

Final Report

Project MO86015 – Modeling Natural Regeneration in Mountain Pine Beetle Impacted Stands.

April 2008

Proponent: Dr. Peter Marshall, RPF
Professor, Forest Resources Management Dept.
University of British Columbia
2424 Main Mall
Vancouver, BC V6T 1Z4
604-822-4918; Peter.Marshall@ubc.ca

Co-Investigators: Dr. Valerie LeMay, RPF
Professor, Forest Resources Management Dept.
University of British Columbia

Dr. David Coates, RPF
Research Silviculturalist,
BC Ministry of Forests and Range

Dr. Abdel-Azim Zumrawi, RPF
Scientist, Research Branch
BC Ministry of Forests and Range

Executive Summary

The goal of this project was to estimate the amount of natural regeneration that will occur in MPB-attacked lodgepole pine (*Pinus contorta* var. *latifolia* Dougl.) dominated stands that have not been salvaged, and to add regeneration prediction in these stands as a module to an existing growth and yield model, Prognosis^{BC}. In order to achieve this, overstory and understory tree data were collected in lodgepole pine-leading stands that were attacked by MPB in the few decades leading up to the present attack. Sampling during the first year of this project took place between June and August, 2006, in the vicinity of Williams Lake. Sampling during the second year of this study took place between June and August, 2007 in the vicinity of Kamloops (June) and Kelowna (July and August).

Two to six sample points in the 2006 field season and one to six points in the 2007 field season were located within each selected stand using systematic sampling with a random start. A plot was located at each sample point. Each plot consisted of seven circular sub-plots: one for large trees (11.28 m radius), another for small trees (5.64 m radius), and five for regeneration (2.07 m radius). In the large tree plot (overstory trees), all trees ≥ 7.5 cm diameter at breast height (dbh) were measured for several attributes. In the small tree plot, all trees from 2 cm to < 7.5 cm dbh were included and measured for several attributes. In the regeneration subplots, the number of live seedlings less than 2 cm dbh and over 15 cm in height were recorded by species into four height classes: 1) >0.15 to ≤ 0.5 m; 2) >0.5 to ≤ 1 m; 3) >1.0 to ≤ 1.5 m; and 4) >1.5 m in height and < 2.0 cm DBH.

In 2006, 175 plots from 55 stands were sampled, while in 2007, 92 plots from 40 stands were sampled. The smaller number of stands and plots in the second field season reflected the difficulty of finding suitable stands in the southern interior that had not been salvaged following the MPB attack in the 1980s or early 1990s. Collected data were entered into Excel[®] spreadsheet files and summarized by subplot. All stem counts and areal summaries were expressed on a per ha basis.

In the 2006 data, the large tree plots were mainly composed of lodgepole pine (about 80%), Douglas-fir (*Pseudotsuga menziesii* var. *glauca*; 7%), and interior spruce (*Picea engelmanni* $\times$ *glauca*; 5%). The species composition was altered somewhat in the small tree plots; although lodgepole pine still represented the majority of the small trees. In the 2007 data, again the large tree plots were mainly composed of lodgepole pine (about 60%); Douglas-fir (25%) and interior spruce (6%) were the next most common species. The species composition altered considerably in the small tree plots; Douglas-fir was the most common species (44%), followed by interior spruce (18%). Lodgepole pine and subalpine fir each comprised only about 13% of the regeneration sampled.

In order to perform MSN imputation for estimating regeneration estimates of the overstory conditions at each plot shortly after the time of the MPB attack (Time 1) were required and needed to be linked to the regeneration present on this occasion (Time 2). These overstory estimates were obtained using the measurements taken on the live and dead trees in the large tree plots at Time 2 and growing them back in time using diameter growth functions in 10-year time steps. Prorating from the nearest decadal value was used for times-of-attack that were not evenly divisible by 10. Heights were estimated from dbh using existing regression equations, which were localized for each tree by multiplying by the ratio of measured height to estimated height for the 2006 and 2007 measurements. For dead trees, the decay class was used to decide whether the tree was live or dead shortly after attack. For all trees that were assumed to be alive at some point after the MBP attack, the crown ratio was estimated using crown ratio functions developed for this area. Ten-year DG was then estimated using the estimated crown ratio. Consequently, an estimated tree-list of all assumed alive trees, greater than or equal to 7.5 cm dbh, was obtained for each

plot shortly after attack (Time 1), and coupled with the regeneration (seedlings/saplings taller than 0.15 m and less than 7.5 cm dbh) measured in 2006 or 2007 (Time 2).

Most similar neighbour (MSN) imputation was then used to impute regeneration. In MSN imputation, data are divided into reference data (where all attributes including the variables of interest (Y) and auxiliary variables (X) are available) and target data (where only the X variables are available). A search of the reference data is used to find neighbours with X attributes similar to that of the target observation. The Y variables for the neighbours are then imputed to the target observation. In the approach developed for imputing regeneration levels, the X variables are overstory variables measured at Time 1 (following disturbance) and the Y variables are regeneration levels at Time 2. To evaluate the results of regeneration imputation, the combined plot data for each BEC zone were randomly divided into four approximately equal sets of data prior to MSN analysis. One of these four sets (25% of plots) was the target data, considered to have only overstory variables, and the remaining 75% of plots were used as reference data, with both overstory and regeneration variables. Analyses were repeated four times, once for each set of target data. The differences between observed and predicted (estimated) regeneration for all target data was then summarized into bias (average difference) and root mean squared error (RMSE) statistics for each regeneration variable.

LeMay *et al.* (2007) provided detail on the MSN analyses conducted for imputing levels of regeneration using the data collected in Year 1 of this study and only the results obtained using the 2007 data are presented in this report. MSN analyses of the 2007 data were based on two data groupings: IDF (comprised of 57 plots from the dk1, dk2, mw1, and mw2 subzone variants) and MS (comprised of the 35 plots in dm1 and dm2 collected in 2007 and the four xv plots collected in 2006 for a total of 39 plots). The great majority of all regeneration, observed and predicted, fell into the 'conifer other than pine' species group. Pine regeneration was sparse. On average, more regeneration was present in the MS zone than in the IDF zone. Overall, the predicted regeneration by BEC zone, size class, and species group was generally similar to the observed regeneration. The principal exception was the smallest size class in IDF, where the estimated value was lower than the observed stems value. The great majority of all regeneration, observed and predicted, fell into the 'conifer other than pine' species group. Pine regeneration was sparse. On average, more regeneration was present in the MS zone than in the IDF zone. Although bias was low, variability was high (i.e., low precision), especially in the two smallest height classes.

If a larger database were available for the purposes of imputation, it would likely lead to reductions in the variability associated with regeneration predictions using MSN imputation since there would be a better chance of finding good matches. It is possible that measuring (rather than predicting) overstory conditions following a MPB attack would improve the predictability of regeneration levels on a site. Finally, improvements in precision may be possible using a more process-based approach to estimation. To this end, the data collected in this project are being used in another FSP-funded project (Y081048) aimed at adapting the light-driven regeneration component of Sortie-ND to work with the overstory prediction capabilities of Prognosis^{BC} using a hybrid modeling approach. Regardless of the modeling approach used, natural regeneration levels at a plot level are inherently variable, and it is likely that predictions made at this level will remain relatively imprecise.

