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Dawson Creek Mountain Pine Beetle Spread Analysis: Application of the SELES-MPB Landscape-Scale Mountain Pine Beetle Model in the Dawson Timber Supply Area and Tree Farm License 48

A. Fall, T. L. Shore and W.G. Riel

Mountain Pine Beetle Initiative
Working Paper 2006-18

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Executive Summary

The Dawson Creek Landscape Model (DCLM) was developed to assess the impacts of mountain pine beetle management activities in the Dawson Creek, British Columbia (B.C.), area (the Dawson Creek Timber Supply Area, Tree Farm License 48 and area parks) and to analyze the potential spread of the current beetle outbreak across this region and potentially into the boreal forest of Alberta. Using the best available inputs from inventory, weather data, management activities and infestation maps, the DCLM projects beetle spread on an annual basis. A range of scenarios was analyzed to assess expected impacts of management and assumptions regarding climate and external beetle pressure. The scenarios include:

(i) Starting conditions based on 2004 or 2005 survey information;
(ii) External mountain pine beetle pressure—assumed to be either no pressure (closed-world assumption), pressure based on 2004 levels, or dynamic pressure derived using the provincial-scale beetle model BCMPB (Eng et al. 2005);
(iii) Climatic suitability for mountain pine beetle based on either recent historical averages (1970 to 2000) or estimated near future climate (2000 to 2030);
(iv) Management regime options that included general beetle management (i.e., similar to elsewhere in the province), current practices, salvage only, and no beetle management (no harvesting or single-tree treatments).
(v) Harvest levels that were either the current annual allowable cut (AAC) or a 50% increase.
(vi) Fell and burn levels based on levels applied in 2005, current targets, or other levels to assess the role of fell and burn in managing this outbreak.

Our focus was primarily on short-term effects (10 years of attack). The base case scenario was assumed to be current management practices under climate change conditions, with dynamic external pressure. As this analysis assessed over 60 scenarios, one of the challenges was to find clear methods to present results.

In general, our analysis indicates that beetle management in the Dawson Creek area could significantly effect the spread and impact of the beetle outbreak over the next 10 years, provided that high levels of fell and burn and survey efforts are maintained. The results apply only to the specific conditions (current forest inventory and beetle infestations) and management regimes run on the study area. In particular, results are significantly affected by assumptions regarding external pressure from the main outbreak, as estimated using the provincial-scale projection. If mountain pine beetle populations can be held low until the main outbreak subsides (which will likely occur within the next five years due to availability of hosts), management should be able to curtail major losses in the Dawson Creek area. Due to inherent uncertainties in model inputs and understanding of key processes, the results would best be used to weigh the relative differences between scenarios rather than as exact predictions.

Résumé

Le modèle paysager de Dawson Creek a été mis au point afin d’évaluer l’impact des activités de cette lutte contre le dendroctone du pin ponderosa sur la région de Dawson Creek en Colombie-Britannique (la zone étudiée comprend la zone d’approvisionnement en bois de Dawson Creek, la licence de propriété forestière 48 et les parcs de la région) et d’analyser la propagation potentielle de la flambée actuelle de dendroctone dans la région et dans la forêt boréale de l’Alberta. Utilisant les meilleurs renseignements disponibles tirés de l’inventaire, des données météorologiques, des activités de lutte et des cartes représentant l’infestation par le dendroctone, le projet du modèle paysager de Dawson Creek prévoit une prolifération annuelle du scolyte. Différents scénarios ont été analysés afin d’évaluer les effets prévus de la lutte, ainsi que des hypothèses relatives au climat et aux pressions externes que subit le dendroctone, notamment :

(vii) Les conditions de départ, d'après les résultats de l'étude de 2004 ou de 2005.

(viii) On a supposé plusieurs niveaux de pressions externes sur le dendroctone : aucune (hypothèse du monde clos), pression aux niveaux de 2004 et pression dynamique calculées à l'aide du modèle BCMPB (BC Provincial Scale Mountain Pine Beetle Model) (Eng et al., 2005).

(ix) Les conditions climatiques favorables au dendroctone ont été établies à partir des moyennes historiques récentes (de 1970 à 2000) ou des moyennes estimées dans un avenir rapproché (de 2000 à 2030).

(x) Les solutions de lutte comprenaient la lutte générale contre le dendroctone (c.-à-d., semblable à ce qui se passe dans le reste de la province), les pratiques actuelles, des activités de récupération seulement, et aucune lutte (pas de récolte ou de traitements sélectifs des arbres).

(xi) Le niveau de récolte appliqué était soit celui de la coupe annuelle autorisée, soit une augmentation de 50 %.

(xii) Les niveaux de coupe ou de brûlé s'appuyaient sur les niveaux de 2005, les objectifs actuels ou d'autres niveaux afin d'évaluer le rôle des coupes et des brûlés dans la lutte contre l'infestation.

Cette étude était principalement axée sur les effets à court terme (dix années d'infestation). Le scénario de référence représentait les activités de lutte actuelles dans les conditions des changements climatiques avec des pressions externes dynamiques. Cette analyse portant sur plus de 60 scénarios, l'un des défis était de déterminer des méthodes claires pour présenter les résultats.

En règle générale, l'analyse a indiqué que la lutte contre le dendroctone dans la région de Dawson Creek pourrait avoir un effet significatif sur la propagation et l'impact du dendroctone du pin ponderosa au cours des dix prochaines années si l'on peut maintenir les niveaux élevés de coupe et de brûlé ainsi que les études. Ces résultats ne s'appliquent qu'aux conditions (inventaire forestier et infestations par le dendroctone actuels) et aux activités de lutte particulières à la zone d'étude. Ils dépendent notamment considérablement des hypothèses sur les pressions externes relatives à la flambée principale, telles qu'elles ont été évaluées à l'aide d'une projection à l'échelle de la province. Si on peut maintenir les populations de dendroctone à un niveau faible jusqu'à ce que la flambée principale diminue (ce qui devrait se produire dans les cinq prochaines années en raison de la disponibilité des hôtes), la lutte devrait permettre de limiter les pertes les plus graves dans la région de Dawson Creek. En raison des incertitudes inhérentes aux données du modèle et à la compréhension des processus clés, il est préférable d'utiliser les résultats pour comparer les différences relatives entre les scénarios plutôt que comme des prédictions exactes.

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1 Introduction

Mountain pine beetle attack in the Dawson Creek British Columbia area was first confirmed in February, 2004. The main provincial outbreak has been expanding rapidly, and it appeared that the Rocky Mountains could provide the only opportunity for a break large enough to disrupt the beetle's spread. Spots recently detected in Dawson Creek most likely originated from the main outbreak, and were transported over long distance via wind and through mountain passes. Growth rates, as indicated by green:red attack ratios, have been relatively low (compared to elsewhere in the beetle's range), but nonetheless show potential for population growth. This suggests that weather has been sufficiently favourable to support an outbreak, whereas historic climate likely precluded outbreaks.

Substantial effort in Dawson Creek has focused on dealing with detection and treatment of infestation spots, with cooperation among licensees, the forest service and parks. A landscape-scale projection of outbreak potential may be useful to inform this process and to help clarify some tradeoffs between options available. It may also be useful to assess the risk of spread into Alberta and the boreal forest.

The core of the landscape model described in this document was developed largely with support for prior projects (Fall et al. 2001; 2002; 2003a; 2003b) from the B.C. Ministry of Forests. The mountain pine beetle models were derived by the authors and Les Safranyik (emeritus, Pacific Forestry Centre, Canadian Forest Service). The general concept involves using geographic, forest inventory, weather and beetle-infestation data for the study area, and projecting it forward using a landscape model to evaluate the course of the infestation, primarily in terms of area infested and volume killed by the beetle. The beetle outbreak model is combined with management models for harvesting, and fell and burn treatments, so that interactions between management and beetles can be assessed. The model is not designed to predict when an outbreak may end, but we decided to artificially terminate it after 10 years, which is in line with expectations for collapse of the main outbreak in British Columbia's interior plateau. Through comparison of various scenarios, potential benefits of beetle management were identified. This information could be used to assess impacts directly, or could serve as input for further analysis of economic, social and ecological cost/benefits (e.g., by an economist or ecologist), although such analysis was not a direct part of this project.

