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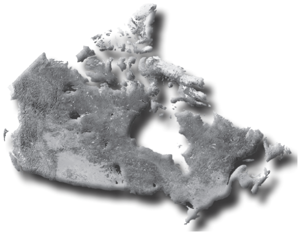

Predicting Mountain Pine Beetle Impacts on Lodgepole Pine Stands and Woody Debris Characteristics in a Mixed Severity Fire Regime Using Prognosis^{BC} and the Fire and Fuels Extension

B. Hawkes; S. Taylor; C. Stockdale; T. Shore;
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Mountain Pine Beetle Initiative
Working Paper 2005–22

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ABSTRACT

This paper examines the use of Prognosis^{BC} (the BC variant of the Forest Vegetation Simulator) and the Northern Idaho variant of the Fire and Fuels Extension (FFE) to project changes in stand structure, fuel loading, snag density, and potential fire behaviour following a mountain pine beetle outbreak in a mixed severity fire regime on the Chilcotin Plateau in central interior British Columbia. Lodgepole pine stands on the dry cold Chilcotin Plateau have a complex structure (multi-age and size) because of previous mountain pine beetle (MPB) outbreaks, mixed-severity fires and as a result of lodgepole pine's ability to regenerate under its own canopy in dry ecosystems. To accommodate modelling this complex structure, stand inventory data were obtained from 15 stands in 1987, following an outbreak that lasted from approximately the late 1970s to 1985, and in 2001. Three model simulations were carried out for each of the 15 stands (45 total). Two scenarios were simulated using the 1987 data set: one including MPB mortality and one assuming no MPB mortality. A third scenario was carried out using 2001 base data and projected to 2031. The Stand Visualization System (SVS) was used to generate images of the condition of each stand. Quantitative and visual results clearly show that the Prognosis^{BC}–FFE model is sensitive to differences in initial stand structure and composition, and that these differences persist over time. Projections with and without MPB mortality differ when there is significant MPB mortality in the sampled stands. Evaluation of the model's ability to simulate growth from the initial 1987 inventory to the 2001 remeasurement was confounded by additional mortality by MPB and *Ips* species, and evaluation of woody debris accumulation was limited by the absence of coarse woody debris in the 1987 inventory. Prognosis^{BC} does not capture this mortality because attack from these bark beetles is not considered part of the "background" mortality used to calibrate Prognosis^{BC}'s mortality model. In stands with limited additional mortality, the model performs reasonably well for the live tree characteristics. Downed coarse woody debris accumulations projected by FFE due to fall down of standing dead trees are plausible in comparison to woody debris loads in 2001. Some calibration of the FFE will be necessary to better represent fuel dynamics, especially the snag dynamics for Chilcotin Plateau conditions. The FFE model predictions indicate that there is a need to increase the decay rate for small fuels and decrease it for large fuels.

RÉSUMÉ

Le présent document se penche sur l'utilisation du Prognosis^{BC} (la variante britanno-colombienne du simulateur de la végétation forestière) et de la variante du nord de l'Idaho du *Fire and Fuels Extension* (FFE) (extension sur le feu et le combustible) pour extrapoler les changements au niveau de la structure des peuplements, de la charge combustible, de la densité des chicots et du comportement potentiel du feu à la suite d'une infestation du dendroctone du pin ponderosa (DPP) sur le plateau de Chilcotin (région centrale intérieure de la Colombie-Britannique) sous un régime de feux de gravité variable. Les peuplements de pins tordus latifoliés établis sur le plateau froid et sec de Chilcotin présentent une structure complexe (multiples classes d'âges et de dimensions) attribuable aux infestations antérieures du dendroctone du pin ponderosa, aux feux de gravité variable et à la capacité du pin tordu de se régénérer sous son propre couvert dans les écosystèmes secs. Pour faciliter la modélisation de cette structure complexe, des données d'inventaire sur 15 peuplements ont été rassemblées en 1987, à la suite d'une infestation qui a sévi de la fin des années 1970 à 1985, et en 2001. Chacun des 15 peuplements a fait l'objet de

trois simulations (total de 45). Deux scénarios ont été exécutés à l'aide de l'ensemble de données de 1987, l'un incorporant une mortalité due au DPP et l'autre supposant l'absence de mortalité due au DPP. Un troisième scénario a été exécuté à l'aide des données de base de 2001 et extrapolé jusqu'en 2031. Le système de visualisation de peuplement (Stand Visualization System (SVS)) a été utilisé pour produire des images de l'état de chaque peuplement. Les résultats quantitatifs et visuels laissent clairement voir que le Prognosis^{BC}–FFE est sensible aux différences dans la structure et la composition initiales du peuplement et que ces différences persistent dans le temps. Les extrapolations avec et sans mortalité due au DPP diffèrent lorsque la mortalité causée par le DPP dans les peuplements échantillonnés est importante. En raison de la mortalité additionnelle due au DPP et à des espèces du genre *Ips*, la capacité du modèle de simuler la croissance au cours de la période écoulée entre l'inventaire initial de 1987 et celui de 2001 n'a pu être évaluée adéquatement, et l'absence de données sur les débris ligneux grossiers dans l'inventaire de 1987 a limité l'évaluation de l'accumulation de débris ligneux grossiers. Le Prognosis^{BC} ne rend pas compte de cette mortalité parce que les attaques de ces scolytes ne sont pas considérées comme faisant partie de la mortalité « naturelle » utilisée pour étalonner le modèle de mortalité de Prognosis^{BC}. Dans les peuplements où la mortalité additionnelle est limitée, le modèle a assez bien réussi à cerner les caractéristiques des arbres vivants. Les extrapolations établies par le FFE à l'égard de l'accumulation de débris ligneux grossiers résultant de la chute des arbres morts sur pied sont plausibles, compte tenu des charges de débris ligneux de 2001. Il faudra effectuer certains travaux d'étalonnage du FFE afin de mieux représenter la dynamique des combustibles, notamment celle des chicots qui sont présents sur le plateau de Chilcotin. Les prévisions établies à l'aide du modèle FFE mettent en évidence la nécessité d'augmenter le taux de décomposition du combustible léger et de réduire celui du combustible lourd.

