameter outside bark at the point of interest on the stem

III. DATA

The data were supplied by Francis Herman of the U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station. These data consisted of stem analysis of 265 bucked trees on 94 plots scattered along the upper slopes of the Cascade Mountain Range between the McKenzie River in Oregon and the Skykomish River in Washington. In the remainder of this study, the data will be referred to as being from Oregon and Washington, when in fact, the data were from only part of these states.

Measurements were made at each point where the trees were bucked and recorded on computer cards. The following information was utilized in this study:

1. Diameter outside bark at breast height measured to a tenth of an inch.

2. Age of the tree at breast height.

3. Height above ground to the point of measurement (as if the trees were still standing).

4. Diameter inside and outside bark at the point of measurement, to a hundredth of an inch.

5. Age of the tree at the point of measurement.

Data from four species, noble fir, Pacific silver fir, Douglas-fir, and western hemlock were analysed.

To account for the wide diversity of site quality, age, and diameter that could be encountered in the use of the results of this study, the plots were selected so that observations were obtained over the range of these three variables. The range of diameters and ages along with the number of observations and number of trees of each species sampled are listed in Table 1.

TABLE 1. SUMMARY OF DATA

Species	Number of Observations	Number of Trees	Range of Diameter Outside Bark	Range of Ages
			INCHES	YEARS
Noble fir	1907	87	4.00-83.43	45-382
Pacific silver fir	788	69	4.00-56.20	47-501
Douglas-fir	755	65	4.00-72.50	51-445
Western hemlock	601	54	4.00-55.70	52-451

IV. METHODS

A. Statistical Design

The data were analysed by the Oregon State University CDC 3300 computer using a stepwise multiple regression program described by Yates (25). The plotter attachment was used in one case to determine trends in the data.

The basic regression model according to Draper and Smith (6) is:

$$Y = \beta_0 + \beta_1 x_1 + \ldots + \beta_K x_K + \varepsilon$$

where:

Y = value of random dependent variable

$\beta_1, \ldots, \beta_K$ = parameters of the model

$x_1, \ldots, x_K$ = values of random independent variables

ε = random unobserved error,

$N(0, \sigma^2)$

A sample prediction equation can be written as:

$$\hat{Y} = b_0 + b_1 x_1 + b_2 x_2 + \ldots$$

where:

$\hat{Y}$ = predicted value of dependent variable

$b_0, b_1, \ldots$ = sample estimates of $\beta_0, \beta_1, \ldots$

$x_1 x_2, \ldots$ = values of independent variables

The F-level for entering and removing variables from the regression equation was set at the 99 percent confidence level. The standard deviation about the regression line, simple correlation coefficients (with the dependent variable), and the percentage variation explained by the regression equation (R^2) were examined to determine the practicality and reliability of the regression equations. The ease of field measurements used in the equation were also examined for feasibility and practicality. Using standard deviation about the regression line to examine precision, changes of ± 0.05 inches or greater in standard deviation when an independent variable is entered into the regression equation has a change of 0.10 inches or greater over the interval around the regression line. Therefore, for this study when the standard deviation was reduced by more than 0.05 of an inch by the addition of another variable then that variable was used in the final regression equation.

Simple correlation coefficients with the dependent variable were examined to determine the relationship with the independent variables. The R^2 values of a regression equation were also examined to determine the decrease in the variation explained by the addition of another independent variable. When the addition of another variable increased the R^2 value by 0.0001 (tolerance level) or less, the variable was not used in the regression equation.

B. Procedures

Data analysis consisted of developing separate regression equations for each tree species. The first equation for each species used the combined data from Oregon and Washington. A dummy variable as described by Draper and Smith (6) was used in this equation to determine the effect of location. Location refers to the difference of the data between states. If the location variable was significant, separate equations were developed for each state.

