ORGANON Calibration for Western Hemlock Project

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Diameter Growth Prediction Equation

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Introduction

The ORGANON model (Hann, et al., 1992) predicts the diameter growth of individual trees in a stand using a regression equation of the form:

$$\Delta DBH = \beta_0 \left(DBH + 1\right)^{\beta_1} e^{\beta_2 DBH^2} \left[\frac{\left(CR + 0.2\right)}{1.2}\right]^{\beta_3} \left(SI - 4.5\right)^{\beta_4} e^{\beta_5 \left[\frac{BAL^2}{\ln\left(DBH + 5.0\right)}\right]} e^{\beta_6 BA^{0.5}} \tag{1}$$

where DBH = diameter at breast height, BA = basal area per acre, CR = crown ratio, BAL = basal area per acre in larger trees, and SI = 50-year site index. The SMC variant of ORGANON set β_6 to zero for western hemlock and uses Flewelling's (Bonnor, et al., 1995) western hemlock site index.

The parameter estimates for Equation 1 were obtained from a fit to 833 observations from 21 permanent plots in the SMC/ORGANON database (Marshall, 1998). This paper presents the results of a re-estimation of the parameters using five new datasets described in the following sections (the SMC data used to fit the western hemlock equation currently in use was not available for this analysis).

Rayonier Dataset

The Rayonier dataset was constructed from remeasured permanent plots where trees had initial crown ratio measurements (a subset of all trees on the plots). No attempt was made at this time to impute crown ratio data for the remaining observations. Plots were established in two study types: a PCT study and a Silviculture study. Each study had control and treated plots. A summary of the data appears in the table below:

Control

n = 308	Mean	Minimum	Maximum
ΔDBH	0.68	0.0	2.6
DBH	8.2	2.1	20.1
CR	0.58	0.19	1.0
BA	273.3	141.0	351.9
BAL	145.6	0.0	344.3
SI	126.3	101.9	153.0

Treated

n = 3120	Mean	Minimum	Maximum
ΔDBH	0.98	0.0	3.25
DBH	10.0	1.2	28.6
CR	0.68	0.15	1.0
BA	213.1	76.9	336.7
BAL	132.4	0.0	331.8
SI	110.5	63.0	144.4

Equation 1 was not developed to predict the growth of trees under active density management; therefore, the performance of Equation 1 was tested using a Welch modified two sample t-Test on the residuals. The hypothesis that the model performs equally well on the thinned and unthinned data was rejected. The treated dataset therefore, was excluded from subsequent analyses.

Champion Dataset

The Champion dataset was also constructed from remeasured untreated permanent plots where trees had initial crown ratio measurements. Again, no attempt was made at this time to impute crown ratio data for trees where crowns where not measured. A summary of the complete dataset appears in the table below:

n = 519	Mean	Minimum	Maximum
ΔDBH	0.55	0.08	2.5
DBH	10.8	4.4	26.2
CR	0.33	0.10	0.85
BA	297.1	194.7	389.8
BAL	170.5	0.0	362.3
SI	135.4	110.8	156.0

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. Diameter growth was obtained by backdating each tree based on diameter increment measurements taken on the tree. The field crew noted whether a thinning (usually a PCT operation) had occurred within the last 15 years. Summaries of the dataset by thinning code appear in the tables below:

Unthinned

n = 1520	Mean	Minimum	Maximum
ΔDBH	1.05	0.0	4.28
DBH	12.4	0.1	47.3
CR	0.52	0.01	0.95
BA	240.2	46.1	450.1
BAL	127.8	0.0	450.5
SI	111.6	99.9	133.2

Thinned

n = 548	Mean	Minimum	Maximum
ΔDBH	1.40	0.0	5.53
DBH	11.2	0.1	32.9
CR	0.57	0.17	0.97
BA	197.5	32.8	360.0
BAL	106.6	0.0	380.0
SI	115.6	97.9	137.3

A procedure similar to that used to test treatment effects in the Rayonier data was employed to test the same hypothesis for the Willamette dataset. The hypothesis that the thinned and unthinned residuals were the same was accepted. Trees from thinned stands were therefore included in subsequent analyses.

SMC Dataset

The Stand Management Cooperative (SMC) dataset was collected from Type I permanent plots using a protocol developed by the SMC (Rinehart, 1986). Although all trees on the permanent plots were tagged and measured for DBH, not all trees were measured for crown ratio and total height. The dataset used here contains only those trees with a full complement of tree measurements. All plots are controls, with no known density control or fertilization treatments. A summary of the dataset appears in the table below:

n = 1282	Mean	Minimum	Maximum
ΔDBH	2.21	0.0	6.0
DBH	3.8	0.1	14.2
CR	0.80	0.13	0.99
BA	60.6	11.6	325.3
BAL	32.3	0.0	274.0
SI	122.5	98.0	127.0

Maguire Dataset

Dr. Doug Maguire collected data using the same techniques used for the Willamette dataset. The plots were chosen to represent western hemlock trees from a wide range of site index, densities, and particularly, trees from plots with suppressed diameter classes.

n = 511	Mean	Minimum	Maximum
ΔDBH	0.50	0.05	2.96
DBH	19.6	0.84	65.7
CR	0.47	0.05	1.00
BA	268.6	32.8	558.2
BAL	181.2	0.0	555.5
SI	108.0	64.3	160.8

Diameter Growth Analysis

The first step in the analysis process was to fit Equation 1 to all datasets combined and then separately. This allows a test of the hypothesis that there are no source effects in the residuals. This hypothesis was rejected however. Apparently, the datasets are not compatible with each other.

The following graph (Figure 1) displays histograms of observed diameter growth for each dataset. Both the Maguire and Willamette datasets display the expected distribution of diameter growth rates – a large number of slow to moderately growing trees with a skew to faster growing trees. The Maguire dataset does not exhibit exceptionally high growth rates, however, this is expected due to the plot selection criteria focused on high-density stands with suppressed trees. The SMC dataset is unusual in the high growth rates and uniform spread across its range. This may be an artifact of the relatively young, free-to-grow status of SMC plots at the time of measurement. The Rayonier and Champion datasets have low growth rates, with no trees exhibiting growth at the upper end of either the SMC or Willamette datasets.

Figure 1. Observed five-year diameter growth for each dataset. (MAG=Maguire, smc=SMC, WII=Willamette, RAY=Rayonier, and CHA=Champion).

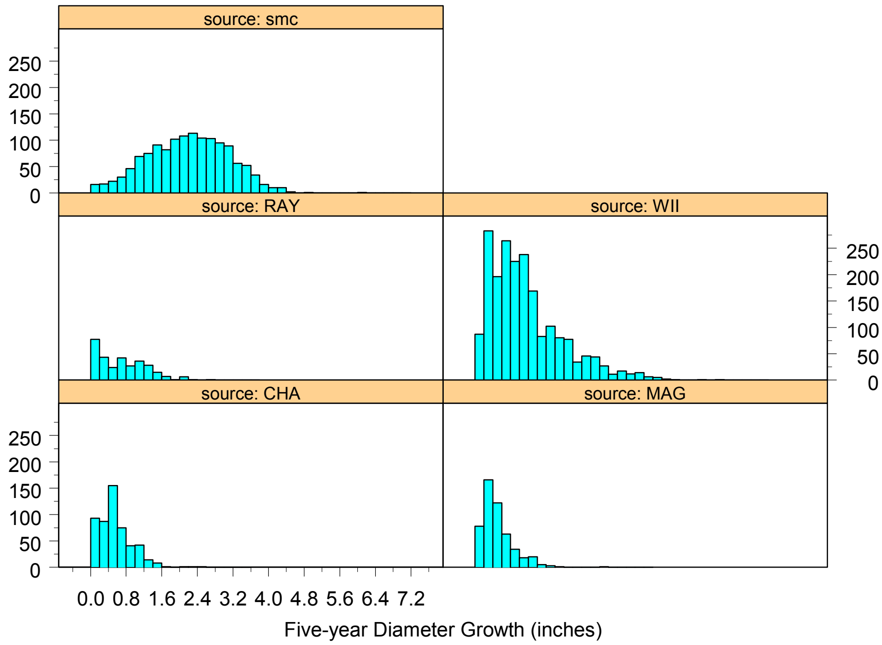
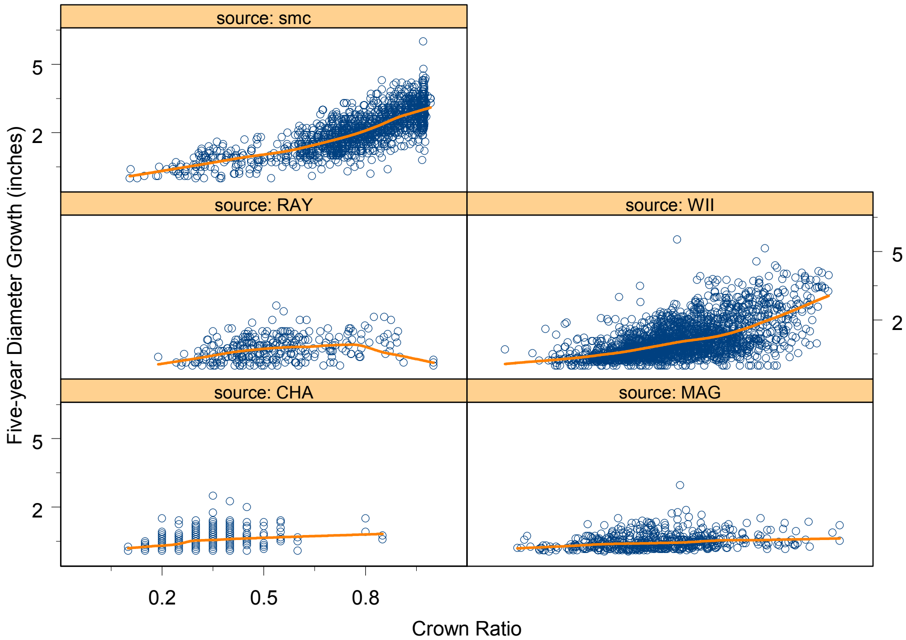


