RESEARCH REPORT

25

Juvenile Height Models for Lodgepole Pine and Interior Spruce: Validation of Existing Models and Development of New Models

Gordon D. Nigh

2004

British Columbia
Ministry of Forests
Forest Science Program

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Library and Archives Canada Cataloguing in Publication Data

Nigh, Gordon D. (Gordon Donald), 1956-

Juvenile height models for lodgepole pine and interior spruce : validation of existing models and development of new models

(Research report ; 25)

Includes bibliographical references: p.

ISBN 0-7726-5193-0

1. Lodgepole pine - British Columbia - Growth - Mathematical models. 2. Spruce - British Columbia - Growth - Mathematical models. 3. Lodgepole pine - Yields - British Columbia. 4. Spruce - Yields - British Columbia. 5. Site index (Forestry) - British Columbia. I. British Columbia. Forest Science Program. II. Title. III. Series: Research report (British Columbia. Forest Science Program) ; 25.

SD397.P585N53 2004 634.9'75128'09711 C2004-960087-7

Citation

Nigh, G.D. 2004. Juvenile height models for lodgepole pine and interior spruce: validation of existing models and development of new models. B.C. Min. For., Res. Br., Victoria, B.C. Res. Rep. 25. <http://www.for.gov.bc.ca/hfd/pubs/Docs/Rr/Rr25.htm>

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ABSTRACT

Juvenile height models are available for lodgepole pine (*Pinus contorta* var. *latifolia* Dougl. ex Loud.) and interior spruce (*Picea glauca* (Moench) Voss, *P. engelmanni* Parry ex Engelmann, and *P. glauca* x *engelmanni*). These models were developed with data collected from a small area of British Columbia but are widely used because they are the best available information. The purpose of this project is to validate these models with data from six biogeoclimatic zones where lodgepole pine and interior spruce commonly occur. The target sample size of 10 plots per species per zone could not be met for one of the targeted zones, so another zone was added to the sample plan. One site tree per species in each plot was selected for sampling. The tree was felled and split lengthwise to reveal the pith nodes. Annual height was measured directly from the pith nodes. A rigorous validation procedure was used to validate the models for the province as a whole and on a zone-by-zone basis. The models showed evidence of a slight bias and therefore new models were re-fit to the new data. The functional form of the new model was modified to: 1) prevent predicted heights from being negative for low site indices; 2) improve the fit by allowing the exponent parameter to be a function of site index; and 3) allow all parameters to take on zone-specific values. Most of the difference in height growth across the zones, for a given level of site index, occurred below breast height. Early height growth was greater in the more productive zones. For situations where the models are applied in a zone that was not sampled or where the zone is unknown, the estimated heights are based on averages across all sampled zones. A small validation of the new model for lodgepole pine shows that it is adequate for estimating juvenile heights in the Interior Douglas-fir zone.

ACKNOWLEDGEMENTS

Forest Renewal BC and Forest Innovation Investment Ltd. provided funding for this project. Highland Forestry and Robin B. Clark Inc. collected the data. Peter Ott and Mario di Lucca, Research Branch, B.C. Ministry of Forests, provided valuable review comments.

CONTENTS

INTRODUCTION

The development of juvenile height models in British Columbia started with lodgepole pine (*Pinus contorta* var. *latifolia* Dougl. ex Loud.) (Nigh and Love 1999) and white spruce (*Picea glauca* (Moench) Voss) (Nigh and Love 2000). The white spruce models are applied to interior spruce (*P. glauca*, *P. engelmanni* Parry ex Engelmann, and *P. glauca* x *engelmanni*). The data for these models came mainly from the Sub-Boreal Spruce (SBS) biogeoclimatic zone, with a few plots from the Interior Cedar-Hemlock (ICH) and Engelmann Spruce–Subalpine Fir (ESSF) zones (see Meidinger and Pojar 1991 for a description of all biogeoclimatic zones in British Columbia). All plots were located near Smithers, B.C. Although these projects were pilots, their results are applied throughout the province because they have been the best available information to date. The sampling for other species was more extensive and the results are applicable across the species' range (Nigh 2002; Nigh and Mitchell 2003). The purpose of this study is to validate the juvenile height models for lodgepole pine and interior spruce in the biogeoclimatic zones where these species are common. These zones are the ICH, ESSF, SBS, Interior Douglas-fir (IDF), Montane Spruce (MS), Boreal White and Black Spruce (BWBS), and Sub-Boreal Pine-Spruce (SBPS) zones.

DATA

The original sampling plan called for 10 samples of each species in the ICHmc1/2, ESSFwk1/2, BWBSmw1 or wk1/2/3 (for spruce and pine, respectively), SBPSxc, MSdm1, and IDFdk1/2/3 variants, resulting in 60 plots for each species. However, it was difficult to find enough managed stands in the ESSF zone that met the age requirements, so the SBSdw3 variant was sampled as well.