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INTRODUCTION

Stands dominated by lodgepole pine (*Pinus contorta* var *latifolia* Dougl.) comprise some 14 million ha of forest in BC; roughly 25% of the provincial timber supply (British Columbia Ministry of Forests 1995). Between 1959 and 2002 a cumulative area of approximately 4.7 million ha of pine-leading stands have been affected by mountain pine beetle (*Dendroctonus ponderosae* Hopk.) (MPB) (Taylor and Carroll 2004). The current outbreak was estimated to cover 4.2 million ha in 2003 (Ebata 2004).

On the dry cold Chilcotin Plateau in the BC interior, lodgepole pine is the principal tree species. Lodgepole pine stands have a complex structure (multi-age and size) because of previous MPB outbreaks, mixed-severity fires and as a result of lodgepole pine's ability to regenerate under its own canopy in dry ecosystems (Hawkes et al. 2004).

Lodgepole pine is a seral species in many ecosystems, but can be a self-perpetuating climax species where climate, disturbance, and edaphic factors limit the regeneration of other species (Agee 1993). Although lodgepole pine produces both serotinous and non-serotinous cones permitting successful regeneration in either the presence or absence of fire, it is considered to be a fire dependent species (Lotan et al. 1985). The landscape level age-class structure of lodgepole pine can be described as a mosaic of even-aged and uneven-aged patches intermingling in space and time (Agee 1993). Whether a given patch or stand is even-aged or uneven-aged depends upon the disturbance history of the site: in the absence of fire, consecutive MPB attacks in the stand contribute to the conversion of an even-aged stand to an uneven-aged stand (Roe and Amman 1970). Non-stand-replacement fires (i.e., surface fires) also lead to the creation of uneven-aged stands (Agee 1993), whereas high-intensity stand-replacement fires create even-aged stands. Stuart et al. (1989) and Mitchell and Preisler (1998) noted that the structure of lodgepole pine forests in central and southern Oregon were uneven-aged, with distinct episodic pulses of regeneration strongly correlated to MPB outbreaks and fire. Delong and Kessler (2000) investigated the ecological characteristics of mature forest remnants left by wildfire in Sub-Boreal landscapes near Prince George, British Columbia (BC), and found some remnants had an uneven-aged, episodic pattern of lodgepole pine regeneration consistent with MPB or low intensity fire. Thus lodgepole pine may form a mosaic of even-aged and uneven-aged patches on a landscape intermingling in space and time depending on disturbance history (Agee 1993).

Understanding the impact of MPB outbreaks on stand structure and fuel dynamics, the growth and yield of surviving host and non-host trees, fall down of snags, regeneration, volume at harvest, and potential fire behaviour is necessary so that resource managers can better understand the available options for the management of residual MPB-affected stands. For example, while past and present MPB outbreaks in BC have created substantial pools of timber available for salvage harvest, the volume of salvageable timber exceeds the capacity to extract and process. Therefore, a significant proportion of MPB-affected stands will not be salvage-logged in the short term, and possibly not at all. Mountain pine beetle impacted stands are also found in protected areas such as Tweedsmuir Provincial Park, where extensive salvage of dead lodgepole pine is not permitted.

Although it seems clear that the mortality caused by a MPB outbreak will influence the fuel complex and subsequent fire behaviour, there are few quantitative tools to provide a link between the death of trees in forests under attack by MPB and the subsequent fuel loading of the stand over time. Taylor et al. (1998) used Prognosis^{BC}, the BC variant of the Forest Vegetation Simulator (FVS) (Stage 1973; Snowdon 1997) linked to an early version of the Fire and Fuels Extension (FFE) (Beukema et al. 1997, 2000; Reinhardt and Crookston 2003) to project changes in fine and coarse woody fuels and potential fire behaviour in relation to stand development for five locations in the dry forests of the southern BC interior. The linked Prognosis^{BC}–FFE model has not been used to model the impact of MPB outbreaks in the BC interior.

Similar approaches have been taken in the Idaho Panhandle National Forests using the linked FVS–FFE to explore the effects of a variety of management actions including salvage logging and fuel treatments, for forests that have experienced Douglas-fir beetle outbreaks (IPNF 2001a, 2001b). The fire models that are part of the FFE show that fuel loading and wildfire flame length are expected to increase over time as stands mature and surface fuels accumulate faster than the decay rate can remove them. In an unmanaged scenario, bark beetle induced changes in stand structure make these changes occur at an accelerated rate.