Figure 2 displays diameter growth over crown ratio – a highly influential independent variable. The Maguire, SMC, and Willamette datasets obtain the expected trend – higher diameter growth with increasing crown ratio (the Maguire dataset is flatter than the others due to the high stand basal areas on these plots). The Rayonier and Champion data do not display a strong relationship with crown ratio given their plot characteristics. This throws some suspicion on the methods used to measure crown ratio on these plots.

Figure 2. Five-year diameter growth over crown ratio for each dataset.



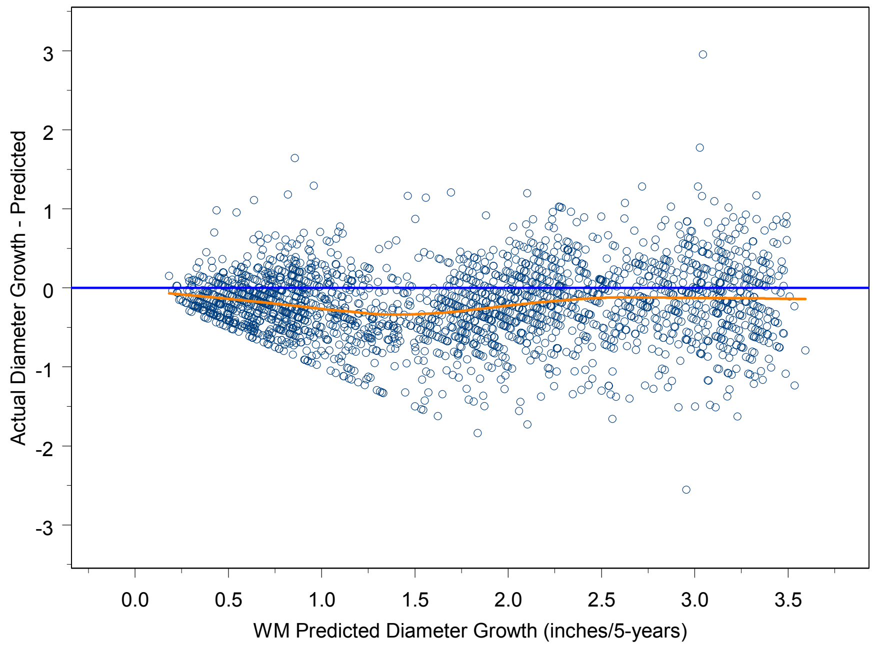
Due to the apparent large differences among datasets, it was decided to perform an initial fit to the data from the Willamette and Maguire sources. This decision was motivated by two factors: 1) both datasets were collected using the same protocol (temporary plots using Hann's procedures), and 2) the data spanned the largest range of dbh, basal area, site index, and crown ratio among all the available sources. The presumption is that the data would be compatible across source and would be comprehensive enough to define the parameter space well. The table below presents the coefficients estimated using these data.

	Parameter Estimate	se
$\log(\beta_0)$	-4.49867000	4.41344e-001
β_1	0.36236900	3.82399e-002
β_2	-0.00153907	1.09783e-004
β_3	1.15570000	7.07052e-002
β_4	1.12154000	8.91959e-002
β_5	-0.0000201041	2.22611e-006
β_6	-0.04173880	5.20707e-003

The fit resulted in a residual standard error of 0.5726 inches and an r^2 of 0.4863. Appendix A displays scatterplots of the residuals over the independent variables. An examination of the residuals did not reveal any significant problems with the fit.

The Willamette/Maguire fit (WM) was used to predict diameter growth for the remaining three datasets. Figure 3 displays the residuals plotted over the WM predictions.

Figure 3. WM fit predictions on SMC, Rayonier, and Champion datasets.



The mean residual was -0.1953 inches. Given the large differences in growth rates among these datasets, the Figure 4 was prepared to examine the residuals by data source. The SMC data source seems to be predicted well by the WM equation, however, the Champion and particularly Rayonier data sources are obviously over predicted (means residuals of –0.14, -0.46 and –0.16 for the Champion, Rayonier, and SMC sources respectively).

When the WM equation is plotted over the range of its independent variables, the predictions are substantially higher than the existing ORGANON equation (WM fit/ORGANON = 1.9669 (with the 0.7 modifier in ORGANON) and are likely to result in very high predicted growth rates in the model. Experience with the use of temporary plots in other regions of Oregon has led to adjustments based on data from permanent plots (Hann, personal communication). The ratio of actual diameter growth to WM predicted diameter growth is close to 1 for the SMC dataset (mean=1.1957) and the residual plot does not reveal obvious problems. Thus, we decided to use only the Champion and Rayonier data for computing an adjustment factor. The following factor was derived from the data:

$$\frac{\text{Actual Diameter Growth}}{\text{WM Predicted Diameter Growth}} = 0.7163 \qquad (2)$$

Figure 4. WM residuals plotted over WM predictions on the SMC, Rayonier, and Champion data sources.

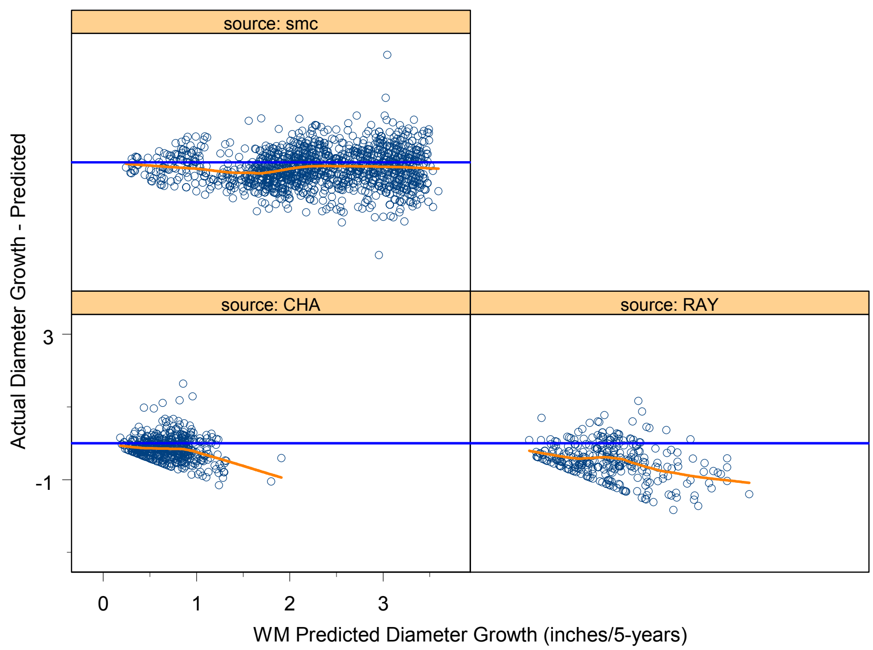
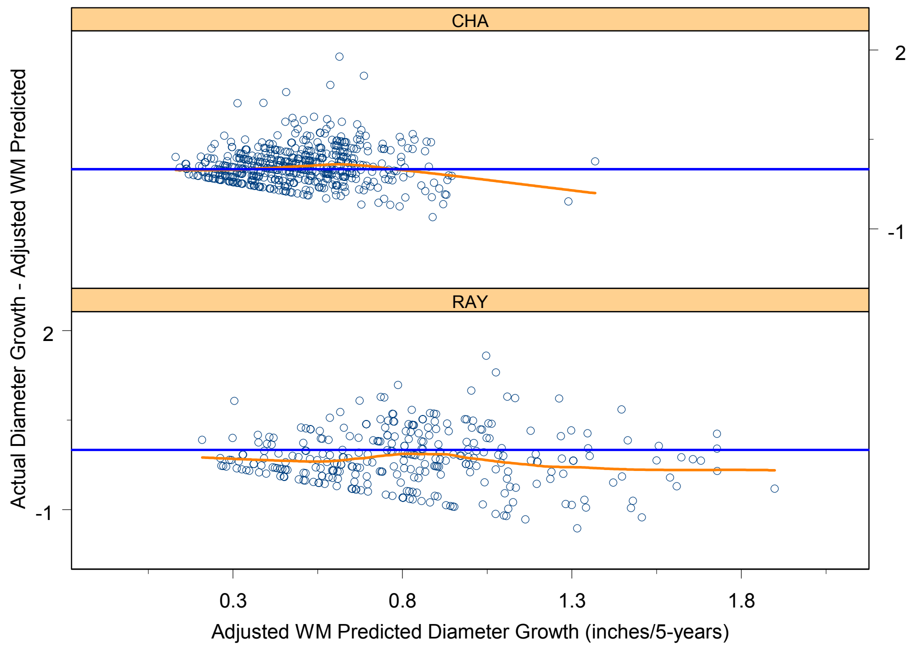