Data collection proceeded by first using inventory information (electronic files and forest cover maps) to identify managed stands in the appropriate biogeoclimatic variants. These stands were visited in the field, and plots were established if a plot that met the age requirement and the SIBEC sampling standards

(British Columbia Ministry of Forests 2001) could be found. The ages of the sample trees should be a minimum of 15 and 20 years for lodgepole pine and interior spruce, respectively, because this is the age range of the respective juvenile height models. The SIBEC standards call for a 10 m radius ecosystem plot centred on a 5.64 m radius site index plot. The ecosystem plot is homogeneous with respect to site series, and the site index plot must have a suitable site tree of the target species. A site tree is one that is growing at its potential for a given site, and therefore it must be undamaged, unsuppressed, healthy, and vigorous.

Species, diameter at breast height (1.3 m), and crown class of each tree in the site index plot were recorded. The ecosystem was classified using the Ground Inspection Form (British Columbia Ministry of Environment, Lands and Parks and British Columbia Ministry of Forests 1998).

The lodgepole pine and/or interior spruce site trees in each plot were identified and their height growth was measured from the pith nodes. To expose the pith nodes, the roots of the tree were severed below ground and the tree was pushed over and de-limbed. Traverse cuts were then made along the stem at about 20-cm intervals from the base up to where the stem narrowed to about 4 cm. The cuts did not sever the stem but were deep enough to pass through the pith. A wedge and sledgehammer were used to split the sections of the stem to reveal the pith. The pith nodes were identified and the heights of the nodes above the point of germination were recorded, along with any indications of damage.

METHODS

The height–total age data were plotted by species to detect trees with abnormal growth patterns, which indicate that the tree was damaged or suppressed and hence was not a suitable site tree. Any trees that were deemed to be unsuitable site trees were deleted from future analyses. Site index for each tree was estimated using growth intercept models (Nigh 1997, 2004).

The validation procedure is described by Nigh and Sit (1996). The juvenile height models to be validated for lodgepole pine (Nigh and Love 1999) and interior spruce (Nigh and Love 2000) are given in equations 1 and 2, respectively.

$$H = (-0.03993 + 0.004828 \times SI) \times A^{1.902} \times 0.9645^{A} \quad (1)$$

$$H = (-0.01666 + 0.001722 \times SI) \times A^{1.858} \times 0.9982^{A} \quad (2)$$

where: H = tree height (m),
SI = site index (m), and
A = age (yr).

The validation procedure was done by species and by zone within species. The zone within species validation was done to determine whether the height models were valid in some zones but not others.

A fourth-degree polynomial with no intercept term was fit to the errors (actual height minus predicted height) for each tree with powers of age as the "x" (i.e., independent) variables. A fourth-degree polynomial was chosen because it was the lowest-degree polynomial that fit the data well, as judged by the reduction in the mean of the squared errors. A no-intercept polynomial model was used because the height models are conditioned to predict a height of zero at total age zero, so there is no error at age zero. The parameters of these models are used as data in the validation procedure discussed by Nigh and Sit (1996).

The validation procedure indicated that new height-age models for interior spruce and lodgepole pine should be developed. Models developed with the data collected for this project will have a wider geographic range than the existing models because the sampling was more extensive. As well, there are more plots available for the modelling procedure. The old data were not re-used in this analysis because data collection standards have changed since those data were collected. A similar base model was used for both species to model the height-age relationship:

$$H = a_1 \times SI \times A^{a_2 + a_3 \times SI} \times a_4^{A} \quad (3)$$

where: a_1, a_2, a_3, and a_4 = model parameters to be estimated, and the remaining variables are as previously defined.

The difference between model 3 and models 1 and 2 is that the leading coefficient is a constant rather than a function of site index. Models 1 and 2 have the unfortunate property of returning negative heights for small values of site index, which is biologically impossible. Fitting model 3 eliminated this property without giving up significant accuracy. Also in model 3, the exponent for variable A is a linear function of site index. This is the result of a preliminary analysis whereby model 3 was fit without the re-parameterization to each plot individually, and the parameter estimates were plotted against site index. The exponent for variable A varied linearly with site index.

