

Project Title: Estimating Natural Regeneration and Yield in Pine-Dominated Stands Following Mountain Pine Beetle Attack Using SORTIE-ND and Prognosis^{BC} in a Hybrid Modelling Approach.

FIA-FSP Project Number: Y081048

Year 1 Executive Summary

Derek Sattler¹, Valerie LeMay (contact person)^{1,2}, and Peter Marshall¹

Project Purpose and Management Implications

In the wake of the current Mountain Pine Beetle (*Dendroctonus ponderosae* Hopkins, MPB) outbreak, harvesting operations have been firmly focused on the recovery of timber from beetle affected stands (Hawkes *et al.* 2004). However, due to limits in the shelf-life and the industrial capacity to process recovered logs, a large proportion of MPB-affected stands will go unsalvaged (Nelson *et al.* 2006). Furthermore, forest managers are beginning to identify and protect MPB-affected stands that harbour a healthy and vigorous understory (personal communication). It is from these unsalvaged stands that we expect to obtain much of the Province's mid and long-term timber supply.

Traditionally, we have relied on empirically based growth and yield models to provide estimates of future timber volume. The reliability of the estimates provided from these models is largely achieved through the use of extensive historical measurements on tree and stand level variables (Robinson and Ek 2003; Valentine and Makela 2005). However, in the face of rapidly changing forest conditions such as we are seeing with the current MPB outbreak, the reliability of empirically based estimates of growth and yield can become compromised as observed stand conditions no longer match with historical data. Thus, the relatively rapid pace of change in forest structure following MPB attack has placed considerable importance on the need to develop dynamic quantitative growth and yield models, commonly referred to as hybrid models. Within a hybrid model system, estimates of future tree growth and stand conditions are obtained through a feedback system between empirically based predictions and processed based predictions the latter of which model the basic building blocks related to tree growth.

The purpose of this project is to develop a dynamic method for estimating the growth and yield of pine-dominated stands (*Pinus contorta* var. *contorta*) that have been attacked by MPB yet have remained unsalvaged and unmanaged. We have focused on the integration

¹ Department of Forest Resources Management, University of Vancouver, 2045 2424 Main Mall, Vancouver, BC V6T 1Z4

² Valerie.LeMay@ubc.ca; Phone 604-822-4770; Fax 604-822-9106

of two models, the empirically-based model Prognosis^{BC}, and the light-mediated processed based model SORTIE-ND. The specific objectives of the project are:

1. to examine the strengths of SORTIE-ND and Prognosis^{BC} in estimating the establishment and growth of MPB-affected stands;
2. to examine the factors affecting natural regeneration following MPB-attack across a range of site and stand conditions using existing datasets;
3. to alter parameters and sub-models of SORTIE-ND and Prognosis^{BC} based on findings from the previous objective; and
4. to link SORTIE-ND and Prognosis^{BC} and estimate the growth and yield of trees following MPB-attack.

There are several high-priority management implications directly associated with this project. To begin, a hybrid model that combines the strengths of the processed-based and empirically-based functions of SORTIE-ND and Prognosis^{BC} would be a very useful tool for the projection of mid- to long-term yields. The information provided from these projections is critical in determining the allowable annual cut and influences decisions within annual operating plans. Secondly, the structure of the hybrid model allows for forest managers to explore different scenarios for regenerating MPB-affected stands. This sort of exploration would be extremely useful in identifying stands that are suitable for under-planting (Coates and Hall, 2005) and contribute to the development a strategic plan focused on minimizing the expected mid-term timber supply shortage. Lastly, the hybrid model could be used to obtain estimates of the expected volume to come out of stands that are being guarded from current salvage operations in order to protect an understory that is likely to reach merchantable limits in 30 to 50 years. Results from these projections could be used to refine the current provincial guidelines for identifying stands that are suitable candidates for salvage protection.

Project Start Date, Length, and Relationship to Other Projects

This project began April 1, 2007 and will continue for two years ending March 31, 2009, with a final report and deliverables by April 30, 2009. Some of the data used in this project was gathered under an affiliated project (FSP Project M07-5015) also funded by the Forest Science Program.

Methodology overview

Data description

The research conducted for this project focused on MPB-attacked stands in the Central Interior (Quesnel/Williams Lake) and Southern Interior (Kamloops, BC) areas of the Province. Two sources of plot data were used in this project.

