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Modeling the effects of a mountain pine beetle outbreak and potential management responses in Alberta's eastern slopes

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Abstract

We used a simulation model and two management scenarios to investigate possible effects of a severe mountain pine beetle *(Dendroctonus ponderosae* Hopkins*)* epidemic in Alberta, Canada. Our simulated outbreak was based on the current epidemic in British Columbia, which may kill close to 80% of the province's pine volume. Our two management scenarios were conventional harvest and a pine-reduction strategy modeled on a component of Alberta's Mountain Pine Beetle Management Strategy.

The pine strategy seeks to reduce the number of susceptible pine stands by 75% over the next 20 years through targeted harvesting by the forest industry. Our simulations showed that the pine strategy could not be effectively implemented, even if the beetle outbreak was delayed for 20 years. Even though we increased mill capacity by 20% and directed all harvesting to high volume pine stands during the pine strategy's surge cut, the amount of highly susceptible pine was reduced by only 43%. Additional pine volume remained within mixed stands that were not targeted by the pine strategy. When the outbreak occurred in each scenario, sufficient pine remained on the landscape for the beetle to cause the timber supply to collapse. Alternative management approaches and avenues for future research are discussed.

Keywords: mountain pine beetle; Dendroctonus ponderosae; Alberta; lodgepole pine; forest management; simulation model.

Résumé

Nous avons utilisé un modèle de simulation pour étudier les effets potentiels d'une infestation sévère de dendroctone du pin ponderosa (*Dendroctonus ponderosae* Hopkins) en Alberta, au Canada, selon deux scénarios de gestion. Notre épidémie simulée a été conçue sur le modèle de l'infestation ravageant actuellement la Colombie-Britannique, pour laquelle les prévisions annoncent la perte de près de 80% des pins de la province. Nos deux scénarios de gestion étaient la récolte classique et une stratégie de réduction des pins conçue sur le modèle de la stratégie de l'Alberta en matière de gestion des dendroctones du pin ponderosa.

Cette stratégie prescrit une réduction de 75 % des peuplements de pins susceptibles au cours des 20 prochaines années, par une coupe ciblée réalisée par l'industrie forestière. Nos simulations ont montré que cette stratégie ne pouvait pas être mise en œuvre efficacement, même si l'infestation du dendroctone du pin était retardée de 20 ans. Même en augmentant la capacité des usines de 20 % et en cessant totalement la coupe de peuplements ne contenant pas un nombre élevé de pins durant la coupe stratégique, la quantité de pins présentant un risque n'a été réduite que de 43 %. Des pins supplémentaires sont restés au sein des forêts mixtes qui n'étaient pas visées par la stratégie. Dans les deux scénarios, lorsque l'infestation s'est produite, il restait suffisamment de pins dans le paysage pour que le dendroctone provoque un effondrement de l'approvisionnement en bois. D'autres approches de gestion et débouchés pour des projets de recherche à l'avenir sont discutées.

Mots clés: dendroctone du pin ponderosa; Dendroctonus ponderosae; Alberta; pins tordus latifoliés; gestion forestière; modèle de simulation.

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1 Introduction

The mountain pine beetle (MPB; *Dendroctonus ponderosae* Hopkins) is currently in the outbreak phase of an infestation cycle throughout much of its range in British Columbia, Canada (Walton et al. 2008). The beetle is also expanding into areas previously considered beyond its natural ecological range (Carroll et al. 2006).

For the first time in recorded history, large numbers of beetles from British Columbia have crossed the Rocky Mountains and are attacking lodgepole pine (*Pinus contorta*) forests all along the foothills of Alberta (ASRD 2007). The size and intensity of the current outbreak in British Columbia have been so great that control efforts have been overwhelmed (Coops et al. 2008). The British Columbia Ministry of Forests predicts that 77% of the province's pine volume will be killed by the time the infestation subsides (Walton et al. 2008). The course of the infestation in Alberta is not yet known but it could resemble the current epidemic in British Columbia.

Many of the factors that led to the outbreak in British Columbia are increasingly prevalent in Alberta: milder winters, fire suppression leading to extensive mature pine stands, limited access, administrative and economic constraints, and infection sources with the potential for rapid population expansion (ASRD 2007; Raffa et al. 2008). However, the climate in Alberta's foothills is generally cooler than in the Interior of British Columbia, and much of the pine in Alberta's foothills grows in mixed stands (Carroll et al. 2006). Managers hope that these factors will sufficiently slow the spread of MPB in Alberta so that control efforts will be able to maintain beetle populations at endemic levels.

