Incorporating Mountain Pine Beetle Impacts on Stand Dynamics in Stand and Landscape Models: A Problem Analysis

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Abstract

Due to numerous operational, legal and ecological constraints, a large portion of the millions of ha of lodgepole pine affected by the current mountain pine beetle outbreak will not be salvage logged. Understanding how unsalvaged stands and landscapes will develop is critical for assessing the socio-economic and ecological impacts of the outbreak. Most modelling work in British Columbia has been of mountain pine beetle population development, outbreak spread, and interaction with management treatments. Further work is needed to project impacts on stand and forest development. Data obtained from our companion study have some implications for stand modelling. In the Chilcotin outbreak, surviving trees in all diameter classes continued to grow well during the course of the outbreak. Many more small diameter trees are killed in an outbreak than mountain pine beetle population models predict. There was extensive mortality due to *Ips* spp. after the collapse of the mountain pine beetle outbreak. Surviving pine and non-host species responded well to release from overstory competition. This project will identify pathways to include mountain pine beetle impacts in stand and forest growth models focussing primarily on Prognosis^{BC} and its extensions, the Fuels and Fire Effects Model, and the Westwide Pine Beetle Model.

Introduction

During a mountain pine beetle (*Dendroctonus ponderosae* Hopkins) outbreak, managers need to forecast pine beetle population development and spread to assist in planning harvesting and other control measures to reduce populations and mitigate impacts. Most mountain pine beetle modelling efforts have been focussed on this problem. Where mountain pine beetle populations are beyond control, or an outbreak has collapsed, there is a need to schedule harvesting to maximize value-recovery of dead timber and to assess the long term impacts on annual allowable cuts (AAC) and other resource values. This requires an assessment of the immediate mortality, the shelf-life of standing dead trees, the impact on growth, and regeneration of residual stands.

Our understanding of the long-term effects of mountain pine beetle epidemics is limited. Lodgepole-dominated stands comprise some 14 million ha of forest land in British Columbia (BC) (British Columbia

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Ministry of Forests, 1994). Analysis of the cumulative mountain pine beetle outbreak area from the Canadian Forest Service's Forest Insect and Disease Survey annual aerial records shows that a cumulative area of approximately 4.7 million ha of pine-dominant stands were affected between 1959 and 2002 (Canadian Forest Service, unpublished data). The long-term effects of these past epidemics are largely unknown.

The current mountain pine beetle outbreak has affected an estimated area of 4.1 million ha in 2003 alone (Ebata 2004). Due to numerous operational, legal, and ecological constraints, a large portion of this affected landscape will not be salvage-logged. A comprehensive suite of methods or models is needed to improve our understanding of the effects of this outbreak on the growth and future condition of residual stands, long-term impacts on harvest levels, and habitat supply and other forest characteristics. This paper will briefly review the biological and ecological processes that underly the management questions and the models that are presently available that represent these processes.

Mountain pine beetle effects on stand dynamics

The dynamics of both live and dead trees during and following a mountain pine beetle infestation are important to answering questions of stand volume, value, composition, and future conditions. Live tree processes include mortality of host trees, growth of residual host and non-host trees, and regeneration of host and non-host trees. Dead tree processes that are important are breakage, falldown, and decomposition rates, which affect wood quality and value.

The project outlined by Hawkes et al. (2004), is a companion study, and, among other things, is assessing tree mortality, growth, and regeneration of residual stands following mountain pine beetle outbreak in permanent sample plots located in the Southern Interior Region (former Cariboo, Kamloops and Nelson Forest Regions), Waterton National Park (from the epidemic of 1977-1985), Kootenay National Park (epidemic in 1990's), Tweedsmuir Provincial Park/Entiako Protected Area and Manning Provincial Park (current epidemic). Hawkes et al. (2004) is the most comprehensive study to date in BC investigating both immediate impacts of mountain pine beetle epidemics and the long-term changes in forest structure over wide temporal and spatial scales. Combined with other research on the impacts of mountain pine beetle on lodgepole pine stand dynamics, we know the following:

