03 Extension Note

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A Variable Growth Intercept Model for Sitka Spruce

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Abstract

Thirty-eight Sitka spruce stem analysis plots in the Queen Charlotte Islands were sampled and the height growth of the top height trees was reconstructed. A variable growth intercept model was developed for Sitka spruce from these data. This model (or a table) will be used to estimate site index for silviculture planning and other applications. Further research areas are identified that could improve the model.

Introduction

Growth intercept models allow site index to be accurately estimated in young stands. In British Columbia, site index is the top height of a stand at breast height (bh) age 50 (i.e., when the trees have 50 annual growth rings at breast height). Traditional growth intercept models estimate site index from the average annual height growth immediately above breast height. Typically, the height growth is identified from the annual branch whorls and is averaged over a 5-year period. The average annual height growth is called the growth intercept. The variable growth intercept modelling technique generalizes this procedure by estimating site index from the average height growth above breast height using all the height, not just 5 years. This technique is applied to Sitka spruce (*Picea sitchensis* (Bong.) Carr.) in the Queen Charlotte Islands of British Columbia, Canada, and the results are reported here.

Data

The data for this study come from 40 sample plots (10.75-m radius) located in edatopically uniform areas of even-aged Sitka spruce leading (>60% basal area) stands in the Queen Charlotte Islands. Sampling was targeted to uniformly cover the range of observed site indices for Sitka spruce. Three trees in each plot whose height growth reflected the productivity of the site were identified and marked for stem analysis. To reflect the productivity, the rate at which these trees grew in height must have been a function of site quality; hence, trees whose height growth was impeded by other factors such as insect/disease attacks or suppression were unacceptable. The sample trees were at least 50 years bh age and the range of their estimated site indices (Barker and Goudie 1987) was targeted to be less than 2 metres. The 2-metre range helped winnow out rogue trees. Plot data included species and diameter at breast height (dbh) of all trees in the plot greater than 7.5 cm dbh.[1]

The three sample trees in each plot were felled and sectioned. Sectioning was done at stump height (30 cm), breast height (1.3 m), and at nine other equally spaced locations between breast height and the top of the tree. The rings on each disk were counted twice or until two identical counts were obtained.

Methods

The height-ring count data were converted to height-bh age data by subtraction, and a correction was applied to the tree heights to remove stem sectioning bias (Newberry 1991; Nigh 1995b). Top height was calculated by averaging the heights of the three sample trees in each plot for each bh age from one up to the age of the youngest sample tree in the plot. The individual tree height and top height data were graphed (by plot) against bh age to detect damaged or suppressed trees. Some trees and plots had abnormal growth that may have been caused by damage or suppression. A residual analysis indicated that two of these plots (plots 35 and 39) were outliers. Therefore, these plots were deleted from the analysis.

The site index (the predicted variable) and the growth intercepts (the predictor variables) for each plot were obtained from the height-age data. The growth intercepts were calculated (equation [1]) for each bh age between one and 30.

[1] $$GI_{i,BHA} = \frac{H_i - 1.3}{BHA - 0.5} \times 100$$

where: $GI_{i,\,BHA}$ = growth intercept (cm/year) for plot i at bh age BHA years,
and H_i = top height (m) of plot i at bh age BHA years.

In equation [1], 0.5 is subtracted from the bh age (ring count at breast height) because, on average, the innermost ring represents only a half year's growth (Nigh 1995b).

The relationship between site index and growth intercept for each bh age between one and 30 was modelled with a power function (Sit and Poulin-Costello 1994) (equation 2), which has worked well for other species (Nigh 1995a, 1995c, 1995d).

[2] $$SI_i = f(b_0) \times GI_{i,BHA}^{b_1} + \varepsilon_i$$

where: SI_i = site index (m @ bh age 50) for plot i,
$f(b_o)$ = e^{b_0},
b_o, b_1 = model parameters,
ε_i = random error term for plot i,
and all other parameters are as previously defined.

The model parameters were estimated with procedure NLIN (SAS Institute Inc. 1988). Each model was analyzed for intrinsic and parameter-effects nonlinearity and parameter bias (Ratkowsky 1983). Parameter b_o is expressed as a function to reduce parameter-effects nonlinearity. An analysis of the residuals was done to confirm the regression assumptions of unbiasedness, normality, and homoscedasticity (Sen and Srivastava 1990).

