ORGANON Calibration for Western Hemlock Project

November 29, 2002

Crown Width, and Height to Crown Base Equations

Greg Johnson
Research Director

Introduction

The ORGANON model (Hann, et al., 1992) uses several equations describing the form and depth of the crown for each tree. Currently, the SMC variant of ORGANON uses the following equations (Marshall, 1998):

1. Maximum crown width (MCW) (a open-grown tree's crown width):
   $$MCW = \beta_0 + \beta_1 DBH + \beta_2 DBH^2$$

2. Largest crown width (LCW) (a stand-grown tree's crown width):
   $$LCW = MCW \times CR^{\theta_0 + \theta_1 CL + \theta_2 \frac{DBH}{HEIGHT}}$$

3. Distance above crown base to LCW (DACB):
   $$DACB = \lambda_0 CL$$

4. Height to crown base (HCB) (distance from the ground to the base of the live crown as defined by the balanced crown method):
   $$HCB = \frac{HEIGHT}{\left[1 + e^{\rho_0 + \rho_1 HEIGHT + \rho_2 CCFL + \rho_3 \ln(BA) + \rho_4 \frac{DBH}{HEIGHT} + \rho_5 SITE}\right]}$$

5. Crown width above largest crown width height (CWA):
   $$CWA = LCW \times RP^{\alpha_0 + \alpha_1 RP^{0.5} + \alpha_2 \frac{HEIGHT}{DBH}}$$

where: DBH = diameter at breast height, CR = crown ratio, HEIGHT = total tree height, CL = crown length, CCFL = crown competition factor in larger trees, BA = basal area per acre, SITE = 50-year site index, and RP = relative position in the crown.

The purpose of this paper is to document the estimation of the coefficients for equations 2, and 4 for western hemlock. Equations 1, 3 and 5's coefficients could not be estimated at this time due to a lack of data.

Willamette Dataset

The Willamette dataset was collected from temporary plots using a protocol developed by Hann (1992). Complete, compatible tree measurements were taken on all sample observations. Summaries of the dataset by thinning code appear in the tables below:

MCW/LCW Data

n = 2293	Mean	Minimum	Maximum
CW (crown width)	20.0	1.6	48.9
DBH	13.4	0.1	47.8
HEIGHT	82.6	4.9	152.9
BA	264.9	66.6	483.6
SITE (western hemlock)	112.9	97.9	137.3
CR	0.54	0.01	1.00
CL	44.3	1.0	132.5

HCB Data

n = 2340	Mean	Minimum	Maximum
HCB	37.8	0.0	92.5
DBH	13.2	0.1	47.8
HEIGHT	81.6	4.6	152.9
CCFL	132.5	0.0	520.0
BA	258.6	15.3	460.4
SITE (western hemlock)	113.0	97.9	137.3

Figures 1 and 2 show the distribution of crown widths and height to crown base in the dataset respectively.

Figure 1. Distribution of largest crown widths.

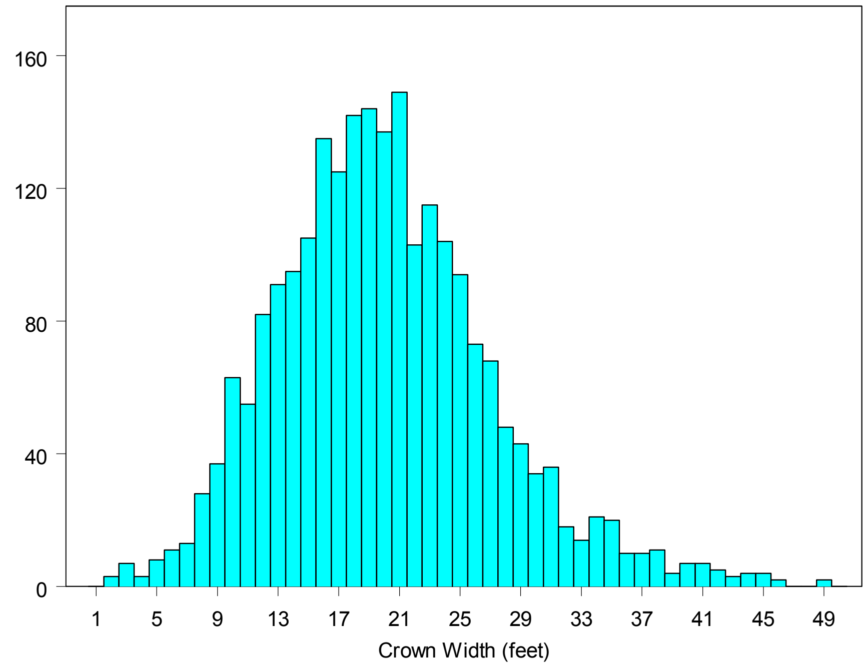
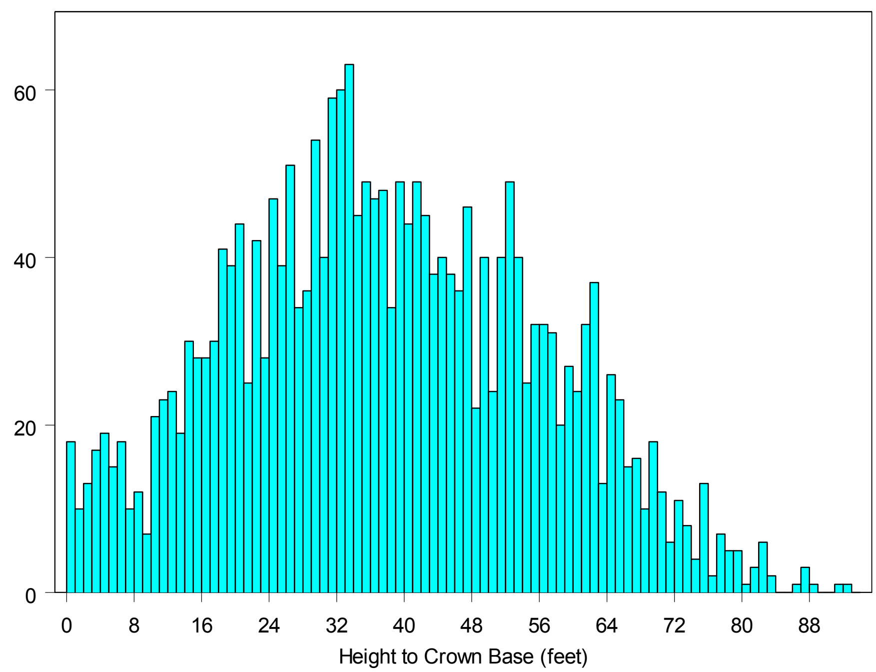