Table of Contents

Executive Summary	ii
Table of Contents	iv
List of Tables.....	iv
List of Figures	iv
Introduction	1
Methods.....	2
Sampling Design	2
Data Preparation and Entry into the Prognosis ^{BC} Regeneration Database.....	3
Most Similar Neighbour (MSN) Imputation.....	4
Results	5
Summaries of Stand Characteristics and Regeneration.....	5
MSN Imputation.....	9
Discussion	11
Conclusions and Management Implications	14
Literature Cited	15

List of Tables

Table 1. Distribution of sample plots by BEC zone.....	5
Table 2. Summary of large trees and small trees in stands sampled in 2006 by BEC subzone.....	7
Table 3. Summary of regeneration (stems per ha) in stands sampled in 2006 by BEC subzone.....	8
Table 4. Summary of large trees and small trees in stands sampled in 2007 by BEC subzone.....	8
Table 5. Summary of regeneration (stems per ha) in stands sampled in 2007 by BEC subzone.....	9
Table 6. Number of target plots in each 2007 test data set by BEC zone.....	10
Table 7. Average observed regeneration (stems per ha) versus average predicted regeneration based on MSN by BEC zone, size class, and species group.....	10
Table 8. Bias and RMSE of regeneration predictions (stems per ha) by BEC zone and size class.....	11

List of Figures

Figure 1. Plot layout.....	3
Figure 2. Distribution of the sample plots around Williams Lake.....	6
Figure 3. Distribution of the sample plots around Kamloops and Kelowna.....	6
Figure 4. Observed vs. predicted regeneration (stems per ha) based on the 2007 data in the IDF zone by size class: (a) 0.15 - 0.5 m in height; (b) 0.5 -1.0 m in height; (c) 1.0 - 1.5 m in height; (d) 0.1 - 7.5 cm dbh.....	12
Figure 5. Observed vs. predicted regeneration (stems per ha) based on the 2007 data in the MS zone by size class: (a) 0.15 - 0.5 m in height; (b) 0.5 -1.0 m in height; (c) 1.0 - 1.5 m in height; (d) 0.1 - 7.5 cm dbh.....	13

Introduction

Because of the large number of hectares impacted by Mountain Pine Beetle (MPB; *Dendroctonus ponderosae*) in British Columbia, some stands will not be salvage-logged and planted following MPB attack. Consequently, the accurate projection of future timber production in MPB-affected stands will depend in part on our ability to estimate natural regeneration following MPB disturbances.

This project targeted critical areas of uncertainty associated with the prediction of natural regeneration following MPB attack in non-salvaged stands. Our aim was to estimate the amount of natural regeneration that will occur in MPB-attacked lodgepole pine (*Pinus contorta* var. *latifolia* Dougl.) dominated stands that have not been salvaged, and to add regeneration prediction in these stands as a module to an existing growth and yield model, Prognosis^{BC} (Snowdon 1997, Zumrawi *et al.* 2002). In order to achieve this, overstory and understory tree data were collected in lodgepole pine-leading stands that were attacked by MPB in the few decades leading up to the present attack to augment limited data collected previously by Natural Resources Canada (NRC) and reported on in LeMay *et al.* (2006 and 2007). The intent was to sample over a considerably wider range of site and stand conditions than are present in the NRC data. This project was of two years duration, starting April 1, 2006 and ending March 30, 2008.

For the first year, this project was linked to a project funded for the 2005-2006 and 2006-2007 fiscal years by Natural Resources Canada Mountain Pine Beetle Initiative (MPBI)¹, which involved several of the members of the research team for this project. The MPBI project contributed the NRC data, provided the preliminary analyses for the use of the statistical approach followed, and covered the cost of creating a regeneration database linked to Prognosis^{BC} that combined the NRC data and the data collected in this project. The cost of testing the imputation approach for predicting regeneration was shared between the two projects.

For the second year, this project was linked to an FSP project (Y081048)² funded for the 2007-2008 and 2008-2009 fiscal years. Y081048 is focused on developing a new regeneration model that will be a hybrid between SORTIE-ND (Coates *et al.* 1999; 2003), a light-mediated growth and yield projection model, and Prognosis^{BC}. The data collected under the auspices of this project provided the foundational data for the analyses and model development occurring under the auspices of Y081048.

¹ MPBI Project #8.35 – Modeling Natural Regeneration Following Mountain Pine Beetle Attacks in Southern and Central Interior of British Columbia.

² Project Y081048 – Estimating Natural Regeneration and Yield in Pine-Dominated Stands Following Mountain Pine Beetle Attack Using SORTIE-ND and Prognosis^{BC} in a Hybrid Modeling Approach.

Methods

Sampling Design

Sampling during the first year of this project took place between June and August, 2006, in the vicinity of Williams Lake. Sampling during the second year of this study took place between June and August, 2007 in the vicinity of Kamloops (June) and Kelowna (July and August). At all locations, topographical maps, inventory data, MPB survey data (if available) and other available records, including local knowledge, were used to identify potential sites for sampling. Potential sites were stratified by, time of MPB disturbance, stand age and density, Biogeoclimatic Ecosystem Classification (BEC) subzone, and species composition. Site visits were used to verify that sites (or at least sizeable portions of sites) had not been salvaged. A sample of polygons (stands) from each possible combination of these variables was selected for further sampling.

Two to six sample points in the 2006 field season and one to six points in the 2007 field season were located within each stand using systematic sampling with a random start. Sample points in 2006 were established at least 50 m from roads, landings or other openings to reduce edge effect. In 2007, due to the difficulty of finding non-salvaged areas for sampling, distances from edges was reduced to 20 m when necessary. Adjacent sample points were at least 50 m apart. The number of sample points within a stand and the distance between sample points depended on the area of the stand and the degree of structural variability available. Stands with higher structural variability were sampled more heavily than more homogenous stands.

A plot was located at each sample point. Each plot consisted of seven circular sub-plots: one for large trees (11.28 m radius), another for small trees (5.64 m radius), and five for regeneration (2.07 m radius) (Figure 1). In the large tree plot (overstory trees), all trees ≥ 7.5 cm diameter at breast height (dbh) were measured. Each dead standing or downed tree was classified into a decay class. Height to live crown (m) was measured for all live trees. Species, dbh (cm), and height (m) of each standing tree, live or dead, were recorded. For downed trees in decay class 7 or greater, species, dbh, and height were recorded. For trees with broken tops, the height to the broken top (m) was measured, and the total height of the tree was estimated. Crown width was measured along two axes at right angles for two trees selected randomly for each species. In the small tree plot, all trees from 2 cm to < 7.5 cm dbh were included and species, dbh, status (live or dead), visual estimate of live crown ratio (live only), and height was recorded for each tree. In the regeneration subplots, the number of live seedlings less than 2 cm DBH and over 15 cm in height were recorded by species into four height classes: 1) >0.15 to ≤ 0.5 m; 2) >0.5 to ≤ 1 m; 3) >1.0 to ≤ 1.5 m; and 4) >1.5 m in height and < 2.0 cm dbh. See the field sampling summaries (Lee and Marshall 2007, 2008a) for more detail on sampling and measurement procedures.