The first set of plot data, referred to as the UBC data set, includes samples from Interior Douglas Fir (IDF), Sub-Boreal Spruce (SBS), Sub-Boreal Pine Spruce (SBPS) and the Mountain Spruce (MS) Biogeoclimatic Ecological Classification (BEC zones). Through an affiliated project (FSP Project M07-5015), lodgepole pine-dominated stands that showed clear evidence of historic mountain pine beetle attack were selected for sampling (56 stands). For the majority of the areas which were sampled in 2006, the most recent severe

attacks occurred 25 years ago, although some stands were sampled that showed evidence of attack roughly 8 to 10 years ago. For the UBC dataset, reconstruction of the overstory conditions at the time of MPB-attack was done. Tree class measures on standing and downed trees were used to decide which trees were alive at the time of disturbance, and diameter increment models and height models developed for Prognosis^{BC} are being used to reduce (back case) the diameter and height of each tree. The specific time of the MPB-attack for the UBC data was based on previous sampling in the area by UBC research team members, map information, and knowledge obtained by local foresters and biologists during sampling. The result was measures of the overstory at time of attack and also at time of sampling, and regeneration at time of sampling.

The other source of plot data was an existing dataset collected for a Natural Resources Canada study in the Caribou-Chilcotin forest region (Brad Hawkes, NRC data; Hawkes et al. 2004). The NRC data include measures of overstory and understory trees in the IDF, SBPS and MS BEC zones for 41 stands, measured in 1987, shortly after MPB attack, and re-measured in 2001. These data have overstory measures in 1987 and 2001, and regeneration measures in 2001.

Collectively, these data were used to modify the submodels of the two linked models, and to test the effectiveness of the linked models in estimating regeneration following MPB attack.

Analyses for Objective 1: Examining the Strengths of SORTIE-ND and Prognosis^{BC} for Predicting Natural Regeneration Following MPB Attack.

SORTIE-ND is a light mediated, spatially explicit growth model that is founded on a process-based approach to simulating stand conditions. Conversely, Prognosis^{BC} is an empirical tree-level model that projects future stand growth without spatially referencing individual trees. Thus, the fundamental philosophies on which these two models operate differs, resulting in different model strengths and weaknesses.

The differences in the approaches used to simulate tree growth are being assessed within the context of the models' applicability to predicting the establishment and subsequent growth of natural regeneration following MPB attack. Comparisons of the processes and components of SORTIE-ND and Prognosis^{BC} are being made in terms of: 1) the variables and functions used to drive the sub-models housed within each model; 2) predicted results from model simulations; and 3) the adaptability of the models to the study areas. The results of these comparisons are helping to identify where further linkages between these two models need to be developed.

Analyses for Objective 2: Examining the factors affecting Natural Regeneration Following MPB Attack.

The pooled data are being analyzed to identify factors that are important for predicting the establishment and growth of natural regeneration following MPB attack. By examining historical outbreaks of MPB, we are identifying patterns of forest structure, including species composition, diameter distribution, and density that are more likely to support natural regeneration following disturbance. Correlations and causal relationships

between forest structure and natural regeneration are being examined through statistical analyses and summarized in tables and graphs.

By gaining insight into the historical patterns of natural regeneration following MPB attack, we are establishing upper and lower bounds on acceptable error resulting from model predictions. If model predictions deviate from these bounds, then we can apply the knowledge gained from the historical data and focus in on attributes of forest structure that are poorly represented within the models. For example, preliminary tests of the SORTIE-ND model presented in LeMay *et al.* (2006) using the NRC data resulted in large under-estimates of regeneration 16 years after MPB attack. Based on the known relationships in forest structure that existed in these stands, we were able to trace the source of poor model estimates back to inadequate allometric relationships for crown allometry and height to diameter at breast height (dbh) functions.

Analyses for Objective 3: Adjustments to the Parameters and Sub-Models of SORTIE-ND and Prognosis^{BC}.

SORTIE-ND and Prognosis^{BC} each house a separate series of sub-models that predict changes to forest behaviours, such as seedling establishment, growth, competition for growing resources and mortality. We are examining the sub-models and adjusting some sub-models to improve predictions, based on the knowledge gained from historical data, our understanding of the sub-models, and on previous literature (e.g., Staudhammer and LeMay, 2000; Temesgen et al. 2005). The adjusted models are being tested, initially to determine if predictions fall within the upper and lower bounds of acceptable error. Each sub-model is also validated using sub-setting of the data. Following thorough testing, sub-models are being revised and the new equations are being incorporated into the SORTIE-ND and Prognosis^{BC} software.

