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EQUATIONS FOR PREDICTING THE HEIGHT TO CROWN BASE OF SIX TREE SPECIES IN THE CENTRAL WESTERN WILLAMETTE VALLEY OF OREGON

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Key to abbreviations

BA = basal area
BR = bole ratio
CCF = crown competition factor
CCFL = crown competition from trees larger than subject tree
CL = crown length
CR = crown ratio
D = diameter at breast height
H = total tree height
HCB = height to crown base

Abstract

This paper presents equations developed to predict the height to live crown base of six species in the central western Willamette Valley of Oregon. Weighted nonlinear regression was used to fit a separate logistic equation for each species. The predictor variables are total tree height, crown competition factor in trees with larger diameter at breast height than the subject tree, stand basal area, and diameter-height ratio. The equations will be used in two ways: 1) to estimate crown ratio on trees for which that measurement is missing, and 2) to simulate crown change in a single-tree/distance-independent growth and yield model. Application of these equations will be most reliable in stands that are free from thinning effect.

Introduction

The live crown ratio of a tree, defined as its crown length divided by total tree height, largely determines its growth and development and is therefore extensively used as a predictor variable in growth models (Stage 1973, Wykoff *et al.* 1982, Wensel and Koehler 1985). It is also used to provide measures of the effect of competition on tree vigor and development (e.g., Wensel and Koehler 1985). A procedure to predict change in the crown ratio is thus essential for simulating growth and yield. Crown development can be difficult to predict directly (Maguire 1986, Ritchie and Hann 1987), but equations for height to crown base can be used for estimating change in the crown ratio indirectly (Stage 1973, Van Deusen and Biging 1985, Ritchie and Hann 1987). These same equations can be used to predict the crown ratio in situations in which crown ratio has not been measured in the field.

The relationship of crown ratio (CR) to height to crown base (HCB), crown length (CL), total tree height (H), and bole ratio (BR) can be expressed simply as

$$CR = \frac{CL}{H} = 1.0 - BR,$$

$$BR = \frac{HCB}{H}, \text{ and}$$

$$HCB = H - CL.$$

Therefore, if tree height is known, it is sufficient to estimate only one other value—CR, BR, CL, or HCB—in order to calculate the rest.

The objective of this study was to develop equations for predicting HCB of six species found in the western Willamette Valley of Oregon:

Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Grand fir	*Abies grandis* (Dougl.) Lindl.
Bigleaf maple	*Acer macrophyllum* Pursh
Madrone	*Arbutus menziesii* Pursh
Oregon white oak	*Quercus garryana* Dougl. ex Hook.
Red alder	*Alnus rubra* Bong.

The equations will be used both to predict crown change and to estimate missing CR in a single-tree/distance-independent growth and yield model (Munro 1974) being developed for Oregon State University forest properties.

The Data Base

Data for this study were previously used by Ritchie and Hann (1985, 1986) to develop diameter and height-growth models. The data base consists of measurements from 136 stands on the McDonald and Dunn Research Forests of Oregon State University. Stands were selected that had received no silvicultural treatment in the 5 years before measurements were taken. Site index (King 1966) was estimated for each, and temporary plots were established on a systematic grid. Each plot contained a 20 basal-area factor (BAF) variable radius point and two nested fixed-area subplots that were used to ensure better coverage of smaller diameter classes. Figure 1 shows the location of the study area. A detailed description of both study area and data collection are given by Ritchie and Hann (1985).

For this analysis, data were screened to remove values for all stands receiving thinning treatment in the 20 years before measurement. Trees shorter than 4.5 feet were also excluded.