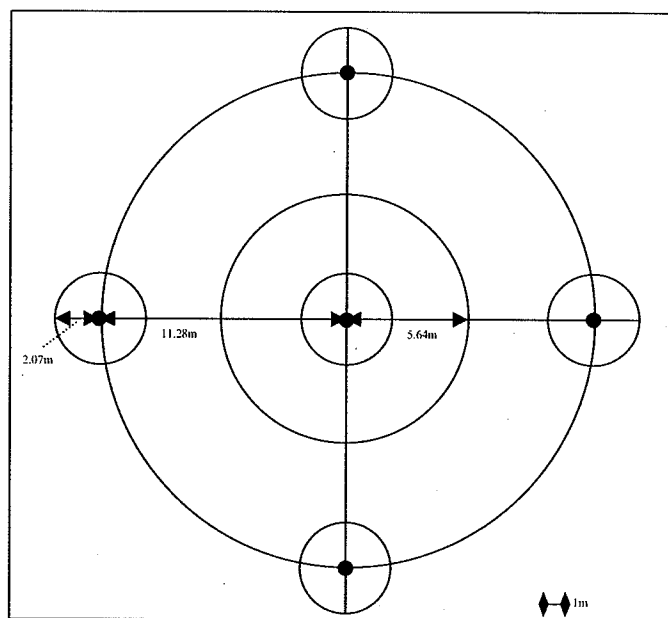


Figure 1. Plot layout.

Data Preparation and Entry into the Prognosis^{BC} Regeneration Database

Collected data were entered into Excel[®] spreadsheet files and summarized by subplot. All stem counts and areal summaries were expressed on a per ha basis. In order to perform MSN imputation for estimating regeneration (explained in the next section), estimates of the overstory conditions at each plot shortly after the time of the MPB attack (Time 1) were required and needed to be linked to the regeneration present on at the time of sampling (Time 2).

The overstory estimates at Time 1 were obtained using the measurements taken on the live and dead trees in the large tree plots at Time 2. Each live tree was grown back in time to the attributed time-of-attack by subtracting estimated 10-year diameter growth (DG), using functions fit by Zumrawi *et al.* (2005). For times-of-attack longer than 10 years ago, this process was repeated in 10 year time steps. Since measures of competition are used in the DG functions, these were summarized for each 10-year interval and used in estimating the DG. Prorating from the nearest decadal value was used for times-of-attack that were not evenly divisible by 10. Once dbh shortly after the attack was estimated for each live tree, heights were estimated from dbh using existing regression equations (provided by Zumrawi). These were localized for each tree by multiplying by the ratio of measured height to estimated height for the 2006 and 2007 measurements. For dead trees, the decay class was used to decide whether the tree was live or dead shortly after attack. For all trees that were assumed to be alive at some point after the MBP attack, the crown ratio was estimated using crown ratio functions developed for this area. Ten-year DG was then estimated using the estimated crown ratio.

Consequently, an estimated tree-list of all assumed alive trees greater than or equal to 7.5 cm dbh was obtained for each plot shortly after attack (Time 1), and coupled with the regeneration

(seedlings/saplings taller than 0.15 m and less than 7.5 cm dbh) measured in 2006 or 2007 (Time 2). These data were entered into the Prognosis^{BC} regeneration database in Microsoft Access[®] format for use with its regeneration imputation routine. See Lee and Marshall (2008b) for a description of the metadata for this database. In addition, the accuracy and precision of predictions of regeneration using MSN imputation with the data collected in this project were tested, as explained below.

Most Similar Neighbour (MSN) Imputation

Much of the material in this section is taken from Lemay *et al.* (2007).

In most similar neighbour (MSN) imputation, data are divided into reference data (where all attributes including the variables of interest (Y) and auxiliary variables (X) are available) and target data (where only the X variables are available). A search of the reference data is used to find neighbours with X attributes similar to that of the target observation. The Y variables for the neighbours are then imputed to the target observation. A single neighbour or an average of several neighbours can be used, along with different measures of similarity (LeMay and Temesgen 2005). Unlike regression analysis, all Y variables are imputed at once (multivariate analysis), and the variance of the reference data is retained if a single neighbour is used.

In the approach developed for imputing regeneration levels, the X variables are overstory variables measured at Time 1 (following disturbance) and the Y variables are regeneration levels at Time 2 (Hassani *et al.* 2004, LeMay and Temesgen 2005). The MSN imputation program developed by Moeur and Stage (1995), and extended by Crookston *et al.* (2002) was used for all imputations.

For partially cut stands, the overstory following cutting at Time 1 is expected to be the same (or nearly) as the overstory at Time 2. However, the use of multivariate imputation of regeneration following MPB attack is more difficult, since dead stems remain standing, causing a shaded environment for new seedlings (Mitchell and Preisler 1998; Zumrawi *et al.* 2005a). After some time, these snags fall down, reducing the amount of available substrate. The overstory measured shortly after MPB-attack differs from the overstory later on as dead trees fall, and regeneration may continue to occur for a long period of time after the MPB-attack. Also, in partially cut complex stands, a variety of diameter distributions are left following cutting. In MPB-affected stands, lodgepole pine trees killed by MPB are more commonly large diameter trees, resulting in the mostly smaller diameter trees as survivors (Hawkes *et al.* 2002, 2004).

Based on preliminary analyses, the X variables used included: elevation; live stems per ha and basal area per ha by three species classes (conifer except pine, pine, deciduous); crown competition factor (CCF); quadratic mean diameter (QMD); and stems per ha, basal area per ha, and QMD for standing dead pine (snags). Since the numbers of years following MPB-attack varied, years-since-disturbance (YSD) was also included as an X variable. Site series formed the last of the X variables. The selected Y variables were regenerated stems per ha by three species groups (conifer except pine, pine, deciduous), in four size classes (0 to 0.5 m height; 0.5 to 1 m height; 1 to 1.5 m height; and 0.1 to 7.5 cm dbh) for a total of 12 variables.

To evaluate the results of regeneration imputation, the combined plot data for each BEC zone were randomly divided into four approximately equal sets of data prior to MSN analysis (Snee 1977). One of these four sets (25% of plots) was the target data, considered to have only overstory variables, and the remaining 75% of plots were used as reference data, with both overstory and regeneration variables. Analyses were repeated four times, once for each set of target data. The differences between observed and predicted (estimated) regeneration for all target data was then summarized into bias (average difference) and root mean squared error (RMSE) statistics for each regeneration variable.

$$Bias = \sum_{i=1}^n \left[\frac{(y_i - \hat{y}_i)}{n} \right]$$

$$RMSE = \sqrt{\sum_{i=1}^n \left[\frac{(y_i - \hat{y}_i)^2}{n} \right]}$$

where y_i is observed regeneration per ha; $\hat{y}_i$ is predicted regeneration per ha by MSN analysis; and n is the number of target plots for which regeneration was estimated.

