

**Examination of Large Tree Height and Diameter Increment
Models Modified for Prognosis^{BC}**

Prepared by:

**H. Temesgen, Ph.D. and V. LeMay
University of British Columbia
Department of Forest Resources Management
2nd Floor, Forest Sciences Centre
2045-2424 Main Mall
Vancouver, BC V6T 1Z4**

March 31, 1999

Executive Summary

Prognosis^{BC} is an adaptation of the northern Idaho (NI) variant. The small tree height and large tree diameter increment model drive the growth of small and trees in the model. The height and diameter increment models of Prognosis^{BC} were evaluated for accuracy using an independent stem analysis and permanent sample plots (PSPs) data sets. The mortality model of Prognosis^{BC} was also evaluated using the PSP data sets. Independent data sets were also used to verify the built-in height-diameter equation coefficients of the Prognosis^{BC}. The methods used and the results obtained in verifying these models are presented.

The small and large tree height increment models were found to be biased. High bias due to the height-dubbing equation and the height growth model were found in the ESSF and PP BEC zones. The mortality model of Prognosis^{BC} was also found biased and this bias could be attributed to the use of the Northern Idaho maximum basal area (BAMAX) values for predicting the probability of individual tree mortality rates and for maintaining the stand within reasonable biological limits. Recommendations to improve the accuracy of the small and large tree height increment, the height-dubbing equation, and the mortality models of Prognosis^{BC} are:

1. The small tree height increment model should be examined using large independent data sets for both the Kamloops and Nelson forest regions. The large tree height increment model for Kamloops region should be modified to avoid the consistent over-estimation of tree height.
2. The inclusion of the ESSF and PP BEC zones in the current version of Prognosis^{BC} should be reviewed. The new height-diameter equation coefficients should be used at the subzone group level instead of at zonal level and the Prognosis^{BC} code should be changed accordingly.
3. BAMAX values (using BC data) should be estimated for each zone, subzone, and site series combination considered in Prognosis^{BC}, and subsequently, the tree- and stand-based mortality functions should be re-fitted.
4. Additional PSPs or temporary sample plots with core data (TSPs) should be collected and Prognosis^{BC} be refitted using BC data. If new TSPs or PSPs data are to be collected a different form of the existing diameter increment model is warranted.
5. Mapping the habitat type of the unmapped PSPs is required, if Prognosis^{BC} is to remain as is (modeled after NI).

Acknowledgments

We gratefully acknowledge the cooperation and support provided by several people in various phases of this project. We thank Mr. Ralph Winter and Mr. Barry Snowdon (both at the Ministry of Forests, Forest Practices Branch) and Mr. Jon Vivian (at the Ministry of Forests, Resources Inventory Branch), Mr. Barry Phillips and Dr. Abdel-Azim Zumrawi (both at the Ministry of Forests, Research Branch) for their continued support.

We also thank Dr. A. Kozak and Mr. Ian Cameron for providing independent data sets for this project. This project was funded by Forest Renewal BC and administered by Ministry of Forests, Forest Practices Branch.

Table of Contents

Executive Summary	i
Acknowledgments	ii
Table of Contents	iii
List of Tables	vi
List of Figures	viii
List of Species Codes Used	viii
1. INTRODUCTION	1
2. METHODS	2
2.1 Verification Using Permanent Sample Plots Data	2
2.1.1 Height dubbing equation	2
2.1.2 Height increment model	3
2.1.3 Mortality model	4
2.2 Verification Using Independent Stem Analysis Data	6
2.2.1 Diameter increment model	7
2.2.2 Height increment model	10
2.3 Height-diameter equation coefficient assessment	12
3. RESULTS AND DISCUSSION	17
3.1 Verification Using Permanent Sample Plots Data	17
3.1.1 Height dubbing equation	17
3.1.2 Height increment model	19
3.1.3 Mortality model	23
3.2 Verification Independent Stem Analysis Data	27
3.2.1 Diameter increment model	27
3.2.2 Height increment model	29
3.3 Height-diameter equation coefficient assessment	29
4. ADDITIONAL STUDIES	34
4.1 Examination of Merchantable Volume	34
4.2. Maximum Basal Area by Site Series	35
4.3 Crown Ratio Data	35
5. EXTENSION WORK	36
5.1 Inland Growth and Yield Cooperative (INGY) Presentation	36
5.2 Meetings	36
5.3 Branch Lines and Meetings	37

6. CONCLUSIONS AND RECOMMENDATIONS 37

7. LITERATURE CITED..... 40

APPENDIX A - Summary of percent bias (m) due to the height dubbing equation by species/BEC zone/subzone for Nelson PSP data set..... 42

APPENDIX B - Summary of percent bias (m) due to the height dubbing equation by species/BEC zone/subzone for Kamloops PSP data set. 56

APPENDIX C - Summary of percent bias (m) due to the height growth model by species/BEC zone/subzone for one projection cycle using the Nelson PSP data set..... 62

APPENDIX D - Summary of percent bias (m) due to the height growth model by species/BEC zone/subzone for one projection cycle using the Kamloops PSP data set..... 76

APPENDIX E - Summary of percent bias (m) due to the height growth model by species/BEC zone/subzone for two projection cycles using the Nelson PSP data set..... 82

APPENDIX F - Summary of percent bias (m) due to the height growth model by species/BEC zone/subzone for three projection cycles using the Nelson PSP data set. 97

APPENDIX G - Chi-square statistics (X^2), number of live trees (N_TOTAL), observed (N_DEAD) and expected (N_EXPEC) number of dead trees, and observed (OBS_MORT) and predicted mortality rate (PRED_MORT), and Multipliers (MULT) by species and diameter class for Nelson PSPs..... 105

APPENDIX H - Chi-square statistics (X^2), number of live trees (N_TOTAL), observed (N_DEAD) and expected (N_EXPEC) number of dead trees, and observed (OBS_MORT) and predicted mortality rate (PRED_MORT), and Multipliers (MULT) by species and diameter class for Kamloops PSPs..... 109

APPENDIX I - Summary of number of live trees (N_TOTAL), observed (N_DEAD) and expected (N_EXPEC) number of dead trees, and observed (OBS_MORT) and predicted mortality rate (PRED_MORT), and Multipliers (MULT) by zone, subzone, site series, species, and diameter class for Nelson PSPs. 111

APPENDIX J - Summary of number of live trees (N_TOTAL), observed (N_DEAD) and expected (N_EXPEC) number of dead trees, and observed (OBS_MORT) and predicted mortality rate (PRED_MORT), and Multipliers (MULT) by zone, subzone, site series, species, and diameter class for Kamloops PSPs..... 117

APPENDIX K - Summary of volume projections for 15 selected PSPs..... 120

APPENDIX L - Summary of maximum basal area and volume by BEC zone, subzone, and site series by leading tree species for Nelson PSPs..... 136

APPENDIX M - Summary of maximum basal area and volume by BEC zone, subzone, and site series by leading tree species for Kamloops PSPs. 141

List of Tables

Table 1. Number of sample trees (N) and summary of sample plot attributes for the ICH stem analysis data set. Only live, undamaged, coniferous trees > 7.5 cm diameter at breast height (DBH) were considered..... 7

Table 2. Number of trees used to assess the diameter and height increment models of Prognosis^{BC} by species, site series, and subzone for the ICH stem analysis data set. Only live, undamaged, coniferous trees > 7.5 cm diameter at breast height were considered..... 8

Table 3. Bark growth adjustment factor (*k*) and species-dependent coefficient (*b*₀) for the mortality model. 9

Table 4. Number of trees by species, subzones, and biogeoclimatic zones used to assess differences in BEC zones/subzones. 14

Table 5. Table of critical values for Scheffe’s test for 95% probability and large sample sizes.. 16

Table 6. Average percent bias (%BIAS) due to the height dubbing equation and number of trees (n) by DBH class, BEC zone, and species for Nelson PSP data set..... 18

Table 7. Average percent bias (%BIAS) due to the height dubbing equation and number of trees (n) by DBH class, BEC zone, and species for Kamloops PSP data set..... 19

Table 8. Average percent bias (%BIAS) due to the height growth models and number of trees (n) by DBH class, BEC zone and species for one projection cycle using the Nelson PSP data set. 20

Table 9. Average percent bias (%BIAS) due to the tree height growth models and number of trees (n) by DBH class, BEC zone and species for one projection cycle using the Kamloops PSP data set. 21

Table 10. Average percent bias (%BIAS) due to the height growth models and number of trees (n) by DBH class, BEC zone and species for two projection cycles using the Nelson PSP data set. 22

Table 11. Average percent bias (%BIAS) due to the height growth models and number of trees (n) by DBH class, BEC zone and species for three projection cycles using the Nelson PSP data set..... 23

Table 12. Chi-square statistics (X^2), number of live trees (N_TOTAL), observed (N_DEAD) and expected (N_EXPEC) number of dead trees, and observed (OBS_MORT) and predicted mortality rate (PRED_MORT), and Multipliers (MULT) for Douglas-fir by diameter class for Nelson PSPs..... 24

Table 13. Chi-square statistics (X^2), number of live trees (N_TOTAL), observed (N_DEAD) and expected (N_EXPEC) number of dead trees, and observed (OBS_MORT) and predicted mortality rate (PRED_MORT), and Multiplier (MULT) for Douglas-fir by diameter class for Kamloops PSPs. 25

Table 14. Chi-square statistics (X^2), number of live trees (N_TOTAL), observed (N_DEAD) and expected (N_EXPEC) number of dead trees, and observed (OBS_MORT), predicted mortality rate (PRED_MORT), and Multiplier (MULT) by zone subzone and site series... 26

Table 15. Number of trees used for assessing the diameter and height increment models of Prognosis^{BC} and their minimum (MIN), mean, maximum (MAX), and standard deviation (STD) of DBH and height by species. Only live, coniferous, trees > 7.5 cm were considered. 27

Table 16. Bias (cm) and percent bias (%) of 10-year diameter increment by species for two sets of backdated trees (i.e., DBH₁₀ and DBH₂₀). Only live, undamaged, coniferous trees > 7.5 cm were considered..... 28

Table 17. Bias (cm) and percent bias (%) of 10-year height increment with or without diameter increment (DG) by species. Only live undamaged coniferous trees > 7.5 cm were considered. 29

Table 18. Number of trees and the minimum (MIN), mean, maximum (MAX), and standard deviation (STD) for DBH and tree height by species and BEC zone for data used in comparing zones and subzones. 31

Table 19. Coefficients obtained for the height-diameter equation using Northern Idaho and BC data sets. 32

Table 20. Coefficient and root mean square error (RMSE in metres) for the height-diameter equation by species/BEC zone/subzone combinations. Shaded cells refer to RMSE error obtained by fitting the respective pooled zones separately. 33

Table 21. Maximum basal area (and number of PSPs in brackets) by zone, subzone, and site series combinations for Nelson and Kamloops PSPs..... 36

List of Figures

Figure 1. Diameter increment % bias by diameter class for DF and CW.	28
Figure 2. Ten-year height increment % bias (cm over 10 years) by diameter class for DF and CW when diameter increment data was considered.	30

List of Species Codes Used

BL	Subalpine fir (<i>Abies lasiocarpa</i>)
PL	Lodgepole pine (<i>Pinus contorta</i>)
PW	Western white pine (<i>Pinus monticola</i>)
CW	Western red cedar (<i>Thuja plicata</i>)
FD	Douglas-fir (<i>Pseudotsuga menziesii</i>)
HM	Mountain hemlock (<i>Tsuga mertensiana</i>)
HW	Western hemlock (<i>Tsuga heterophylla</i>) .
PY	Ponderosa pine (<i>Pinus ponderosa</i>)
SE	Englemann spruce (<i>Picea engelmannii</i>)
LW	Western larch (<i>Larix occidentalis</i>)

1. INTRODUCTION

Predicting the growth and yield of trees and forests is essential for managing forest resources in perpetuity. Growth and yield of uneven aged and mixed species stands are more difficult to estimate than the growth and yield of uniform stands. In order to predict the growth of multi-species and multi-aged stands in the southeastern interior of BC (SEI), Prognosis^{BC} was modified from the northern Idaho (NI) stand Prognosis model (Stage 1973 and Wykoff *et al.* 1982), as forests of SEI are similar to those found in Northern Idaho.

Built-in multipliers were used to adjust the growth rates of trees to make NI more responsive to selected biogeoclimatic zones, subzones, and site series in the SEI. The predictive ability the growth and mortality models such as the diameter and height increment and the mortality model is not certain when these multipliers are used. Accordingly, verifying the predictive ability of these models in Prognosis^{BC} is essential.