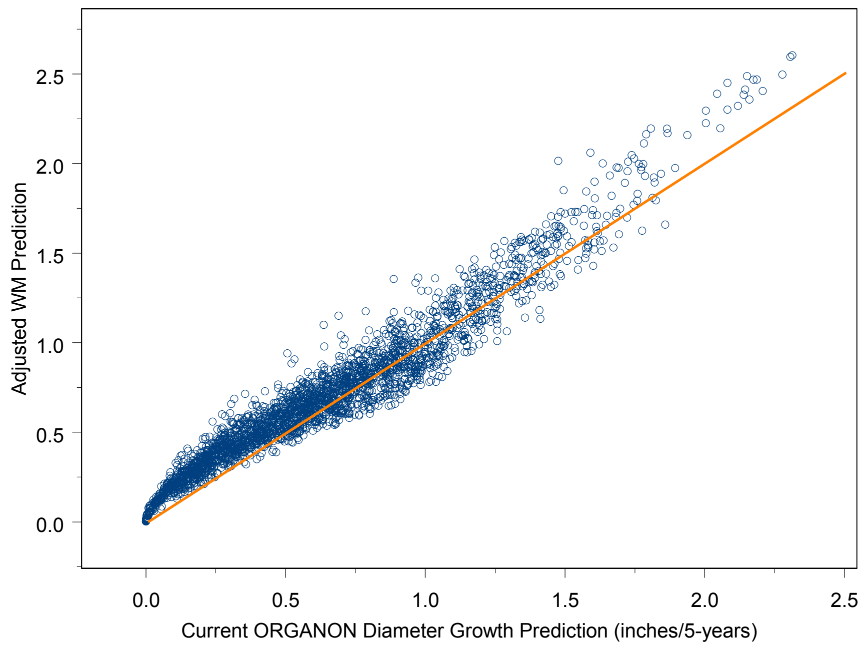
Figure 5 displays the residuals from the WM fit adjusted by equation 2 for the Champion and Rayonier data sources. The plots reveal no trends over predicted diameter growth.

Figure 5. Residual scatterplot of the adjusted WM fit for the Champion and Rayonier data sources.



Appendix B graphs the components of adjusted WM over relevant ranges of the independent variables for the Willamette and Maguire datasets. Figure 6 compares the adjusted WM fit to the current SMC western hemlock equation. Examination of Figure 6 shows that the SMC variant predicts slower growth for slow-growing trees, and about equal growth for fast-growing trees.

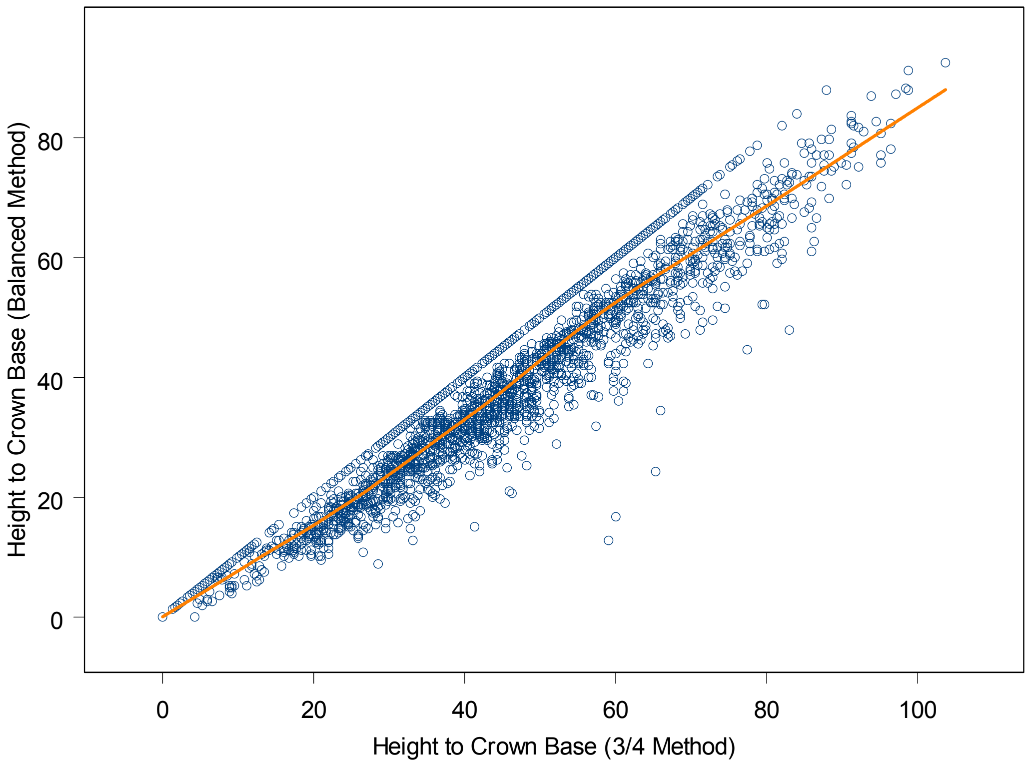
Figure 6. Comparison of adjusted WM diameter growth predictions to the SMC variant.



Crown Ratio Definition Analysis

There exist a number of definitions of crown ratio (or the more fundamental, height to crown base). Since the crown ratio modifier in the WM fit plays such an important role in diameter growth predictions, the use or conversion to the method used in defining crown ratio here is critical. The method used for this analysis is called the "balanced crown" approach. The observer "balances" asymmetrical crowns by visually moving the lower asymmetric part of the crown up the tree until the crown is symmetric. Willamette uses a method designated the "¾ crown" system. Here, the base of the live crown is defined as the height at which there are live branches in 3 of 4 quadrants of the bole. In many cases the balanced crown and ¾ crown methods are the same. However, there are a number of trees where these two measures differ (see Figure 7).

Figure 7. Scatter of ¾-crown height to crown base over balanced-crown height to crown base.



To give Willamette and others the ability to use the WM model, an adjustment equation was developed. Equation 3 was fit to the Willamette dataset where both height to crown base measurements were recorded for each tree. The resulting fit has a SE = 4.90 feet and explains 92.9% of the variation in balanced height to crown base.

$$HCB_{bal} = HCB_{34}{}^{\beta_0} e^{\beta_1 + \beta_2 DBH} \quad (3)$$

where HCB_{bal} = height to crown base balanced method and HCB_{34} = height to crown base ¾ crown method. The parameter estimates are listed in the following table.

	Parameter Estimate	se
β_0	1.10844000	0.0081697
β_1	-0.49929600	0.0316102
β_2	-0.00688992	0.0004820

The residuals of the fit to Equation 3 are plotted in Figure 8 and the performance of Equation 3 over the independent variables is illustrated in Figure 9.

Figure 8. Residuals (predicted – actual) from Equation 3 plotted over balanced-crown height to crown base.