The Government of Alberta has implemented a MBP Management Strategy intended to contain the infestation and maintain the long-term timber supply (ASRD 2007). Single-tree and stand-level harvest of infested trees are the primary beetle control measures and are supplemented with pheromone treatments to concentrate beetles before and after harvest. There is also a preventive pine reduction strategy that seeks to reduce the number of susceptible pine stands by 75% over the next 20 years through targeted harvesting by the forest industry (ASRD 2007). A temporary increase in the Annual Allowable Cut (AAC) is permitted during this time; however, long-term even flow requirements are to be maintained.

The core elements of the Alberta MPB Management Strategy — control, salvage, and prevention — all involve forest harvesting. Given the limited harvesting capacity in the region, allocating harvest effort among these options requires a tradeoff decision. The effects of beetle and management activities on environmental and economic indicators further complicate the decision (Kimmins et al. 2005). We simulated the effects of a severe MPB epidemic in western Alberta under two management scenarios: conventional harvest and a preventive pine reduction strategy. Our objective was to describe the potential outcomes of these alternative management approaches over the medium and longer-term.

2 Material and Methods

2.1 The ALCES Model

We used an existing simulation model, ALCES®[1], to investigate the effects of a MPB outbreak and associated management responses in Alberta. ALCES is designed to track the cumulative effects of ecological processes and human activities under alternative management scenarios. The user must supply the initial state of the landscape and provide quantitative assumptions

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[1] Information on ALCES can be found at: www.alces.ca

concerning natural disturbances, industrial activities, and regeneration trajectories for each disturbance type. Based on values provided, the model tracks and updates the state of the landscape in time steps of one year for as long as requested. When considering only forest harvesting and regeneration, the model is functionally equivalent to the aspatial timber supply models used by forestry companies for long-term harvest planning (Forestry Corp. 2002). However, ALCES has greater capacity for incorporating natural and human origin disturbances than timber supply models and can provide a greater range of ecological output measures.

In ALCES, the landscape can be stratified into multiple independently tracked classes. For example, a forest land base can be stratified into several stand types and age classes, and different harvest and regeneration strategies can be applied to each stratum. Because we were specifically interested in tracking the effects of the MPB, we used forest inventory data to stratify stands containing pine into three categories: Pure_Pine (> 80% pine); High_Pine (50-79% pine); and Low_Pine (< 50% pine). High_Pine and Low_Pine were mixed stands that contained pine in combination with hardwoods, other softwoods, or both. The remaining merchantable forest stands were classified as Hardwood (> 80% hardwood) or Non-pine Softwood (> 80% non-pine softwood). Stands were also stratified into 20-year seral stage classes.

The disturbance and regeneration modules in ALCES are user specified. We used the insect disturbance module to specify the type and age of stands subject to MPB infestation as well as the temporal trajectory of the outbreak (i.e. ha disturbed in each year of the outbreak). The model has the capacity to allow stands to transition to a different stand type after disturbance. The age of stands after disturbance can also be defined by the user (i.e. reset to the zero age class is not necessary).

2.2 Modeling Experiment

Our study area is comprised of six forest management areas in the foothills of central Alberta (Figure 1). The total area is 3.6 million ha, of which 2.5 million ha is forested. Lodgepole pine, white spruce (*Picea glauca*) and aspen (*Populus tremuloides*) are the three leading tree species, each accounting for approximately one-third of the total.

We did not model the population dynamics of the MPB per se, but the projected effects of the beetle on pine stands. We assumed, as a worst-case scenario, that 80% of pine stands would be attacked during the outbreak. This is consistent with projections for the MPB outbreaks occurring in many parts of British Columbia (BCMoFR 2007; Walton et al. 2008). All stands containing pine were assumed to be susceptible to attack, except those under 20 years of age. The temporal trajectory of our outbreak was based on a composite of the projected trajectories of outbreaks in 22 Timber Supply Areas in British Columbia (Figure 2; Walton et al. 2008). In stands that were attacked, we assumed that 75% of the pine volume would be killed (Eng et al. 2004).

