Decision Support Framework for Assessing Alternative Mountain Pine Beetle Management Strategies on Sustainable Forest Management

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Abstract

We developed a decision support framework that facilitates the assessment of alternative mountain pine beetle (MPB) management strategies on wildlife and other sustainable management indicators. Specifically, the framework permits the evaluation of ecological trade-offs (i.e., the probability of occurrence of bird species; landscape composition and configuration; wildlife habitat supply) under alternative salvage logging strategies. An additional function of the framework is to identify areas of uncertainty where data gaps continue to limit decision-making. We demonstrated the application of the decision support framework by evaluating the consequences of five specific salvage harvesting strategies in a case study of a forest landscape in northeastern British Columbia. The five strategies included: 1) a baseline scenario based on current management practices in MPB-affected landscapes; 2) a scenario for salvage–logging-only stands with high pine composition; 3) a scenario for salvage logging stands that included minimal pine; 4) a low retention scenario where relatively few trees are retained within large cutblocks; and 5) a high retention scenario where more trees are retained in large cutblocks than currently practiced. In our case study, we used a subset of the components identified in the conceptual framework since many parameters (e.g., stand-level attributes) were not widely available and could not be scaled up to the case study landscape. The components were for: 1) simulating infestation, salvage logging and forest succession, 2) tracking landscape-level changes in avian probability of occurrence and supply of broad habitat types, and 3) facilitating scenario analysis and decision-making. We identified some broad patterns in species responses over time and helped to identify areas of uncertainty that are the result of model limitations and data gaps. In our case study, avian response was dictated more by the bird species' natural history traits than by differences between management regimes. However, eligibility criterion for salvage logging (i.e., the amount of pine in the stand) was generally more important than the stand retention levels used in our simulations in governing post-harvesting avian response.

Keywords: mountain pine beetle, decision support framework, alternative management strategies, sustainable forest management, beetle control, wildlife, wildlife habitat, birds

Résumé

Nous avons mis au point un cadre d'aide à la décision, destiné à faciliter l'évaluation de stratégies alternatives de gestion du dendroctone du pin ponderosa (DPP) basées sur les espèces sauvages, ainsi que sur d'autres indicateurs de gestion durable. Plus précisément, ce cadre permet d'évaluer différents paramètres écologiques (c'est-à-dire : probabilité de la présence de certaines espèces aviaires; composition et configuration du paysage; disponibilité des habitats fauniques) dans le cadre de stratégies alternatives de coupe de récupération. Ce cadre entend par ailleurs permettre de définir les zones d'incertitude pour lesquelles la carence de données continue à entraver les prises de décision. Pour démontrer l'application de ce cadre d'aide à la décision, nous avons procédé à l'évaluation des conséquences de 5 stratégies de coupe de récupération spécifiques dans une étude de cas concernant une zone forestière du nord-est de la Colombie-Britannique. Les cinq stratégies sont les suivantes : 1) un scénario de référence qui s'appuie sur les pratiques actuelles de gestion des zones infestées par le DPP; 2) un scénario spécifique de coupe de récupération visant exclusivement les zones à forte concentration de pins; 3) un scénario de coupe de récupération comprenant les peuplements à faible concentration de pins; 4) un scénario de rétention minimale selon lequel relativement peu d'arbres seraient conservés dans les blocs forestiers importants; 5) un scénario de rétention maximale selon lequel un nombre d'arbres plus élevé que dans la pratique actuelle serait conservé dans les blocs forestiers importants. Pour cette étude de cas, nous avons utilisé un sous-ensemble des éléments répertoriés dans le cadre conceptuel, compte tenu de l'insuffisante disponibilité de certains paramètres (notamment, attributs du peuplement) et de l'impossibilité de les rapporter à l'échelle de la zone géographique faisant l'objet de notre étude de cas. Les éléments visaient à : 1) simuler l'infestation, la coupe de récupération et la succession forestière; 2) surveiller l'évolution de la probabilité de la présence de certaines espèces d'oiseaux en fonction des paysages et la disponibilité des grands habitats; 3) faciliter l'analyse des scénarios et la prise de décision. Nous avons cerner plusieurs grandes tendances d'évolution dans le temps de la réaction des différentes espèces; nous avons également contribué à définir certaines zones d'incertitude dues aux limites du modèle et à des données lacunaires. Notre étude de cas indique que le comportement des oiseaux était davantage lié à l'histoire naturelle de l'espèce qu'au régime de gestion choisi. Néanmoins, la réaction des oiseaux à la suite d'une coupe semble être généralement davantage influencée par le critère d'admissibilité en vue de la coupe de récupération (à savoir, la concentration de pins dans le peuplement) que par le niveau de rétention au niveau de chaque peuplement utilisé dans les simulations.

Mots-clés : dendroctone du pin ponderosa, cadre d'aide à la décision, stratégies alternatives de gestion, gestion durable des forêts, lutte contre les coléoptères, espèces sauvages, habitat faunique, oiseaux

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1 Introduction

The current mountain pine beetle (MPB) epidemic has spawned several studies on the ecological legacies of the beetle epidemic and on the effects of alternative beetle control measures on wildlife and wildlife habitats. Although these studies have generated valuable information that will help guide management prescriptions, forest managers are still limited in their ability to easily assess the effects of alternative mountain pine beetle management strategies on wildlife and sustainable forest management indicators. The situation is further complicated by the need to evaluate the economic and ecological trade-offs associated with short- and long-term management strategies. Decision support systems that integrate key decision factors can facilitate these tasks by permitting the evaluation of alternative management scenarios and trade-offs over large multiple spatial and temporal scales.

The management of MPB-infested forest lands must balance economic factors such as salvaging affected stands before their economic value drops too low with ecological factors such as sustaining biodiversity and other ecological values in those same forests. A decision support system can facilitate such decisions by using information, data, and knowledge about MPB-forest-wildlife systems to assess the ecological consequences of various salvaging strategies including reserving affected stands and retaining structures within affected stands. Such systems can generate quantitative predictions about selected indicators, provide guidance on how to manage trade-offs between salvaging strategies and ecological outcomes, and identify areas of uncertainties.

In this report, we describe the development of a decision support framework that facilitates the assessment of alternative MPB management strategies on wildlife and other sustainable management indicators. The framework is intended to facilitate decision-making on complex issues such as the manner and extent to which salvage logging should proceed, and to prioritize locations where beetle-attacked stands should be left unharvested. The framework integrates a number of important components that have a bearing on sustainable forest management, including direct wildlife response, the supply of wildlife habitat attributes, and how these change over time. The decision support framework will also help identify areas of uncertainty where data gaps continue to limit decision-making. We illustrate the application of the framework by evaluating the consequences of five specific management strategies in a managed forest landscape in northeast BC.

2 Methods

We compiled literature on the relationships between the mountain pine beetle and ecological factors under scenarios of salvage logging as well as scenarios where there is no salvage logging. Information was compiled from on-line searches of published literature (using, for example, databases such as Web of Science as well as homepages of relevant journals), the gray literature, and unpublished reports from mountain-pine beetle researchers whose studies were not yet in press. We focused on six major areas: 1) socio-economic-political constraints; 2) anthropogenic disturbances and practices; 3) natural disturbances and stand ecological practices, including insect disturbances such as the mountain pine beetle epidemic; 4) existing site features; 5) landscape attributes; and 6) biotic and ecological processes. From >1000 papers that were identified in our searches, we selected the ones that provided the most relevant data for use in a multicriteria decision analysis. We catalogued each paper for factors important to multicriteria decision analysis, including ecosystem types to which the study applied, response variables, range of values in dependent and independent variables, and units for dependent and independent variables. Where data were rare or lacking (e.g., large scale MPB effects on wildlife), we used surrogate studies that provided data on similar relationships (e.g., effects of other insect epidemics, effects of salvage logging post-fire, etc.). We also reviewed studies examining sequential disturbances because salvage logging of beetle-killed stands represents an anthropogenic disturbance superimposed on a natural disturbance.

Following the literature compilation, we drafted a framework that incorporated critical considerations and factors in a decision-making sequence that would streamline the decision-making process, using the best available information from the literature. The draft framework included linkages among 61 critical factors and ecological processes, documenting both input variables dictating the factor or process in question, as well as output variables affected by the factor or process. Because quantified relationships and landscape-level spatial data were lacking for many of these generalized linkages, we adopted a subset of nodes and linkages that we could initially work with as a prototype for the decision-making framework. These nodes include landscape dynamics, biodiversity assessment, and decision analysis, and are reported in detail in the results for the framework (Section 3.1).