A contract between the University of British Columbia, Forest Resources Management Department, and the BC Ministry of Forests, Forest Practices Branch, was established with the following objectives:

- 1) To verify the predictive ability of the modified large tree height and diameter growth model for selected tree species and site series using independent data sources;
- 2) To revise the effects of the modified small- and large-tree height models on stand height and other stand attributes. The stand height and quadratic mean diameter (QMD) relationship will be used as a basis for comparison in the absence of tree height data;
- 3) To assess the mortality model of the Prognosis^{BC} variant using permanent sample plot data;
and
- 4) To provide an interim recommendation based on preliminary findings of (1), (2), and (3).

The objectives were changed somewhat to meet current needs as expressed by Mr. Barry Snowdon of the BC Ministry of Forests, Forest Practices Branch. Also, meetings were held to re-evaluate the objectives and alter the research priorities, as new information became available. In addition to this work, brief results on three extra analyses are presented and a brief note on extension work are presented.

2. METHODS

The Prognosis^{BC} variant was evaluated for accuracy in height, diameter, and mortality prediction using an independent stem analysis and permanent sample plots (PSPs) data sets. The height and diameter increment predictions were assessed using both an independent stem analysis and permanent sample plots (PSPs) data sets. The mortality model was evaluated using the PSP data sets only, as these data sets have repeated measurements. Independent data sets were also used to verify the built-in height-diameter equation coefficients of the Prognosis^{BC} variant.

2.1 Verification Using Permanent Sample Plots Data

The PSPs data sets that were used to develop Prognosis^{BC} were used in this verification study. These data sets are described in detail in LeMay and Temesgen (1998).

2.1.1 Height dubbing equation

Initially, height prediction bias due to the built-in height dubbing equation (i.e., when tree heights are missing) was assessed. Trees with measured heights were selected from the permanent sample plots (PSPs) data provided by BC Ministry of Forests, Research Branch and heights were estimated using the built-in height dubbing equation. The estimated heights were then compared to their actual measured heights. Steps used were:

1. The PROGNOISIS sample plot compiler (FVSDATA1.EXE) and the PROGNOISIS tree file builder (FVSDATA2.EXE) programs were compiled for measurement sequence of 0 (at establishment) and 1 (at the first re-measurement).
2. The NOTRIPLE keyword was included in all KEYWORD files to prevent bias due to record tripling.
3. From the extracted tree files, only trees with measured heights were selected (tree heights > 1.3 m) and their heights were estimated using the built-in tree height dubbing equation. The differences (biases) between the measured and estimated heights were calculated, and averaged by species, biogeoclimatic (BEC) zones, and subzones.
4. Six diameter classes were established (i.e., < 5.0 cm, 5.0 to 12.4 cm, 12.5 to 25.0 cm, 25.1 to 45.0 cm, 45.1 to 60.0 cm, and > 60.0 cm) and the minimum, mean, and maximum percent biases in height prediction were extracted to assess the accuracy of the modified diameter growth models by species, BEC zone, and subzone. Percent bias was defined as measured

minus estimated height divided by measured height and multiplied by 100. A z-test was conducted for each species/BEC zone/subzone combination to test whether the percent bias could be zero.

2.1.2 Height increment model

Height prediction bias due to small and large tree height increment models was assessed. Trees with remeasured heights were selected (from the provided PSP data), and heights and other attributes were projected for three cycles at their subsequent re-measurement period interval. The projected heights were compared to the remeasured heights for the same measurement periods. For example, trees with remeasured heights in measurement sequence of 0 and 1 (at the establishment and at the first re-measurement) were selected. The projected height (using Prognosis^{BC}) using data with measurement sequence of 0 was compared to the remeasured heights at measurement sequence of 1. Steps used were:

1. The PROGNOSIS sample plot compiler (FVSDATA1.EXE) and the PROGNOSIS tree file builder (FVSDATA2.EXE) programs were compiled. Three sets of projections were made for three projection cycles using the initial measures (measurement at the establishment) for Nelson PSP data set and one set of projection was made for Kamloops PSP data set.
2. The NOTRIPLE keyword was included in all KEYWORD files to prevent bias due to record tripling.
3. From the extracted tree files, only trees with remeasured heights were selected (tree with heights > 1.3 m) from the three measurement periods (measurement sequence of 0 and 1, 1 and 2, and 2 and 3) and the heights and other attributes were projected for three subsequent cycles at their subsequent re-measurement period interval.
4. The difference between the projected height from (3) and the associated remeasured height at the same measurement period was calculated. Six diameter classes were established (i.e., < 5.0 cm, 5.0 to 12.4 cm, 12.5 to 25.0 cm, 25.1 to 45.0 cm, 45.1 to 60.0 cm, and > 60.1 cm) and the minimum, mean, and maximum biases were extracted to assess the accuracy of the height increment models. These six diameter classes were deliberately chosen to represent bias due to: 1) small tree height increment models (i.e., for trees < 5.0 cm); 2) both the small and large tree height increment model (for trees of 5.0 to 25.0 cm diameter); and 3) the large tree height

increment model (i.e., for trees > 25.0 cm diameter), as outlined in Wykoff *et al.* (1982, p. 67). These diameter classes give an indication as to which height increment model may need some adjustment.

Percent bias and T-values were calculated as for the first assessment. A z-test was conducted for each species/BEC zone/subzone combination to test whether the percent bias could be zero.

2.1.3 Mortality model

The predictive ability of the mortality model was evaluated using the PSP data sets. First, the PROGNOSIS sample plot compiler (FVSDATA1.EXE) and the PROGNOSIS tree file builder (FVSDATA2.EXE) programs were compiled for measurement sequence of 1 (at the first re-measurement) and 2 for both Nelson and Kamloops PSPs. Live trees were enumerated by species and diameter classes from each tree file (PSP). The list of live trees between two consecutive measurement periods was compared, and the number of dead trees between two consecutive measurements period was enumerated (e.g., the number of dead trees between measurement period 1 and 2) by species and by diameter classes. One KEYWORD file for each plot was prepared. The NOTRIPLE and NOAUTOES keywords were included in all KEYWORD files to prevent biases due to record tripling and the regeneration model, respectively.

Next, each PSP tree file was projected forward using Prognosis^{BC} and the periodic mortality rate for each tree was obtained. The periodic mortality rate refers to the mortality rate between two consecutive measurement periods. In Prognosis^{BC}, the periodic mortality rate for each tree is predicted using two separate mortality functions (i.e., tree and stand based mortality functions) as outlined in Wykoff *et al.* (1982) and Wykoff (1986). The tree based mortality function (R_a) is an inverse function of tree size taken in context of stand structure.

$$R_a = \left\{ 1 + \exp \left[b_0 + b_1 * \sqrt{DBH} + b_2 * \sqrt{BA} + b_3 * g + b_4 * RDBH + (b_5 + b_6 * g) * DBH^{-1} \right] \right\}^{-1}$$

Where: R_a = estimated annual mortality rate; g = periodic annual DBH increment for previous growth period adjusted for differences in potential annual DBH increment indexed by habitat type and National Forest; $RDBH$ = the ratio of tree DBH to the arithmetic mean stand DBH ; b_0 = species-dependent constant; and $b_1 = 0.2223$, $b_2 = -0.0460$, $b_3 = 10.0810$, $b_4 = 0.2463$, $b_5 = -0.5544$, and $b_6 = 6.0713$.

The stand based mortality function (R_b) operates as a convergence on normal basal area stocking and convergence on maximum basal area. This convergence is habitat specific whereby the specific maximum basal area varies among the habitat types considered in Prognosis^{BC}. Current stocking, stocking at the end of the growth cycle and maximum basal area ($BAMAX$) are used to compute a mortality rate which will cause the stand to converge on $BAMAX$. This function operates whether the stand is below or above normal stocking. The closer the stand is to this limit or the faster it is approaching the limit and the greater the mortality reported by Prognosis^{BC}.

$$R_b = 1 - \left\{ 1 - \left[\frac{(S_0 - SB_{10})}{S_0} \right] \right\}^{0.1}$$

Where: R_b = the annual approach to maximum basal area mortality rate and S_0 = current stocking density in stems per hectare.

$$SB_{10} = \frac{BA + (1 - \frac{BA}{BAMAX}) * BAI}{TB_{10}}$$

Where: TB_{10} = average basal area per tree 10 year hence and BAI = proportion of gross stand basal area increment. If BA is exactly equal to $BAMAX$, the rate estimate will be such that BAI is equal to zero.

Mortality from the tree and stand based functions is weighted and allocated to each stand as:

$$R_t = W * R_b + (1 - W) * R_a$$

R_t = annual mortality rate applied to tree t ; $W = BA/BAMAX$; and BA = basal area per ha (m^2/ha).

The periodic mortality rate (R_n) for each tree is computed as:

$$R_n = 1 - (1 - R_t)^n$$

Where: n = number of years between two consecutive measurement periods.

After the periodic mortality rate for each tree was calculated using Prognosis^{BC}, trees were summarized by species and by diameter classes. The probability of mortality for each tree in each

diameter class was averaged and was later used to obtain the expected number of trees that would die, as discussed in Hamilton and Edwards (1976).

The predictive ability of the mortality model was determined for each tree species by comparing the observed (from the PSP data set) and expected number of dead trees (reported by Prognosis^{BC}) in each diameter class. The mortality model was tested using the chi-square goodness-of-fit test.

$$X_c^2 = \sum_{i=1}^n (O_i - E_i)^2 / E_i$$

Where: O_i = observed number of mortality trees falling in the i^{th} diameter class; E_i = expected number of mortality trees falling in the i^{th} diameter class; X_c^2 = Chi-square statistics; and n is the number of diameter classes.

Since the Chi-square test is more powerful if all the expected frequencies are at least five, some diameter classes were combined together. This, in turn, reduced the number of degrees of freedom in the overall test.

The numbers of live and dead trees between two consecutive measurement periods were also enumerated by species, zone, subzone, and site series. Subsequently, the predictive ability of the mortality model was assessed by zone, subzone, and site series.

2.2 Verification Using Independent Stem Analysis Data

The Prognosis^{BC} variant was evaluated for accuracy in diameter and height increment prediction using an independent (stem analysis) data set. An independent data set that was used to evaluate several silvicultural practices in Interior Cedar Hemlock (ICH) biogeoclimatic zone was obtained from Mr. Ian Cameron, formerly of the Ministry of Forests, Research Branch. This data set was collected from three site series (i.e., 01, 04, and 06) and in two subzones (i.e., mw2 and mw3) of ICH in the Prince Rupert Forest Region. Data were collected from circular plots that varied from: 0.01 to 0.05 ha in area, 0 to 28% in slope, 0 to 360 (degrees) in azimuth, and 685 to 835 m in elevation (Table 1).

Table 1. Number of sample trees (N) and summary of sample plot attributes for the ICH stem analysis data set. Only live, undamaged, coniferous trees > 7.5 cm diameter at breast height (DBH) were considered.

PLOT no.	N	AREA (ha)	Subzone	Site Series	SLOPE (%)	AZIMUTH (degrees)	ELEVATION (m)
301	22	0.01	mw3	01	8	360	685
400	22	0.02	mw3	01	10	350	715
403	23	0.03	mw3	04	30	139	830
700	3	0.05	mw2	04	15	321	710
801	22	0.02	mw3	06	0	0	765
808	22	0.04	mw2	04	20	263	720
902	13	0.04	mw2	04	28	311	775
1001	23	0.02	mw2	01	10	335	800
1803	17	0.02	mw3	04	5	75	770
Total	167						

2.2.1 Diameter increment model

The independent data set was prepared in accordance with Prognosis^{BC} input (i.e., tree file format) requirement for further projections using this model (Table 2). Steps for verifying the diameter increment model included:

1. From the stem analysis data set, only plots with mapped subzone and site series were selected. All hardwoods, conifers < 7.5 cm, and damaged trees (i.e., trees with broken tops or missing crowns), and snags were excluded in this verification.
2. Species codes in the stem analysis data set were converted to species codes supported in Prognosis^{BC}.
3. Two sets of diameter increments (i.e., diameter increment of the last 10-years (DG_{10}) and diameter increment between the last 10 and 20-year periods (DG_{10} and DG_{20})) were extracted from the sample disks taken at the breast height of the sample trees.

Table 2. Number of trees used to assess the diameter and height increment models of Prognosis^{BC} by species, site series, and subzone for the ICH stem analysis data set. Only live, undamaged, coniferous trees > 7.5 cm diameter at breast height were considered.