After being attacked, stands were either salvaged and replanted (see below) or left to regenerate naturally. In unsalvaged mixed stands, we accounted for the change in internal composition and volume resulting from pine mortality but left the age of the stand unchanged (Table 1). In High_Pine stands, the loss of 75% of the pine volume forced a transition to Low_Pine or Non-pine Softwood, depending on the composition of the original stand. Low_Pine stands stayed as Low_Pine or transitioned to either Hardwood or Non-pine Softwood, again depending on the original stand composition. In the case of Pure_Pine, we treated the beetle attack as a stand-replacing disturbance and reset stands to age class zero. We assumed that stands on dry sites and mesic sites with low productivity would grow back to Pure_Pine and stands on productive mesic sites would grow back to Low_Pine (Table 1; Astrup et al. 2008; Stadt and Greenway 2008).

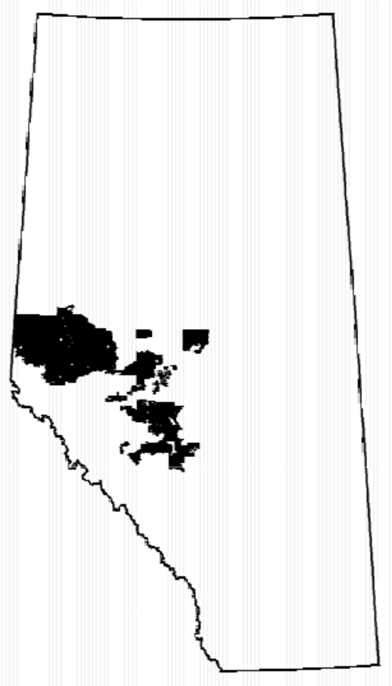

Figure 1. The province of Alberta, showing the location of our study area.

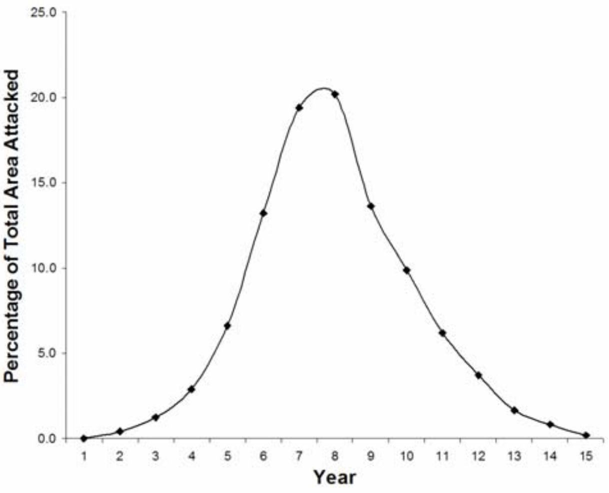

Figure 2. Temporal trajectory of the simulated MPB outbreak, expressed as the annual percentage of the total area attacked.

Table 1. Transition matrix used to determine the fate of stands after MPB attack in the absence of salvage operations.

Before MPB Attack		**After MPB Attack**	
Forest Type	**Area (ha)**	**Forest Type**	**Proportion**[a]
Pure_Pine		Pure_Pine	0.29
(pine ≥ 80%)	637,132	Low_Pine	0.71
High_Pine		Low_Pine	0.20
(pine 50-80%)	304,191	Non-pine Softwood	0.80
Low_Pine		Hardwood	0.10
(pine < 50%)		Low_Pine	0.56
	366,507	Non-pine Softwood	0.34
Hardwood (pine < 20%)	770,374	Hardwood	1.00
Non-pine Softwood (pine < 20%)	382,132	Non-pine Softwood	1.00

[a] All calculations were done at the stand level using forest inventory data. For each forest type we determined the composition of stands before attack, applied the transition rules described in the text, and then reclassified the stands based on their new composition.

In the Alberta MPB Management Strategy, the removal of infected stands serves as a primary beetle control measure (ASRD 2007). Therefore, in our simulations the salvage of infected stands was given priority over scheduled harvesting operations. To maintain tractability, salvage operations were assumed to occur within one year of MPB attack. Salvaged stands followed the same regeneration process as normally harvested stands. Stand age was reset to zero and then stands followed standard growth and yield curves provided by the forest companies in our study area. We assumed that the regeneration efforts applied to salvaged stands would ensure that no changes in stand type would occur.