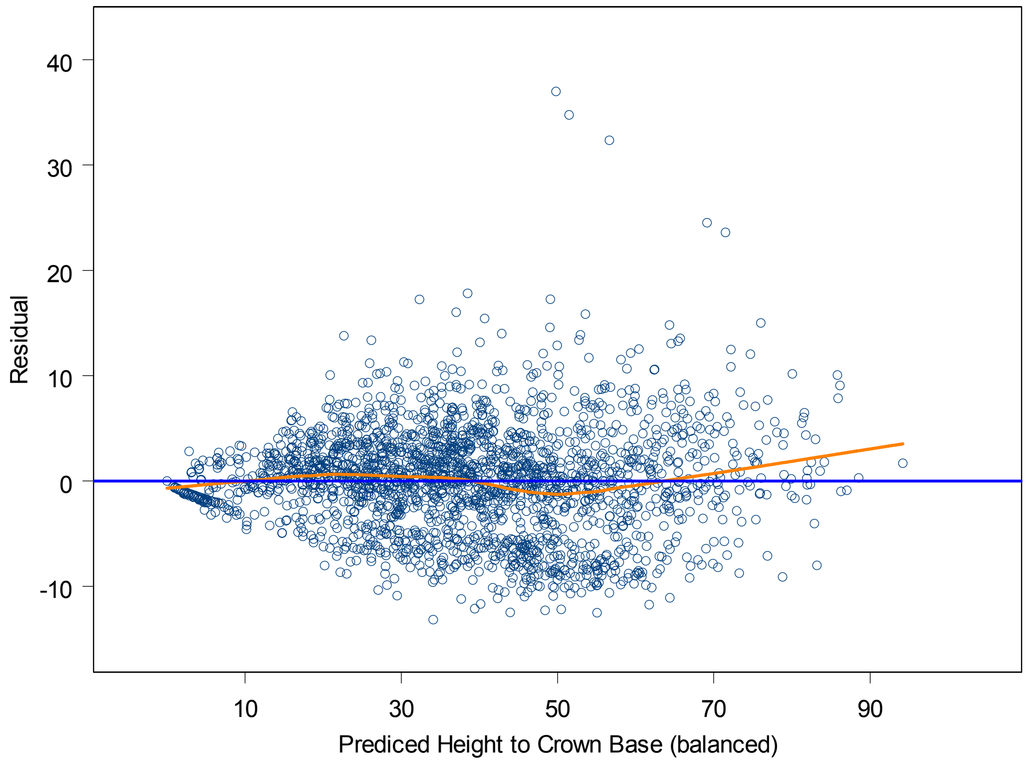
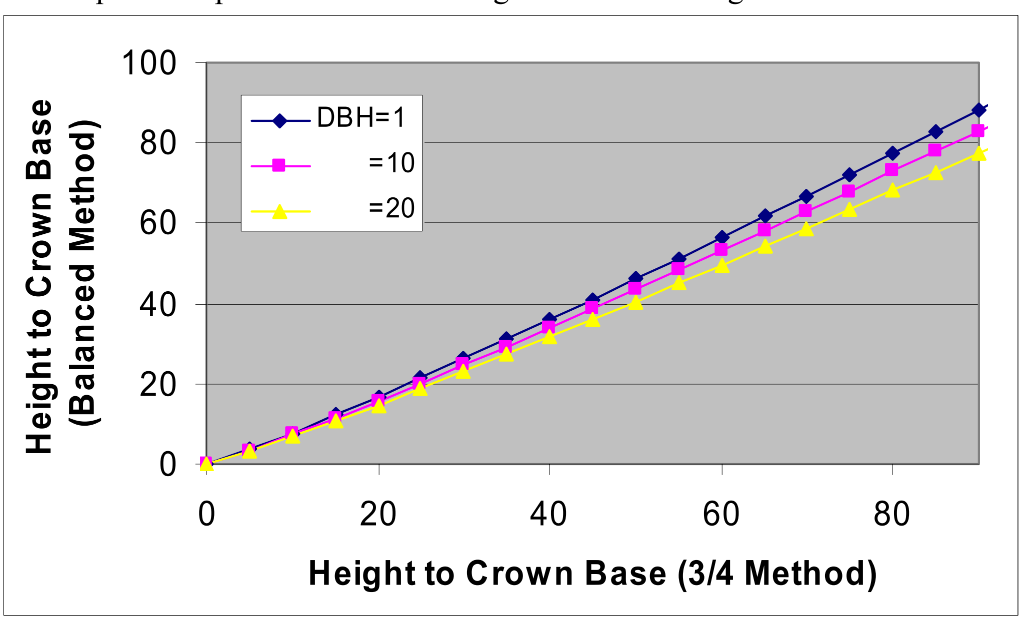


Figure 9. Equation 3 predictions over a range of ¾-crown height to crown base values.



Discussion

Appendix C graphically compares the existing SMC variant[1] western hemlock equation to the adjusted WM fit. Because of the complexity of the equation it is difficult to draw conclusions from these graphs. However, there are some points of interest. First, basal area was insignificant in the SMC fit while it enters the WM fit significantly. Since the effect of basal area is negative on diameter growth, this may account for the related BAL term having a greater influence in the SMC fit. The net result of this trade-off is that adjusted WM gives greater emphasis on two-sided competition than the SMC variant.

Second, the maximum diameter growth is greater in adjusted WM than in the SMC variant. This also may be a result of the moderating influence of the basal area term on diameter growth. Nonetheless, WM will produce substantially higher growth rates for open-grown trees.

Third, maximum, open-grown diameter growth peaks approximately 3-5 inches DBH later in WM than in the SMC variant. Therefore, the expected dynamics of stand structures between the two versions will be different. Adjusted WM will produce acceleration in diameter growth for a broader range of trees than its predecessor.

Fourth, the adjustment to WM required to fit the permanent plot data from the Champion and Rayonier data sources remains unexplained. The Willamette, Maguire, and SMC sources represent a single 5 year period, whereas, the Champion and Rayonier data span time frames up to 10 years. This would make the temporary plots and SMC more sensitive to a particular climatic effect than the permanent plots. The crown measurements on the Willamette, Maguire, and SMC trees were taken with more recent definitions of crown ratio (though the SMC definition differs from the Willamette and Maguire definition). Therefore, the relationship between crown ratio (an influential variable in the WM equation) and growth may be distorted in the permanent plot data.

These reasons are neither satisfying nor complete. Further work remains to be done to explore this effect. Willamette is considering permanently monumenting a subset of the temporary plots and following their development over time. This will allow us to test the temporary versus permanent plot effect on the same trees.

[1] The SMC variant used here includes the 0.7 modifier employed in the current release of ORGANON.

Literature Cited

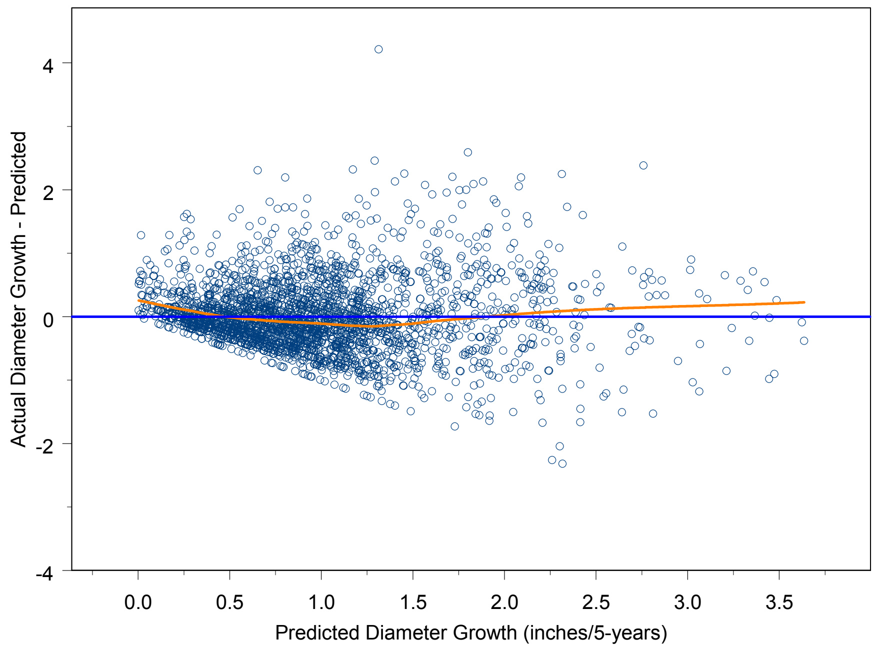
Bonnor, G.M., R.J. De Jong, P. Boudewyn, and J.W. Flewelling. 1995. A guide to the STIM growth model. Information Report BC-X-353. Natural Resources Canada, Canadian Forest Service, Pacific and Yukon Region, Pacific Forestry Centre, Victoria, B.C.

