ORGANON Calibration for Western Hemlock Project

January 24, 2000

Maximum Size-Density Relationships

Greg Johnson
Forest Research Coordinator

Introduction

The ORGANON model (1992) uses a maximum size-density relationship similar to that developed by Reineke (1933) as a constraint on the growth and development of stands. Specifically, the mortality equations are constrained to stay under the maximum size-density line defined in the model for a given species. The SMC variant of ORGANON uses a Reineke slope of 1.605 and a constant of 593.2 to define its maximum size-density line for western hemlock:

$$TPA = \left(\frac{593.2}{QMD} \right)^{1.605}$$

The maximum stand density index (SDI) defined by this line is 701.4. In contrast, Wiley and Chambers (1981) showed maximum SDI as a function of percent normal basal area (PNBA) ranging from 292 to 593 for PNBA of 60 and 120 respectively. Meyer's (1937) yield tables estimated maximum SDI at approximately 517, although it varied slightly with site quality and was confounded with Sitka spruce.

The purpose of the present effort is to verify that data from permanent plots independent of the SMC dataset conform to these assumptions and if not, suggest new parameter estimates for the above equation.

Material and Methods

Permanent plot data were received from Champion International and Rayonier for this calibration effort. Upon examination of the size-density graphs for all contributed plots, 23 plots from the Rayonier dataset exhibited linear mortality trends (on a log-log scale) for 4 or more growth periods and were pure (>80% basal area) western hemlock. These screening criteria are similar to Marshall's (1998) procedures used in the SMC modeling effort.

The 23 plots are summarized below by study type:

"PCT" Study Control Plots	Mean Site = 116	N_g = 55 growth periods	N_p = 15 plots
	Mean	**Min**	**Max**
Trees per Acre (TPA)	1303.3	570.0	3320.0
Basal Area per Acre (BA)	280.3	217.2	363.6
Quadratic Mean Diameter (QMD)	6.7	3.9	10.5
Stand Density Index (SDI)	606.8	499.1	743.5

"Silviculture" Study Control Plots	Mean Site = 106.7	N_g = 40 growth periods	N_p = 8 plots
	Mean	**Min**	**Max**
Trees per Acre (TPA)	1313.3	560.0	3800.0
Basal Area per Acre (BA)	298.7	248.4	336.3
Quadratic Mean Diameter (QMD)	7.0	3.6	10.3
Stand Density Index (SDI)	637.1	550.5	743.9

Rayonier installed two series of plots, the "PCT" series to track growth and development of stands ready for precommercial thinning, and the "Silviculture" series to investigate different stocking levels and species mixtures.

Three approaches to fitting the maximum size-density line where used. Each approach is described next.

