Mountain Pine Beetle Audit Project
Kamloops Forest District Landscape Model

Final Report

Andrew Fall, Gowlland Technologies Ltd.
Marvin Eng, Research Branch, B.C. Min. of Forests
Terry Shore, Les Safranyik and Bill Riel, Pacific Forestry Centre, Canadian Forest Service
Don Sachs, Forest Research Consultant
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Executive Summary

The Kamloops Landscape Model (KLM) was developed to assess the effectiveness of current levels of beetle management activities in Kamloops forest district in terms of affecting growth of beetle populations and timber impacts of the current outbreak. In general, the approach showed that beetle management in the Kamloops district is likely have a significant impact on the growth of the MPB outbreak, even under various assumptions regarding the rate of beetle growth. If beetle management activities are lessened, the model indicates that beetles may increase their hold, but if beetle management is increased, the benefits are marginal. These results only apply to the specific conditions (forest and beetle infestations) and management regime of this district. In particular, this district has somewhat fragmented beetle "habitat", with many mixed stands and susceptible areas separated by non-forest (e.g. grasslands, Thompson river) and higher elevation plateaus that are not as susceptible to outbreak conditions. Also, the district has been vigilant in their approach to beetle management, with a lot of effort being expended to address beetle concerns. The results of this modeling approach indicate that these efforts have likely been effective. This modeling approach also has potential to be applied as a strategic planning tool in any district in the province with a history (past or present) of beetle outbreaks.

This document describes the objectives, methods and results of the KLM. It also gives information required to apply this approach in other districts and a list of tasks to refine the current methodology. Detailed information on the model design and specification can be found in the companion model design document.

Project Objectives

The mountain pine beetle is the most destructive insect pest affecting the forest resource in British Columbia. Each year millions of mature pine trees are killed during epidemics of this insect. The magnitude of these losses creates havoc in the forest industry by disrupting the planning process. It forces the redirection of the allowable cut towards reducing the beetle population and salvaging beetle-killed timber.

In the past few years the Ministry of Forests has been given a significant amount of money to deal with the mountain pine beetle situation. This money has been allocated to the regions and districts to augment their management activities directed at the beetle. The purpose of this study is to develop a methodology for evaluating the effectiveness of the ministry's bark beetle management activities in reducing losses to the mountain pine beetle.

Specifically, the goal of this project is to address three questions:

(i) What would the likely range of impacts of the current beetle outbreak (starting in 1998) be if no beetle management was taken?

(ii) What is the likely range of impacts of the current beetle outbreak if the current level of beetle management continues?

(iii) What would the likely range of impacts of the current beetle outbreak be under a range of alternative beetle management regimes?

Our goal was to start with the conditions in 1998, and project likely outcomes under the various scenarios over a period of 10 years.

Another objective of this project was to develop a general methodology to assist strategic level planning of mountain pine beetle management activities over large land bases.

Methods

The KLM is an initial step in the development of a process for evaluating the effectiveness of the ministry's bark beetle management program, and as such can be viewed as a test case. The general idea is to input the TSAs geographic, forest inventory and beetle maps and data into our system and project forward (for 10 years) using the landscape model to evaluate the course of the infestation in terms of area and volumes killed by the beetle. The beetle outbreak process would proceed with interactions with management activities (e.g. no logging, no beetle management, approximation of the beetle management activities that are being conducted or could be considered). Through comparison of the no management versus management scenarios we could identify potential benefits of the beetle management program in terms of area and volumes killed. This information could be used to assess impacts directly, or could serve as input for further analysis of economic, social and/or ecological cost/benefits of the program for this particular TSA (e.g., by an economist or ecologist), although such analysis is not a direct part of this approach. This process can be refined and expanded in the future to give a broader base to the evaluation. See the model design documentation for details of the landscape model.

<u>Landscape scale MPB model</u>

The Bark Beetle Research Project at the Canadian Forest Service research centre in Victoria has been developing models for predicting the spread and impact of mountain pine beetle infestations for a number of years. In the past year CFS bark beetle researchers have been collaborating with Dr. Andrew Fall to utilize his Spatially Explicit Landscape Event Simulator (SELES) landscape modelling tool to extend our stand level models to the landscape level.

The CFS stand level model projects expected development of a beetle outbreak in a stand of up to several hectares. Since the 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. Conceptually, the landscape model runs the stand model in every cell of the landscape that has beetles. Since it is not feasible or desirable to do this through a direct link, we scale the stand model by running it under a wide range of conditions and producing 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 landscape level model then 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 starting an outbreak in an currently uninfested cell. The latter may result in expanding a current beetle spot, or starting a new spot.

<u>Harvesting Strategies</u>

The following general harvesting strategies were included in the model. Their relative import was based on the beetle management activities carried out in the district. See the model design document for more details.

Clearcutting

(i) Status quo: based on current policy, the current timber supply review and the 1998 forest development plan.

(ii) Targeted clearcuts: target infested and/or high susceptibility stands. Depends on detection of infestations (survey quality).

(iii) Salvage: recover standing dead wood and incidental green wood with a goal of minimizing lost volume.

Single tree treatments: treat single trees with identified beetle attacks. This is generally applied in inaccessible areas or areas with low beetle population sizes.

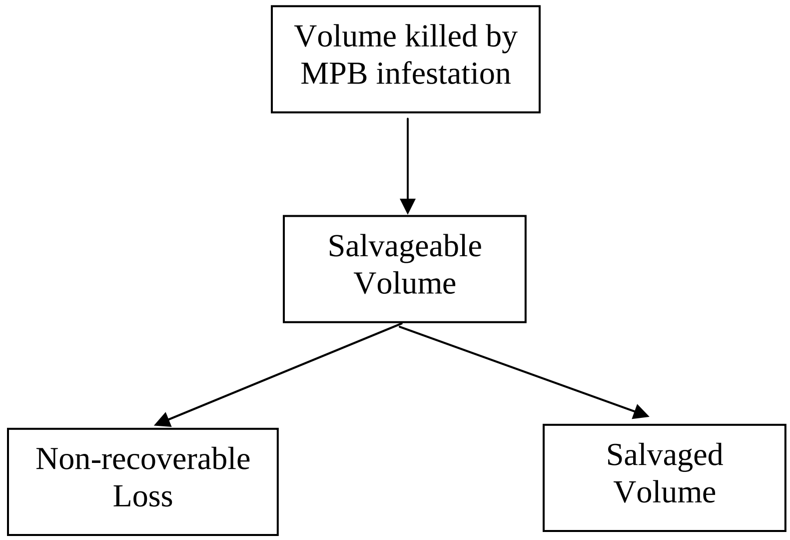
(i) Fell and burn: cut infested trees and burn on site.