We simulated two versions of the MPB epidemic. In one, the outbreak began immediately. In the other, the outbreak was delayed by 20-years. For comparison, we also conducted a simulation in which there was no MPB outbreak. Each of the three MPB scenarios was run in combination with two management scenarios: conventional harvest (CH) and pine strategy (PS). In the CH scenario, conventional harvest rules were applied, as described in the Detailed Forest Management Plans of forestry companies in our study area. The PS scenario was based on the pine strategy component of the Alberta MPB Management Strategy, which seeks to reduce the number of susceptible pine stands by 75% over the next 20 years (ASRD 2007). To simulate the pine strategy we focused all harvesting on Pure_Pine and High_Pine stands for the first 20 years. In all other respects, PS was the same as CH. The six combined scenarios were as follows:

1. CH-None: CH with no MPB outbreak.
2. PS-None: PS with no MPB outbreak.
3. CH-Immed: same as CH-None, but with a MPB outbreak in year one.
4. PS-Immed: same as PS-None, but with a MPB outbreak in year one.
5. CH-Delay: same as CH-None, but with a MPB outbreak in year 21.
6. PS-Delay: same as PS-None but with a MPB outbreak in year 21.

The models simulated 100 years of activity. We assumed that MPB was the only form of disturbance on the landscape (i.e. other forms of industrial development and natural disturbance were not simulated) and that only one MPB outbreak would occur over the course of the simulation. The target AAC for softwoods was set at 4.1 million m^3, based on data provided by the forestry companies in our study area. We assumed that mill capacity and AAC could be temporarily increased by 20% to accommodate the surge in wood flow from the pine strategy and from salvage related to the MPB outbreak. Wood volume harvested during the surge cut was applied against long-term even flow requirements, but as per current provincial policy, salvage wood was not. The AAC was not recalculated after the MPB attack.

3 Results

3.1 Scenarios without MPB

In both CH-None and PS-None the softwood AAC was achieved throughout the entire 100-year simulation. The relative proportion of forest types did not change in these runs because all harvested stands were regenerated to their original stand type. Fifty-eight percent of the forest was classified as old-growth forest at the start of the simulation (where old-growth is defined as stands older than 80 years for hardwood and older than 100 years for all other stand types). By year 70, the percentage of forest classified as old-growth had declined to 22% and 25% in CH-None and PS-None, respectively. The declines in old-growth were relatively balanced among forest types in PS-None, but in CH-None the declines were most pronounced in the hardwood and mixedwood forest types (Figure 3).

PS-None was unable to achieve its objective of reducing the amount of susceptible pine forest by 75%. The area of Pure_Pine and High_Pine older than 60 years (i.e. the highly susceptible stands) was only reduced by 43% at the conclusion of the surge cut in year 20. Over the same period CH-None reduced the area of susceptible stands by 5%.

3.2 Scenarios with an Immediate MPB Outbreak

The CH and PS scenarios were functionally similar when subjected to an immediate MPB attack. Harvesting operations in both cases focused on salvage by year three of the simulation. Once the outbreak subsided, harvesting efforts in both scenarios switched largely to non-pine forest types because little merchantable pine remained on the landscape.