We used the GIS-based prototype developed in conjunction with an earlier study (Chan-McLeod and Vernier 2008) to demonstrate the utility of the decision support framework and to conduct a case study for a realistic landscape that is based on vegetation resources inventory (VRI) data but that has not yet been infested by the mountain pine beetle. The landscape for the case study consisted of a 14,000 ha area of pine, spruce-fir, aspen, and aspen-mixedwood forests from northeast BC (Figure 1). Although our case study was of an uninfected landscape, the framework can be applied to MPB-affected managed forest landscapes for which current forest inventory data (preferably VRI data) and habitat supply models are available.

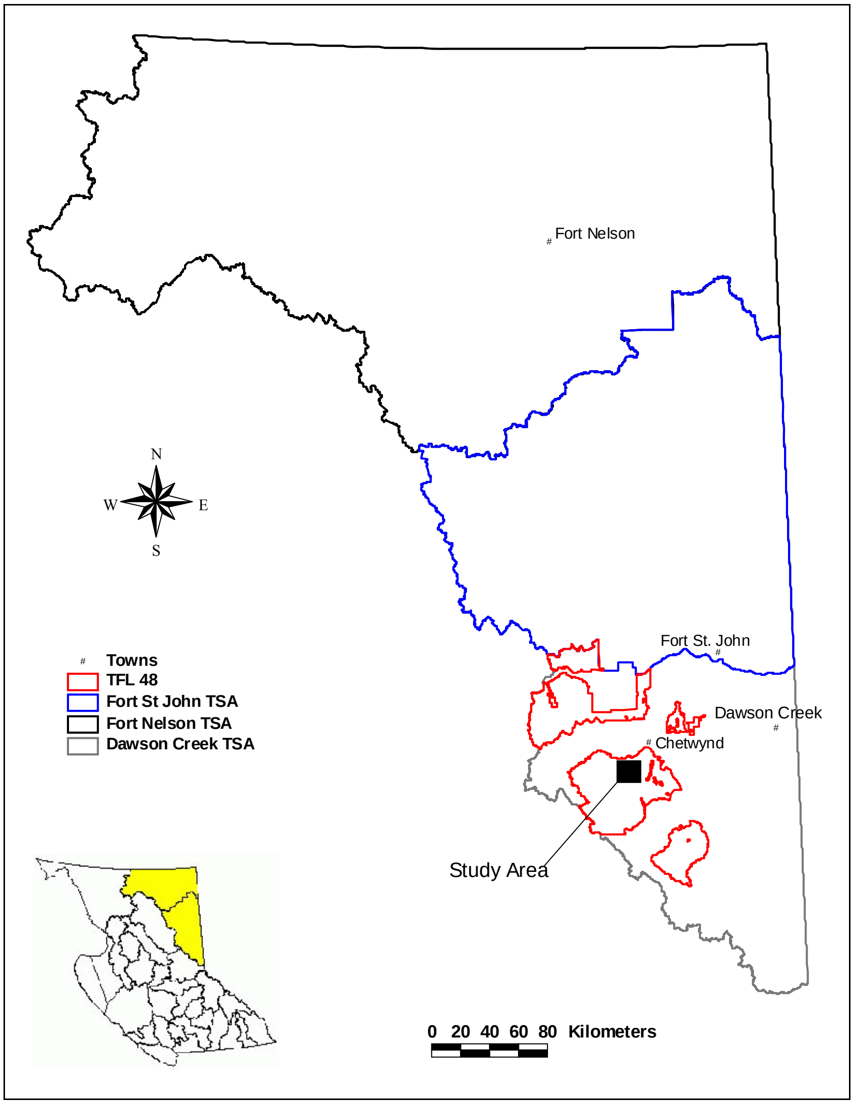

Figure 1. Location of the study area in TFL 48.

In our case study, we simulated five scenarios of MPB infestation and salvage harvesting. All scenarios assumed that 80% of all pine above 10 cm diameter at breast height (DBH) would be infested during the outbreak. The different scenarios harboured different assumptions about the types of infested stands in the landscape that will be salvaged, and the tree cover that will be retained within harvested stands (Table 1). Our baseline scenario is based on current management practices in MPB infested landscapes. The other scenarios bracket the baseline scenario in terms of eligibility criteria for salvage logging stands, and in terms of retention level for large cutblocks. From our framework models, we generated a probability of occurrence map for individual bird species. These are summed up across all pixels for the landscape to provide an index of the suitability of the landscape for each species. We standardized the values for the summed probability of occurrence so that users can easily compare the explicit consequences of alternate management scenarios.

Table 1. Description of parameters for five management scenarios evaluated in the case study.

	Baseline	**Low pine stands are salvaged**	**Only high pine stands salvaged**	**Low retention**	**High retention**
Infestation level	80% of all pine above 10 cm dbh	Baseline	Baseline	Baseline	Baseline
Stands selected for salvage logging	Salvage stands with at least 70% pine	Salvage stands with at least 50% pine	Salvage stands with at least 80% pine	Baseline	Baseline
	Partial cut half the stands with 30-70% pine; other half is fully logged	Partial cut half the stands with 20-50% pine; other half is fully logged	Partial cut all stands with 50-80% pine	Baseline	Baseline
	Do not salvage stands < 30% pine	Do not salvage stands < 20% pine	Do not salvage stands < 50% pine	Baseline	Baseline
Retention level[1] (% of basal area)	< 50 ha – 10% 50 – 250 ha – 12.5% 250 – 1000 ha **– 20%** > 1000 ha – 25%	Baseline	Baseline	Same as baseline for cutblocks < 250 ha; 250 – 1000 ha – 12.5% > 1000 ha – 15%	Same as baseline for cutblocks < 250 ha; 250 – 1000 ha – 25% > 1000 ha – 30%

[1] Retain species proportionally to their pre-harvest levels.

To develop our landscape models, we used multiple logistic regression analysis to model the occurrence of bird species in relation to the neighbourhood habitat characteristics (Figure 3). Definitions of model covariates along with coefficients and standard errors for statistically significant models used in the decision support framework can be viewed at http://biod.forestry.ubc.ca/mpb/mpb855.html (accessed Sept. 24, 2008). We used the resultant logistic regression functions to generate a probability of occurrence map (and output summary table) for each species, thus providing a quantitative assessment of the suitability of a landscape for a specific species. This information complements the coarse filter evaluation of the habitat pattern indicators (see Section 3.1.2).

3 Results and Discussion

3.1 Framework Description

The main function of the current framework is to support forest management decisions by assessing the impacts of different salvage logging scenarios on ecological indicators. More specifically, the framework was designed to simulate MPB infestation and salvage logging, and to quantify changes in wildlife habitat supply as well as landscape composition and configuration. It thus provides a generalized decision-making process for managers that can be applied to different MPB related scenarios. The decision support framework consists of several components (models) that we have organized under three broad categories: landscape dynamics, biodiversity assessment, and decision analysis (Table 2).

Table 2. Summary description of model components that make up the decision support framework.

Category	Model	Description
Landscape Dynamics	MPB Infestation	Infests pine stands in a landscape. Proportion of pine trees infested and their size (age) are defined by the user.
	Salvage Harvesting	Simulates salvage harvesting after an MPB infestation. Several parameters including opening size and retention level can be modified.
	Forest Succession	Ages all forested stands in a landscape. Currently does not allow species transitions e.g., deciduous to conifer.
Biodiversity Assessment	Habitat Classification and Pattern	Classifies landscapes based on tree species and seral stages and summarizes landscape level habitat composition and configuration.
	Avian Habitat Supply	Maps and summarizes habitat supply for selected forest songbirds and guilds (e.g., mature forest-dwelling species).
	Habitat Attribute Supply	Projects supply of specific wildlife habitat attributes, such as snags. Not currently functional.
Decision Analysis	Scenario Analysis	Define and run scenarios to simulate MPB infestation and salvage harvesting strategies.
	Landscape Retention	Identify and prioritize areas where beetle-attacked stands should be left unharvested.
	Stand Retention	Select manner and extent to which salvage logging should proceed.

3.1.1 Landscape Dynamics

The models for simulating MPB infestation and post-infestation salvage harvesting are implemented as Python scripts for use with ArcGIS (Chan-McLeod and Vernier 2008). The model scripts can eventually be integrated with existing tools such as LANDIS II or SELES, which allow more sophisticated simulation and projections of harvesting strategies, natural disturbances (insect outbreaks, fire, and windthrow), and succession than our own scripts. These tools can be used to generate information on the state of the forest at various time steps which would feed into the habitat and decision support models described below. The main disadvantage of this approach is that it would create a need for importing and exporting data layers to and from the GIS.

