# Estimating Natural Regeneration Following Mountain Pine Beetle Attacks in British Columbia Using Nearest Neighbour Analyses

by

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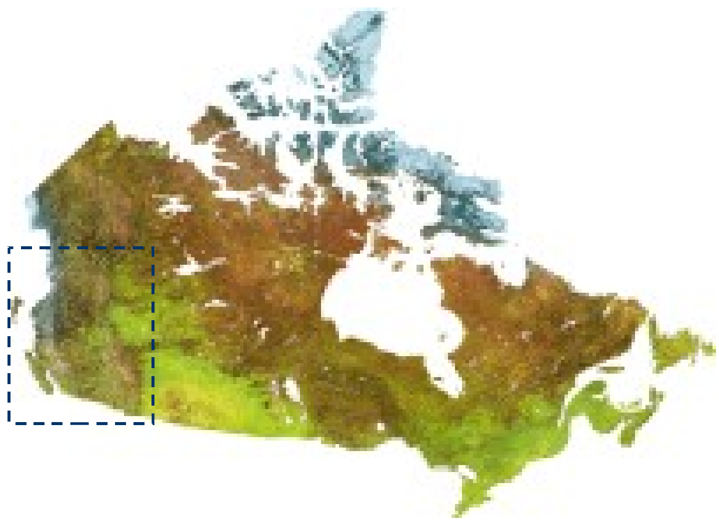
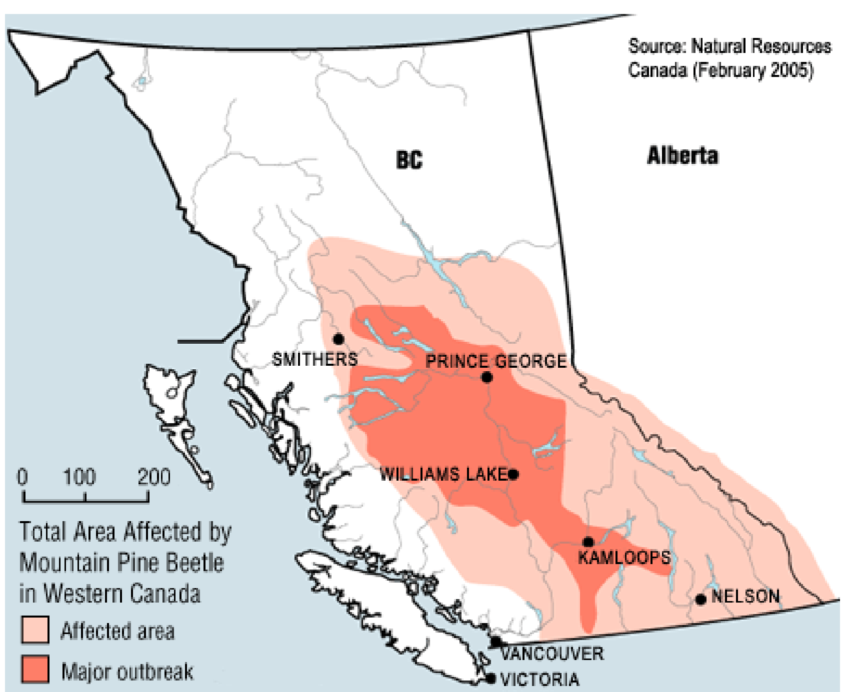
## Introduction

- Mountain Pine Beetle (MPB) is a destructive insect of mature pine forests of western North America.
- Pine, predominantly lodgepole pine (*Pinus contorta*) covers almost 14,000,000 ha of British Columbia (BC)
- MPB is endemic in these forests, periodically becoming epidemic.
- The present epidemic, beginning in the late-1990s, is unprecedented, both in terms of the severity and the extent of the outbreak

# Introduction – continued

## Area of BC Affected by MPB





# Provincial Level Projection of the Current MPB Outbreak

## Cumulative percentage of pine killed data 1999 to 2004 projection 2005 to 2014

*Supported by the*
*Mountain Pine Beetle Initiative of the Canadian Forest Service and the BC Forest Service*

Canada

British Columbia

# Objective

Predict the number and species of natural regeneration which would occur following MPB attack and no human intervention.

- not all attacked stands will be salvage logged

- planting will not be able to take place in every attacked stand

-need to be able to predict regeneration to link into growth models to ascertain impacts of current MPB attack on long-term timber supply

# Approach

We chose to apply imputation using most similar neighbour methods.

- We had reasonably good success predicting regeneration for several different species following partial harvesting using these methods previously.

  (Hassani, B.T., 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.)

- Auxiliary variables were particular overstory variables measured at Time 1, following the disturbance.

- Variables of interest were quantities of regeneration, by species and height class, at some subsequent time (Time 2).

- Overstory variable values at Time 2 were the same (or nearly the same) as they were at Time 1.

# Caveat

Levels of natural regeneration in MPB-attacked stands are expected to be affected by:

- extent and timing of mortality
- rate of defoliation of dead trees
- rate of fall of snags

It was not clear to us how much these factors, which essentially result in the overstory at Time 2 being considerably different than at Time 1, would impact on the effectiveness of the NN methods we used successfully in partially cut stands.

