

Preliminary Investigations into a Model for Assessing the Effectiveness of Mountain Pine Beetle (*Dendroctonus ponderosae*) Management Strategies in Banff National Park, Alberta, Canada

Joanna M. Wilson¹ and Jane Park²

Abstract

Mountain pine beetle populations are increasing in Banff National Park, Alberta, Canada, and there are concerns that they will expand eastward onto provincial lands. In response to these concerns, Parks Canada has divided the park into two zones: a 'monitoring zone' where prescribed fire is the only tool for beetle management, and a 'management zone' where more direct control measures are used. We are developing a model to assess the effectiveness of this management strategy for slowing the eastward spread of mountain pine beetle. In particular, we wish to determine whether the boundary of the 'management zone' and the level of active management were well chosen. We also wish to determine whether a similar strategy would be appropriate in other mountain parks susceptible to mountain pine beetle.

Our model is a modified version of an incidence function model. Using data on beetle distribution and abundance, it predicts beetle densities in a particular area based on that area's connectivity with other infested areas. In this paper we describe the basic model and give an example of preliminary results for illustrative purposes. Further work is needed to refine and validate the model. Once the model has been tested, we will use it to predict the distribution of mountain pine beetle in Banff under current conditions, as well as under different management scenarios.

Introduction

Mountain pine beetle (*Dendroctonus ponderosae*, Coleoptera: Scolytidae) is a bark beetle that colonises living lodgepole pine trees (*Pinus contorta*). When populations reach significant levels, there is a potential for significant economic losses to the logging industry. Currently, mountain pine beetle populations are at epidemic levels in British Columbia with over 7 million hectares of pine forests affected in 2004 (Westfall 2005). Furthermore, the projection for this infestation to continue for another ten years predicts that up to 80% of the merchantable timber in British

1 Protected Areas Biologist, Department of Environment and Natural Resources, Government of the Northwest Territories, P.O. Box 1320, Yellowknife NT, X1A 2L9

2 Senior Park Warden, Vuntut National Park, General Delivery, Old Crow, YT, Y0B 1N0

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Columbia will be affected. On the other side of the continental divide, . in Banff National Park, Alberta, populations have been increasing since 1997 (Parks Canada 2002). Further spread is likely, because decades of fire suppression have resulted in large areas of mature pine forest susceptible to mountain pine beetle (Shore and Safranyik 1992; Kay et al. 1999).

The mountain pine beetle is a native insect and thus a natural disturbance agent. However, there are concerns that beetles will expand eastward from Banff Park into commercial timber located on Alberta provincial lands (Figure 1), where they could cause economic losses. In 2002, Parks Canada responded to these concerns by developing a Regional Forest Management Strategy for Banff National Park (Parks Canada 2002). The Strategy outlines two distinct zones: a 'monitoring zone' located west of the Town of Banff, and a 'management zone' east of the town. Prescribed fire is the main tool for forest management, and is used in both zones. Besides reducing the susceptibility of forest stands to mountain pine beetle (Cole and Amman 1980), fire also helps to restore the historic stand age distribution, and increases habitat for some wildlife (e.g., Canon et al. 1987; Hamer 1996). In the 'management zone' additional tools are used to mitigate the spread of mountain pine beetle into neighbouring lands. Sanitation cutting, pheromone baiting, and fell-and-burn of infested trees are used to remove beetle broods from the population before adults can emerge and disperse (McMullen et al. 1986).

The goal of this research is to assess the effectiveness of Banff's management strategy for slowing the eastward spread of mountain pine beetle. In particular, we wish to determine whether the boundary of the 'management zone' and the level of active management were well chosen. We also wish to determine whether a similar strategy would be appropriate in other mountain parks susceptible to mountain pine beetle. We explore the potential of the incidence function model to predict mountain pine beetle infestation rates and the utility of the model in evaluating management strategies. The results are preliminary and serve to highlight the advantages of using this particular modelling approach.