2 Project Objectives

The main purpose of this study was to apply and refine a model methodology to evaluate the effectiveness of landscape-scale bark beetle-management activities in reducing losses to mountain pine beetle, and to analyze the potential spread of the beetle across the study area. Specifically, the goal of this project was to address the question: what would be the likely trajectory and impacts from the current beetle outbreak under a range of alternative beetle-management regimes? To achieve this goal, we start with the current conditions and project likely outcomes under the various scenarios. The beetle outbreak terminates after 10 years, but the model may be run longer to assess the decay of killed merchantable wood over the following decade and the long-term implications on growing stock and other timber-supply indicators.

3 Methods

3.1 Landscape Model Design

The Dawson Creek Landscape Model (DCLM) is a specific application and refinement of the SELES-MPB/MPBSIM Mountain Pine Beetle Landscape Model (Riel et al. 2004; Fall et al. 2004). Rather than provide many details, we focus here on a high-level description of the model, including the state space and process sub-models. Figure 1 shows the general design of the model in terms of linkages between model state, landscape processes and output files. For a description of the Spatial Timber Supply Model (STSM) that underlies the main aspects of the harvesting, aging and inventory sub-models, see Fall (2002a).

3.1.1 <u>Model State Space</u>

All layers, except where noted, were derived using information from the current forest inventory in the Dawson Creek area.

3.1.1.1 General landscape structure. Landscape biogeographical context and the limits of the study area are defined with the following spatial variables:

- (i) BEC—biogeoeclimatic classification by variant;
- (ii) Elevation in metres;
- (iii) Wind—wind speed and direction distributions (based on weather-station information from Environment Canada).

3.1.1.2 Forest State. The forest is represented by the following layers:

- (i) Stand age in years;
- (ii) Spp1—leading tree species;
- (iii) Height and volume—derived from growth and yield tables;
- (iv) Percent pine;
- (v) Stand density (stems per hectare) estimated from plot data;
- (vi) Site index—expected height in metres at 50 years
- (vii) AU (Analysis units)—representing sites with similar stand growing conditions based on species, management history and site index (derived using the most recent timber supply review report). This is accompanied by a table with minimum harvest age and regeneration information.

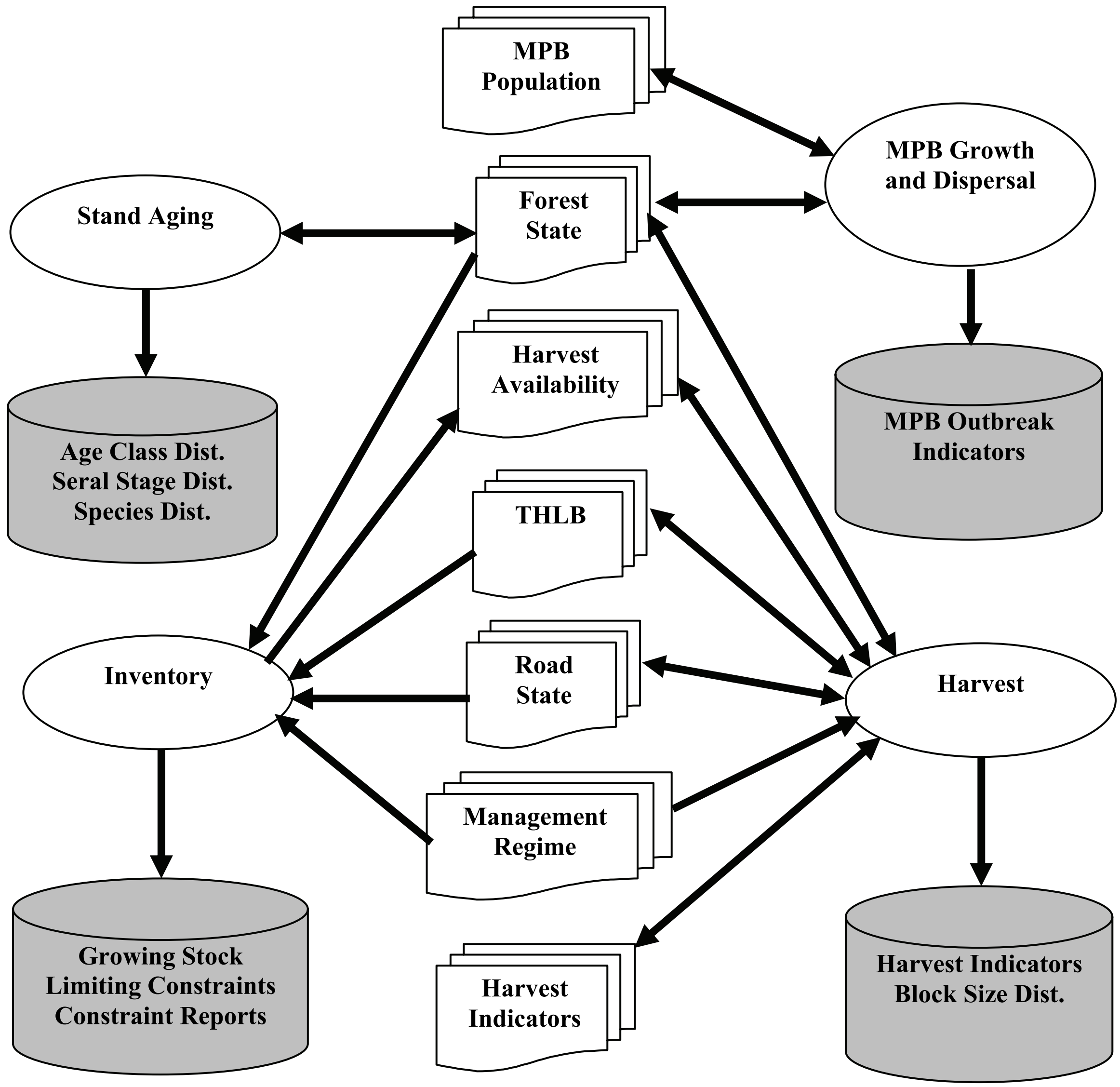

Figure 1. Linkages between primary components of state (shown in the centre), model processes (shown in ovals) and output files (shown as grey drums). MPB = mountain pine beetle; THLB = timber harvesting landbase

3.1.1.3 Management Zones. Some management zones are common to most analyses, whereas others are study-area specific. Zones used for Dawson Creek include:

(i) Management unit—to distinguish timber supply area (TSA), tree farm license (TFL), parks and private land;
(ii) VQO (visual quality objective) zones;
(iii) Caribou—caribou management zones;
(iv) Grizzly—grizzly management zones;
(v) BecBeo—overlay of biogeoclimatic zones and biodiversity emphasis options;
(vi) LU—Landscape units;
(vii) BMU—beetle management units (same as LU);

(viii) Productive forest. Each forested cell is classified as productive operable, productive inoperable or non-productive.

3.1.1.4 Timber-harvesting landbase (THLB) is derived from the productive operable forests via a net-down process that removes forest for various reasons described in the recent timber supply review (B.C. Ministry of Forests 2002). Most cases remove entire cells (e.g., non-merchantable forest), but some remove only portions of a cell (e.g., roads, riparian zones): hence, the THLB is represented as a percentage of each cell.

3.1.1.5 Harvest Availability.
(i) Potential treatment type. The available forest is stratified into the type of treatment that would be applied if a harvest block were initiated at that cell;
(ii) Salvageable volume—amount of salvageable volume based on volume killed in different years and shelf life. This is used to track standing dead volume that could be salvaged. There is no initial state for this information. The volume killed by mountain pine beetle is tracked as a list in each cell of the landscape, with each item storing the year of attack and volume killed that year;
(iii) BMU Type—beetle management unit rating (monitor, suppression, holding action, salvage).

3.1.1.6 Management Parameters. A range of parameters and tables to set up the harvesting regime, including:
(i) AAC—modeled annual allowable cut (separate for timber supply area and for tree farm licence);
(ii) Management constraints;
(iii) Management preferences—including beetle management strategies for different stand types and BMU ratings;
(iv) Yield tables—volume and height curves from growth and yield information [from the timber supply review (B.C. Ministry of Forests 2002)].

3.1.1.7 Roads.
(i) Distance to roads—distance to existing roads in metres;
(ii) Nearest road location—cell location of nearest road.