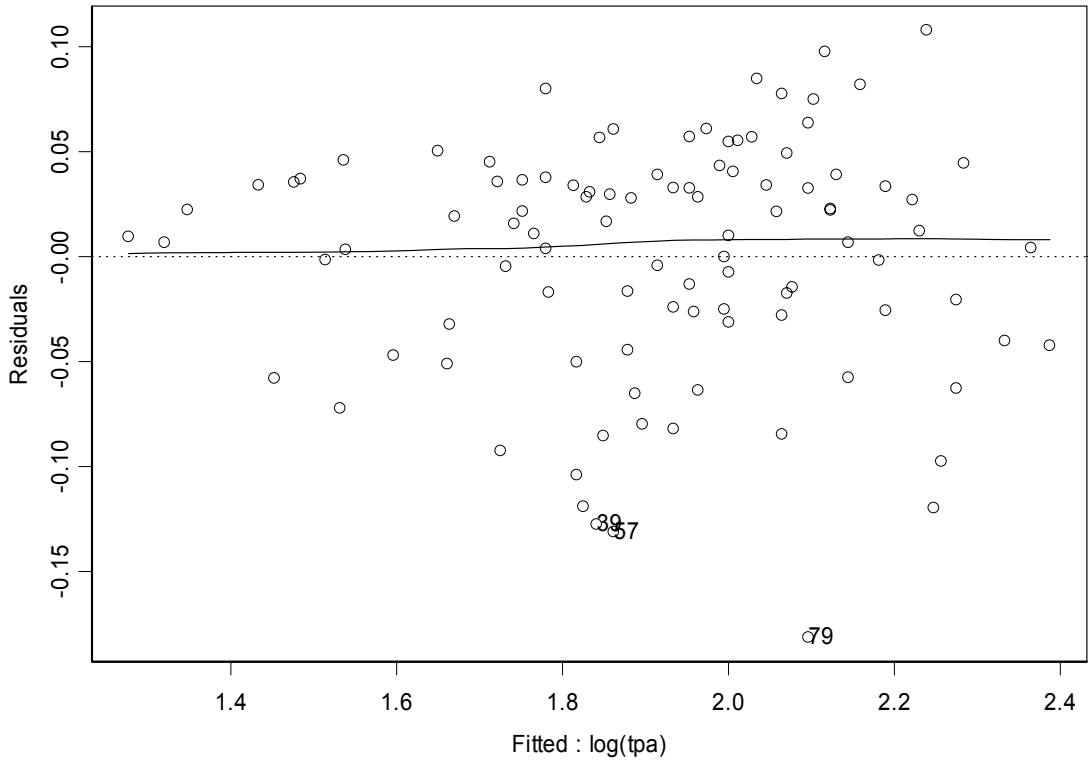
Approach 1: Pooled Across All Plots

This approach takes all the TPA and QMD coordinates from the linear portions of the size-density curves for qualifying plots and fits a log-log regression to QMD and TPA. The regression estimates (from a log-log fit) are:

$$TPA = \left(\frac{273.746}{QMD} \right)^{1.902} \qquad (1)$$

Residual SE = 1.05787 (back-transformed inches); $r^2 = 0.948$ (log-log equation).

The 95% confidence interval about the slope estimate is: $1.8165 \leq \text{slope} \leq 1.9948$, which does not overlap Reineke's slope of 1.605. The resulting equation yields a maximum SDI of 540.9. A residual scatter with a loess line is show below.



Approach 2: Individual Plot Regressions

Here, each plot's trajectory is fit separately, allowing each plot to define its own size-density relationship. This results in 23 estimates of the slope and intercept of the maximum size-density line. All of the plot regressions were significant at the 95% confidence level. Histograms for the estimates appear on page 4. Taking the average intercept and slope of the 23 log-log regressions yields the following size-density line:

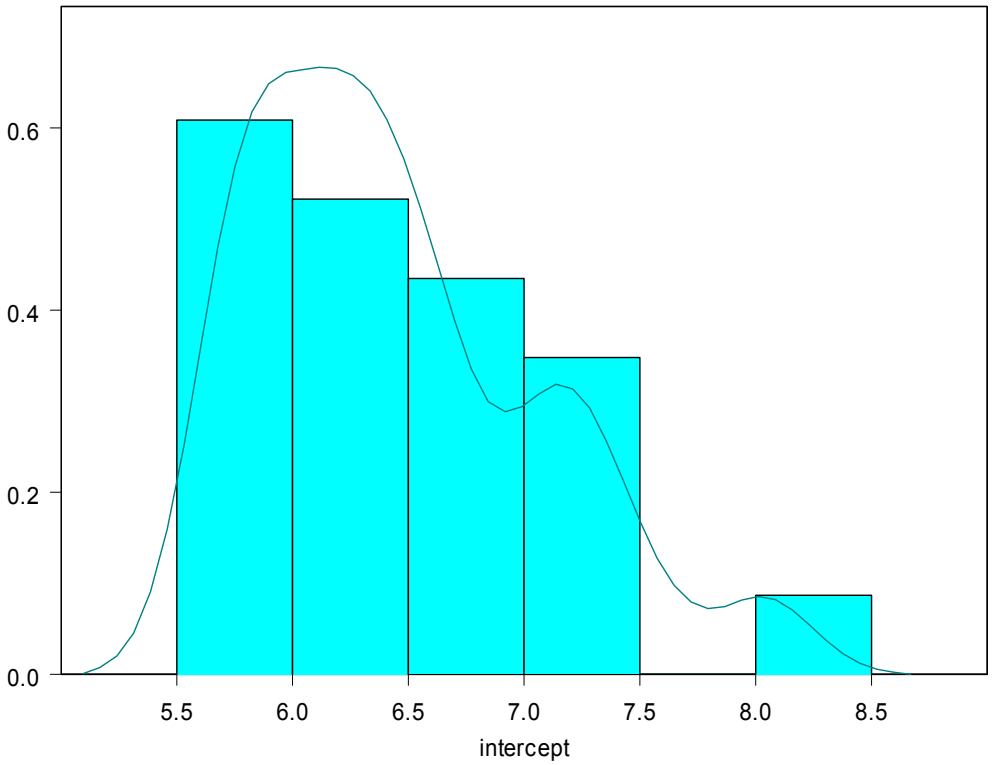
$$TPA = \left(\frac{688.0}{QMD} \right)^{1.5159} \qquad (2)$$