Analyses for Objective 4: Linking SORTIE-ND and Prognosis^{BC}

Following a preliminary analysis and changes to sub-models within SORTIE-ND (see LeMay *et al.* 2006) and Prognosis^{BC}, the two models are being linked to allow for the transfer of projected regeneration lists (trees less than 7.5 cm dbh) from SORTIE-ND to Prognosis^{BC}, to provide forecasts of growth and yield over a 25 year time period following MPB attack. The projection and transfer of regeneration lists using the linked models occurs in four stages:

- 1) tree-lists representing the overstory (O/S) and understory (U/S; regeneration) stand structure shortly after MPB attack (Time 1) are input to SORTIE-ND and to Prognosis^{BC};
- 2) tree-lists are then be projected to Time 2 using each model;
- 3) at Time 2, the understory trees produced via recruitment in SORTIE-ND, are added to the projected tree-list from Prognosis^{BC}; and, finally,
- 4) the augmented tree-lists are projected to Time 3 using Prognosis^{BC}, assuming no further disturbance nor recruitment.

The timing of the “hand-off” (progression of tree lists from stage 2 to 3) is based on the time when responses of regeneration to changes in the overstory are expected to have occurred, and was simulated at 5, 10, 15 and 20 years. Model outputs following stage 4 are being compared to actual data and assessed for their accuracy in terms of density

(stems per hectare, basal area per hectare), diameter at breast height distribution, and tree height distribution.

Based on these results, further adjustments are being made to the two models, and the linkages in terms of different “hand-off” times. Several iterations of simulations and adjustments have been performed, and this work will continue in the second year of this project. The technical linkage aspects are being examined by Don Robinson of ESSA Technologies, Vancouver, as part of this project.

If the hybrid modelling approach results in acceptable accuracy in estimation, steps could then be taken to implement these for use in MPB-affected stands, and to investigate the use of this hybrid modelling approach for other disturbance types. These subsequent tasks are outside the scope of this two-year research plan.

Project Scope and Regional Applicability

Although the project focus is on linking models to project stand development following MPB-attack, the development of a hybrid model, as we have described here, could be extended for use in other complex and disturbed stands of BC. By focusing on the accurate prediction of natural regeneration, this study represents an important step in the development of a hybrid model that could be used to inform management decisions that have direct implications on the mid and long-term timber supply. Results from tests of the hybrid model, using the UBC and NRC datasets, are being disseminated to provincial, national and international researches through peer reviewed articles. Furthermore, results will be readily accessible via the UBC-Prognosis and/or biometrics websites: (<http://www.forestry.ubc.ca/Prognosis> or www.forestry.ubc.ca/biometrics).

Interim Conclusions

Objective 1: Identifying Strengths of SORTIE-ND and Prognosis^{BC}

To initiate SORTIE-ND, users must input parameters estimated from field measurements. Whether this is seen as a strength or hindrance depends on the type of field measurements at the user’s disposal. The greater the suite of field measurements (i.e., beyond conventional mensuration data), the greater the flexibility the user is afforded in terms of adapting the model to a study area. For this project, parameters have been estimated from field data for SORTIE-ND’s allometric functions, including height-diameter relationships for saplings, and adults, and crown dimension relationships. Additionally, parameters related to forest floor substrate have been input into SORTIE-ND. All remaining parameters used in SORTIE-ND have been obtained either through personal communication or through peer-reviewed literature. A distinct strength of SORTIE-ND is the liberty with which new predictive equations can be added to the freely available source code. We have used this feature to develop a new set of equations used to predict crown dimensions, results of which are presented in the appropriate section.

Prognosis^{BC} carries with it several project specific advantages, including: 1) extensive use of PSP data to calibrate the growth equations to even and complex stands; 2) the use of

site and climate factors (e.g., slope aspect, elevation) to adjust model predictions; and 3) the ability to accept a tree-lists from a variety of inventory formats. However, the lack of an effective sub-model capable of predicting the abundance and species composition of natural regeneration for MPB-attacked stands is a major limitation of Prognosis^{BC}.

Objective 2: Factors affecting natural regeneration following MPB attack.

Analysis of historical data indicated that the amount of natural regeneration following MPB attack was highly variable for mixed-species and pine-dominated stands. Data suggest that species composition and the density of live overstory trees at the time of MPB attack are important predictors of the amount of natural regeneration that observed 16 years hence. Stands in the SBPS that were characterized by low basal area of standing dead trees (< 15 m²/ha) at the time of MPB attack tended to show an increase in the amount of pine seedlings and samplings 16 years hence. Generally, this increase in seedling and sampling density was also associated with an increase in the basal area of snags, indicating a greater intensity of beetle impacts. For many of the stands located in the IDF, the amount of live basal area (m²/ha) remained relatively constant from the time of attack to 16 years later. In the same stands, the density of pine seedlings (stems/ha) decreased sharply over the 16 year time period.