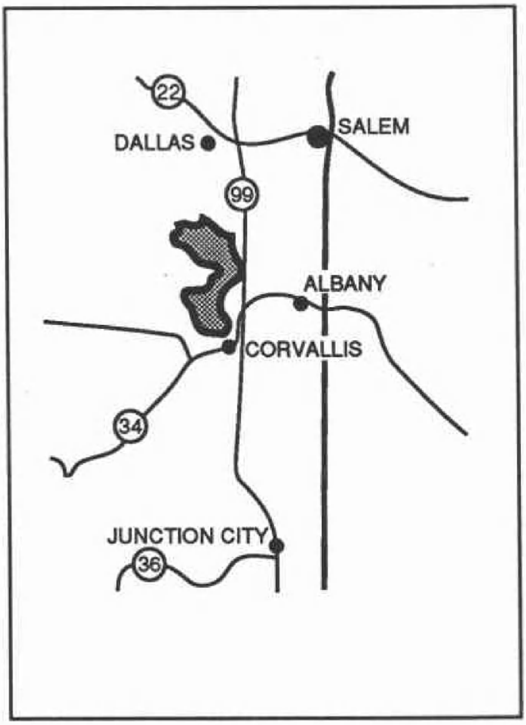

Figure 1. Location of the study area near Corvallis, Oregon.

Measurements relevant to this study were diameter at breast height (D), H, and HCB. Crown base was determined in the field by visually reconstructing the crown, so that a symmetrical, even base was mentally produced by filling gaps with branches from below. Further calculations made with the original data provided estimates of density (basal area per acre) and of structure (crown competition factor, Krajicek *et al.* 1961) in trees with diameters larger than that of the subject tree. Table 1 presents a summary, by species, of data used in the analysis.

Table 1. Summary of data used for developing equations for height to crown base of six western Oregon tree species.

Species	No. of obser-vations	Diameter (in.)			Height (ft)			Crown ratio		
		Mini-mum	Maxi-mum	Mean	Mini-mum	Maxi-mum	Mean	Mini-mum	Maxi-mum	Mean
Douglas-fir	3,770	0.1	83.7	17.4	4.6	227.5	85.4	0.01	1.0	0.47
Grand fir	570	0.1	46.0	11.5	4.6	182.7	63.9	0.05	0.93	0.46
Bigleaf maple	927	0.1	46.8	9.6	4.7	128.3	50.9	0.02	1.00	0.47
Red alder	133	0.3	29.5	10.3	6.5	105.8	58.4	0.21	0.79	0.50
Madrone	118	0.3	23.1	7.9	5.7	87.6	37.7	0.14	0.82	0.44
Oregon white oak	199	0.1	36.4	11.1	5.0	109.9	53.1	0.01	0.85	0.36

Analysis and Results

Different forms of equations have been presented for predicting CR and HCB. Wykoff *et al.* (1982) used a logarithmic equation of the form

$$\ln(CR) = \sum_{i=0}^{k} b_i x_i, \qquad [1]$$

where

$\ln$ = natural log,
K = number of parameters to be estimated,
b_i = parameter estimates, and
x_i = independent variables.

The independent variables include various transformations of basal area (BA), crown competition factor (CCF), D, and H. Where CR is constrained to less than 1, equation [1] can produce predictions that exceed 1 at the extremes of the data (Ritchie and Hann 1987).

A similar nonlinear function was presented by Van Deusen and Biging (1985) for predicting HCB:

$$HCB = H\left[1.0 - EXP\left(\sum_{i=1}^{K} b_i x_i\right)^2\right]. \qquad [2]$$

The independent variables in equation [2] are the natural log of the basal area and the ratio of D to H (D/H). Like equation [1]—but for the bole rather than CR—equation [2] can predict values less than 0 or greater than 1 at the extremes of the data (Ritchie and Hann 1987).

Walters and Hann (1986) used the following logistic function for predicting HCB:

$$HCB = \frac{H}{1.0 + EXP\left(\sum_{i=1}^{K} b_i x_i\right)}. \qquad [3]$$

Various transformations of D and H are the independent variables. The logistic function has the advantage of constraining predicted values of CR between 0 and 1. Ritchie and Hann (1987) found that it also provides a better fit to the data for different southwestern Oregon species; therefore, it was chosen for this study.