The objective of this study was to determine how well-suited Prognosis^{BC}–FFE is for projecting post-outbreak MPB stand and fuel dynamics and potential fire behaviour in lodgepole pine-dominated stands on the Chilcotin Plateau in central interior B.C.

METHODS

Field Data Collection

In 1987 the Canadian Forest Service established semi-permanent plots in 30 randomly located stands on the Chilcotin Plateau in the BC interior (Figure 1) to assess the impact of a MPB attack that ended in 1985. Most of the stands are located in the Sub-Boreal Pine Spruce very dry and cold biogeoclimatic (BEC) subzone (SBPSxc), while the remainder are located in the Interior Douglas-fir dry and cool BEC subzone (IDFdk), directly adjacent to the SBPSxc stands.

Ten plots were established in each stand using a systematic grid 100 metres square (a block with a dimension of 2 plots by 5 plots), making a total of 300 plots. The centre of each plot was marked and a prism cruise was made using a Basal Area Factor that included 8-10 trees. Cause of death (MPB, *Ips* species beetles or other mortality) was noted for standing dead trees, and heights and diameters were measured. In selected plots two cores were taken from each tree for growth analysis. A fixed area regeneration plot (3.1 m radius) was also established in each plot.

Subsequently, a number of stands and plots were disturbed through fire or harvest. In 2001 we relocated and re-sampled 15 undisturbed stands (130 plots) following similar methods except that two classes of sapling (>1.5m and $\leq$3.9cm dbh) and (>3.9cm and $\leq$7.0cm dbh) were sampled using a fixed area plot (saplings were not sampled in 1987).

In 2001 line transects were also established to assess fuel loading using procedures given in Trowbridge et al. (1986). A more complete description of field stand and fuel data methodology is provided in Hawkes et al. (2004).

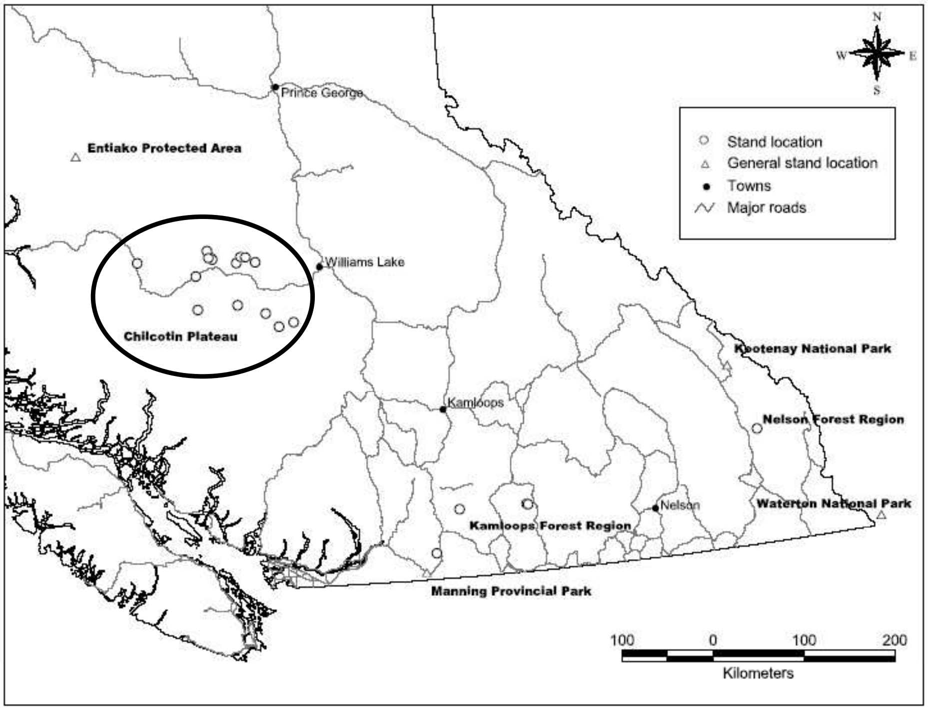

Figure 1. Location (highlighted with ellipse) of stands on the Chilcotin Plateau in the BC interior sampled in 1987 and remeasured in 2001.

Model Simulations

The Fire and Fuels Extension (Reinhardt and Crookston 2003, Beukema et al. 1997) is an FVS extension that, among other functions, predicts changes in the volume of standing and down woody debris over time based on litterfall, tree mortality, falldown and decay rates. The FFE also predicts changes in potential fire behaviour (using US algorithms that are not used in Canada). The FFE has not yet been calibrated for BC, but 19 geographic variants exist in the US. The Northern Idaho variant was chosen because of its similarities to the southern BC interior. This variant was linked to Version 3.0 of Prognosis^{BC}.