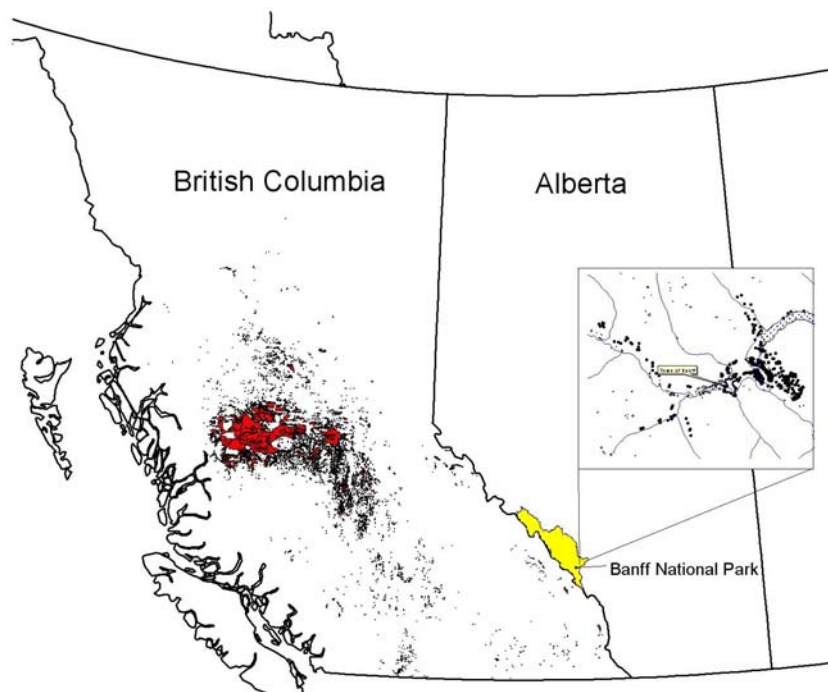


Figure 1. Banff National Park and the study area (inset) in relation to the MPB epidemic in British Columbia. BC mountain pine beetle data from BC Ministry of Forests.

The Model

Complex, process-oriented models exist for predicting the spread of mountain pine beetle populations across a landscape (e.g., Fall et al. 2004). However, we wish to develop a simple model that requires only basic data on the distribution and abundance of beetles on the landscape. The most readily available data on beetle distribution are from aerial surveys of red-attack trees done by the Canadian Forest Service (Unger 2003). Red-attack trees are trees killed by mountain pine beetle. After beetles leave the tree, there is a one-year time lag before the foliage turns red. Therefore red-attack trees reflect beetle activity in the previous year.

Incidence Function Models (IFMs) have been proposed as a practical method of inferring dispersal from data on the distribution and abundance of organisms (Hanski 1994; Hanski 1998). When several local populations inhabit spatially distinct habitat patches (a metapopulation), incidence functions can be used to estimate the probability of colonization and extinction in a particular habitat patch, based on the previous pattern of patch occupancy. The probability of a patch being colonized depends on its connectivity with other occupied patches.

Mountain pine beetles in Banff Park do not inhabit distinct, isolated habitat patches. Rather, they are patchily distributed throughout a continuous 'swath' of apparently suitable habitat. We divide the landscape into cells of equal size, so that we could work with beetle densities. We then used a modified version of an incidence function model to describe the relationship between the distribution of beetles and habitat connectivity. Hanski's original model assumes that the number of migrants is influenced by the presence or absence of individuals in a nearby patch (p in Hanski's model). Since the probability of beetles settling in a nearby patch is not solely influenced by the presence of beetles in nearby patches, but the productivity of neighbouring patches, we used the parameter S to scale the number of trees attacked last year to the number of beetles emigrating next year.

Mountain pine beetles have one generation per year. Every summer the population is redistributed, as adult beetles emerge from the tree in which they developed, and fly to a new host tree. We assumed that the probability of local extinction is 1, so that cells must be colonized anew every year. The number of beetles present in a cell thus depends on the number of successful colonists.