Figure 2. Distribution of height to crown base.



Analysis

- **Equations 1 and 2.**

The data collected by Willamette did not include open-grown trees. Therefore, Equation 1 (MCW) could not be fit separately. As a starting point, Equation 2 was fit to the data using the SMC-variant's estimates for MCW (Hann, 1997). The SMC equation is:

$$MCW = 4.5652 + 1.4147DBH + 0.0000DBH^2$$

When Equation 2's parameters were estimated using the SMC MCW equation, θ_0 and θ_2 were not significant. Graphical analysis of the residuals indicated trends in the residuals with DBH. Hann (personal communication, 2000) adjusted the SMC-variant's equation by using estimates of the MCW parameters obtained from a combined fit of Equation 1 and Equation 2 to the Willamette dataset. The resulting MCW estimates where then fit to the original MCW data using the Willamette MCW estimate as the independent variable in a linear regression. The resulting equation is:

$$MCW = 4.3586 + 1.57458DBH - 0.0102651DBH^2$$

Figure 3 compares Hann's adjusted MCW component to the current SMC western hemlock equation. The figure illustrates that the adjusted MCW equation generally follows the SMC equation except in large diameters trees. This occurs because the SMC variant's β_2 coefficient is set to zero, while the adjusted estimate is negative.

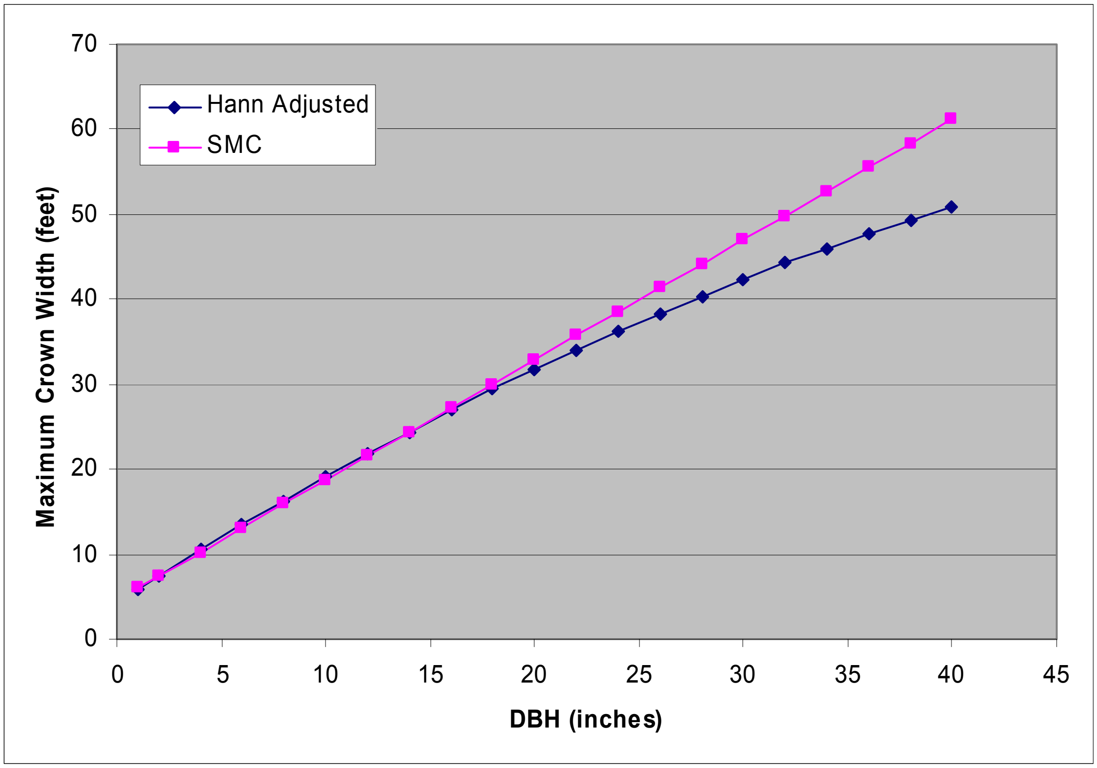
The revised equation was used to provide the MCW estimates needed in Equation 2. When Equation 2 was fit to the Willamette dataset, the following parameter estimates were obtained:

	Parameter Estimate	se
θ_0	0.1055900	0.0128238
θ_1	0.0035662	0.0003349
θ_2	0.0000000	0.0000000

The residual standard error was 3.60 feet and $r^2 = 0.7430$. Appendix A graphs the residuals against all the independent variables. Of particular note is that θ_2 is set to zero because the fit always resulted in a negative value. A negative sign is not consistent with estimates for other species and therefore the term was dropped from the equation.