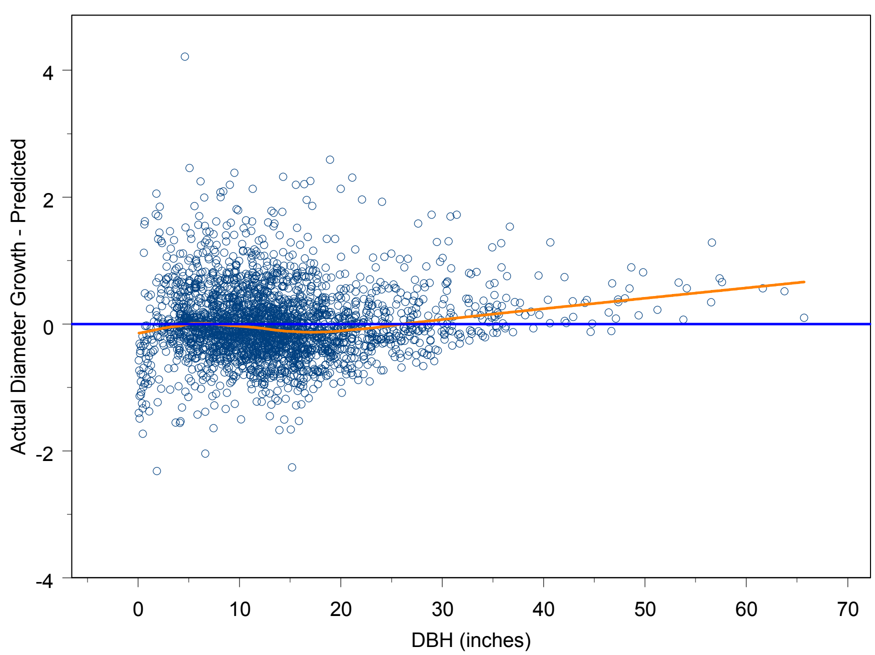
Hann, D.W. 1992. Field procedures for measurement of standing trees. Southwest Oregon Northern Spotted Owl Habitat Project. Department of Forest Resources, Oregon State University.

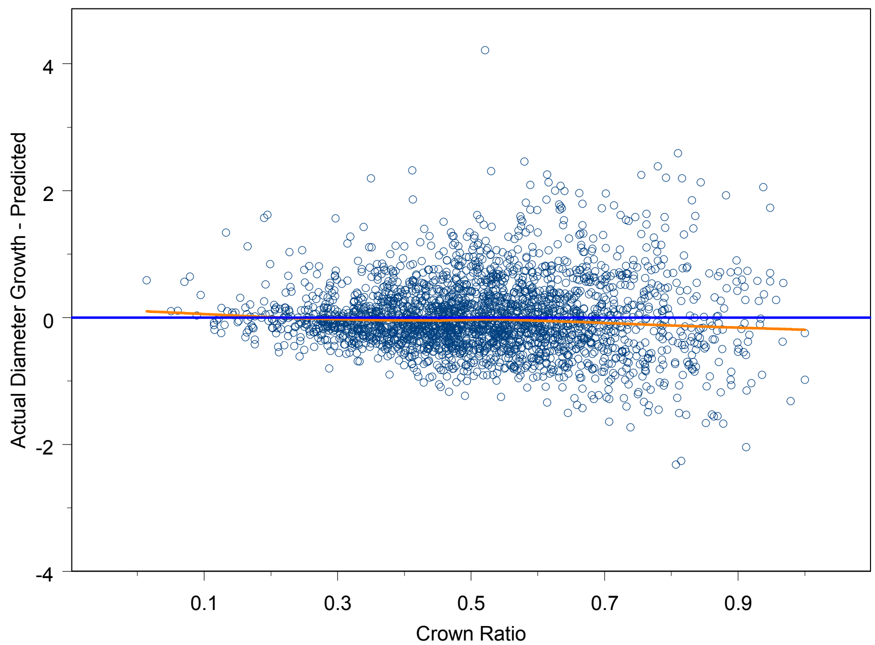
Marshall, D.M. 1998. Unpublished notes from SMC Modeling Technical Advisory Committee. Oregon State University.

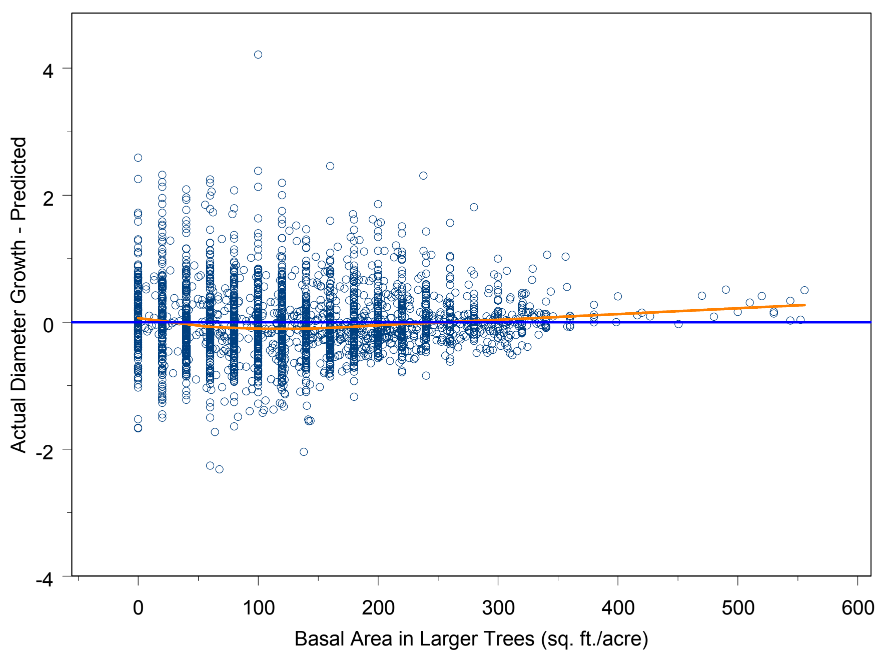
Rinehart, M.L. 1986. Stand Management Cooperative field procedures manual. Stand Management Cooperative, University of Washington.

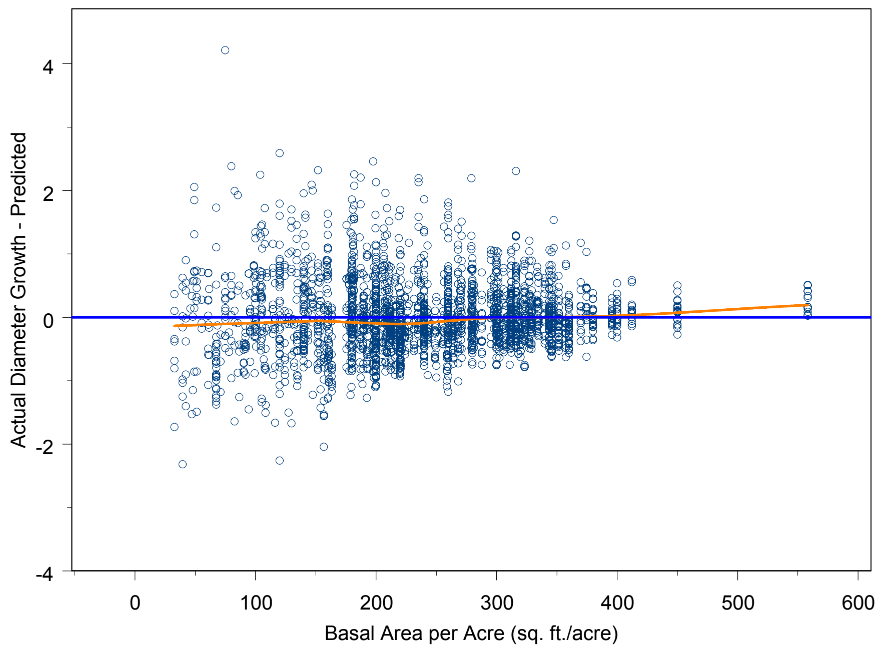
Appendix A. Residual Scatterplots for the Willamette and Maguire data source model (WM model) (Loess lines are plotted through each residual cloud)...