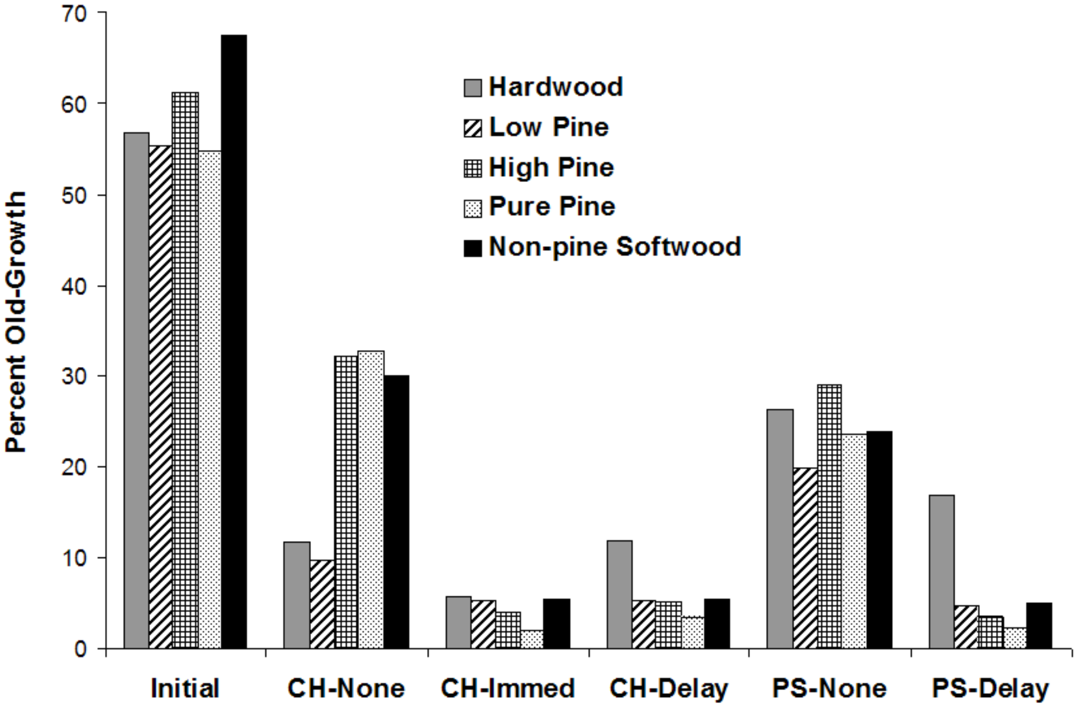

Figure 3. Representation of old-growth forest in the study area at year 70 of the simulation for each of the management scenarios, by stand type.

In both immediate outbreak scenarios, the beetle attacked 39% of the forested land base. Constraints on mill capacity meant only 57% of the merchantable pine volume killed by the MPB was salvaged. Stands that were not salvaged were subjected to the model's transition matrix (Table 1) resulting in changes in the composition of the forest. Pure_Pine and High_Pine declined by 33% and 49%, respectively (Figure 4).

After the outbreak, in both scenarios, the softwood AAC was maintained mostly through the harvest of Low_Pine and Non-pine Softwood stands. This land base could only sustain the original rate of harvest until year 60, at which time a shortage of timber precipitated a 75% decline in softwood harvest volume. Only 7% of the forest was in the old-growth category at the point of collapse, and 5% remained at year 70 (Figure 3).

3.3 Scenarios with a Delayed MPB Outbreak

The proportion of the land base attacked by the MBP in CH-Delay and PS-Delay was 37% and 31%, respectively. Of the merchantable pine volume killed by the beetle, 59% was salvaged in CH-Delay and 97% in PS-Delay. More than 30% of the stands attacked by the beetle in PS-Delay were stands regenerating from the pine strategy's surge harvest. Since these stands were old enough to be attacked by the MBP, but too young to be considered for salvage, the rate of salvage (which only considers eligible stands) was artificially inflated.