The logistic function was linearized so that the independent variables could be screened with ordinary least squares techniques. Those selected by means of the screening were H, crown competition factor in larger trees (CCFL), BA, and D/H. The basic logistic function represented by equation [3] was then transformed by dividing both sides of the equation by H, producing

$$BR = \frac{1.0}{1.0 + EXP\left(\sum_{i=1}^{K} b_i x_i\right)}.$$

This transformation, equivalent to applying weighted regression, was used to homogenize the variance in HCB, which increases with increasing H. The transformed equation was then fitted separately to data sets for each of the six species by means of nonlinear regression techniques and the final equation form

$$BR = \frac{1.0}{1.0 + EXP\,(b_0 + b_1 H + b_2 CCFL + b_3 \ln(BA) + b_4 D/H)}. \quad [4]$$

Tree HCB is estimated by multiplying the BR predicted with equation [4] by H. Table 2 gives final parameter estimates, the weighted mean square error (MSE), and the weighted, adjusted R^2 for each species. Figure 2 shows residuals for Douglas-fir plotted across predicted BR, H, CCFL, the natural log of BA, and D/H. The residual plots show no trend over predicted BR or any other predictor variable. Plots of residuals across predicted BR for grand fir, bigleaf maple, madrone, red alder, and Oregon white oak (Figure 3) also show no obvious trend.

Table 2. Parameter estimates, weighted mean square error, and adjusted R^2 for equations predicting height to crown base of six tree species.

Species	b_0	b_1	b_2	b_3	b_4	MSE	R^2
Douglas-fir	1.94093	-0.0065029	-0.0048737	-0.261573	1.08785	0.01888	0.3363
Grand fir	1.04746	-0.0066643	-0.0067129	*	*	0.02538	0.2514
Bigleaf maple	2.12011	*	*	-0.542355	1.51126	0.02026	0.2116
Red alder	0.34302	-0.0077925	-0.0030230	*	2.13626	0.01896	0.1613
Madrone	0.15855	-0.0104484	-0.0046372	*	1.84792	0.01871	0.2213
Oregon white oak	0.84634	-0.0139552	-0.0047966	*	*	0.02479	0.1780

* The variable is not included in the model.

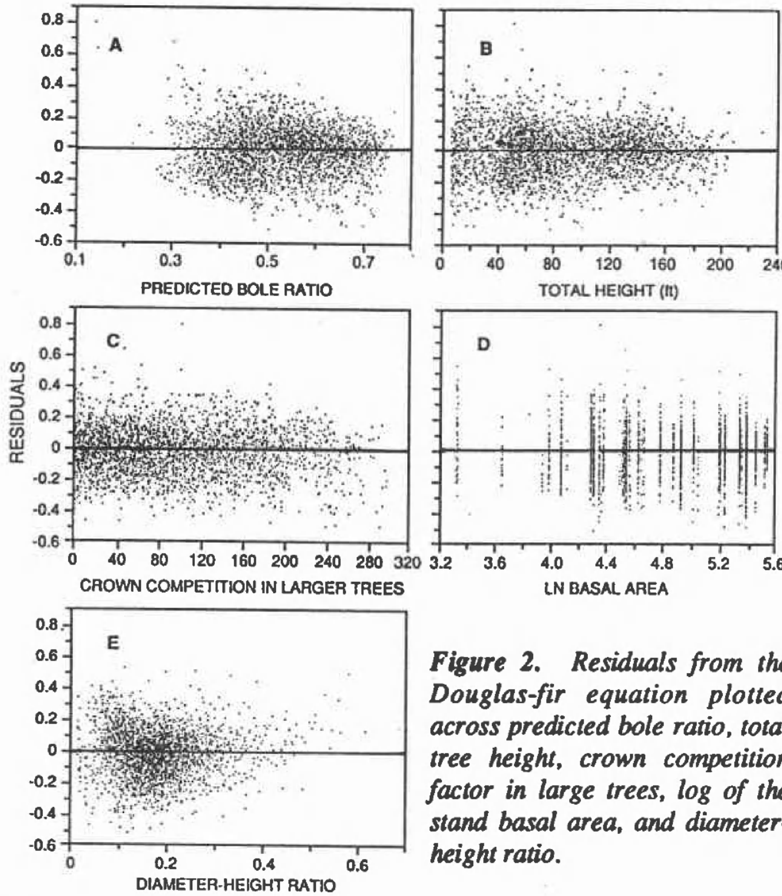

Figure 2. Residuals from the Douglas-fir equation plotted across predicted bole ratio, total tree height, crown competition factor in large trees, log of the stand basal area, and diameter-height ratio.

