FOREST RESEARCH LABORATORY

RESEARCH NOTE 77

Equations for Predicting Diameter and Squared Diameter Inside Bark at Breast Height for Six Major Conifers of Southwest Oregon

David R. Larsen
David W. Hann

Abstract

Equations for predicting breast-height diameter and squared diameter inside bark were developed as a function of diameter and squared diameter outside bark for six major tree species of the southwest Oregon mixed-conifer region. Predictions for diameter inside bark are needed to properly apply radial growth measurements for reconstructing temporary plots in the past.

Equations of squared diameter inside bark are used to estimate basal area growth. The equations for white and grand fir, sugar pine, and incense-cedar were developed by weighted linear regression; weighted nonlinear regression was found appropriate for Douglas-fir and ponderosa pine.

Introduction

Estimates of the relationship between breast-height diameter inside bark (DIB) and breast-height diameter outside bark (DOB) are important for estimating wood volume, bark thickness, bark growth, and basal area growth; and for reconstructing temporary plots in the past. This relationship describes the amount of volume and growth attributed to bark and wood and can be used indirectly to estimate bark thickness and bark growth (Johnson 1955, 1956; Spada 1960; Dolph 1981). In addition, estimates of the relationship between squared diameter inside to squared diameter outside bark are necessary to use measurements of radial increments for determining basal area change (Monserud 1979; Dolph 1981; Ritchie and Hann 1984).

This paper presents equations to predict DIB and DIB^2 as functions of DOB and DOB^2, respectively, for Douglas-fir (Pseudotsuga menziesii [Mirb.] Franco), white fir (Abies concolor [Gord. and Glend.] Lindl.), grand fir (Abies grandis [Dougl.] Lindl.), ponderosa pine (Pinus ponderosa Laws.), sugar pine (Pinus lambertiana Dougl.), and incense-cedar (Calocedrus decurrens Torr.) in the mixed-conifer zone in southwest Oregon.

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Oregon State University, College of Forestry
Corvallis, OR 97331-5704 503-753-9166

Source of Data

The data for this analysis are a portion of the felled- and sectioned-tree data taken by the southwest Oregon Forestry Intensified Research (FIR) Growth and Yield Project during the summers of 1981, 1982, and 1983. The data consist of the DIB and DOB along the long and short axes of a section removed from the stem at breast height on 1,952 felled trees. The diameters were measured to the nearest 0.1 inch and ranged from 0.8 to 44.0 inches. For each section, the long and short axes measurements were averaged by the geometric mean for both DIB and DOB as it yields the correct cross-sectional area (Brickell 1976). A summary of the data is presented in Table 1 and a map showing the boundaries of the study area is shown in Figure 1.

TABLE 1.

DESCRIPTIVE STATISTICS FOR SAMPLE OF FELLED TREES FROM SOUTHWEST OREGON.

Species	Number of trees in sample	Diameter range (inches)	Mean	Standard deviation
Douglas-fir	1,237	0.9 – 43.2	13.9	8.186
White fir	126	3.1 – 37.7	13.4	7.687
Grand fir	127	1.3 – 42.9	12.7	6.921
Ponderosa pine	172	1.3 – 35.6	15.1	7.892
Sugar pine	105	1.9 – 42.2	17.9	8.531
Incense-cedar	180	.8 – 36.4	10.0	6.710

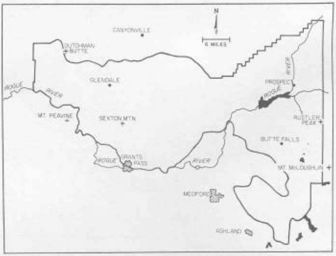

FIGURE 1.

STUDY AREA MAP.

Analysis Methods

Many of the equations presented in the literature include an intercept term (Johnson 1955, 1956; Spada 1960; Dolph 1981). An equation with the intercept forced through the origin was chosen, because without an intercept term, predicted DIB cannot exceed DOB for small trees (Ritchie and Hann 1984). The linear model form chosen was

$$DIB = \beta_1 (DOB) + \epsilon_1 \qquad (1)$$

where:

- DIB = diameter inside bark
- β_1 = population parameter value
- DOB = diameter outside bark
- ϵ_1 = a random error component with an expected value of zero and a variance of σ^2.