The linked Prognosis^{BC}–FFE model was used to project changes in stand structure, fuel loading, snag density, and potential fire behaviour for the 15 Chilcotin stands remeasured in 2001. Prognosis^{BC} has been designed to work well in complex, multi-species, multi-age stands like those in the Chilcotin Plateau (Robinson 2000). Prognosis^{BC} (version 3.0) has been calibrated for most of the Interior Douglas-fir (IDF) and Interior Cedar-Hemlock (ICH) BEC subzones of southern interior British Columbia (Zumrawi et al. 2002), but not specifically for any of the SBPS subzones. The best available growth model for the Chilcotin Plateau was judged to be the IDFdk4/01. Based on an analysis of 10-year growth increment data, a large tree diameter-growth scaling value of 0.52 was chosen for all the Chilcotin stands. This growth modifier assisted in mitigating errors in the prediction of large-tree growth (Beukema and Robinson 2004).

A total of 45 simulations were carried out for the 15 stands (3 scenarios per stand). Two different scenarios used the 1987 data set: one with MPB mortality included as snags, and one assuming no MPB mortality (i.e., snags were assumed to be live). Simulations were run to 2031 using 5-year time steps, although one time step was shortened to four years to enable model predictions to be compared with the re-measurement data collected in 2001. A third scenario was begun in 2001 and projected to 2031 with MPB mortality included as snags. The only source of mortality simulated was the basic “background” mortality predicted by Prognosis^{BC}. A key driver of mortality in Prognosis^{BC} is the maximum basal area of the stand. For the Chilcotin Plateau, a local expert (D. Conly, Lignum Ltd., pers. comm.) was consulted, who recommended using a maximum basal area of 25 m^2 ha^{-1}. Although no additional sources of mortality were simulated, it is known that beetles such as MPB and *Ips* species were still actively killing trees between 1987 and 2001 in some stands on the Chilcotin Plateau.

As input, Prognosis^{BC} uses a statistical inventory of live and dead trees in each stand. Tree lists were created for stand conditions in 1987 and 2001 by combining information about live trees, snags, saplings, and seedling regeneration. Regenerating seedlings were entered into the tree list using four height-classes: 0.5 m, 1.0 m, 1.5 m, and 2.0 m. Saplings (measured in 2001) were entered into the tree list using a diameter based on the mid-point of the 0-3.9 cm and 4.0-7.0 cm size classes allowing the model to interpolate initial height. The sapling height-dbh ratio measured in 2001, utilizing 90 destructively sampled saplings, was used to back-project the diameter of 1987 saplings. The 2001 proportion of saplings in the 0-3.9 cm and 4.0-7.0 cm size classes was used to estimate 1987 sapling density.

Fuel loading estimates were available for most stands sampled in 2001 by stand and size class. The size classes were: 0.5 cm, 1 cm, 3 cm, 5 cm, 7 cm, and >7 cm. These breakpoints are slightly different from those used by FFE. The first two classes were therefore combined to make the <2.5 cm class needed by the FFE. The 3 cm to 7 cm size classes were combined, and the remainder put into the 7.6-15.2 cm class used by the FFE. No fuel loading data was available for three of the 2001 stands, so the average of the other stands was used for these cases. No woody fuel loading data were available for 1987. Without stand-specific woody fuel loading data, fuel loading was set to zero t ha^{-1}. (This is admittedly unrealistic, so the predicted fire behaviour of these stands is expected to be low for the first few years until woody fuels start to accumulate from tree mortality and crown lifting and turnover.) In all cases the initial fuel loading of litter and duff was set at the FFE default level for lodgepole pine dominated stands. These values will affect the reported litter and duff values and the potential smoke production but have no impact on potential fire behaviour as predicted by FFE. Additional detail on input data and assumptions can be found in Beukema and Robinson (2004).

The stand visualization system (McGaughey 1997) was used to generate images of each stand to depict stand conditions.

RESULTS

The 45 simulation runs made with Prognosis^{BC}–FFE model changes in each stand over time, as measured by a variety of indicators such as: live trees, fuel, snags, and fire potential. These indicators are clearly sensitive to differences in stand conditions, including the presence of recent MPB mortality. Results from the simulations are compared to the empirical measurements of stand and fuel data from the Chilcotin stands, to compare how well Prognosis^{BC}–FFE was able to project the changes of each stand over time.

Not all simulation results are discussed in this paper: selected results have been chosen to illustrate Prognosis^{BC}–FFE model strengths and weaknesses. Chilcotin Stand 104 was one of the best fits between the simulation and empirical data. Comparing a simulation beginning in 1987 with MPB mortality and comparing that run's predictions for 2001 to remeasurement data collected in 2001, observed and predicted basal areas differed by only 1 m^2 ha^{-1} at the remeasurement, and remain very similar over the course of the run. Volume estimates are also similar for the 30-year simulation (Figure 2).