(ii) MSMA: apply to infested trees. Timing is critical (must be within 3 weeks of attack). Required survey information must be more detailed.

Success of both of these depends on area of application and tree characteristics, but model also assumes 100% effectiveness.

<u>Non-recoverable loss due to MPB</u>

One goal of beetle management is to minimize the loss of wood volume (NRL) in the short and long term. This can be visualized using the following diagram:



Reducing the volume of non-recoverable loss can be achieved by either reducing the volume killed by beetles (input to salvageable volume) or increasing the volume salvaged (the second “drain” of salvageable volume). The way these processes interact over time is critical, since the variability as well as the volume of flow of MPB killed volume is important (since a large influx can quickly overwhelm capacity to salvage wood in time). Thus, a good management strategy will not only reduce MPB killed volume, but will also reduce the inter-annual variation.

The processes shown in the diagram are essentially tracked individually in each cell in the landscape. Thus, the spatial variation as well as temporal variation influences the efficacy of a particular management scenario for a given MPB population and host pattern. Non-recoverable loss is essentially a short-term measure of the impact of an outbreak on timber supply. Analysis of the resulting the age-class structure can be done to explore potential long-term impacts (e.g., an excessively large cohort can cause problems for long-term sustained yield projections and could also lead to future outbreak problems).

Experiments

A series of experiments were performed to explore and test model behaviour and response (*sensitivity experiments)* and to address the objective questions (*production experiments).* We focus first on the latter. The production experiments were designed to examine the effects of forest landscape management scenarios containing various levels of bark beetle management on MPB populations and volume losses. Scenarios ranged from harvesting without regard to bark beetles to high levels of beetle management.

Scenarios with no beetle management:

TSR: Strategic level harvesting according to the TSR (same seral constraints, volume curves, etc.). Small cutblocks (according to FPC) and road access (max: 2km from a road). No specific beetle management (although beetles may be incidentally killed during harvest).

FDP1998: Tactical level harvesting according to the 1998 FDP. Same as TSR except:
1. Cutblocks are constrained to be within the polygons in the FDP map
2. Once a cutblock is initiated within a polygon, the entire polygon is cut (at least, the part that is available for harvesting).

Scenarios with varying levels of bark beetle management:

BM: Current level of beetle management. Same as TSR except:
1. Beetle blocks: cutblocks strategically placed in infestations have a relatively high preference. At the start, about 1200-1300 ha / year of beetle blocks are cut (out of a total of approximately 5300 ha harvested annually), based on information from the district. This varies through time depending on how the outbreak proceeds. There is a delay between the first time a cell is attacked and detection. Beetle blocks are only placed in cells with at least 50 killed trees.
2. Salvage of beetle-killed wood has a moderate preference. At least 25 m^3 / ha must be available. Killed wood "degrades" at a rate of 20% per year, starting in the second year after initial attack. Salvaged area in the model is generally less than 200 ha (this needs to be verified, since we didn't have information on this mgmt option).
3. Susceptibility blocks: blocks strategically placed in high susceptible cells, according to an estimate of the CFS beetle susceptibility rating index. These have a moderate preference. This needs to be verified, since we didn't have information on this management option.
4. Single tree treatments (Fell and burn, MSMA). Both are controlled by a specified number of hectares to treat. Fell and burn results in immediate loss of volume. MSMA creates standing dead wood that may be salvaged (if it is reached in time). The amount of area treated annually is: 75 ha Fell and burn, 40 ha MSMA (based on information from the district). In all cases, the model currently assumes 100% removal of beetles in treated cells.

BM/2: Reduced level of beetle management. Same as BM except:
1. Preference for beetle blocks, salvage and susceptible stands is reduced by approximately half (for the same level of beetle outbreak). Since these preferences are specified as relative probabilities, the actual amount of blocks treated by these options may be higher than BM if the beetle outbreak grows more than in BM.
2. Single tree treatments reduced by half: Fell and burn: 38 ha / year, MSMA: 20 ha / year.

BM*2: Increased level of beetle management. Same as BM except:
1. Preference for beetle blocks, salvage and susceptible stands is approximately doubled (for the same level of beetle outbreak). Since these preferences are specified as relative probabilities, the actual amount of blocks treated by these options may be lower than BM if the beetle outbreak declines more than in BM.

2. Minimum volume to salvage is reduced to 20 m^3 / ha.
3. Single tree treatments quadrupled: Fell and burn: 300ha / year, MSMA 160ha / year.

BM*10: Increased level of beetle management. Same as BM*2 except:

1. Single tree treatments multiplied by 10 over BM: Fell and burn: 50 ha / year, MSMA 400 ha / year.

Results

The KLM could produce output for any parameter or variable in the model. For this analysis we focus on the annual changes in four important variables:

1. Total volume killed inside the timber harvesting land base (THLB).
2. Total number of trees in the landscape killed by beetles.
3. Total number of attacking beetles in the landscape.
4. Total size of the beetle attack (ha).

Because the model is stochastic (i.e., it relies on probabilities for some aspects) no two runs of any scenario will be identical. Therefore, each scenario was run 10 times and all figures show the mean of the 10 runs except where noted. Due to uncertainty about the beetle population growth rate all scenarios were run at low, medium, and high beetle growth rates. Results are reported from scenarios using the medium beetle growth rate except where noted.

The TSR and FDP1998 scenarios resulted in very similar levels of volume losses (Figure 1) and total number of trees killed by beetles (Figure 2). The current level of beetle management, scenario BM, resulted in large reductions in volume lost and number of trees killed (Figures 1, 2). The graph on the right side of each composite figure focuses on just the scenarios featuring beetle management. Increasing the intensity of beetle management (scenarios BM*2 and BM*10) over current efforts resulted in a slight reduction in both volume lost and the number of trees killed, but halving the beetle management effort (scenario BM/2) resulted in significant increases in volume lost and trees killed. Results for the total number of attacking beetles and size of attack were very similar (Figures 3, 4). Again, the TSR and FDP1998 scenarios were very similar, and any level of beetle management caused significant reductions in the size of the beetle population and area of the outbreak. Decreasing the intensity of the beetle management effort caused a larger effect than increases to beetle management efforts.