Some researchers have fitted their data by weighted linear regression because the residuals have shown a heterogeneous variance (Powers 1969; Monserud 1979; Dolph 1981; Ritchie and Hann 1984). Two different weights have been selected for equation (1): Monserud (1979) suggested a weight of 1.0/DOB and Powers (1969) suggested a weight of $1.0/DOB^2$.

Ritchie and Hann (1984) compared the two weights and found that, for Douglas-fir in the Oregon coast range, $1.0/DOB^2$ was better. A plot of their data, however, revealed a trend in the residuals from the linear model and therefore they decided to test both a log linear model and a weighted nonlinear model. Of these two models, the nonlinear model was found to be the best and the exponent differed significantly from one. Their final model was:

$$DIB = \beta_1 (DOB)^{\beta_2} + \epsilon_1 \qquad (2)$$

Because equation (1) is the reduced form of equation (2), initially only equation (2) was fitted (with a weight of 1.0/DOB²) and the significance of the estimated b_2 coefficient from 1.0 determined if the relationship was linear or nonlinear for the southwest Oregon data sets. Tests were also made to see if data sets could be combined across species and to evaluate the effect of crown ratio upon the regression coefficients.

The squared relationship, as given in equation (3), was also modeled for use in projecting basal area growth (Ritchie and Hann 1984):

$$DIB^2 = \beta_1 (DOB^2)^{\beta_2} + \epsilon_2 \qquad (3)$$

Equation (3) was fitted by a weight of 1.0/DOB⁴.

Results and Discussion

Parameters of equations (2) and (3) were estimated for each species-specific data set with weighted nonlinear least squares regression. For Douglas-fir and ponderosa pine, b_2 differed significantly from 1.0 at the 99 percent confidence level. This finding indicates that the nonlinear equation form is appropriate for these two species.

The coefficients for white fir and grand fir in both equations did not differ significantly from each other at the 95 percent confidence level. Therefore, the white fir and grand fir data were pooled, and a set of "true fir" coefficients was estimated. Three data sets, grand/white fir, sugar pine, and incense-cedar, were then refitted by weighted linear least squares regression.

Additional tests indicated that the DIB and DIB² relationships were not significantly related to crown ratio.

The parameter estimates for equation (2) for each species, adjusted coefficients of determination ($\bar{R}^2$), and weighted mean square errors are presented in Table 2. Table 3 contains the same summary statistics for equation (3).

The value of b_2 for the ponderosa pine model is greater than 1.0 and will cause the prediction of DIB to exceed DOB above some value of DOB. This "boundary" value was computed and found to be well outside of the feasible range of DOB for ponderosa pine.

TABLE 2.

SUMMARY OF COEFFICIENTS AND STATISTICS FOR EQUATIONS TO PREDICT DIAMETERS INSIDE BARK FOR SIX SPECIES OF CONIFER.

Species	b_1	b_2	Mean square error	Adjusted coefficient of determination ($\bar{R}^2$)
Douglas-fir	0.903563	0.989388	0.000633	0.9955
Grand/white fir	.90497	1.0	.000664	.9992
Ponderosa pine	.809427	1.016866	.001056	.9946
Sugar pine	.85904	1.0	.000521	.9993
Incense-cedar	.83729	1.0	.001217	.9983

TABLE 3.

SUMMARY OF COEFFICIENTS AND STATISTICS FOR EQUATIONS TO PREDICT SQUARED DIAMETERS INSIDE BARK FOR SIX SPECIES OF CONIFER.

Species	b_1	b_2	Mean square error	Adjusted coefficient of determination ($\bar{R}^2$)
Douglas-fir	0.817063	0.989451	0.002033	0.9933
Grand/white fir	.819639	1.0	.002119	.9969
Ponderosa pine	.655524	1.01719	.002933	.9912
Sugar pine	.738474	1.0	.001497	.9973
Incense-cedar	.837291	1.0	.001217	.9983

Conclusion

The equations developed in this study predict the diameter relationships very well, differ significantly when compared between species, and provide reasonable predictions across the range of diameters found in our data. They confirm or improve upon previously published equations and provide new information about the forests of southwest Oregon.

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The Authors

Larsen is Research Assistant and Hann is Associate Professor, Department of Forest Management, Oregon State University.

Forest Research Laboratory
College of Forestry
Corvallis, OR 97331-5704

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