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DIAMETER GROWTH EQUATIONS FOR DOUGLAS-FIR AND GRAND FIR IN THE WESTERN WILLAMETTE VALLEY OF OREGON

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Abdel Azim Zumrawi
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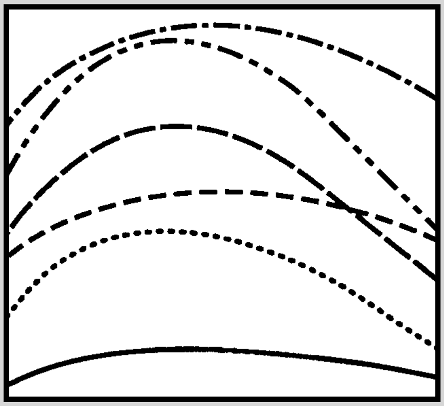

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Introduction

Equations for predicting diameter growth are an essential component of single-tree growth and yield models (Munro 1974). Diameter growth predictions are used to characterize individual-tree development and to project the growth of stand basal area and volume. Both diameter growth and basal area growth have been used as the dependent variable in modeling the development of a tree's diameter (Holdaway 1984, Ritchie and Hann 1985, Wykoff 1986, Wensel et al. 1987, Dolph 1988). The choice of which dependent variable to use has usually been suggested by the data, including the behavior of the residuals and the goodness-of-fit of the resulting equations.

Ritchie and Hann (1985) developed nonlinear basal-area growth equations for Douglas-fir (Pseudotsuga menziesii) and grand fir (Abies grandis). It was intended that the equations would be used to predict individual-tree diameter growth in the western Willamette Valley version of ORGANON (Hann et al. 1992). However, Hann and Larsen (1991) found that using a basal-area growth equation to predict diameter growth could result in erratic and unreasonable predictions of diameter growth for trees with small diameters. Therefore, the objective of the present study was to develop diameter growth equations for Douglas-fir and grand fir in the western Willamette Valley of Oregon by using the equation form of Hann and Larsen (1991).

Data Base

The data used in this study were previously used by Ritchie and Hann (1985). They were collected from 136 stands on Oregon State University's research forests located to the northwest of Corvallis (Figure 1). The stands were selected on the basis of having at least 80 percent of their basal area in Douglas-fir and having had no silvicultural treatment in the previous 5 years. For most stands, sampling points were established on a systematic grid in the stand at the rate of one point every 2 acres. However, sampling intensity was higher in young stands to ensure adequate coverage of the younger age classes.

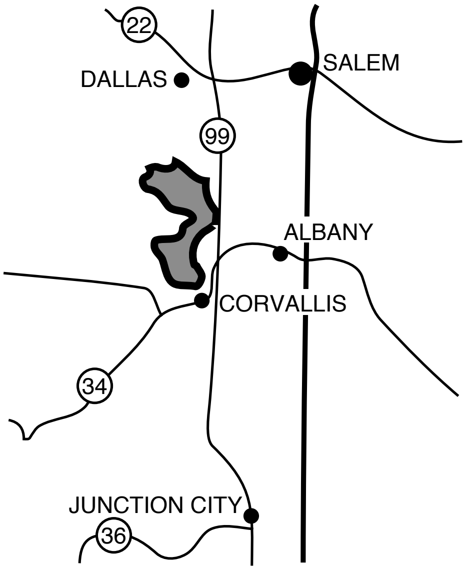


Figure 1. Location of the study area near Corvallis, Oregon.

A variable-radius subplot and two nested, fixed-area subplots were used at each sampling point to select trees for measurement. The smaller fixed-area subplot (radius, 7.78 ft) was used to sample trees with diameters at breast height (DBH) under 4.1 inches, and the larger fixed-area subplot was used to sample trees 4.1 to 8.0 inches DBH. The variable-radius subplot with a basal area factor (BAF) of 20 was used to sample trees with DBH greater than 8.0 inches.

Measurements on each sampled tree included DBH, total tree height (HT), and height to live crown base (HCB). Previous 5-year radial growth of trees with DBH greater than 3.0 inches was measured on increment cores to the nearest 1/40 inch. Inside-bark diameter growth was converted to outside-bark diameter growth by using the bark thickness equations of Ritchie and Hann (1984) and Larsen and Hann (1985). The bias-correction equations of Zumrawi (1990) were then used to adjust outside-bark diameter growth in order to eliminate bias resulting from measurements on increment cores. Because temporary sample plots were used, procedures described in Ritchie and Hann (1985) were followed to backdate the stands and obtain values at the beginning of the 5-year growth period. A summary of the data by species is given in Table 1.