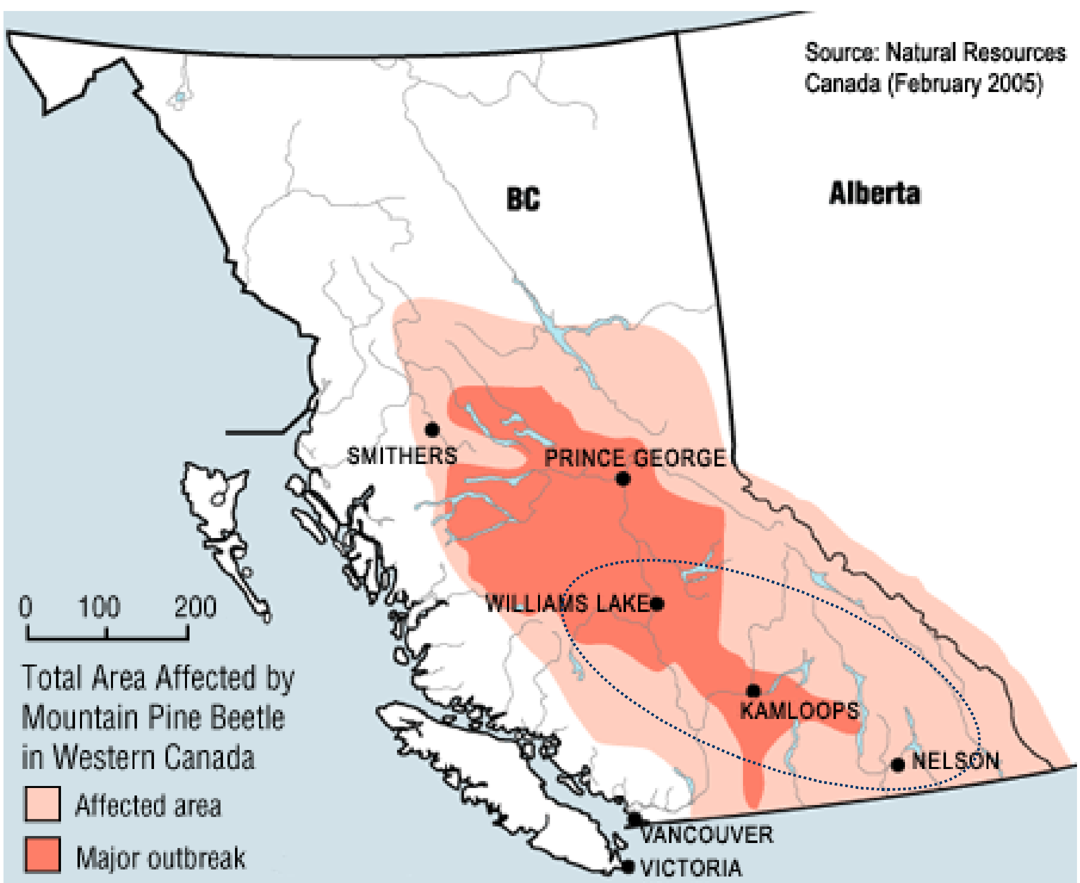
# Data

- 41 stands that were attacked by MPB in the mid-1980s were sampled in 1987 and 1988 as part of a Natural Resources Canada project.
  (Short, T. and L. Safranyik. 1996. The impact of the mountain pine beetle, Dendroctonus ponderosae, on lodgepole pine stands in British Columbia, Canada. In: Korpilahti, E, Salonen, T., S. Ojal (eds). Caring for the forests: research in a changing world: abstract of invited papers, IUFRO XX World Congress, 6-12 August 1995. Tampere, Finland.)
- Regeneration plots established in 20 of these stands (175 plots in total) were reassessed in 2001. The remaining 21 stands were no longer available due to logging or wildfire.

| Year | IDF | | SBPS | | MS | | All Zones | |
|---|---|---|---|---|---|---|---|---|
| | Stands | Plots | Stands | Plots | Stands | Plots | Stands | Plots |
| 1987 | 13 | 129 | 20 | 220 | 3 | 31 | 36 | 380 |
| **2001** | **9** | **80** | **9** | **75** | **2** | **20** | **20** | **175** |

# Data – continued

## General Location of the Sampled Stands



# Data – continued

- For each plot at both times, large trees (> 7.5 cm dbh) were measured for status (live/dead), species, and dbh.
  - measured on a variable radius plot with either a 2.3 $m^2$/ha or a 4.59 $m^2$/ha BAF

- Regeneration was considered to be those trees ≤ 7.5 cm dbh.
  - divided into saplings (0.1 to 7.5 cm dbh) and seedlings (< 1.5 m in height)
  - saplings were divided into two dbh classes (0.1 to 3.9 cm; 4.0 to 7.5 cm) and were measured on either 5.64 or 7.98 m radius circular plots and species and dbh recorded
  - seedlings were divided into four height classes (< 0.10 m; 0.10 to 0.49 m; 0.50 to 0.99 m; 1.00 to 1.50 m) and species and height class recorded.

# NN Imputation Analysis

- The Most Similar Neighbour (MSN) imputation program (Version 2.12) was used to select the nearest neighbour from the reference dataset.

- The squared distance (similarity) measure used was:

$$d^2_{ij} = (X_i - X_j)W(X_i - X_j)'$$

where $X_i$ is the vector of normalized X variables for the reference data, $X_j$ is the vector of normalized X variables for the target data, and W is a weight matrix.

- W was calculated as:

$$W = \Gamma \Lambda^2 \Gamma'$$

where $\Gamma$ is the matrix of the standardized canonical coefficients for the X variables and $\Lambda^2$ is the diagonal matrix of squared canonical correlations between the X and the Y variables.