3.1.1.8 Mountain Pine Beetle (MPB) Population.
(i) MPB population (beetles/cell)—this includes an estimate of the initial beetles per cell derived from current infestation data (from survey data);
(ii) MPB climate zone—beetle climatic suitability zone;
(iii) External MPB relative pressure—relative pressure of mountain pine beetle immigration from the west (used as a probability surface for immigration);
(iv) Stand table—stand-scale dynamics for range of stand conditions produced by MPBSim;
(v) MPB susceptibility—computed according to the index developed by the Canadian Forest Service (Shore and Safranyik 1992);
(vi) MPB risk—computed by combining susceptibility with beetle locations (but using a different method than in Shore and Safranyik 1992).

3.1.1.9 Mountain Pine Beetle Impact.
(i) Percent pine killed—cumulative percent of live pine killed;
(ii) Trees killed—cumulative number of trees killed;

(iii) Shelf life information—estimated decay rates for various products (e.g., sawlogs, chips) in different BEC zones.

3.1.2 Stand Aging

This event increments stand age at each time step, and updates the age class and seral stage information. This event is also responsible for changes to analysis units upon stand regeneration. Species shifts were not modeled due to the relatively short time horizon.

3.1.3 Inventory

This event performs an inventory analysis at each time step. It tracks the amounts of forest above and below the thresholds specified for each constraint within the relevant zones, and determines which cells are available for harvest. For cells that are unavailable, outputs identify which constraint(s) were responsible. For constraints for which recruitment is appropriate (e.g., minimum old growth requirements), cells are recruited in order of age.

In addition to the above, this event also computes beetle management unit (BMU) ratings, based on harvest level, fell and burn budget, and outbreak state. In general, BMUs with no beetles are assigned to monitor status. If beetle attack levels are low enough to treat at least 80%, the BMU is assigned a suppression status. If only 50% can be treated, a BMU is assigned holding action status. Otherwise, a BMU is assigned salvage status. These ratings affect the allocation of fell and burn budgets and harvest focus within beetle management regimes (e.g., harvesting will target attack in suppression units before salvaging dead wood in salvage units). See Eng et al. (2005) for more details on how BMU ratings are assigned and applied in the provincial-scale model BCMPB.

3.1.4 Harvesting

This event performs forest harvesting in available cells. The basis of this model is the SELES spatial timber supply model (Fall 2002a), and is designed so that under conditions with no beetle outbreak, the model can be parameterized to match the results of the most recent timber supply review analysis (B.C. Ministry of Forests 2002). Harvest rate (m^3/yr) and growth and yield (volume per hectare curves for each analysis unit) were taken from the analysis document. In general, this sub-model simulates the allocation of cutblocks across the landscape. The annual allowable cut and mean volume per hectare determine the area logged and, in part, the number of cutblocks. The default cutblock size was 10 ha to 100 ha. Cutblocks had to fall on eligible land (determined by the timber-harvesting land base, stand age, access, forest cover rules, and salvage opportunity); location also reflected the economic and environmental differences (including distance to road and stand age) among eligible stands (Table 1).

Table 1. Steps used to choose cutblocks in the logging sub-model

Step	Description
1	Limit harvesting disturbance to eligible land: • timber-harvesting landbase; • eligible zones (age class structure allows harvesting; status updated each period); • areas within 2 km of an existing road; • **stands older than minimum harvest age or with sufficient salvage volume.**
2	**Process cells in potential block type order described below.**
3	Within each type, assign preference of new harvesting to each map cell based on • stand age; • potential block type (e.g., salvage opportunity for salvage cells, in order to increase probability of selecting a cell in proportion to salvageable volume); • **distance to road (linear decrease in preference between 500 m and 2 km).**
4	Select new cutblock location (first map cell to harvest) based on eligibility and probability: • pick the size of the cutblock from a block-size distribution; • build a spur road from the cell to the nearest existing road cell; • harvest the cell. Only clearcuts were modeled for all treatment types; • update tracking variables (e.g., annual volume harvested and seral distribution for applicable zones); • reduce the area of THLB timber-harvesting landbase in the cell to account for new access roads and for within-block development; • **Currently, the model assumes 98% effectiveness of killed beetles in a treated cell.**
5	Continue harvesting cutblock (spread to adjacent cells) based on eligibility until maximum cutblock size is reached or until no more eligible adjacent cells exist: • update distance to road information; • **harvest the cell (as above).**

Beetle management was incorporated in the logging sub-model as a range of potential strategies for placing treatment blocks. Salvage opportunity, beetle susceptibility, beetle risk, and detectable attack at different intensities may form part of the stand-selection preference, capturing block-level beetle management activities. The following general harvesting strategies were included in the model:

(i) Beetle blocks were applied in areas with significant detectable infested trees. A beetle block included adjacent high-risk, high-susceptibility and salvage areas.

(ii) Salvage blocks were applied in areas with significant detectable standing dead wood. A salvage block included adjacent high-risk, high-susceptibility and salvage areas.

(iii) Risk blocks were applied in areas with high risk of beetle attack. A risk block included adjacent high-risk, high-susceptibility and salvage areas.

(iv) Susceptibility blocks were applied in areas with high mountain pine beetle susceptibility. A susceptibility block included adjacent high-risk, high-susceptibility and salvage areas.

(v) Green-tree blocks were placed outside the above areas, and blocks were cut using clearcuts.

Generally, treatments in a year were placed according to the order given above. That is: first, all beetle blocks were treated; if there was AAC remaining, then salvage blocks were treated, and so on. Parameters could be varied to change this ordering. Success of treatments depends on area of application and tree characteristics, but the model assumed 98% effectiveness for block treatments, in terms of percentage of beetles removed.

To apply the above order, at the start of each year, every cell in the THLB was classified probabilistically (based on detection uncertainty and planning rules) into one of five potential cell-type categories based on the following:

(i) Beetle cells: sufficient level of detectable green (year of attack) or red (one year after attack) trees (> 5 detectable trees). The default probability was 1% per detectable tree (i.e., 100% chance for > 100 trees), but declined with distance from roads for distances greater than 1 km

(ii) Salvage cells: cells that had a sufficient level of salvageable timber (> 25m^3/ha)

(iii) Risk cells: cells that had a sufficiently high risk index (default: 1% chance per unit of risk, which ranges from 0 to 100%)

(iv) Susceptibility cells: cells that had a sufficiently high susceptibility index (default: 1% chance per unit of susceptibility, which ranges from 0 to 100%)

(v) Green-tree cells: all other cells.

Once a harvest block was initiated, the harvest model attempted to log adjacent cells until a chosen block size was reached or until the adjacent eligible area was exhausted (in which case a smaller block was created).

The logging sub-model explicitly connected cutblocks to the main road network by adding a link from the first cell harvested in the block to the nearest existing road. It then updated a map that stored the distance from each cell to the nearest existing road. This feature permits estimation of the amount of road constructed under a given management regime.

3.1.5 <u>Single-Tree Treatments</u>

This sub-model simulated fell and burn treatment methods. Based on treatment data for 2005, the base area treated annually was estimated to be 750 ha. Fell and burn treatments are generally applied in inaccessible areas or areas with low beetle population sizes (B.C. Ministry of Forests 1995). These treatments were applied to individual cells, and the volume was not recovered. The model assumed 95% effectiveness of beetles killed in a treated hectare.

3.1.6 Mountain Pine Beetle Population Model

The Bark Beetle Research Project at the Canadian Forest Service (CFS), Pacific Forestry Centre in Victoria has been developing models for predicting the spread and impact of mountain pine beetle infestations for a number of years (Riel et al. 2004; Safranyik et al. 1999). Recently, we have been collaborating to use the Spatially Explicit Landscape Event Simulator (SELES) landscape-modelling tool to extend stand-level CFS models to the landscape level (Riel et al. 2004; Fall et al. 2004). The CFS stand-level model MPBSim projects expected development of a beetle outbreak in stands of up to several hectares. Because a stand is not taken in the landscape context, there is no influence of incoming beetles from other stands. We developed methods to scale from this model to the landscape level. Conceptually, the landscape model runs the stand model in every cell of the landscape that has beetles. Because it is neither feasible nor desirable to do this through a direct link, the stand model is scaled by running it under a wide range of conditions to produce a table where each row is of the form:

Condition => Consequence

Conditions refer to stand attributes (e.g., age, percentage of pine), outbreak status (e.g., number of attacking beetles), etc. Consequences refer to the effect of one year of attack under those conditions (e.g., number of dispersers and number of trees killed). The approach to scaling MPBSim to the landscape scale was refined last year to include beetle climatic suitability as a stand-level factor that can then be applied spatially at the landscape scale.