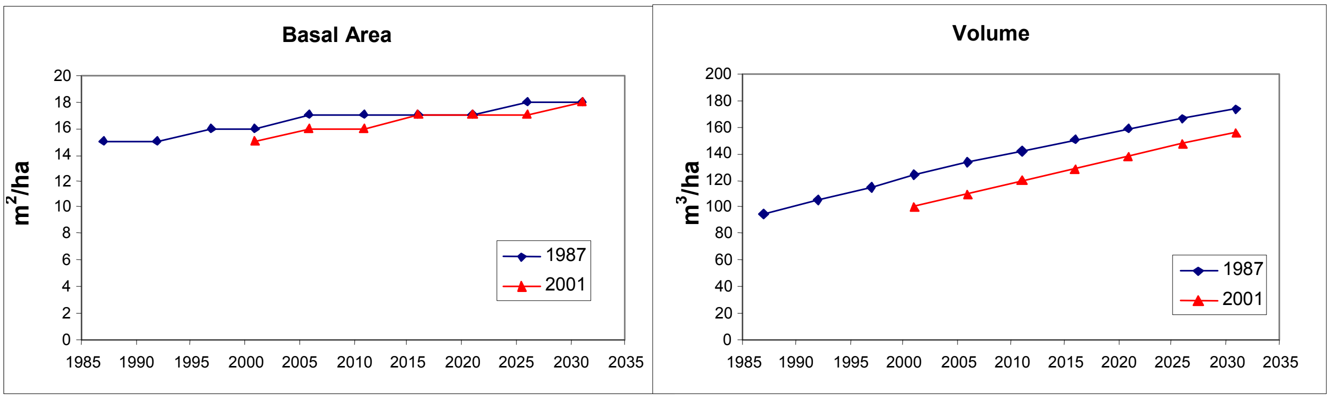

Figure 2. Basal area (left) and total volume (right), over time in Chilcotin Stand 104 starting in 1987 with MPB mortality, and as remeasured in 2001.

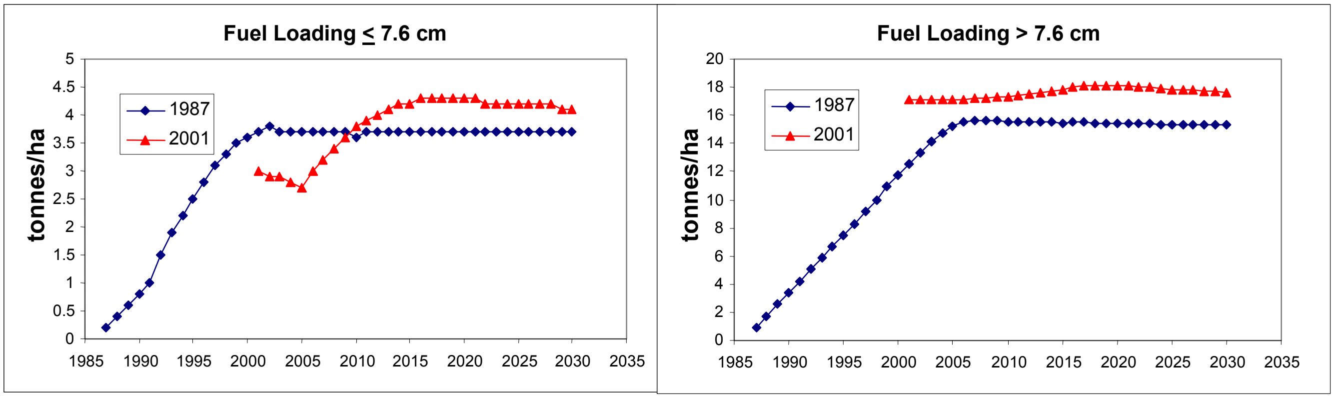

Figure 3. Fuel loading over time in Chilcotin Stand 104 beginning in 1987 (no fuel loading) with MPB mortality and as remeasured in 2001. The left graph is for fine fuels, and the right graph shows coarse fuels.

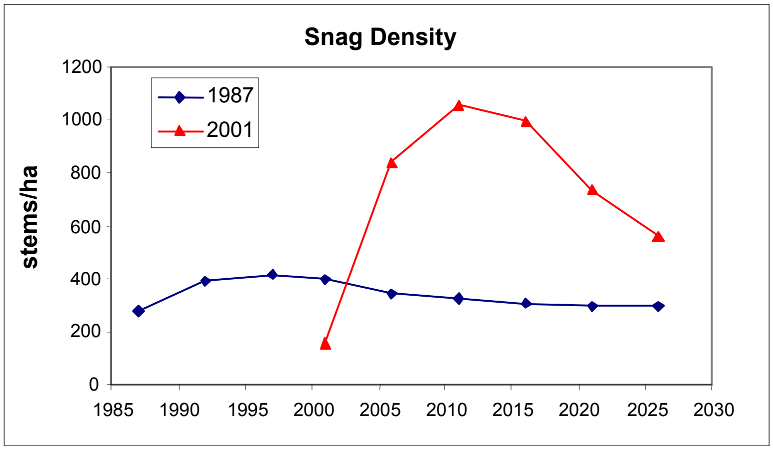

Figure 4. Density of snags over time in Chilcotin Stand 104 beginning in 1987 with MPB mortality, and as remeasured in 2001.

In spite of reasonable agreement for timber attributes, differences for the non-timber attributes of Chilcotin Stand 104 simulations are very pronounced: coarse fuels are underestimated and fine fuels are overestimated (Figure 3). The absolute differences in fuel loading, in terms of tonnes per hectare, were within the standard deviation for all stand projections (Figure 8), as well as line intersect fuel sampling error. Some differences in fuel loading are expected since the simulations starting in 1987 were assumed to contain no surface woody fuels, and given this simplifying assumption the model is not expected to accurately predict the fuel loads observed in 2001.