This study was limited to five basic independent variables:

1. Diameter outside bark at breast height (d.b.h.o.b.).
2. Age of the tree at breast height.
3. Height above the ground to the point of measurement.
4. Diameter outside bark at point of measurement (d.o.b.).
5. Age of the tree at the point of measurement.

The literature review turned up nine transformations involving three of these variables which have been used in previous studies. The basic independent variables and their transformation were:

x_1 = d.b.h.o.b.

x_2 = age at breast height

x_3 = height at point of measurement

x_4 = d.o.b.

x_5 = age at point of measurement

$x_6 = x_3^2$

$x_7 = x_4/x_1$

$x_8 = [x_4/x_1]^2$

$x_9 = x_4^2$

$x_{10} = x_3x_4^2$

$x_{11} = x_3x_4$

$x_{12} = x_1 x_3$

$x_{13} = [x_3 x_4]/x_1$

$x_{14} = x_1 x_4$

The 14 independent variables were evaluated using the combined Oregon-Washington data for the species with the most observations, noble fir. Using the stepwise regression program and an entering F-level at the one percent significance level, seven of the independent variables entered the regression equation. The seven variables, in order of entering the equation were:

x_4 = d.o.b.

x_9 = d.o.b.^{2}

x_7 = d.o.b./d.b.h.o.b.

x_{14} = d.o.b.(d.b.h.o.b.)

x_{11} = d.o.b.(height at point of measurement)

x_{13} = d.o.b.(height at point of measurement)/d.b.h.o.b.

x_{10} = (d.o.b.)^2(height at point of measurement)

All seven independent variables were considered in all the remaining computer runs along with the other variables required for transformations. The notation was changed to match the notation of the computer programs. The independent variables used in this study were redefined as follows:

x_1 = d.b.h.o.b.

x_2 = height at point of measurement

x_3 = d.o.b.

$x_4 = x_3^2$

$x_5 = x_1x_3$

$x_6 = x_3/x_1$

$x_7 = x_2x_3$

$x_8 = x_2x_3/x_1$

$x_9 = x_2x_3^2$

x_{10} = dummy variable for location

The dummy variable for location was used to take into account variation in the results of the regression equation due to some observations being from Oregon and others from Washington. This variable had values assigned so that a distinction could be made as to where the observations were made. According to Draper and Smith (6) any value would work, but they recommended using zeros and ones. For this study zeros were used for observations from the state of Oregon, and ones were used for observations from the state of Washington.

The dummy variable was treated as any other independent variable by the stepwise regression program. If the dummy variable entered the regression equation, then location had a significant effect on the equation.

V. RESULTS

A. Noble Fir

Ten independent variables, including the dummy variable for location, were analysed using the stepwise program. Eight of the variables were significant, including the location variable. The location variable entered fourth into the regression equation and had a significant entering F value of 40.90.

The R^2 value for the regression equation was 0.9982 after the first variable, increased to 0.9990 after entering the third variable, and then only increased to 0.9991 after entering the last variable. By looking at R^2 values, only three variables would be used in the regression equation; but other facts were considered.

The standard deviation of the predicted value at the end of each step of the stepwise program was observed. The decrease in standard deviation was greater than 0.05 of an inch for the first three steps and then the decrease was less than this level for the remaining entering variables.

When the increases in R^2 and the decreases in standard deviation were considered, the eight significant entering variables were reduced to three for a practical regression equation that follows:

$$\text{d.i.b.} = -0.0911 + 0.8415x_3 + 0.1381x_4 + 1.2477x_6$$

where:

x_3 = d.o.b.

$x_4 = x_3^{\ 2}$

x_6 = d.o.b./d.b.h.o.b.

The simple correlation coefficients with the dependent variable were 0.9991, 0.9560, and 0.7538 for each of the independent variables respectfully. All three show a high correlation with the dependent variable.