Table 1. Summary by species of the diameter growth data.

Species and variable	Minimum	Mean	Maximum	Standard deviation
Douglas-fir[1]				
Diameter (in.)	1.2	20.9	87.1	13.4
Diameter growth (in.)	0.00	1.36	5.74	0.83
Crown ratio	0.0352	0.4379	0.9717	0.1473
Site index (ft)	90.0	111.2	142.0	9.3
Stand BA (ft^2)	11.7	159.5	274.2	50.4
Grand fir[2]				
Diameter (in.)	2.6	14.7	48.1	9.4
Diameter growth (in.)	0.00	1.25	4.70	0.88
Crown ratio	0.0561	0.4850	0.9290	0.1730
Site index (ft)	93.0	111.8	142.0	9.2
Stand BA (ft^2)	26.0	153.9	255.6	57.1

[1] 9,526 observations.
[2] 595 observations.

Data Analysis

The model form used by Hann and Larsen (1991) was

$$DGRO=EXP\{B_0+B_1 \cdot \ln(DBH+1)+B_2 \cdot DBH^2+B_3 \cdot \ln[(CR+0.2)/1.2]+ B_4 \cdot \ln(SI-4.5)+B_5 \cdot BAL^2/\ln(DBH+5)+B_6 \cdot BA^{0.5}\} \quad (1)$$

where

DGRO = 5-year diameter growth (inches),

DBH = Diameter at breast height at the start of the growth period (inches),

CR = Crown ratio at the start of the growth period,

SI = King's (1966) site index,

BAL = Stand basal area in trees with DBH larger than that of the subject tree at the start of the growth period (ft^2),

BA = Stand basal area at the start of the growth period, and

B_0, B_1,...B6 = Parameters to be estimated.

Weighted nonlinear regression procedures were used to estimate the parameters of this equation. The nonlinear form of the equation was chosen rather than a log-linearized form because the residuals from the log-transformed model were not normally distributed. Thus, standard procedures for log bias correction (Flewelling and Pienaar 1981) could not be used to estimate diameter growth from the log-transformed equation, i.e., the model predictions would have been biased. Similar findings were reported by Ritchie and Hann (1985) and Hann and Larsen (1991). Different weighting schemes were tried to homogenize the variance of the residuals. Weighting by the predicted diameter growth resulted in a homogeneous variance and the best index of fit (Furnival 1961). The iterative fitting procedure described by Hann and Larsen (1991) was then used to make the parameter estimates.

As a final check of the equations, both the weighted and the unweighted residuals were examined for systematic trends across predicted diameter growth and the independent variables according to the procedures described in Hann and Larsen (1991).

Results and Discussion

The final parameter estimates and their standard errors are given for both species in Table 2. Plots of residuals over predicted diameter growth and the predictor variables in the model indicated no obvious systematic trends.

The maximum predicted 5-year diameter growth rates at various site indices and DBH values are given for both species in Figure 2. Predicted diameter growth rates reach their peak for both species at DBH values around 17 inches. Grand fir has a slightly higher peak growth rate; however, Douglas-fir maintains the highest growth rate at larger DBH values.

The effect of BA on diameter growth is given as a proportion of the maximum predicted growth rate for both species in Figure 3. Diam-

Table 2. Parameter estimates for Equation 1 and associated standard errors (in parentheses) and adjusted coefficients of determination ($\overline{R}^2$) for the unweighted residuals.

Parameter	Douglas-fir[1]	Grand fir[2]
b_0	-4.69624 (0.29913)	-2.34619 (1.36319)
b_1	0.339513 (0.01751)	0.594640 (0.0805128)
b_2	-0.00042826 (0.0000124)	-0.000976092 (0.0001465)
b_3	1.19952 (0.02374)	1.12712 (0.105817)
b_4	1.15612 (0.06069)	0.555333 (0.276866)
b_5	-0.0000446327 (0.000002571)	-0.0000290672 (0.000008624)
b_6	-0.0237003 (0.00396039)	-0.0470848 (0.0173778)
$\overline{R}^2$	0.4864	0.4605

[1] 9,526 observations.
[2] 595 observations.