The snag dynamics of the two simulations also show remarkably different patterns (Figure 4), indicating that the mortality predicted by the model differs from observed mortality. The snag fall-down rate algorithm coefficients in the North Idaho variant of FFE clearly need calibration for the cold and dry Chilcotin Plateau. Potential flame lengths (not shown) were similar because of the low fuel values and similarities in stand structure.

In comparison to Chilcotin Stand 104, the Prognosis^{BC}–FFE model does not fare as well for other Chilcotin Plateau stands. For example, in Chilcotin Stand 113, predicted basal area was expected to be 30% higher than the basal area actually remeasured in 2001 (Figure 5). This anomalous result clearly shows that significant (un-modelled) mortality occurred in the stand between 1987 and 2001. In another analysis, Hawkes et al. (2004) report that from 1987 to 2001 post-outbreak live tree volume was reduced by 22% on average for the 15 stands, although there was significant between-stand variation due to differences in stand structure. The reduction in live tree volume was found to be mainly the result of additional MPB and *Ips* species mortality between 1987 and 2001. Bark beetles such as *Ips* species were quite active killing trees for a number of years after the Chilcotin Plateau MPB outbreak collapsed in 1985. *Ips* species beetles are thought to have over-wintered in the forest floor, where snow would protect them from extremely cold winter temperatures. As in Chilcotin Stand 104, the model overestimated fine fuel loading, underestimated coarse fuel loadings (Figure 6) and underestimated snag density (Figure 7). Downed coarse woody debris accumulations projected by FFE for Stand 114 due to fall down of standing dead trees are plausible in comparison to woody debris loads in 2001, considering the variability in coarse woody debris stand predictions (Figure 8).

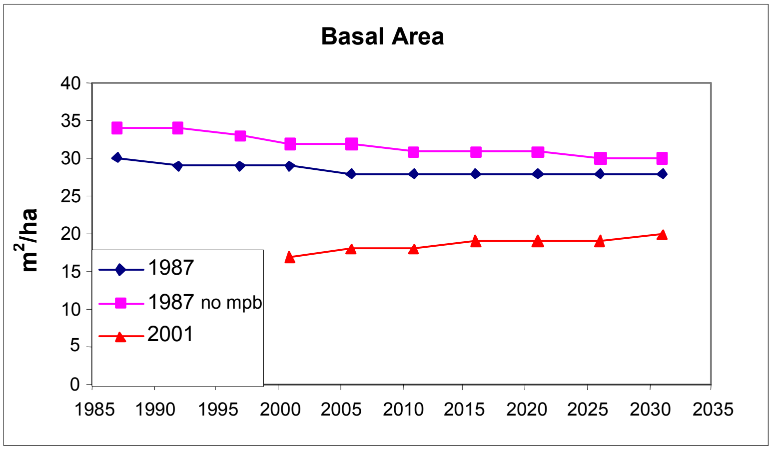

Figure 5. Basal area over time in Chilcotin Stand 113 beginning in 1987 (with and without MPB mortality) and in 2001 (with MPB mortality).

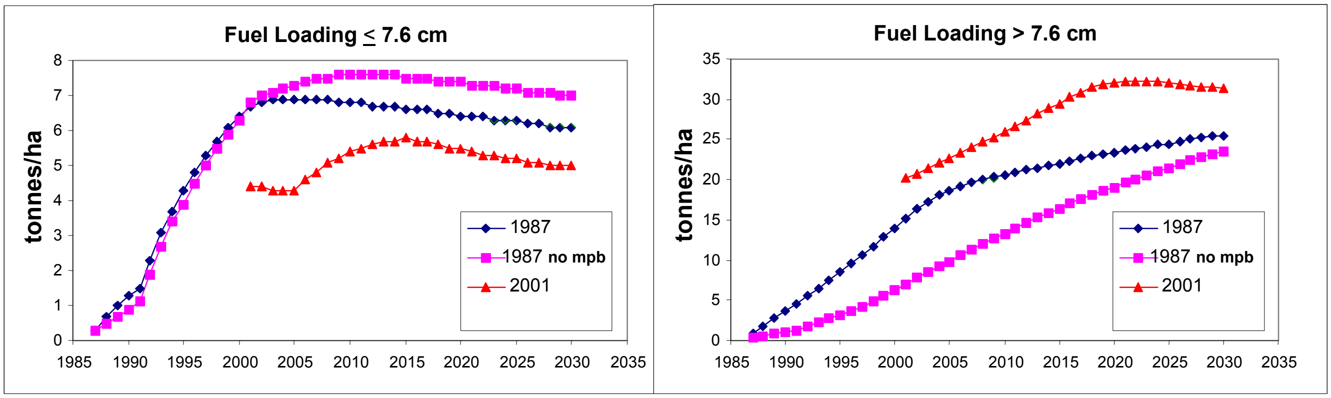

Figure 6. Fuel loading over time in Chilcotin Stand 113 beginning in 1987 (with and without MPB mortality) and 2001 (with MPB mortality). The left graph is for fine fuels; the right graph shows coarse fuels.