## NN Imputation Analysis – continued

- Different sets of X and Y variables were tested.
- Y variables consisted of the regeneration data divided into species groupings and size classes
  - Two different species groupings were used: (1) shade tolerance classes (tolerant, semi-tolerant, intolerant); and (2) species classes (conifer expect pine, pine, deciduous)
  - Four size classes were used: (1) < 0.50 m in height; (2) 0.50 to 0.99 m in height; (3) 1.00 to 1.49 m in height; and (4) 0.10 to 7.49 cm dbh
- X variables consisted of the overstory data from 1987 and elevation, augmented by overstory data and snag fall-down rate from 2001
  - Normally, measurements from a second date would not be available
  - However, if they proved useful, they could be predicted from an overstory growth model and a snag recruitment model

# NN Imputation Analysis – continued

## Description of Predictor Sets

| Overstory (X) Variables | Symbol |
|---|---|
| Elevation; live stems/ha, basal area/ha (BA), crown competition factor, and quadratic mean diameter (QMD) | ALL |
| Elevation; live stems/ha, basal area/ha, crown competition factor, quadratic mean diameter; **number, BA, and QMD of snags** | ALLWS |
| Elevation; live stems/ha and basal area/ha **by three species classes (shade tolerant, semi-shade tolerant, shade intolerant)**, crown competition factor, and quadratic mean diameter | TC |
| Elevation; live stems/ha and basal area/ha by three species classes (shade tolerant, semi-shade tolerant, shade intolerant), crown competition factor, quadratic mean diameter; **number, BA, and QMD of snags** | TCWS |
| Elevation; live stems/ha and basal area/ha by three species classes (shade tolerant, semi-shade tolerant, shade intolerant), crown competition factor, quadratic mean diameter; number, BA, QMD, and **fall down rate of snags** | TCWS_RFY |
| Elevation; live stems/ha and basal area/ha **by three species classes (conifer except pine, pine, deciduous)**, crown competition factor, quadratic mean diameter | 3C |
| Elevation; live stems/ha and basal area/ha by three species classes (conifer except pine, pine, deciduous), crown competition factor, quadratic mean diameter; **number, BA, and QMD of snags** | 3CWS |
| Elevation; live stems/ha and basal area/ha by three species classes (conifer except pine, pine, deciduous), crown competition factor, quadratic mean diameter; number, BA, QMD, and **fall down rate of snags** | 3CWS_RFY |

# Assessment of Performance

- For validation, plot data from each of the three BEC zones were divided randomly into four approximately equal sets of plots.
- One of these four sets (25%) was used as the target data and the remaining plots were used as the reference data
- The imputed regeneration for each target plots was then compared to the actual regeneration and bias (average difference) and root mean squared error (RMSE) determined for each regeneration variable
- This analysis was repeated four times, using each set of plots in turn as the target data

| BEC Zone | Dataset 1 | Dataset 2 | Dataset 3 | Dataset 4 | Total Plots |
|---|---|---|---|---|---|
| IDF | 18 | 18 | 20 | 24 | **75** |
| MS | 5 | 5 | 4 | 6 | **20** |
| SBPS | 17 | 17 | 20 | 21 | **80** |
| **Total** | **40** | **40** | **44** | **51** | **175** |

# Assessment of Performance – continued

## Prediction Using 1987 Variables – Best All Sizes

| MSN Variables | | BEC | Bias | | | | RMSE | | | | All Sizes | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Over-story | Reg | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | Bias | RMSE |
| ALL | TC | IDF | -128 | 174 | 70 | -210 | 8102 | 2865 | 1126 | 1397 | -94 | 10999 |
| | | MS | 2136 | -265 | -50 | -48 | 11875 | 1217 | 339 | 461 | 1774 | 12543 |
| | | SBPS | 102 | 44 | 18 | -216 | 3687 | 1662 | 990 | 1788 | -53 | 5626 |
| ALLWS | TC | IDF | 306 | -116 | -12 | -27 | 8530 | 2317 | 972 | 1331 | 151 | 10930 |
| | | MS | 580 | -282 | -99 | -18 | 8439 | 996 | 378 | 632 | 181 | 7988 |
| | | SBPS | 0 | 88 | 88 | 87 | 3067 | 1704 | 1064 | 1840 | 264 | 5332 |
| TC | TC | IDF | 410 | 265 | 157 | 123 | 8943 | 2769 | 1403 | 1541 | 955 | 11868 |
| | | MS | 3263 | -215 | -50 | -75 | 10100 | 951 | 287 | 645 | 2923 | 10599 |
| | | SBPS | 71 | 26 | 0 | -323 | 3761 | 1683 | 993 | 1677 | -226 | 5854 |
| TCWS | TC | IDF | -393 | 215 | 128 | 135 | 7586 | 2743 | 1455 | 1376 | 85 | 10812 |
| | | MS | 1275 | -232 | -149 | -205 | 12194 | 1026 | 451 | 449 | 689 | 12081 |
| | | SBPS | 53 | 40 | 79 | 14 | 2676 | 1694 | 1060 | 1838 | 186 | 5357 |
| 3C | 3C | IDF | -853 | 50 | -41 | -18 | 7889 | 2643 | 1151 | 1564 | -862 | 10573 |
| | | MS | 50 | -431 | -83 | 50 | 9589 | 1109 | 355 | 453 | -413 | 10124 |
| | | SBPS | 133 | -97 | -124 | -300 | 3167 | 1548 | 826 | 1772 | -653 | 5194 |
| 3CWS | 3C | IDF | 608 | -352 | -50 | -41 | 9920 | 2109 | 1068 | 1244 | 166 | 11837 |
| | | MS | 812 | -331 | -116 | -108 | 9098 | 943 | 426 | 661 | 257 | 8744 |
| | | SBPS | 477 | 40 | 13 | 73 | 3360 | 1605 | 881 | 1913 | 603 | 5485 |
| **Actual** | | **IDF** | **3826** | **1213** | **563** | **1016** | | | | | **6618** | |
| | | **MS** | **5035** | **729** | **265** | **595** | | | | | **6624** | |
| | | **SBPS** | **1404** | **764** | **415** | **1528** | | | | | **4111** | |