Appendix B illustrates the performance of the LCW equation over the range of independent variables. There is no comparison to the SMC variant available, because the SMC variant does not have estimates for LCW.

Figure 3. Comparison of SMC MCW performance to Hann's adjusted equation.



- **Equation 4.**

The height to crown base equation parameter estimates were obtained by fitting a suitable form of Equation 4 to the data using nonlinear regression. For this equation, additional data were available from a collection effort by Dr. Doug Maguire. The following table summarizes this additional data.

n = 665	**Mean**	**Minimum**	**Maximum**
HCB	52.0	1.5	127.9
DBH	21.7	0.1	65.8
HEIGHT	99.9	4.6	236.3
CCFL	147.9	0.0	466.5
BA	275.0	39.3	560.5
SITE (western hemlock)	108.7	64.3	160.8

The table below lists the estimates resulting from fitting Equation 4 to the Willamette and Maguire datasets.

	Parameter Estimate	se
ρ_0	1.92682000	0.203515000
ρ_1	-0.00280478	0.000397097
ρ_2	-0.00119390	0.000137248
ρ_3	-0.51313400	0.037227400
ρ_4	3.68901000	0.226691000
ρ_5	0.00742219	0.000693026

The regression had a residual standard error of 11.78 feet and $r^2 = 0.6915$. Appendix C graphs the residuals against all the independent variables and Appendix D graphs the performance of the equation over relevant ranges of the independent variables.

The HCB equation recently has been fit to all trees and an undamaged tree subset (personal communication, David Hann). A test of the hypothesis that the undamaged trees and damaged trees are predicted equivalently by Equation 4 was rejected using a Welch Modified Two-Sample t-Test ($t = -6.74$, $p=0.00$). However, the mean difference was 2.9 feet and a fit to each subset yielded substantially similar equations. Based on this, we decided to retain the all-trees equation presented above.

Discussion

Of the five equations required by ORGANON, the Willamette dataset was able to yield estimates for two. The MCW, DACB and CWA equations require field data collection efforts that are on-going, although MCW may not require additional work. The net change to ORGANON's crown dynamics is difficult to gauge due to the SMC variant's lack of a LCW equation.

We have some concern over the HCB equation. The estimated model rarely predicts crown ratios (via height to crown base) below about 0.25. Both the data and real world experience suggest that this behavior is suspect. The interaction between the HCB equation and diameter growth, through its prediction of crown ratio is important. If the change in HCB predicted upon successive calls to Equation 4 during growth slows (as should be the case given the behavior illustrated in Appendix D) then crown recession would also slow. This in turn would maintain a higher than expected rate of diameter growth.

It is possible that a revised equation form will be required to address this issue. However, such an effort is beyond the scope of the current project. The new LCW and HCB equations reported here, should be an improvement over the SMC variant equations.