Results

Summaries of Stand Characteristics and Regeneration

Sampled stands were located in the IDF, SBPS, MS, and SBS BEC subzones in the vicinity of Williams Lake (Figure 1), Kamloops, and Kelowna (Figure 2). In the first field season (2006), 175 plots from 55 stands were sampled, while in the second field season (2007), 92 plots from 40 stands were sampled (Table 1). The smaller number of stands and plots in the second field season reflected the difficulty of finding suitable stands in the southern interior that had not been salvaged following the MPB attack in the 1980s or early 1990s.

Table 1. Distribution of sample plots by BEC zone.

BEC Zone	2006 Sampling		2007 Sampling		Total	
	No. of Stands	No. of Plots	No. of Stands	No. of Plots	No. of Stands	No. of Plots
IDF	16	58	25	57	41	115
SBPS	32	100			32	100
SBS	5	13			5	13
MS	2	4	15	35	17	39
All Zones	55	175	40	92	95	267

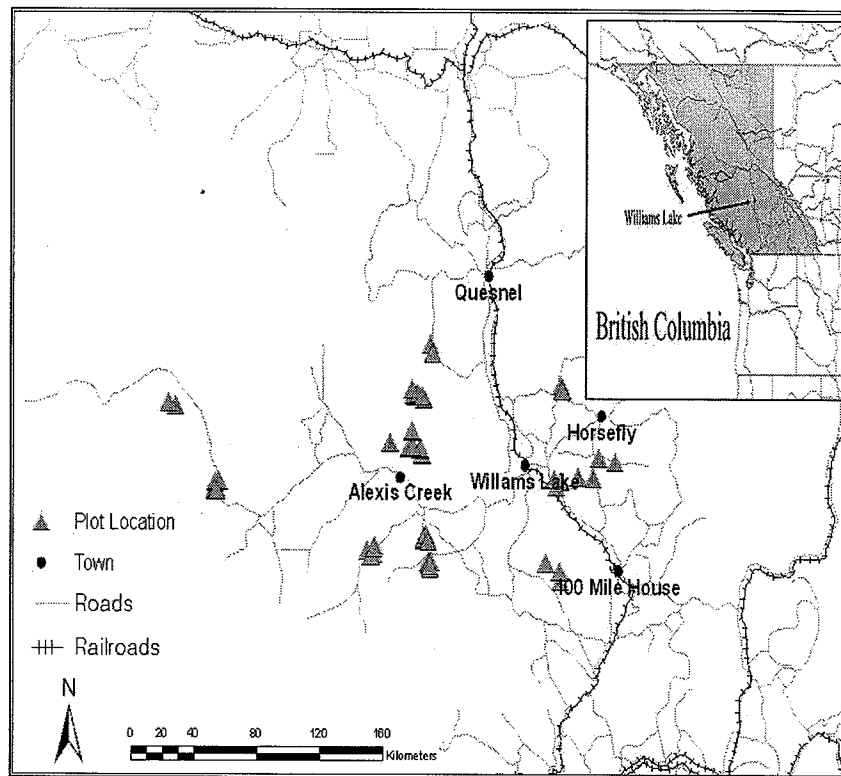


Figure 2. Distribution of the sample plots around Williams Lake

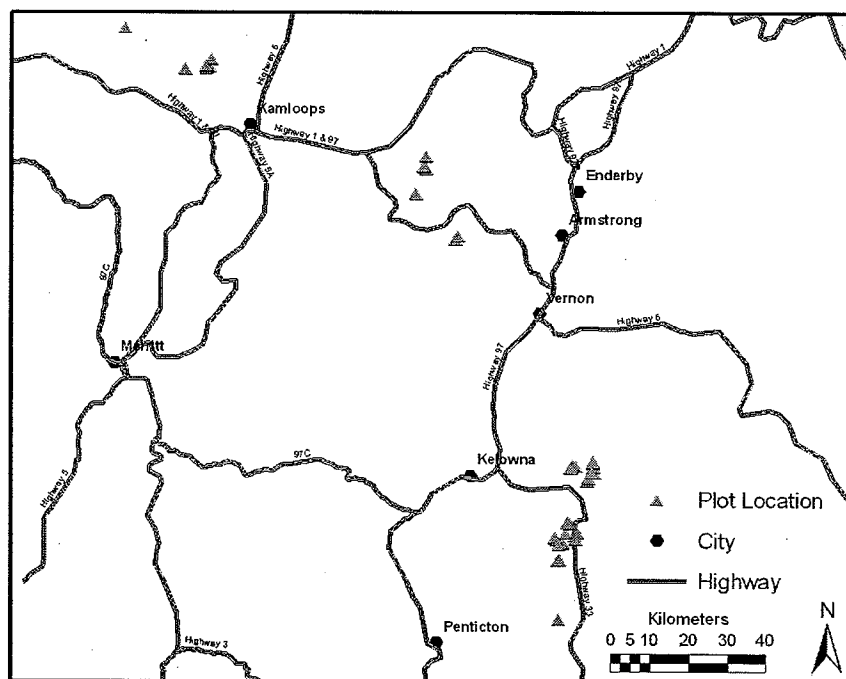


Figure 3. Distribution of the sample plots around Kamloops and Kelowna

Fifty-five stands and 175 plots were sampled in the 2006 field season (Tables 2 and 3). One of stands located on the boundary of the MSxv and SBPSmk subzones had two plots in each of these subzones. Consequently, 56 stands are shown in the Tables 2 and 3. Eight different BEC subzones were sampled.

In the 2006 data, the large tree plots were mainly composed of lodgepole pine (about 80%), Douglas-fir (*Pseudotsuga menziesii* var. *glauca*; 7%), and interior spruce (*Picea engelmanni* × *glauca*; 5%). Paper birch (*Betula papyrifera*), trembling aspen (*Populus tremuloides*) and subalpine-fir (*Abies lasiocarpa*) were present, but in small numbers overall. The species composition was altered somewhat in the small tree plots; although lodgepole pine still represented the majority of the small trees; trembling aspen represented almost 10% of these trees.

Table 2. Summary of large trees and small trees in stands sampled in 2006 by BEC subzone.