To examine the effect of variability between individual runs on model results, individual results from 10 runs of two different scenarios were plotted instead of the mean as in the preceding figures. Clearly, the differences between scenarios far exceeded any variation in the results within individual runs of the same scenario (Figures 5, 6). Additionally, all management scenarios were run at three levels of beetle growth rates. Even at the lowest beetle growth rate there were much greater volume losses in the TSR scenario than with current beetle management practices (Figure 7). Increasing the beetle growth rate caused a greater difference between scenarios. Our best guess is that the intrinsic beetle growth rate is bounded by the medium and high levels used in these scenarios, since these most closely fit the expected growth rate for this region (based on historical information).

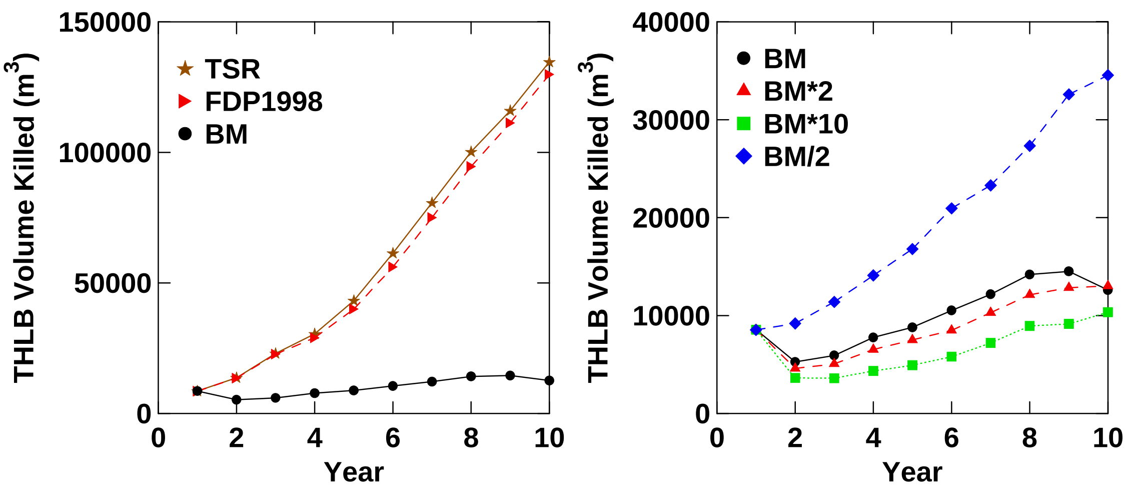


Figure 1. Volume killed in the THLB under different management scenarios (see text for detailed descriptions of the scenarios).

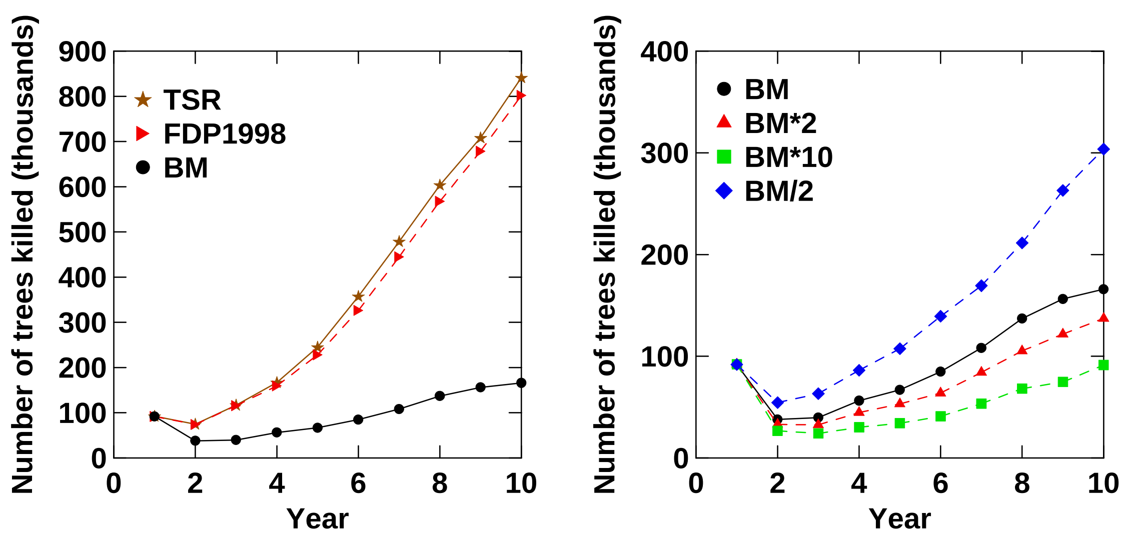


Figure 2. Total number of trees killed under different management scenarios (see text for detailed descriptions of the scenarios).

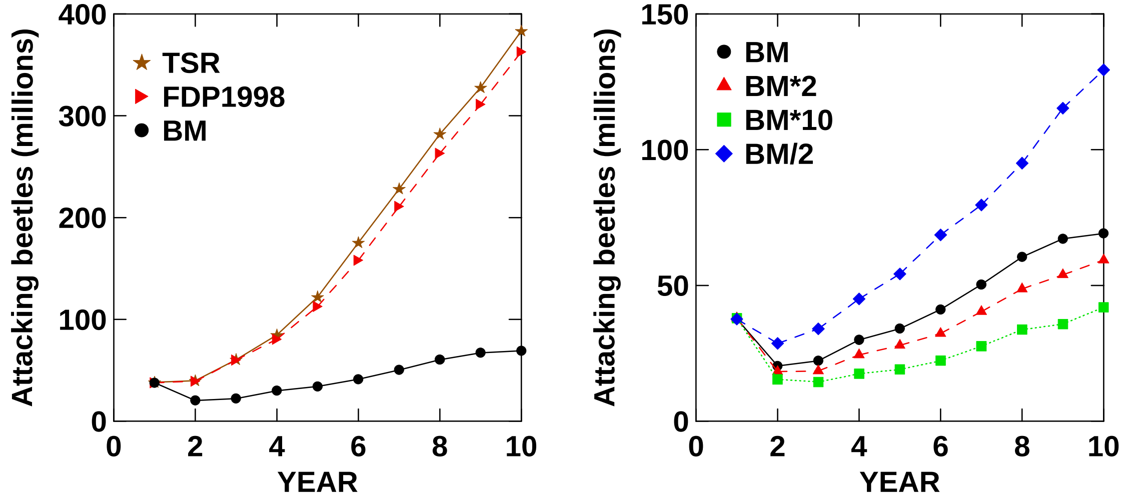


Figure 3. Total number of attacking beetles in the landscape under different management scenarios (see text for detailed descriptions of the scenarios).