Subzone	Site Series	SPECIES							Total
		BL	CW	FD	HW	LW	PL	SE	
mw2	01		12	3	2	6			23
	04			19		4	13	2	38
mw3	01		21	10	10			3	44
	04	2	28	5			2	3	40
	06	8						14	22
Total		10	61	37	12	10	15	22	167

4. From the stem analysis data set, only live, undamaged, coniferous trees with *DBH* > 7.5 cm were selected. Following this, two sets of tree files (without diameter increments) were created. The first set of tree files consisted of trees that were backdated to the start of the previous 10-year periods. These trees were backdated by subtracting the last 10-year diameter increment (twice the 10-year radial increment) from the *DBH* of each tree and by adjusting for the bark thickness. Bark adjustment factors that are used in Prognosis^{BC} were used in creating the previous *DBH* values (Table 3). Diameter outside bark values for the backdated trees (*DG₁₀*) were estimated from the equation:

$$DBH_{10} = DBH - k * DG_{10}$$

Where: *k*= bark adjustment factor (see Table 3) and *DG₁₀*= periodic diameter increment of the last 10 year periods.

The second set of tree files consisted of trees that were backdated to the start of the previous 20-year periods. These trees were backdated by subtracting the last 20-year diameter increment from the *DBH* of the sample trees and by adjusting for the bark thickness. Diameter outside bark for the 20-year backdated trees (*DBH₂₀*) was estimated from the equation:

$$DBH_{20} = DBH - k * DG_{10} - DG_{10/20}$$

Where: $DG_{10/20}$ = periodic diameter increment between the last 10 and 20 years (i.e, twice the radial difference between the last 10 and 20 years growth).

Table 3. Bark growth adjustment factor (k) and species-dependent coefficient (b_0) for the mortality model.

Species	k	b_0
<i>Western white pine</i>	1.037	0.0
<i>Western larch</i>	1.175	-0.176
<i>Douglas fir</i>	1.153	0.3179
<i>Grand fir</i>	1.093	0.3179
<i>Western hemlock</i>	1.071	0.6077
<i>Western red cedar</i>	1.053	1.5798
<i>Lodgepole pine</i>	1.032	-0.1206
<i>Engelmann spruce</i>	1.047	0.9402
<i>Subalpine fir</i>	1.063	0.2118
<i>Ponderosa pine</i>	1.128	0.2118
<i>Mountain hemlock</i>	1.053	0.0

Note: k and b_0 are coefficients as given in Wykoff *et al.* (1982) and Wykoff (1986), respectively.

5. One KEYWORD file for each plot was prepared. The NOTRIPLE and NOAUTOES keywords were included in all KEYWORD files to prevent biases due to record tripling and the regeneration model, respectively.

6. The two sets of tree files (i.e., DBH_{10} and DBH_{20}) allowed two sets of projections using Prognosis^{BC}. In these projections, it was assumed that no significant mortality has occurred over the last 20-years of the stand history. Diameter growth for the subsequent 10-year period was predicted for the two sets of projections, separately.

7. The predicted 10-year diameter increment for each tree was compared with the measured 10-year diameter increment values for each set of projection. The difference between the predicted

10-year diameter increment and the associated measured 10-year diameter increment (i.e., from the stem analysis data) was calculated. Five diameter classes were established (i.e., < 12.5 cm, 12.5 to 25.0 cm, 25.1 to 45.0 cm, 45.1 to 60.0 cm, and > 60.1 cm) and the minimum, mean, and maximum biases were extracted to assess the accuracy of the diameter increment models. These diameter classes give an indication as to which increment model may need some adjustment.

8. Percent bias and standard errors of estimate (SEE) in cm were calculated for the two sets of projections, separately.

2.2.2 Height increment model

For testing the tree height increment model, only trees with measured heights (i.e., measured directly after felling or measured by Angle Distance method – SUUNTO) were included. Trees whose heights were estimated by a height-DBH function, by a taper function, or by an ocular method were excluded in this verification. Steps in height increment model verification included:

1. From the stem analysis data set, only plots with mapped subzone and site series were selected. All hardwoods, conifers < 7.5 cm, and damaged trees (i.e., trees with broken tops or missing crowns), and snags were also excluded in this verification. Species codes in the stem analysis data set were converted to species codes supported in Prognosis^{BC}.
2. In the stem analysis data set, sample disks were taken out at various heights of each tree. The first, second, and third disks were taken at 0.3, 0.8, and 1.3 metres above ground. The fourth and the subsequent sample disks were taken out at varying heights of the sample trees.
3. Diameter increment (DG_{S4}) between the third (i.e., sample disks taken at DBH) and fourth sample disks was calculated by taking the radial differences between these two points and then by multiplying it by two.
4. Trees were backdated to the start of the age of the fourth sample disk. These trees were backdated by subtracting DG_{S4} from the DBH of each tree and by adjusting for the bark thickness. Diameter outside bark for the backdated trees (DBH_{S4}) was estimated as:

$$DBH_{s4} = DBH - k * DG_{s4}$$

5. Using the backdated trees (i.e., DBH_{s4}), two sets of tree files (i.e., with and without diameter increment) were created. The measured 10-year diameter increment values (from stem analysis data) were used to create tree files with diameter increment values. These, in turn, allowed two sets of projections using Prognosis^{BC}. Height growth for the subsequent 10-year was predicted for the two sets of projections, separately.

6. One KEYWORD file for each plot was prepared. The NOTRIPLE and NOAUTOES keywords were included in all KEYWORD files to prevent biases due to record tripling and the regeneration model, respectively for both sets of projections.

7. From the ring data set, Carmean's adjusted heights were used to calculate the average 10-year (recent) height increment. Average 10-year height growth (HTG_{10}) between the fourth sample disk and the tip of the tree was estimated.

$$HTG_{10} = \left(\frac{HT - HT_{s4}}{RNG_4} \right) * 10$$

Where: RNG_4 is the number of rings at section 4; HT = tree height in metre; and HT_{s4} = height at which section 4 was taken. The difference between HT and HT_{s4} is the height growth between section 4 and the tip of the tree.

8. The differences (bias) between the measured 10 year height increment and the associated predicted 10 year height increment were calculated and average bias by species were calculated. Five diameter classes were established (i.e., < 12.5 cm, 12.5 to 25.0 cm, 25.1 to 45.0 cm, 45.1 to 60.0 cm, and > 60.1 cm) and the minimum, mean, and maximum biases were extracted to assess the accuracy of the height increment models. These diameter classes give an indication as to which height increment model may need some adjustment.

9. Percent bias and standard errors of estimates (SEE) in metres were calculated.

2.3 Height-diameter equation coefficient assessment

Height-diameter equations developed by Stage (1973) and Flewelling and de Jong (1994) were compared to assess consistency among growth and yield models in BC. The former is used for estimating missing heights in Prognosis^{BC} and the later is used by the MOF Inventory Branch for estimating missing heights in PSP data sets. The height-diameter equation by Stage is:

$$\hat{HT} = 1.3 + EXP[C_0 + C_1 * \frac{1}{(DBH+1)}]$$

Where C_0 and C_1 are species-dependent coefficients, HT is tree height in metres, DBH is the diameter outside bark at breast height in cm, and EXP is the Naperian constant (*i.e.*, 2.718) raised to the power of the expression in brackets. This can be linearized as:

$$HT - 1.3 = EXP[C_0 + C_1 * \frac{1}{(DBH+1)}]$$

$$LN[HT - 1.3] = [C_0 + C_1 * \frac{1}{(DBH+1)}]$$

The height-diameter function by Flewelling and de Jong (1994) is:

$$\hat{HT} = 1.3 + C_2 * EXP[C_3 * (DBH)^{-C_4}]$$

This can be linearized using natural logarithms (LN) as:

$$[HT - 1.3] = C_2 * EXP[(C_3 * DBH)^{-C_4}]$$

$$LN[HT - 1.3] = LN[C_2] + [(C_3 * DBH)^{-C_4}]$$

Flewelling and de Jong (1994) found C_4 to be 0.9564. If we restrict C_4 to be 1.0, the model form will reduce to:

$$LN[HT - 1.3] = LN[C_2] + [C_3 * \frac{1}{DBH}]$$

Letting $LN(C_2) = C_0$ and $C_1 = C_3$, the two model forms are identical except the addition of a value of one to the DBH of each tree record in Stage's model. Thus, further analysis will focus only on Stage's model.

In Prognosis^{BC}, missing heights are predicted from species dependent height-diameter equations. For each species, identical height-diameter equation coefficients are used in all BEC zones and subzones. However, these equations were not assessed or verified as to whether they vary among BEC zones, and among subzones of a BEC zone.

Regression equations differ if the intercept or any of the slope coefficients differ. Therefore, testing whether the height-diameter equation differs among BEC zones or subzones, becomes a problem of testing whether any of the coefficients in the model differ among zones or subzones. A difference in any of the coefficients will result in a different equation. If the height-diameter coefficients vary significantly among BEC zones and subzones, this will indirectly verify the potential for improving the precision in height prediction in the Prognosis^{BC} variant.

Independent data sets were used to verify the built-in height-diameter equation coefficients of the Prognosis^{BC}. Resources Inventory Branch data for nine tree species were obtained from Dr. A. Kozak of UBC (Table 4). The data were previously used to develop taper equations by BEC zone for BC.

To reduce the number of subzones to be tested, the data were divided into species/BEC zone/subzone combinations. Many species/BEC zone/subzone combinations were sparsely represented in the data set. No attempt was made to fit the height-diameter equations when less than 30 observations were available for each species/BEC zone/subzone combination. An overall test of zonal differences among the five main BEC zones included in the Prognosis^{BC} variant (i.e., Engelman Spruce Subalpine Fir (ESSF), Interior Cedar Hemlock (ICH), Interior Douglas Fir (IDF), Montane Spruce (MS), and Ponderosa Pine (PP)) was initially performed for each species.

Table 4. Number of trees by species, subzones, and biogeoclimatic zones used to assess differences in BEC zones/subzones.

BEC	SPECIES	SUBZONE												Total
		dk	mm	mw	wk	wm	wc	dc	mc	mk	mv	wv	xv	
ESSF	BL	169		410	419	347	273	185	554	35	55	61		2508
	CW	76			69		65							210
	DF	231		46										277
	HW		30	196			202					103		531
	LW	86												86
	PL	162			208			143			31		59	603
	SE	325		37	334	255	177	191	64		41			1424
ICH		dw	mk	mw	vk	wk	mc	mm	vc					
	BL		512	160	58	177	239							1146
	CW		454	1055	212	1623	164	86						3594
	DF	92	337	256		79								764
	HW			1759	315	1189	2569		216					6048
	LW	77	83	173										333
	PL		142	189			112							443
	PW			257		50								307
	PY	103	32											135
SE		594	319		252	109							1274	
IDF		dk	dm	ms	mw	ww	xh	xm						
	BL	64												64
	CW		45			71								116
	DF	891	151		41	94	427	56						1660
	HW					37								37
	LW		188				73							261
	PL	606	202				49							857
	PY	199	74				42							315
SE	63	169											232	
MS		dk	dm	xv										
	BL	172												172
	CW	147												147
	DF	370												370
	LW	413												413
	PL	159	111	321										591
SE	478	134											612	
PP		dh	xh											
	DF	33	360											393
	PY	38	154											192
TOTAL														26115

In order to reduce the number of equations developed, tests were conducted to determine which zones could be pooled together (i.e., an equation might be developed for use in more than one zone). For significantly different zones, a test for difference in pairs of subzones was also carried out.

For each species, the partial F value was calculated to detect a significant difference ($\alpha=0.10$) between the sum of squared errors for the height-diameter model for all zones, versus the sum of squared error for the height-diameter model with zones and zone by variable interactions.

$$Partial\ F = \frac{[SSE(all\ zones) - SSE(by\ zone)] / p}{MSE(by\ zone)}$$

Where SSE is the sum of squared error; MSE is the mean squared error; and p is the number of coefficients restricted, which is equal to the number of coefficients in the model by BEC zone minus the number of coefficients for all zones combined. If differences in equations (intercept and/or slope differ) among zones were detected by partial F test, a subsequent test was used to determine which pairs of zones differ. When no differences in equations were detected by the partial F test, no further testing was performed.

The test assumes that the data follow a normal distribution, the variances in height prediction are constant across the range of the DBHs, and each data point is independent of all data points in the sample set. For the height-DBH equation, the data points are most likely independent, but the normality and equal variance assumption was not strictly met for some situations. However, the F test is somewhat robust to these problems (Neter and Wasserman 1974), but the tests still should be used with caution.

Scheffe's test for multiple comparisons was used to detect differences in coefficients (see Neter and Wasserman, 1974. pp. 689-713) for pairs of BEC zones or pairs of subzones. This test gives results that are consistent with the overall partial F test for differences. Each of the two coefficients for the height-DBH equation was tested for differences. When any of the coefficients was different for the pair of species/BEC zone/subzone combination, the equations were considered different.