The dummy variable entered the regression equation significantly. The regression equation that follows takes location into account:

$$\text{d.i.b.} = -0.2343 + 0.8440x_3 + 0.0014x_4 + 1.2151x_6 + 0.1815x_{10}$$

where x_3, x_4, and x_6 have already been defined and x_{10} was a dummy variable for location. The dummy variable had a value of zero if the observations were from the state of Oregon and a one if from the state of Washington.

When the value zero was used in the regression equation for the value of x_{10}, the only effect was the dropping of x_{10} and its coefficient from the equation. But when the value one was substituted for x_{10}, the intercept increased by the value of the coefficient of x_{10}. The result was two parallel lines, one for observations from Oregon and one for observations from Washington that differ by the coefficient of the dummy variable.

Another way that the effect of location was taken into account was to develop separate regression equations for each of the two states. For the state of Oregon only three of the nine independent variables entered the equation. The standard deviation decreased one tenth of an inch between entering of the first variable and the second to a value of ± 0.3740 inches. Adding the third variable decreased the standard deviation by less than the 0.05 of an inch as described in the procedures.

The R^2 value increased from 0.9985 to 0.9991 after the second independent variable was entered, but only increased 0.0001 after the third variable was entered. Thus, the regression equation arrived at contained two independent variables and is:

$$\text{d.i.b.} = -0.2059 + 0.9340x_3 - 0.0003x_7$$

where:

x_3 = d.o.b.

x_7 = d.o.b.(height at point of measurement)

The independent variables were highly correlated with the dependent variable. The simple correlation coefficient of x_3 was 0.9992, while x_7 was negatively correlated with a coefficient of 0.7126.

The regression equation developed from data for the state of Washington had seven independent variables enter the equation. The R^2 for the first step in the stepwise program was 0.9982 and this value increased to 0.9990 for the third step. The increase of the R^2 value to only 0.9992 for the last step was a small enough increase as stipulated in the procedures that the last four variables were not entered into the equation. Evaluating the standard deviation of the predicted values, the decrease was large enough for the addition of the first three variables. After the third step, the decrease was less than the established 0.05 of an inch. The equation then is:

$$\text{d.i.b.} = -0.1516 + 0.8495x_3 + 0.0013x_4 + 1.2503x_6$$

where:

x_3 = d.o.b.

$x_4 = {x_3}^2$

x_6 = d.o.b./d.b.h.o.b.

The correlation coefficient with the dependent variable for the three independent variables were 0.9991, 0.9548, and 0.7140, respectfully.

B. Pacific Silver Fir

When the data for Pacific silver fir were analysed for the combined data, location had a significant effect at the one percent level. Four other independent variables also entered and are listed in order of entering:

x_3 = d.o.b.

x_7 = d.o.b.(height at point of measurement)

x_{10} = location

$x_4 = {x_3}^2$

x_2 = height at point of measurement

Examining the increase in the R^2 value and the decrease in the standard deviation about the regression line, the equation was reduced to:

$$\text{d.i.b.} = -0.4598 + 0.9588x_3$$

where x_3 is d.o.b. The R^2 value for this equation was 0.9985 and had a standard deviation of ± 0.3661 inches. To expand the equation to take into account the location term, two independent variables were added to the regression equation because the location term was the third term entered. The equation is then in the form:

$$\text{d.i.b.} = -0.1715 + 0.9487x_3 - 0.0001x_7 + 0.1283x_{10}$$

where:

x_3 = d.o.b.

x_7 = d.o.b.(height at point of measurement)

x_{10} = location

The dummy variable was zero for Oregon and one for Washington. By the addition of these two independent variables, the R^2 value increased to 0.9988 and the standard deviation decreased to ± 0.3331 inches.

Variable x_3 was highly correlated with the dependent variable with a correlation coefficient of 0.9993 while x_7 was negatively correlated with a coefficient of -0.1538.