Results and Discussion

The growth intercept model for bh ages one to 30 are in Table 1. Table 2 presents the parameter estimates, their standard errors, and the root mean squared error for the 30 models. The residual analysis indicates that the models are unbiased and that the residuals are homoscedastic and normally distributed, except for slight evidence of non-normality in the models for bh ages 29 and 30. No significant trends were detected when

1 Additional data available include site and vegetation descriptions (Luttmerding et al. 1990), soil moisture and nutrient regimes, and biogeoclimatic site series (Green and Klinka 1994).

TABLE 1 *Sitka spruce growth intercept model for bh ages one to 30*

bh age	Model	bh age	Model
1	$\hat{SI} = 3.317 \times GI_1^{0.5634}$	16	$\hat{SI} = 2.248 \times GI_{16}^{0.6373}$
2	$\hat{SI} = 3.277 \times GI_2^{0.5663}$	17	$\hat{SI} = 2.056 \times GI_{17}^{0.6574}$
3	$\hat{SI} = 3.287 \times GI_3^{0.5654}$	18	$\hat{SI} = 1.911 \times GI_{18}^{0.6738}$
4	$\hat{SI} = 3.232 \times GI_4^{0.5699}$	19	$\hat{SI} = 1.794 \times GI_{19}^{0.6879}$
5	$\hat{SI} = 3.164 \times GI_5^{0.5756}$	20	$\hat{SI} = 1.680 \times GI_{20}^{0.7026}$
6	$\hat{SI} = 3.140 \times GI_6^{0.5776}$	21	$\hat{SI} = 1.568 \times GI_{21}^{0.7182}$
7	$\hat{SI} = 3.281 \times GI_7^{0.5658}$	22	$\hat{SI} = 1.456 \times GI_{22}^{0.7349}$
8	$\hat{SI} = 3.463 \times GI_8^{0.5502}$	23	$\hat{SI} = 1.355 \times GI_{23}^{0.7514}$
9	$\hat{SI} = 3.540 \times GI_9^{0.5421}$	24	$\hat{SI} = 1.273 \times GI_{24}^{0.7656}$
10	$\hat{SI} = 3.508 \times GI_{10}^{0.5418}$	25	$\hat{SI} = 1.220 \times GI_{25}^{0.7753}$
11	$\hat{SI} = 3.386 \times GI_{11}^{0.5481}$	26	$\hat{SI} = 1.185 \times GI_{26}^{0.7820}$
12	$\hat{SI} = 3.224 \times GI_{12}^{0.5578}$	27	$\hat{SI} = 1.155 \times GI_{27}^{0.7877}$
13	$\hat{SI} = 2.982 \times GI_{13}^{0.5746}$	28	$\hat{SI} = 1.126 \times GI_{28}^{0.7938}$
14	$\hat{SI} = 2.708 \times GI_{14}^{0.5959}$	29	$\hat{SI} = 1.089 \times GI_{29}^{0.8020}$
15	$\hat{SI} = 2.474 \times GI_{15}^{0.6158}$	30	$\hat{SI} = 1.074 \times GI_{30}^{0.8052}$

$\hat{SI}$ = estimated site index
GI_n = growth intercept for bh age n

the residuals were plotted against the soil moisture and nutrient regimes, slope, aspect, elevation, basal area, and number of stems per hectare. The nonlinearity analysis indicates that the model parameters have an acceptably low nonlinear behaviour. Figure 1 is a graphical example of the data points and model (bh age 10).

A variable growth intercept model is now available for Sitka spruce for bh ages one to 30. This modelling procedure has become methodical; more information about it can be found in Nigh (1995a, 1995c, 1995d). The height-age model should be used to estimate site index for stands older than age 30.