For each pair of zones, a separate test to detect a difference in the intercept and in the slope was performed. Therefore, the alpha level of 0.10 was divided by two for each of the two tests. The test statistics for Scheffe’s multiple comparisons are given below and the critical values for the tests are listed in Table 5.

$$S^2 = \frac{(b_i - b_j)^2}{s^2_{b_i} + s^2_{b_j} - 2*s_{b_i b_j}}$$

Where b_i and b_j are the coefficients to be tested; $s^2_{b_i}$ and $s^2_{b_j}$ are the variances for the two coefficients; and $s_{b_i b_j}$ is the covariance for these two coefficients. This value was compared to:

$$S^2 = (k - 1)* F_{k-1, n-k, 1-\alpha}$$

Where n is the sample size and k is the number of groups (zones or subzones) to be tested.

Table 5. Table of critical values for Scheffe’s test for 95% probability and large sample sizes.

<i>Number of Groups</i>	<i>F value</i>	<i>S² Value</i>
2	3.84	3.84
3	3.00	6.00
4	2.60	7.80
5	2.37	9.48
6	2.21	11.05
7	2.10	12.60
8	2.01	14.07
9	1.94	15.52
10	1.88	16.92

The pairwise zone test was used to decide which zones to combine together. An equation was developed for each combination, using all data for the combined zones. Once the equations were developed for each combination of species/BEC zone/subzone, the coefficients, and precision of the equation were obtained. It is important to know that when a **very large sample size is used in testing for zonal differences, even a very small difference between zones will be detected by the partial F and Scheffe’s tests**. Conversely, when the regression lines are not very precise, as with the height dubbing equation, the differences in coefficients must be very large before differences are detected.

3. RESULTS AND DISCUSSION

3.1 Verification Using Permanent Sample Plots Data

3.1.1 Height dubbing equation

For the Nelson PSP data set, the highest percent biases for BL, PL and PW were found in ESSF for all DBH classes (Table 6). The highest percent biases were obtained in trees < 5.0 cm diameter for CW, FD, HM, and HW (Table 6). However, this higher percent bias is due to the small denominator in percent bias calculation for small trees. Also, it should be noted that there were very few trees in the 0 to 5.0 cm DBH class. The percent bias due to the height dubbing equation consistently increased with diameter class for BL in ESSF and ICH, PL in IDF, PW in ICH, and for SE in ESSF. There was consistent over-estimation (negative percent bias) of height for BL in ESSF, for CW in ICH, and for PL in ESSF. On the other hand, consistent under-estimation of height (positive percent bias) was observed for BL, FD, HW, PL, and SE in ICH, for HM and LW in ICH and IDF, for FD in IDF, MS, and PP, and for PL in ESSF. HM followed by PY showed the highest percent bias (> 20% bias) for all DBH classes. These biases could be attributed to the lack of calibration of HM in Prognosis^{BC} and to the limited number of PY trees (with measured heights) in Nelson PSP data set.

Smaller percent biases due to the height dubbing equation were found in IDF than in PP for all diameter classes in the Kamloops PSP data set (Table 7). In PP, the average percent bias due to height dubbing equation increased with diameter class for FD and PY. Similar to the Nelson PSP data set, HM followed by PY showed the highest percent bias in Kamloops PSP data set. Heights were mostly over-estimated (negative percent bias) for all trees < 45.0 cm diameter except for HM in IDF for Kamloops PSP data set.

Table 6. Average percent bias (%BIAS) due to the height dubbing equation and number of trees (n) by DBH class, BEC zone, and species for Nelson PSP data set.

SPECIES	BEC ZONE	DBH CLASS (cm)					
		0- 5.0	5.0 - 12.4	12.5 - 25.0	25.1 - 45.0	45.1 - 60.0	60.1+
BL	ESSF		-18.20(14)	-31.00(56)	-41.4(9)		
	ICH		7.91(15)	8.44(37)	14.57(6)		
	IDF		32.48(1)				
	ALL		-4.69(29)	-14.8(94)	-19(15)		
CW	ICH	22.65(10)	-2.75(199)	-5.10(272)	-9.20(59)	-9.08(4)	
	IDF		-6.31(1)				
	ALL	22.65(10)	-2.75(199)	-5.11(273)	-9.2(59)	9.08(4)	
FD	ICH	15.44(3)	9.16(435)	1.28(756)	6.38(393)	2.89(19)	9.51(1)
	IDF		-10.8(120)	-15.9(342)	-9.62(186)	2.89(19)	-0.70(3)
	MS		-24.00(1)	-4.69(3)			
	PP		-10.7(7)	-26.00(34)	-35.7(9)		
	ALL	15.44(3)	4.65(562)	-4.73(1133)	0.65(591)	9.87(59)	1.85(4)
HM	ICH	59.02(4)	46.80(85)	33.25(187)	22.27(34)		
	IDF		39.46(17)	21.70(39)	7.97(1)		
	ALL	59.02(4)	45.57(102)	31.26(226)	21.86(35)		
HW	ICH	23.55(7)	0.89(192)	-1.66(334)	-7.57(50)		
LW	ICH		-4.31(233)	-11.00(507)	-4.55(118)	6.52(8)	
	IDF		-8.27(68)	-16.8(330)	-12.2(82)	-3.45(1)	
	MS				-6.13(1)		
	ALL		-5.2(301)	-13.3(837)	-7.66(201)	5.41(9)	
PL	ESSF		-51.2(3)	-70.00(2)			
	ICH		8.30(471)	4.46(938)	8.05(106)	4.73(3)	
	IDF		1.23(60)	-5.00(245)	-7.99(20)		
	ALL		7.17(5.34)	2.4(1192)	5.51(126)	4.73(3)	
PW	ESSF			-137(1)			
	ICH		-0.12(87)	-7.53(190)	-10.6(112)	-13.0(6)	
	ALL		-0.12(87)	-8.21(191)	-10.6(112)	-13(6)	
PY	ICH			-30.9(1)			
	IDF		8.35(9)	-19.6(39)	-23.4(11)		
	PP		16.32(5)	-15.6(36)	-21.0(4)		
	ALL		11.2(14)	-17.9(76)	-22.7(15)		
SE	ESSF		-23.6(2)	-47.5(9)	-61.4(1)		
	ICH		8.29(35)	1.89(75)	2.89(43)		
	IDF		-15.7(4)	-9.31(10)	-2.17(11)		
	ALL		4.39(41)	-4.04(94)	0.71(55)		

Table 7. Average percent bias (%BIAS) due to the height dubbing equation and number of trees (n) by DBH class, BEC zone, and species for Kamloops PSP data set.

SPECIES	BEC ZONE	DBH CLASS (cm)					
		0- 5.0	5.0 - 12.4	12.5 - 25.0	25.1 - 45.0	45.1 - 60.0	60.1+
FD	IDF		-6.12(133)	-11.80(465)	-6.14(246)	2.98(11)	12.74(1)
	PP		-12.4(3)	-36.00(27)	-33.90(12)		
	ALL		-6.26(136)	-13.1(492)	-7.43(258)	2.98(11)	12.74(1)
HM	IDF		32.1(13)	17.94(29)	21.18(1)		
PL	IDF		-4.31(112)	-4.78(341)	8.32(85)	11.28(1)	
PY	IDF		-6.49(10)	-16.5(58)	-26.7(30)	-1.63(3)	
	PP		-13.4(7)	-18.20(27)	-18.2(4)		
	ALL		-9.32(17)	-17.1(85)	-25.7(34)	-1.63(3)	
SE	IDF			1.37(3)	-7.71(6)		

Percent bias due to height-dubbing equation varied widely (i.e., higher standard deviation) by tree species and DBH classes. The detailed summary (mean, standard deviation, minimum, maximum, and z-test (labeled as T)) of percent bias due to the height dubbing equation by BEC zone, subzone, species, and DBH classes are given in Appendices A and B for the Nelson and Kamloops PSP data sets.

3.1.2 Height increment model

Bias based on one projection cycle

For the Nelson data set, the large tree height increment model (for trees > 25 cm DBH) resulted in the lowest percent biases for HM, and HW in ICH, for FD in IDF and MS, for LW, PL, and SE in ICH and IDF, and for PY in IDF (Table 8). The small tree height increment model resulted in the highest percent biases for BL, CW, and PW in ICH. This high percent bias is again due to the smaller denominator in percent bias calculation for small trees. Also, there were very few trees in the 0 to 5.0 cm DBH class.

The large tree height increment model (for trees >25 cm DBH) also consistently resulted in the lowest percent bias for FD in IDF and PP, PL in IDF, and PY in PP in the Kamloops PSP data set (Table 9). Both the small and large tree height increment model consistently over-estimated tree height, as shown by the negative biases for all species/BEC zone/subzone combinations.

Table 8. Average percent bias (%BIAS) due to the height growth models and number of trees (n) by DBH class, BEC zone and species for one projection cycle using the Nelson PSP data set.

SPECIES	BEC ZONE	DBH CLASS (cm)					
		0- 5.0	5.0 - 12.4	12.5 - 25.0	25.1 - 45.0	45.1 - 60.0	60.1+
BL	ESSF		5.02(9)	2.56(28)	-6.79(8)		
	ICH	-8.57(1)	1.61(14)	4.86(30)	3.15(12)		
	IDF			-54.7(1)			
	ALL	-8.57(1)	2.94(23)	2.76(59)	-0.83(20)		
CW	ICH	-6.15(12)	4.05(166)	4.39(322)	0.42(73)	0.17(10)	
	IDF			-7.91(4)			
	ALL	-6.15(12)	4.05(166)	4.24(326)	0.42(73)	0.17(10)	
FD	ICH	3.18(9)	-0.39(310)	0.34(762)	-0.43(461)	0.65(49)	-2.20(4)
	IDF	7.68(4)	1.76(64)	-1.13(443)	-0.08(304)	-0.72(29)	1.01(4)
	MS		-20.3(4)	-36.2(7)	-0.37(5)		
	PP		5.07(4)	0.10(42)	-1.49(18)		
	ALL	4.57(13)	-0.18(382)	-0.39(1254)	-0.32(788)	0.14(78)	-0.6(8)
HM	ICH	16.67(1)	15.76(56)	8.12(19)	-0.92(48)	0.65(1)	
	IDF		17.04(19)	7.35(48)	7.80(1)		
	ALL	16.67(1)	16.09(75)	7.97(243)	-0.75(49)	0.65(1)	
HW	ICH	-2.8(4)	3.00(147)	2.75(331)	0.25(73)		
LW	ICH		7.16(87)	3.92(539)	1.10(158)	1.20(9)	
	IDF		9.71(79)	4.04(402)	0.22(130)	-1.13(2)	
	MS				-13.00(2)		
	ALL		8.37(166)	3.97(941)	0.61(290)	0.62(12)	
PL	ESSF		-2.97(1)	6.06(1)			
	ICH		3.94(224)	4.71(1067)	1.72(131)	3.71(3)	
	IDF		5.47(68)	4.91(345)	2.46(32)		
	MS		0.57(1)	-2.37(22)	2.60(1)		
	ALL		4.26(294)	4.65(1435)	1.87(164)	3.71(3)	
PW	ESSF			-65.50(2)			
	ICH	12.56(2)	-2.08(52)	2.47(133)	-3.05(103)	-4.57(6)	
	ALL	12.56(2)	-2.08(52)	1.46(135)	-3.05(103)	-4.57(6)	
PY	ICH		5.92(1)				
	IDF		8.84(6)	2.93(39)	0.09(11)	5.85(1)	
	PP		0.15(4)	-0.94(43)	1.72(11)		
	ALL		5.37(10)	0.96(83)	0.91(22)	5.85(1)	
SE	ESSF			-12.5(3)	-45.2(2)		
	ICH		-1.73(17)	4.64(56)	1.26(52)	1.55(1)	
	IDF		15.08(3)	3.27(32)	-1.07(22)	-1.41(1)	
	ALL		0.79(20)	3.6(91)	-0.63(76)	0.07(2)	

Table 9. Average percent bias (%BIAS) due to the tree height growth models and number of trees (n) by DBH class, BEC zone and species for one projection cycle using the Kamloops PSP data set.