Mountain pine beetle induced mortality

Mortality caused by primary mountain pine beetle infestation is highly variable, and is dependent upon stand structure and species composition. In general, a higher proportion of larger trees are killed by mountain pine beetle, as evidenced in the Cariboo Forest Region outbreak of 1977-1985 (Fig. 1). As population pressure increases, smaller trees are attacked, which is seen clearly in the Tweedsmuir Park/ Entiako Protected Area (Fig. 2), which is in the epicentre of the current epidemic. Variable and uneven levels of mortality can create uneven sized and mixed species stands.

Preliminary data analysis in the companion study on stand dynamics has shown that small-tree (dbh<17.5 cm) mortality over the course of a beetle epidemic is considerably greater than that predicted by current scenarios run with MPB-SELES. MPB-SELES does not fix a lower-size limit on which trees will be killed by beetles, but for the purposes of modelling short-term spread of beetles and impacts on timber volume, these parameters have been set so that they limit mortality of small diameter trees (B. Riel, personal communication). Small diameter trees have limited impact on timber volume, and tend towards being beetle-sinks as opposed to beetle sources. For the purpose of modelling long-term impacts of the beetle epidemic on stand structure and development, however, it is important to set model parameters for tree mortality as accurately as possible.

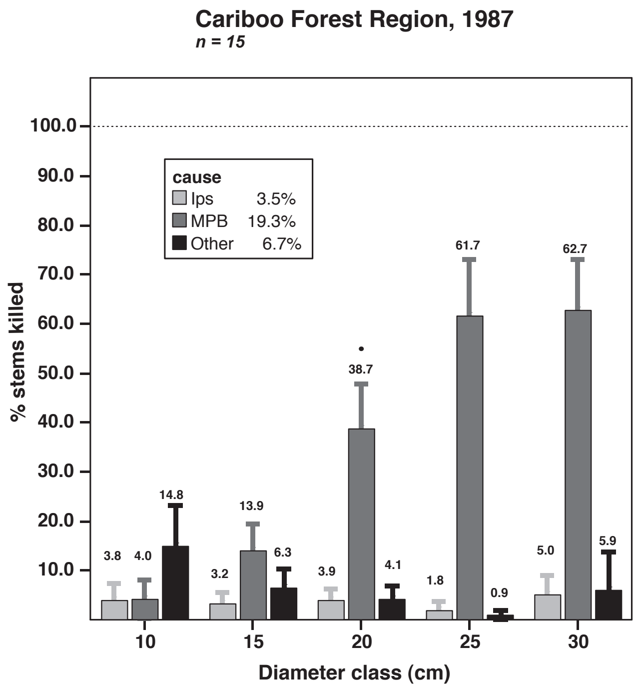

Figure 1. Mortality by diameter class in the Cariboo Forest Region's mountain pine beetle epidemic of 1977-1985. Mortality by mountain pine beetle is significantly skewed to larger diameter trees.