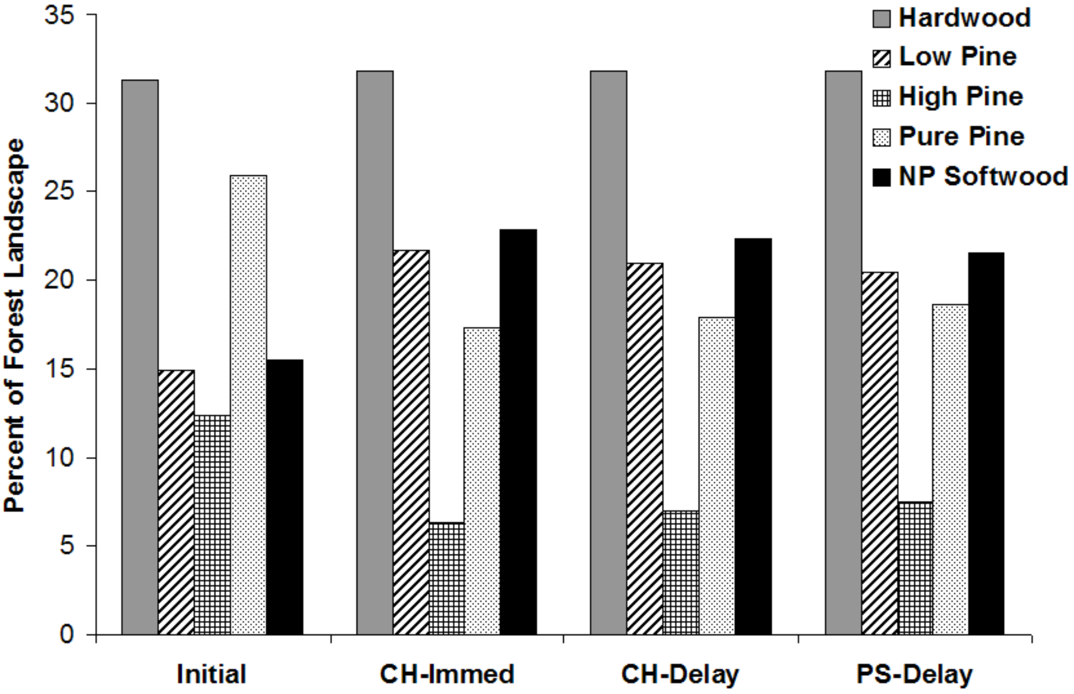

Figure 4. Composition of the forest land base in the study area at year 70. Scenarios without MPB are not shown because forest composition does not change in the absence of MPB.

Softwood harvest collapsed in both delayed outbreak scenarios, but occurred about ten years later than in the immediate outbreak scenarios. The changes in forest composition observed in CH-Delay and PS-Delay were not appreciably different than those observed in CH-Immed (Figure 4). The percentage of old growth forest at year 70 was 7% and 8% for the CH-Delay and PS-Delay scenarios, respectively (Figure 3).

4 Discussion

Our study suggests that the current rate of softwood harvest in our study area cannot be maintained if Alberta's pine beetle infestation follows a trajectory similar to the outbreak in British Columbia. To do so, forestry companies would have to increase their harvest of non-pine species to levels that are not sustainable. According to our simulations, maintaining current harvest levels after the MPB attack would lead to a general collapse in the softwood timber supply in 60-70 years. If other forms of disturbance such as fire and petroleum development had been included in our simulations, the collapse in timber supply would have occurred even earlier.

The proactive pine strategy, meant to reduce the number of highly susceptible stands, could not be effectively implemented in the face of an immediate MPB outbreak. By year three of our simulation of the pine strategy, harvesting operations were focused on salvage instead of green-tree harvest. Following the outbreak, almost no merchantable pine remained to be harvested. The pine strategy was, therefore, no different than conventional harvest in terms of what was harvested.

Although we did not model it, the endpoint would have been the same if harvesting under the pine strategy had continued to focus on green trees. This is because harvesting operations and the MPB compete for the same target species, and the near-total removal of pine from the land base is the ultimate outcome, regardless of the source of mortality (in our worst-case scenario).

The simulated pine strategy failed to prevent the collapse in wood supply even if the epidemic stage of the infestation was delayed for 20 years, for two main reasons: not enough pine had been removed from the land base to prevent substantial beetle losses, and the pine strategy itself contributed to the timber shortfall. Mill capacity constraints limited the pine strategy's removal of highly susceptible pine to 43%. Additional pine trees remained within Low_Pine stands that were not targeted by the pine strategy. Finally, stands harvested at the beginning of the pine strategy's surge cut were old enough to be attacked by the peak of the delayed MPB outbreak.

The harvest rules in our conventional harvest scenario were designed to produce an even-aged forest. As a result, the proportion of old-growth forest in the conventional harvest scenario decreased from 58% at the start of the simulation to 22% by year 70. When the MPB was added to the system, the amount of old-growth declined to 8% or less. All stand types were affected because the pine killed by the beetle caused a general shortfall in timber supply that forced the model to increase the rate of harvest of other species to maintain the AAC. There was no appreciable difference between the conventional harvest and pine strategy with respect to old-growth because the collapse in overall timber supply was similar in both scenarios. A reduction in old-growth forest of this magnitude would significantly reduce habitat supply for species dependent on older forest, potentially reducing their abundance and range.

The harvest rules in our simulation specified that stands be regenerated to their original type. As a result, the composition of the land base in the absence of MPB stayed the same. But when the MPB was added to the system, up to 37% of the Pure_Pine and High_Pine stands transitioned to Low_Pine and Non-pine Softwood. These transitions occurred in stands that were left to regenerate naturally, because they were either too young to be salvaged or there was insufficient mill capacity to process them.