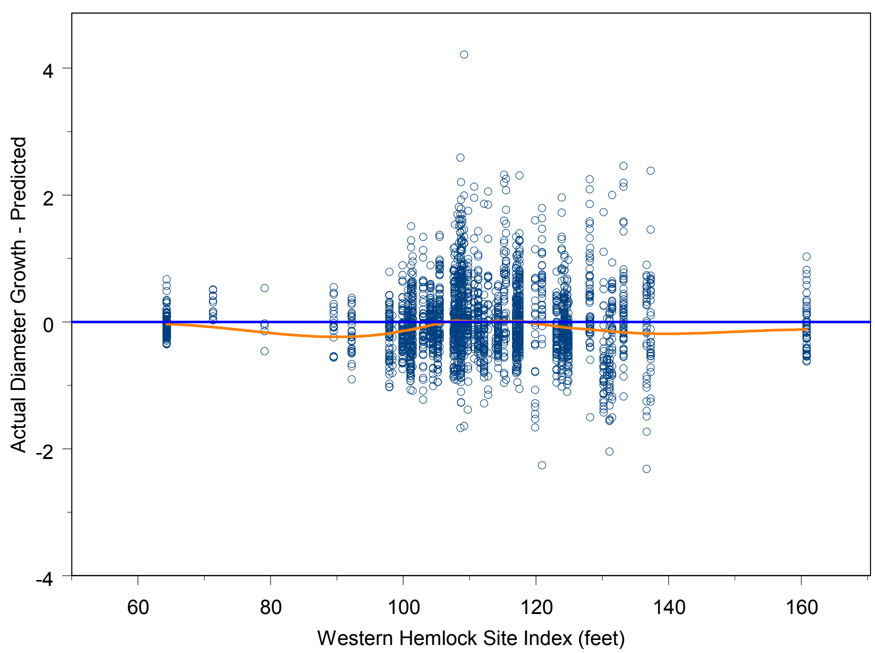




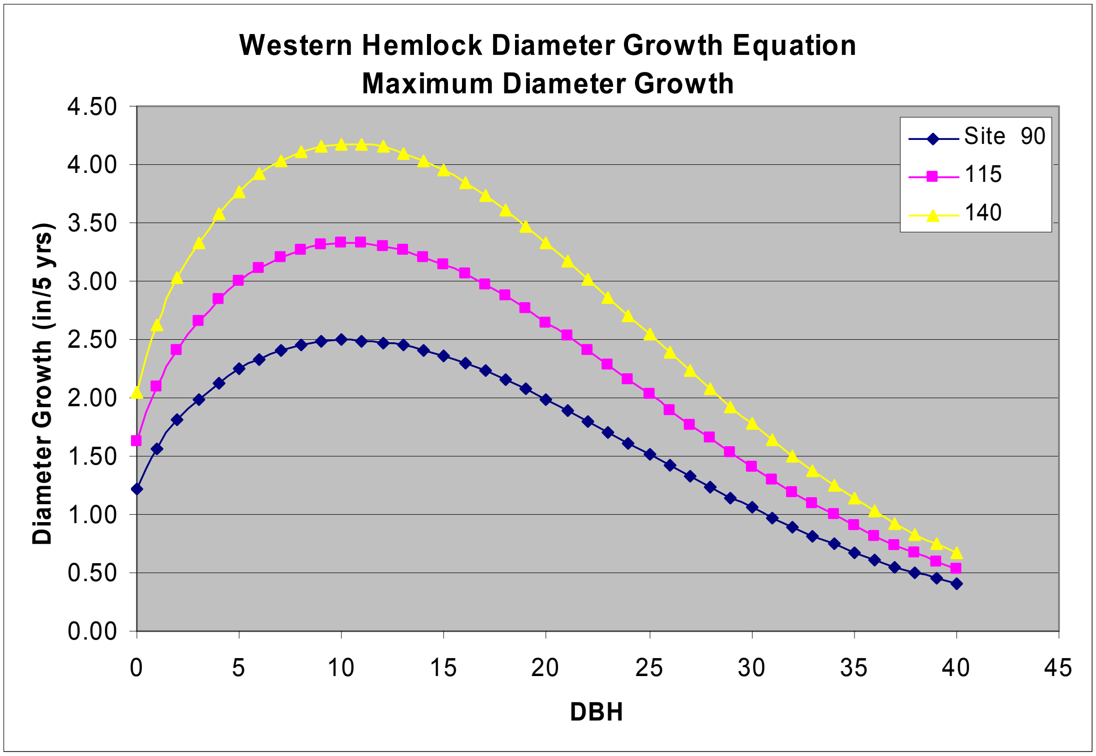

Actual Diameter Growth - Predicted
4
2
0
-2
-4
0.1
0.3
0.5
0.7
0.9
Crown Ratio

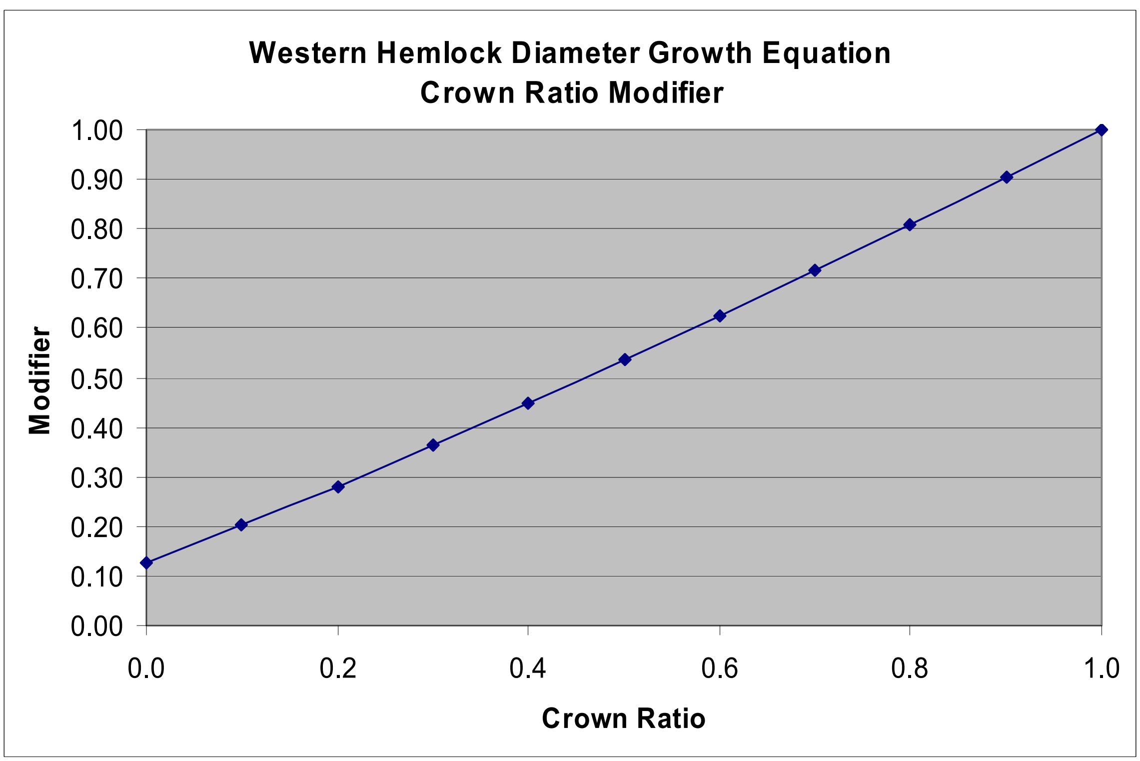

Actual Diameter Growth - Predicted
4
2
0
-2
-4
0
100
200
300
400
500
600
Basal Area in Larger Trees (sq. ft./acre)