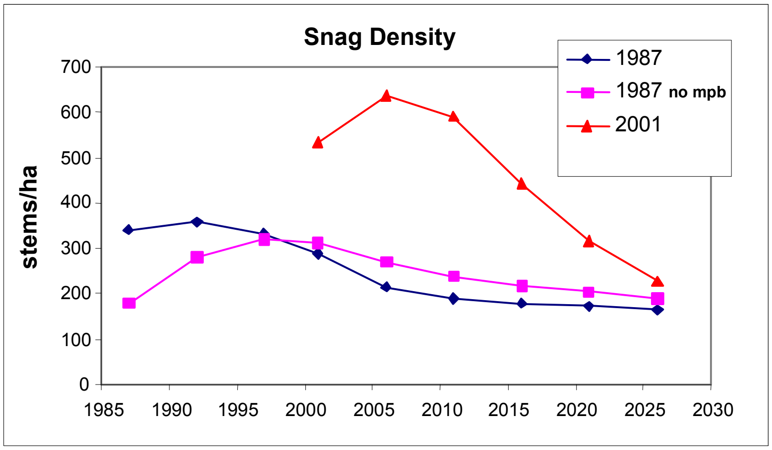

Figure 7. Density of snags over time in Chilcotin Stand 113 beginning in 1987 (with and without MPB mortality), and as re-measured in 2001 (with MPB mortality).

Chilcotin Plateau stands affected by MPB also show a high degree of variability in stand structure and fuel loading over time, a result that indicates the Prognosis^{BC}–FFE model is sensitive to initial differences in stand characteristics. Fuel loadings from the simulation runs beginning in 1987 show this variability most clearly (Figure 8). All Chilcotin stands simulations starting in 1987 began with no fuels, as shown by the low value and low standard deviation in the first time step. Over the first half of the simulation, variability rises as each stand develops and produces unique fuel loadings based on its structure and stand development, reaching a steady state after about 20 years. Figure 9 shows examples of stand structure in 1987, 2001, and 2031 using SVS projections.

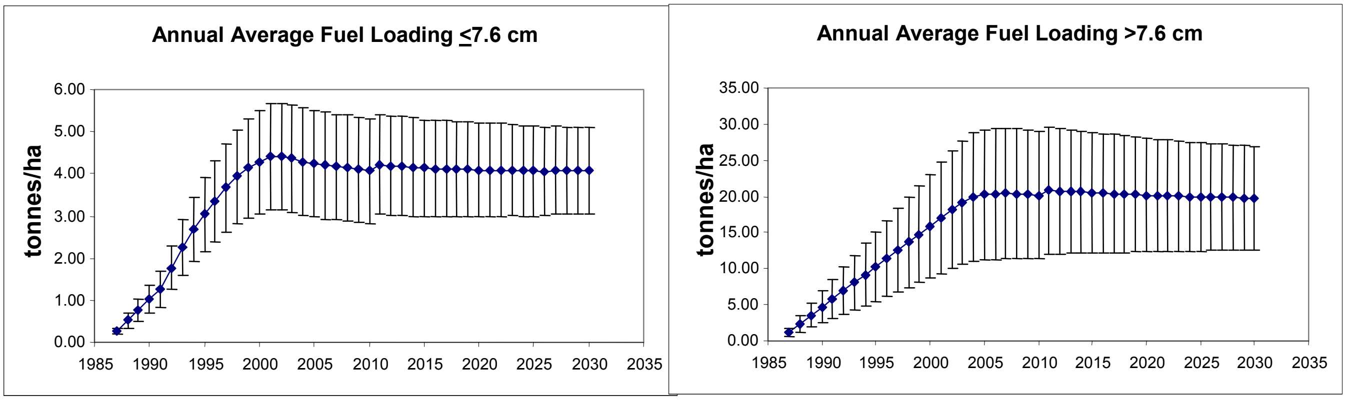

Figure 8. Average and standard deviation of fuel loading over time in one scenario of the 1987 Chilcotin stands. The left graph is for fine fuels, and the right graph shows coarse fuels. Note that the first data point is printed after some fuels have been created in each stand, so that the value is greater than 0.