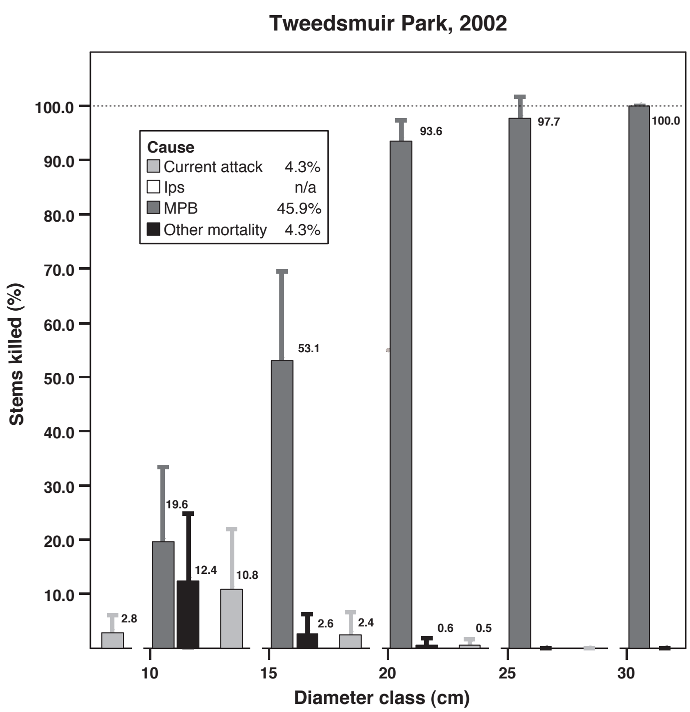

Figure 2. Mortality by diameter class in the current epidemic in Tweedsmuir Provincial Park/Entiako Protected Area. Mortality by mountain pine beetle has affected many more smaller diameter trees than in the Cariboo Forest Region. There is significant current attack taking place in these smaller trees.

Considerable variation in small tree mortality has been observed in past epidemics (Table 1) and in the current epidemic (Table 2). The stands located in the Tweedsmuir/Entiako area show the highest levels of small tree mortality, likely due to being in the epicentre of the current outbreak. Beetles have been active in this region at extreme population levels for several years.

Table 1. Mortality of small diameter trees in three regions affected by the 1977-1985 mountain pine beetle epidemic. Figures expressed in percentage of stems killed.

		Source of mortality		
Diameter class	Region	Mountain pine beetle	*Ips* spp.	Other mortality
7.0 cm-12.4 cm	Cariboo	4.0%	3.8%	14.8%
	Nelson	0	0	13.1%
	Kamloops	0	0	58.3%
12.5 cm–17.4 cm	Cariboo	13.9%	3.2%	6.3%
	Nelson	33.3%	0	16.3%
	Kamloops	18.4%	0	34.2%

Table 2. Mortality of small diameter trees in current mountain pine beetle epidemic (MPB). Figures expressed in percentage of stems killed. Current attack describes trees under attack at time of sampling (September, 2002 in Tweedsmuir/Entiako, August, 2002 for Manning Park). Most trees under current attack are likely dead now.

		Source of mortality		
Diameter class	Region	Mountain pine beetle	Current MPB attack	Other mortality
7.0 cm-12.4 cm	Tweedsmuir/Entiako	19.6%	2.8%	12.4%
	Manning Park	2.3%	3.7%	64.8%
12.5 cm-17.4 cm	Tweedsmuir/Entiako	53.1%	10.8%	2.6%
	Manning Park	13.1%	6.0%	10.0%

Ips spp. induced mortality

In addition to mountain pine beetle induced mortality (primary mortality), preliminary analysis of the stand dynamics companion study (Hawkes et al., these proceedings) has shown that significant secondary mortality may occur as *Ips* spp. populations build up in dead trees to levels where they begin attacking live trees. Furthermore, the mortality caused by these two insect species opens the stand canopy, which in turn may facilitate tertiary mortality in the stand (increased vulnerability to windthrow and other pathogens). Evidence of the extent of secondary and tertiary stand mortality after the collapse of the primary outbreak on trees of all sizes in the Chilcotin Plateau is presented in Figure 3. It is difficult in practice to determine the principal cause of mortality, as dead trees often show evidence of attack from both mountain pine beetle and *Ips*. However, taken together, the mortality between 1987 and 2001 from bark beetles killed a third of the trees that survived the initial mountain pine beetle outbreak between 1977-85.