Figure 2. *How DBH affects maximum predicted 5-year diameter growth rates for Douglas-fir and grand fir. Curves represent growth at various site indices for an open-grown tree: CR = 1.0; BA and BAL = 0.*

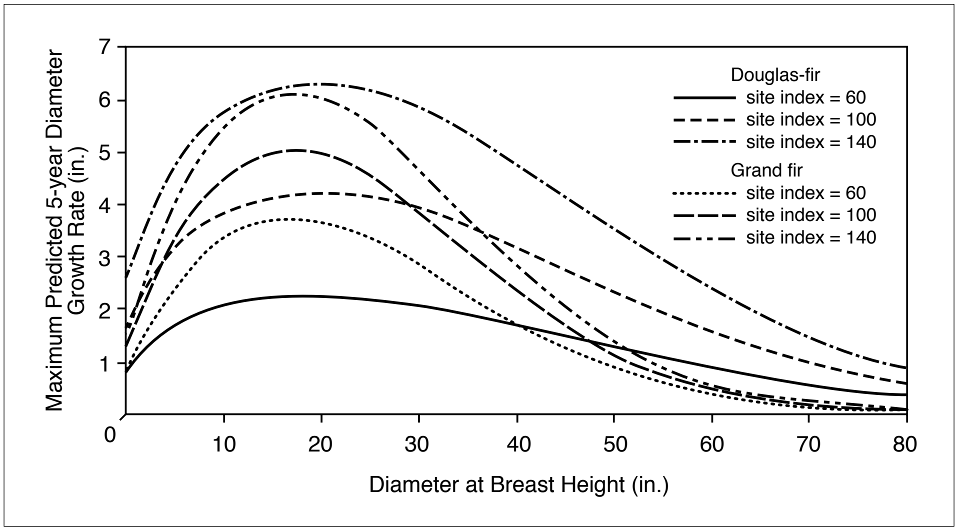
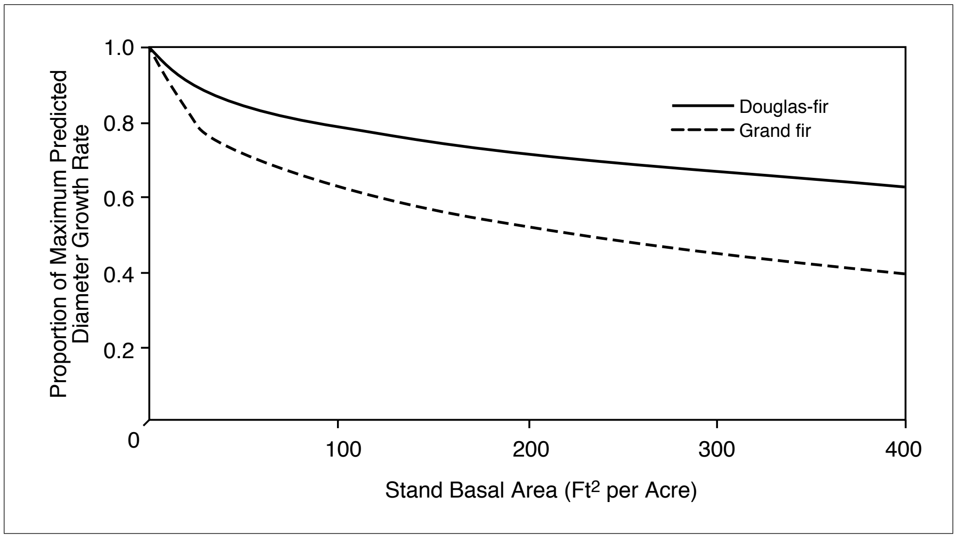


Figure 3. *How stand basal area affects the proportion of the maximum predicted 5-year diameter growth rate attained by the tree. Curves represent Douglas-fir and grand fir.*



eter growth of grand fir is more negatively influenced by stand density (in terms of BA) than is that of Douglas-fir.

On the other hand, competition from above, as expressed by the BAL term in Equation 1, has a more negative effect on Douglas-fir than on grand fir. The effect of BAL on diameter growth is given, as a proportion of the maximum predicted growth rate, for Douglas-fir in Figure 4A and for grand fir in Figure 4B.

For both species, diameter growth is negatively affected by crown recession (Figure 5). Douglas-fir is slightly more sensitive to change in crown ratio than is grand fir.

The behavior of these equations is very similar to that reported by Hann and Larsen (1991) for equations designed for southwest Oregon and is consistent with our current biological and silvicultural knowledge of the species. However, it should be remembered that the data used to develop these equations came from temporary plots measured over a short period.

Therefore, long-term predictions from these equations should be viewed as being reasonable hypotheses based on current, limited knowledge.