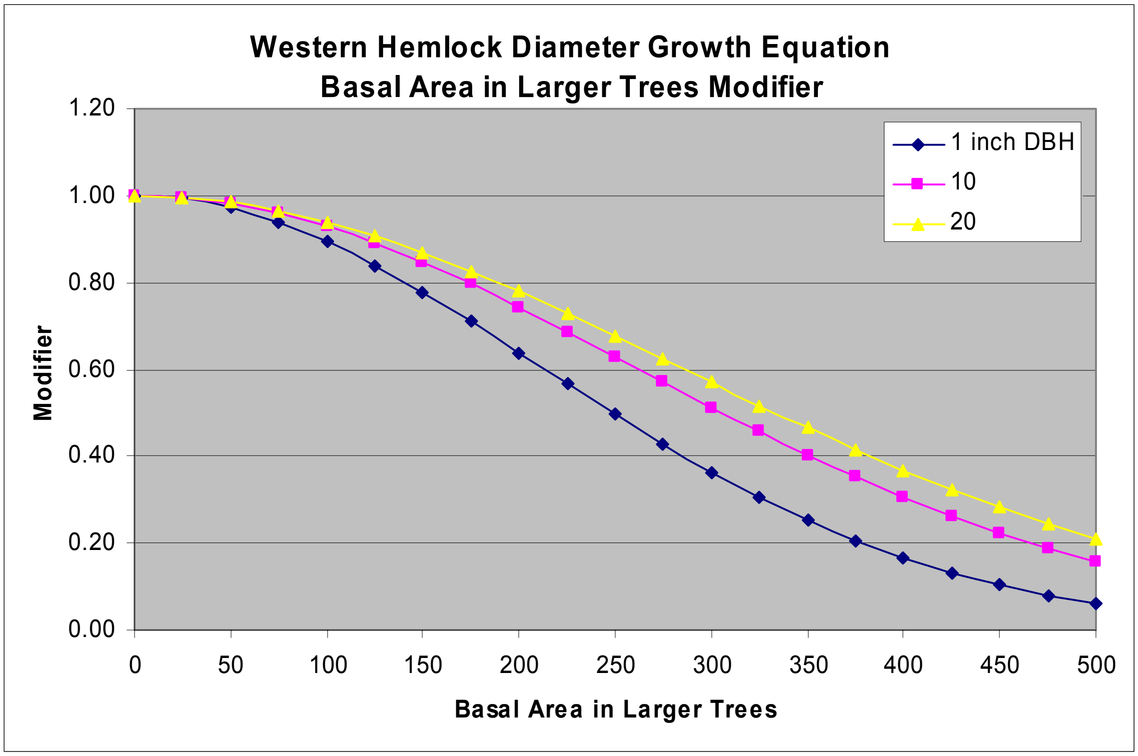

Actual Diameter Growth - Predicted
4
2
0
-2
-4
0
100
200
300
400
500
600
Basal Area per Acre (sq. ft./acre)

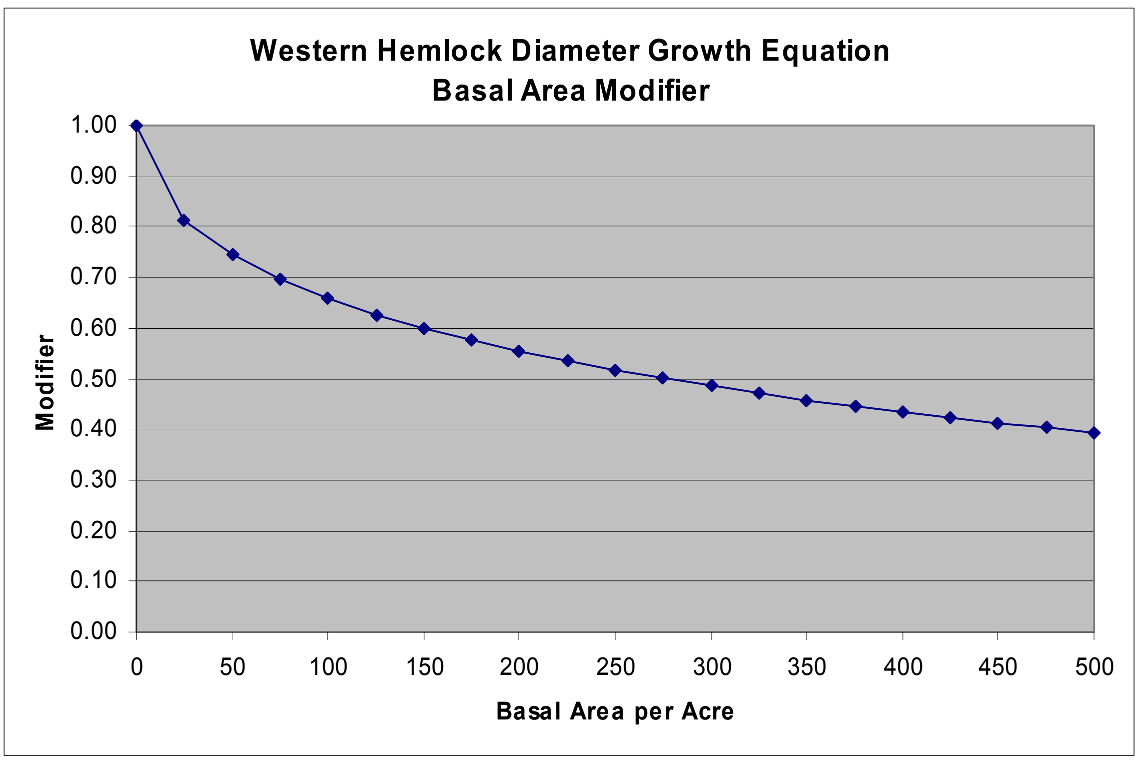

Actual Diameter Growth - Predicted
4
2
0
-2
-4
60
80
100
120
140
160
Western Hemlock Site Index (feet)

Appendix B. Adjusted WM model component performance across the range of independent variables.