In our simulations, we assumed that all pure and mixed stands containing pine older than 20 years will support the same rate of MPB attack and spread. This assumption is inconsistent with studies that have shown that stand age and pine density are important determinants of susceptibility to MPB (Schenk et al. 1980; Shore and Safranyik 1992; Shore et al. 2000). But without this assumption, our simulations could not have achieved the 80% reduction in pine volume projected for British Columbia (BCMoFR 2007).

An important area of research over the next few years will be to determine the actual rate of MBP attack and spread in Alberta and to use this information to undertake more refined projections than those used in our study. It may well be that, in Alberta, the combination of younger stands (via the pine strategy), lower density of pine in mixed forests, and cooler temperatures will collectively serve to slow MPB population growth to a manageable level—or at least, to avoid catastrophic loss.

Our simulations show that forestry companies lack the capacity for fully implementing the surge cut prescribed by the pine strategy. Even though we increased mill capacity by 20% and completely stopped harvesting stands with low pine volume, the 20-year surge cut reduced the amount of susceptible pine by only 43%. The actual outcome will likely be even lower.

The economic case for increasing mill capacity by even 20% is weak, given the current glut of pine on the market due to the MPB outbreak in British Columbia and the high likelihood of a fall-down in future wood supply (BCMoFR 2007). Furthermore, some companies will continue to harvest hardwood and non-pine softwood stands to meet specific needs, reducing the available capacity for harvesting pine.

Given the inability of the pine strategy to achieve its stated objectives, and given that the surge cut itself contributes to the future shortage in wood supply, alternative management options should be explored. For example, consideration should be given to converting the pine land base to mixed forest to increase its resistance to the effects of the MPB (Whitehead et al. 2004; Nitschke and Innes 2008). In this approach, all harvest capacity would focus on pure pine stands, both healthy and infested, and regeneration efforts would convert as many as possible to mixed stands. Existing mixed stands under MPB attack would not be salvaged. In contrast, harvest efforts under the government's pine strategy are allocated more broadly and regeneration efforts aim to maintain pure pine sites as pure pine.

The mixedwood approach offers several advantages over the existing pine strategy. First, by focusing on a smaller land base (pure pine only) it is more achievable with existing mill capacity. Second, if left standing, the non-pine volume in infested mixed stands will help maintain continuity of the timber supply, especially during the mid-term (BCMoFR 2007). The loss of volume in mixed stands may even be partially offset by increased growth of the non-pine trees because of reduced competition. Third, in contrast to pure pine stands, mixed stands attacked by MPB will retain or increase in structural complexity (Dordel et al. 2008). Protecting these stands from harvest and focusing instead on pure pine stands will retain more structure on the land base. This would help support ecological integrity by maintaining habitat supply and reducing erosion. It is worth noting that the mixed stand approach does not confer the aforementioned benefits if pine stands, particularly pure pine stands, are not destined to be killed by the MPB.

5 Conclusions

Given that the MPB is now widely distributed across the eastern slopes of the Rocky Mountains of Alberta and British Columbia, the likelihood of a winter-kill affecting the entire beetle population is low (Eng et al. 2004). Moreover, the odds of such an event will decrease over time because of the general warming trend that is now underway (Carroll et al. 2006). This suggests that the MPB may be in Alberta to stay. That said, the trajectory of the infestation may well differ from the worst-case scenarios modeled.

If the outbreak in Alberta does follow the trajectory observed in British Columbia, then management interventions will have little impact and a catastrophic outcome is likely (Walton et al. 2008). In this case, care should be taken to ensure that social and environmental values are not jeopardized by management actions themselves. For example, the AAC should be immediately recalculated to prevent a total collapse in wood supply and the loss of old-growth forest observed in our simulations. On the other hand, if the outbreak proceeds at a much slower pace due to local climatic and pine density factors in combination with management efforts, then a positive outcome may be possible. In this case, additional field research and modeling studies would help to determine the best way of allocating harvest efforts to slow the rate of spread of the beetle and minimize its overall impact. (Björklund et al. 2009; Nelson et al. 2008; Trzcinski and Reid 2008).

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