# Assessment of Performance – continued

## Prediction Using 2001 Variables – Best All Sizes

| MSN Variables | | BEC | Bias | | | | RMSE | | | | All Sizes | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Over-story | Reg | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | Bias | RMSE |
| ALL | TC | IDF | 679 | 66 | 112 | -53 | 9816 | 2396 | 1195 | 1146 | 804 | 11576 |
| | | MS | 265 | -315 | -116 | 18 | 7209 | 1126 | 425 | 445 | -148 | 8098 |
| | | SBPS | 314 | 71 | 9 | -30 | 3017 | 1711 | 899 | 1711 | 393 | 5156 |
| ALLWS | TC | IDF | -402 | 215 | 87 | 141 | 8839 | 2534 | 1082 | 1474 | 41 | 10954 |
| | | MS | -248 | -414 | -116 | -5 | 7422 | 1055 | 425 | 394 | -783 | 8028 |
| | | SBPS | 318 | -110 | -84 | 209 | 2862 | 1400 | 785 | 1540 | 333 | 4722 |
| TC | TC | IDF | 348 | 542 | 248 | 314 | 9526 | 3080 | 1312 | 1606 | 1453 | 12137 |
| | | MS | 166 | -149 | -17 | -25 | 9476 | 1159 | 451 | 432 | -25 | 9893 |
| | | SBPS | 322 | 27 | 35 | 402 | 3164 | 1443 | 860 | 1765 | 723 | 4723 |
| TCWS | TC | IDF | -869 | 480 | 41 | 93 | 8523 | 2795 | 1034 | 1766 | -255 | 10172 |
| | | MS | -1192 | 215 | 17 | 30 | 9756 | 1050 | 399 | 439 | -931 | 10012 |
| | | SBPS | 238 | -225 | -57 | 258 | 2905 | 1374 | 871 | 1691 | 213 | 4652 |
| TCWS_RFY | TC | IDF | 108 | 749 | 190 | 241 | 9755 | 3209 | 1217 | 1944 | 1288 | 12723 |
| | | MS | -530 | 116 | 50 | 35 | 8255 | 1034 | 425 | 363 | -329 | 8411 |
| | | SBPS | 181 | -181 | -53 | -55 | 3223 | 1308 | 859 | 1726 | -108 | 4418 |
| **Actual** | | **IDF** | **3826** | **1213** | **563** | **1016** | | | | | **6618** | |
| | | **MS** | **5035** | **729** | **265** | **595** | | | | | **6624** | |
| | | **SBPS** | **1404** | **764** | **415** | **1528** | | | | | **4111** | |