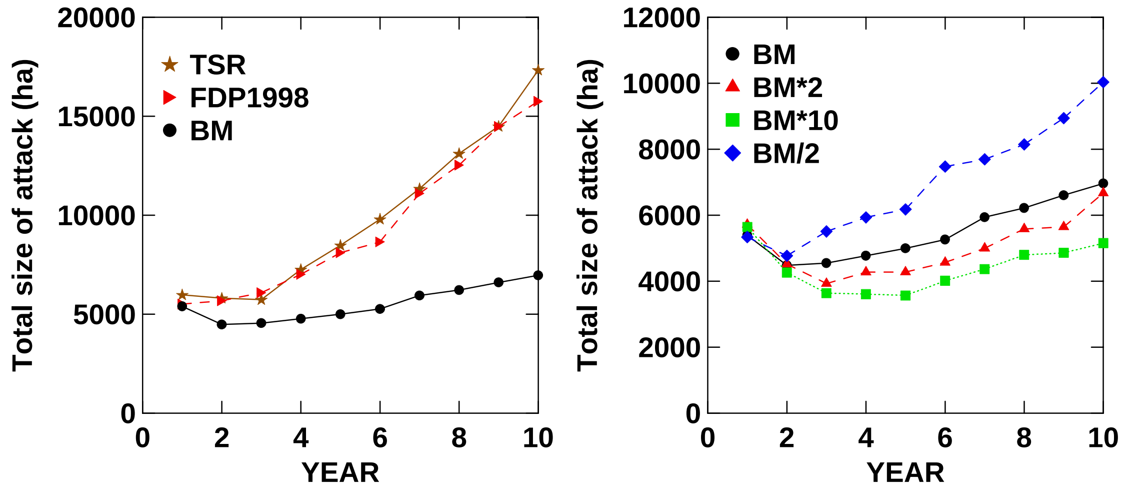


Figure 4. Total number of hectares attacked by beetles under different management scenarios (see text for detailed descriptions of the scenarios).

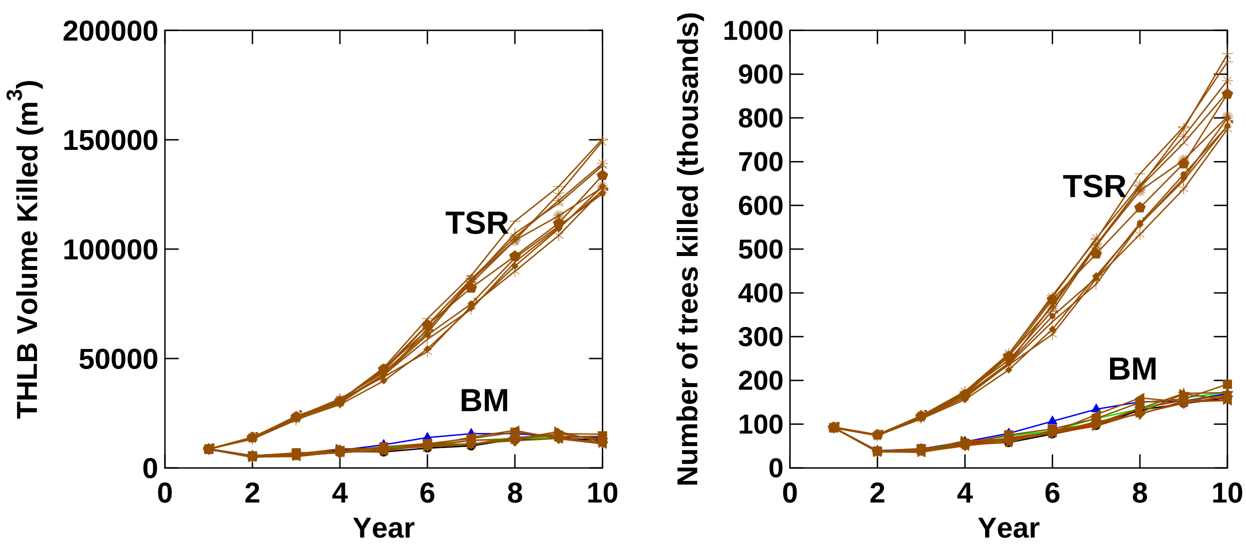


Figure 5. Total volume killed in the THLB and number of trees killed by beetles. Graphs show results from 10 individual runs under both the TSR and BM scenarios.

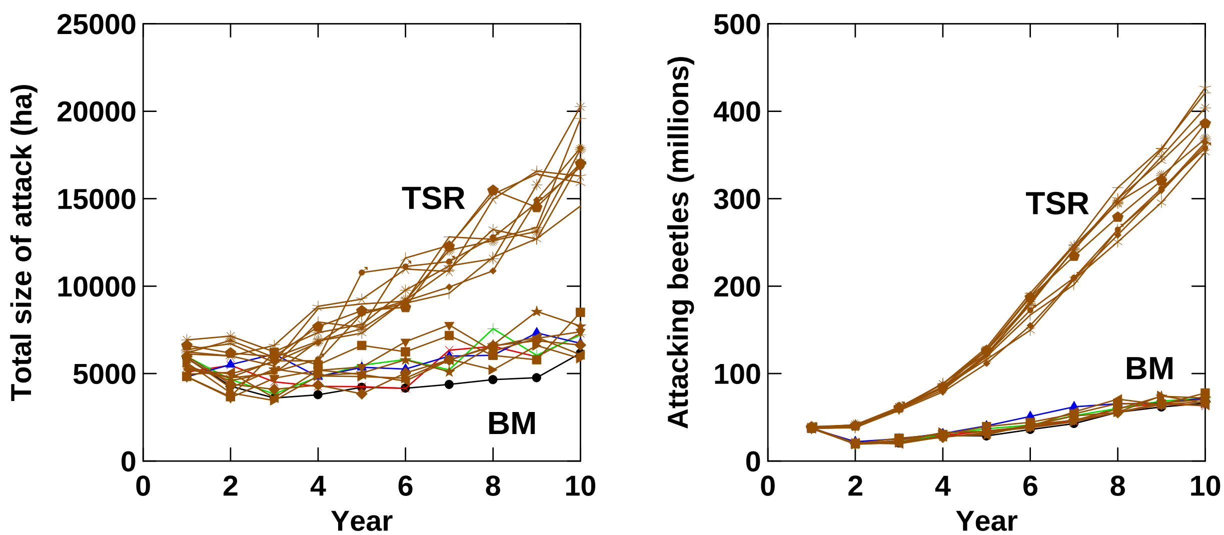


Figure 6. Total area attacked and number of attacking beetles. Graphs show results from 10 individual runs under both the TSR and BM scenarios