Mountain Pine Beetle Infestation

The purpose of the Infestation model is to simulate the impact of an outbreak on the pine-leading stands at the landscape level. Currently, the model can be used to infest pine trees located within forested stands. The user can select any percentage between 0-100% for infestation. Stands are randomly selected from a landscape until the desired level of infestation is reached. The size of pine trees to be infested is also set by the user, who selects the age of the stand as a surrogate variable for diameter at breast height (DBH), which is not available in all databases. In the case study, we specified that 80% of pine trees >30 years (roughly equivalent to >10 cm DBH) should be infested. This model is currently not spatially explicit as stands are randomly selected from a list of available stands.

Salvage Harvesting

The Salvage Harvesting model simulates salvage harvesting strategies after a landscape has been infested by the mountain pine beetle. It is a rule-based model that incorporates several user-modifiable parameters for cutblock size, retention level, and the composition of the trees retained. Similar to the Infestation model, stands are randomly selected from a list of available stands within a landscape.

Forest Succession

The Forest Succession model ages forest stands for a number of years (as defined by the user) after the initial infestation and salvage harvesting are completed. It facilitates evaluation of possible stand trajectories over the short term. Currently, the model assumes that the composition of stands that are not harvested remains fixed. Future development may incorporate species transition matrices to more realistically simulate forest succession.

3.1.2 Biodiversity Assessment

The Biodiversity Assessment model allows evaluation of current and future forest landscapes in terms of a set of biodiversity indicators. Two groups of indicators are currently incorporated into the framework. The first group characterizes the composition and configuration of the landscape (Table 3) while the second group evaluates the quantity and quality of habitat for selected species and guilds. Selected species and their associated habitat models can be found at http://biod.forestry.ubc.ca/mpb (accessed Sept. 24, 2008). Both sets of indicators are used to evaluate alternative forest management strategies.

Habitat Classification and Pattern

The quantification of landscape structure (i.e., the composition and configuration of forest and non-forest habitats) provides a coarse filter assessment of the suitability of the landscape for various elements of biodiversity. The Habitat Classification and Pattern component of the framework is used to quantify landscape characteristics including the proportion of habitat types, the connectivity and spatial arrangement of habitat types, and the amount of forest interior and edge habitats. Currently, 10 broad habitat classes are used to track landscape composition and develop the habitat supply models (Table 3).

Table 3. Habitat classification system used to calculate neighbourhood-level habitat variables.

Class #	Habitat class	Case study area (%)	Description
1	Water	0.2%	Rivers, lakes, and reservoirs
2	Non-vegetated	0.9%	Non-vegetated habitat (natural or anthropogenic)
3	Non-forested	2.0%	Non-forested habitat (vegetated upland and wetland)
4	Recent disturbance	11.0%	≤30 years (e.g., recent clearcuts)
5	Young deciduous	0.8%	Deciduous forest (≥75% deciduous species) and 31-90 years
6	Old deciduous	0.7%	Deciduous forest (≥75% deciduous species) and > 90 years
7	Young coniferous	9.1%	Coniferous forest (≥75% coniferous species) and 31-90 years
8	Old coniferous	71.4%	Coniferous forest (≥75% coniferous species) and > 90 years
9	Young mixedwood	1.4%	Mixedwood forest (<75% deciduous or coniferous species) and 31-90 years
10	Old mixedwood	2.4%	Mixedwood forest (<75% deciduous or coniferous species) and >90 years

Avian Habitat Supply

The habitat sub-models predict habitat quality and supply for selected species (currently forest birds) based on relationships with stand and landscape level attributes (Figures 2 and 3). These different-scaled models are used to explore how forest management-induced changes in stand and landscape composition affect habitat supply. The models are used independently – the landscape models are first used to project broad patterns and then the stand models are used to modify local projections at salvageable sites. Because spatially explicit VRI data are not widely available for landscapes, we used only the landscape level models in our prototype for the case study.

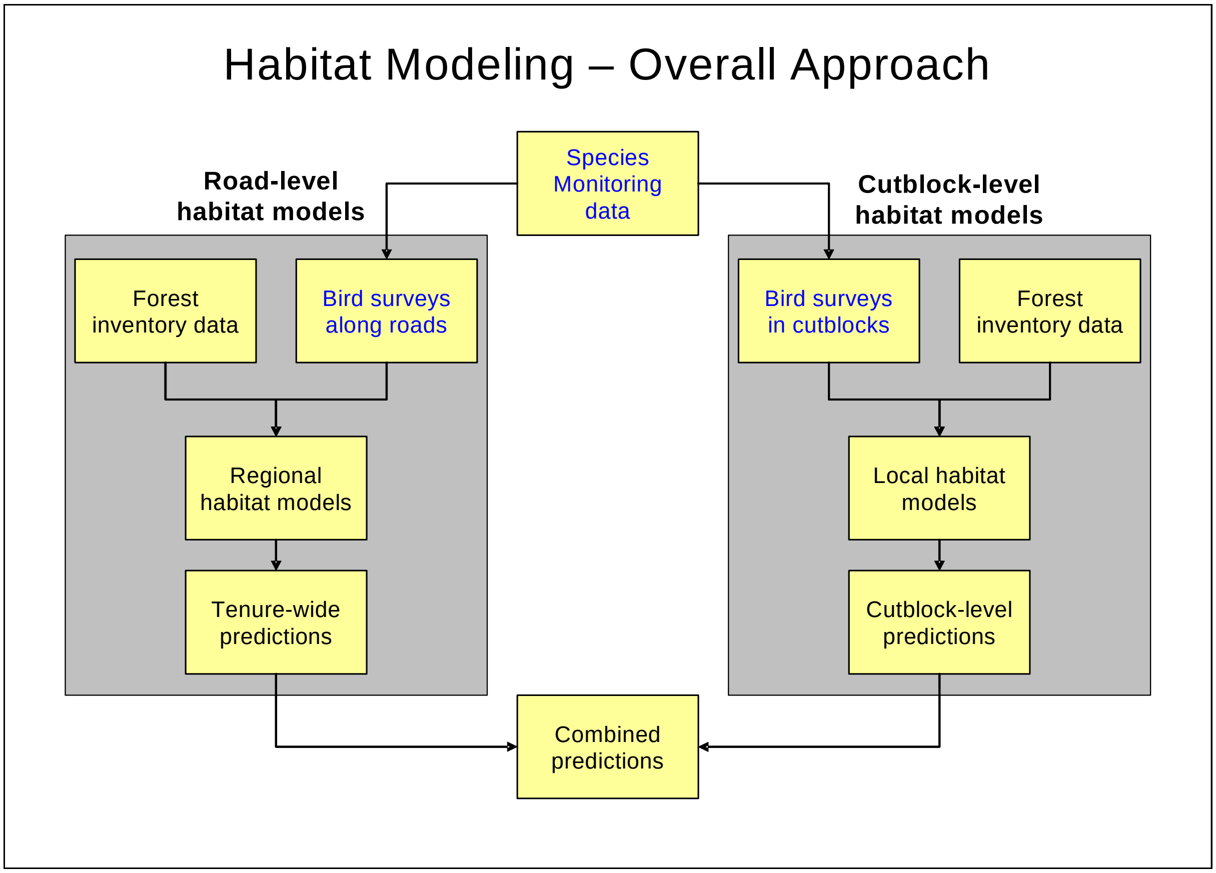

Figure 2. Habitat modeling approach combining local and regional bird and habitat data.

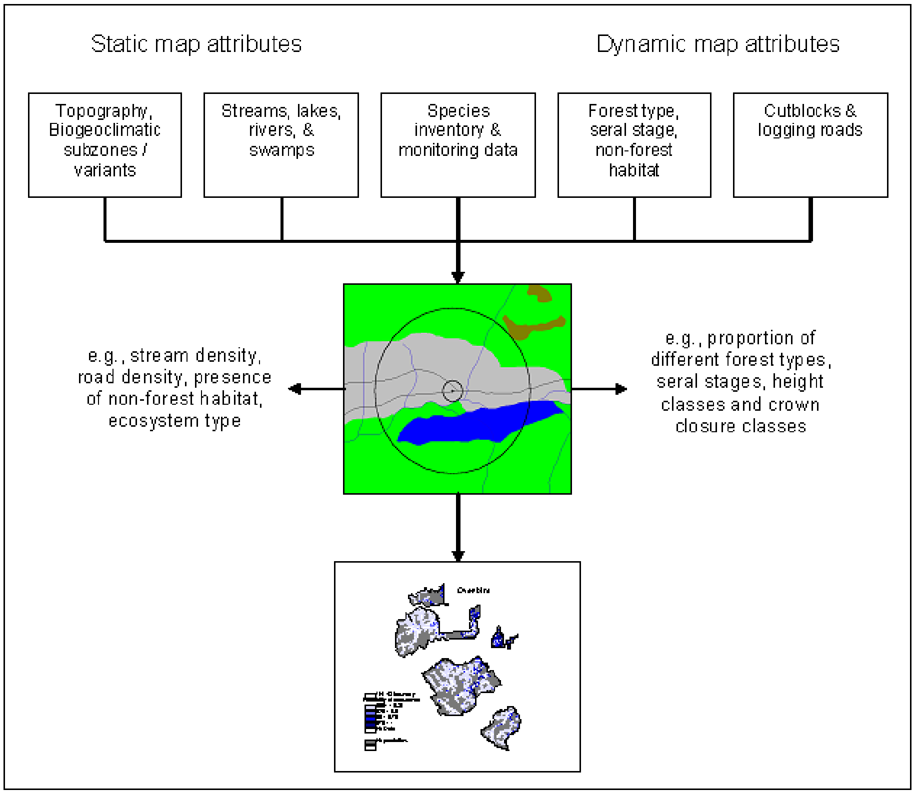

Figure 3. Overview of landscape-level (neighbourhood) habitat modelling approach.