# Assessment of Performance – continued

## Prediction Using 2001 Variables – Best All Sizes (Cont.)

| **MSN Variables** | | **BEC** | **Bias** | | | | **RMSE** | | | | **All Sizes** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Over-story | Reg | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | Bias | RMSE |
| 3C | 3C | IDF | -716 | -166 | -29 | -207 | 8022 | 2285 | 1027 | 1191 | -1118 | 10482 |
| | | MS | 4405 | 431 | 133 | 18 | 12092 | 1695 | 646 | 531 | 4986 | 12555 |
| | | SBPS | 181 | 13 | -22 | -82 | 3525 | 1631 | 803 | 1957 | 90 | 5060 |
| 3CWS | 3C | IDF | 2041 | -104 | 25 | -204 | 12012 | 2265 | 1085 | 1227 | 1759 | 13778 |
| | | MS | -431 | -331 | -133 | -38 | 10031 | 1005 | 406 | 436 | -932 | 10332 |
| | | SBPS | 504 | -62 | -75 | 252 | 3395 | 1450 | 798 | 1620 | 619 | 5183 |
| TCWS_ RFY | 3C | IDF | 1147 | 137 | 62 | -58 | 11161 | 2165 | 1099 | 1187 | 1288 | 12848 |
| | | MS | 563 | -199 | -133 | -100 | 9471 | 1180 | 406 | 521 | 132 | 9550 |
| | | SBPS | 446 | 18 | -9 | 38 | 3529 | 1419 | 806 | 1675 | 493 | 4958 |
| **Actual** | | **IDF** | **3826** | **1213** | **563** | **1016** | | | | | **6618** | |
| | | **MS** | **5035** | **729** | **265** | **595** | | | | | **6624** | |
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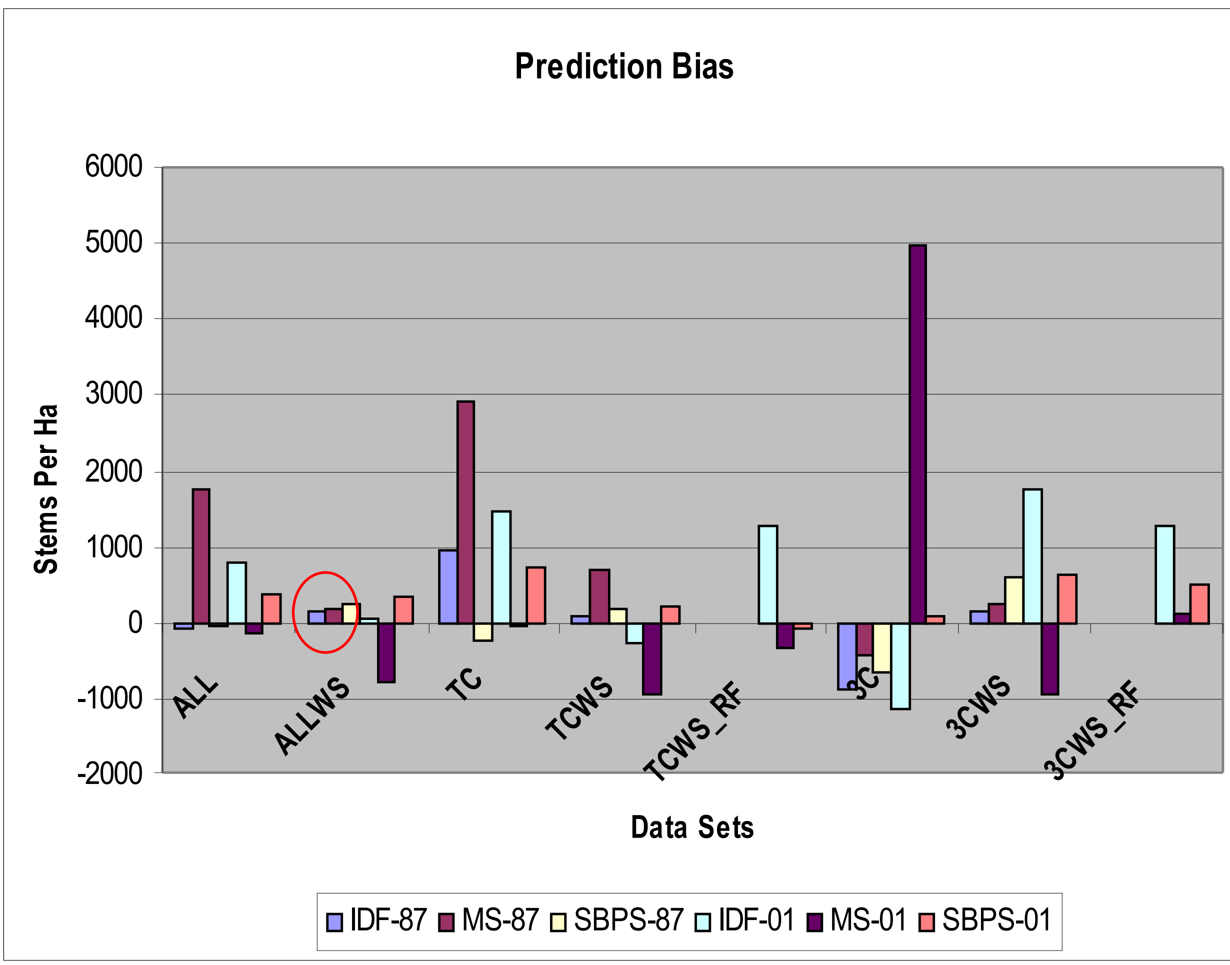
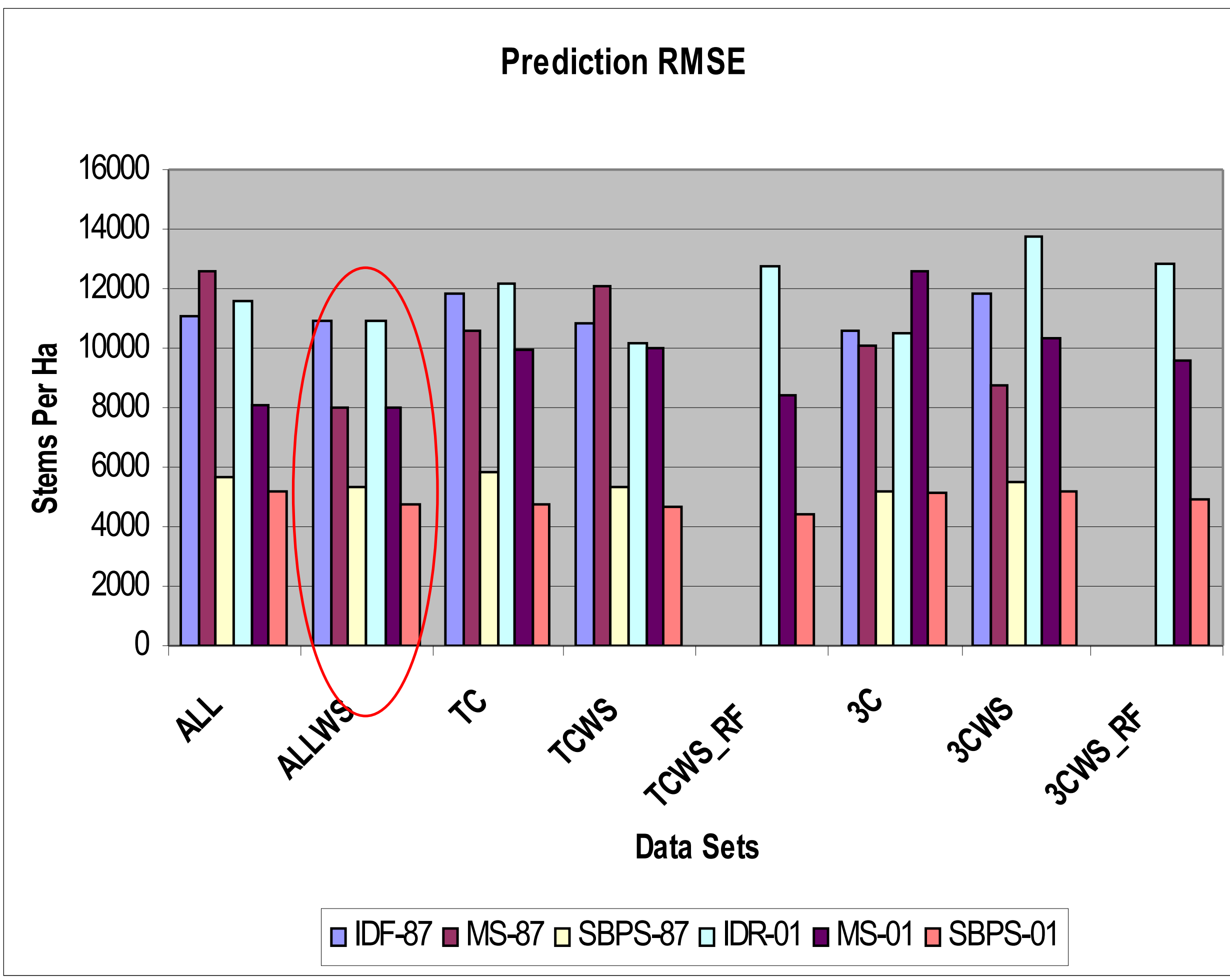
# Assessment of Performance – continued