BEC Subzone/ Variant	Number of stands	Number of plots	Large Trees (live)/ha		BA(live) m ² /ha		Large Trees (snag)/ha		BA(snag) m ² /ha		Small Trees/ha	
			Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
IDFdk3	6	21	100	720	6	120	55	570	11	59	100	700
IDFdk4	10	37	145	620	7	36	113	695	18	75	10	3300
MSxv	2	4	80	220	10	14	420	660	75	107	150	800
SBPSdc	6	16	55	487	3	29	40	653	15	70	467	2850
SBPSmk	5	15	110	807	12	72	247	800	55	108	250	2233
SBPSxc	21	69	233	1160	8	141	33	740	3	56	67	2675
SBSdw1	5	13	420	930	26	141	200	1253	27	109	133	667
SBSdw2	1	2	100		16		130		47		6000	
Total	56	177	55	1160	3	141	40	1253	3	109	10	6000

Forty stands and 92 plots were sampled in the 2007 field season (Tables 4 and 5). Six different BEC subzones were sampled, although only one stand was sampled in three of the subzones (IDFdk1, IDFmw2, and MSdm2). Each of these stands contained two plots. The large tree plots were mainly composed of lodgepole pine (about 60%). Douglas-fir (25%) and interior spruce (6%) were the next most common species. Western redcedar (*Thuja plicata*; 4%), trembling aspen (3%) and subalpine fir (3%) represented a minor component. The species composition altered considerably in the small tree plots; Douglas-fir was the most common species (44%), followed by interior spruce (18%). Lodgepole pine and subalpine fir each comprised only about 13% of the regeneration sampled.

Table 3. Summary of regeneration (stems per ha) in stands sampled in 2006 by BEC subzone.

BEC Subzone/ Variant	Number of stands	Number of plots	C1 ^a		C2		C3		C4	
			Min	Max	Min	Max	Min	Max	Min	Max
IDFdk3	6	21	1288	11291	111	4457	37	2266	74	891
IDFdk4	10	37	1300	3863	780	2575	334	1436	297	2575
MSxv	2	4	74	149	74	446	0	446	0	371
SBPSdc	6	16	198	4086	297	2526	149	1189	149	2526
SBPSmk	5	15	297	743	50	941	50	792	50	693
SBPSxc	21	69	149	9211	0	5399	0	1981	0	1832
SBSdw1	5	13	50	1411	0	446	0	446	149	495
SBSdw2	1	2	16348		2600		3863		12108	
Total	56	177	50	11291	0	5399	0	2266	0	2575
BEC Subzone/ Variant	Number of stands	Number of plots	P_C1 ^b		P_C2		P_C3		P_C4	
			Min	Max	Min	Max	Min	Max	Min	Max
IDFdk3	6	21	0	11180	0	4457	0	2229	0	594
IDFdk4	10	37	409	1981	223	2030	149	1585	0	1981
MSxv	2	4	0	0	0	74	0	371	0	297
SBPSdc	6	16	149	3863	149	2526	223	1040	149	1151
SBPSmk	5	15	0	396	0	297	0	186	0	198
SBPSxc	21	69	50	6488	0	4011	0	1189	0	693
SBSdw1	5	13	0	446	0	-	0	-	0	-
SBSdw2	1	2	74		149		0		74	
Total	56	177	0	11180	0	4457	0	2229	0	1981

^a Size classes: 1 = 0.15 to 0.5 m in height; 2 = 0.5 to 1.0 m in height; 3 = 1.0 to 1.5 m in height; 4 = > 1.5 m in height and < 2.0 cm dbh.

^b Size classes for lodgepole pine.

Table 4. Summary of large trees and small trees in stands sampled in 2007 by BEC subzone.

BEC Subzone/ Variant	Number of stands	Number of plots	Large Trees (live)/ha		BA(live)m ² /ha		Large Trees (snag)/ha		BA(snag) m ² /ha		Small Trees/ha	
			Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
IDFdk1	1	2	851	851	20	20	288	288	7	7	951	951
IDFdk2	12	20	175	1201	4	34	100	725	2	23	0	900
IDFmw1	11	33	363	1401	26	52	50	294	2	6	0	1050
IDFmw2	1	2	1113	1113	34	34	175	175	2	2	540	540
MSdm1	14	33	400	2026	11	51	113	675	3	13	0	1626
MSdm2	1	2	926	926	16	16	776	776	21	21	550	550
Total	40	92	175	2026	4	52	50	725	2	23	0	1626

Table 5. Summary of regeneration (stems per ha) in stands sampled in 2007 by BEC subzone.

BEC Subzone/ Variant	Number of stands	Number of plots	C1 ^a		C2		C3		C4	
			Min	Max	Min	Max	Min	Max	Min	Max
IDFdk1	1	2	74	74	446	446	520	520	1189	1189
IDFdk2	12	20	0	5051	0	2229	0	743	0	1634
IDFmw1	11	33	37	4717	74	2526	0	1129	0	669
IDFmw2	1	2	0	0	0	0	0	0	0	0
MSdm1	14	33	74	7057	0	5200	0	2971	0	817
MSdm2	1	2	2657	2657	223	223	594	594	30	30
Total	40	92	0	7057	0	5200	0	2971	0	1634

BEC Subzone/ Variant	Number of stands	Number of plots	P_C1 ^b		P_C2		P_C3		P_C4	
			Min	Max	Min	Max	Min	Max	Min	Max
IDFdk1	1	2	0	0	0	0	0	0	0	0
IDFdk2	12	20	0	149	0	297	0	0	0	74
IDFmw1	11	33	0	0	0	0	0	0	0	0
IDFmw2	1	2	0	0	0	0	0	0	0	0
MSdm1	14	33	0	297	0	297	0	149	0	149
MSdm2	1	2	0	0	0	0	0	0	0	0
Total	40	92	0	297	0	297	0	149	0	149

^a Size classes: 1 = 0.15 to 0.5 m in height; 2 = 0.5 to 1.0 m in height; 3 = 1.0 to 1.5 m in height; 4 = > 1.5 m in height and < 2.0 cm dbh.

^b Size classes for lodgepole pine.

MSN Imputation

LeMay *et al.* (2007) provided detail on the MSN analyses conducted for imputing levels of regeneration using the data collected in Year 1 of this study combined with the NRC data. These results will not be repeated here. In summary, although considerable variability remained in the projections, they were relatively unbiased. The bias in total regeneration for all plots was -43 stems per ha for the IDF zone and -59 stems per ha for the SBPS/SBS zones. These are relative to averages of 6842 stems per ha (-0.6% bias) and 4343 stems per ha (-1.3% bias), respectively, for the two BEC zone groupings. Bias and root mean square error values were lower than those obtained using the NRC data alone (as reported in LeMay *et al.* 2006, Section 3.3), indicating the expected improvements because of a larger reference dataset.

MSN analyses of the 2007 data were based on two data groupings: IDF (comprised of the 57 plots from the dk1, dk2, mw1, and mw2 subzone variants) and MS (comprised of the 35 plots in dm1 and dm2 collected in 2007 and the four xv plots collected in 2006 for a total of 39 plots). For analysis purposes, the data were divided into the groups shown in Table 6.

Table 6. Number of target plots in each 2007 test data set by BEC zone.