To reduce serial correlation, the first derivative of model 3 with respect to age was fit to growth data. This resulted in parameter estimates for a_1, a_2, a_3, and a_4 for both interior spruce and lodgepole pine. Next, indicator variables were used to detect differences in growth patterns across the different biogeoclimatic zones that were sampled. Adding a linear function of indicator variables (Sen and Srivastava 1990) to the parameter estimates modified the values of the parameters. The indicator variables take on the value of 0 or 1 depending on which zone the plot came from. The parameters were re-parameterized as:

$$\begin{aligned} a_i = {} & a_{i0} + a_{i1} \times \text{BWBS} + a_{i2} \times \text{ESSF} + a_{i3} \\ & \times \text{ICH} + a_{i4} \times \text{IDF} + a_{i5} \times \text{MS} + a_{i6} \times \text{SBS} \\ & + a_{i7} \times \text{SBPS}, \text{ for } i = 1, 2, 3, \text{ and } 4 \end{aligned} \qquad (4)$$

where: BWBS, ESSF, ICH, IDF, MS, SBS, and SBPS are indicator variables that take on the value 1 if the plot came from the Boreal White and Black Spruce, Engelmann Spruce–Subalpine Fir, Interior Cedar-Hemlock, Interior Douglas-fir, Montane Spruce, Sub-Boreal Spruce, or Sub-Boreal Pine-Spruce zone, respectively, 0 otherwise, and

a_{ij}, j = 1, 2, 3, 4, 5, 6, or 7 are parameters to be estimated.

The intercept parameters a_{i0} are taken from model 3; that is, $a_{i0} = a_i$, i = 1, 2, 3, and 4, where a_i is from model 3. The parameters from model 3 represent provincial averages and equation 4 allows these parameters to change incrementally depending on the biogeoclimatic zone. Models were fit to the interior spruce and lodgepole pine data separately. Terms in equation 4 were:

1) deleted if their parameter estimates were not significantly different from zero, or
2) combined if their parameter estimates were close to each other, where the standard error of the parameter estimate was used to evaluate closeness.

No formal statistical test was done for combining terms, but terms were combined only if a noticeable increase in the mean squared error did not occur.

A residual analysis was done to check the regression assumptions of unbiasedness, normality, and homoscedasticity. Unbiasedness was checked with a t-test. Normality was confirmed with the w-statistic (Shapiro and Wilk 1965). Homoscedasticity was observed using graphics of the residuals plotted against age.

The trees in the small validation data set for lodgepole pine were screened for suitability. The validation of the newly developed juvenile height model proceeded as described above for the original models, except that a fifth-degree polynomial with no intercept term was chosen to model the error structure.

RESULTS

One hundred and thirty-six trees were sampled in total. Of these, one lodgepole pine and 13 interior spruce trees had enough damage or suppression to be removed from the data. This left 65 lodgepole pine plots and 57 interior spruce plots for model validation and development. Table 1 shows the mean, minimum, and maximum values for total age, total height, and estimated site index by biogeoclimatic zone.

The validation of models 1 and 2 is presented graphically. Figure 1 shows the results for lodgepole pine and Figure 2 shows the results for interior spruce. Each Figure has multiple parts: one part shows the validation graph for all the data combined and the other parts show the validation graphs for each biogeoclimatic zone. The graphs shows the bias and precision of the models as a function of age. The bias is the mean error in height estimate plotted against total age, and is represented by a solid line. Two dashed lines around the solid line represent the 95% confidence interval for the mean error. The rule used to deem

TABLE 1 *Summary statistics for the sample trees. Means are presented on one line and ranges (minimum–maximum) are presented on the following line.*

	Lodgepole pine				Interior spruce			
Zone	Number of trees	Total age (yr)	Total height (m)	Estimated site index (m)	Number of trees	Total age (yr)	Total height (m)	Estimated site index (m)
BWBS	9	20	7.40	19.48	8	28	7.93	21.50
		(17–28)	(5.98–10.09)	(17.99–22.35)		(21–42)	(5.51–10.10)	(17.01–27.36)
ESSF	4	29	9.91	18.54	5	29	7.04	21.60
		(20–38)	(5.18–13.25)	(16.25–21.20)		(24–35)	(5.25–10.19)	(19.00–24.42)
ICH	10	22	9.46	21.09	9	22	8.53	23.81
		(16–32)	(7.29–12.74)	(16.29–22.99)		(15–33)	(6.22–13.05)	(20.63–30.48)
IDF	11	28	11.15	21.27	10	33	7.53	21.15
		(22–39)	(7.87–14.55)	(19.42–23.23)		(20–46)	(5.58–10.22)	(17.51–23.34)
MS	11	22	10.20	22.85	8	26	7.48	23.01
		(16–27)	(7.54–12.49)	(20.70–24.78)		(19–32)	(5.81–8.92)	(18.07–24.86)
SBPS	10	26	8.21	18.17	11	31	6.47	20.55
		(19–30)	(4.95–10.35)	(16.26–19.77)		(23–43)	(4.86–9.01)	(18.62–22.66)
SBS	10	20	8.52	20.81	6	30	9.98	23.72
		(15–29)	(6.98–10.49)	(17.27–23.50)		(23–43)	(7.21–13.35)	(20.34–27.93)
Total	65	23	9.28	20.55	57	29	7.75	22.08
		(15–39)	(4.95–14.55)	(16.25–24.78)		(15–46)	(4.86–13.35)	(17.01–30.48)