SPECIES	BEC ZONE	DBH CLASS (cm)					
		0- 5.0	5.0 - 12.4	12.5 - 25.0	25.1 - 45.0	45.1 - 60.0	60.1+
FD	IDF		-16.3(133)	-14.00(465)	-8.62(246)	-6.72(11)	-3.60(1)
	PP		-28.5(3)	-19.5(27)	-9.73(12)		
	ALL		-16.5(136)	-14.3(492)	-8.67(258)	-6.72(11)	-3.6(1)
HM	IDF		-2.31(13)	-3.13(29)	-5.55(1)		
PL	IDF		-9.94(112)	-6.74(341)	-3.16(85)	-1.03(1)	
PY	IDF		-19.5(10)	-21.4(58)	-20.7(30)	-2.63(3)	
	PP		-33.9(7)	-24.8(27)	-9.06(4)		
	ALL		-25.4(17)	-22.4(85)	-19.4(34)	-2.63(3)	
SE	IDF			-5.91(3)	-4.2(6)		

Percent bias due to the tree height increment model varied widely (i.e., higher standard deviation) by tree species and DBH classes. The detailed summary (mean, standard deviation, minimum, maximum, and z- test (labeled as T)) of percent biases due to tree height increment model by BEC zone, subzone, species, and DBH classes are given in Appendices C and D for the Nelson and Kamloops PSP data sets.

Bias based on two and three projection cycles

The large tree height increment model consistently showed reasonable bias over the two additional projections on the Nelson PSP data set (Tables 10 and 11). The high bias due to the small tree height increment model is consistently observed in the two consecutive projections for CW, FD, HM, and HW in ICH, and for LW in IDF of the Nelson PSP data sets. However, this higher percent bias may be due to the small denominator for small trees. The detailed summary (mean, standard deviation, minimum, maximum, and z- test (labeled as T)) of percent biases due to tree height increment model by BEC zone, subzone, species, and DBH classes for two and three projection cycles are given in Appendices E and F.

Table 10. Average percent bias (%BIAS) due to the height growth models and number of trees (n) by DBH class, BEC zone and species for two projection cycles using the Nelson PSP data set.

SPECIES	BEC ZONE	DBH CLASS (cm)					
		0- 5.0	5.0 - 12.4	12.5 - 25.0	25.1 - 45.0	45.1 - 60.0	60.1+
BL	ESSF		-13.3(14)	-4.93(84)	-11.30(47)		
	ICH		10.52(9)	4.50(22)	0.69(9)		
	IDF			-53.5(1)			
	ALL		-3.97(23)	-3.45(107)	-9.34(56)		
CW	ICH	27.35(5)	4.07(99)	6.89(283)	3.16(78)	4.38(4)	
	IDF			3.82(3)			
	ALL	27.35(5)	4.07(99)	6.86(286)	3.16(78)	4.38(4)	
FD	ICH	59.08(4)	2.31(211)	1.31(766)	1.50(557)	1.42(50)	-1.34(4)
	IDF		27.16(22)	5.16(231)	1.45(329)	-0.75(28)	-2.02(2)
	MS		-16.2(1)	-28.40(9)	-4.72(4)	0.36(2)	
	PP		36.04(2)	8.37(23)	2.07(21)		
	ALL	59.08(4)	4.84(236)	2.07(1029)	1.47(911)	0.64(80)	-1.57(6)
HM	ICH	73.83(2)	35.17(21)	14.52(143)	8.78(53)	18.87(1)	
	IDF		33.79(4)	11.58(32)	7.41(1)		
	ALL	73.83(2)	34.95(25)	13.98(175)	8.76(54)	18.87(1)	
HW	ICH	40.43(2)	-4.50(87)	2.64(324)	1.34(88)		
LW	ICH		12.16(101)	9.64(749)	3.58(256)	0.13(14)	
	IDF	65.37(1)	15.21(28)	8.29(332)	3.09(191)	-2.70(1)	
	MS				-14.0(2)		
	ALL	65.37(1)	12.82(129)	9.23(1081)	3.3(449)	-0.3(15)	
PL	ESSF		-32.0(11)	-53.8(18)	-144(2)		
	ICH		7.05(156)	7.68(1275)	7.01(195)		
	IDF		5.15(15)	9.17(238)	6.54(34)		
	MS		16.49(1)	-0.51(15)	-3.45(4)		
	ALL		4.6(183)	7.11(1546)	5.49(235)		
PW	ICH		-11.90(20)	-1.45(97)	-2.38(94)	-11.1(5)	
PY	IDF		23.85(3)	14.64(19)	10.32(10)	-11.10(1)	
	PP		-9.98(3)	8.30(40)	1.38(18)		
	ALL		6.94(6)	10.34(59)	4.57(28)	-11.1(1)	
SE	ESSF		-20.00(3)	-12.70(22)	-35.8(22)	-72.6(1)	
	ICH		5.85(17)	6.33(90)	0.78(47)	-9.66(2)	
	IDF			15.60(24)	6.56(29)	-0.65(1)	
	ALL		1.97(20)	4.88(136)	-5.72(98)	-23.1(4)	

Table 11. Average percent bias (%BIAS) due to the height growth models and number of trees (n) by DBH class, BEC zone and species for three projection cycles using the Nelson PSP data set.

SPECIES	BEC ZONE	DBH CLASS (cm)					
		0- 5.0	5.0 - 12.4	12.5 - 25.0	25.1 - 45.0	45.1 - 60.0	60.1+
BL	ESSF			-63.9(8)	-77.6(1)		
	ICH		-3.47(4)	1.24(19)	3.71(5)		
	ALL						
CW	ICH	56.30(4)	-0.89(141)	2.20(350)	0.37(102)	4.22(5)	
FD	ICH	47.21(1)	-1.49(167)	-2.99(544)	-1.11(430)	1.87(50)	2.79(8)
HM	ICH	55.03(2)	46.08(31)	28.22(50)	6.72(22)		
HW	ICH	24.37(4)	-2.60(117)	0.56(315)	-4.03(109)		
LW	ICH		2.29(19)	-2.05(143)	-2.69(121)	0.75(15)	-3.23(2)
PL	ESSF		-53.70(3)	-56.1(2)			
	ICH		0.18(44)	4.20(379)	4.37(126)		
	ALL						
PW	ICH		-3.98(52)	0.14(115)	-5.50(71)	-5.15(8)	
SE	ESSF		-74.9(1)	-16.3(3)	4.14(28)	0.70(29)	
	ICH		-16.3(3)	4.14(28)	0.70(29)	8.06(3)	
	ALL						

3.1.3 Mortality model

Mortality rate varied considerably among tree species. The observed number of live and dead trees (in the PSP data sets) were significantly different from the projected number of live and dead trees for each species considered in Prognosis^{BC} (Appendix G). The detailed summary for the number of live and dead trees in each zone, subzone, and site series combination for tree species are given in Appendix H.

Only detailed analysis of the mortality model for FD is presented and discussed for brevity. The average mortality rate for DF was 4.64 and 4.93 % in Nelson and Kamloops PSPs, respectively (Tables 12 and 13). The goodness of fit statistics showed significant differences between the observed and predicted mortality rate for DF. For example, for the calculated Chi-square value ($X^2_c = 83.7$) was greater than the tabulated chi-square value ($X^2_T = 25.0$) at the 95% confidence level at 15 degree of freedom. Therefore, the hypothesis that the Prognosis^{BC} mortality model predicts the observed mortality at reasonable rate was rejected (Table 12). However, there was no consistent under- or over-estimation of mortality over the diameter classes for DF.

Table 12. Chi-square statistics (X^2), number of live trees (N_TOTAL), observed (N_DEAD) and expected (N_EXPEC) number of dead trees, and observed (OBS_MORT) and predicted mortality rate (PRED_MORT), and Multipliers (MULT) for Douglas-fir by diameter class for Nelson PSPs.

DBHCLS	N_TOTAL	N_DEAD	PRED_MORT	OBS_MORT	NO_EXPEC	MULT	X^2
<5.00	392	29	0.0719	0.0772	26	1.07	0.3
10.01-12.50	2081	174	0.0585	0.1068	110	1.82	37.2
12.51-15.00	1480	69	0.0404	0.0562	57	1.39	2.5
15.01-17.50	1131	53	0.03357	0.05344	31	1.59	15.1
17.51-20.00	711	21	0.03050	0.03053	22	1.00	0.1
20.01-22.50	585	11	0.0212	0.0136	13	0.64	0.3
22.51-25.00	403	4	0.0311	0.0135	12	0.44	5.5
25.01-27.50	325	2	0.0233	0.0044	8	0.19	5.0
27.51-30.00	223	3	0.0927	0.0607	6	0.65	1.4
30.01-32.50	141	0	0.1024	0.0000	5	0.00	4.8
32.51-35.00	101	0	0.0389	0.0000	2	0.00	2.1
35.01-37.50	52	0	0.0112	0.0000	1	0.00	0.6
37.51-40.00	30	0	0.0211	0.0000	1	0.00	0.6
40.01-42.50	30	0	0.0143	0.0000	0	0.00	0.4
>42.50	268	3	0.0480	0.0080	13	0.16	7.7
AVERAGE			0.04260	0.02828		0.59703	
TOTAL	7953	369			308		83.7

In Nelson data set, out of 7953 Douglas-fir trees measured during measurement period 1, 369 (4.6%) were dead by measurement 2 (Table 12); out of 4499 DF trees in measurement period 222 (4.9%) trees died by measurement period 2 in Kamloops data set (Table 13). For DF, significant differences between the observed and predicted mortality rates were also found in the Kamloops PSP data set. Unlike the Nelson data set, there was consistent over-estimation of mortality (observed < predicted) in all diameter class in the Kamloops data set (Table 13).

In Nelson PSPs, there was significant difference between the observed and expected mortality rates among these zones, subzones, and site series considered in Prognosis^{BC}. However, there was no consistent over- or under-estimation of mortality among these various zones, subzones, and site series. The highest difference was observed in IDFdm site series 01 where Prognosis^{BC} predicted more than twice the observed mortality in Nelson PSPs (Table 14).

Table 13. Chi-square statistics (X^2), number of live trees (N_TOTAL), observed (N_DEAD) and expected (N_EXPECT) number of dead trees, and observed (OBS_MORT) and predicted mortality rate (PRED_MORT), and Multiplier (MULT) for Douglas-fir by diameter class for Kamloops PSPs.

DBHCLS	N_TOTAL	N_DEAD	PRED_MORT	OBS_MORT	NO_EXPECT	MULT	X^2
7.51-10.00	276	44	0.73884	0.16511	200	0.2235	121.9
10.01-12.50	959	40	0.1349	0.0343	132	0.2543	64.3
12.51-15.00	565	13	0.0773	0.0204	46	0.2633	23.6
15.01-17.50	1800	97	0.0564	0.0112	378	0.1985	209.3
17.51-20.00	238	5	0.0499	0.0168	13	0.3376	4.6
20.01-22.50	161	3	0.0402	0.0199	6	0.4952	1.9
22.51-25.00	146	2	0.0796	0.0207	5	0.2596	1.7
25.01-27.50	43	3	0.0374	0.0698	2	1.8649	1.2
>27.50	311	15	0.0630	0.0320	20	0.5079	1.3
AVERAGE			0.15183	0.04477		0.48713	
TOTAL	4499	222			802		429.8

In Kamloops PSPs, there was significant difference between the observed and expected mortality rates among trees species is considered (Table 14). However, no significant difference was found when the various zones, subzones, and site series were compared (Table 14). This can be attributed to the balance between over- and under-estimation by the tree species found Kamloops.

For Nelson PSPs, the observed and predicted mortality rates varied by species and diameter class. There was consistent under estimation (observed > predicted) of mortality for HM, HW, and PW. On the other hand there was consistent over-estimation (predicted > observed) of mortality for LW (APPENDIX G). For Kamloops PSP data set, there was consistent over-estimation (predicted > observed) of mortality for DF and PL except trees in the range of 20.0 to 25.0 cm (Table 13 and APPENDIX H).

The chi-square statistics besides providing the measure of goodness-of-fit, it provides a measure of the adequacy of the mortality model over the range of the DBH classes. The mortality rate generated by Prognosis^{BC} is disconcerting, especially in young stands and in small tree diameters. Under these conditions, high mortality rate will occur, often at a rate, which makes the density management prescription inoperable.

Table 14. Chi-square statistics (X^2), number of live trees (N_TOTAL), observed (N_DEAD) and expected (N_EXPEC) number of dead trees, and observed (OBS_MORT), predicted mortality rate (PRED_MORT), and Multiplier (MULT) by zone subzone and site series.