## Overall Regeneration



# Assessment of Performance – continued

## Overall Regeneration



# Assessment of Performance – continued

## Prediction Using 1987 Variables – Best for Saplings

| MSN Variables | | BEC | Bias | | | | RMSE | | | | All Sizes | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Over-story | Reg | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | Bias | RMSE |
| ALL | TC | IDF | -128 | 174 | 70 | -210 | 8102 | 2865 | 1126 | 1397 | -94 | 10999 |
| | | MS | 2136 | -265 | -50 | -48 | 11875 | 1217 | 339 | 461 | 1774 | 12543 |
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| | | SBPS | 0 | 88 | 88 | 87 | 3067 | 1704 | 1064 | 1840 | 264 | 5332 |
| TC | TC | IDF | 410 | 265 | 157 | 123 | 8943 | 2769 | 1403 | 1541 | 955 | 11868 |
| | | MS | 3263 | -215 | -50 | -75 | 10100 | 951 | 287 | 645 | 2923 | 10599 |
| | | SBPS | 71 | 26 | 0 | -323 | 3761 | 1683 | 993 | 1677 | -226 | 5854 |
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| | | MS | 1275 | -232 | -149 | -205 | 12194 | 1026 | 451 | 449 | 689 | 12081 |
| | | SBPS | 53 | 40 | 79 | 14 | 2676 | 1694 | 1060 | 1838 | 186 | 5357 |
| 3C | 3C | IDF | -853 | 50 | -41 | -18 | 7889 | 2643 | 1151 | 1564 | -862 | 10573 |
| | | MS | 50 | -431 | -83 | 50 | 9589 | 1109 | 355 | 453 | -413 | 10124 |
| | | SBPS | 133 | -97 | -124 | -300 | 3167 | 1548 | 826 | 1772 | -653 | 5194 |
| 3CWS | 3C | IDF | 608 | -352 | -50 | -41 | 9920 | 2109 | 1068 | 1244 | 166 | 11837 |
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| | | SBPS | 477 | 40 | 13 | 73 | 3360 | 1605 | 881 | 1913 | 603 | 5485 |
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| | | **SBPS** | **1404** | **764** | **415** | **1528** | | | | | **4111** | |

# Assessment of Performance – continued

## Prediction Using 2001 Variables – Best for Saplings

| MSN Variables | | BEC | Bias | | | | RMSE | | | | All Sizes | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Over-story | Reg | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | Bias | RMSE |
| ALL | TC | IDF | 679 | 66 | 112 | -53 | 9816 | 2396 | 1195 | 1146 | 804 | 11576 |
| | | MS | 265 | -315 | -116 | 18 | 7209 | 1126 | 425 | 445 | -148 | 8098 |
| | | SBPS | 314 | 71 | 9 | -30 | 3017 | 1711 | 899 | 1711 | 393 | 5156 |
| ALLWS | TC | IDF | -402 | 215 | 87 | 141 | 8839 | 2534 | 1082 | 1474 | 41 | 10954 |
| | | MS | -248 | -414 | -116 | -5 | 7422 | 1055 | 425 | 394 | -783 | 8028 |
| | | SBPS | 318 | -110 | -84 | 209 | 2862 | 1400 | 785 | 1540 | 333 | 4722 |
| TC | TC | IDF | 348 | 542 | 248 | 314 | 9526 | 3080 | 1312 | 1606 | 1453 | 12137 |
| | | MS | 166 | -149 | -17 | -25 | 9476 | 1159 | 451 | 432 | -25 | 9893 |
| | | SBPS | 322 | 27 | 35 | 402 | 3164 | 1443 | 860 | 1765 | 723 | 4723 |
| TCWS | TC | IDF | -869 | 480 | 41 | 93 | 8523 | 2795 | 1034 | 1766 | -255 | 10172 |
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| | | MS | -530 | 116 | 50 | 35 | 8255 | 1034 | 425 | 363 | -329 | 8411 |
| | | SBPS | 181 | -181 | -53 | -55 | 3223 | 1308 | 859 | 1726 | -108 | 4418 |
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| | | **SBPS** | **1404** | **764** | **415** | **1528** | | | | | **4111** | |