BEC Zone	Dataset 1	Dataset 2	Dataset 3	Dataset 4	Total Number of Plots
IDF	14	13	14	16	57
MS	10	10	10	9	39

The great majority of all regeneration, observed and predicted, fell into the 'conifer other than pine' species group (Table 7). Pine regeneration was sparse. On average, more regeneration was present in the MS zone than in the IDF zone. Overall, the predicted regeneration by BEC zone, size class, and species group was generally similar to the observed regeneration. The principal exception was the smallest size class in IDF, where the estimated value was lower than the observed stems value.

Table 7. Average observed regeneration (stems per ha) versus average predicted regeneration based on MSN by BEC zone, size class, and species group.

BEC Zone	Species Group ^a	Observed regeneration					Predicted regeneration				
		1 ^b	2 ^b	3 ^b	4 ^b	All	1 ^b	2 ^b	3 ^b	4 ^b	All
IDF	C	665	344	240	647	1896	472	334	255	626	1687
	P	3	0	0	25	28	3	0	0	39	48
	D	5	5	0	17	27	5	5	0	9	19
	All	673	349	240	689	1951	480	339	255	674	1754
MS	C	1189	541	366	562	2658	968	507	400	541	2416
	P	4	0	0	33	37	4	0	0	18	22
	D	0	0	0	0	0	0	0	0	0	0
	All	1193	541	366	595	2695	972	507	400	559	2438

^a C = conifers (except pine); P = pine; D = deciduous.

^b Size classes: 1 = 0.15 to 0.5 m in height; 2 = 0.5 to 1m in height; 3 = 1 to 1.5 m in height; and 4 = 0.1 to 7.5 cm dbh.

Predictions of regeneration by size classes, without accounting for species grouping, generally were slightly better overall (Table 8). The bias in regeneration amount for all plots was 51 stems per ha for the IDF zone (2.6%) and 69 stems per ha for the MS zone (2.4%), respectively. The variability of the predictions (RMSE) was lowest for height class 3 (1.0 to 1.5 m) and highest for height class 1 (0.15 to 0.5 m) for the two zones.

Although bias was low, variability was high (i.e., low precision), especially in the two smallest height classes. This is evident from graphs of the predicted versus observed regeneration for the IDF zone (Figure 4) and the MS zone (Figure 5). The points are balanced around the 45 degree lines (little overall bias), but very scattered with only a poor relationship between predicted and observed regeneration.

Table 8. Bias and RMSE of regeneration predictions (stems per ha) by BEC zone and size class.

BEC Zone	Bias				RMSE				Overall	
	1 ^a	2 ^a	3 ^a	4 ^a	1 ^a	2 ^a	3 ^a	4 ^a	Bias	RMSE
IDF	193	10	-16	15	2387	1343	520	991	51	1310
MS	221	34	-34	36	3491	1882	1297	1362	64	2008

^a Size classes: 1 = 0.15 to 0.5 m in height; 2 = 0.5 to 1m in height; 3 = 1 to 1.5 m in height; and 4 = 0.1 to 7.5 cm dbh.

Discussion

Lodgepole pine formed a major component of the regeneration in the stands sampled primarily west of Williams Lake in 2006 (LeMay *et al.* 2007), but it was present only in relatively small numbers in the stands sampled in the vicinity of Kamloops and Kelowna in 2007. This is certainly due, in part, to more mixed-species composition of the overstory in many of these stands and the generally moister conditions found in the subzone/variants sampled in 2007 compared to those sampled in 2006. However, it may also be an artifact of the relatively heavy salvage harvesting which occurred following the MPB attacked in southern interior of BC in the 1980s. Since we sampled stands that had not been salvage harvested, if salvage harvesting occurred more frequently in stands that might have regenerated more heavily to lodgepole pine, then those types of stands are under-represented (or perhaps even missing) in our database. A representative sample of stands in the IDF and MS zone would be necessary before drawing any broad conclusions regarding the quantity of naturally regenerating lodgepole pine present in such stands.

Although regeneration was abundant in some stands, and average regeneration levels across each of the zones were reasonable, regeneration at a plot level and consequently our predictions, were highly variable. The overall RMSE of our regeneration predictions for the MS zone (2008; Table 8) was comparable in magnitude to what we found for the combined SBS and SBPS zones using the 2006 data (2078; Table 3.5 – LeMay *et al.* 2007). However, the average level of regeneration in the MS zone (2438; Table 7) was only about half of that found for the SBS and SBPS zones (4769; Table 3.4 – LeMay *et al.* 2007), so the MS regeneration predictions were approximately twice as variable on a relative basis. Our predictions for the IDF zone (subzone/variants dk1 and dk2) using the 2007 data had a RMSE (1310; Table 8); this was slightly less than half the size of the RMSE found for the IDF zone (subzone/variants dk3 and dk4) using the 2006 data (2977; Table 3.5 – LeMay *et al.* 2007). However, the average level of regeneration found in the IDF subzone/variants sampled in 2007 (1754; Table 7) was only about one quarter of the average level found in the subzone/variants sampled in 2006 (7014; Table 3.4 – LeMay *et al.* 2007). Consequently, the 2007 IDF regeneration predictions, like the MS regeneration predictions, were approximately twice as variable as the comparable 2006 predictions on a relative basis.