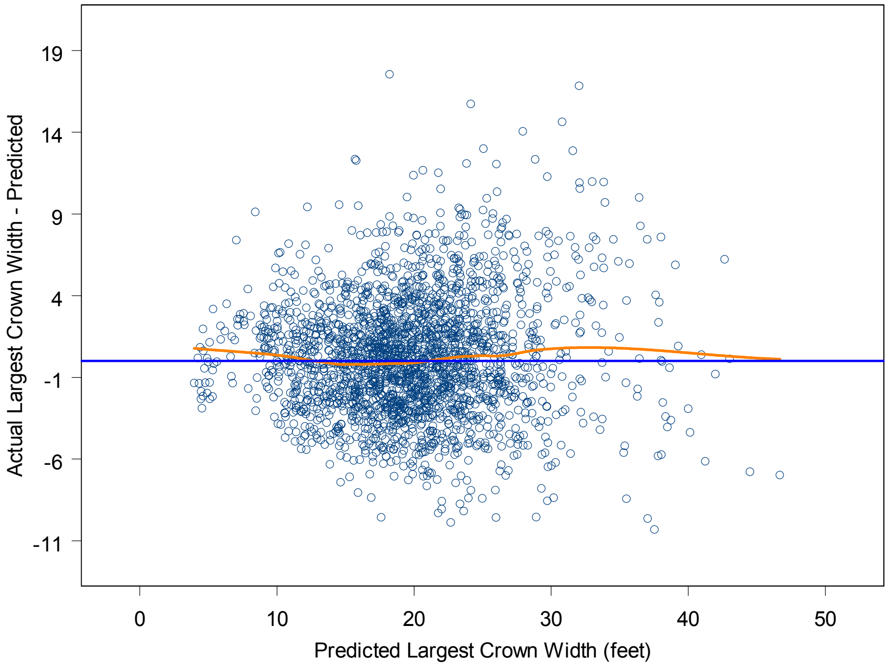
Literature Cited

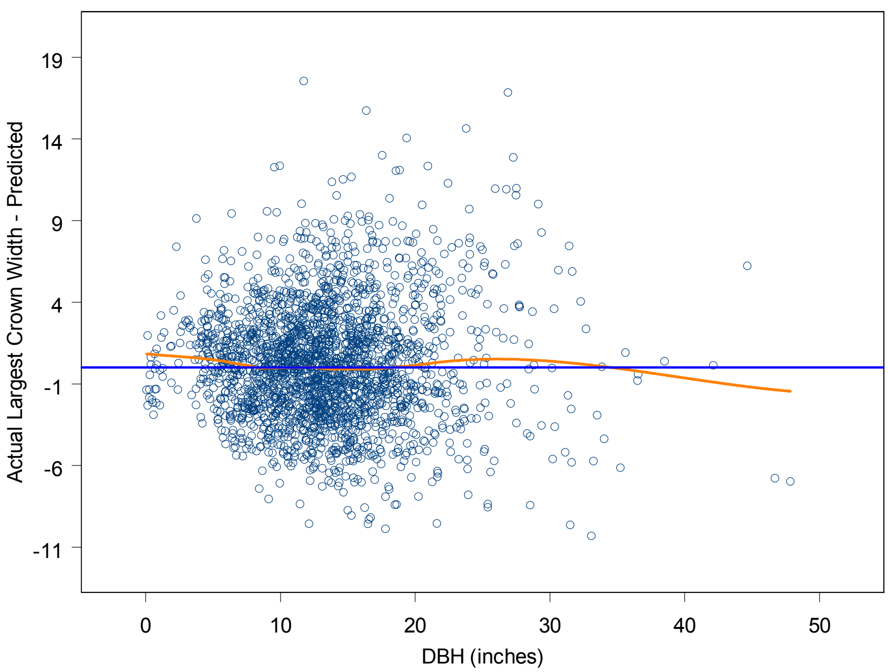
Hann, D.W. 1997. Equations for predicting the largest crown width of stand-grown trees in western Oregon. Forest Research Lab., Oregon State University, Corvallis, Oregon. Research Contribution 17. 14p.

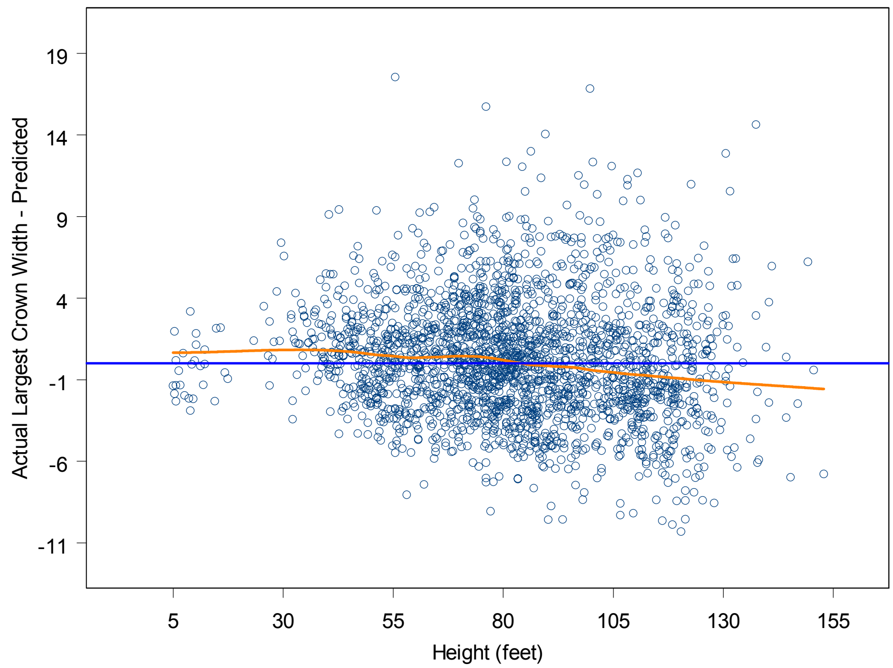
Hann, D.W. 1992. Field procedures for measurement of standing trees. Southwest Oregon Northern Spotted Owl Habitat Project. Department of Forest Resources, Oregon State University.

Marshall, D.M. 1998. Unpublished notes from SMC Modeling Technical Advisory Committee. Oregon State University.

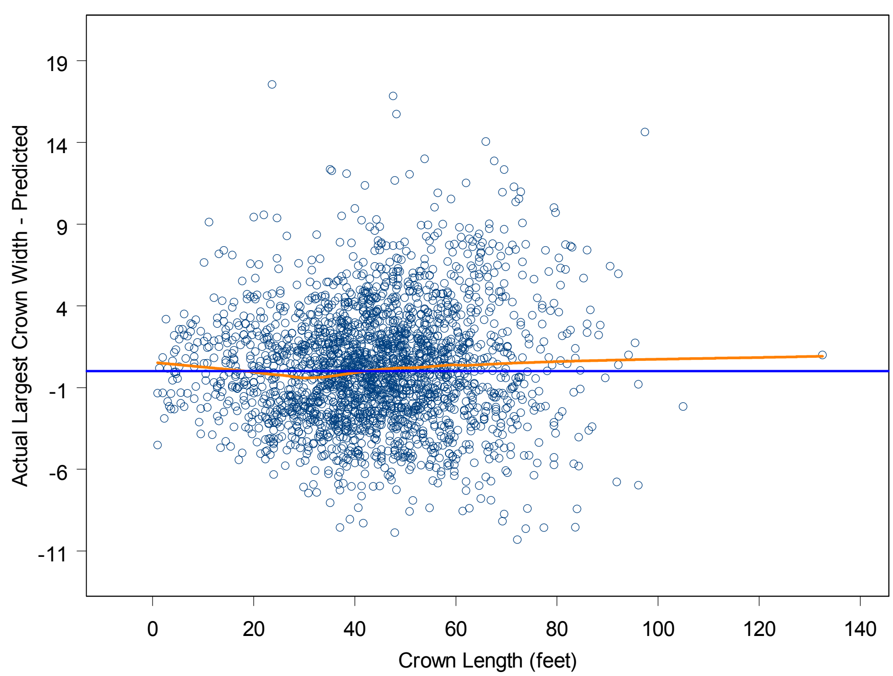
Appendix A. Residual scatterplots for the LCW equation (Loess lines are plotted through each residual cloud.)