3.1.3 Decision Analysis

The decision analysis component includes scenario and trade-off analyses, multi-criteria analysis, and sensitivity analysis.

Scenario Analysis

The Scenario Analysis component provides the main approach for evaluating alternative forest management strategies and trade-offs among ecological and economic indicators. Since our primary concern was with evaluating the consequences of salvage harvesting decisions, this component facilitated the exploration of several key decision factors related to alternative management strategies. The Scenario Analysis component is intended to be linked to the biodiversity assessment and multi-criteria analysis models.

Multi-criteria Analysis

Multi-criteria Analysis (MCA) describes a structured approach to determine overall preferences among alternative options, where the options are designed to accomplish several objectives (e.g., maintain habitat supply for bird species associated with early and late successional forests). Multi-criteria Analysis thus complements the assessment of individual biodiversity indicators (e.g., habitat supply for cavity nesters) by considering several criteria simultaneously. The MCA component is not part of our prototype but should eventually be included as an integral part of a decision support system for analysing trade-offs among different management scenarios.

Sensitivity Analysis

The Sensitivity Analysis component of the framework helps to identify the contribution of various sources of variation to the uncertainty in model output. By re-running scenarios under various assumptions it may be possible to identify key uncertainties or knowledge gaps as well as important decision factors. Theoretically, uncertainty analysis can be performed to evaluate all other model components within the framework. This component is not part of our existing prototype but should be included as an integral part of a decision support system.

3.2 Case Study: Response of Birds to Management Scenarios

Sample output for our decision support framework is provided by our results for the probability of occurrence indices for individual bird species (Figures 4 to 10) and for habitat class areas (Figures 11 to 17). More specifically, these figures depict the ecological consequences of five alternative management regimes for the case study area. Management consequences can be evaluated relative to starting values, compared across management regimes, and monitored over time. Our framework can be adapted for use at other mountain pine beetle-impacted areas of interest, but currently does not have the capacity to easily input parameters and spatial data for other areas.

In our case study, avian response was dictated more by the bird's natural history traits than by differences between management regimes. Thus, species preferring open or edge habitats, or those requiring shrub and deciduous habitats (e.g., alder flycatcher, least flycatcher, warbling vireo; Figures 4, 6, 9) generally increased in abundance following salvage logging, regardless of management scenario. Although differences in avian response were sometimes apparent between management scenarios, these differences were generally much less than the interspecific response of birds possessing different habitat requirements. In contrast to the open or deciduous dwelling species, species commonly inhabiting closed conifer forests (e.g., golden-crowned kinglet, Townsend's warbler; Figures 5 and 8) declined in abundance following salvage logging, regardless of management scenario.

In our case study, eligibility criterion for salvage logging (i.e., the amount of pine in the stand) was generally more important than the stand retention levels used in our simulations in governing post-harvesting avian response. For example, salvage logging stands with low pine composition resulted in higher indices of least flycatcher, red-eyed vireo, warbling vireo, and yellow warbler (Figures 6, 9, and 10) than baseline practices that completely harvested stands with at least 70% pine and partially harvested stands with 30 – 70% pine, regardless of retention level. Salvage logging only stands with high pine composition resulted in the lowest species indices for these birds. This may be because the models are sensitive to the composition of habitat types regardless of whether the specific habitats are within a cutblock (retention patch) or whether the habitats form part of the forest. In general, the amount of habitat retained within retention-harvested cutblocks is small compared to that which occurs at the landscape level.

Eligibility criterion for salvage logging (i.e., the amount of pine in a stand) was also a more important factor than retention level in dictating post-harvesting response of some, but not all, mature forest dwelling species. For example, salvage logging only stands with high pine composition resulted in 29% more golden-crowned kinglets than if salvage logging occurred under conventional harvesting practices, and 63% greater kinglet abundance than if salvage logging occurred in stands with low pine composition (Figure 5). Alternately, retention level did not affect golden-crowned kinglet abundance when salvage logging criteria did not differ. In contrast to golden-crowned kinglet, alternate management regimes had virtually no effect on the probability of occurrence for Townsend's warbler, a species that is highly sensitive to harvesting. In our case study, Townsend's warbler indices declined to zero 50 years post-harvesting, regardless of salvage logging scenario. However, Townsend's warbler had recovered to approximately 73% pre-beetle and pre-harvesting levels, 100 years after salvage logging, for all management scenarios.

For all bird species in the case study, differences between management scenarios were most pronounced within 50 years of salvage logging. All observed differences between management scenarios had converged by year 100 post-harvest, with avian response being comparable at that time.

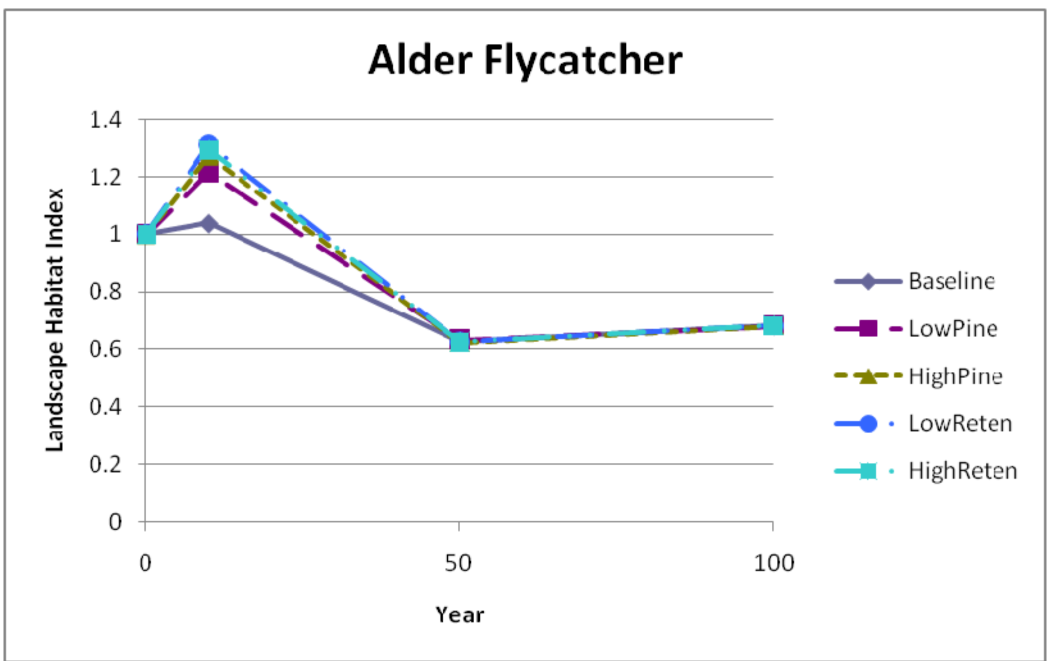

Figure 4. Preliminary sample output for sum predicted probability of occurrence in the landscape as a proportion of the amount at year 0 under five alternative salvage harvesting scenarios.