Applying the model involves identifying the target stand or silviculture opening and establishing growth intercept plots. In each plot, the top height tree(s) are identified and the total height and ring count at breast height (i.e., bh age) are recorded. The growth intercept is calculated (equation [1]) and the site index is predicted from the model for the tree's bh age (Table 1). Alternatively, the site index can be obtained by inputting bh age and height into Table 3. The predicted site indices from the trees in each

TABLE 2 *Results of the analysis of the variable growth intercept model*

bh age	Parameter estimate[a]		Root mean squared error	bh age	Parameter estimate[a]		Root mean squared error
1	b_0: 1.199	(0.2667)	4.150	16	b_0: 0.8100	(0.2752)	3.691
	b_1: 0.5634	(0.06749)			b_1: 0.6373	(0.06696)	
2	b_0: 1.187	(0.2702)	4.175	17	b_0: 0.7210	(0.2735)	3.570
	b_1: 0.5663	(0.06837)			b_1: 0.6574	(0.06634)	
3	b_0: 1.190	(0.2700)	4.175	18	b_0: 0.6478	(0.2702)	3.457
	b_1: 0.5654	(0.06831)			b_1: 0.6738	(0.06538)	
4	b_0: 1.173	(0.2711)	4.165	19	b_0: 0.5844	(0.2643)	3.334
	b_1: 0.5699	(0.06859)			b_1: 0.6879	(0.06382)	
5	b_0: 1.152	(0.2706)	4.132	20	b_0: 0.5189	(0.2574)	3.200
	b_1: 0.5756	(0.06851)			b_1: 0.7026	(0.06201)	
6	b_0: 1.144	(0.2704)	4.122	21	b_0: 0.4497	(0.2495)	3.056
	b_1: 0.5776	(0.06847)			b_1: 0.7182	(0.06001)	
7	b_0: 1.188	(0.2668)	4.143	22	b_0: 0.3758	(0.2398)	2.893
	b_1: 0.5658	(0.06746)			b_1: 0.7349	(0.05756)	
8	b_0: 1.242	(0.2653)	4.199	23	b_0: 0.3035	(0.2302)	2.738
	b_1: 0.5502	(0.06688)			b_1: 0.7514	(0.05517)	
9	b_0: 1.264	(0.2674)	4.247	24	b_0: 0.2414	(0.2217)	2.605
	b_1: 0.5421	(0.06711)			b_1: 0.7656	(0.05307)	
10	b_0: 1.255	(0.2704)	4.257	25	b_0: 0.1989	(0.2147)	2.502
	b_1: 0.5418	(0.06755)			b_1: 0.7753	(0.05136)	
11	b_0: 1.220	(0.2743)	4.239	26	b_0: 0.1695	(0.2078)	2.410
	b_1: 0.5481	(0.06820)			b_1: 0.7820	(0.04968)	
12	b_0: 1.171	(0.2777)	4.199	27	b_0: 0.1445	(0.2001)	2.313
	b_1: 0.5578	(0.06873)			b_1: 0.7877	(0.04781)	
13	b_0: 1.092	(0.2778)	4.089	28	b_0: 0.1187	(0.1921)	2.212
	b_1: 0.5746	(0.06841)			b_1: 0.7938	(0.04588)	
14	b_0: 0.9960	(0.2757)	3.933	29	b_0: 0.08506	(0.1852)	2.118
	b_1: 0.5959	(0.06757)			b_1: 0.8020	(0.04423)	
15	b_0: 0.9060	(0.2750)	3.807	30	b_0: 0.07145	(0.1785)	2.040
	b_1: 0.6158	(0.06714)			b_1: 0.8052	(0.04263)	

[a]The standard errors of the parameter estimates are in brackets.

sample plot are averaged to give a plot site index. The plot site indices are averaged to give a stand site index. The growth intercept survey should be delayed as long as possible to improve the accuracy of site index estimates because, in general, site index estimates improve when the sample trees are closer to bh age 50. A field guide with details on growth intercept sampling is available (British Columbia Ministry of Forests 1995).

Spruce weevil (*Pissodes strobi* Peck) is a major pest of Sitka spruce trees in coastal British Columbia (Alfaro and Omule 1990). Since this insect attacks trees primarily when they are young, growth intercept measurements may be biased in infested stands. Therefore, growth intercepts calculated from these trees will lead to biased site index estimates. Site index estimates can still be obtained from damaged trees if the growth intercept is measured below the damage. Details of this technique can be found in the growth intercept survey manual (British Columbia Ministry of Forests 1995).

There are several areas where more research could be done on the model:

1. Other geographic regions could be sampled. There is no evidence that the site index – growth intercept relationship varies across geographic and biogeoclimatic zones for other species. Therefore, the Sitka spruce growth intercept model will probably not change significantly with extended sampling. However, this sampling eliminates the need to extrapolate the model to other areas.
2. The model should be tested with an independent data set.
3. The model is substantially less precise than those for other species. The source of this variation could be identified and incorporated into the model.