We assumed that the number of migrant beetles arriving in a certain cell i per unit time (M_i) would be correlated with the number of beetles coming from a nearby cell j :

$$\text{(eqn. 1)} \quad M_i = S_j A_j e^{\alpha d_{ij}} \quad (\text{modified from Hanski et al. 1996})$$

where S_j refers to the beetle productivity of cell j , A_j refers to the size of the beetle population in cell j , and e is the base of the natural logarithm. The number of beetles travelling from cell j to cell i depends on the distance between them, d_{ij} , and on the permeability of the intervening habitat to dispersal, α . The permeability parameter α includes beetle mortality during migration, beetles that settle in the intervening habitat, and the ability of a beetle to move through the intervening habitat. The number of migrants coming from unoccupied patches is zero. Several different source cells j can supply migrant beetles to cell i , including cell i itself. Therefore, the number of migrants is summed for all source cells, including cell i :

$$\text{(eqn. 2)} \quad M_i = \sum_{j=1}^n [S_j A_j e^{\alpha d_{ij}}]$$

If K represents the propensity for beetles to settle in a certain type of habitat, then the density of beetles B colonizing cell i will be (K in our model represents β in Hanski's model since we use B to denote the density of beetles in cell i):

$$\text{(eqn. 3)} \quad B_i = K_i \sum_{j=1}^n [S_j A_j e^{(\alpha d_{ij})}] \quad \text{or more simply:} \quad B_i = K_i * M_i$$

This type of model can be modified to include effects of habitat quality and landscape structure (Moilanen and Hanski 1998; Roland et al. 2000). For example, dispersal distances (d_{ij}) may be manipulated to reflect the prevailing wind direction. Different habitat types can have different permeabilities (α), productivities (S), and propensities for beetles to settle there (K). We predict that α , K , and especially S will be affected by mountain pine beetle management actions.

Methods

The model was used to derive the mountain pine beetle distribution in Banff, for each year since 2002, with the beetle distribution being a function of the previous year's distribution. Spatial data were manipulated using ArcView GIS 3.3. We divided the park landscape into cells of equal size (1 km²) using a randomly imposed grid drawn by the EditTools 3.6 extension. Since we did not have data on actual beetle density, we approximated B_i as the area of red-attack trees divided by the area of available habitat in each cell, and assumed a log-normal distribution. Since we did not have data on the numbers of beetles emerging per tree, we approximated A_j as the area of red-attack trees in each cell and assumed a linear relationship between the area of red-attack trees and the number of beetles ($S_j A_j$). We calculated the centroid for each cell, then calculated pairwise distances (d_{ij}) between all the centroids using a custom script (Chruszcz 2000).

Maximum likelihood estimation (Hilborn and Mangel 1997) was used to calculate the parameter estimates for α , K , and S . When parameter values are unknown, this method can be used to find values that maximize the likelihood of the observed data. However, the certainty with which parameters can be estimated decreases when there are multiple unknown parameters and a high degree of correlation among parameters. As well, when a nonlinear model is used, there may be more than one possible parameter value that maximizes the likelihood.

Iterations were run in Microsoft Excel software using the Solver tool (Microsoft Office 2000), by minimizing the negative log-likelihood to a precision of 0.000001 (less than 200 iterations). We began with a simple model in which parameters were constant across the landscape. We then increased the complexity of the model by allowing the parameters to vary between the 'monitoring' and 'management' zones. The nested models were then compared using a likelihood ratio test (Hilborn and Mangel 1997).

Results

The following results are preliminary and are intended only to illustrate the performance and applicability of the developed model.