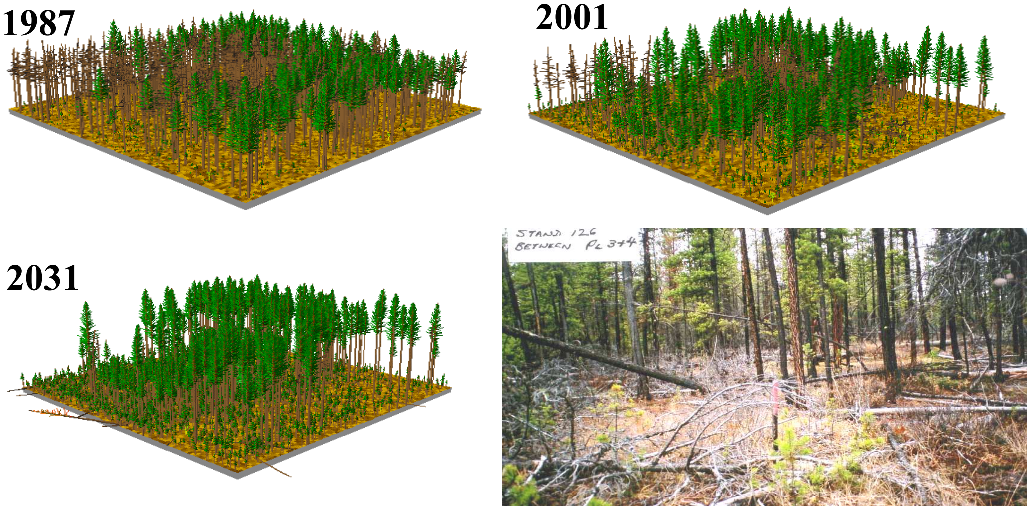

Figure 9. Stand Visualization System projections illustrating the stand structure in 1987 after initial MPB mortality (35% volume loss – 145 to 89 m^3/ha); in 2001 with 22% additional volume loss (standing volume 68 m^3/ha) due to mountain pine and *Ips* species beetle mortality; and in 2031 with no additional beetle mortality (predicted volume 112 m^3/ha). Fuel loading in 2001 was 4 tonnes/ha (fine) and 20 tonnes/ha (coarse). Fuel loading in 2031 was predicted as 5 tonnes/ha (fine) and 32 tonnes/ha (coarse). Photograph shows typical stand structure on the Chilcotin Plateau in 2001.

SUMMARY AND CONCLUSIONS

The results clearly show that the Prognosis^{BC}–FFE model is sensitive to differences in stand structure and composition, and that these differences persist over time. Projections of stands with and without MPB mortality differ in cases where there is significant MPB mortality in the sampled stands. Because the model has not yet been calibrated for BC and because of a lack of an initial fine and coarse fuel inventory, the model has a limited ability to make empirical comparisons of the 1987 inventory projected up to the 2001 remeasurement. The discrepancy is amplified by additional sources of un-modelled mortality experienced by many Chilcotin stands between 1987 and 2001, such as mountain pine and *Ips* species beetles. The base Prognosis^{BC} model does not capture this mortality because these bark beetle outbreaks are not considered in the "background" mortality that was part of the model calibration. In stands with limited additional mortality, the model performed reasonably well for the live tree characteristics.

The version of FFE used for these simulations is a prototype in BC, originally calibrated for the Northern Idaho region of the US. The results shown here indicate that the FFE snag dynamics should be revised when a model is developed for BC (Beukema and Robinson 2004), resulting in better representation of the fuel and snag dynamics of the Chilcotin Plateau. Downed coarse woody debris accumulations projected by FFE due to fall down of standing dead trees are plausible in comparison to woody debris loads in 2001. The FFE model predictions indicate that there is also a need to increase the decay rate for fine fuels and decrease it for coarse fuels.

The British Columbia Ministry of Forests Prognosis^{BC} development team is currently using results of this project as part of Prognosis^{BC} model development and testing, specifically in the development of a regeneration module and in the extension of the model to the SBPS BEC zone. A growth and yield model linked to a calibrated fuel and snag dynamics modelling system will then be available to assist resource and fire managers to determine impacts of MPB outbreaks, especially on timber supply and in making salvage decisions.

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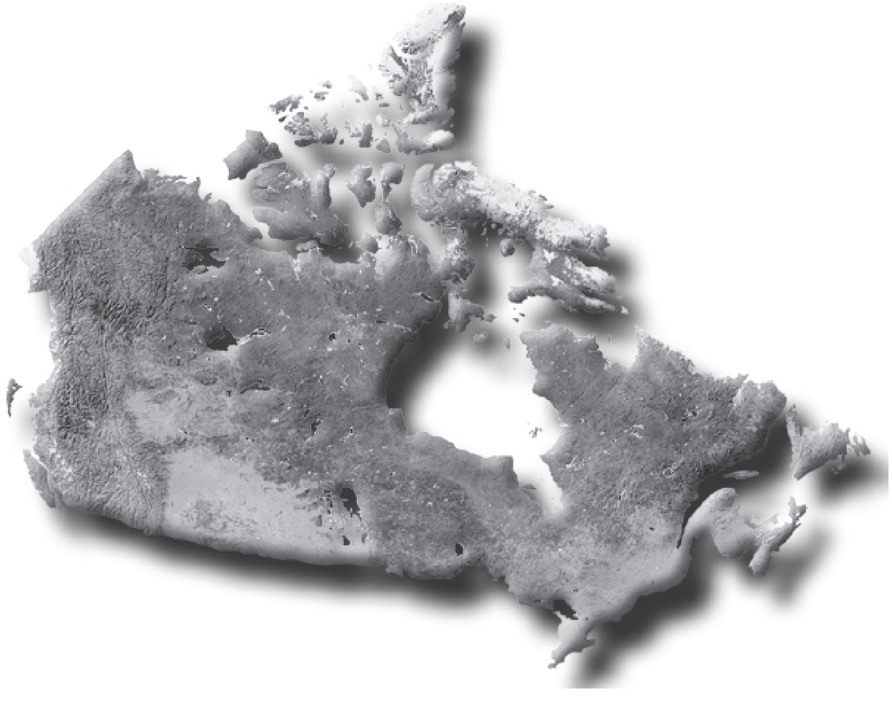

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