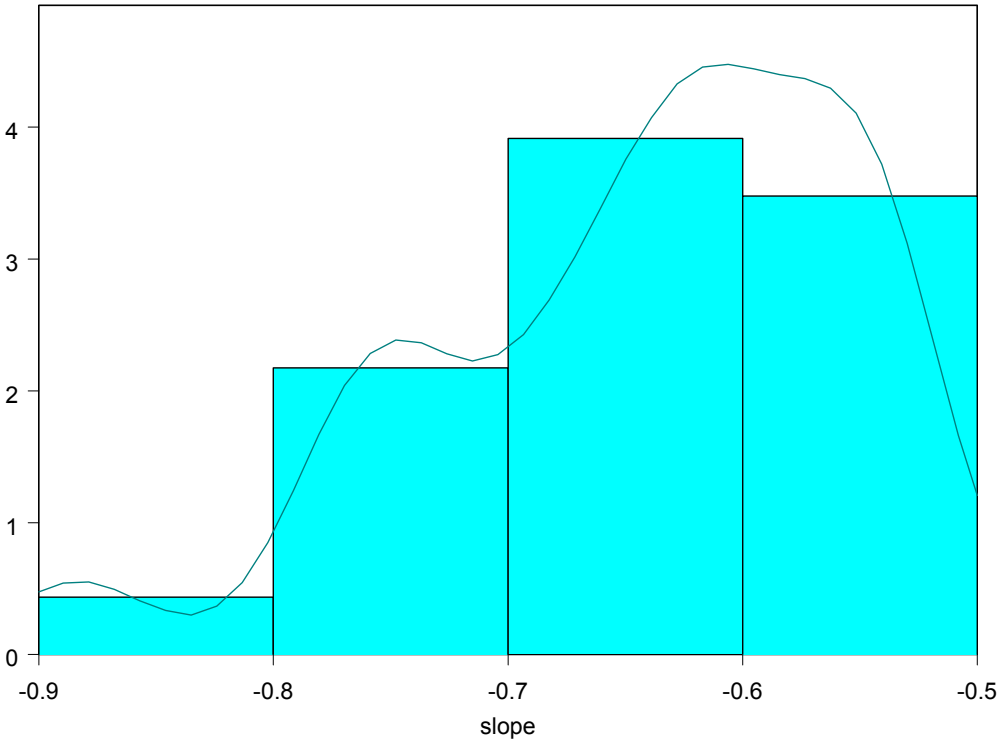
The confidence interval about the slope estimate is: $1.4151 \leq \text{slope} \leq 1.6323$ which overlaps Reineke's slope. The maximum SDI from equation (2) is 610.5.

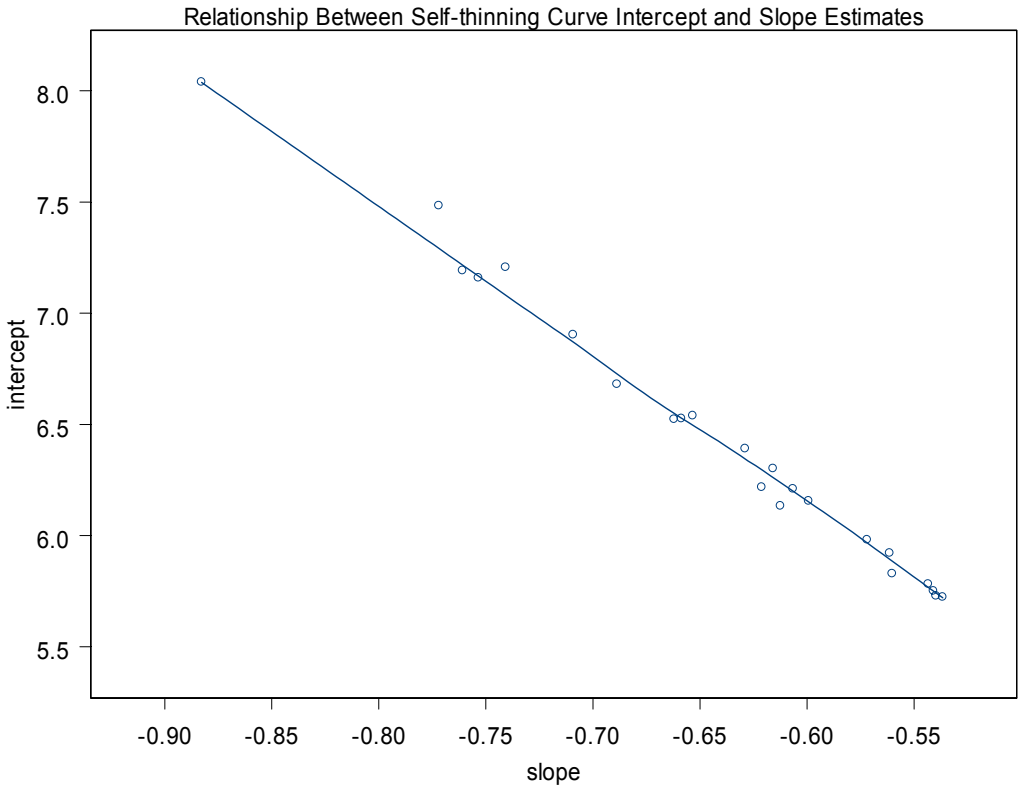
A near linear relationship between the intercept and slope exists for the 23 plots (shown on page 5). A linear regression of these points resulted in the following equation (note that the slope value used in the regression and following graphs is the negative inverse of the slope used in the size-density equations presented):

$$intercept = 2.0348 - 6.8544 * slope \quad (3)$$

Residual SE = 0.05985; $r^2 = 0.9913$.