The landscape-level model applies this table in each cell of the landscape containing beetles. This approach provides the spatial context for an outbreak with dispersing beetles emigrating from source cells, and has the effect of increasing the beetle population in cells within a current outbreak, or of starting an outbreak in a currently uninfested cell. The latter may result in expanding a current beetle spot, or starting a new spot.

In the landscape model, the flight period, which includes beetle dispersal and pheromone production and diffusion, is modeled as a spatial process. During attack, beetles kill pine trees, producing red trees (recently killed) and standing dead volume that may be salvaged by the logging sub-model. This model also tracks the loss of salvageable wood resulting from attack. Economic standing dead wood is a subset of ecological standing dead wood, as the latter contains non-merchantable snags. Hence, salvageable wood “decays” at quite a fast rate (20% starting 3 years after attack), depending on tree species.

3.2 Model Outputs

The primary model outputs relevant to this analysis are described below. In this analysis, we focus on mountain pine beetle outbreak, harvest report and growing stock indicators.

3.2.1 Forest State Indicators

3.2.1.1 Age-Class Distribution: Annual output of the number of hectares of productive forest in 10-year age classes (up to 400 years), stratified by the amount within the THLB and outside the THLB.

3.2.1.2 Seral Stage Distribution: Annual output of the number of hectares in various seral stages (young, mature, old) according to the biodiversity guidebook (B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1999), stratified by BEC zone.

3.2.2 Mountain Pine Beetle Outbreak Indicators

3.2.2.1 Summary: Population size, volume killed (overall and within the THLB), number of trees killed, area attacked (annually and cumulative) and a range of verification indicators (e.g., number of long distance spots).

3.2.2.2 Stratified by BMU (LU in Dawson Creek): Volume killed (overall and within the THLB) and area attacked (annually and cumulative).

3.2.3 Inventory Indicators

3.2.3.1 Growing Stock comprises the cubic metres of live forest in various stratifications of the landbase (e.g., total within THLB, mature stock), and is a primary indicator of sustainability;

3.2.3.2 Limiting Constraints track the area of forest unavailable for harvest according to the various constraints. This is output as net and gross values, where the net value is the incremental area constrained after preceding constraints have been accounted for, and the gross value is the total amount that would be constrained independent of the other constraints. The primary order of constraints applied is minimum harvest age, road access (if enabled), adjacency, forest cover constraints (applied in order specified in input file).

3.2.4 Harvest Indicators

3.2.4.1 Harvest Report: A range of output values that track key aspects of the harvesting process, including volume and area harvested, mean age harvested, mean volume per hectare harvested, volume salvaged, and amount of spur road created during harvest. All are means across the period.

3.2.5 Spatial output

The DCLM is a spatial model, and any of the spatial dynamic layers may be output during a model run. However, because multiple replicates of each scenario are run, it would be difficult to process such information post-simulation. Additionally, we needed to consider how to deal with the temporal aspect. The aspatial indicators described above summarize information across space, providing time-series information (which we then average over replicates or sum up across time as well). We designed the model to track several cumulative spatial indicators that summarize information across time and replicate:

(i) *TimesAttacked* is the number of runs in which each 1-ha cell was attacked at least once by beetles. If a cell was attacked in every simulation, it received a value of 10; if a cell was attacked in only one simulation, it received a value of 1, and so forth. These values can be thought of as roughly the probability that a cell will be attacked by beetles at some point in the 10-year horizon.

(ii) *THLBVolumeKilled* is the total volume killed within the THLB over the time horizon of the run. This layer provides information on the areas of the landscape that are *likely to have the highest impacts in terms of volume killed (timber impacts).*

(iii) *PercentPineKilled* is the percentage of pine killed summed over the time horizon of the run. This layer provides information on the areas of the landscape that are likely to have higher ecological impacts.

3.3 Scenarios Evaluated

A wide range of scenarios were run to verify the model prior to making the main scenarios described below. These verification scenarios led to model improvements and refinements, as well as to greater understanding of model interactions and feedback. We do not describe the results of the verification runs here, but focus instead on scenarios that produced information relevant for more operational and strategic beetle management at the district and provincial levels. There are a number of stochastic factors in the DCLM affecting primarily dispersal due to wind and cells selected by beetles. We ran all scenarios for 10 replicates in order to be able to report means and standard errors.

A number of factors were varied to assess uncertainties in beetle conditions and to highlight the potential impacts of management on beetle dynamics. Two starting conditions for mountain pine beetle attack were available, based on 2004 and 2005 survey information. Most runs were assessed using 2004 starting conditions, so that the 2005 data could be used for validation testing.

Uncertainty regarding the level of external mountain pine beetle pressure and beetle climatic suitability exists. For the former, external pressure was assumed to be either no pressure, pressure based on 2004 attack levels, or dynamic pressure derived using the provincial-scale mountain pine beetle model BCMPB (Eng et al. 2005), which is calibrated to empirical overview data (Figure 2). External pressure influences both the location and magnitude of beetle immigration. Location of immigration was assessed by generating a likelihood surface (probability surface) based on relative change in severe outbreak patches to the west (both amount and location). It is produced using a diffusion model constrained by distance and elevation (details of which are beyond the scope of this report). A wide range of options were tested, and the best match for current outbreak data was used. Magnitude of beetle immigration was estimated by relative changes between a given year and the 2004 likelihood surfaces (Figure 3). Future severity was estimated using a time series from BCMPB projected under the base scenario.

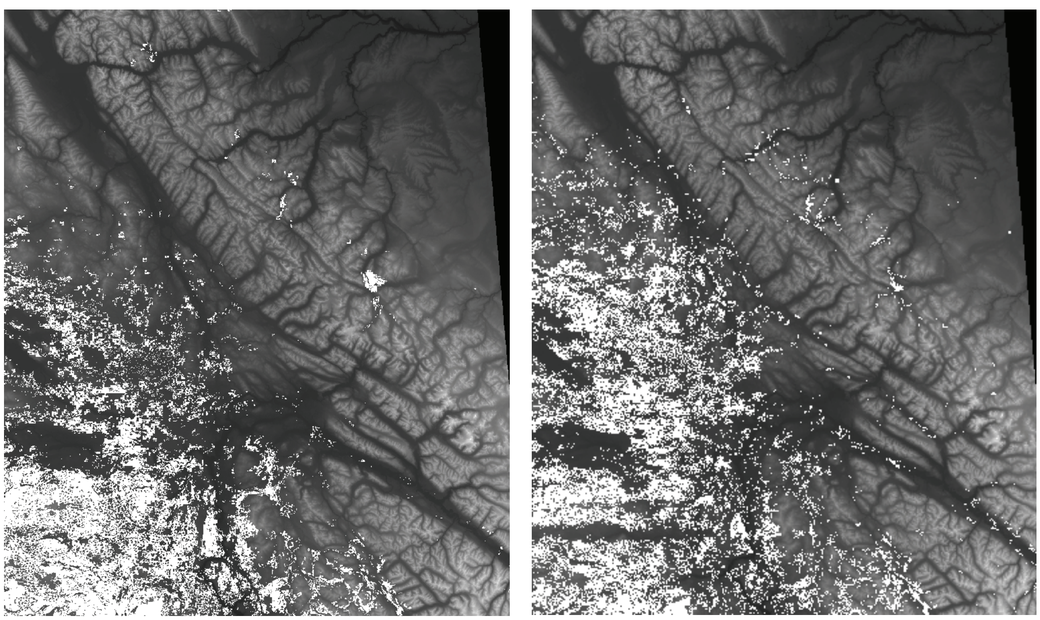

Figure 2. Severe outbreak areas (white) shown on an elevation map for the area southwest of the study area for 2004 (left) and 2005 (right) provincial overview surveys.