Tree growth rates

Tree growth rates have been observed to increase during and after the course of an epidemic (Heath and Alfaro 1990). The degree of response is likely variable, depending upon the amount of canopy opening (mortality level) and residual stand structure. Mortality may occur over a period of several years within a stand, as not all trees are killed in the same year. We need to better understand the time course of mortality during the outbreak and how growth processes are affected during an infestation that can last for years, often more than a decade. Data currently available from our companion study indicates that during the epidemic of 1977-1985 in the IDFdk4 and SBPSxc biogeoclimatic subzones on the Chilcotin Plateau, surviving lodgepole pine trees grew an average of 10% in diameter-at-breast-height (dbh) across all diameter classes from 7 cm-30+cm (Fig. 4) between 1977, the year the epidemic began, to 1987 (year of sampling), two years after the epidemic collapsed due to winter cold. When converted to basal area, the increase is 21.8% (Fig. 5). This increase in basal area applies to 81% of the trees in these stands, as only 19% of trees were killed in the epidemic. We are currently cross-dating increment cores from the dead trees to identify when mortality occurred.

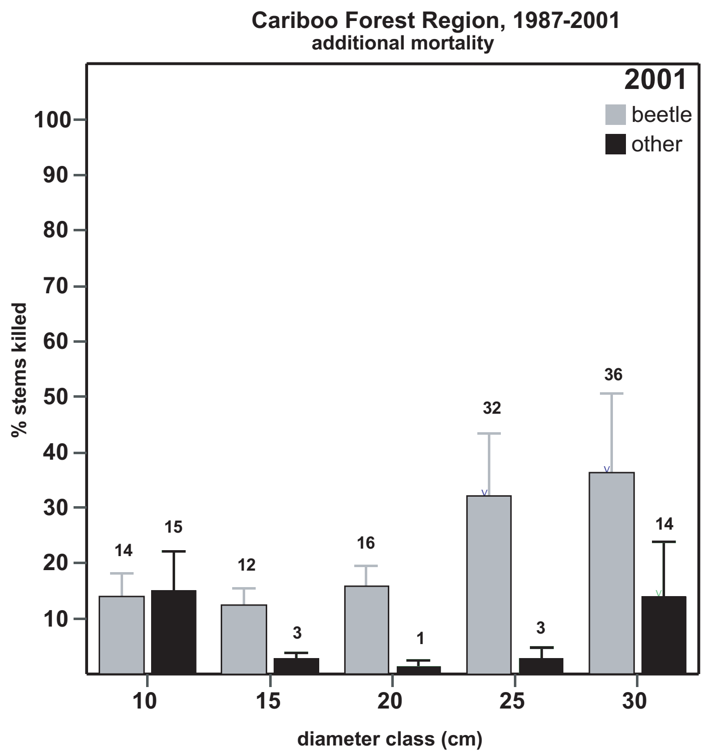

Figure 3: Post-epidemic mortality of lodgepole pine in the Cariboo Forest Region from 1987 to 2001. Figures are expressed as percentage of stems killed that were living in 1987, two years after the end of the MPB epidemic. The two causes indicated in the figure are beetle (MPB and *Ips* spp. combined) and all other mortality sources (other).

Falldown and regeneration rates

In order to assess salvage and forest fire behaviour potential following a mountain pine beetle infestation, we need to determine the falldown rate of beetle-killed trees and their decomposition rates. As epidemics progress and canopy disturbances increase light available to the forest floor, we also need to determine how regeneration of host and non- host trees will be affected in order to predict the future condition and growth of stands on the landscape.