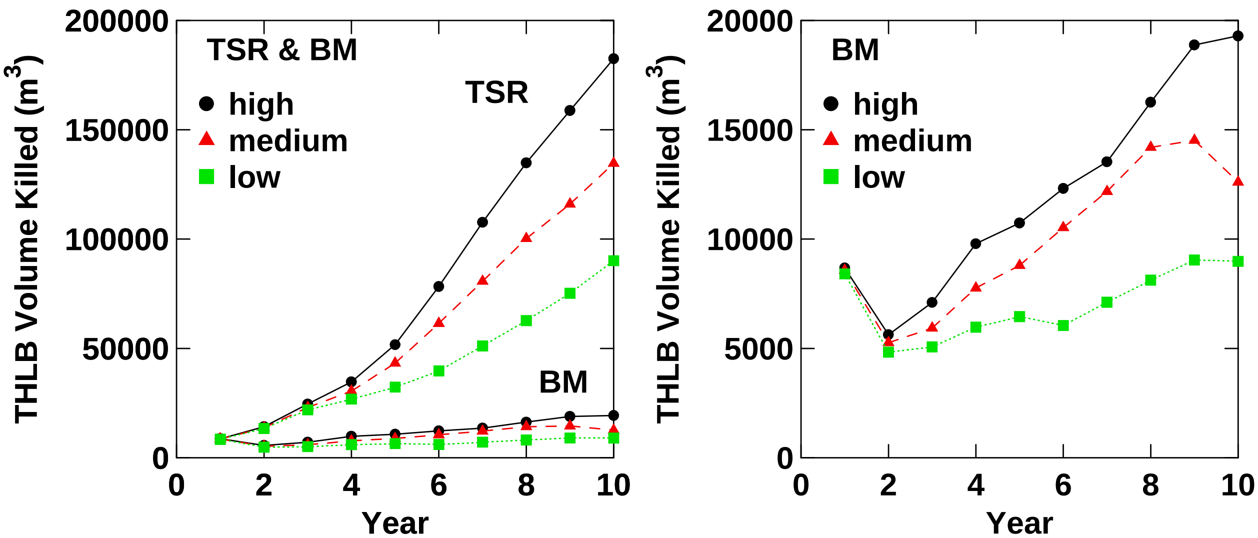


Figure 7. Effect of assumptions about beetle population growth rates on volume killed in the THLB under the TSR and BM scenarios.

The beetle management scenarios actually consist of four separate management techniques as noted in the scenario descriptions. These include clearcut harvesting of beetle infestations (beetle blocks), targeted logging of susceptible stands (susceptibility logging), single tree treatments (fell and burn and MSMA), and salvage. To test the relative effects of each of these techniques a suite of sensitivity experiments was made with each of these options enabled individually and the rest disabled. Enabling beetle blocks caused the largest reduction in volume lost compared to the TSR scenario (where all beetle management options are disabled) (Figure 8). The next largest effect was caused by salvage, followed by susceptibility logging and single tree treatments. The model assumes that all beetles are eradicated by cutting a beetle block. Given that these cuts influence the largest area of all treatments in any year, they are most effective technique. Salvage logging is effective because all trees in a cell are logged if the cell is a candidate for salvage. Thus any beetles in that cell are removed. However, salvage impacts less area annually than beetle blocks. Susceptibility logging is less effective because susceptible stands are chosen regardless of proximity to outbreak. There is currently no simulation of risk of attack. For example, two identical stands may have the same susceptibility rating, but one could be at far higher risk of attack if there is an infestation in an adjacent stand. The current model does not account for this and therefore susceptibility logging could just as easily target stands that are well away from an infestation. Note that at higher beetle growth rates the effectiveness of susceptibility logging increases because there are more infestations on the landscape. Single tree treatments appear less effective simply because they treat far less area than the other techniques. They do reduce beetle populations and save volume, but under the current district practices (scenario BM) there are only about 115 ha treated annually. If the results are expressed as the percentage of the total volume losses in the district that are within the THLB (Figure 9) the relative ranking of the four beetle management techniques is the same. It is interesting to note that beetle management saved volume in the THLB, but was not applied to other areas such as parks. Therefore the percentage of the total volume loss that lies within the THLB decreased significantly.

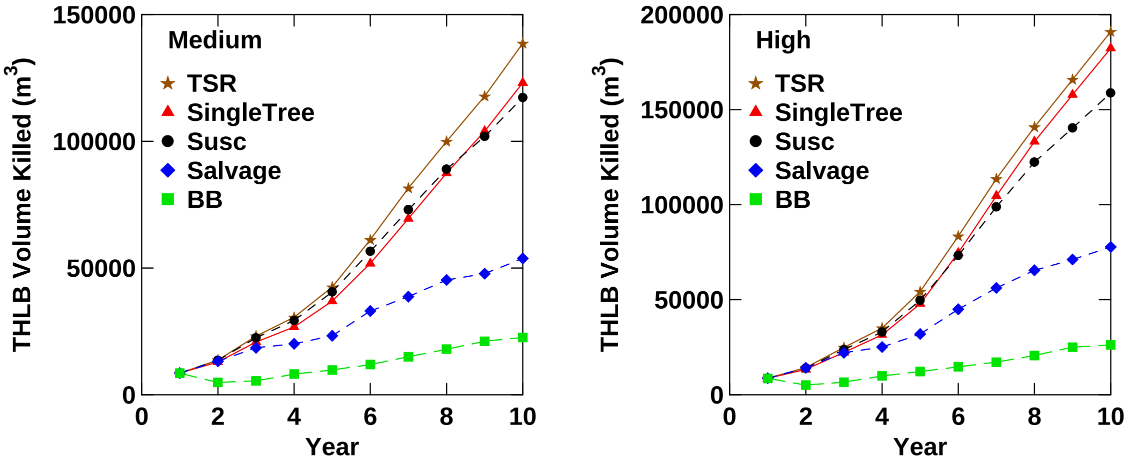


Figure 8. The effect of individual beetle management options on total volume killed in the THLB under both medium and high beetle growth rates. BB1 = Beetle blocks, Susc = logging of susceptible stands.