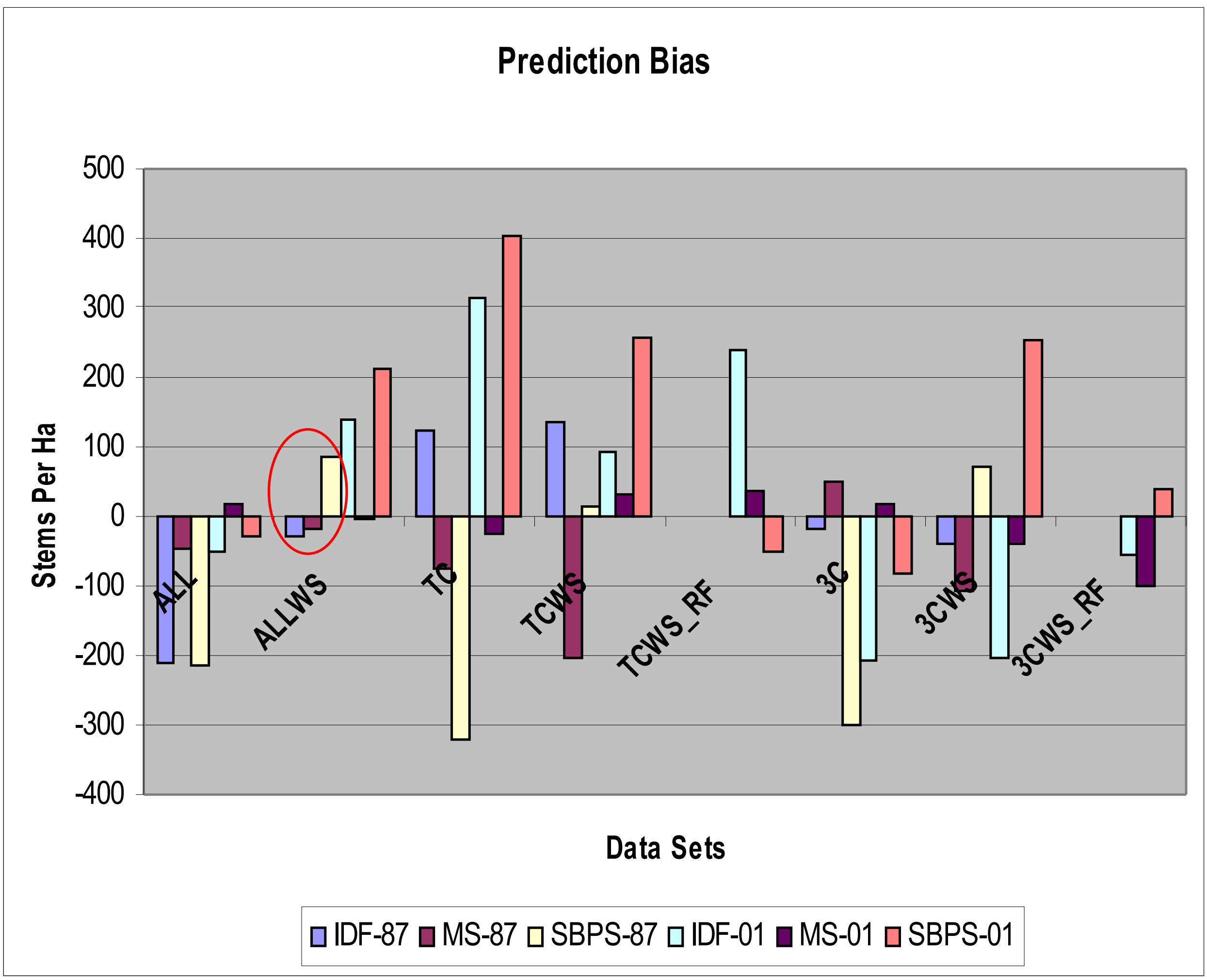
# Assessment of Performance – continued

## Prediction Using 2001 Variables – Best for Saplings (Cont.)

| MSN Variables | | BEC | Bias | | | | RMSE | | | | All Sizes | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Over-story | Reg | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | Bias | RMSE |
| 3C | 3C | IDF | -716 | -166 | -29 | -207 | 8022 | 2285 | 1027 | 1191 | -1118 | 10482 |
| | | MS | 4405 | 431 | 133 | 18 | 12092 | 1695 | 646 | 531 | 4986 | 12555 |
| | | SBPS | 181 | 13 | -22 | -82 | 3525 | 1631 | 803 | 1957 | 90 | 5060 |
| 3CWS | 3C | IDF | 2041 | -104 | 25 | -204 | 12012 | 2265 | 1085 | 1227 | 1759 | 13778 |
| | | MS | -431 | -331 | -133 | -38 | 10031 | 1005 | 406 | 436 | -932 | 10332 |
| | | SBPS | 504 | -62 | -75 | 252 | 3395 | 1450 | 798 | 1620 | 619 | 5183 |
| TCWS_ RFY TC | 3C | IDF | 1147 | 137 | 62 | -58 | 11161 | 2165 | 1099 | 1187 | 1288 | 12848 |
| | | MS | 563 | -199 | -133 | -100 | 9471 | 1180 | 406 | 521 | 132 | 9550 |
| | | SBPS | 446 | 18 | -9 | 38 | 3529 | 1419 | 806 | 1675 | 493 | 4958 |
| **Actual** | | **IDF** | **3826** | **1213** | **563** | **1016** | | | | | **6618** | |
| | | **MS** | **5035** | **729** | **265** | **595** | | | | | **6624** | |
| | | **SBPS** | **1404** | **764** | **415** | **1528** | | | | | **4111** | |