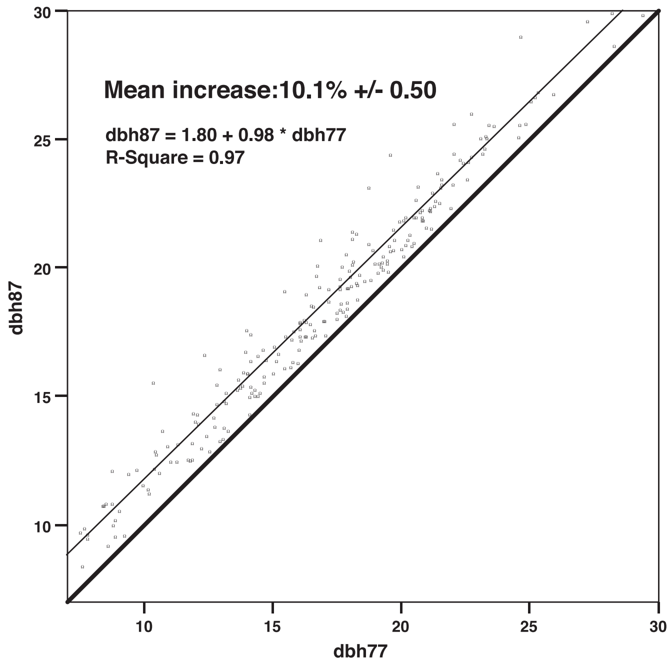

Figure 3. Surviving host-tree diameter growth through the course of the mountain pine beetle epidemic in the Chilcotin Plateau. Bold line indicates line of zero-growth (no change in DBH), lighter line is best-fit line of linear regression of initial DBH in 1977 (dbh77) versus DBH at time of measurement, two years post-epidemic in 1987 (dbh87).

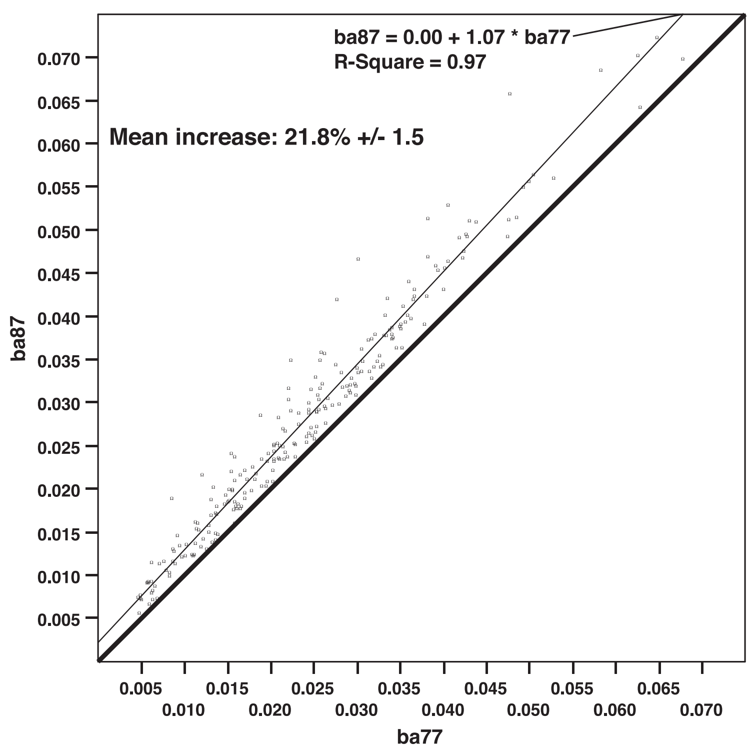

Figure 5. Surviving host-tree basal area growth through the course of the mountain pine beetle epidemic in the Chilcotin Plateau. Bold line indicates line of zero-growth (no change in basal area), lighter line is best-fit line of linear regression of initial basal area in 1977 (ba77) versus basal area at time of measurement, two years post-epidemic in 1987 (ba87).

Modelling framework

A variety of models that represent the processes of beetle mortality, woody debris falldown, growth and regeneration of stands oriented to stands or forest/landscapes, are presently used or can be easily adapted for use in BC. These include, but are not limited to, MPBSIM (Riel et al. 2004), SELES-MPB (Riel et al. 2004; Fall et al. 2004, 2002a, b), Prognosis^{BC} (Zumrawi et al. 2002), the Prognosis Westwide Pine Beetle (Beukema et al. 1997) and Fire Models (Beukema et al. 1996), Woodstock and Stanley (http://www.remsoft.com/forest/index.html). As well as representing different processes, the models are at different temporal and spatial scales: 1) mountain pine beetle population dynamics and spread (immediate impact); 2) stand growth and yield (immediate and long term impacts); and 3) forest/landscape models (longer term, larger spatial scales). The components of a modelling framework will be briefly reviewed from the process point of view.