Nelson		SS	N_TOTAL	N_DEAD	NO_EXPEC	PRED_MORT	OBS_MOR	MULT	X^2
ICH	mk	1	4707	318	480	0.1019	0.0676	0.66	54.6
		3	3508	208	200	0.0570	0.0593	1.04	0.3
		4	2820	171	206	0.0729	0.0606	0.83	5.8
mw		1	1646	130	147	0.0892	0.0790	0.89	1.9
		3	9991	1058	1157	0.1158	0.1059	0.91	8.4
		4	9251	1180	1063	0.1149	0.1276	1.11	12.8
IDF	dm	1	3810	169	420	0.1103	0.0444	0.40	150.3
		4	389	85	128	0.3294	0.2185	0.66	14.5
PP	dh	1	24	8	7	0.2889	0.3333	1.15	0.2
Total			36146	3327	3807.86223				248.9
Kamloops		SS	N_TOTAL	N_DEAD	NO_EXPEC	PRED_MORT	OBS_MOR	MULT	X^2
IDF	dk	1	2935	221	194	0.0660	0.0753	1.14	3.8
		3	842	36	34	0.0406	0.0428	1.05	0.1
		4	837	37	46	0.0545	0.0442	0.81	1.6
xh		1	496	9	10	0.0211	0.0181	0.86	0.2
		5	88	0	0	0.0000	0.0000		
		6	34	0	0	0.0000	0.0000		
Total			5232	303					5.775

The mortality model of Prognosis^{BC} is biased and needs to be re-calibrated. After realizing significant differences between the observed and predicted mortality rates, multipliers (i.e., the ratio of average observed periodic mortality rate to average predicted periodic mortality rate) were calculated, as an interim measure to adjust the mortality model.

To avoid bias, multipliers were calculated if there area more than 30 trees in each diameter class and in each zone, subzone and site series considered in Prognosis^{BC}. These multipliers are given for DF in Tables 12 and 13. Zone, subzone, and site series-based multipliers for Nelson and Kamloops PSPs are given in Table 14. Multipliers for the remaining tree species are given in Appendices G and H. The multipliers varied widely, as only measurement period of 1 and 2 were considered due to time constraints and planned re-fitting of the mortality model. Summary of multipliers by BEC zone, subzone, site series, species, and diameter class for Nelson and Kamloops PSPs are given in Appendices I and J.

3.2 Verification Independent Stem Analysis Data

The independent stem analysis data set that was used to evaluate the diameter and height increment model covered three site series (i.e., 01, 04, and 06), and a wide range of slope, azimuth and elevation (Table 1). The data set contained seven of the eleven tree species that are considered in Prognosis^{BC}. The data covered a wide range of DBHs (i.e., from 7.53 to 70.16) and heights (i.e., from 6.02 to 40.45) for these species (Table 15). Although the independent data set is obtained from a location outside the geographical range of Prognosis^{BC}, it provided an opportunity to verify the height and diameter increment model Prognosis^{BC}.

Out of the 876 trees in the stem analysis data set, only 167 trees were used as independent data set for verifying the diameter and height increment models of Prognosis^{BC}. This is due to the exclusion of hardwoods, conifers < 7.5 cm, damaged trees (i.e., broken trees or crowns) and snags in the data set.

3.2.1 Diameter increment model

The standard error of the estimate in predicting diameter growth using Prognosis^{BC} was 2.18 cm over 10 years. Among the seven tree species considered in the stem analysis data set, CW (i.e., - 3.03 cm over 10 years) showed the highest diameter increment bias while PL (i.e., -1.08 cm over 10 years) showed the lowest bias. DF showed the widest range of diameter increment bias (i.e., - 6.62 to 6.4 cm over 10 years) (Table 16).

Table 15. Number of trees used for assessing the diameter and height increment models of Prognosis^{BC} and their minimum (MIN), mean, maximum (MAX), and standard deviation (STD) of DBH and height by species. Only live, coniferous, trees > 7.5 cm were considered.

SPP	N	DBH				HT			
		MEAN	STD	MIN	MAX	MEAN	STD	MIN	MAX
BL	10	15.31	8.72	7.53	34.78	15.96	6.41	8.60	27.13
CW	61	14.69	9.14	7.54	70.16	12.98	5.63	6.02	36.60
FD	37	27.66	15.28	7.66	59.05	25.77	9.04	7.95	38.93
HW	12	12.55	4.37	8.41	21.46	14.01	4.93	8.71	24.87
LW	10	29.60	10.18	10.86	43.38	29.53	6.74	17.32	40.45
PL	15	27.95	5.17	19.67	38.51	26.64	2.73	19.00	30.00
SE	22	18.31	7.61	8.64	38.51	18.92	4.93	10.15	31.00
Total	167								

Despite the limited sample size, diameter increment was consistently over-estimated for the seven tree species considered in this verification (Table 16). Due to small sample size, analysis on the accuracy of the diameter increment model by diameter class was only made for CW and FD (Figure 1).

Table 16. Bias (cm) and percent bias (%) of 10-year diameter increment by species for two sets of backdated trees (i.e., DBH₁₀ and DBH₂₀). Only live, undamaged, coniferous trees > 7.5 cm were considered.

SPP	N	DBH ₁₀ – bias(cm) over 10 years				N	DBH ₂₀ – bias (cm) 10 year cm over			
		MEAN(%BIAS)	STD	MIN	MAX		MEAN(%BIAS)	STD	MIN	MAX
BL	10	-2.73(-27.21)	3.47	-8.53	1.46	7	-1.50(-13.42)	5.96	-11.58	3.80
CW	61	-3.03(-25.10)	1.68	-7.93	0.45	51	-2.86(-26.96)	1.88	-7.32	3.78
FD	37	-1.69(-10.52)	2.95	-6.62	6.40	32	-1.19(-10.15)	3.01	-8.16	2.66
HW	12	-2.47(-22.96)	0.99	-4.24	-0.78	9	-2.08(-12.34)	0.8	-3.43	-0.82
LW	10	-1.84(-8.26)	1.44	-4.46	1.07	10	-2.02(-12.34)	1.75	-4.62	1.53
PL	15	-1.08(-3.91)	1.25	-2.9	1.99	15	-0.71(-3.23)	1.45	-3.01	2.22
SE	22	-2.04(-13.87)	1.96	-7.94	1.77	19	-1.11(-8.62)	2.32	-4.5	3.61
Total	167					143				

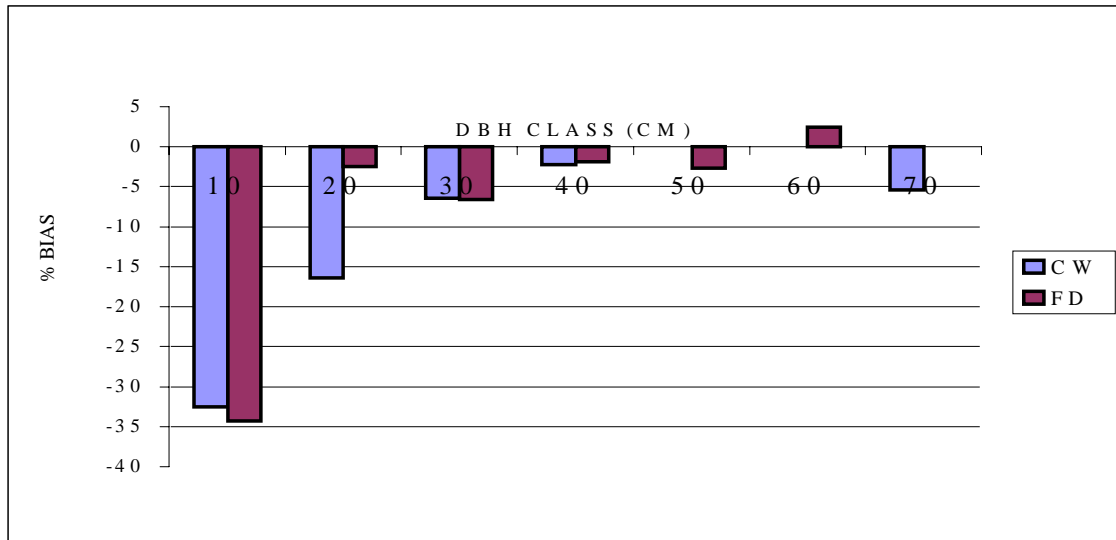


Figure 1. Diameter increment % bias by diameter class for DF and CW.

3.2.2 Height increment model

The standard error of the estimate in predicting average 10-year height increment using Prognosis^{BC} was 2.14 metres. LW followed by SE showed highest 10-year height increment bias. The lowest bias was showed by CW followed by BL. When trees were projected without the self-calibration feature of Prognosis^{BC}, biases in height increment increased for all tree species except PL and SE for (Table 17). Due to small sample size, analysis on the accuracy of the height increment model by diameter class was only made for CW and FD (Figure 2).

Table 17. Bias (cm) and percent bias (%) of 10-year height increment with or without diameter increment (DG) by species. Only live undamaged coniferous trees > 7.5 cm were considered.

SPP	N	Bias in m - with DG				Bias in m - without DG			
		MEAN(%BIAS)	STD	MIN	MAX	MEAN(%BIAS)	STD	MIN	MAX
BL	10	-0.45(1.21)	2.37	-4.13	2.64	1.05(7.94)	2.83	-3.17	5.94
CW	61	0.14(3.02)	1.29	-6.13	1.62	0.63(5.26)	1.36	-5.47	2.35
FD	37	1.06(7.98)	2.47	-3.99	7.18	1.67(9.86)	2.70	-3.86	8.32
HW	12	1.34(9.04)	1.01	-0.38	3.38	1.52(10.30)	0.84	0.49	2.78
LW	10	2.27(10.84)	1.77	0.96	5.74	2.86(13.68)	2.06	0.91	7.18
PL	15	0.62(2.63)	1.05	-1.49	2.23	0.54(2.17)	1.06	-1.60	1.98
SE	22	-1.80(-9.92)	2.56	-6.66	1.39	-0.70(-2.67)	2.28	-5.19	2.85
Total	167								

3.3 Height-diameter equation coefficient assessment

The data set used to test the uniformity of the height-diameter coefficients covered a wide range of DBHs and heights for each species/BEC zone/subzone combination (Table 18). There were no substantial differences in the first coefficient (C_0) of the height-diameter equation between Northern Idaho and BC data sets (Table 19). However, the second coefficient (C_1) varied substantially for all tree species except for western white pine. C_1 is a direct multiple of the reciprocal of DBH (see equation on page 12). Thus, it can be assumed that an inaccurate C_1 estimate can result in considerable bias in height estimation.

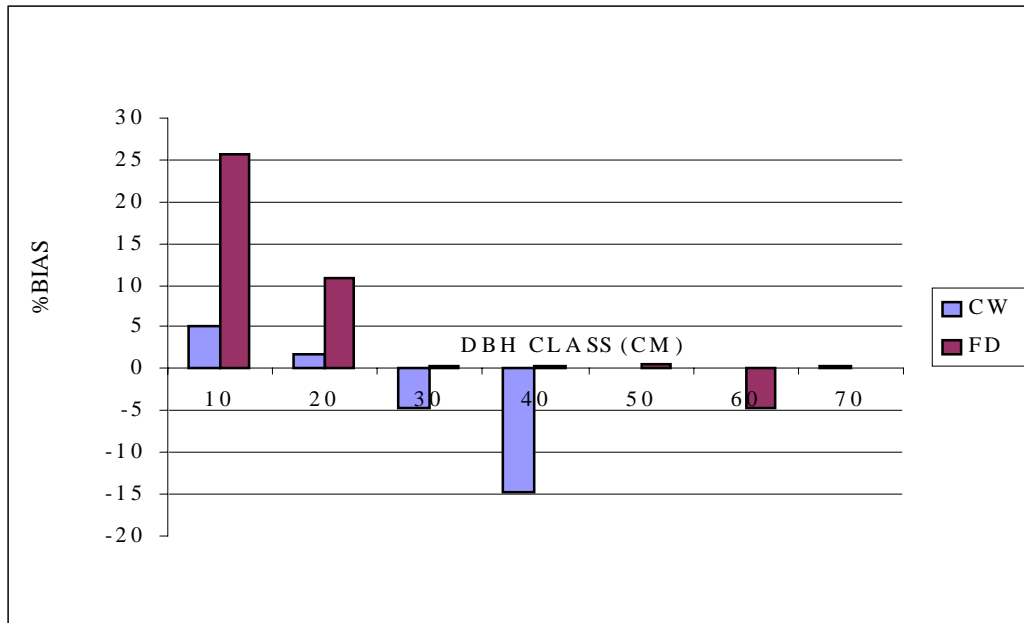


Figure 2. Ten-year height increment % bias (cm over 10 years) by diameter class for DF and CW when diameter increment data was considered.

The height-diameter equation was fitted for each species/BEC zone/subzone combination. The results indicated that C_0 and C_1 of the height-diameter coefficients differ significantly among BEC zones, and among some subzones within a BEC zone using Scheffe's multiple comparison test. The height-dbh equation was then fitted for each group of subzones that were similar (Table 20). To indicate the gain in precision by fitting by subzone group rather than by BEC zone, by BEC zone group rather than by BEC zones and finally for all zones rather than by BEC zone group, the root mean square values are shown. For example, the C_0 and C_1 coefficients of DF in the IDF, PP, MS BEC zones were significantly different from each other and those in the ICH and ESSF BEC zones. However, the coefficients were not significantly different between the ICH and ESSF BEC zones. Thus, the data set for ICH and ESSF BEC zones can be pooled together.