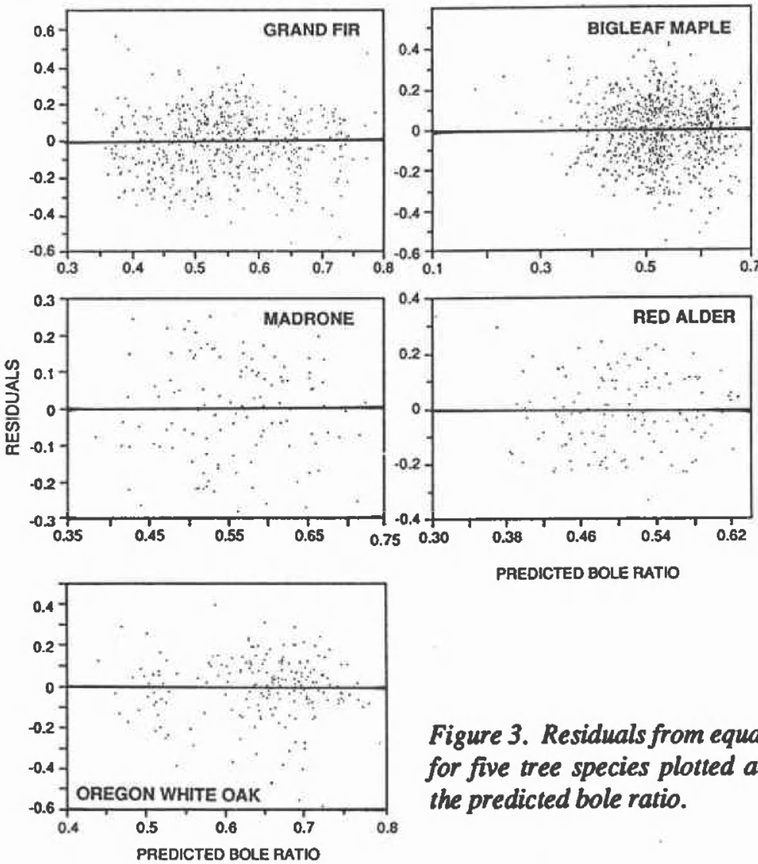

Figure 3. Residuals from equations for five tree species plotted across the predicted bole ratio.

Discussion

For estimates derived with equation [4], a negative sign indicates that the bole ratio increases and a positive sign that it decreases with an increase in the associated independent variable. Taper, shown by the diameter-height ratio, increases with increasing crown ratio (Walters and Hann 1986). Therefore, it would be expected that the bole ratio would decrease as the diameter-height ratio increases. A tree crown recedes faster with increasing stand density, as shown by stand basal area, and with poor position in the stand, as shown by crown-competition in larger trees. The bole ratio would therefore be expected to increase as those variables increase. The negative signs of the parameters for height, basal area, and crown competition in larger trees, and the positive sign on the parameter for diameter-height ratio, shown in Table 2, indicate that equation [4] does predict the expected behavior.

With the exception of site index, which was an insignificant predictor for all species in this study, the parameter estimates in Table 2 are similar in nature and magnitude to the estimates previously obtained by Ritchie and Hann (1987) for the same species in southwest Oregon. The adjusted R^2 values are lower than those obtained in southwest Oregon. This could be a result of differences in measurement errors in the two studies, or possibly of differences in stand structure. Many of the southwest Oregon stands showed characteristics of uneven-aged stands, while most of the stands in this study were even-aged. Because bole ratios are more uniform in even-aged stands, there may be less variation to be explained by the equation for bole-ratio (i.e., for weighted height to crown base).

Estimation of missing crown ratios or simulation of crown recession with equation [4] will be most reliable in stands free from thinning effects, *i.e.*, stands that have not been thinned in the last 20 years. Ritchie and Hann (1987) suggest that such static equations may also be used in thinned stands if the predictions are constrained such that height to crown base does not decrease.

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