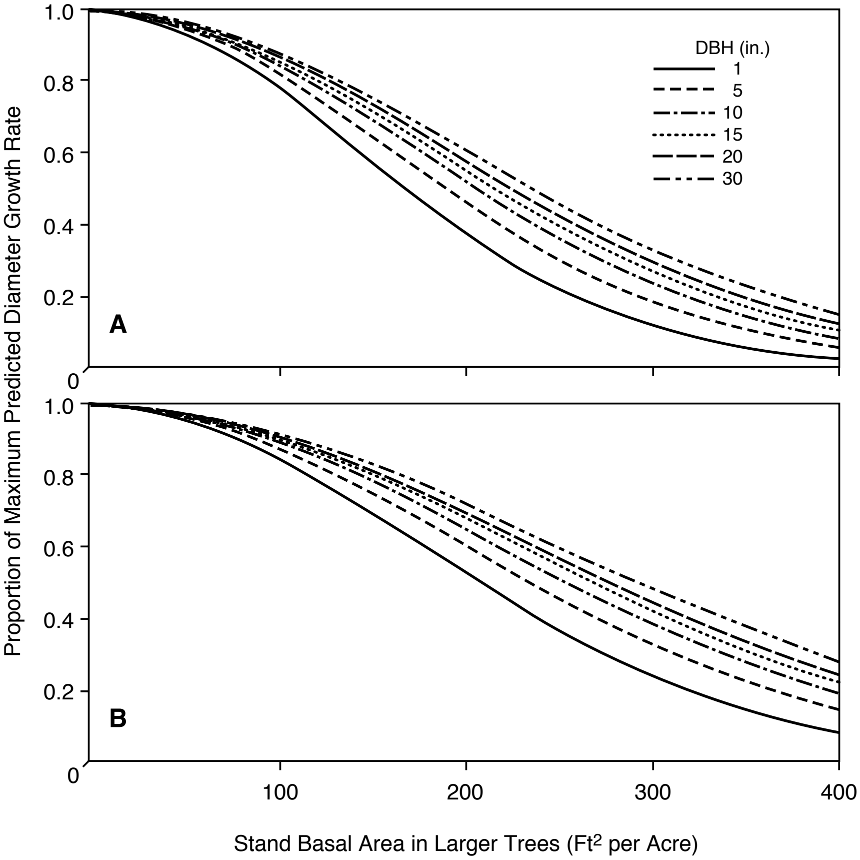


Figure 4. How stand basal area in trees with DBH values larger than that of the subject tree affects the proportion of the maximum predicted 5-year diameter growth rate attained by that tree. Curves represent various DBH values for (A) Douglas-fir and (B) grand fir.

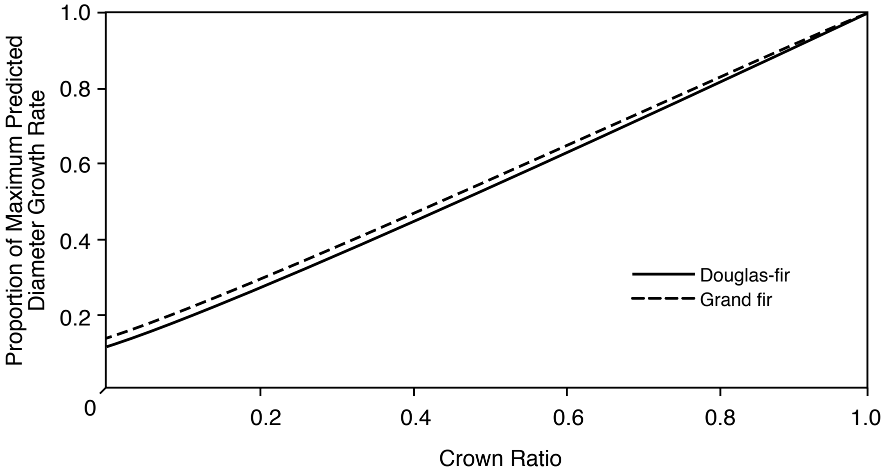


Figure 5. How the tree's crown ratio affects the proportion of the maximum predicted 5-year diameter growth rate attained by that tree. Curves represent Douglas-fir and grand fir.

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Equations are presented that predict individual-tree 5-year diameter growth, outside bark, for Douglas-fir and grand fir in the western Willamette Valley of Oregon. The data used to develop the equations came from 10,121 trees sampled from 136 stands. These equations express diameter growth as a function of diameter at breast height, crown ratio, site index, total stand basal area, and stand basal area in trees with diameters larger than the subject tree's diameter. The parameters of the equations were estimated by using weighted, nonlinear regression.

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