Table 18. Number of trees and the minimum (MIN), mean, maximum (MAX), and standard deviation (STD) for DBH and tree height by species and BEC zone for data used in comparing zones and subzones.

SP- CIES	BEC	N	DBH				HEIGHT			
			MIN	MEAN	MAX	STD	MIN	MEAN	MAX	STD
BL	ESSF	2508	3.9	27.8	96.0	13.6	3.3	20.0	53.3	8.3
	ICH	1146	6.7	27.7	86.2	11.9	5.9	22.0	44.5	7.7
	IDF	64	5.4	18.4	45.7	9.7	4.4	14.0	26.5	5.8
	MS	172	13.0	22.9	46.2	8.7	8.9	19.1	37.4	6.0
CW	ESSF	210	13.0	43.4	127.3	20.1	7.4	25.8	46.0	7.9
	ICH	3594	4.7	50.6	179.7	30.1	3.3	26.7	54.9	10.0
	IDF	116	3.3	37.9	172.4	30.5	4.1	21.5	49.6	10.5
	MS	147	13.0	39.4	123.6	26.0	7.3	21.3	42.8	10.4
DF	ESSF	277	13.0	39.4	118.0	19.6	8.0	26.5	52.4	9.0
	ICH	764	10.0	40.2	119.6	18.9	5.7	28.2	49.4	9.3
	IDF	1660	2.1	36.7	147.6	20.0	2.6	21.7	54.3	7.8
	MS	370	4.4	33.3	93.8	16.8	4.8	22.6	47.8	8.9
	PP	393	12.8	34.4	113.1	17.2	6.3	19.2	40.8	6.9
HW	ESSF	531	13.0	39.8	96.5	16.3	8.8	27.5	49.1	8.7
	ICH	6048	3.8	37.5	135.3	15.8	3.2	25.6	50.4	7.9
	IDF	37	14.0	26.3	52.4	9.7	8.3	19.5	33.7	7.0
LW	ESSF	86	15.3	44.9	81.7	15.1	19.4	33.4	46.4	6.5
	ICH	333	6.7	34.6	97.5	16.4	7.4	26.9	53.7	8.4
	IDF	261	4.1	30.4	89.7	18.9	4.2	24.5	50.9	10.8
	MS	413	12.3	41.5	103.3	16.6	13.5	30.8	50.2	7.7
PL	ESSF	603	4.3	24.9	54.1	8.8	4.9	20.6	34.6	6.0
	ICH	443	12.5	24.4	48.2	8.2	10.5	22.8	38.2	6.0
	IDF	857	3.8	18.7	46.1	7.1	3.1	15.8	36.8	5.2
	MS	591	13.0	23.0	70.0	7.6	7.6	18.8	40.8	5.3
PW	ICH	307	7.1	38.7	105.4	16.7	6.8	30.4	53.7	8.1
PY	ICH	135	14.2	55.8	112.7	20.8	6.2	32.2	48.7	8.8
	IDF	315	3.1	34.1	102.9	20.9	3.2	18.6	40.9	8.8
	PP	192	6.2	36.0	99.1	16.2	4.1	16.9	36.6	7.3
SE	ESSF	1424	4.1	30.5	110.7	17.0	3.0	21.9	51.8	9.8
	ICH	1274	4.1	35.5	110.0	18.4	4.4	26.5	55.8	10.2
	IDF	232	5.3	23.1	65.2	12.3	4.6	19.6	45.8	9.0
	MS	612	7.4	35.2	87.7	16.0	6.3	27.3	52.1	9.6

Table 19. Coefficients obtained for the height-diameter equation using Northern Idaho and BC data sets.

Species	C ₀	C ₁	C _{0BC}	C _{1BC}
Western white pine	5.19988	-9.26718	5.2077	-9.4801
Western larch	4.97407	-6.78347	5.1400	-8.9379
Douglas fir	4.81519	-7.29306	5.0344	-10.3185
Grand fir	5.00233	-8.19365	5.1341	-10.8497
Western hemlock	4.97331	-8.19730	5.1428	-11.0063
Western red cedar	4.89564	-8.39057	5.1502	-12.7658
Lodgepole pine	4.62171	-5.32481	4.8969	-7.7542
Engelmann spruce	4.92190	-8.30289	5.2272	-11.1327
Subalpine fir	4.76537	-7.61062	-	-
Ponderosa pine	4.92880	-9.32795	5.1735	-14.9339
Mountain hemlock	4.77951	-9.31743	-	-

Note: C₀ and C₁ are coefficients obtained using Northern Idaho data, as given in Wykoff *et al.* (1983), while C_{0BC} and C_{1BC} are coefficients obtained using BC data.

The two coefficients were significantly different among some subzones of IDF. Subzone xh was found to be significantly different from dk, mw, xm, dm and ww subzones. The coefficients are given for these subzones groups (Table 20). The root mean square error (RMSE) for DF in xh decreased from 4.67 m to 2.97 m by fitting the height-diameter equation for this subzone rather than for all BEC zones of the species. On the other hand, RMSE for the same subzone decreased from 4.67 m to 3.76 m by fitting this equation by BEC zone rather than for all BEC zones. Substantial reductions in RMSE were obtained for some of the species/BEC zone/subzone combination. For instance, RMSE for CW in IDF dm reduced from 3.89 m to 1.28 m (64 % reduction in RMSE) by fitting the height-diameter equation at the subzone level rather than at BEC zone level (Table 20).

The C₀ and C₁ coefficients are self-calibrated when there are more than three records for each species with measured heights and undamaged tops. Thus, equations fitted by subzones will often provide higher precision for input data with fewer than four height measurements.

Table 20. Coefficient and root mean square error (RMSE in metres) for the height-diameter equation by species/BEC zone/subzone combinations. Shaded cells refer to RMSE error obtained by fitting the respective pooled zones separately.

SPECIES	ZONE(S)	SUBZONE(S)	N	C ₀	C ₁	RMSE subzn	RMSE zone	RMSE Total	
BL	ICH+IDF	mk+vk+dk	634	5.0010	-9.1004	2.91	3.17/2.60	3.47	
		mw+wk+mc	588	5.1893	-10.5923	3.19	3.16		
	ESSF+MS	dk+wc+mc+mk+mv	1258	4.9735	-9.5213	2.98	3.49/2.90		
		mw+dc	595	5.3607	-14.0449	3.19	3.48		
		wk	419	4.9056	-10.2126	2.93			
CW	ICH	mw	1055	5.0713	-11.1453	3.57	3.60	3.57	
		mm+vk	298	5.3259	-17.3369	4.05			
		wk+mc+mk	2241	5.1541	-12.9964	3.36			
	IDF	dm	45	4.5231	-5.0204	1.28	3.89		
		ww	71	5.2649	-15.5587	3.71			
	ESSF + MS	wc	65	5.2127	-13.6008	3.18	3.13/2.89		
		dk+wk	292	5.1002	-12.1830	2.85	3.06		
DF	ICH + ESSF	dk+mk	568	5.1619	-11.2213	4.07	4.13/4.42	4.67	
		mw	302	5.1403	-8.7176	3.40	4.26		
		wk	79	5.3281	-12.4620	3.48			
		dw	92	5.0413	-10.0333	4.08			
	IDF	dk+mw+xm	988	4.9200	-9.9590	3.98	3.76		
		dm+ww	245	5.0091	-10.1147	3.39			
		xh	427	4.8550	-8.1272	2.97			
	PP	dh+xh	393	4.8169	-9.6455	4.06	4.06		
	MS	dk	370	5.1135	-11.0179	3.81	3.81		
	HW	ICH	vc+vk	531	5.1829	-12.9844	3.84	3.77	3.79
mw+wk			2948	5.1723	-11.3757	3.77			
mc			2569	5.0314	-9.2156	3.58			
IDF + ESSF		mm	202	5.2629	-11.5864	3.48	2.90/3.74		
		wv + ww +wc	103	5.3234	-13.4049	4.05			
LW	ICH	dw+mk	160	5.1429	-9.8217	4.41	4.46	3.89	
		mw	173	4.9879	-6.3027	3.97			
	IDF	dm+xh	261	5.1274	-8.5554	3.22	3.22		
		dk	499	5.1659	-9.2489	3.78			3.71/3.81
	MS+ESSF								
PL	ICH	mk +mw+mc	443	5.0826	-8.3420	2.68	2.72	3.86	
		xh+dm	251	4.8777	-6.6367	2.00			3.66
	ESSF +MS	dk	606	4.3366	-3.7890	3.79	3.49/3.57		
		dk+dc+dm	575	4.8819	-6.5269	3.03			
		wk+dc+dm	462	4.9783	-8.3323	3.44			3.56
		xv+mv	411	4.4564	-5.2739	1.98			
PW	ICH	mw	257	5.1939	-9.1411	2.69	2.75	2.94	
		wk	50	4.9835	-6.8249	2.26			

Table 20. Coefficient and root mean square error (RMSE in metres) for the height-diameter equation by species/BEC zone/subzone combinations. Shaded cells refer to RMSE error obtained by fitting the respective pooled zones separately (continued).

SPECIES	ZONE(S)	SUBZONE(S)	N	C ₀	C ₁	RMSE	RMSE	RMS E Total
						subzn	zone	
PY	ICH	dw	103	5.2244	-11.5008	3.24	4.42	4.59
		mk	32	4.9967	-12.4568	2.89		
	IDF	xh+dm	116	5.0282	-11.8080	2.84	2.94	
		dk	199	5.0334	-12.8709	2.91		
	PP	dh	38	5.1168	-15.0042	2.47	3.79	
		xh	154	4.8643	-13.6723	3.77		
SE	ICH+IDF	dk	63	4.9229	-8.4108	1.75	3.32/2.76	3.69
		dm+mk+mc	872	5.2396	-11.0095	3.15	3.23	
		mw+mc	447	5.2029	-10.0429	3.31		
		wk	252	5.3430	-12.5309	3.18		
	ESSF	dk+mw+wc+mv	579	5.1209	-9.5772	4.05	3.84	
		dc	191	5.2309	-11.4880	2.73		
	MS	wk+mc	398	4.9348	-10.2506	2.88		
		dk	478	5.2832	-11.2074	3.05	3.46	
		dm	134	5.3422	-12.4948	3.82		

4. ADDITIONAL STUDIES

4.1 Examination of Merchantable Volume

The accuracy of volume estimates from Prognosis^{BC} was examined on 15 PSPs, subjectively selected to represent various subzones and site series by the Prognosis^{BC} modelling group. These PSPs were used to compare the net merchantable volume estimates from Prognosis^{BC}, the northern Idaho Prognosis variant (NI), and Variable Density Yield Projection system (VDYP). Comparisons were made by overlaying six sets of volume estimates that were obtained from: The six sets of volume estimates were obtained from:

- 1) Prognosis^{BC} with the self-calibration feature (i.e., using diameter increment samples);
- 2) Prognosis^{BC} without the self-calibration feature;
- 3) NI variant with the self-calibration feature;
- 4) NI variants without the self-calibration feature;
- 5) Variable density yield projection system; and
- 6) PSP data (i.e., observed volume estimates).

Net merchantable volume was estimated using a 1% operational adjustment factor and a 10% decay for ease of comparison.

The comparisons found that there was no consistent over- or under-estimation of volume by Prognosis^{BC} for the selected 15 PSPs. Prognosis^{BC} with the self-calibration feature tracked the observed net merchantable volume in 9 of the 15 PSPs assessed (Appendix K). These preliminary results indicate that the self-calibration feature of Prognosis^{BC} is essential for accurate estimation of volume. However, these trends are only indicative and should be considered with caution, as only 15 subjectively selected PSPs were assessed. It is expected that the predictive ability of Prognosis^{BC} will be improved once the biases found in the height dubbing, height increment models, and mortality model are corrected.