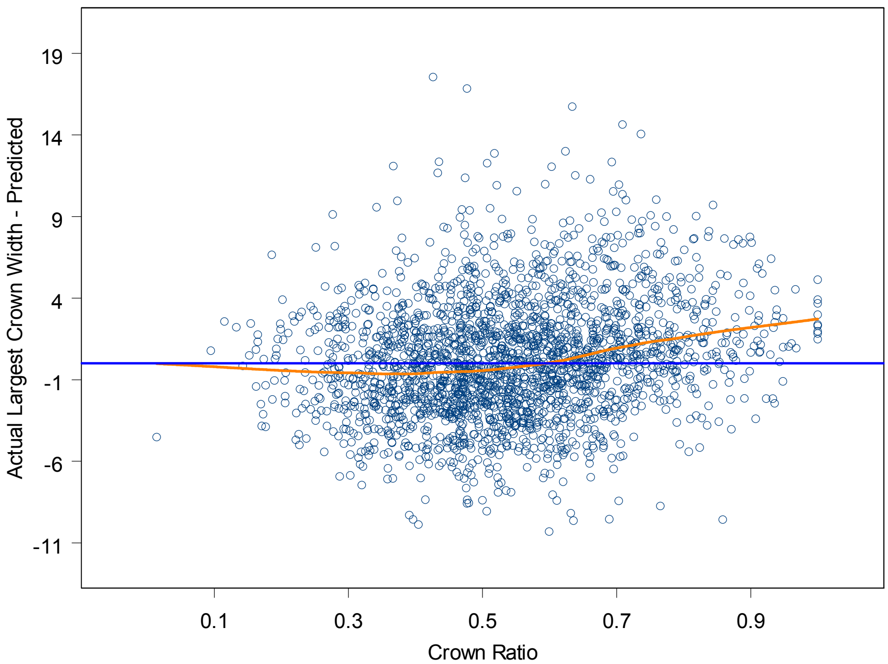




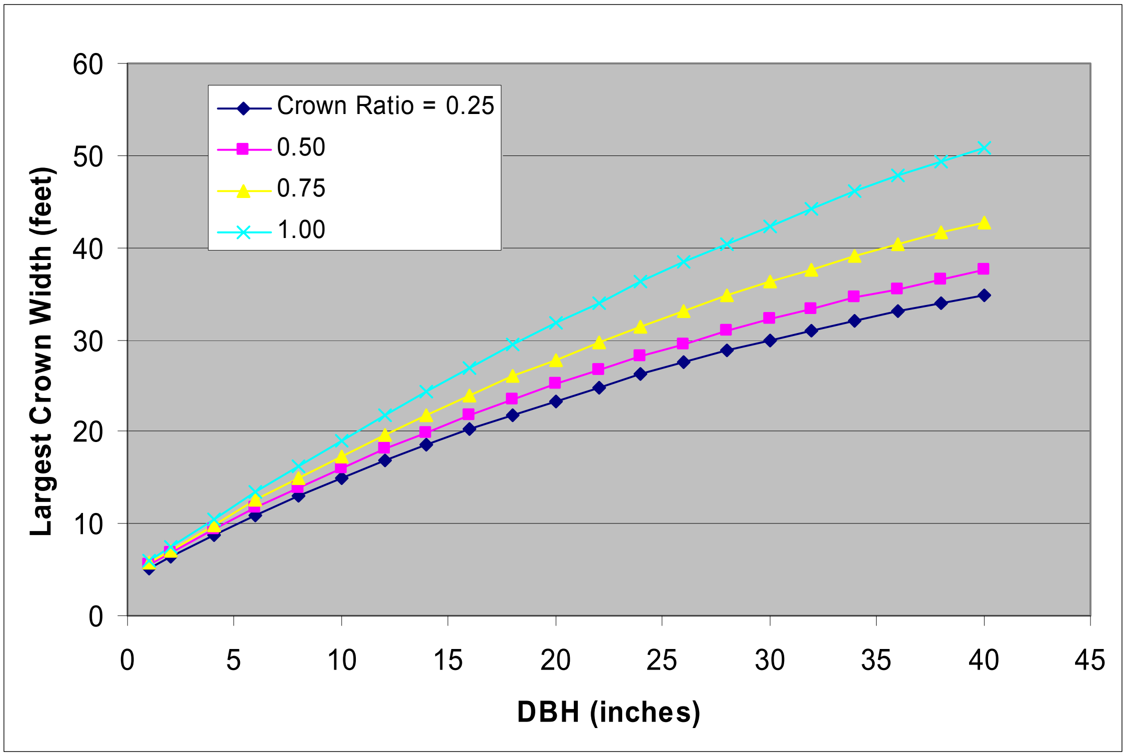
19
14
9
4
-1
-6
-11
Actual Largest Crown Width - Predicted
5
30
55
80
105
130
155
Height (feet)