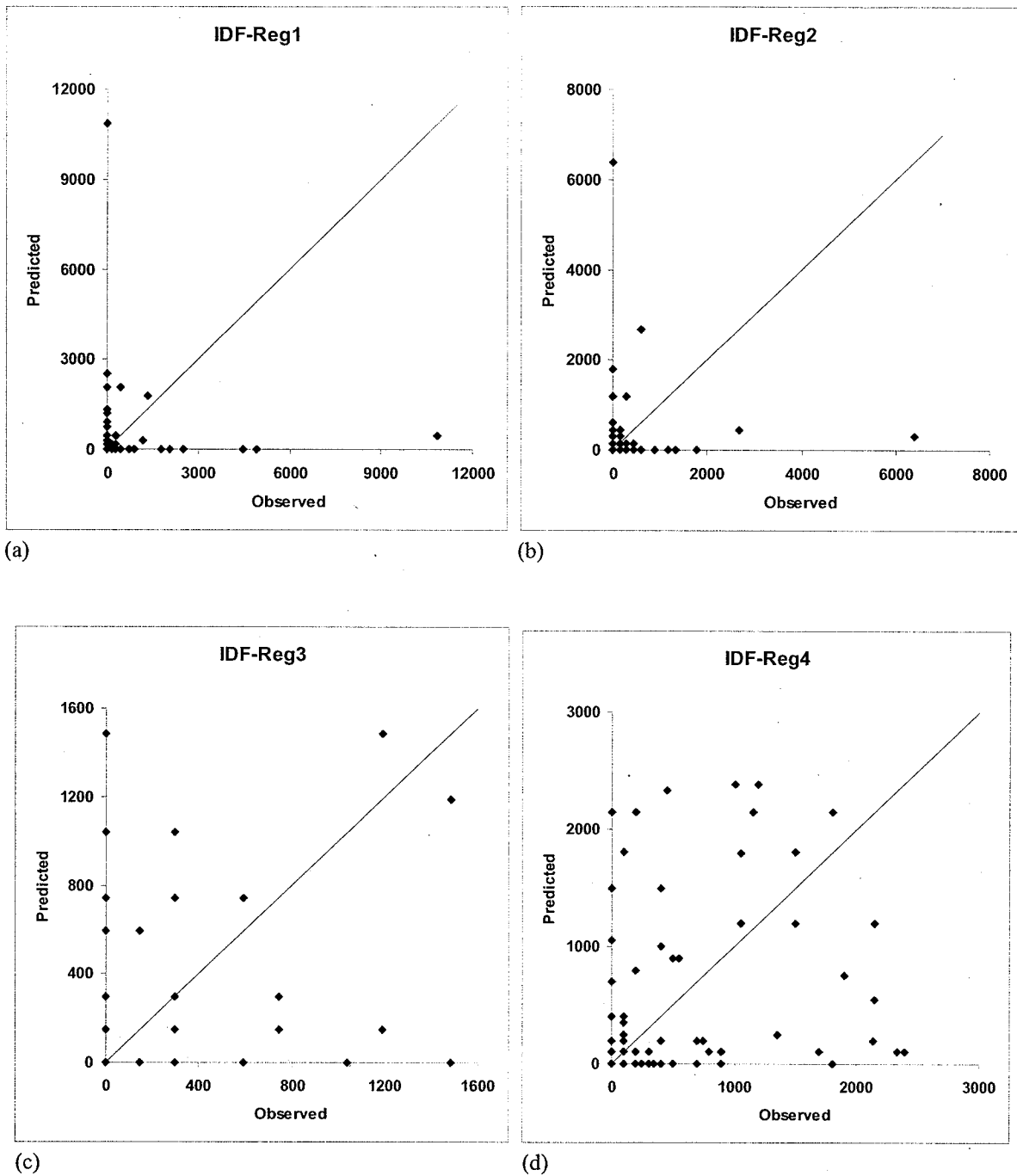


Figure 4. Observed vs. predicted regeneration (stems per ha) based on the 2007 data in the IDF zone by size class: (a) 0.15 - 0.5 m in height; (b) 0.5 -1.0 m in height; (c) 1.0 - 1.5 m in height; (d) 0.1 - 7.5 cm dbh.

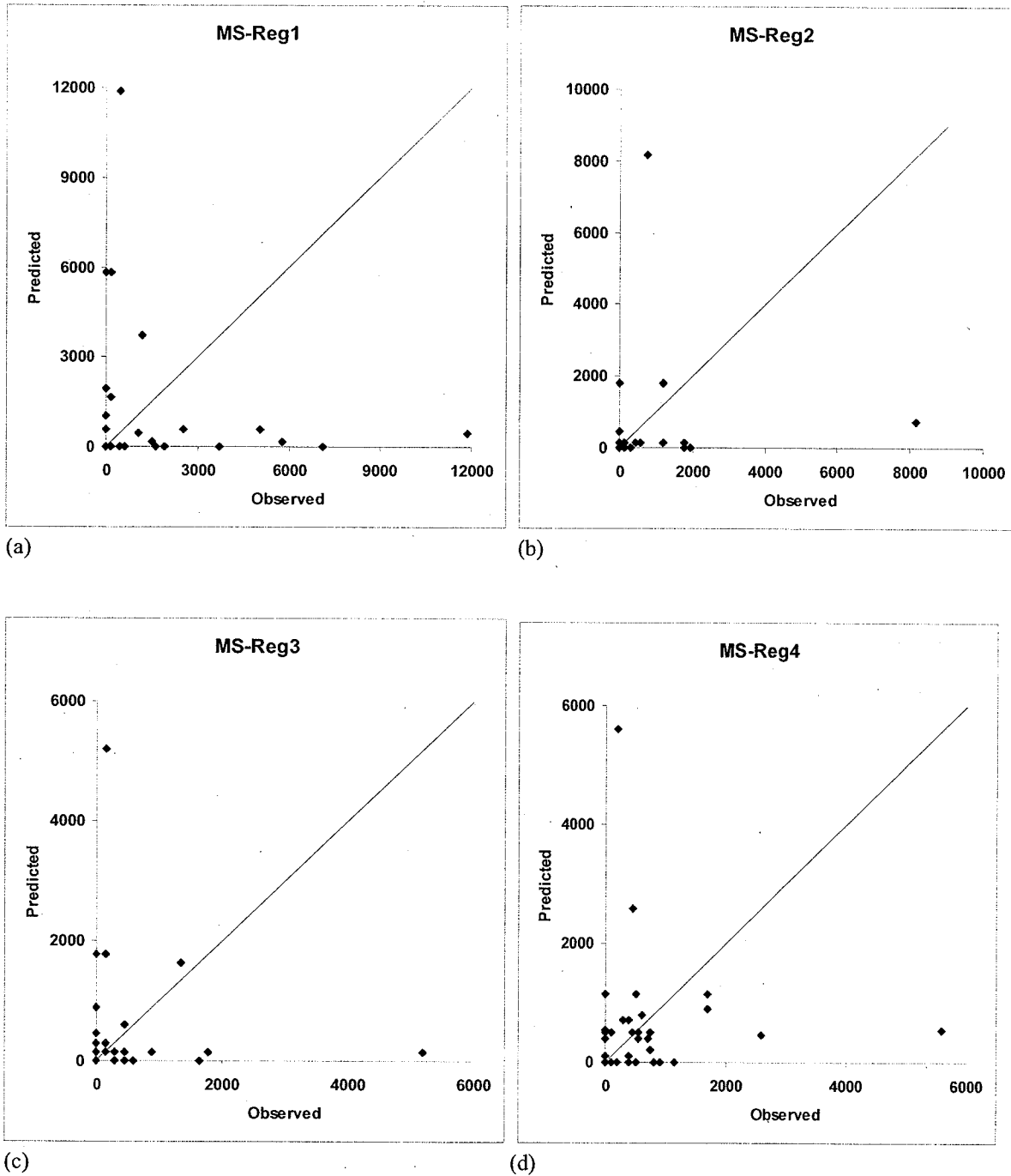


Figure 5. Observed vs. predicted regeneration (stems per ha) based on the 2007 data in the MS zone by size class: (a) 0.15 - 0.5 m in height; (b) 0.5 - 1.0 m in height; (c) 1.0 - 1.5 m in height; (d) 0.1 - 7.5 cm dbh.

If a larger database were available for the purposes of imputation, it would likely lead to reductions in the variability associated with regeneration predictions using MSN imputation since there would be a better chance of finding good matches. It is possible that measuring (rather than predicting) overstory conditions following a MPB attack would improve the predictability of regeneration levels on a site. Finally, improvements in precision may be possible using a more process-based approach to estimation. To this end, the data collected in this project are being used in another FSP-funded project (Y081048) aimed at adapting the light-driven regeneration component of Sortie-ND (Kobe and Coates 1997, Wright *et al.* 1998) to work with the overstory prediction capabilities of Prognosis^{BC} (Snowdon 1997; Zumrawi *et al.* 2002) using a hybrid modeling approach. Regardless of the modeling approach used, natural regeneration levels at a plot level are inherently variable, and it is likely that predictions made at this level will remain relatively imprecise.