4.2. Maximum Basal Area by Site Series

The mortality estimates from Prognosis^{BC} are biased and the model needs to be refitted. This bias could be attributed to the default maximum basal area (BAMAX) values used in the mortality model. Prognosis^{BC} uses BAMAX values that are borrowed from the northern Idaho; these values need to be replaced using BC data, as these values influence both the tree- and stand-level mortality functions (see pages 5 and 6). In attempt to refit the mortality model, the observed maximum basal area values were compiled from the PSP data set for each zone, subzone, and site series combination considered in Prognosis^{BC}. Since BAMAX is a theoretical value (i.e., potential maximum basal area obtained on a given site series), the maximum basal area values that were extracted from the PSPs were increased by 10% to ensure a potential maximum basal area. This approach assumes that the PSPs are collected in healthy and fully stocked stands, as they are set as research installations. The BAMAX values vary by site series, these values ranged from 19.91 to 61.60 and 20.5 to 92.84 m²/ha in Kamloops and Nelson Forest PSPs, respectively. The highest variability was observed in ICHmw subzone and in site series 4. On the other hand, the lowest BAMAX was obtained in PPxh subzone and site series 3 (Table 21). The detailed summaries of maximum basal area and volume by BEC zone, subzone, and site series by leading tree species for Nelson and Kamloops PSPs are given in Appendices L and M.

4.3 Crown Ratio Data

Both the Nelson and Kamloops PSPs were assessed. PSPs that had crown ratios were extracted and compiled for further analysis in a different project. The search found 88 PSPs (all in Nelson) with crown ratio codes. Of the 88 PSPs, 21 PSPs were found in measurement period one; 21 PSPs were found in measurement period two, and one PSP was found in measurement period

three; and 45 PSPs were found in measurement period four. These files were submitted to the Ministry of Forests, Forest Practices Branch in electronic form, as requested.

Table 21. Maximum basal area (and number of PSPs in brackets) by zone, subzone, and site series combinations for Nelson and Kamloops PSPs.

Region/ Zone	Subzone	Site Series						
		1	2	3	4	5	6	7
Nelson	ESSF	68.816(7)	41.294(5)	48.191(5)				
	ICH	62.733(27)	20.449(1)	54.802(30)	46.563(16)	62.832(3)		
		76.835(29)		74.063(84)	92.84(75)	74.239(1)	62.568(1)	72.512(2)
		wk			41.393(1)	53.735(1)		
	IDF	dm	55.781(68)		30.393(4)	51.304(26)	31.449(1)	
	MS	dm				23.969(2)		
	PP	dh	33.715(5)					
Kamloops	IDF	60.885 (38)		60.819 (15)	55.583(17)	44.374(6)		
		47.993(19)			61.589(5)	42.768(2)	29.194(1)	
	MS	dm	65.758(3)		51.986(1)	44.935(1)		
	PP	xh	21.835 (1)		19.91(3)	23.309(1)		

5. EXTENSION WORK

5.1 Inland Growth and Yield Cooperative (INGY) Presentation

A presentation on the mortality model of Prognosis^{BC} was made for the 1999 Winter Inland Growth and Yield Cooperative (INGY) meeting. This presentation helped in obtaining feedback and further cooperation with other researchers in the Northwest of the North America. A copy of this presentation was submitted to the Ministry of Forests, Forest Practices Branch in electronic form.

5.2 Meetings

Several meetings were also held with the Forest Biometricians at the University of Minnesota, and the US Forest Service, North Central Forest Experiment Station (USFS NC) to discuss:

- current issues in growth and yield modelling around the world;

- the integration of growth and yield models such as the lakes states variant of Prognosis and the STEMS growth model;
- long term inventory projections in timber supply analysis in partial cut areas; and
- forest inventory systems.

5.3 Branch Lines and Meetings

A research profile on Prognosis^{BC} was submitted, as the Forest Resources Management Research highlight in the March 1999 issue of Branch Lines newsletter of UBC. This newsletter will be circulated to 12,000 readers around the world. A copy of this submission is provided to the Ministry of Forests, Silvicultural Practices Branch.

6. CONCLUSIONS AND RECOMMENDATIONS

Prognosis^{BC} is modeled after the NI variant due to lack of data. The small tree height and large tree diameter increment models drive the growth of small and large trees in the model. However, the small and large tree height increment and the mortality model are biased, as outlined in this report. These biases will affect basal area, volume, crown ratio, and other estimates obtained from the model. Based on the research results, recommendations are:

- 1) *The small tree height increment model should be examined using large independent data sets for both the Kamloops and Nelson forest regions. Also, the large tree height increment model for Kamloops region should be modified to avoid the consistent over-estimation of tree height.*

The independent stem analysis data set used in this study gave an opportunity to assess the predictive ability of Prognosis^{BC} in a different geographical region of ICH. However, this data set beside being outside the geographical range of Prognosis^{BC}, it had limited sample trees for most tree species found in the data set. Thus, the results should be interpreted with caution.

- 2) *The inclusion of the ESSF and PP BEC zones in the current version of Prognosis^{BC} should be reviewed.*

This is due to the high bias found in the height dubbing equation and the height increment model in the ESSF and PP BEC zones.

- 3) *The new height-diameter equation coefficients should be used at the subzone group level instead of at zonal level and the Prognosis^{BC} code should be changed accordingly.*

Prognosis^{BC} should account for the significant differences in the height-diameter equation coefficients among zones and among subzones within a BEC zone. The new use height-diameter equation coefficients at the subzone group level instead of at zonal level will increase the precision and the resolution of the height dubbing equation.

- 4) *BAMAX values (using BC data) should be estimated for each zone, subzone, and site series combination considered in Prognosis^{BC}, and subsequently, the tree- and stand-based mortality functions should be re-fitted.*

In Prognosis^{BC}, the Northern Idaho maximum basal area (BAMAX) values are used for predicting the probability of individual tree mortality rates and for maintaining the stand within reasonable biological limits. However, the accuracy of these values for the various zone, subzone, and site series combinations considered in Prognosis^{BC} is unknown. An alternative approach to using BAMAX values is to use stand density index (SDI) to limit the maximum potential density of a stand, as it is used in the South Oregon and North East California (SORNEC) (Johnson *et al.* 1986). However, we suggest the use of BAMAX in Prognosis^{BC}, as BAMAX is a better indicator of maximum potential of multi-aged and multi-species stands.

- 5) *Additional PSPs or temporary sample plots with core data (TSPs) should be collected and Prognosis^{BC} be refitted using BC data.*

The diameter increment model is the most important component of the model. Thus, careful calibration of the diameter increment model using BC data will increase the accuracy of Prognosis^{BC}. The use of TSPs for fitting growth and yield model is not uncommon. Growth models such as the Douglas-fir Simulator (DFSIM) (Curtis *et al.* 1981), the Oregon Growth Analysis and Projections (ORGANON) (Hann *et al.* 1995), and several variants of Prognosis including the Northern Idaho Variant (Wykoff *et al.* 1982) are fitted using TSPs and PSPs.

- 6) *Mapping the habitat type of the unmapped PSPs is required, if Prognosis^{BC} is to remain as is (modeled after NI).*

This will improve the precision of the multiplier used for adjusting Prognosis^{BC} and in turn it will increase the overall accuracy of the model. Although mapping the unmapped PSPs provide a temporary solution, habitat mapping is subjective.

- 7) *If new TSPs or PSPs data are to be collected a different form of the existing diameter increment model is warranted.*

For example, the habitat and national forest type constants could be replaced by a different term for BC if a relationship between site series and geographic location exist. Dolph (1988) replaced the habitat and national forest type constant by a latitude-dependent constant term in the Sierra Nevada Prognosis variant. However, the use of different form of diameter increment model in Prognosis^{BC} would require an extensive change in its codes.

In summary, the small and large tree height increment and the mortality models should be improved or refitted to improve the accuracy of the Prognosis^{BC}. This will, in turn, improve basal area, volume, crown ratio, and other estimates obtained from the model. Refitting the entire model using BC data would be the best approach. However, substantial data collection efforts would likely be needed.

7. LITERATURE CITED

- Curtis, R.O., G. W. Clendenen, and D. J. DeMars. 1981. A new stand simulator for coast Douglas-fir: DFSIM Users's guide. U.S. For. Serv., Gen. Tech. Rep. PNW-128.
- Dolph, K.L. 1988. Prediction of periodic basal area increment for young growth mixed conifers in the Sierra Nevada. USDA, For. Serv. Pacific Southwest Forest and Range Exp. Station. Berkeley, California. Res. Pap. PSW-190. 20 p.
- Flewelling, J.W. and R.D. de Jong. 1994. Considerations in Simultaneous curve fitting for repeated height-diameter measurements. *Can. J. For. Res.* 24: 1408-1414.
- Hann, D.W., A. S. Hester, and C.L. Olsen. 1995. ORGANON. User's Manual. 5th Ed. Forest Research Laboratory, Oregon State University, Corvallis. 127 pp.
- Hamilton, D.A. and B.M. Edwards. 1976. Modeling the probability of individual tree mortality. USDA, For. Serv. Res. Pap. Intermountain Forest and Range Exp. Station. INT-185. Ogden, UT. 22 pp.
- Johnson, R.R., G.E. Dixon, and D.I. Schroeder. 1986. The Southcentral Oregon/northeastern California PROGNOSIS (SORNEC). USDA, For. Serv. Washington Office Timber Management, Fort Collins, Colorado 46 pp.
- LeMay, V. and H. Temesgen. 1998. Report on the Examination of Diameter Growth Model Modified for SEI variant. A report submitted to BC Ministry of Forests, Resources Inventory Branch. 12 pp.
- Neter, J. and W. Wasserman. 1974. Applied linear statistical models: Regression, analysis of variance, and experimental design. Irwin-Dorsey Limited, Georgetown Ontario. 842 pp.
- Stage, A. R. 1973. Prognosis model for stand development. USDA, For. Serv. Res. Pap. Intermountain Forest and Range Exp. Station. INT-137. Ogden, UT. 32 pp.

Wykoff, W. R., N. L. Crookston, and A. R. Stage. 1982. User's guide to the Stand Prognosis Model. Gen. Tech. Rprt. INT-133. USDA For. Serv., Ogden, UT. 112 pp.

Wykoff, W. R. 1986. Supplement to the User's Guide for the Stand Prognosis Model – Version 5.0. Gen. Tech. Rprt. INT-208. USDA For. Serv., Ogden, UT 36 pp.

APPENDIX A - Summary of percent bias (m) due to the height dubbing equation by species/BEC zone/subzone for Nelson PSP data set.

APPENDIX B - Summary of percent bias (m) due to the height dubbing equation by species/BEC zone/subzone for Kamloops PSP data set.

APPENDIX C - Summary of percent bias (m) due to the height growth model by species/BEC zone/subzone for one projection cycle using the Nelson PSP data set.

APPENDIX D - Summary of percent bias (m) due to the height growth model by species/BEC zone/subzone for one projection cycle using the Kamloops PSP data set.

APPENDIX E - Summary of percent bias (m) due to the height growth model by species/BEC zone/subzone for two projection cycles using the Nelson PSP data set.

APPENDIX F - Summary of percent bias (m) due to the height growth model by species/BEC zone/subzone for three projection cycles using the Nelson PSP data set.

APPENDIX G - Chi-square statistics (X^2), number of live trees (N_TOTAL), observed (N_DEAD) and expected (N_EXPEC) number of dead trees, and observed (OBS_MORT) and predicted mortality rate (PRED_MORT), and Multipliers (MULT) by species and diameter class for Nelson PSPs.

APPENDIX H - Chi-square statistics (X^2), number of live trees (N_TOTAL), observed (N_DEAD) and expected (N_EXPEC) number of dead trees, and observed (OBS_MORT) and predicted mortality rate (PRED_MORT), and Multipliers (MULT) by species and diameter class for Kamloops PSPs

APPENDIX I - Summary of number of live trees (N_TOTAL), observed (N_DEAD) and expected (N_EXPEC) number of dead trees, and observed (OBS_MORT) and predicted mortality rate (PRED_MORT), and Multipliers (MULT) by zone, subzone, site series, species, and diameter class for Nelson PSPs.

APPENDIX J - Summary of number of live trees (N_TOTAL), observed (N_DEAD) and expected (N_EXPEC) number of dead trees, and observed (OBS_MORT) and predicted mortality rate (PRED_MORT), and Multipliers (MULT) by zone, subzone, site series, species, and diameter class for Kamloops PSPs.

APPENDIX K - Summary of volume projections for 15 selected PSPs.

The six sets of volume estimates were obtained from:

- 1) Prognosis^{BC} with the self-calibration feature (SEI+DG)
- 2) Prognosis^{BC} without the self-calibration feature (SEI-NODG)
- 3) NI variant with the self-calibration feature (NI+DG)
- 4) NI variants without the self-calibration feature (NI-NODG);
- 5) the PSP data (i.e., observed volume estimates) and
- 6) Variable density yield projection system (VDYP).

Net merchantable volume was estimated using a 1% operational adjustment factor and a 10% decay for ease of comparison.

APPENDIX L - Summary of maximum basal area and volume by BEC zone, subzone, and site series by leading tree species for Nelson PSPs.

APPENDIX M - Summary of maximum basal area and volume by BEC zone, subzone, and site series by leading tree species for Kamloops PSPs.