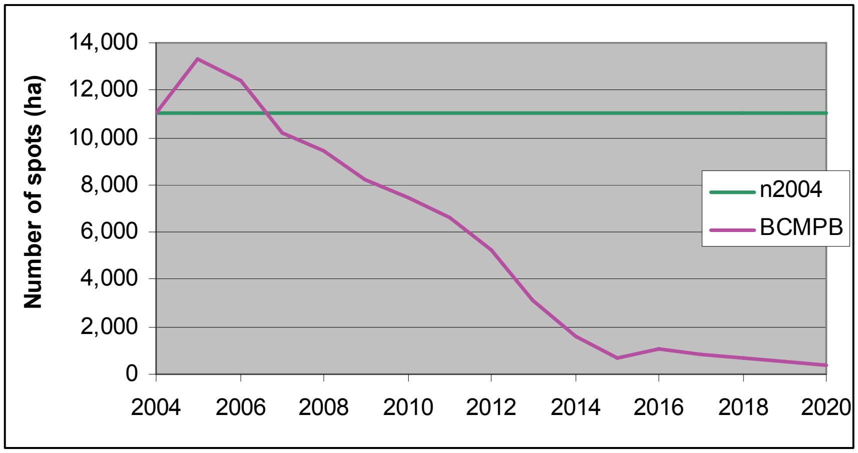

Figure 3. Number of immigration spots applied annually using 2004 survey data and estimated dynamically using BCMPB projections.

Climatic suitability was based on either recent historical averages (1970 to 2000) or estimated near-future climate (2000 to 2030) to capture projected climate change (Figure 4).

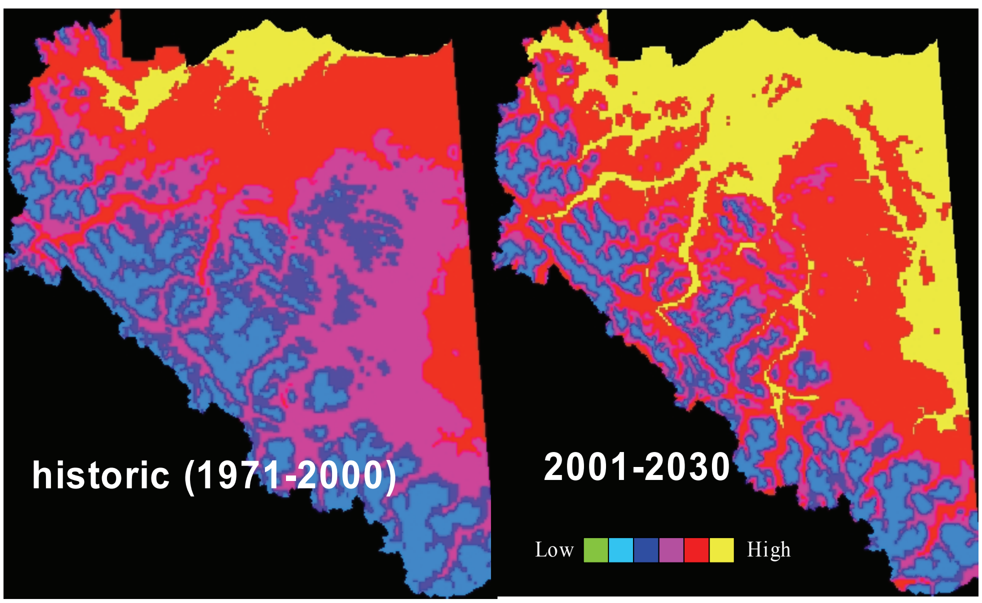

Figure 4. Climatic suitability surfaces for historic period and future projection.

Management regime options included general beetle management (i.e., similar to elsewhere in the province), current practices as described at meetings in Dawson Creek, salvage only—with a focus on recovering dead wood, and no beetle management (no harvesting or single-tree treatments). The general beetle management (BM) and current practices (CP) scenarios differ primarily in how beetle management units (BMUs) are rated, and in fell and burn targets. The BM scenario assesses BMU ratings dynamically at the start of each year, whereas the CP scenario uses a static treatment-priority map that is provided; the BM scenario applies a fixed fell and burn budget (specified as an area to treat per year), whereas the CP strategy applies a variable budget based on the target treatment levels in the priority map; the BM scenario limits stands for fell and burn treatment to those with a maximum of 1% pine attacked in the current year, whereas the CP scenario applies no limit. To support comparison of these scenarios, two intermediate management regimes were assessed. The CP rule set 1 (r1CP) is identical to the BM scenario, except that the static BMU ratings were used. The CP rule set 2 (r2CP) additionally applies a variable fell and burn budget (and hence differs from the CP scenario only in the 1% cap on percent pine attacked). To match with current practices, the default fell and burn budget for r1CP is 2250 ha (in line with 2006 targets), whereas the default for the BM scenario is 750 ha (based on 2005 levels).

Harvest level was based on the current AAC for the tree farm license and timber supply area (each processed independently). Fell and burn treatment levels were based on levels applied in 2005, current targets, or other levels to assess the role of fell and burn in managing the outbreak. This was either applied as a fixed area to treat each year, or as a variable target consistent with current practices.

3.3.1 No Management Baseline Scenarios

A set of baseline scenarios that have no harvesting or fell and burn treatments were applied to provide a baseline for the potential of the beetle outbreak to expand within the study area. We consider the scenario NoMgmtcc_extBCMPB, which includes both climate change and dynamic immigration pressure, to be the most plausible trajectory.

Scenario Name	Management Type	Beetle Climatic Suitability	External Immigration Pressure
NoMgmt	None	Historic	None
NoMgmtcc	None	Future (climate change)	None
NoMgmt_extBCMPB	None	Historic	Dynamic based on BCMPB
NoMgmtcc_extBCMPB	None	Future (climate change)	Dynamic based on BCMPB

3.3.2 Base Management Scenarios

The base scenarios are designed to address the primary questions of this analysis regarding the expected impact of beetle management. Although we assessed all of these in the absence of climate change and external pressure, here we analyze only the results with both climate change and external pressure (to compare with the most likely baseline scenario NoMgmtcc_epBCMPB). Hence all the scenarios in the following table have both the “cc” (climate change) and “epBCMPB” (external pressure, BCMPB model) suffixes.

The Salvage Only scenario focuses on harvest based on volume of standing dead timber rather than current attack (with a goal of reducing non-recovered losses, generally applied when beetle control is deemed ineffective).

The BM scenario is for general beetle management. Beetle management unit ratings are computed dynamically based on attack level and budgets (AAC and fell and burn). Ratings include any one of monitor, suppression, holding action, or salvage. The fell and burn budget is assumed to be constant (based on 2005 treatment information, this was set at 750 ha/year). As targets in the study area for 2006 are closer to 2,250 ha, we included one of the scenarios from the sensitivity analysis in the base scenarios, BMcc_FB3, to be more comparable with the r1CPcc scenario. Beetle Management scenarios additionally impose a limit on stands treatable by fell and burn to a maximum of 1% of the pine killed in a given year.

Current practices in the study area include use of a BMU rating map that aims to reduce the population as well as minimize risk of eastward spread (a good neighbour policy). The BMU rating map specifies target-treatment levels. The CP scenario aims to capture current practices by using the BMU rating map as a fixed input. Fell and burn levels are variable to meet the targets, and there was no limit on stands treatable by fell and burn (as applied in the BM scenario).

Two variations of current practices were assessed to help compare BM and CP scenarios. Current practices rule 1 (r1CP) uses the fixed BMU rating map, but is otherwise identical to the BM scenario. It applies 2250 ha/year for fell and burn to match current targets for 2006. As in the BM scenario, it limits stands treatable by fell and burn. Current practices rule 2 (r2CP) is identical to the CP scenario except it applies the limit on stands treatable by fell and burn. Hence, is it identical to r1CP, except in that the fell and burn target is variable rather than fixed.