The analyses for Oregon and Washington separately concluded that a linear relationship existed between diameter inside bark and diameter outside bark. The equation for Oregon is:

$$\text{d.i.b.} = -0.2664 + 0.9447x_3$$

The equation for Washington is:

$$\text{d.i.b.} = -0.4891 + 0.9610x_3$$

where x_3 is d.o.b. Four independent variables were significant for entering the regression equation, but when evaluating the R^2 values and the standard deviation, the above linear equations were the most practical. The R^2 for the Oregon equation was 0.9979 and the standard deviation about the regression line was ± 0.3502 inches. The decrease in standard deviation between entering the first and fourth variables was less than the 0.05 of an inch cut off point.

For the Washington equation the R^2 value was 0.9986 and the standard deviation was ± 0.3643 inches.

C. Douglas-Fir

Six of the ten independent variables entered the regression equation when the data for the state of Oregon and Washington were analysed. Once again, the location variable was one of the significant entering variables. Two of the independent variables, d.o.b./d.b.h.o.b. and d.o.b.(d.b.h.o.b.), were dropped from the equation because they only decreased the standard deviation by 0.0279. The following equation resulted:

$$\text{d.i.b.} = 0.3096 - 0.0072x_2 + 0.8454x_3 + 0.0286x_8 + 0.2806x_{10}$$

where:

x_2 = height at point of measurement

x_3 = d.o.b.

x_8 = d.o.b.(height at point of measurement)/d.b.h.o.b.

x_{10} = location (zero for Oregon; one for Washington)

The R^2 value for this equation was 0.9954 and the standard deviation about the regression line was ± 0.7268 inches. The dummy variable for location was the only other independent variable that was dropped from the equation because of its small effect on the R^2 value and the standard deviation. The equation meeting the stipulation of this study is:

$$d.i.b. = 0.3899 - 0.0067x_2 + 0.8475x_3 + 0.0288x_8$$

The R^2 value was 0.9953 and the standard deviation was ± 0.7391 inches.

Evaluating the data separately for Oregon and Washington, three independent variables entered the Oregon regression equation. They were the same independent variables as in the preceding equation. The R^2 value was 0.9958 and had a standard deviation of ± 0.6273 inches. None of the independent variables were dropped from the equation because they did not have a small effect on the results. The equation follows:

$$d.i.b. = 0.6311 - 0.0085x_2 + 0.8259x_3 + 0.0349x_8$$

where:

x_2 = height at point of measurement

x_3 = d.o.b.

x_8 = d.o.b.(height at point of measurement)/d.b.h.o.b.

Five independent variables entered the Washington regression equation significantly. Two of these variables were dropped because the standard deviation decreased from 0.7548 to 0.7174 and the difference was less than the cut off point set for this study. The effect of the two independent variables on the R^2 value was also small. The R^2 value after the two variables were deleted was 0.9956. The equation for Douglas-fir in Washington is:

$$\text{d.i.b.} = 0.4961 - 0.0070x_2 + 0.8547x_3 + 0.0245x_8$$

where:

x_2 = height at point of measurement

x_3 = d.o.b.

x_8 = d.o.b.(height at point of measurement)/d.b.h.o.b.

The simple correlation coefficients with the dependent variable were -0.1940 for x_2, 0.9973 for x_3, and -0.6227 for x_8. The trend of x_3 being highly correlated, x_8 being negatively, but highly correlated, and x_2 being negatively, but not highly correlated held true for the Oregon data and the combined data.

D. Western Hemlock

When the data for western hemlock from Oregon and Washington were analysed, four independent variables entered the regression equation:

x_3 = d.o.b.

x_7 = d.o.b.(height at point of measurement)

x_4 = x_3^2

x_1 = d.b.h.o.b.

The dummy variable for location did not enter the equation this time; therefore, only one equation was developed for western hemlock.

The standard deviation of an equation with one independent variable was ± 0.3661 inches. The difference between the two values was less than the 0.05 inch cut off point; therefore, the equation was reduced to a single independent variable.

