Hardwood Silviculture Cooperative

Annual Report
2005–2006

Oregon State University

Current research has shown treatment effects in conifers, but no work has been done on hardwoods. This dataset/project provides a great opportunity to test these effects.

Red Alder Diameter and Height Growth Equations

The value of the HSC dataset extends beyond the realm of this cooperative and into many other aspects of regional forestry research. As previously mentioned, the HSC dataset will be used in conjunction with the taper project data to test how stand conditions (i.e. treatments) affect tree shape. In addition, researchers interested in developing annualized diameter and height growth equations knew about this dataset and therefore asked the HSC if they could use the dataset to develop these equations for red alder. The full manuscript will be published in the very near future but included below are the preliminary results pertaining to red alder.

Development of Annualized Diameter and Height Growth Equations for Red Alder: Preliminary Results

Aaron Weiskittel[1], Sean M. Garber[1], Greg Johnson[2], Doug Maguire[1], and Robert A. Monserud[3]

Introduction

Most individual-tree based growth and yield models use a 5- to 10-year time step, which can make projections for a fast-growing species like red alder quite difficult. Further, it is rather cumbersome to simulate the effects of intensive silvicultural treatments such as thinning or pruning on a time step longer than one year given the highly dynamic nature of growth following treatment. The goal of this project was to provide preliminary annualized individual tree diameter and height growth equations for untreated red alder using a technique that can incorporate data with varying remeasurement intervals. An additional modeling technique was used to partition out the variation in growth unexplained by attributes of the tree and stands and an attempt was made to relate it to installation edaphic characteristics.

Methods

For this analysis, the untreated control plots from Hardwood Silviculture Cooperative Type 2

[1]Department of Forest Science, Oregon State University, Corvallis, OR 97333
[2]Weyerhaeuser Company, P.O. Box 9777, Federal Way, WA 98063-9777
[3]PNW Research Station, USDA Forest Service, 620 SW Main, Suite 400, Portland, OR USA 97205

(variable density alder plantations) were used (Table 7). The diameter and height growth equations of Hann et al. (2003) were used:

[1]

$$\Delta DBH = e^{\beta_{10}+\beta_{11}\log(DBH+1)+\beta_{12}DBH^2+\beta_{13}\log\left(\frac{UCR+0.2}{1.2}\right)+\beta_{14}\log(SI-1.37)+\beta_{15}\frac{BAL^2}{\log(DBH+5)}+\beta_{16}\sqrt{SBA}+\beta_{17}I_{CR}} + \varepsilon_1$$

[2]

$$\Delta HT = PHT * \beta_{20}\left[\beta_{21}\, e^{\beta_{22}CCH} + (e^{\beta_{23}\sqrt{CCH}} - \beta_{21}\, e^{\beta_{22}CCH})\, e^{-\beta_{26}(1-UCR)^2}\, e^{\beta_{25}\sqrt{CCH}}\right] + \varepsilon_2$$

where: ΔDBH is the annual diameter growth in cm, DBH is diameter at breast height (cm), UCR is uncompacted crown ratio estimated using the equation of Monleon et al. (2004), SI is 25-year site index, BAL is basal area in larger trees ($m^2\ ha^{-1}$), SBA is stand basal area ($m^2\ ha^{-1}$), I_{CR} is an indicator crown ratio measurement (1 if CR wasn't measured, 0 otherwise), PHT is potential height growth estimated from a dominant height growth curve and tree growth effective age (Ritchie and Hann, 1986), CCH is percent crown closure of the plot at the tip of the subject tree estimated with the largest crown width equation of Hann (1997) the β_i's are parameters to be estimated from the data using the iterative method of Cao (1999), and $\varepsilon_i \sim MVN(0, \Sigma)$. Site index was calculated using the equations of Harrington (1986), Harrington and Curtis (1986), and Nigh and Courtin (1998).

Table 7. Description of the diameter and height growth rate data sets for red alder. Definition of variables are: DBH is diameter at breast height (cm), UCR is uncompacted crown ratio, BAL is basal area in larger trees ($m^2\ ha^{-1}$), SBA is stand basal area ($m^2\ ha^{-1}$), BH AGE is mean breast-height stand age, and SI is site index

	Diameter growth		Height growth	
Variable	Range	Mean	Range	Mean
Individual Tree	*N = 46, 546*		*N = 11, 816*	
DBH (cm)	0.1 – 35.1	5.9	0.1 – 28.2	5.6
UCR	0.47 – 0.99	0.73	0.1 – 0.99	0.78
BAL ($m^2\ ha^{-1}$)	0.0 – 36.9	4.7	0.0 – 36.9	4.7
Individual Plot	*N = 132*		*N = 132*	
SBA ($m^2\ ha^{-1}$)	2.0 – 37.0	6.8	2.0 – 37.0	6.8
BH AGE	6.1 – 33.6	8.5	6.1 – 33.6	8.5
SI (Nigh and Courtin 1998; m at 25-yr)	15.9 – 40.0	26.05	15.9 – 40.0	24.8
length of growing period (years)	2.0 – 4.0	3.0	2.0 – 4.0	3.0

Results

The models fit well and the parameter estimates were consistent with biological expectations (Tables 8, 9). The diameter growth model had a R^2 of 0.66 and a residual standard error of 1.23 cm, while the height growth model had a R^2 of 0.54 and a residual standard error of 0.96 m. The models were significantly better with site index values estimated from Nigh and Courtin (1998) when compared to those of Harrington (1986) and Harrington and Curtis (1986).

Examining the installation random effects uncovered a few interesting relationships (Table 10). The intercept of the diameter growth equation (β_{10}) was related to longitude, slope, and aspect. The parameter estimates indicated that the intercept tended to be highest on north areas with no slope. For the height growth equation, the asymptote (β_{20}) was related to percent slope and aspect. The parameter estimates again indicated that the asymptote was highest on east facing slopes. These models, however, explained a limited amount of the original variation.