Mortality

Mountain pine beetle population dynamics and spread models and resulting mortality have been well developed by the Canadian Forest Service, and are represented by MPBSIM (Riel et al. 2004; http://www.pfc.forestry.ca/entomology/mpb/tools/dss_e.html), which is based on a detailed, process-based population model by Safranyik et al. (1999). By itself, MPBSIM is a stand-level model, but when coupled with the Spatially Explicit Landscape Event Simulator (SELES) (Fall and Fall 2001; Fall et al. 2001, 2002a, b) as SELES-MPB, it successfully scales the short-term impacts of mountain pine beetle across the landscape. Some issues with this modelling system are that it does not kill small trees in the numbers seen in plots in our companion study (Hawkes et al. 2004); although this can be addressed by parameterizing the model accordingly (Riel, W.G., Canadian Forest Service, Victoria, BC, personal communication), it does not include secondary mortality agents (*Ips* spp.), and tree growth is too simplistic for modelling long-term forest conditions.

Mortality due to both mountain pine beetle and *Ips* has been represented in the Westwide Pine Beetle Model (WWPB) extension to the US Forest Service Forest Vegetation Simulator (FVS) (Beukema et al. 1994, 1997). The WWPB model has been designed to run with the Parallel Processing Extension (PPE) (Crookston and Stage 1991), which scales FVS from the stand to landscape level. We have recently (October 2003) had the WWPB and PPE models metrified by ESSA Technologies and linked to Prognosis^{BC} V3.0. Both Prognosis^{BC} and FVS have numerous extensions designed for modelling of woody debris fuel loading, forest cover and other issues regarding the projection of future forest conditions. We plan to run the model to test *Ips* mortality prediction.

Impacts on growth

Existing growth and yield (GY) models may be adaptable to capture post-outbreak stand development. The primary GY models in use by the BC Ministry of Forests are TASS and Prognosis^{BC}. Prognosis^{BC} may be the most suitable stand model for this purpose as the BC Ministry of Forests uses it for modelling uneven size class and mixed species stands. Prognosis^{BC} v3.0 (the latest release) has been calibrated for several biogeoclimatic units, is freely available, and has a well-developed graphical user interface. Prognosis^{BC} is the metrified version of the US Forest Service Forest Vegetation Simulator (FVS) model, which has been in use since the late 1970s.

In this and a companion study, we are investigating/demonstrating the use of Prognosis^{BC} to project growth of residual stands following mountain pine beetle outbreak. Residual stand growth following mountain pine beetle attack has not been previously modeled in BC. However, it is implicitly included in the Westwide Pine Beetle model extension to Prognosis^{BC}. Prognosis^{BC} is widely used for projecting the effects of stand treatments and uneven age stand development in southern and central interior BC.

In operational practice, the impacts of other pests of young pine on stand growth have been accounted for by applying operational adjustment factors (OAFs) in TASS (Woods et al. 2000) to modify yield curves. These yield curves can then be included in forest or landscape models (e.g., FSSim, Woodstock, Stanley, SELES-MPB). While TASS may not be suitable for projecting the impact of mountain pine beetle, Prognosis might be used to develop OAFs or new yield curves for mountain pine beetle impacted stands.

Shelf-life and regeneration

The Prognosis^{BC} model includes a natural regeneration submodel which may be able to be calibrated to mountain pine beetle affected stands. The Fire Model extension to Prognosis projects woody debris dynamics (breakage, falldown, and decay rates), but not degradation in wood quality. It has recently (April, 2004) been linked to Prognosis^{BC} v3.0.