Scenario Name	Management Type	Fell and Burn
SalvageOnlycc_extBCMPB	Salvage	None
BMcc_extBCMPB	Beetle Management	Constant: 750 ha/year
BMcc_FB3_extBCMPB	Beetle Management	Constant: 2250 ha/year
r1CPcc_extBCMPB	Current Practices (rule 1)	Constant: 2250 ha/year
r2CPcc_extBCMPB	Current Practices (rule 2)	Variable (based on BMU targets)
CPcc_extBCMPB	Current Practices	Variable (based on BMU targets)

3.3.3 External Immigration Pressure Sensitivity

In the base scenarios, external pressure was estimated using the provincial-scale projection model BCMPB (Eng et al. 2005). This provides a reasonably realistic estimate of dynamic changes in immigration pressure, but nonetheless introduces reliance on results of another model; i.e., the dynamic external pressure inherits uncertainty embedded in BCMPB. Applying empirical immigration levels observed from 2004 (from beetles flying in 2002/03) is more grounded on observation, but provides a static perspective that is clearly unrealistic (i.e., as the outbreak waxes and wanes to the west, so presumably will the levels of immigrating long-distance dispersers). To address these uncertainties, we compare results of applying immigration based on 2004 survey data with the dynamic levels estimated using BCMPB. As in the previous section, all scenarios apply climate change.

Scenario Name	Management Type	External Immigration Pressure
NoMgmtcc_ep2004	None	Static based on 2004 survey data
BMcc_ep2004	Beetle Management	”
r1CPcc_ep2004	Current Practices (rule 1)	“
r1CPcc_ep2004	Current Practices (rule 2)	“
CPcc_ep2004	Current Practices	“

3.3.4 Fell and Burn-Level Sensitivity

Under current practices, fell and burn levels are variable, based on BMU treatment targets. However, sources of funding and increases in the outbreak raise some uncertainty as to the capacity to carry out this program over time. To address some of the uncertainties surrounding fell and burn levels, we varied amount of fell and burn using the BM and NoMgmt scenarios as a basis. Because 2005 levels were used as the basis for the BM scenario, the base level was about 750 ha/year. We applied a level triple this (2250 ha/year), as that is closer to 2006 targets. Scenarios all apply climate change and dynamic immigration pressure.

Scenario Name	Management Type	Fell and Burn Level
NoMgmtcc_epBMPB	None	None
NoMgmtcc_FB1_ epBMPB	None	750 ha/year
NoMgmtcc_FB2_ epBMPB	None	1,500 ha/year
NoMgmtcc_FB3_ epBMPB	None	2,250 ha/year
NoMgmtcc_FB10_ epBMPB	None	15,000 ha/year
BMcc_FB0_ epBMPB	Beetle Management	None
BMcc_ epBMPB	Beetle Management	750 ha/year
BMcc_FB2_ epBMPB	Beetle Management	1,500 ha/year
BMcc_FB3_ epBMPB	Beetle Management	2,250 ha/year
BMcc_FB10_ epBMPB	Beetle Management	15,000 ha/year

3.3.5 Harvest-Level Sensitivity
These scenarios were designed to assess the effects of different levels of AAC. The percentages are relative to the base run, which applied the AAC level from the last determination. These were compared with the corresponding BM scenarios (with the same level of fell and burn) under climate change and dynamic external immigration.

Scenario Name	Management Type	AAC Level	Fell and Burn Level
BM150cc_FB0_ epBMPB	Beetle Management	150% (50% increase)	None
BM150cc_ epBMPB	"	"	750 ha/year
BM150cc_FB2_ epBMPB	"	"	1,500 ha/year
BM150cc_FB3_ epBMPB	"	"	2,250 ha/year
BM150cc_FB10_ epBMPB	"	"	15,000 ha/year

3.3.6 Validation testing using 2005 starting conditions
Comparing results of scenarios that start with 2004 or 2005 survey mountain pine beetle conditions provides an opportunity to assess both the model's ability to project subsequent years and whether the outbreak is fundamentally changing in nature from expectations. We compared results from the base runs to those with 2005 starting conditions.

4 Results and Discussion

All results reported graphically are the mean and standard error of 10 replicate simulations of each scenario.

4.1 Main scenario results

4.1.1 No Management Baseline Scenarios
The baseline runs of the no management scenario highlight the significant role of both climate change and external pressure (Figure 5). The beetle outbreak, fuelled in part by climate change increasing stand suitability in the study area and by the main outbreak to the west, has a potential of killing a significant amount of pine over the next decade (about 17 million m^3 in the NoMgmtcc_epBCMPB scenario, or about 15% of the total pine). Relative to other areas of the province, however, this is a fairly low attack level, due mostly to the relatively low climatic suitability of the study area and the relatively high mix of other species on the landscape. This should be kept in mind when interpreting results with management interventions.

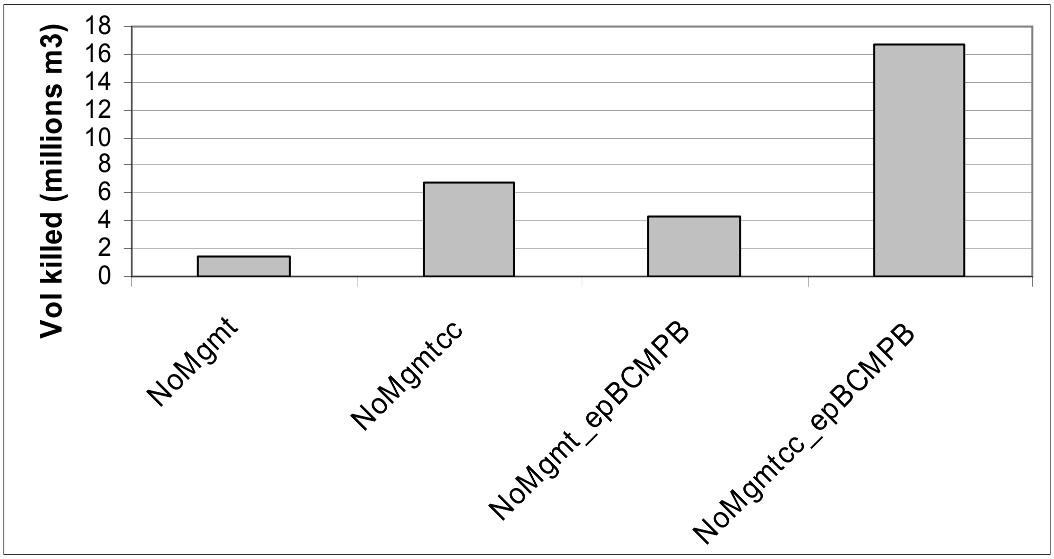

Figure 5. Cumulative volume killed (average of 10 runs over productive forest) for the no management scenario baseline runs.

4.1.2 Base Management Scenarios

Beetle management scenarios all reduce the volume killed significantly compared to the no management scenario (Figure 6). However, scenarios that focus on salvage allow beetles to kill about as much volume as the no management baseline scenario, because this landscape is early in the attack cycle (and hence a salvage-only strategy is not warranted). To compare the BM and CP strategies, it is best to first consider the BM scenario with triple the 2005 fell and burn levels (BMcc_FB3_epBCMPB) and the CP scenario with a fixed fell and burn budget (r1CPcc_epBCMPB), because they both apply 2,250 ha per year. With equal fell and burn budgets, the BM strategy performs better than the CP strategy. This is to be expected, because the BM scenario focuses on population reduction within the study area, whereas the CP strategy adds the additional objective of minimizing spread eastward by fixing BMU ratings. Nonetheless, the CP strategy does not seem to hinder management much. The scenarios with variable fell and burn (r2CP and CP) perform better, because they increase fell and burn budgets to match the beetle outbreak over time.

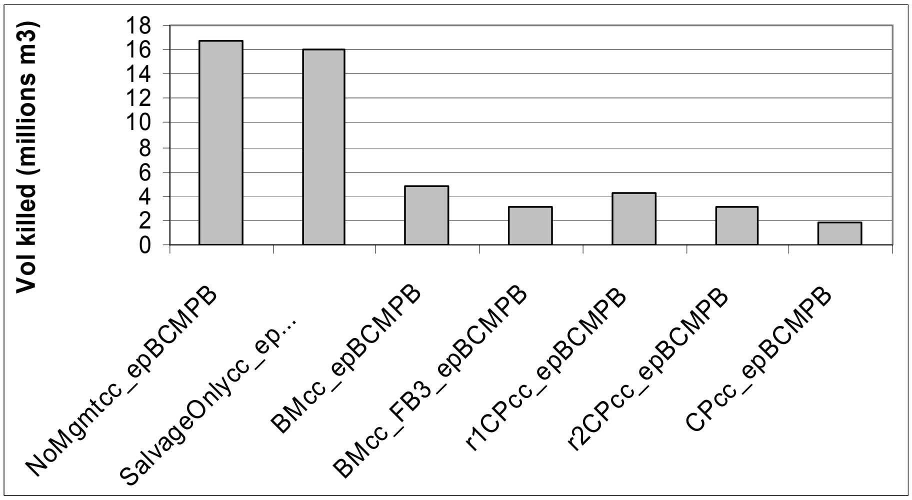

Figure 6. Cumulative volume killed for the base BM scenarios and no harvesting.