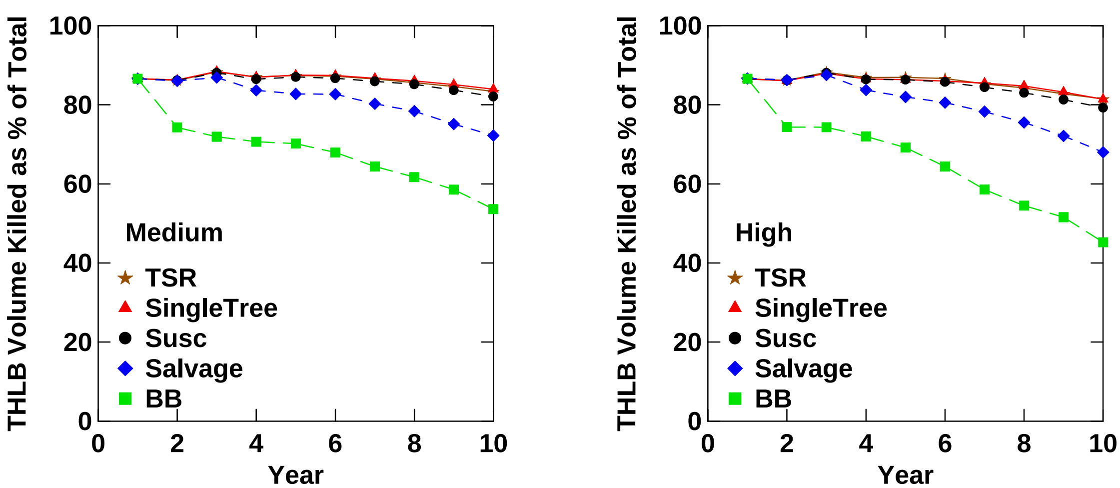


Figure 9. The effect of individual beetle management options on THLB volume killed as a percentage of total volume killed by beetles in the district under both medium and high beetle growth rates.

One consequence of focusing on beetle management was a change in the type of stands being logged as compared to the TSR or FDP scenarios. For example, a change from TSR to the standard BM scenario resulted in a dramatic increase in the percentage of the total volume harvested from Pl - leading stands, and a reduction in the harvest of stands where Fd was the leading species (Figure 10). The FDP1998 scenario was intermediate. The location of harvest units in the TSR scenario is driven primarily by the relative oldest first rule. That is, stands whose age is highest relative to the minimum harvest age for that type are logged first in the absence of other constraints. Clearly, in the Kamloops District the Douglas-fir leading stands are older relative to their minimum harvest age than the pine leading stands. The FDP1998 scenario uses the same rules as TSR, but is constrained to use polygons identified in the current forest development plan, which apparently favours more pine leading stands than an unconstrained TSR run. The BM scenario targets logging at infested and susceptible stands as a high priority and therefore leads to increased harvesting in pine leading stands.

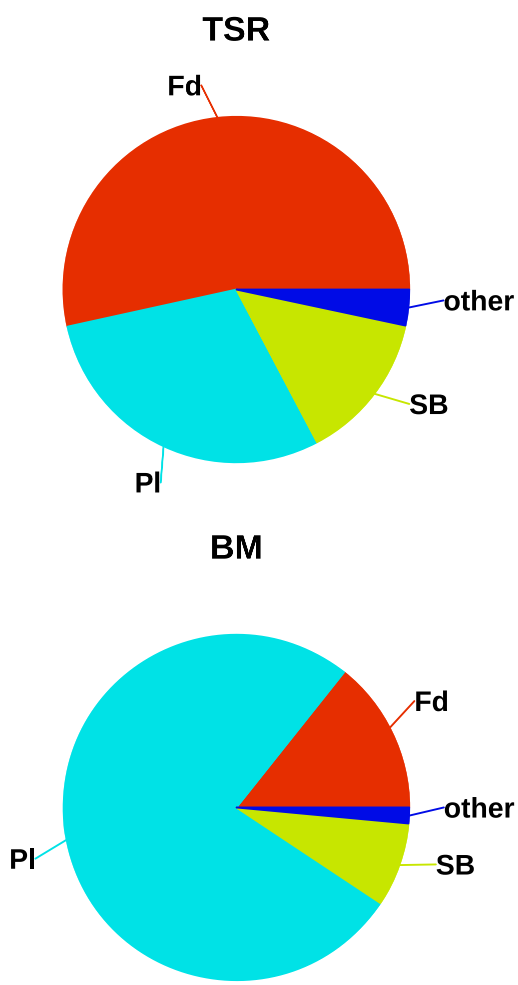


Figure 10. Harvest profile by leading species under 3 different scenarios.

Beetle attack locations were highly dependent on the initial beetle locations at the start of the simulation. Although there was some long distance dispersal of beetles, the bulk of new attacks were in stands adjacent to or near existing infestations. Therefore, under most scenarios, attacks were in the same areas. However, the intensity of the attack varied with levels of beetle management. Although attacks occurred in the same general area, the BM scenario reduced the number of times an area was attacked across 10 simulations as compared to the TSR scenario (Figure 11). This figure can be roughly interpreted as the probability of attack. Note that some of the darkest areas (more frequently attacked) were in the parks (Arrowstone, Opax, Bonaparte) or the timber license area. Since the current model applies no beetle management or harvesting in these areas they are also more frequently attacked in the BM scenario. There is also no beetle management in the TFL in the current simulation. The model could easily be modified to include management in these areas given information on likely management from the respective agencies (B.C. Parks, Weyerhaeuser, and the owners of the timber licenses).