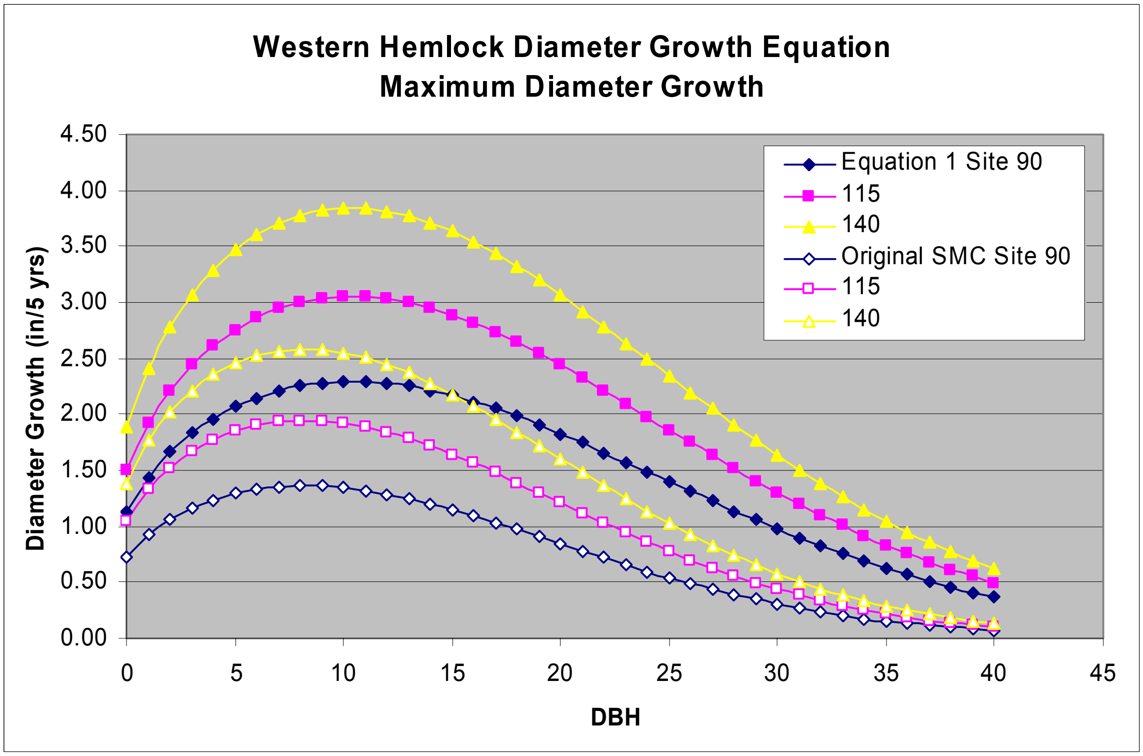


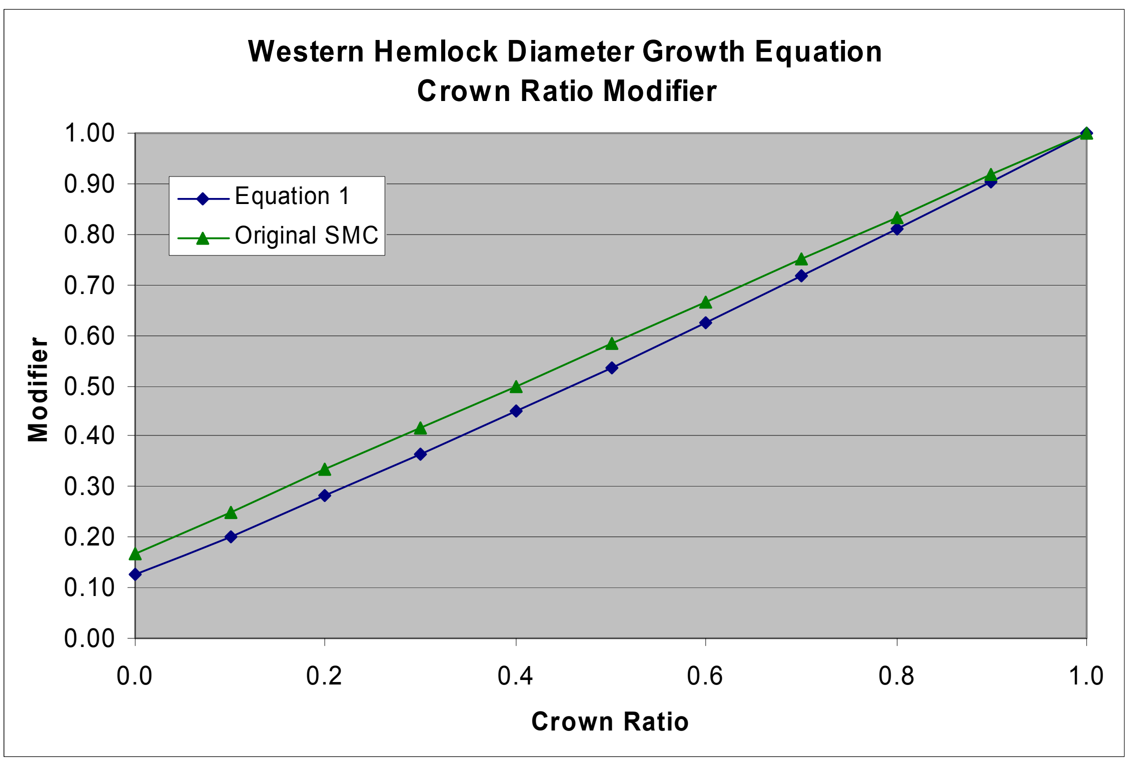


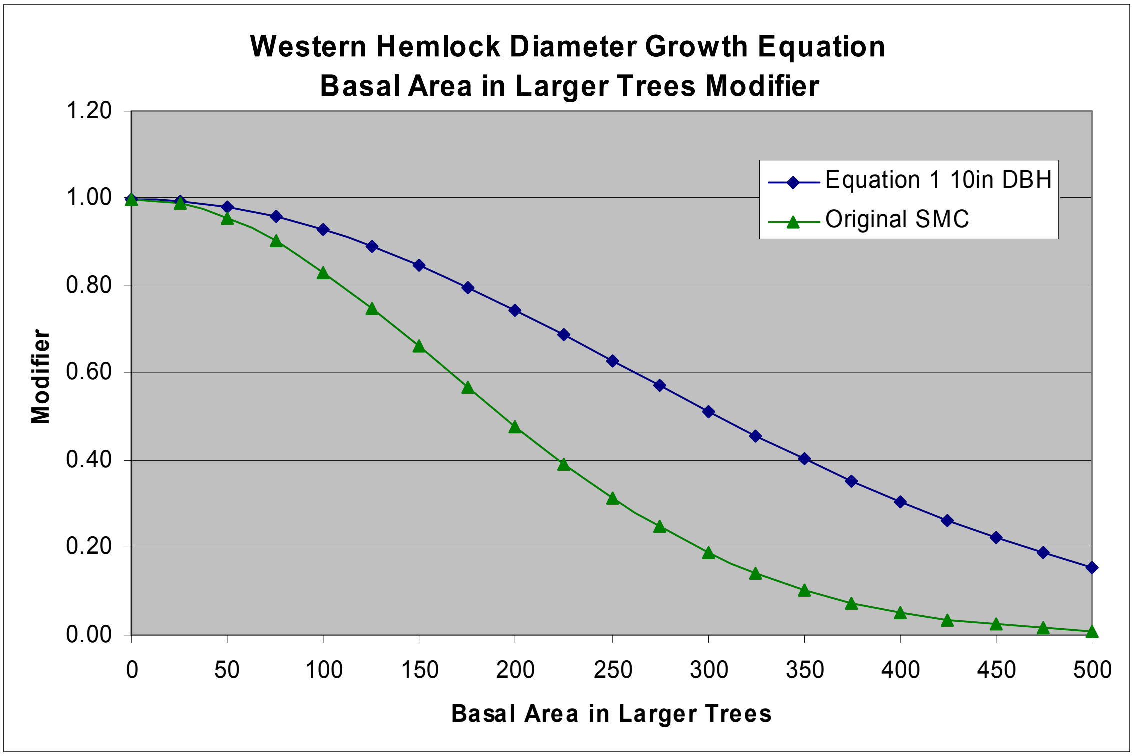

Western Hemlock Diameter Growth Equation
Basal Area in Larger Trees Modifier
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Modifier
0
50
100
150
200
250
300
350
400
450
500
Basal Area in Larger Trees
1 inch DBH
10
20

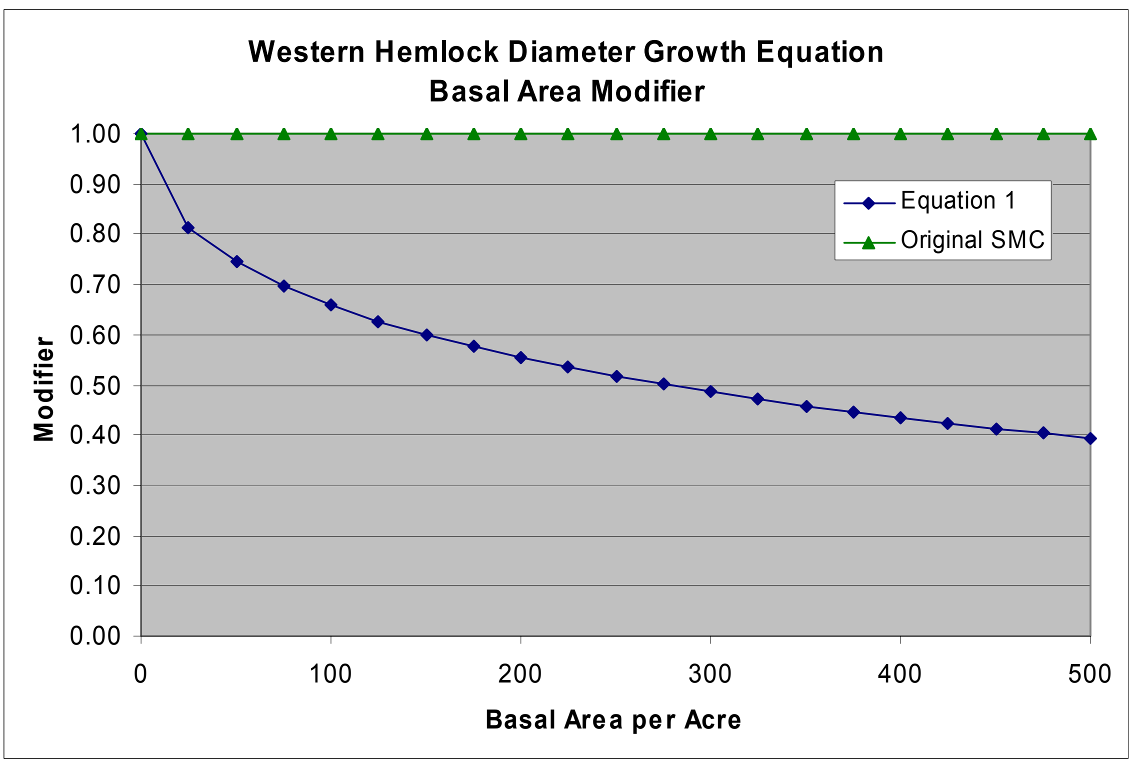

Western Hemlock Diameter Growth Equation
Basal Area Modifier
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Modifier
0
50
100
150
200
250
300
350
400
450
500
Basal Area per Acre

Appendix C. Graphical comparison of the adjusted WM fit to the existing adjusted SMC regression equation.






Western Hemlock Diameter Growth Equation
Basal Area in Larger Trees Modifier
Modifier
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
50
100
150
200
250
300
350
400
450
500
Basal Area in Larger Trees
Equation 1 10in DBH
Original SMC


Western Hemlock Diameter Growth Equation
Basal Area Modifier
Modifier
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0
100
200
300
400
500
Basal Area per Acre
Equation 1
Original SMC