Using equation 3, a maximum SDI estimate can be obtained assuming that the true slope of the size-density curve is equal to Reineke's 1.605. Using that assumption, equation 3 predicts a maximum SDI of 616.8.

Approach 3: Individual Plot Regressions by Study Type

Approach 3 uses the same methodology as approach 2, applying it to the two study type subsets. The following equations are estimated from the procedure:

$$TPA = \left(\frac{789.4}{QMD}\right)^{1.4779} \qquad \text{PCT Control Plots} \qquad (4)$$

$$TPA = \left(\frac{419.4}{QMD}\right)^{1.7129} \qquad \text{Silviculture Study Plots} \qquad (5)$$

The 95% confidence intervals for each equation's slope estimates and their maximum SDIs are:

Study Type	Lower Confidence Limit	Upper Confidence Limit	Maximum SDI
PCT Control	1.3739	1.5990	636.9
Silviculture Control	1.5951	1.8407	601.7

Note that the PCT Control plots' slope estimate does not overlap the Reineke slope. Intercept-slope regressions were performed on each data subset. The estimated equations and their maximum SDI estimates using a Reineke slope are:

PCT:
$intercept = 1.9823 - 6.9300 * slope$, Residual SE= 0.0728 (6)
maximum Reineke SDI = 504.2 *(NOTE: this estimate not supported by the data)*

Silviculture:
$intercept = 2.2639 - 6.4662 * slope$, Residual SE=0.0214 (7)
maximum Reineke SDI = 592.5

Discussion and Final Analysis

The table below summarizes the maximum SDI estimates obtained using the above approaches. The range in estimates is from 504.2 to 636.9. The first observation is that these values are smaller to substantially smaller than the default value in ORGANON. The second observation is that two of the three approaches resulted in trajectory equations with slopes significantly different from Reineke's. Given the consistency of Approach 2 with Reineke's slope and its compatibility with Marshall's (1998) analysis, it was selected as the basis for all further work.

Approach	**Maximum SDI Estimate**
1 – Pooled Across All Plots	540.9
2 – Individual Plot Regressions	610.5*
2 – Reineke Slope Adjusted	616.8
3 – PCT Plots	636.9
3 – Silviculture Plots	601.7*
3 – PCT Plots, Reineke Slope Adjusted	504.2
3 – Silviculture Plots, Reineke Slope Adjusted	592.5

*Slope estimate not significantly different from Reineke slope of 1.605.

The next step in the analysis was to combine the Rayonier data with the data used in the SMC variant. The table below summarizes the SMC dataset.

"PCT" Study Control Plots	Mean Site = 122	N_g = 231 growth periods	N_p = 35 plots
	Mean	**Min**	**Max**
Trees per Acre (TPA)	1190.6	259.0	3750.0
Basal Area per Acre (BA)	289.7	158.2	401.7
Quadratic Mean Diameter (QMD)	7.9	3.5	16.3
Stand Density Index (SDI)	598.1	410.4	832.7

Regression estimates for the log-log stand density equation for each of the 35 plots were added to the 23 estimates from the Rayonier dataset. The following equation results from the intercept and slope means:

$$TPA = \left(\frac{472.3}{QMD} \right)^{1.6546} \tag{8}$$

The confidence interval about the slope estimate is: $1.5912 \leq \text{slope} \leq 1.7232$ which overlaps Reineke's slope. The maximum SDI from equation (8) is 588.9.

The combined dataset also displayed a linear relationship between the intercept and slope. A linear regression on the log-log parameter estimates yielded the following equation:

$$intercept = 2.0397 - 6.8132 * slope \text{ , Residual SE=0.07324, } r^2=0.98 \tag{9}$$

Equation 9 produces a maximum Reineke SDI of 596.6[1]. Thus, the final maximum size-density equation, using a Reineke slope is:

$$TPA = \left(\frac{536.3}{QMD} \right)^{1.605} \tag{10}$$

Equation 10 suggests a lower carrying capacity for western hemlock than the existing ORGANON SMC variant. It is recommended as a replacement for the SMC estimate in future versions of the model.

[1] An alternative method of estimating the intercept of the size-density equation is to fix the slope at 1.605 and compute the intercept. That procedure results in an intercept value of 536.1 versus the 536.3 using the present method.

Literature Cited

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