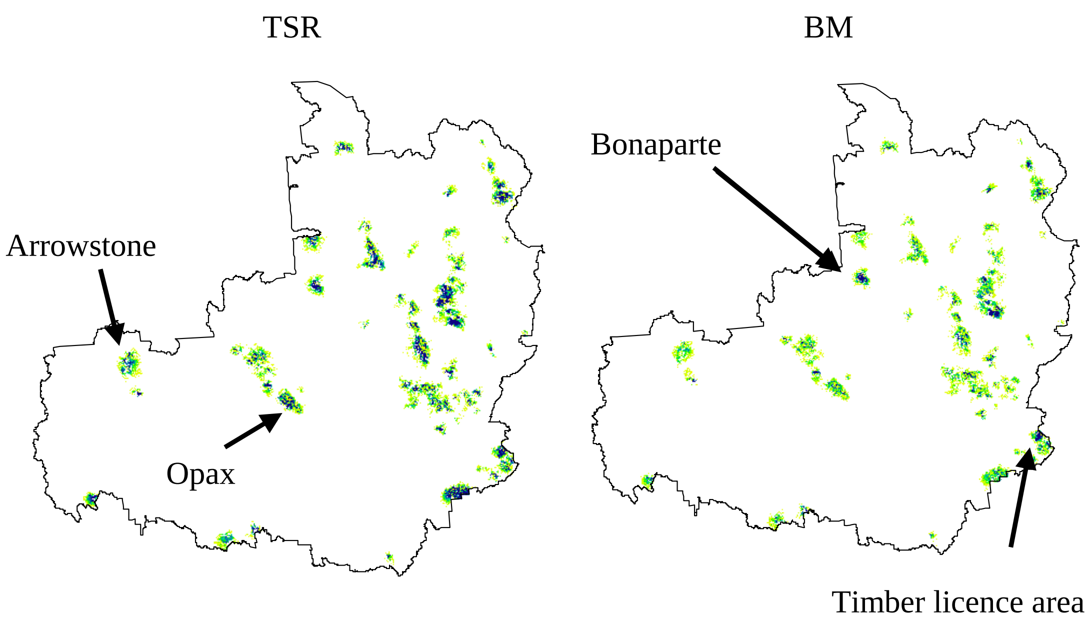


Figure 11. Number of times a cell was attacked during 10 simulations under the TSR and BM scenarios. Darker areas were attacked more frequently than lighter areas.

The results were also stratified by BMU (Figures 12, 13). These figures show that BMUs 4 and 7 are particularly susceptible to attack. Note also that the reduction in beetle damage from enabling beetle management was not proportional across BMUs. The effect of beetles is driven by the relative percentage of the BMU comprised of susceptible stands, and the relative proportion of the BMU inside the THLB. Since there is currently no simulation of beetle management outside the THLB, if a large area of a BMU lies outside the THLB, then beetle management will be less effective in that BMU.

Although each BMU has a specific management target (e.g. suppression or prevention), the current model does not apply any BMU-specific management. The BMU information provides a null hypothesis of expected outcomes in the absence of specific targeting of management. Overall, under the BM scenario, the outcomes are consistent with management direction. One exception to this is BMU 10. Future development might address specific management actions in BMUs that that deviate from desired management direction.

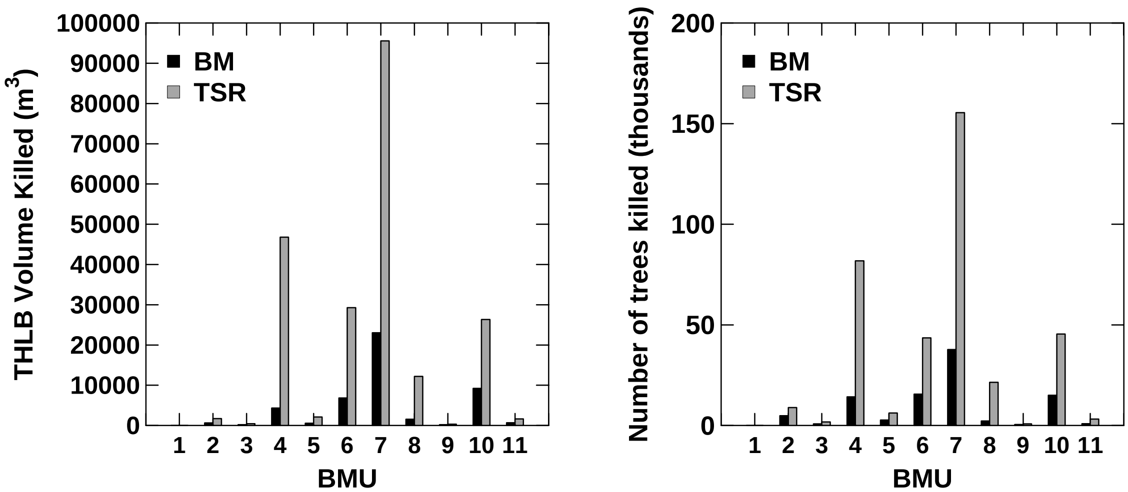


Figure 12. Total volume killed in the THLB and total number trees killed by BMU under the TSR and BM scenarios.

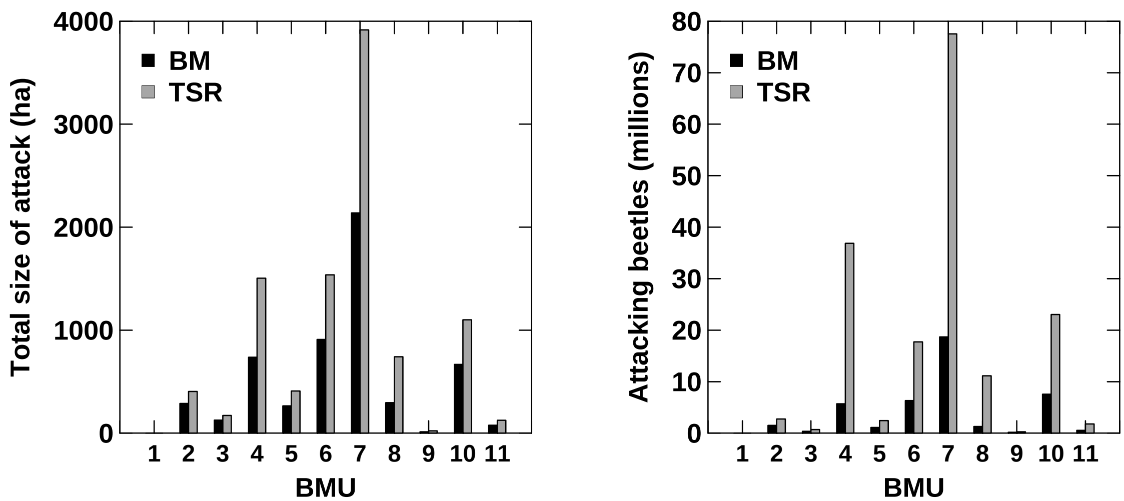


Figure 13. Total size of attack and number of attacking beetles by BMU under the TSR and BM scenarios.