The R^2 value was also considered and the addition of the last three independent variables increased the R^2 value from 0.9986 to 0.9988. The difference was greater than the 0.0001 cut off level established, but no one independent variable increased the R^2 value by the 0.0001 tolerance level; therefore, the last three independent variables that entered the regression equation were dropped from the equation. The equation remaining is:

$$\text{d.i.b.} = -0.3609 + 0.9443x_3$$

where x_3 is diameter outside bark.

VI. SUMMARY AND CONCLUSIONS

The purpcse of this study was to develop regression equations to predict diameter inside bark at various points up the stem for four tree species, noble fir, Pacific silver fir, Douglas-fir, and western hemlock. A stepwise multiple regression computer program was used to develop the equations, and the basic independent variables used were:

1. Diameter outside bark at breast height.
2. Height at the point of measurement.
3. Diameter outside bark at the point of measurement.

A dummy variable was used to test the significance of difference between observations in Oregon and those in Washington.

All independent variables that significantly entered the regression equation at the 99 percent confidence level were evaluated using the standard deviation about the regression line and the percent of variation (100 R^2) accounted for by the regression equation. The study stipulated that when the standard deviation decreased by less than 0.05 of an inch and the R^2 value increased by less than 0.0001 by the addition of an independent variable that variable was dropped from the regression equation. The regression equations that met the stipulations of this study are listed in Table II.

Regression equations were developed using data from both Oregon and Washington. For three species, noble fir, Pacific silver fir, and Douglas-fir, the dummy variable for location entered the regression equation at the 99 percent confidence level. For these three species separate equations were developed for each state.

A less precise, but simpler equation that could be used to predict diameter inside bark would use the single independent variable, diameter outside bark, which always entered the regression equation first. The regression coefficients, R^2 value, and standard deviation for these equations are listed in Table III.

The best equation for a species depends on the requirements of the user. A timber cruiser might want a simple quick equation and be satisfied with the precision of the regression equation with one independent variable, whereas a researcher may want greater precision. The difference in precision of the equations that met the stipulations of this study and the equations with one independent variable can be determined from the list of their R^2 values and standard deviations in Table IV.

For three species, noble fir, Pacific silver fir, and Douglas-fir, the user has to decide between separate equations for each state or combined equation. Also for two species, noble fir and Douglas-fir, a decision has to be made between an equation with one independent variable or an equation with multiple independent variables.

The decision as to the equation to use depends on the precision desired and the cost and time required in using the different equations.

Table II. COEFFICIENTS FOR THE EQUATION $d.i.b. = b_o + b_1x_1 + \ldots + b_{10}x_{10}$[1]

Location and Species	b_o	b_2	b_3	b_4	b_6	b_7	b_8
OREGON							
Noble fir	-0.2059		0.9340			-0.0003	
Pacific silver fir	-0.2664		0.9447				
Douglas-fir	0.6311	-0.0085	0.8257				0.0349
Western hemlock	0.3609		0.9443				
WASHINGTON							
Noble fir	-0.1516		0.8495	0.0013	1.2503		
Pacific silver fir	-0.4891		0.9610				
Douglas-fir	0.4961	-0.0070	0.8547				0.0245
Western hemlock	0.3609		0.9443				
OREGON AND WASHINGTON							
Noble fir	-0.0911		0.8415	0.1381	1.2477		
Pacific silver fir	-0.4598		0.9588				
Douglas-fir	0.3899	-0.0067	0.8475				0.0288
Western hemlock	0.3609		0.9443				

[1] where: x_1 = d.b.h.o.b., x_2 = height of measurement, x_3 = d.o.b., $x_4 = x_3^2$, $x_5 = x_1x_3$, $x_6 = x_3/x_1$, $x_7 = x_2x_3$, $x_8 = x_2x_3/x_1$, $x_9 = x_2x_3^2$, x_{10} = Location; and the coefficients (b_1, b_5, b_9, b_{10}) for the respective variables equals zero.