Conclusions and Management Implications

Data on natural regeneration present in lodgepole pine leading stands, which had been attacked by MPB in the 1980s or 1990s and which had not been salvaged logged nor planted, were collected on 269 plots in 96 stands over two field seasons. The stands were located in the central interior (2006 field season) and southern interior (2007 field season) of the province in four BEC zones and 14 subzone/variants.

These data indicated more plentiful regeneration overall, and much more lodgepole pine regeneration, in the central interior of the province (SBS, SBPS, and IDF BEC zones) than was present in the southern interior of the province (MS and IDF BEC zones). Lodgepole pine regeneration, in particular, was sparse overall in the southern stands sampled. However, there had been considerable salvage activity in the southern interior and this finding may be at least partly an artifact of the stands that were not chosen for salvage logging.

The data collected enabled the calibration of an MSN imputation approach to predicting natural regeneration levels a number of years subsequent to a MPB attack. This approach resulted in logically consistent estimates of regeneration by species group and size class. This is not surprising since a plot in the reference set is selected to represent the regeneration in a target plot using this approach. The averages of the predictions of regeneration levels were quite close to the averages of the observations by size class and species group for each of the BEC zones assessed. However, predictions made at a plot level were quite variable. Consequently, caution should be taken when using this approach for making regeneration predictions for individual sites. It is better used for predicting as an average expected regeneration for certain site and overstory conditions within a region. These predictions may be useful in predicting future yield levels in such stands and in planning mitigation strategies following the current MPB attack.

Literature Cited

- Coates, K.D., C.D. Canham, P. Bartemucci, and S. Quaglia. 1999. Measurement and modeling of spatially explicit variation in light transmission through interior cedar-hemlock forests of British Columbia. *Can. J. For. Res.* 29:1775-1783.
- Coates, K.D., C.D. Canham, M. Beaudet, D.L. Sachs, and C. Messier. 2003. Use of a spatially explicit individual-tree model (SORTIE/BC) to explore the implications of patchiness in structurally complex forests. *Forest Ecology and Management* 186:297-310.
- Crookston, N.L., M. Moeur and D. Renner. 2002. Users guide to the Most Similar Neighbor imputation program Version 2. USDA For. Serv., Rocky Mountain Research Station. Gen. Tech. Rep. RMRS-GTR-96. 35 p.
- Hassani, B., V. LeMay, P. L. Marshall, H. Temesgen, and A.A. Zumrawi. 2004. Regeneration imputation models for complex stands of southeastern British Columbia. *For. Chron.* 80:271-278.
- Hawkes, B., S. Taylor, C. Stockdale, and T. Shore. 2002. Impacts of mountain pine beetle attack on stand and ecosystem dynamics. Can. For. Serv., Victoria BC. FRBC Ref. No. PAR 022003-06.
- Hawkes, B., S. Taylor, C. Stockdale, T.L. Shore, R.I. Alfaro, R. Campbell, and P. Vera. 2004. Impact of mountain pine beetle on stand dynamics in British Columbia. Pages 177-199 in T.L. Shore, J.E. Brooks, and J.E. Stone, editors. *Mountain Pine Beetle Symposium: Challenges and Solutions*, October 30-31, 2003, Kelowna, British Columbia, Canada. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, British Columbia, Information Report BC-X-399. 298 p.
- Kobe, R.K., and K.D. Coates. 1997. Models of sapling mortality as a function of growth to characterize interspecific variation in shade tolerance of eight tree species of northwestern British Columbia. *Can. J. For. Res.* 27:227-236.
- Lee, T. and P.L. Marshall. 2007. Project M075015: Summary of field sampling – June through August, 2006. 15 pp. (Unpublished).
- Lee, T. and P.L. Marshall. 2008a. Project M086015: Summary of field sampling – June through August, 2007. 14 pp. (Unpublished).
- Lee, T. and P.L. Marhsall. 2008b. Project M086015: Metadata for the Prognosis^{BC} regeneration database. (Unpublished).
- LeMay, V. and H. Temesgen. 2005. Comparison of nearest neighbor methods for estimating basal area and stems per ha using aerial auxiliary variables. *For. Sci.* 51(2): 109-119.
- LeMay, V., T. Lee, R.E. Scott, D. Sattler, D. Robinson, A-A. Zumrawi, and P. Marshall. 2006. Modeling Natural Regeneration Following Mountain Pine Beetle Attacks in the Southern and Central Interior of British Columbia: Results for Year 1. Internal report for Natural Resources Canada, MPB Standard Contribution Agreement, PO # 8.35. 70 pp. (www.forestry.ubc.ca/biometrics accessed March, 2007).
- LeMay, V.M., T. Lee, D. Sattler, P. Marshall, D. Robinson, and A.A. Zumrawi. 2007. Modeling natural regeneration following mountain pine beetle attacks in the southern and central Interior of British Columbia. Mountain Pine Beetle Initiative Working Paper 2007-16. 51 pp.
- Mitchell, R.G. and H.K. Preisler. 1998. Fall rate of lodgepole pine killed by the mountain pine beetle in central Oregon. *W. J. For.* 81:598-601.

- Moeur, M. and A.R. Stage. 1995. Most similar neighbour: an improved sampling inference procedure for natural resource planning. *For. Sci.* 41, 337-359.
- Snee, R.D. 1977. Validation of regression models: Methods and examples. *Technometrics* 19:415-428.
- Snowdon, B. 1997. British Columbia's Forest Vegetation Simulator application software. In: *Proceedings of Forest Vegetation Simulator Conference*. R. Teck, M. Moeur, and J. Adams, Technical Editors. Feb. 3-7, 1997, Fort Collins, CO. Gen. Tech. Rep. INT- 373.
- Wright, E.F., K.D. Coates, and P. Bartemucci. 1998. Regeneration from seed of six tree species in the interior cedar-hemlock forests of British Columbia as affected by substrate and gap position. *Can. J. For. Res.* 28:1252-1364.
- Zumrawi, A-A., A. Stage, and B. Snowdon. 2002. Stand level scaling of a single tree distance independent diameter growth model: Interim calibration of Prognosis in the south-eastern interior of British Columbia. In: *Proceedings of Second Forest Vegetation Simulator (FVS) Conference*. N.L. Crookston, and R.N. Havis, compilers. February 12-14, 2002, Fort Collins, CO. USDA For. Serv., Rocky Mountain Research Station. RMRS-P-25. pp. 151-157.
- Zumrawi A-A., P. Marshall, S.O. Akindele, S. Ortlepp, and P. Thony. 2005. Calibrating Prognosis^{BC} in the Sub-Boreal Spruce and the Sub-Boreal Pine-Spruce Biogeoclimatic Zones: Development of growth and mortality models for major tree species. Internal report for Forest Science Program, Project No: Y051356