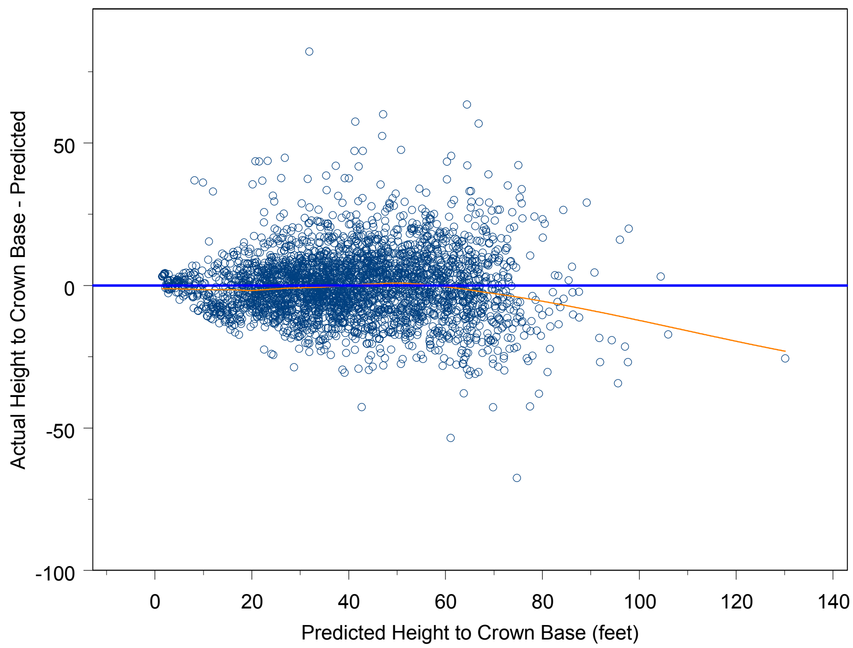
19
14
9
4
-1
-6
-11
Actual Largest Crown Width - Predicted
0
20
40
60
80
100
120
140
Crown Length (feet)

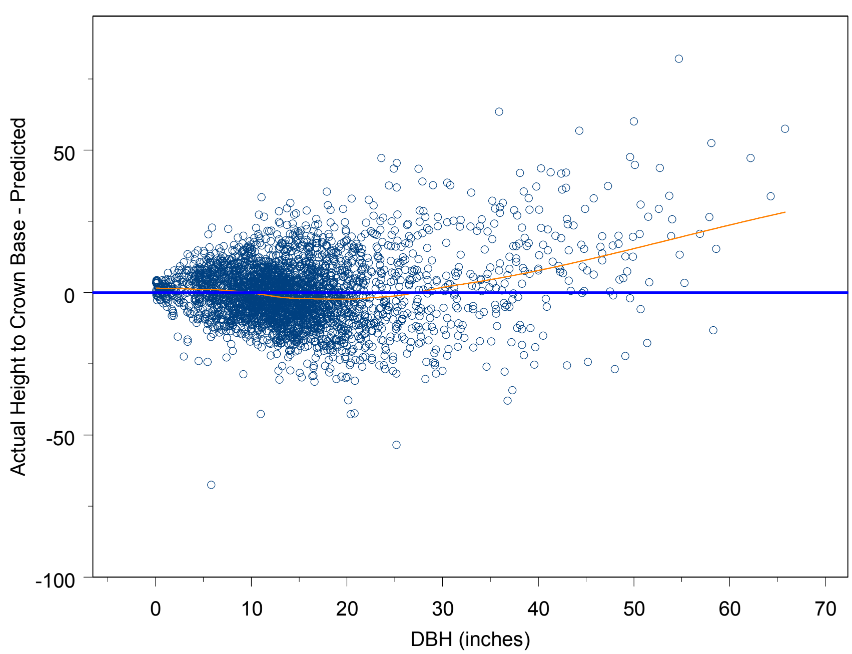

19
14
9
4
-1
-6
-11
Actual Largest Crown Width - Predicted
0.1
0.3
0.5
0.7
0.9
Crown Ratio

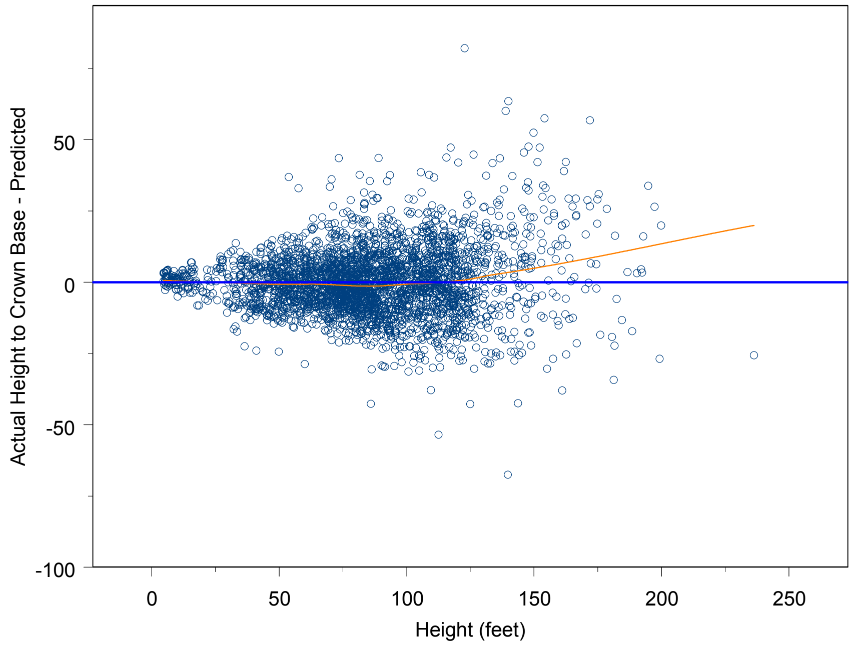
Appendix B. LCW model performance across the range of independent variables (height is set to the SMC variant's height-diameter equation estimate, crown length is a function of crown ratio).