Table III. COEFFICIENTS, R^2 VALUES, AND STANDARD DEVIATIONS FOR THE EQUATION, d.i.b. = $b_o + b_1$ d.o.b.

Location and Species	b_o	b_1	R^2	Standard Deviation
			PERCENT	INCHES
OREGON				
Noble fir	-0.6310	0.9350	99.85	0.4747
Pacific silver fir	-0.2664	0.9450	99.79	0.3502
Douglas-fir	0.7799	0.8370	99.36	0.7332
Western hemlock	-0.3609	0.9443	99.86	0.3949
WASHINGTON				
Noble fir	-0.6198	0.9441	99.82	0.5864
Pacific silver fir	-0.4892	0.9610	99.86	0.3643
Douglas-fir	0.4561	0.8662	99.46	0.8331
Western hemlock	-0.3609	0.9443	99.86	0.3949
OREGON AND WASHINGTON				
Noble fir	-0.6347	0.9418	99.82	0.5672
Pacific silver fir	-0.4598	0.9588	99.85	0.3660
Douglas-fir	0.5468	0.8566	99.39	0.8395
Western hemlock	-0.3609	0.9443	99.86	0.3949

Table IV. R^2 VALUES AND STANDARD DEVIATIONS FOR THE EQUATIONS
$d.i.b. = b_o + b_1\ d.o.b.$ AND
$d.i.b. = b_o + b_1x_1 + \ldots + b_{10}x_{10}$

Location and Species	$d.i.b. = b_o + b_1\ d.o.b.$ R^2	Standard Deviation	$d.i.b. = b_o + b_1x_1 + \ldots + b_{10}x_{10}$ R^2	Standard Deviation
	PERCENT	INCHES	PERCENT	INCHES
Oregon				
Noble fir	99.85	0.4747	99.91	0.3737
Pacific silver fir	99.79	0.3502	99.79	0.3502
Douglas-fir	99.36	0.7332	99.58	0.6273
Western hemlock	99.86	0.3949	99.86	0.3949
Washington				
Noble fir	99.82	0.5864	99.90	0.4456
Pacific silver fir	99.86	0.3643	99.86	0.3643
Douglas-fir	99.46	0.8331	99.56	0.7549
Western hemlock	99.86	0.3949	99.86	0.3949
Oregon and Washington				
Noble fir	99.82	0.5672	99.89	0.4311
Pacific silver fir	99.85	0.3660	99.85	0.3660
Douglas-fir	99.39	0.8395	99.53	0.7395
Western hemlock	99.86	0.3949	99.86	0.3949

BIBLIOGRAPHY

1. Bones, James T. Estimating d.b.h. from stump diameter in the Pacific Northwest. Portland, 1960. 1 p. (U.S. Forest Service. Pacific Northwest Forest and Range Experiment Station. Research Note 186).

2. ______________________ Estimating spruce and hemlock d.b.h. from stump diameter. Juneau, 1961. 2 p. (U.S. Forest Service. Northern Forest Experiment Station. Technical Note 51).

3. Brickell, James E. Test of an equation for predicting bark thickness of western Montana species. Ogden, 1970. 7 p. (U.S. Forest Service. Intermountain Forest and Range Experiment Station. Research Note INT - 107).

4. Church, Thomas W. Jr. Converting Virginia pine stump diameter to diameter breast high. Upper Darby, 1953. 2 p. (U.S. Forest Service. Northeastern Forest Experiment Station. Forest Research Note 23).

5. Cunningham, F. E., S. M. Filip, and M. J. Ferree. Relation of stump diameter to diameter breast high. Upper Darby, 1947. 3 p. (U.S. Forest Service. Northeastern Forest Experiment Station. Station Note 1).

6. Draper, N. R. and H. Smith. Applied Regression Analysis. New York, John Wileys & Sons, 1966. 407 p.

7. Finch, T. L. Effects of bark in measurement of periodic growth of individual trees. Missoula, 1948. 3 p. (U.S. Forest Service. Northern Rocky Mountain Forest and Range Experiment Station. Research Note 60).