Although the CP strategy with varying fell and burn budgets (CPcc_epBCMPB) performs better than the BM strategy (or r1CP), one should consider carefully how the fell and burn budget changes over time (Figure 7). The number of trees treated in scenarios with a fixed fell and burn budget (BM, BM_FB3, r1CP) increases gradually over time, indicating an increase in intensity (i.e., an increase in number of trees per hectare treated, as the budget is a fixed number of hectares per year to treat). The scenarios with variable treatment levels (CP and r2CP) increase more dramatically over time, tracking both the increase in intensity and the increase in total area attacked as the outbreak proceeds. The very high treatment levels for these two scenarios later in the simulations raises the question as to whether such treatment levels are feasible (even if the starting levels are closer to 2006 current targets). If fell and burn budgets are a significant limitation for future management, it may be more conservative to consider the results of the r1CP scenario as perhaps reflecting the most likely outbreak trajectory.

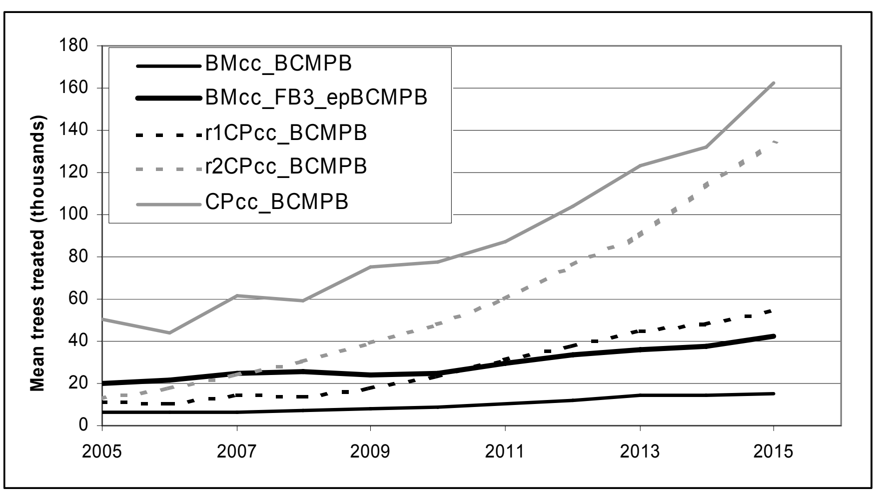

Figure 7. Number of trees treated by fell and burn by base beetle management scenarios.

Most results are reported as projected cumulative volumes killed over the next decade. It is illustrative to present a time series of annual volumes killed (Figure 8). The projected outbreak follows an exponential growth curve, and management has the general impact of dampening the growth rate; i.e., beetle management may slow a population down, but not necessarily extinguish it. However, slowing the outbreak down gives more time for the main outbreak to the west to subside and for poor winter and/or flight weather to occur within the study area and cause the outbreak to collapse.

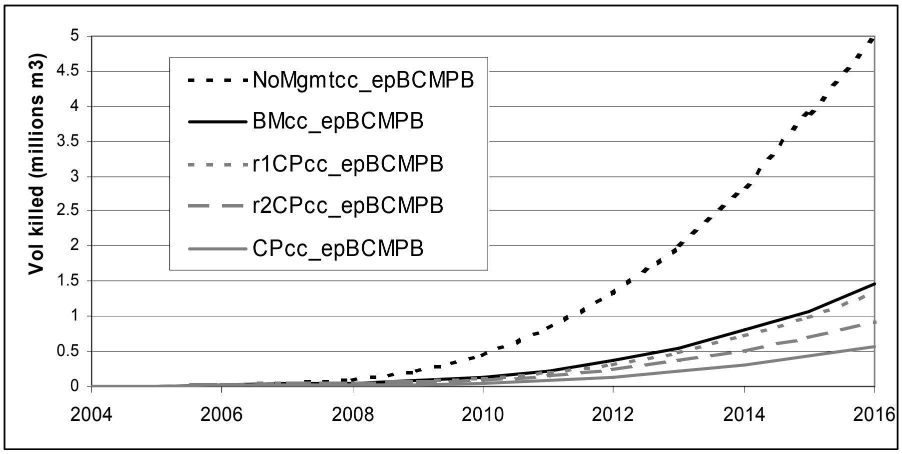

Figure 8. Annual volume killed for the base beetle management scenarios and no harvesting.

4.1.3 External Immigration Pressure Sensitivity

The difference between using static immigration pressure based on 2004 survey data and dynamic pressure derived using the provincial-scale model, BCMPB, is minor (Figure 9). This indicates a low sensitivity to this aspect of the modeled scenarios. That is not to say that immigration is not a critical process (as was shown when comparing the no management scenarios), but rather that the difference between the static and dynamic approach doesn't result in dramatic differences in outcomes. The dynamic pressure increases slightly over the first few years, then declines over the remainder of the run. On reflection, this result suggests that the critical time for immigration in this landscape is within the first several years, when the internal outbreak is fairly low and the outbreak to the west is still high.

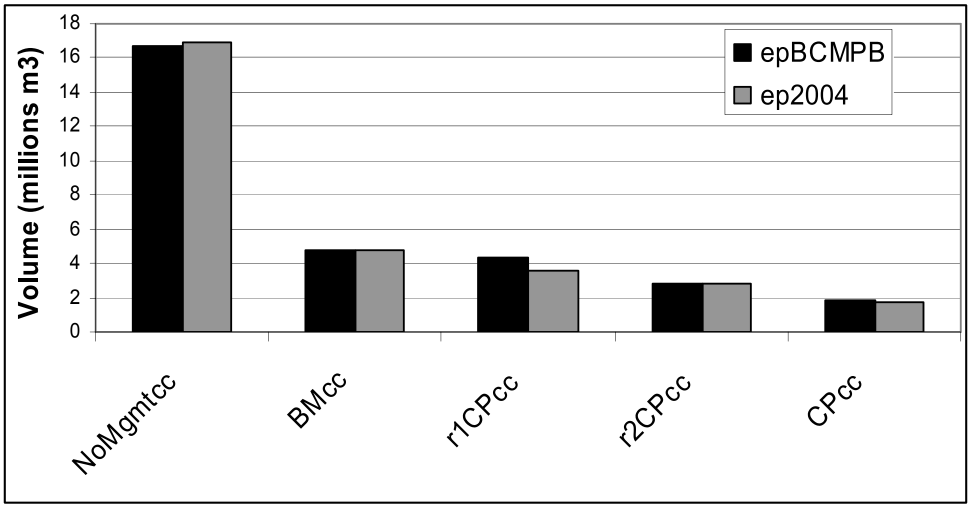

Figure 9. Cumulative volume killed for the base scenarios with static and dynamic immigration.

4.1.4 Fell and Burn-Level Sensitivity

Fell and burn appears to have a potentially significant impact on outbreak dynamics, and is a key element of beetle management (Figure 10). In combination with general beetle management (BM strategy), increasing fell and burn from 0 to 7,500 ha/year reduces volume killed by an order of magnitude. The reduction in volume killed seems to be fairly linear with increasing treatment. Note that, at 7,500 ha/year, fell and burn treatment levels start to approach the area harvested annually in the timber supply area and tree farm license combined. The reason fell and burn is so influential is likely due to the large non-contributing landbase, the large area currently inaccessible by roads and the relatively low and scattered outbreak pattern. Of particular note is the continuing driving force of external immigration, leading to scattered new spots of low intensity infestation. Treating these with fell and burn seems to be appropriate in this landscape. Note that prior analyses of the impact of fell and burn in some other landscapes, which had larger internal populations and higher susceptibility, generally showed fell and burn to be of limited use once an outbreak is fairly large and self-sustaining.