Table 8. Parameters and asymptotic standard errors for predicting the diameter growth rate (equation [1]) of untreated red alder fitted using maximum likelihood and multi-level mixed effects. R^2, residual standard error, and AIC value for each model are also given.

Parameter/ Standard error	Maximum Likelihood	Multi-level mixed effects
β_{10}	-3.616555	-3.480545
SE(β_{10})	(0.05921907)	(0.4565763)
β_{11}	0.384745	0.395343
SE(β_{11})	(0.01246730)	(0.0064997)
β_{12}	-0.001467	-0.000780
SE(β_{12})	(0.00009227)	(0.0000294)
β_{13}	1.300054	1.589029
SE(β_{13})	(0.01793383)	(0.0249642)
β_{14}	1.361945	1.268489
SE(β_{14})	(0.02765335)	(0.1402212)
β_{15}	-0.008478	-0.002222
SE(β_{15})	(0.00034888)	(0.0000703)
β_{16}	-0.242575	-0.392638
SE(β_{16})	(0.00578318)	(0.0042780)
β_{17}	-0.064802	-0.019347
SE(β_{17})	(0.00675081)	(0.0037130)
R^2	0.66	0.83
Residual standard error	1.23	1.04
AIC	157,431.4	147,099.2

Table 9. Parameters and asymptotic standard errors for predicting the height growth rate (equation [2]) of untreated red alder fitted using maximum likelihood and multi-level mixed effects. R^2, residual standard error, and AIC value for each model are also given.

Parameter/ Standard error	Maximum Likelihood	Multi-level mixed effects
β_{20}	0.9286	0.9415
SE(β_{20})	(0.0067)	(0.0230)
β_{21}	0.6176	0.3833
SE(β_{21})	(0.0411)	(0.0816)
β_{22}	-0.0050	-0.0075
SE(β_{22})	(0.0015)	(0.0063)
β_{23}	-0.0048	-0.0089
SE(β_{23})	(0.0024)	(0.0020)
β_{24}	4.1802	2.9185
SE(β_{24})	(0.8516)	(0.6589)
β_{25}	0.0418	0.0
SE(β_{25})	(0.0298)	(NA)
R^2	0.54	0.65
Residual standard error	1.14	0.96
AIC	37,584.1	34,943.6

Table 10. Model, equation form, R^2, and root mean square error (RMSE) for model predicting the influence of physiographic features on the random effects of each model. All parameter estimates were significant at $\alpha = 0.05$. Variable definitions are: ELEV is elevation (m), SLOPE% is percent slope, SINA is the sine transformation of aspect [sin(2*π*(aspect/360))], ASP12 is cosine transformation of slope and aspect [%SLOPE* cos(4*π*(aspect/360))], ASP2 is the percent slope multiplied by SINA, and ASP22 is sine transformation of slope and aspect [SLOPE% * sin(4*π*(aspect/360))]. The transformations of slope and aspect follow those suggested by Stage (1976).

Model	Response parameter	Equation form	R^2	RMSE
[1]	β_{10}	0.5147 – 0.0754*ln(ELEV) – 0.0053*SLOPE% -0.4640*ASP12	0.42	0.10
[2]	β_{20}	-0.0083 + 0.0735*SINA – 0.2458*ASP2 + 0.1978*ASP22	0.30	0.07

Discussion

The diameter growth equation demonstrates a well-defined peaking behavior over initial diameter. There is a rapid increase in diameter growth, peaking around 10 cm, followed by a rapid decrease. The parameter estimates on the transformations of site index and crown ratio were greater than 1.0 suggesting an increasing response in diameter growth with progressive greater site index and larger crowns. This equation also demonstrates the impact of competition on the diameter growth rate via the effect of stand basal area. Red alder is highly responsive to increasing stand basal area relative to similar fits for Douglas-fir (Weiskittel et al., in review).

The dominant height growth equation of Nigh and Courtin (1998) represented the dominant height growth in these plots better than the equations of Harrington (1986) and Harrington and Curtis (1986). Density effects on dominant height growth in red alder are well-known and documented. However, none of the existing red alder dominant height growth equations account for this. A preliminary attempt was made to fit a new a dominant height growth curve that accounted for the effects of density, but the dataset was not extensive enough to provide adequate fits. Efforts were also made to address the effects of density within the height growth modifier; however, the residuals showed no bias with stand density or other variables of importance. Currently, the ability of other individual tree competition variables (e.g. Biging and Dobbertin, 1995) to better account for stand density are being explored.

The equations presented in this report represent a first attempt to model the annual diameter and height growth patterns of red alder. The model forms used here are those that are currently used in ORGANON (Hann, 2003). However, the fit statistics were not as good as those for Douglas-fir (Weiskittel *et al.*, in review). A likely reason for this is these models were primarily developed for coastal Douglas-fir. This suggests that Douglas-fir model forms may need additional adjustments for red alder. Similar findings were made modeling other species in southwest Oregon (Hann and Hanus, 2002; Hann *et al.*, 2003).

The current red alder dataset has limited data from the later stages of stand development. For example, only one installation with its remeasurement at age 17 was available. Therefore, the widest initial planting densities have not reached relative densities where density-dependent mortality is occurring. The continued remeasurement of the HSC Type 2 installations will prove invaluable for developing more robust parameter estimates. Moreover, the iterative technique used to fit the equations proved quite useful and robust. This analytical technique is especially advantageous for these plots because the changing remeasurement interval after year 12 from three to five years. Future efforts will be made to refine the current models, develop silvicultural treatment modifiers for these equations, and develop annualized crown recession and mortality functions.

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