8. Grosenbaugh, L. R. STX - Fortran 4 program -- for estimates of tree population from 3P sample - tree - measurements. Berkeley, 1967. 76 p. (U.S. Forest Service. Pacific Southwest Forest and Range Experiment Station. Research Note PSW - 13).

9. Hampf, Frederick E. Relationship of stump diameter to d.b.h. for American beech in the Northeast. Upper Darby, 1955. 3 p. (U.S. Forest Service. Northeastern Forest Experiment Station. Forest Research Note 43).

10. Hamf, Frederick E. Relationship of stump diameter to d.b.h. for northern red oak in the Northeast. Upper Darby, 1955. 3 p. (U.S. Forest Service. Northeastern Forest Experiment Station. Forest Research Note 55).

11. ________________ Relationship of stump diameter to d.b.h. for pitch pine in the Northeast. Upper Darby, 1957. 3 p. (U.S. Forest Service. Northeastern Forest Experiment Station. Forest Research Note 66).

12. ________________ Relationship of stump diameter to d.b.h. for sugar maple in the Northeast. Upper Darby, 1955. 3 p. (U.S. Forest Service. Northeastern Forest Experiment Station. Forest Research Note 42).

13. ________________ Relationship of stump diameter to d.b.h. for white oak in the Northeast. Upper Darby, 1957. 3 p. (U.S. Forest Service. Northeastern Forest Experiment Station. Forest Research Note 66).

14. ________________ Relationship of stump diameter to d.b.h. for white pine in the Northeast. Upper Darby, 1954. 4 p. (U.S. Forest Service. Northeastern Forest Experiment Station. Forest Research Note 38).

15. ________________ Relationship of stump diameter to d.b.h. for yellow birch in the Northeast. Upper Darby, 1955. 3 p. (U.S. Forest Service. Northeastern Forest Experiment Station. Forest Research Note 45).

16. ________________ Relationship of stump diameter to d.b.h. for yellow poplar in the Northeast. Upper Darby, 1955. 3 p. (U.S. Forest Service. Northeastern Forest Experiment Station. Forest Research Note 55).

17. Honor, T. G. and I. S. Alendag. Equations for estimating inside and outside bark diameters at breast height of eleven tree species from eastern and central Canada. Ottawa, 1972. 11 p. (Canadian Forest Service. Forest Management Institute. Information Report FMR - X - 48).

18. Khan, Fagir Mohammad. Developing an equation for making estimates of diameter inside bark at various heights up the stem in Douglas-fir. Master's thesis. Corvallis, Oregon State University, 1966. 58 numb. leaves.

19. Maezawa, K. Bark thickness at several heights in young Douglas-fir trees. Vancouver, 1956. 4 p. (University of British Columbia. Forestry Club. Research Note 131).

20. McCormack, J. F. An allowance for bark increments in computing tree diameter growth for southern species. Asheirlle, 1955. 6 p. (U.S. Forest Service. Southeastern Forest Experiment Station. Station Paper 60).

21. Meyer, H. A. Bark volume determination in trees. Journal of Forestry 44:1067-1070. 1946.

22. ________________ Methods of forest growth determination. State College, 1942. 93 p. (Pennsylvania State College. Agriculture Experiment Station. Bulletin 435).

23. Minor, Charles O. Loblolly pine bark thickness. Baton Rouge, 1953. 2 p. (Louisiana State University. Forest Note 1).

24. Myer, Clifford A. Estimating volumes and diameters at breast height from stump diameters, southwestern ponderosa pine. Fort Collins, 1963. 2 p. (U.S. Forest Service. Rocky Mountain Forest and Range Experiment Station. Research Note RM - 9).

25. Yates, Thomas L. (ed.) OSU statistical analysis program library. Corvallis, 1969. (Department of Statistics, Oregon State University.