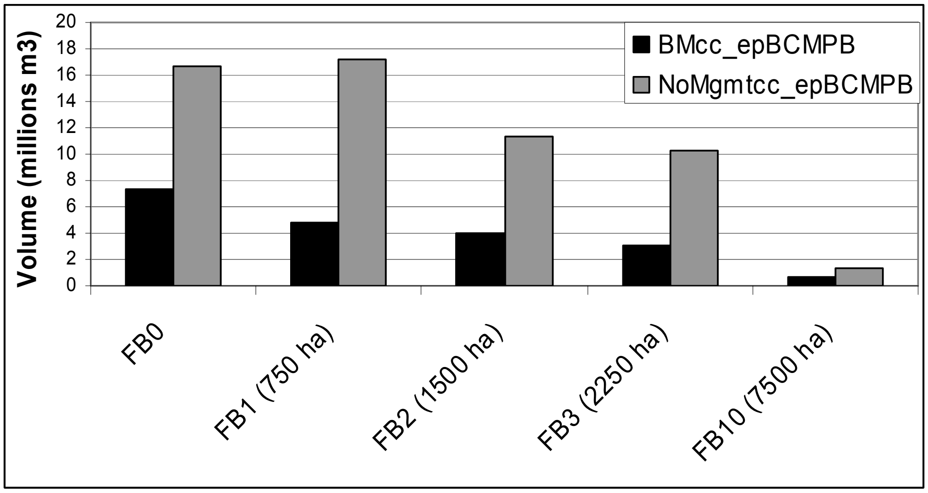

Figure 10. Comparison of cumulative volume killed for beetle management and no management scenarios at varying levels of fell and burn treatment.

4.1.5 Harvest-Level Sensitivity

Increasing harvest levels by 50% has a modest effect that is less than the effect of increasing fell and burn treatment levels (Figure 11). One reason why increased harvest power may not have a large impact is that the outbreak is being partly driven by external immigration. This leads to scattered, low-intensity spots, as can be seen in the current survey data. This fine-grained pattern is difficult to deal with by applying the relatively coarser-scaled pattern of harvest, and seems more appropriately dealt with by applying the fine-scale pattern of fell and burn.

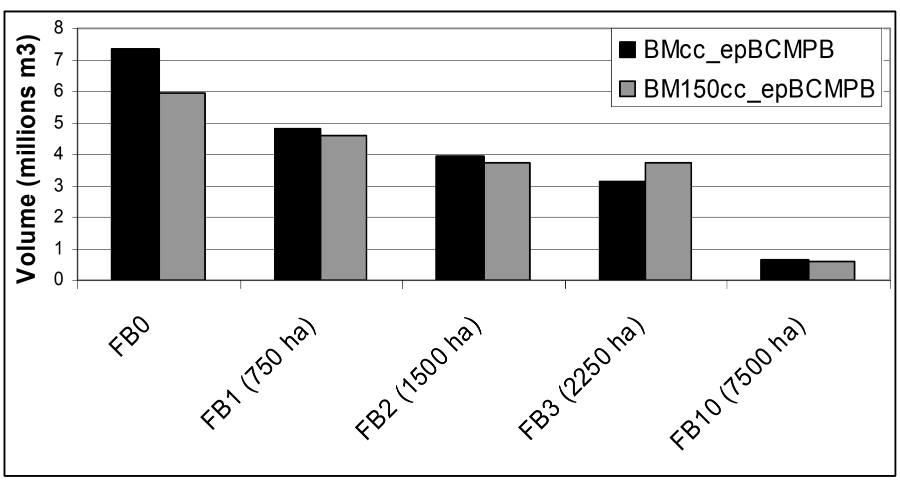

Figure 11. Comparison of cumulative volume killed for beetle management at varying levels of harvest (current and 50% increase) and varying levels of fell and burn treatments.

Note that the differences between pairs in the graph are likely due more to stochastic variation between simulations (e.g., the fact that the scenario with no AAC increase has less volume killed than the scenario with a 50% increase for FB3 should not be misinterpreted).

4.1.6 Validation testing using 2005 starting conditions

Using the 2005 survey data for starting conditions results, in general, in higher cumulative volumes killed. This is to be expected, as the outbreak is one year further advanced, and the simulations were still run for 10 years (Figure 12). Nonetheless, the comparison shows that the general results presented hold whether 2004 or 2005 is used as a start year.

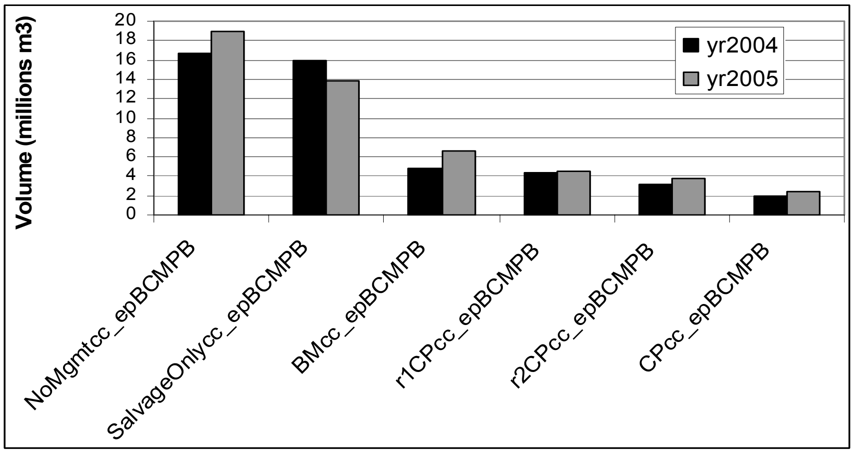

Figure 12. Comparison of cumulative volume killed for base scenarios using 2004 (default) and 2005 starting mountain pine beetle conditions.

To use the 2005 starting conditions for validation, we compare the volume projected to be killed in 2005 by the same scenarios starting with 2004 and 2005 conditions (i.e., the second and first year of projection, respectively). Across the base scenarios, the results from two starting conditions are very close (Figure 13); averaged across these scenarios, the difference is less than 4%.

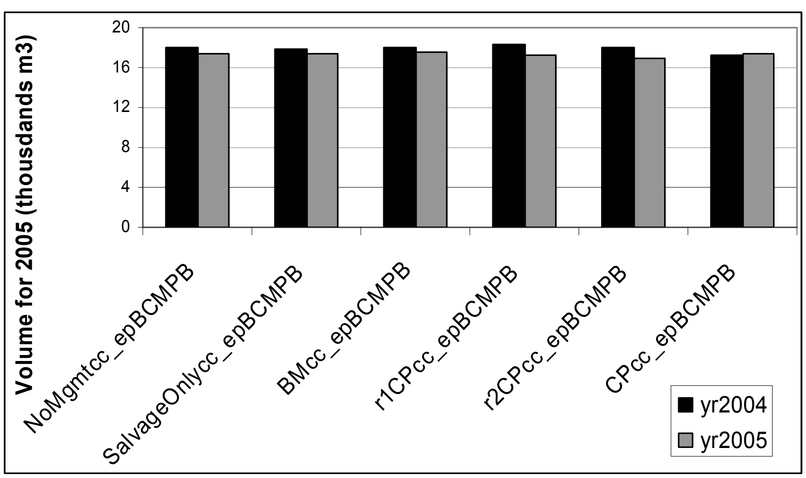

Figure 13. Comparison of annual volume killed projected for 2005 by base scenarios using 2004 (default) and 2005 starting mountain pine beetle conditions.

5 Conclusion

Our analysis of the current beetle outbreak in Dawson Creek suggests that this outbreak is at an incipient scale, driven primarily by external pressure to the west and by changing climatic suitability, and that management efforts can have a significant impact in reducing losses. These results are consistent with conclusions from previous analyses in the Kamloops, Morice, Williams Lake and Lakes regions (Fall et al. 2001; 2002; 2003a; 2003b); i.e., applying fine-scale beetle management and accurate treatment of spot locations is important in areas with small- to medium-scale outbreaks, but has less of an effect in situations with large outbreaks. In this study area, applying treatments in active spots and including small-scale blocks and single-tree treatments are important. This can be achieved either by strong beetle surveying/probing to map infestation locations accurately, and strong fell and burn programs, as managers in the area are currently undertaking. To maintain the outbreak at a low level and to minimize eastward spread will require vigilance, especially while the pandemic to the west continues. It will also require management commitment to ensure that survey and fell and burn treatment budgets are available to match changes in the outbreak level over time.

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