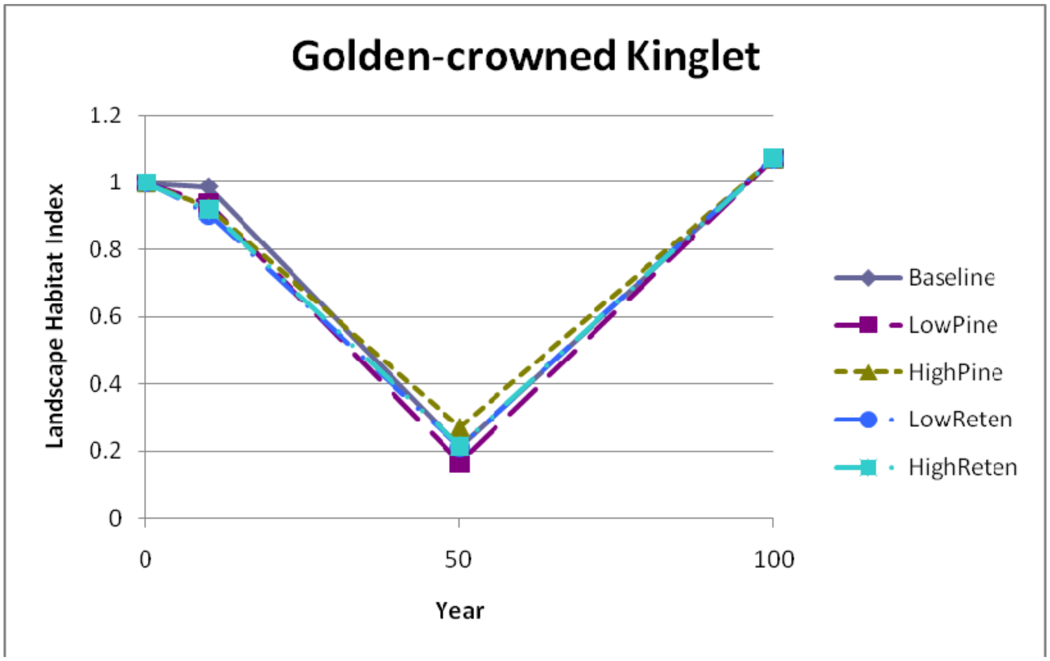

Figure 5. Preliminary sample output for sum predicted probability of occurrence in the landscape as a proportion of the amount at year 0 under five alternative salvage harvesting scenarios.

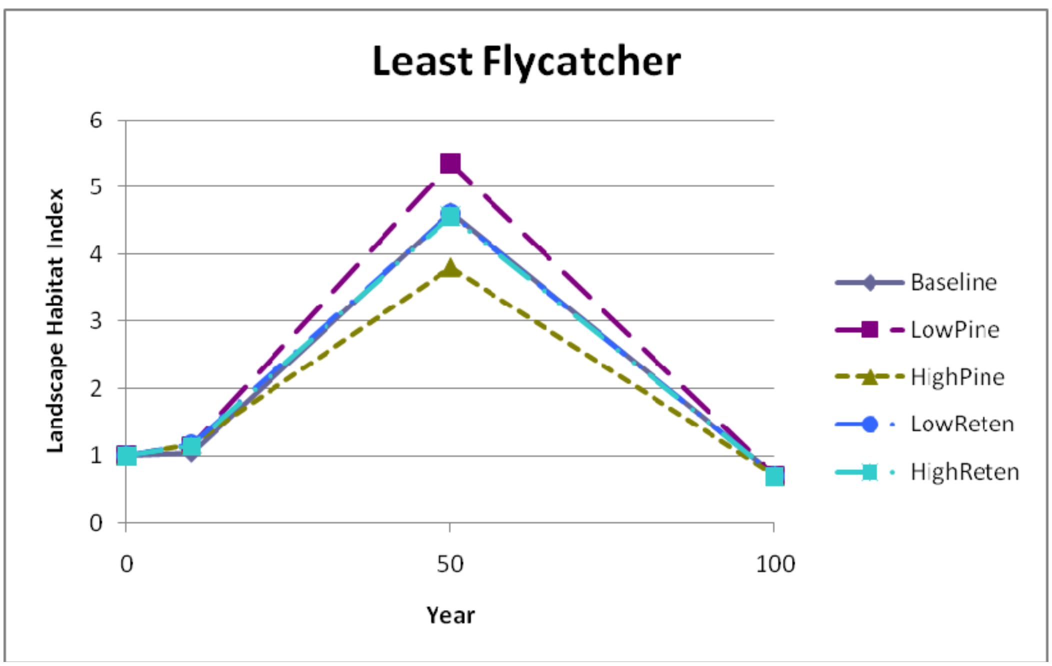

Figure 6. Preliminary sample output for sum predicted probability of occurrence in the landscape as a proportion of the amount at year 0 under five alternative salvage harvesting scenarios.

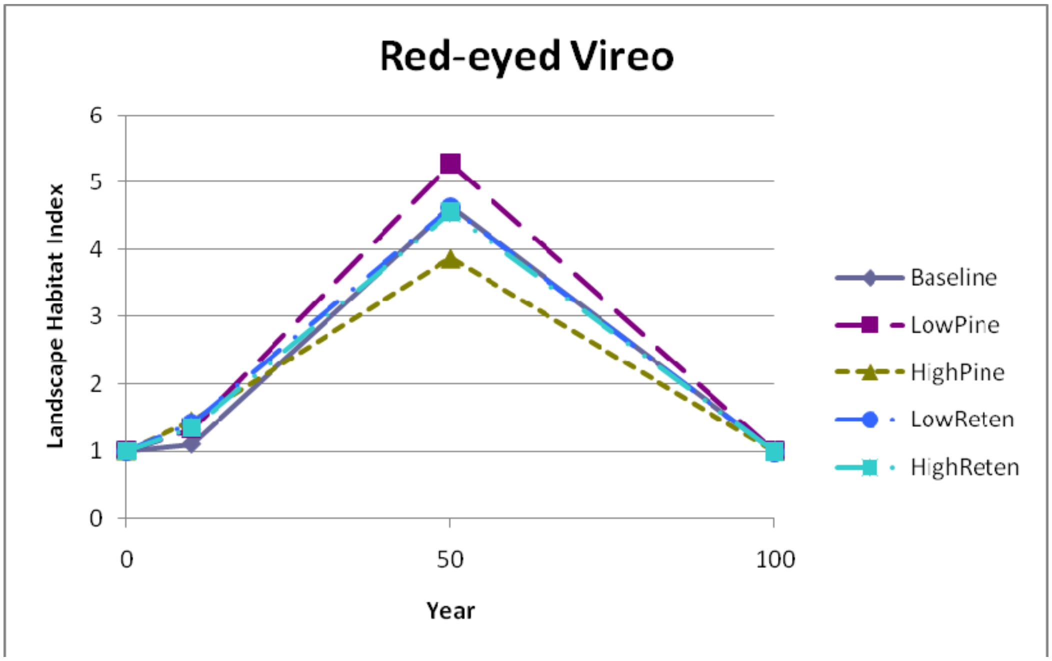

Figure 7. Preliminary sample output for sum predicted probability of occurrence in the landscape as a proportion of the amount at year 0 under five alternative salvage harvesting scenarios.

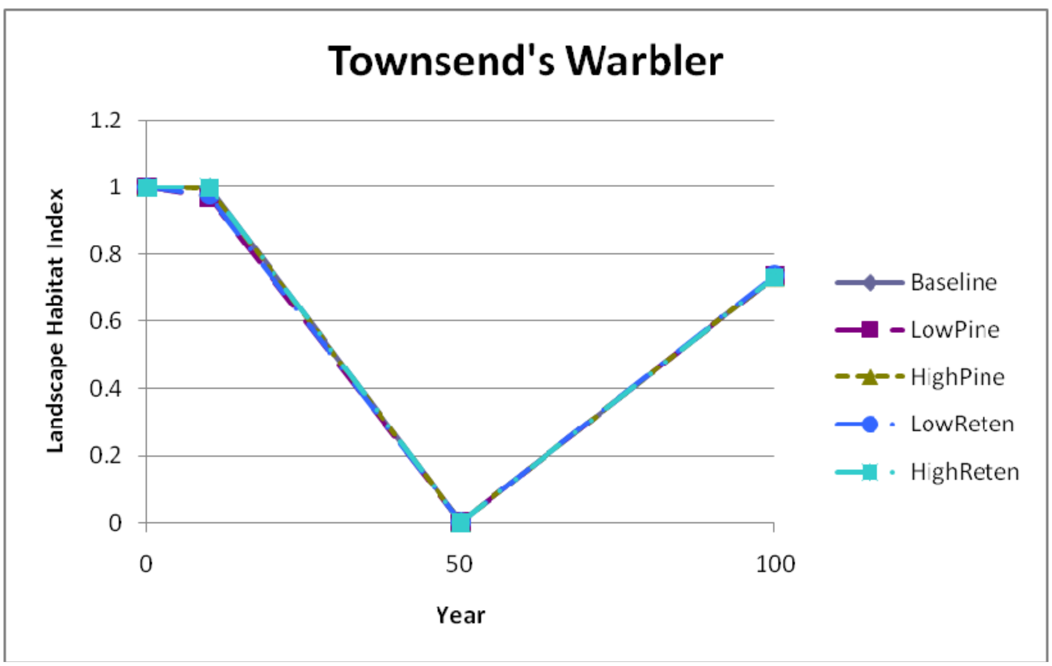

Figure 8. Preliminary sample output for sum predicted probability of occurrence in the landscape as a proportion of the amount at year 0 under five alternative salvage harvesting scenarios.

