

A Spatio-temporal Simulation of Mountain Pine Beetle Impacts on the Landscape

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Abstract

Two mountain pine beetle simulation models, which operate at distinct spatial and temporal scales, are used in combination to produce a third model: a spatially explicit landscape-scale simulation of mountain pine beetle outbreak activity. This model (known as SELES-MPB) is a stochastic, process-based simulation capable of projecting mountain pine beetle spread and impacts on the landscape through time and space, and can be used to explore and evaluate management strategies. In addition to landscape projections of mountain pine beetle impacts, SELES-MPB can project stand level impacts (e.g., trees and volumes killed by diameter class, resulting stand structure) increasing its utility as a decision support tool.

Introduction

The mountain pine beetle (*Dendroctonus ponderosae* Hopk.) is the most destructive insect of mature pine in western North America (Wood 1963). In western Canada, outbreaks have periodically caused catastrophic losses primarily in lodgepole pine (*Pinus contorta* var. *latifolia* Dougl.) (Safranyik et al. 1974; Unger 1993) which affect many forest values and disrupts resource management plans. To better understand mountain pine beetle dynamics and to better manage resources in the presence of mountain pine beetle activity, several simulation models have been developed. Three models, which operate at different scales, are briefly described, and the process of integrating two smaller scale models to create a landscape-scale, spatio-temporal model is presented.

Models

There have been several attempts and approaches to modelling mountain pine beetle activity in British Columbia (BC). With improvements in computer technology, more sophisticated modelling approaches have been applied, and it is expected that this trend will continue. When the province of BC faced a major outbreak in the 1970s to early 1980s, an aspatial landscape-scale model was developed to explore the sensitivity of various management treatments on the mountain pine beetle outbreak (Thomson 1991). Around this time, a more detailed and sophisticated mountain pine beetle population dynamics model was developed (Safranyik et al. 1999).

Mountain Pine Beetle Symposium: Challenges and Solutions. October 30-31, 2003, Kelowna, British Columbia. T.L. Shore, J.E. Brooks, and J.E. Stone (editors). Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Information Report BC-X-399, Victoria, BC. 298 p.

Tree and Stand Level – the Safranyik Model

This population dynamics model (here after referred to as the “Safranyik model”) is a complex process-based simulation of mountain pine beetle activity on a 1-ha stand of pure lodgepole pine. The model uses a daily time step and simulates the process of host colonization, brood development and survival, predation and parasitism of mountain pine beetle as well as tree mortality (Safranyik et al. 1999).

The Safranyik model is composed of four main components (Safranyik et al. 1999): a mountain pine beetle biology sub-model, a forest sub-model, a management sub-model and a user interface handling inputs and outputs. Figure 1 shows a simplified flow chart, which demonstrates program flow.