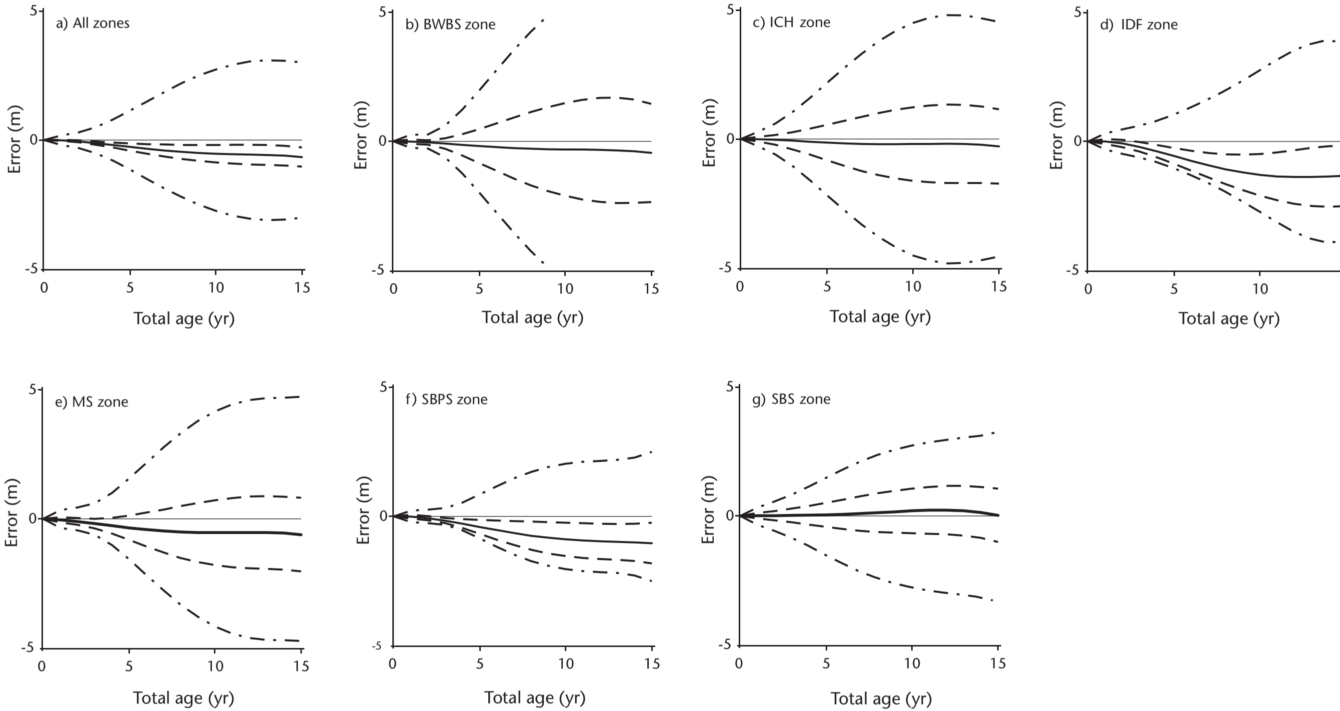

FIGURE 1 *Validation results for lodgepole pine. Part (a) shows the results for all data, parts (b)–(g) show the results for the BWBS, ICH, IDF, MS, SBPS, and SBS biogeoclimatic zones. The mean error in height estimates is shown with a solid line and its 95% confidence interval is shown with dashed lines. The lines with alternating dots and dashes show the precision of the height estimates.*