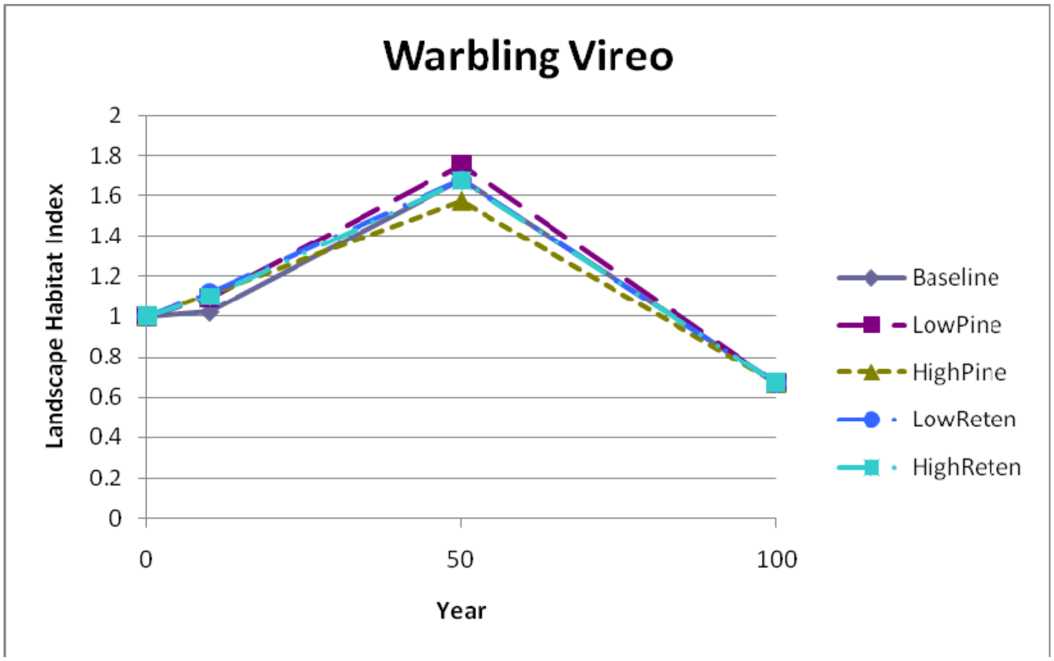

Figure 9. Preliminary sample output for sum predicted probability of occurrence in the landscape as a proportion of the amount at year 0 under five alternative salvage harvesting scenarios.

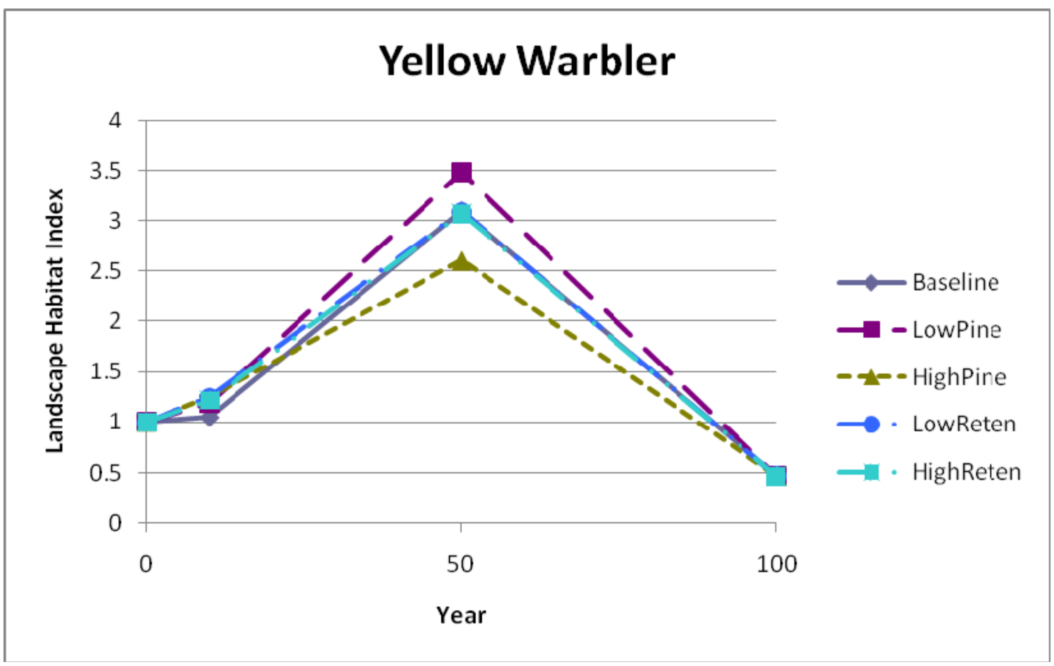

Figure 10. Preliminary sample output for sum predicted probability of occurrence in the landscape as a proportion of the amount at year 0 under five alternative salvage harvesting scenarios.

In addition to tracking avian response, our framework tracked changes in the amount of forested habitat types over time (Figures 11-17). In the short term the amount of recently disturbed areas (i.e., cutblocks) increased largely at the expense of old coniferous forests since this is where much of the infested pine trees occurred. In the mid term there was an increase in all early seral forest types as succession advanced after salvage logging was completed. The results confirmed what was expected in the long term because the prototype does not currently implement infestation and harvesting beyond the initial outbreak and salvage logging period. Consequently, there was a long term increase in late seral forest types (Figures 13, 15, 17) and a concurrent decrease in recently disturbed and early seral forest types (Figures 11, 12, 14, 16).

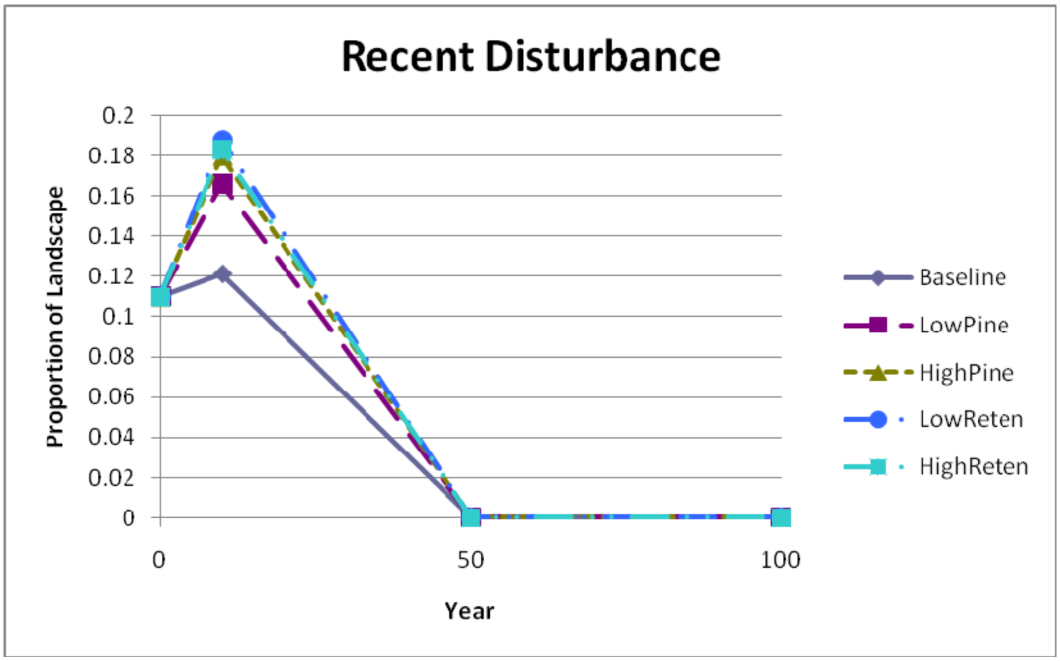

Figure 11. Preliminary sample output for change in the proportion of the landscape that is recently disturbed under five alternative salvage harvesting scenarios.