Data Requirements to Apply this Methodology

Data requirements for applying the MPB landscape model are extensive. The following list is intended to assist in applying this approach elsewhere. In addition to spatial information, a variety of aspatial parameters and global variables are required.

Specific data requirements are:

I. Spatial information
   - physiography: elevation, slope, aspect
   - biogeoclimatic zones
   - forest cover: inventory type group, stand age, analysis unit, site index, %pine
   - distance to roads (or just a binary roads layer)
   - management: resource emphasis zones (e.g. VQO, ungulate winter range, community watersheds), operability, landscape units, biodiversity emphasis options, forest development plan, beetle management units
   - Information required to derive timber harvesting landbase. In Kamloops this included environmentally sensitive areas, stocking class, height class, crown closure, pulpwood agreement area 16, ownership, Hudson's Bay Trail, protected areas, Tod Mountain area, non-sufficiently restocked areas, and tree farm license area.
   - Information on beetle locations: spot data (preferably in percent of trees attacked or some form that allows estimation of current size, intensity and location of beetle infestations). For all years available.
   - Information required for MPB stand model: basal area, stand density (in Kamloops this was derived using a lookup table from the district that used forest inventory zone data, age, height class, percent pine and ITG to estimate stand density, mean diameter and basal area)

Also: additional tables, database, etc. required to interpret spatial information.

II. Additional beetle population status
   - population trend and historical information
   - climate information (long-term temperature and wind records)

III. Management policy
   - timber supply review information report and analysis report.
   - AAC level
   - FSSIM .dat files (especially vols.dat and axs.dat)

IV. Beetle management information
   - levels and locations of beetle management activities, including surveys, susceptibility/risk rating, fell and burn, patch cuts, sanitation cuts, salvage, beetle-proofing, baiting, etc.

Future Work to Improve Methodology and Address a Wider Range of Questions

There appears to be interest in exploring a range of questions that are more specific than the general "overall strategy" level of questions addressed in this project. The model can already be used to address some of these, and others require modification and refinement. Some potential objectives/questions that might be addressed (some of which were raised at the final presentation) are:

(i) How effective are single tree treatments? We need to refine the single tree treatment sub-model to ensure that the location and efficiency of treatments matches current practice as close as possible. This should also include single tree treatment practices in parks.

(ii) How does specific management in BMUs affect an outbreak? This would require a simple model extension to be able to apply rules by BMU.

(iii) How important is treatment efficiency? Currently we assumed that treated stands removed 100% of the beetles. How do outcomes change at different levels of efficiency?

(iv) What is the effect of different block size distributions?

(v) How important is early detection? There is a lag between initial attack by MPB and trees turning red. How might outcomes change if detection could be made earlier?

(vi) What is the long-term timber supply impact of an outbreak under a given management regime? To address this, we need to be able to run the model on a century time scale (at least one rotation), but still only need the detailed MPB information for the current outbreak. No future outbreaks would be modelled, but a TSR-type management strategy would continue post-outbreak to assess the effect of management decisions and beetles on timber supply. This would require enhancements to the logging sub-model, in particular to track growing stock through time. We would also need to develop methods to stop a beetle outbreak.

This methodology is a work in progress. Although the model is reasonable at present, and the major design challenges (in particular related to model scaling and dispersal) have been overcome, a number of research issues ought to be addressed in future refinements or application. These can be roughly divided into several categories.

A. Improvements to the MPB model

(i) Examine the volume figures obtained from the TSR volume tables and come up with methodology that would make these more closely reflect the volumes predicted by the CFS stand model. This would include a detailed examination of the netdown process and how this affects our model, comparison with real stand data, etc.

(ii) Examine results of model with previous years real data, and some site visits.

(iii) Improve susceptibility and risk rating (especially including pine susceptibility and risk) for district and re-run model with a management option focusing on this.

(iv) Improve estimates of attack in next year's survey to improve model accuracy.

(v) Improve modeling of low-population dynamics, which is critical for dispersal.
(vi) Review and improve estimates of the number of out-of-cell dispersers, in particular the ratio of out-of-cell to within-cell dispersers, which is a function of cell size (edge to area ratio).
(vii) Examine and improve long-distance dispersal. Establishment success may be underestimated.

B. Improvement to beetle management
   (i) Improve alignment with TSR. Once the TSR analysis report is finished, this task will be much easier
   (ii) Include management outside THLB (e.g. in provincial parks and timber license areas).
   (iii) Incorporate other options (e.g. patch cut)
   (iv) Add the ability to include BMU-specific management options.

C. Improvement to initial conditions

One of the main uncertainties with this approach is obtaining estimates of the initial beetle population based on beetle spot data. The goal of this project was to use 1998 as the starting year, but the 1998 spot data is quite coarse. Certainty could be improved dramatically by using more recent data that has more resolution on infestation levels as more details on location. Of particular importance is to get improved information on areas of low populations.

Conclusions

Overall, this project was a success in that not only were the project objectives met, but also in that the results were quite complimentary to the management efforts in Kamloops forest district. We successfully developed a methodology to scale the stand level CFS MPB model to the landscape scale. In conjunction with refinement to a previous dispersal model, we produced one of the only spatial MPB outbreak models. Using SELES, we were able to integrate this with models of forest and beetle management to produce the Kamloops Landscape Model.

We ran a variety of sensitivity experiments to verify and refine the MPB model. We then ran experiments to address the objective questions of the project. The results indicate that current beetle management efforts in the Kamloops district are likely having a significant impact on growth of the MPB population size and outbreak area. Also, the results indicate that reducing management effort could lead to an increase in beetle impacts, while on the other hand increases in effort are not likely to reduce impacts to the same degree. Further analysis of the economic, social and ecological impacts estimated by the model could be done for a more in-depth cost/benefit analysis of beetle management.

Finally, this project was successful as a test case for developing and applying a methodology for strategic level planning and assessment of beetle management at the forest district scale. Although the parameterization of the beetle and management models, the suite of management action assessed and the model results are specific to Kamloops district, the methodology is general and could be applied to other districts with beetle concerns. Given the specific nature of beetle dynamics and beetle management, application to other landscapes is not a trivial task; the Kamloops Landscape Model forms a foundation from which application elsewhere can be facilitated.