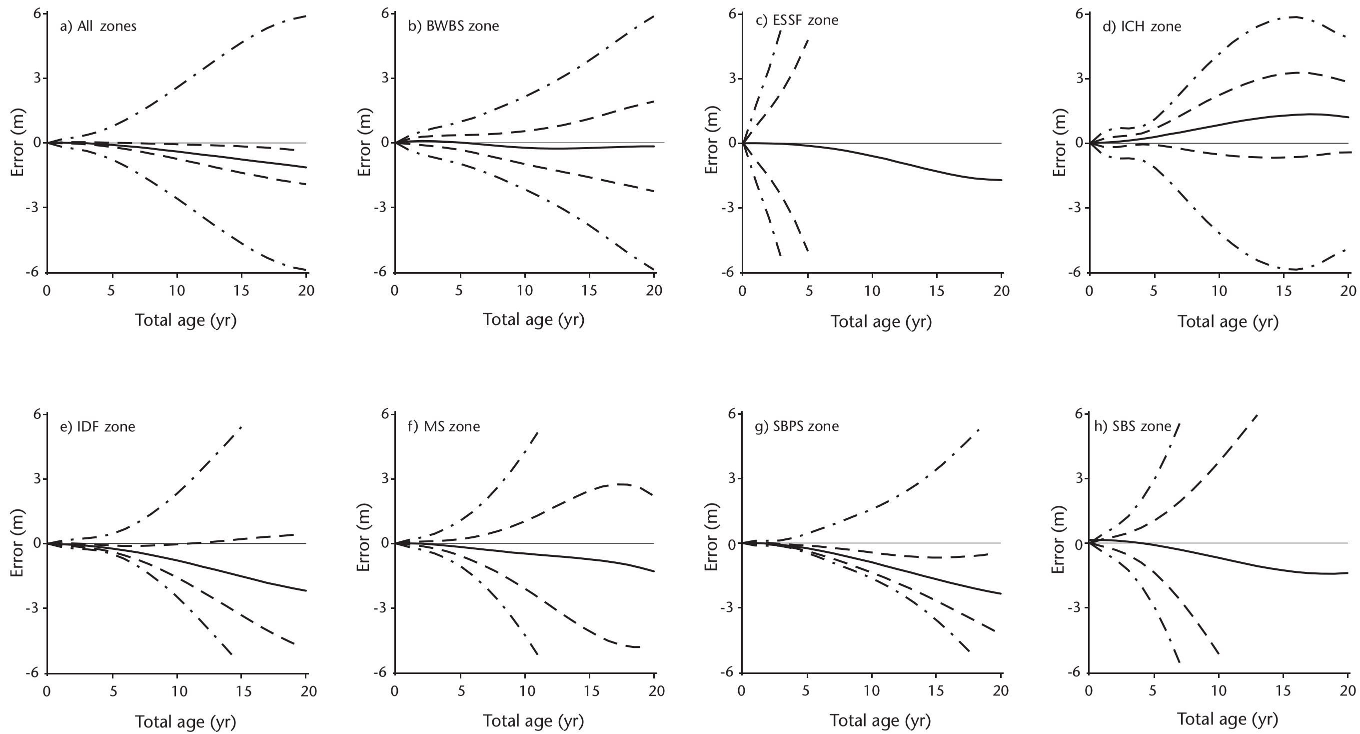

FIGURE 2 *Validation results for interior spruce. Part (a) shows the results for all data, parts (b)–(h) show the results for the BWBS, ESSF, ICH, IDF, MS, SBPS, and SBS biogeoclimatic zones. The mean error in height estimates is shown with a solid line and its 95% confidence interval is shown with dashed lines. The lines with alternating dots and dashes show the precision of the height estimates.*

unbiasedness is that when the confidence interval encloses the horizontal line drawn at zero, then the model is essentially unbiased. The other two lines, consisting of dots and long dashes, show the precision of the models. These lines form an envelope that contains 95% of the errors in height estimates. The model estimates of height are more precise when these lines are closer to zero. The 95% confidence interval for the mean error is sensitive to the sample size. The sample size is small for the individual biogeoclimatic zones, so this must be considered when interpreting the graphs.

The interior spruce and lodgepole pine models both show bias when tested with the complete data set, although the interior spruce curves are unbiased at ages below approximately 5 years total age. The lodgepole pine model is more precise than the spruce model. When examined on a biogeoclimatic zone-by-zone basis, the spruce and pine models were unbiased for the BWBS, ICH, MS, and SBS zones and were biased for the IDF and SBPS zones. There were not enough data to validate the lodgepole pine model for the ESSF zone, and the sample size for spruce was too small to meaningfully validate the spruce model in the ESSF zone. The precision of the models is quite poor when examined on a zone-by-zone basis.

The results of fitting model 3 to the lodgepole pine and interior spruce height-age data are given in Table 2. This Table shows the parameter estimates and their standard errors along with the mean squared error. The models for both species are

TABLE 2 *Results of the fitting of model 3 for lodgepole pine and interior spruce*

	Parameter			Mean squared error
Species	Name	Estimate	Standard error	
Lodgepole pine	a_1	0.001424	0.000198	0.0140
	a_2	1.801	0.0924	
	a_3	0.01820	0.00165	
	a_4	0.9537	0.00654	
Interior spruce	a_1	0.0009952	0.000275	0.0152
	a_2	0.9842	0.149	
	a_3	0.02943	0.00161	
	a_4	1.017	0.00861	

unbiased. There is evidence that the residuals are normally distributed for the lodgepole pine model but not for the spruce model. However, the w-statistic for the spruce model is close to 1, indicating that the residuals are close to normal. The residual plots for both models do not show any severe problems with heteroscedasticity.