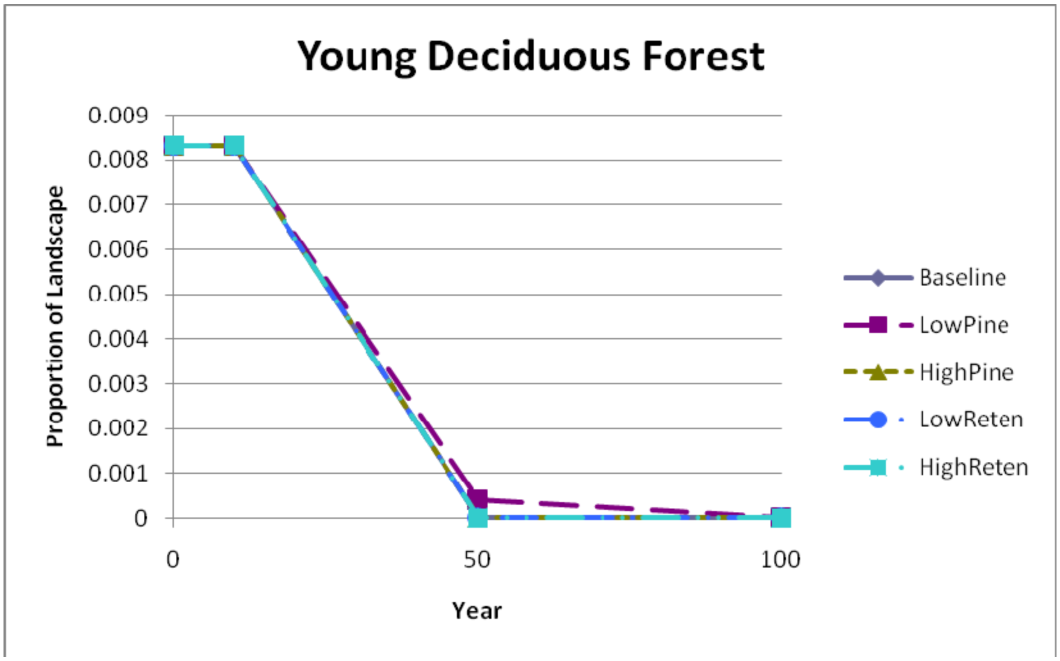

Figure 12. Preliminary sample output for change in the proportion of the landscape that is young deciduous forest under five alternative salvage harvesting scenarios.

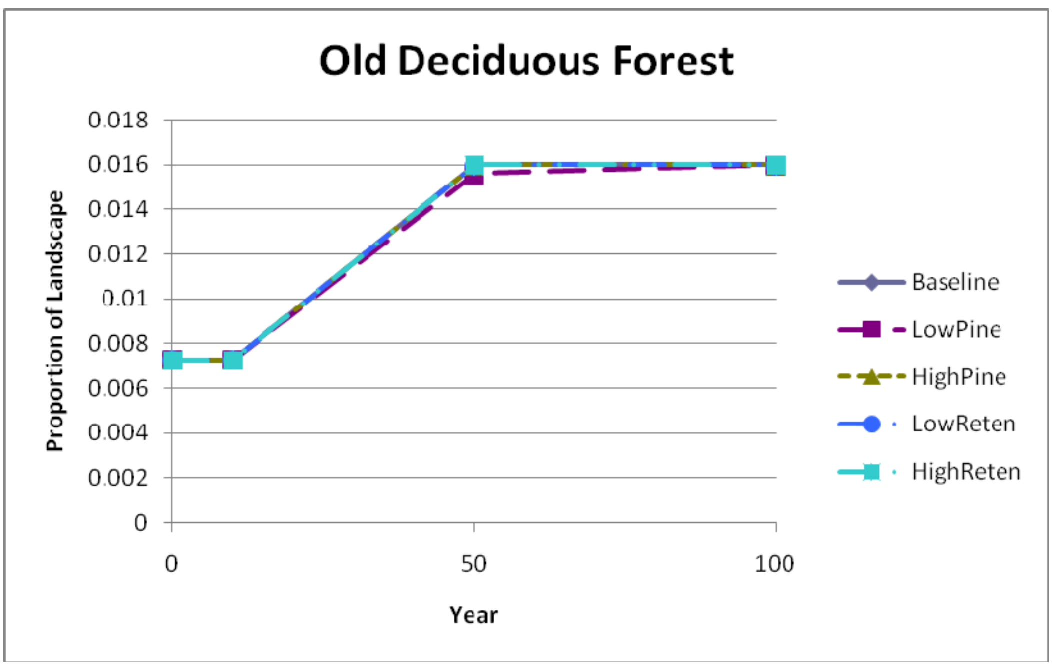

Figure 13. Preliminary sample output for change in the proportion of the landscape that is old deciduous forest under five alternative salvage harvesting scenarios.

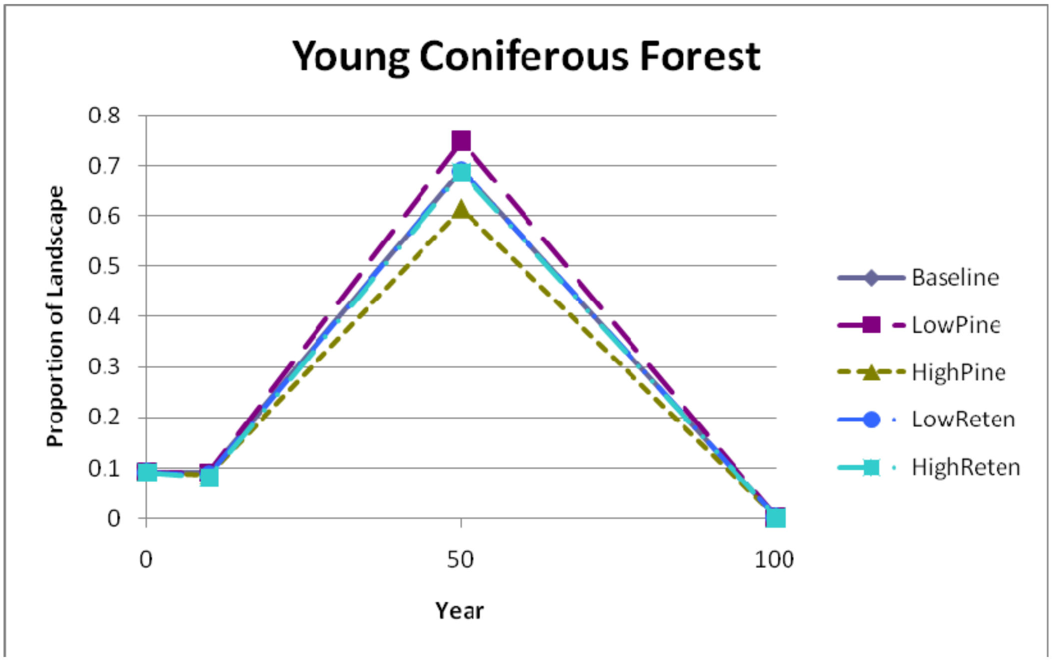

Figure 14. Preliminary sample output for change in the proportion of the landscape that is young coniferous forest under five alternative salvage harvesting scenarios.

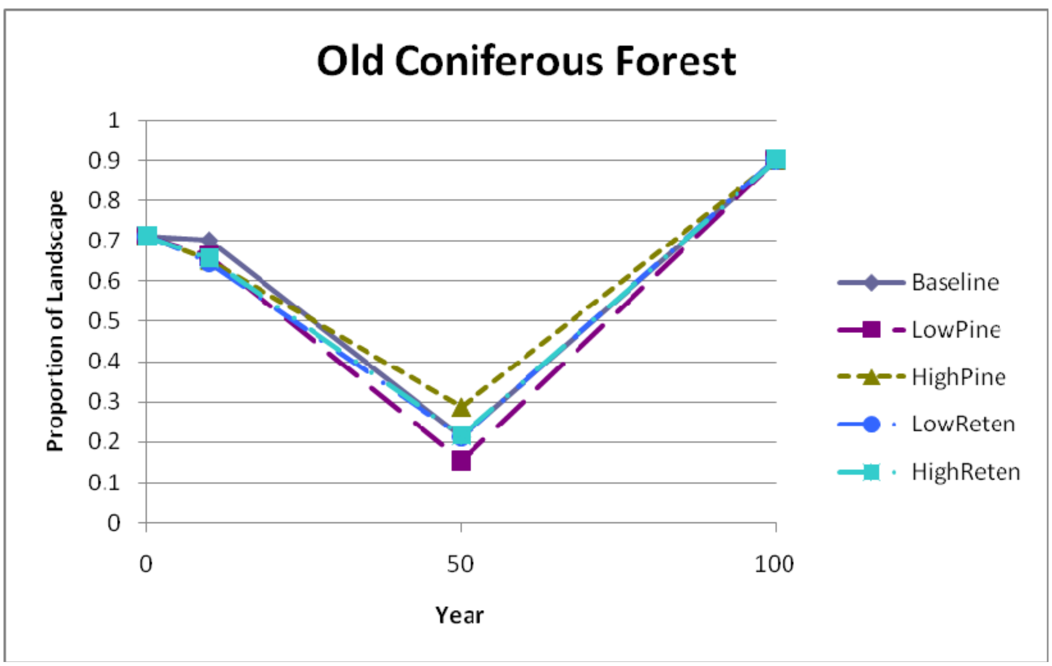

Figure 15. Preliminary sample output for change in the proportion of the landscape that is in old coniferous forest under five alternative salvage harvesting scenarios.