Forest landscape models are used to scale up stand-level impacts and projections to address questions of timber supply, habitat quality/availability and other issues of forest health and condition. Most of these models require input of yield curves for some functions (i.e., growth of residual stands, decomposition of timber). Woodstock uses generalized growth curves, and can handle large data sets. However, it is an aspatial model. In order to project the impact of an epidemic it would be necessary to take the real or projected impact at the end of the outbreak and summarize by analysis unit.

SELES-MPB and Stanley are both spatial models, and allow for simulating spatial harvesting rules. SELES-MPB has been applied at very large spatial scales (Timber Supply Area), and model runs have shown that it accurately predicts the spatial location and extent of the epidemic, but tends to under-predict small tree mortality within stands (Riel, W.G., Canadian Forest Service, Victoria, BC, personal communication). In the absence of a tree growth model component, both SELES-MPB and Stanley would have to depend upon generalized growth curves to project forest stand conditions into the future.

The Westwide Pine Beetle Model, in conjunction with the Parallel Processing Extension and Prognosis^{BC} can maintain individual stand dynamics for up to 10,000 stands, which very loosely translates to 1000 km^2. The benefits of greater detail at the stand level is gained by making a tradeoff in the spatial area that can be handled by the model, which is well under the Timber Supply Area scale. Another significant restricting factor for the use of the Westwide model is the requirement of tree lists for each stand, which exceeds the detail available in our current forest inventory records. Numerous imputation procedures are available, such as Most Similar Neighbour analysis, which can fill in empty cells on the landscape, but a certain number of real-data plots are necessary to make this type of procedure robust. There may also be limitations in harvest scheduling, particularly spatial constraints.

Conclusions

It is unrealistic to hope that a single large model will be able to answer all types of questions regarding the effects of mountain pine beetle epidemics on the landscape and how to best manage the epidemic, schedule harvesting, salvage and assess long term impacts.

The Westwide Pine Beetle Model is being examined in some detail in this study because it incorporates all the biological processes including *Ips* mortality, and has not been previously tested in BC.

It may be more appropriate to link specific models into a larger framework. There are considerable scaling challenges to linking these models (Fig. 6).

We need to scale mountain pine beetle impacts on mortality occurring over a period of years, on stand growth for over a period of decades across a landscape of thousands of square kilometers. Additional work is needed to validate components of a framework and demonstrate their use in an integrated fashion in a pilot study area.

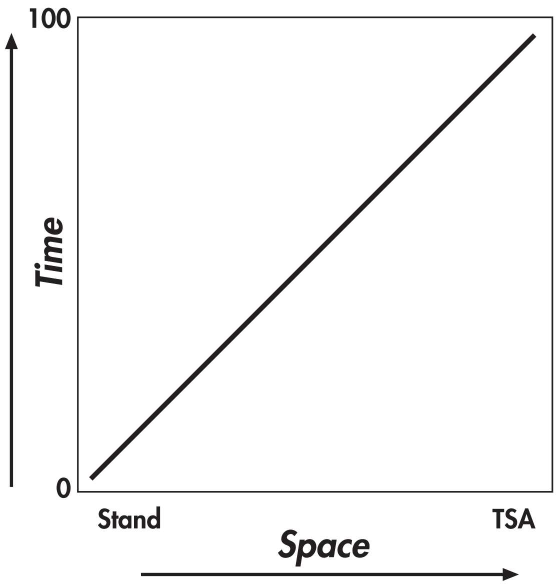

Figure 6. Hypothesized modelling framework: for projecting future forest conditions, we need to be able to examine a stand at time = 0 (bottom left corner) and project it into the future and across a large landscape (TSA = timber supply area) (top right corner).

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Chris Stockdale is a Forest Health Research Officer with the Canadian Forest Service, Pacific Forestry Centre.

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