Conclusion

This report makes a variable growth intercept model available for Sitka spruce. Growth intercept models estimate site index from the sample tree's total height and bh age taken during a survey. These models can be used in weevil-damaged stands if the measurements are taken below the damaged portion of the stem. The data and analysis point out potential areas for further research.

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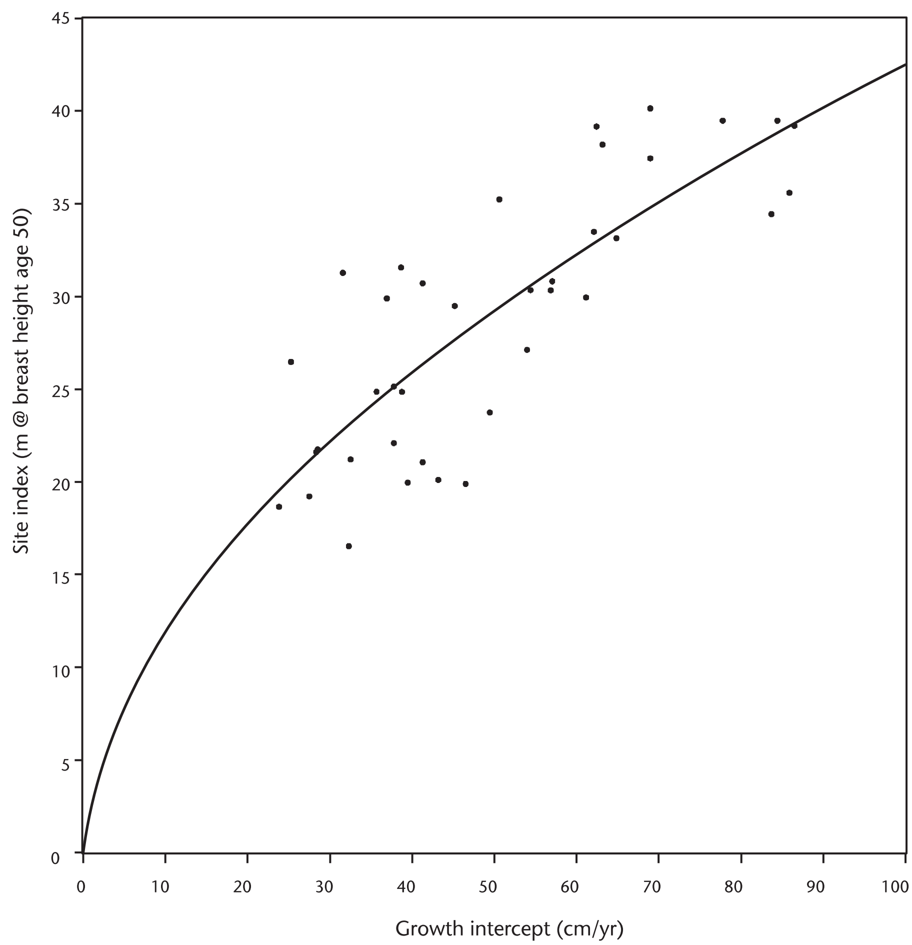

FIGURE 1 *Breast height age 10 growth intercept model (———) overlaid on the data points (•) used to develop the model.*

TABLE 3 *Estimated Sitka spruce site indices from the variable growth intercept model*