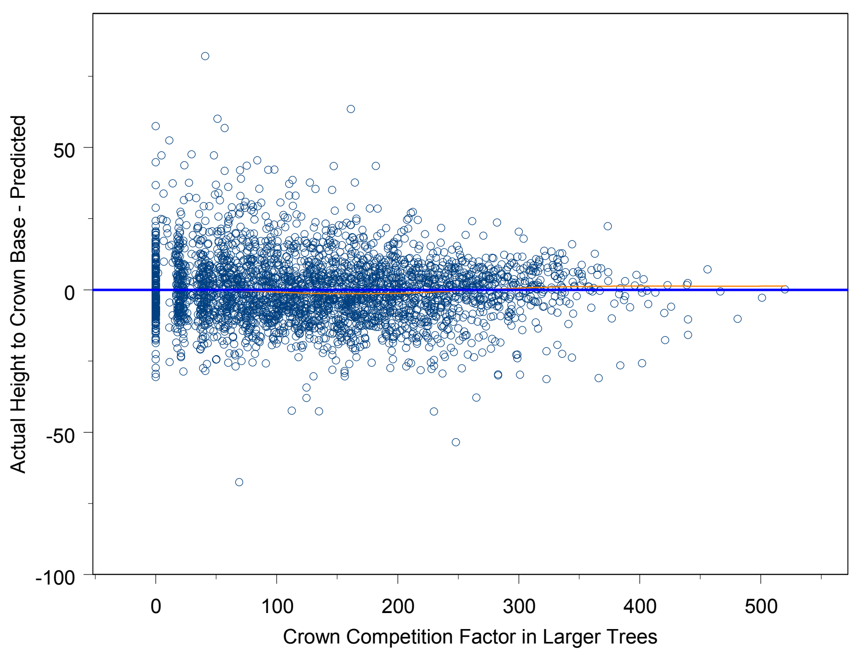


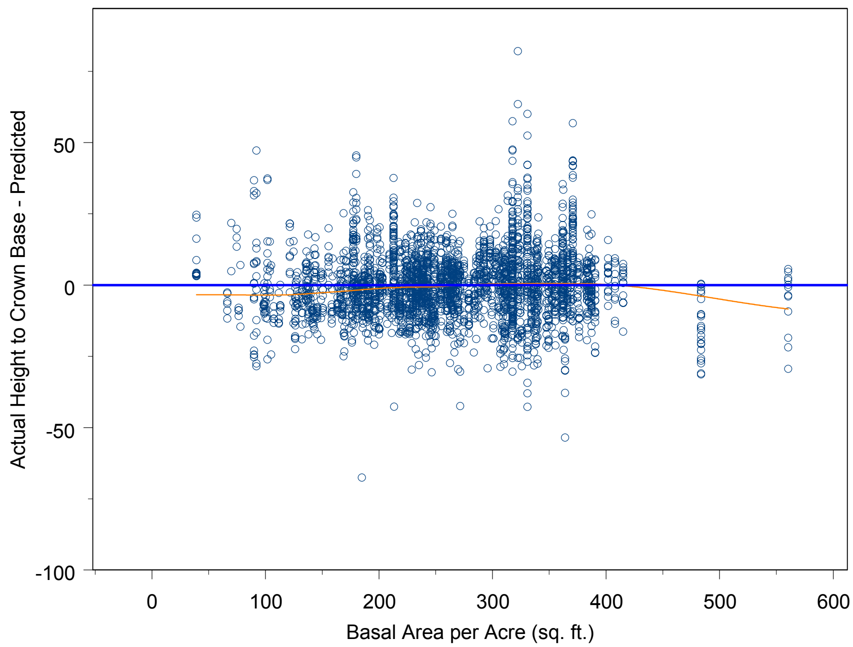
Appendix C. Residual scatterplots for the HCB equation (Loess lines are plotted through each residual cloud.)

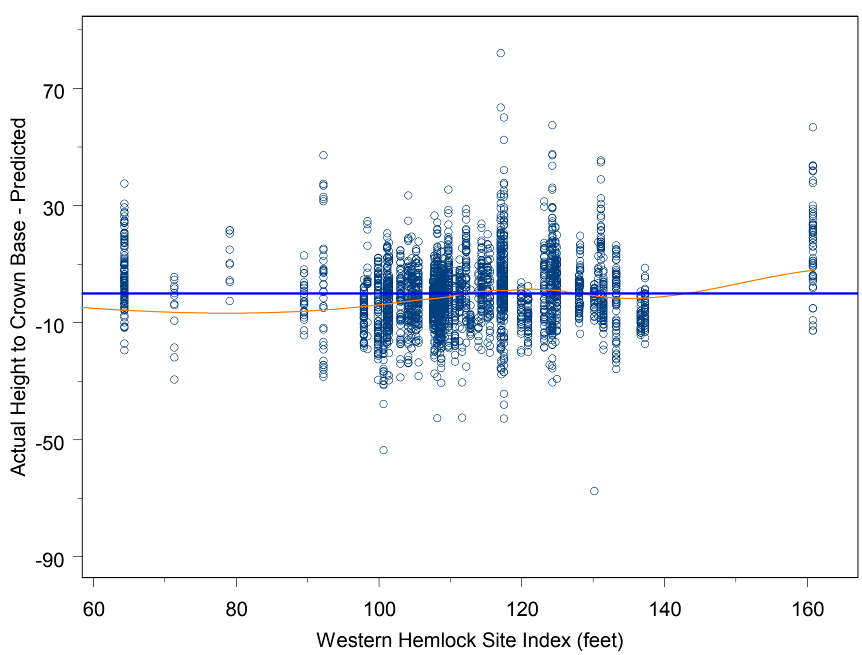





Actual Height to Crown Base - Predicted
50
0
-50
-100
0
50
100
150
200
250
Height (feet)