The equations for parameters a_1, a_2, a_3, and a_4, after deleting and combining terms, for lodgepole pine are:

$$
\begin{aligned}
a_1 &= a_{10} + a_{11} \times (IDF + SBPS) + a_{12} \times SBS \\
a_2 &= a_{20} + a_{21} \times (BWBS + MS) + a_{22} \times (ICH + SBPS) \\
a_3 &= a_{30} + a_{31} \times ESSF + a_{32} \times ICH + a_{33} \times IDF \\
a_4 &= a_{40} + a_{41} \times (BWBS + ICH + MS) + a_{42} \times SBS \qquad (5)
\end{aligned}
$$

and for interior spruce are:

$$
\begin{aligned}
a_1 &= a_{10} + a_{11} \times ICH + a_{12} \times IDF + a_{13} \times (MS + SBPS) \\
a_2 &= a_{20} + a_{21} \times BWBS + a_{22} \times (ESSF + IDF) \\
&\quad + a_{23} \times (ICH + MS + SBPS + SBS) \\
a_3 &= a_{30} + a_{31} \times BWBS + a_{32} \times ICH \\
&\quad + a_{33} \times (IDF + MS) + a_{34} \times SBS \\
a_4 &= a_{40} + a_{41} \times (ESSF + SBS) + a_{42} \\
&\quad \times ICH + a_{43} \times MS \qquad (6)
\end{aligned}
$$

The parameter estimates for model 3 using parameter equations 5 and 6 for lodgepole pine and interior spruce, respectively, are given in Table 3. Note that parameters a_{10}, a_{20}, a_{30}, and a_{40} are obtained from the fitting of model 3, and their estimates are also found in Table 2. Table 3 shows the parameter estimates and their standard errors along with the mean squared error. The models for both species are unbiased. There is evidence that the residuals are not normally distributed for both lodgepole pine and spruce. However, the w-statistics for these models are close to 1, indicating that the residuals are almost normal. The residual plots for both models do not show any significant problems with heteroscedasticity.

A small data set of stem analysis trees from the IDF zone (obtained from Roberta Parish, British Columbia Ministry of Forests) was assembled for validating the new lodgepole pine juvenile height model. Data were not available for interior

TABLE 3 *Results of the fitting of model 3 with parameter sets 5 and 6 for lodgepole pine and interior spruce*

Species	Parameter			Mean squared error
	Name	Estimate	Standard error	
Lodgepole pine	a_{10}	0.001424		0.0119
	a_{11}	-0.0009260	0.000062	
	a_{12}	0.0008032	0.000121	
	a_{20}	1.801		
	a_{21}	0.07098	0.0223	
	a_{22}	0.3509	0.0435	
	a_{30}	0.01820		
	a_{31}	-0.003024	0.000930	
	a_{32}	-0.01257	0.00219	
	a_{33}	0.01581	0.00198	
	a_{40}	0.9537		
	a_{41}	-0.01083	0.00348	
	a_{42}	-0.02025	0.00294	
Interior spruce	a_{10}	0.0009952		0.0104
	a_{11}	0.0005208	0.000237	
	a_{12}	-0.0006785	0.000082	
	a_{13}	-0.0008774	0.000026	
	a_{20}	0.9842		
	a_{21}	0.2521	0.0643	
	a_{22}	-0.2893	0.0539	
	a_{23}	0.5893	0.0703	
	a_{30}	0.02943		
	a_{31}	-0.008403	0.00269	
	a_{32}	-0.01388	0.00184	
	a_{33}	0.02672	0.00261	
	a_{34}	-0.03586	0.00307	
	a_{40}	1.017		
	a_{41}	0.03818	0.00764	
	a_{42}	-0.04231	0.00498	
	a_{43}	-0.07806	0.00806	

spruce. These data were collected using stem analysis sectioning, which is less accurate than measuring nodes. The lowest section was taken as close as possible to ground level, although this would have been above the point of germination. The stem analysis data were converted into height-age data using the method described by Carmean (1972) and Newberry (1991). Eleven trees were free of damage or suppression and were in the range of site index found in the model development data. These data are summarized in Table 4. The validation of the new lodgepole pine juvenile height model using these data is shown graphically in Figure 3. The model tends to underestimate the true heights, although this underestimation is not statistically significant.