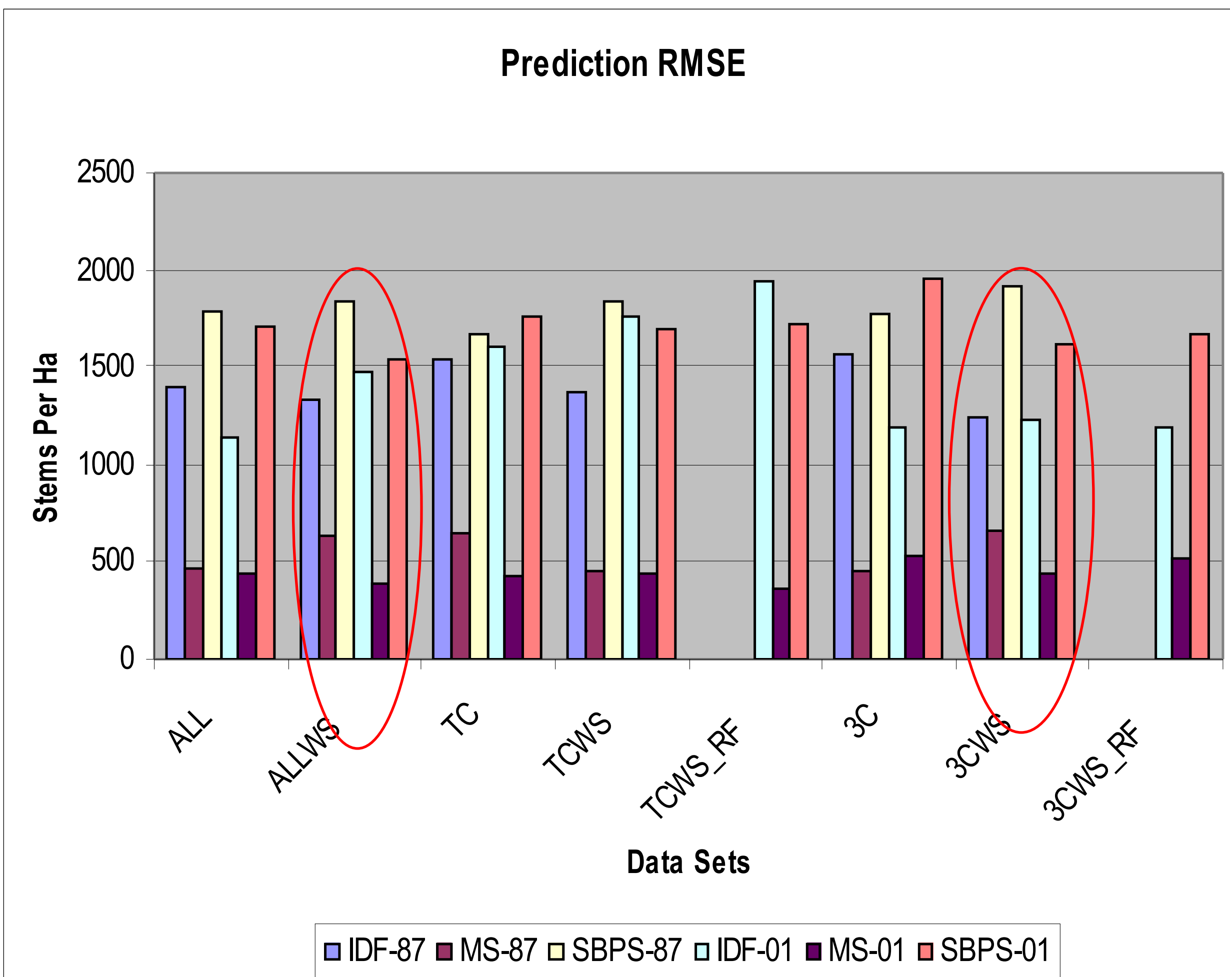
# Assessment of Performance – continued

## Number of Saplings



# Assessment of Performance – continued

## Number of Saplings



# Assessment of Performance – continued

## Observations

- No overstory combination worked best in all cases for either the 1987 or the 2001 datasets for either all regeneration or for saplings alone
- Bias levels generally not too bad, but there was quite high (unacceptable?) variability on a plot-by-plot basis
- In general, using the 2001 overstory and rate-of-fall variables did not improve predictions over using the 1987 overstory information for all predicting regeneration
- There were slight improvements using the 2001 overstory data for predicting the number of saplings
- Using tolerance classes for the regeneration generally resulted in slightly better predictions than using species classes
- Overall, the dataset which incorporated the 1987 overstory data plus snag information, without species or tolerance classes, provided the best predictions

# What next?

- Collect more (and better) regeneration information and overstory data
- Explore alternative imputation methods
  - Focus only on a subset of the largest regeneration
  - Use m-NN to average out variability
- Explore alternative prediction methods

# Acknowledgements

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Natural Resources Canada / Ressources naturelles Canada

CFS CANADIAN FOREST SERVICE

Additional funding was provided by the BC Ministry of Forests and Range to evaluate alternative data sources.

BRITISH COLUMBIA

Ministry of Forests and Range

Any questions?