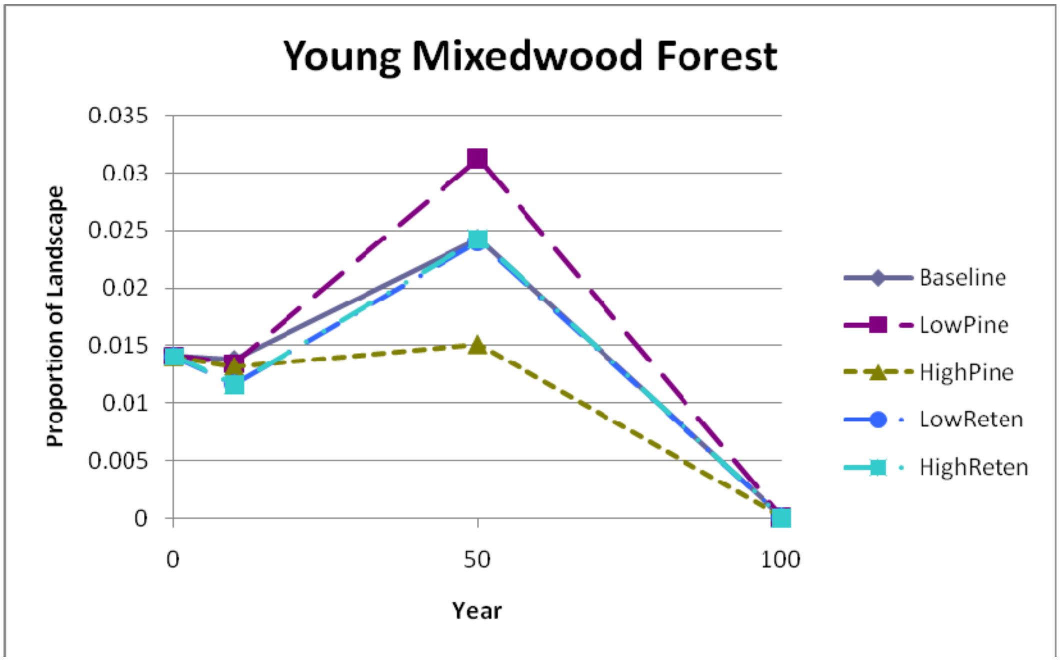

Figure 16. Preliminary sample output for change in the proportion of the landscape that is in young mixedwood forest under five alternative salvage harvesting scenarios.

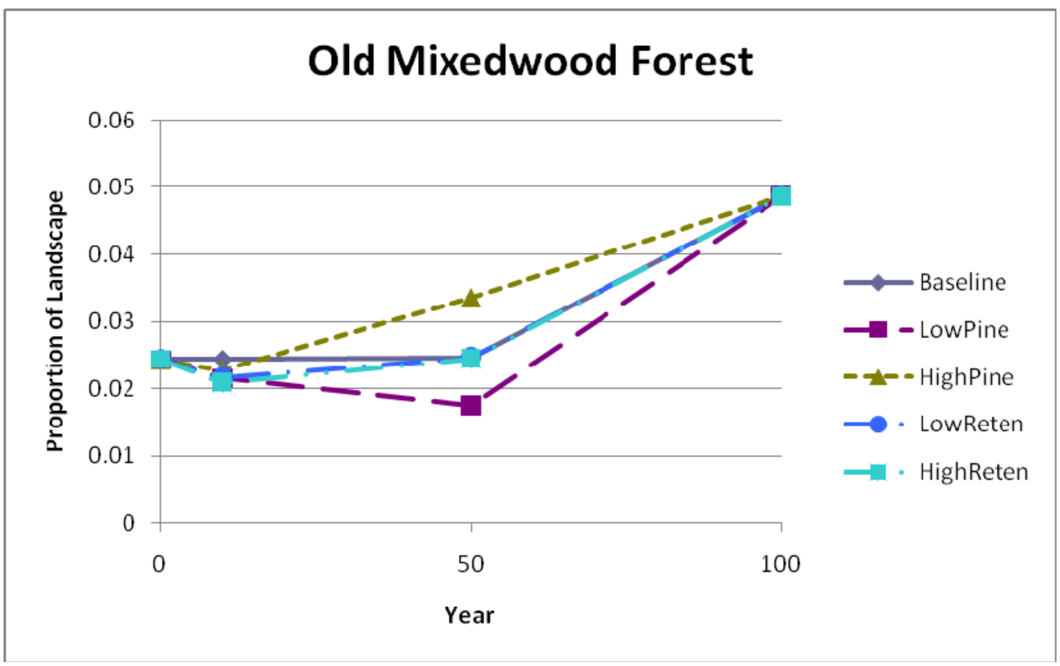

Figure 17. Preliminary sample output for change in the proportion of the landscape that is old mixedwood forest under five alternative salvage harvesting scenarios.

4 Discussion and Conclusions

In this project, we developed a decision support framework that facilitates the assessment of alternative mountain pine beetle management strategies on wildlife and other sustainable management indicators. Specifically, the framework permits the evaluation of ecological trade-offs (i.e., the probability of occurrence of bird species; landscape composition and configuration; wildlife habitat supply) under alternative salvage logging strategies. The framework integrates a number of important components that affect sustainable forest management, including direct wildlife response, the supply of wildlife habitat attributes, and how these change over time. An additional function of the framework is to identify areas of uncertainty where data gaps continue to limit decision-making.

We demonstrated the application of the decision support framework by evaluating the consequences of five specific salvage harvesting strategies in a managed forest landscape in northeastern British Columbia. We used a prototype (developed by Chan-McLeod and Vernier 2008) that consisted of a subset of the components identified in the framework. These included modules for 1) simulating infestation, salvage logging and forest succession, 2) tracking landscape-level changes in avian probability of occurrence and supply of broad habitat types, and 3) facilitating scenario analysis and decision-making. The prototype generated some broad patterns in species responses over time and helped to identify areas of uncertainty that are the result of model limitations and data gaps. In most cases species responses were not easily differentiated between scenarios and appeared to be influenced by natural history characteristics, especially habitat requirements. This can be seen from parallel trends between broad forest cover types and the probability of occurrence of species having requirements for those same cover types.

The prototype framework focused on landscape-level avian responses to stand- and landscape-level salvage harvesting strategies. As such, it does not permit an evaluation of the effects of retaining clusters of trees within cutblocks. Stand-level habitat models have been developed but are not implemented in the prototype because it was not possible to project the required covariates (e.g., snags) over the whole landscape using forest inventory data. We suggest three possible solutions. One would be to project the stand-level habitat attributes over space and time i.e., where they were not sampled. However, this is beyond the scope of the project and we do not know of any existing tool that does this for the set of attributes currently included in the models. A second option would be to develop avian models that are responsive to broad measures such as the distribution, abundance, and type of forest retained within cutblocks; however sample size may be an issue. A third approach would be to explore the correlation structure among stand- and landscape-level habitat attributes. This would allow us to investigate the unique contribution of stand-level attributes to songbird models over and beyond that portion which is correlated with landscape-level attributes. The benefit would likely be a reduced subset of stand-level attributes.

Another limitation of the prototype is the aspatial nature of the landscape dynamics sub-models which we have implemented within the geographic software, ArcGIS. Currently, we ran only one iteration of the simulation, which means confidence intervals cannot be generated around the indicator estimates. Although it is possible to run several hundred simulations, there are some serious performance issues when this is done within ArcGIS i.e., it takes approximately two hours to run one simulation for a small landscape. Consequently, we are exploring the use of an external program to perform the landscape simulations. This would also have the added benefit of incorporating spatially-explicit factors (e.g., spread) into the sub-models.

Further development of a decision support tool should also consider: 1) the use of landscape configuration metrics (e.g., spatial arrangement and connectivity of habitat patches) to assess suitability of habitat types for biodiversity; 2) incorporating the capacity to harvest over the long term and not just during the initial outbreak and salvage logging period; 3) simulating the succession of unsalvaged, MPB-infested stands, which may or may not have an existing understory of trees that may be released by the breakup of beetle-killed trees; and 4) incorporating effects of surrounding beetle-killed landscapes on avian response.

5 Acknowledgements

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6 Literature Cited

Chan-McLeod, A and P. Vernier. 2008. Decision support tool for managing biodiversity and ecosystem resilience in mountain pine beetle-susceptible landscapes. MPBP # 7.26 Progress Report. Unpublished report available from Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Mountain Pine Beetle Program, Victoria, BC.

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