DISCUSSION

The validation results indicate that the juvenile height models for lodgepole pine and interior spruce need to be re-fit to accommodate different growth patterns across British Columbia. The original models were fit to data mainly from the SBS biogeoclimatic zone near Smithers, B.C. For both lodgepole pine and spruce, there was a slight over-prediction in height. When examined on a zone-by-zone basis, both models were unbiased for all zones except the IDF and SBPS. Not surprisingly, the models were accurate for the SBS zone. Note that some of the confidence intervals were extremely wide. This is mainly a result of the small sample sizes within zones. The conclusion drawn from the validation exercise is that gains in accuracy can

TABLE 4 *Summary statistics for the lodgepole pine validation sample trees. Means are presented on one line and ranges (minimum–maximum) are presented on the following line.*

Number of trees	Total age (yr)	Total height (m)	Site index (m)
11	39	13.62	19.55
	(17–75)	(6.43–22.53)	(18.27–20.88)

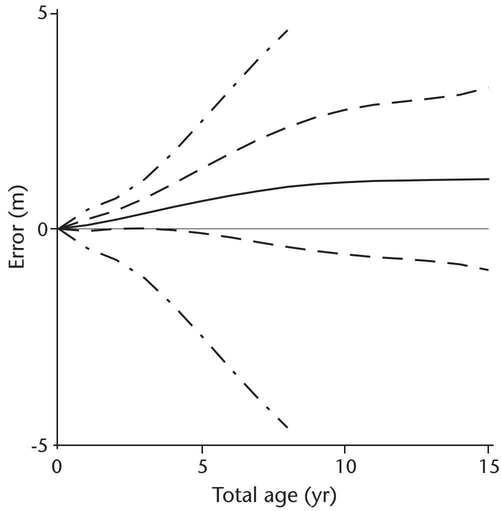

FIGURE 3 *Validation results for the new lodgepole pine juvenile height model for the IDF zone. The mean error in height estimates is shown with a solid line and its 95% confidence interval is shown with dashed lines. The lines with alternating dots and dashes show the precision of the height estimates.*

be achieved if new models for spruce and lodgepole pine are fit to the additional data.

Three changes in the functional form for the new models were implemented. The first change was to remove the negative leading coefficient in models 1 and 2. This was done to prevent the model from returning negative heights for small site indices. The second change was to replace the exponent for A with a linear function of site index. This change was made based on a preliminary analysis that showed that the value of this parameter was a function of site index. The last change was to allow all the coefficients to vary depending on the biogeoclimatic zone. The fitting of the models was done in a two-step procedure. First, the model was fit to all the data without letting the parameters vary by zone. This resulted in parameters that are applicable province-wide. Next, the models were re-fit by using indicator variables that allow adjustments to the value of the province-wide parameters based on biogeoclimatic zone. Although this two-step procedure does not result in the most efficient models, it has the advantage of letting the models default to the province-wide parameters if the zone is not known or is not one of the seven included in the sample. Furthermore, the loss of efficiency is very small.

Figure 4 shows the province-wide models for lodgepole pine and spruce for site indices 10, 15, 20, and 25. This Figure clearly shows that the spruce has slower growth, at least below breast height. It was difficult to find spruce stands in some of the zones that were sampled. In many cases, it is likely that the spruce trees were advance regeneration and hence may have been suppressed at young ages. Efforts were made to avoid trees that were advance regeneration, but it was difficult to identify these trees in stands that are 20 years old or older. Note that the growth trajectories for site indices 10 and 15 for both lodgepole pine and spruce are extrapolations and may not accurately reflect the height growth for stands with these site indices.

Figure 5, parts a and b, shows the height trajectories of lodgepole pine and spruce, respectively, for the province-wide model and for the different biogeoclimatic zones. A site index value of 20 was chosen to generate these Figures because it is approximately the average site index of the data. Since all the

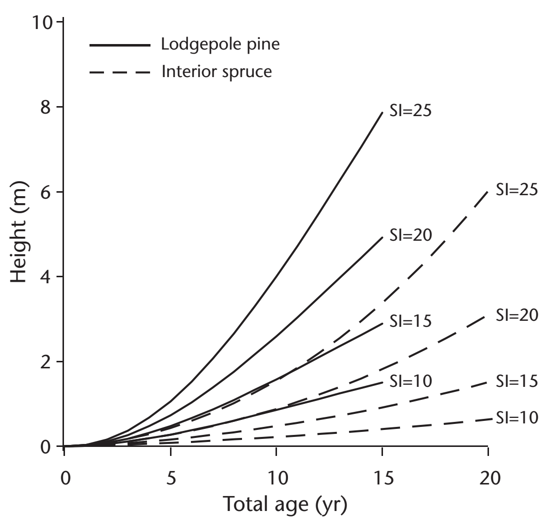

FIGURE 4 *Predicted height trajectories from the province-wide lodgepole pine and spruce models for site indices 10, 15, 20, and 25 m.*

curves have the same site index, they have the same height at breast height age 50. Therefore, most of the differences in the curves will be below breast height. This was confirmed by plotting height against breast height age. These plots showed much smaller variations in height trajectories, with spruce being more variable than lodgepole pine. The predicted height growth of the trees was approximately the same above breast height for all zones. The best height growth occurred in the ICH, SBS, and BWBS zones. The ICH zone is the second-most productive zone in Canada (Meidinger and Pojar 1991). Recent research reveals