The beetle distribution for the summer of 2002 (approximated by red-attack data from 2003) was modelled as a function of beetle distribution in the previous year (approximated by red-attack data from 2002). We modelled the beetle distribution at the landscape-level using a resolution of 1 km² /cell over a total area of 150 km². We wished to limit the number of unknown parameters (Hilborn and Mangel 1997) while still addressing the central management question of whether sanitation

cutting, pheromone baiting, and fell-and-burn of infested trees caused a measurable change in S , the relative beetle productivity of each cell. Therefore, we assumed that parameters K and α were constant across the landscape, then allowed S to differ between the 'monitoring' and 'management' zones. This allowed us to evaluate the sensitivity of the model to changes in the S parameter. The results are summarised in Table 1.

When S was allowed to vary, the maximum likelihood estimate of beetle productivity was less for cells in the management zone than for cells in the monitoring zone. The model predicted mountain pine beetle densities in the management zone that were approximately 36% less than in the monitoring zone. When S was held constant, the predicted beetle densities were intermediate.

The model where S varied did not perform significantly better than the model where S was held constant (likelihood ratio test: $\chi^2 = 0.98$, $p > 0.25$).

Table 1. Results of maximum likelihood estimation for two different versions of the model.

Model	Maximum Likelihood Parameter Estimates		Negative Log-Likelihood
	αS^*K^1		
S held constant	-0.003	0.036	141.99
S differs between zones	-0.004	Monitoring: 0.042 Management: 0.027	141.01
			Likelihood Ratio = 0.98

¹Note: in this version of the model, it is not possible to estimate S and K separately.

Given the parameter estimates for the more complex model, we used the model to predict what beetle densities in the summer of 2002 would have been under a different management scenario. One management option that beetle managers considered in 2001, but did not implement, was the inclusion of Stoney Squaw Mountain in the management zone. We simulated this scenario by artificially expanding the management zone 5 km westward. The average predicted mountain pine beetle density in the management zone was 18% less under this scenario, a significant decrease (two-sample t-test: $t = 3.1$, $p = 0.002$).

Discussion

Allowing the relative beetle productivity of a landscape cell (S) to vary between the monitoring and management zone did not significantly improve the performance of the model. Therefore, a difference in beetle productivity between the monitoring and management zones is not supported. The results suggest that the management techniques used in 2001 did not have an appreciable effect on the distribution of red-attack trees in 2002. This could occur if the techniques used were relatively ineffective, applied too sparingly, or if their effect was masked by other factors influencing mountain pine beetle densities. When the parameter estimates for the more complex model were used to test a hypothetical management scenario, the results suggested that extending the 2001 management zone to include Stoney Squaw Mountain would have produced a significant decrease in the 2002 mountain pine beetle infestation. However, this simulation relies on parameter estimates that are not strongly supported.

Further work will focus on evaluating the model fit and finding the version of the model that best describes the data on mountain pine beetle distributions in Banff National Park. The current exercise used only one time-step of data, from 2001 to 2002. Incorporating data from the 2004 red-attack survey will add a second time-step. The model should also be validated using an independent data set, such as data on the beetle distribution and management activities in another mountain park.

With multiple unknown parameters in the model, it is difficult to estimate any of them with certainty using maximum likelihood methods (Hilborn and Mangel 1997). Therefore, further work will also focus on gathering empirical data on dispersal, productivity, and habitat quality that can be used to derive independent estimates of S , α , and K . For example, a mass mark-recapture study that produces density-distance curves in various habitats (e.g., Safranyik et al. 1992) will be used to estimate α . Data on the number of adult beetles that emerge from brood trees (Safranyik and Linton 1985) will be used to estimate S . Estimates for K could be obtained by combining landscape data with models for stand susceptibility and risk (e.g., Shore and Safranyik 1992).

It would be premature to use this model to draw conclusions about mountain pine beetle management. Further work is needed to refine and test the model before reliable results are obtained. The results in this paper are intended to illustrate how this type of model could be used to evaluate past management practises and test hypothetical scenarios. A robust, validated model would allow us to determine how important the proximity of well-established beetle metapopulations in certain areas are to the growth and proliferation of new beetle metapopulations. This information could be used to plan the intensity and spatial extent of beetle management activities.

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