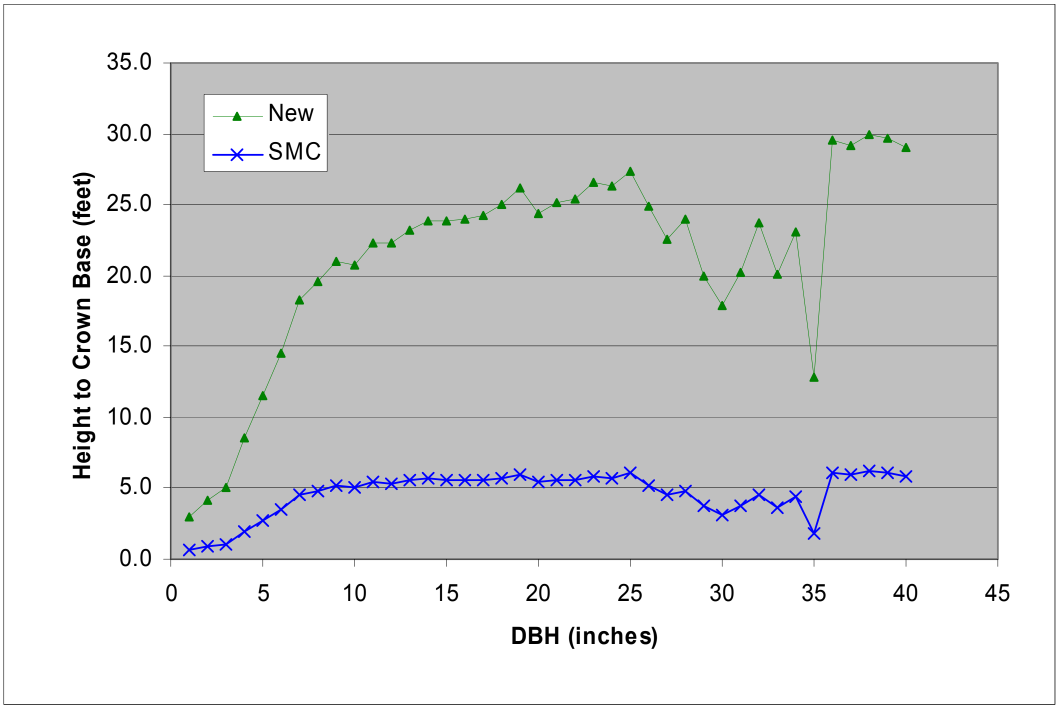

Actual Height to Crown Base - Predicted
50
0
-50
-100
0
100
200
300
400
500
Crown Competition Factor in Larger Trees


Actual Height to Crown Base - Predicted
50
0
-50
-100
0
100
200
300
400
500
600
Basal Area per Acre (sq. ft.)

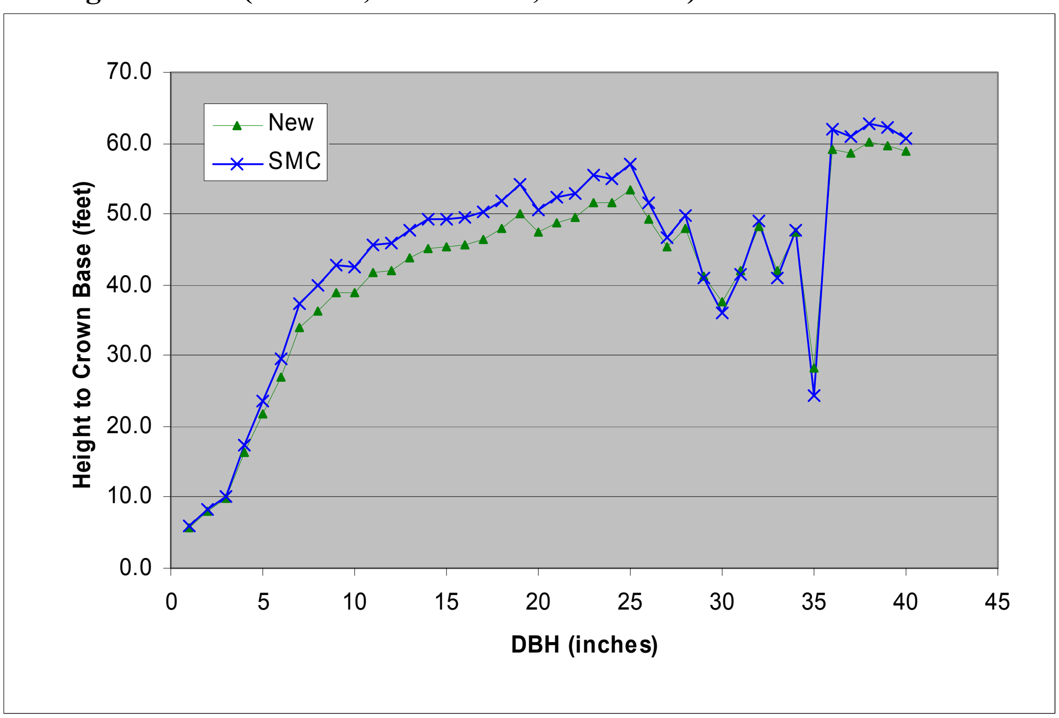

Actual Height to Crown Base - Predicted
70
30
-10
-50
-90
60
80
100
120
140
160
Western Hemlock Site Index (feet)

Appendix D. HCB model performance across the range of independent variables compared to the SMC variant's equation (height is set to the dataset average height for each 1-inch diameter class).

Open-grown tree (BA=50, CCFL=0.0, SITE=115)



Stand-grown tree (BA=260, CCFL=130, SITE=115)



Suppressed tree in dense stand (BA=460, CCFL=520, SITE=115)