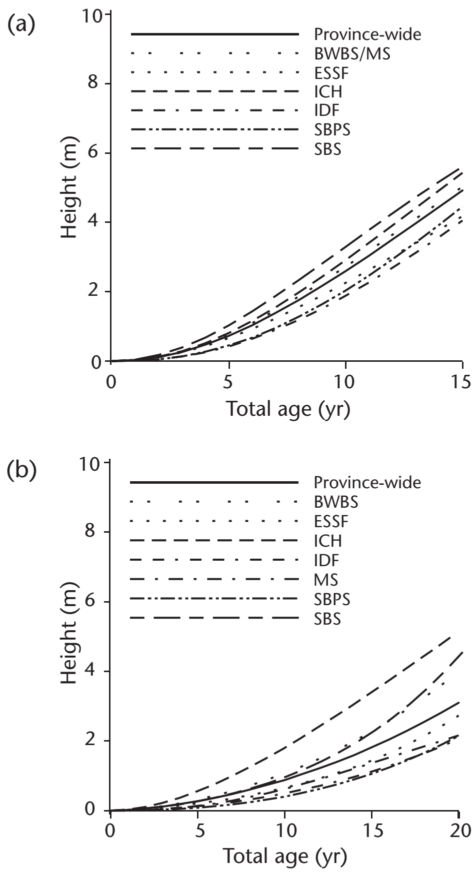

FIGURE 5 *Predicted lodgepole pine (a) and spruce (b) height trajectories from the province-wide and zone-specific juvenile height models at site index 20.*

that the BWBS zone has relatively good productivity (Nigh 2004). The poorest growth occurs in the IDF, ESSF, and SBPS zones. These zones generally have low productivity. The IDF zone is dry, the SBPS zone is dry and cool, and the ESSF zone is cold (Meidinger and Pojar 1991). Early differences in height growth may be due to soil and/or climatic factors, or they may be caused by some other factor such as brush and weed competition. It is not possible to identify the reason for the differences in early height growth with the available data.

The final version of the juvenile height models for lodgepole pine and interior spruce are given in models 7 and 8, respectively.

$$H = [0.001424 - 0.0009260 \times (IDF + SBPS) + 0.0008032 \times SBS] \times SI \times A^{\{1.801 + 0.07098 \times (BWBS + MS) + 0.3509 \times (ICH + SBPS) + [0.01820 - 0.003024 \times ESSF - 0.01257 \times ICH + 0.01581 \times IDF] \times SI\}} \times [0.9537 - 0.01083 \times (BWBS + ICH + MS) - 0.02025 \times SBS]^{A} \quad (7)$$

$$H = [0.0009952 + 0.0005208 \times ICH - 0.0006785 \times IDF - 0.0008774 \times (MS + SBPS)] \times SI \times A^{\{0.9842 + 0.2521 \times BWBS - 0.2893 \times (ESSF + IDF) + 0.5893 \times (ICH + MS + SBPS + SBS) + [0.02943 - 0.008403 \times BWBS - 0.01388 \times ICH + 0.02672 \times (IDF + MS) - 0.03586 \times SBS] \times SI\}} \times [1.017 + 0.03818 \times (ESSF + SBS) - 0.04231 \times ICH - 0.07806 \times MS]^{A} \quad (8)$$

The variables BWBS, ESSF, ICH, IDF, MS, SBPS, and SBS are indicator variables that take on the value of 1 if the model is being used to estimate height for the respective zone; otherwise it is zero. The computer system that the British Columbia Ministry of Forests uses to estimate heights does not accept biogeoclimatic zone as input at this time. The province-wide model must be used until the software is modified to accept zone, or else the zone-specific models must be programmed using other software.

The validation of the new juvenile height model for lodgepole pine shows that this model tends to underestimate the height of lodgepole pine, although this is not a statistically significant result. One explanation for this is that the validation trees were not sampled down to the point of germination. Therefore, age 0 for these trees is actually some point above germination. The height growth at this point would be somewhat greater than the height growth at the true point of germination, and would result in a slight bias.

CONCLUSIONS

The validation of the original juvenile height models for lodgepole pine and interior spruce indicate that the models are slightly biased when applied to some sites outside the SBS zone, where most of the data for these models were collected. These results necessitated the development of new juvenile height models. The new models show that the height growth pattern above breast height is approximately the same in the sampled zones; most of the differences in growth occurred below breast height. A small validation of the new juvenile height model for lodgepole pine indicated that the model is adequate in the IDF zone.

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