Objective 3: Adjustments to Model Parameters and Submodels.

Parameterization of the allometric relationships in SORTIE-ND using UBC data from William's Lake is now complete. Initial tests of the altered model indicated that further adjustments to the equations used to predict crown length and crown radius were required. A system of nonlinear equations has since been developed that incorporates three stand-level measures of density: 1) basal area of trees taller than the target tree; 2) basal area per hectare; and 3) stems per hectare. Testing of the simultaneous equations outside of SORTIE-ND showed increased prediction accuracy for the range of stand densities that are being tested (Sattler *et al.* 2008). It is hypothesized that with these adjustments, predicted understory light levels (Global Light Index - GLI) will increase for dense stands and decrease for open stands. To test this hypothesis, the equations have been programmed into SORTIE-ND and now form part of a beta-version of the model currently undergoing testing.

Objective 4: Linking SORTIE-ND and Prognosis^{BC}.

A linkage has been developed that successfully allows for seedlings and saplings estimated in SORTIE-ND to be passed to Prognosis^{BC}. Tests of the new hybrid model were conducted using a 25-year projection period. The timing of the tree-list hand-off from SORTIE-ND to Prognosis was tested at five and ten years post-MPB attack and compared to simulations using Prognosis^{BC} only and SORTIE-ND only for the entire projection period (Sattler *et al.* in press). For spruce (*Picea glauca*) and aspen (*Populus tremuloides*) trees less than 7.5 cm dbh, the 10 year hand-off simulation provided the best estimate of trees per hectare when compared to actual observations. For lodgepole pine trees less than 7.5 cm dbh, the 5 year hand-off simulation provided the best results. Overall, densities of lodgepole pine were largely underestimated for smaller trees. We expect to see improved estimates following the introduction of the density dependent

crown equations to SORTIE-ND, which will be further tested in the second year of this project.

References Cited:

- Coates, D.K. and E.C. Hall. 2005. Implications of alternative strategies in mountain pine beetle damaged stands. Technical report for Forest Science Program Project Y051161. Bulkley Valley Centre for Natural Resources Research and Management, Smithers.
- Hawkes, B., Taylor, S., Stockdale, C., Shore, T.L., Alfaro, R.I., Campbell, R., Vera, P. 2004. Impacts of mountain pine beetle on stand dynamics in British Columbia. Pages 175-195 in T.L. Shore, J.E. Brooks, and J.E. Stone, editors. *Mountain Pine Beetle Symposium: Challenges and Solutions*. Kelowna, British Columbia October 30-31, 2003, Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Information Report BC-X-399, Victoria, BC. 298p.
- 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.
- Nelson, T., B. Boots, M.A. Wulder, T. Shore, L. Safranyik, and T. Ebata. 2006. Rating the susceptibility of forest to mountain pine beetle infestations: the impact of data. *Can. J. For. Res.* 36: 2815-2825.
- Robinson, A. and A.R. Ek. 2003. Description and validation of a hybrid model of forest growth and stand dynamics for the Great Lakes region. *Ecological Modelling* 170: 73-104.
- Sattler, D.F., V. LeMay, and P. Marshall. 2008. Using SORTIE-ND and Prognosis^{BC} as a linked model to estimate natural regeneration following MPB attack for complex stands in the southern interior of British Columbia. Paper presented at the Timber Growth and Value Conference, in Smithers, BC, February 6-7, 2008.
- Sattler, D.F., V. LeMay, and P. Marshall. In press. Estimating natural regeneration using a linked-model approach. In *Proceedings of the IUFRO conference on process models to wood processing*, Portland, US, Aug. 6-10, 2007.
- Staudhammer, C. and V.M. LeMay. 2000. Height prediction equations using diameter and stand density measures. *Forestry Chronicle* 76(2): 303-309.
- Temesgen, H., V. LeMay, and S. Mitchell. 2005. Tree crown ratio models for multi-species and multi-layered stands. *Forestry Chronicle* 81(1):133-141.
- Valentine, H.T. and A. Makela. 2005. Bridging process-based and empirical approaches to modeling tree growth. *Tree Physiology* 25: 769-779