bh age*	Top Height (m)																												
	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
	Site Index (m at bh age 50)																												
1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	28.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	21.6	35.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	17.8	29.5	38.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	15.4	25.6	33.4	40.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	13.6	22.8	29.8	35.7	41.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	12.6	20.8	27.0	32.3	37.0	41.2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	11.8	19.3	24.9	29.6	33.7	37.5	41.0	44.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	11.1	18.0	23.1	27.4	31.2	34.6	37.8	40.7	43.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	10.4	16.7	21.5	25.5	29.0	32.2	35.2	38.0	40.5	43.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	-	15.6	20.1	23.9	27.2	30.2	33.0	35.6	38.1	40.5	42.7	44.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	-	14.5	18.7	22.4	25.5	28.4	31.1	33.6	36.0	38.3	40.4	42.5	44.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	-	13.4	17.4	20.9	24.0	26.8	29.4	31.8	34.1	36.3	38.5	40.5	42.4	44.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	12.3	16.1	19.5	22.5	25.2	27.7	30.1	32.4	34.6	36.7	38.7	40.6	42.5	44.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	11.3	15.0	18.2	21.1	23.7	26.2	28.6	30.8	32.9	35.0	37.0	38.9	40.7	42.5	44.3	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	10.3	13.9	17.0	19.8	22.4	24.8	27.1	29.3	31.4	33.4	35.4	37.3	39.1	40.9	42.7	44.4	-	-	-	-	-	-	-	-	-	-	-	-
17	-	-	12.9	15.9	18.6	21.1	23.5	25.7	27.9	29.9	31.9	33.9	35.7	37.6	39.3	41.1	42.8	44.4	-	-	-	-	-	-	-	-	-	-	-
18	-	-	12.1	14.9	17.5	20.0	22.3	24.5	26.6	28.6	30.5	32.4	34.3	36.1	37.8	39.5	41.2	42.9	44.5	-	-	-	-	-	-	-	-	-	-
19	-	-	11.3	14.1	16.6	19.0	21.2	23.3	25.4	27.3	29.2	31.1	32.9	34.7	36.4	38.1	39.7	41.3	42.9	44.5	-	-	-	-	-	-	-	-	-
20	-	-	10.6	13.3	15.7	18.0	20.2	22.2	24.2	26.1	28.0	29.8	31.6	33.3	35.0	36.7	38.3	39.9	41.5	43.0	44.5	-	-	-	-	-	-	-	-
21	-	-	10.0	12.5	14.9	17.1	19.2	21.2	23.1	25.0	26.9	28.6	30.4	32.1	33.7	35.4	37.0	38.5	40.1	41.6	43.1	44.6	-	-	-	-	-	-	-
22	-	-	-	11.8	14.1	16.2	18.2	20.2	22.1	23.9	25.7	27.5	29.2	30.8	32.5	34.1	35.7	37.2	38.8	40.3	41.8	43.2	44.7	-	-	-	-	-	-
23	-	-	-	11.1	13.3	15.4	17.4	19.3	21.1	22.9	24.7	26.4	28.1	29.7	31.3	32.9	34.5	36.0	37.5	39.0	40.5	42.0	43.4	44.8	-	-	-	-	-
24	-	-	-	10.5	12.6	14.6	16.5	18.4	20.2	22.0	23.7	25.4	27.0	28.6	30.2	31.8	33.3	34.8	36.3	37.8	39.3	40.7	42.1	43.5	44.9	-	-	-	-
25	-	-	-	10.0	12.1	14.0	15.9	17.7	19.4	21.1	22.8	24.4	26.0	27.6	29.2	30.7	32.2	33.7	35.2	36.6	38.0	39.5	40.9	42.2	43.6	45.0	-	-	-
26	-	-	-	-	11.6	13.5	15.3	17.0	18.7	20.4	22.0	23.6	25.2	26.7	28.2	29.7	31.2	32.6	34.1	35.5	36.9	38.3	39.6	41.0	42.4	43.7	45.0	-	-
27	-	-	-	-	11.1	13.0	14.7	16.4	18.1	19.7	21.3	22.8	24.3	25.8	27.3	28.8	30.2	31.6	33.0	34.4	35.8	37.1	38.5	39.8	41.1	42.4	43.7	45.0	-
28	-	-	-	-	10.7	12.5	14.2	15.9	17.5	19.1	20.6	22.1	23.6	25.1	26.5	27.9	29.3	30.7	32.1	33.4	34.8	36.1	37.4	38.7	40.0	41.3	42.6	43.8	-
29	-	-	-	-	10.3	12.0	13.7	15.3	16.9	18.4	19.9	21.4	22.9	24.3	25.7	27.1	28.5	29.9	31.2	32.5	33.9	35.2	36.5	37.7	39.0	40.3	41.5	42.8	44.0
30	-	-	-	-	10.0	11.7	13.3	14.8	16.4	17.9	19.4	20.8	22.2	23.6	25.0	26.4	27.7	29.0	30.3	31.6	32.9	34.2	35.5	36.7	38.0	39.2	40.4	41.6	42.8

*bh (breast height) age is the number of annual growth rings at breast height.

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