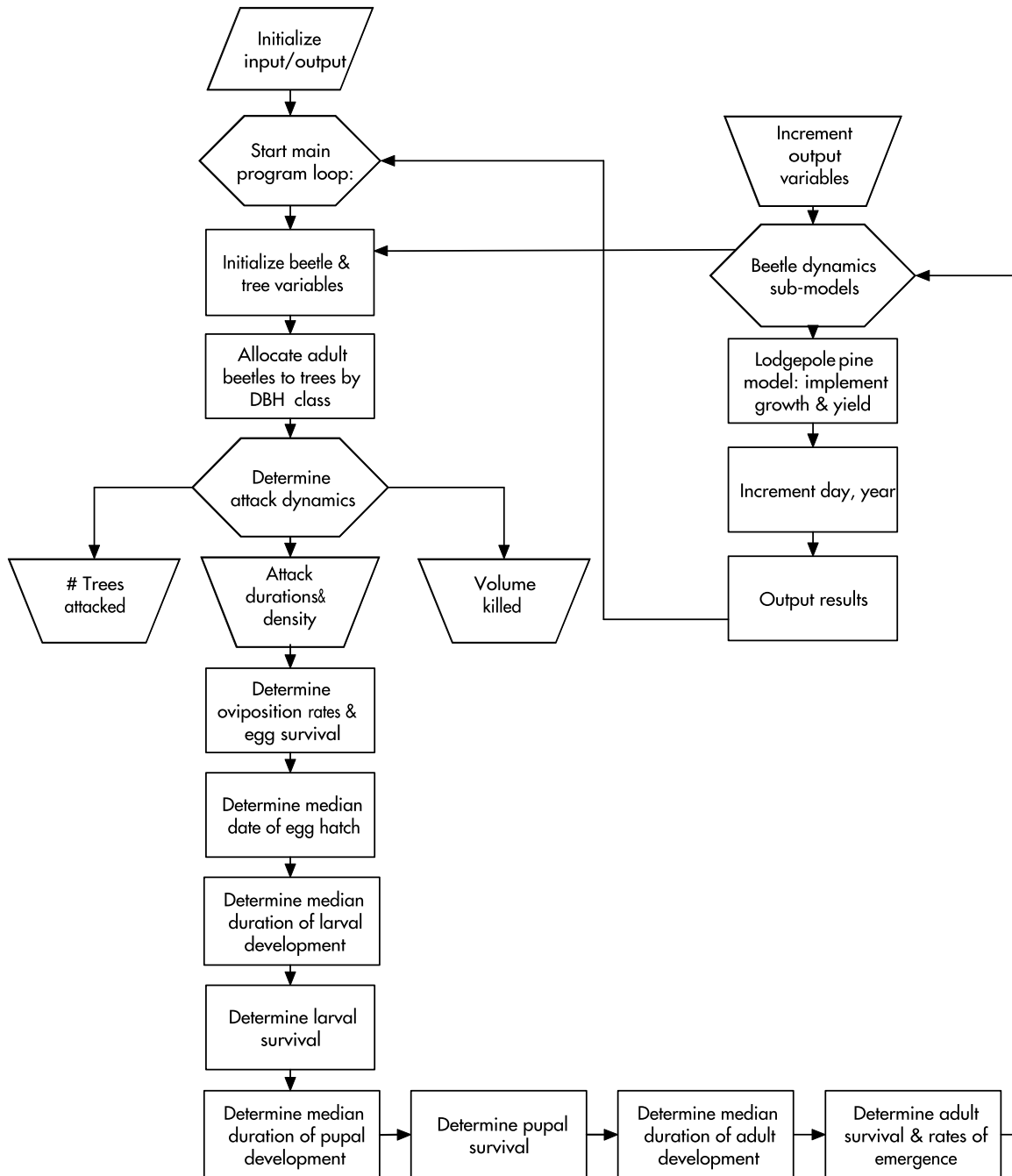


Figure 1. Safranyik model flow diagram (Safranyik et al. 1999).

Stand Level

The Safranyik model represents a sophisticated approach to modelling mountain pine beetle activity and for exploring effects of management intervention at the scale at which it operates. However, the scale of the simulation restricts its utility as a tool for forest managers who must deal with larger stands and stands of mixed tree species. For these reasons, a new simulation called MPBSIM has been developed.

MPBSIM is a stochastic, process based-simulation of mountain pine beetle activity at the stand level. Host stands can be mixed species and can range in size from 1 ha to 50 ha. MPBSIM is a much coarser simulation than the Safranyik model: it simulates host selection, brood development and survival, and beetle emergence and dispersal out of the stand on a yearly time step. Tree mortality is tracked on a year-by-year basis by different diameter at breast height (dbh) classes.

Like the Safranyik model, MPBSIM is composed of four main components: a mountain pine beetle population dynamics sub-model, a stand sub-model, a beetle management sub-model and a graphical user interface for collecting inputs and displaying model outputs.

MPBSIM input requirements include stand parameters and beetle information. Specifically the following inputs are necessary for running the simulation:

- Stand size (in hectares);
- Stand age (in years);
- Stand site index (for lodgepole pine, expressed in metres at 50 years breast height age);
- Percent pine;
- Stand density (stems per hectare); and
- Number of attacking beetles (or, number of currently attacked trees).

The outputs generated by MPBSIM include:

- Projected duration of outbreak (in years);
- The number of trees killed each year;
- The volume of trees killed year by year by diameter class;
- The number of beetles emerging year by year; and
- The number of beetles dispersing out of stand year by year.

Figure 2 shows a highly simplified flow diagram depicting overall program flow in MPBSIM.

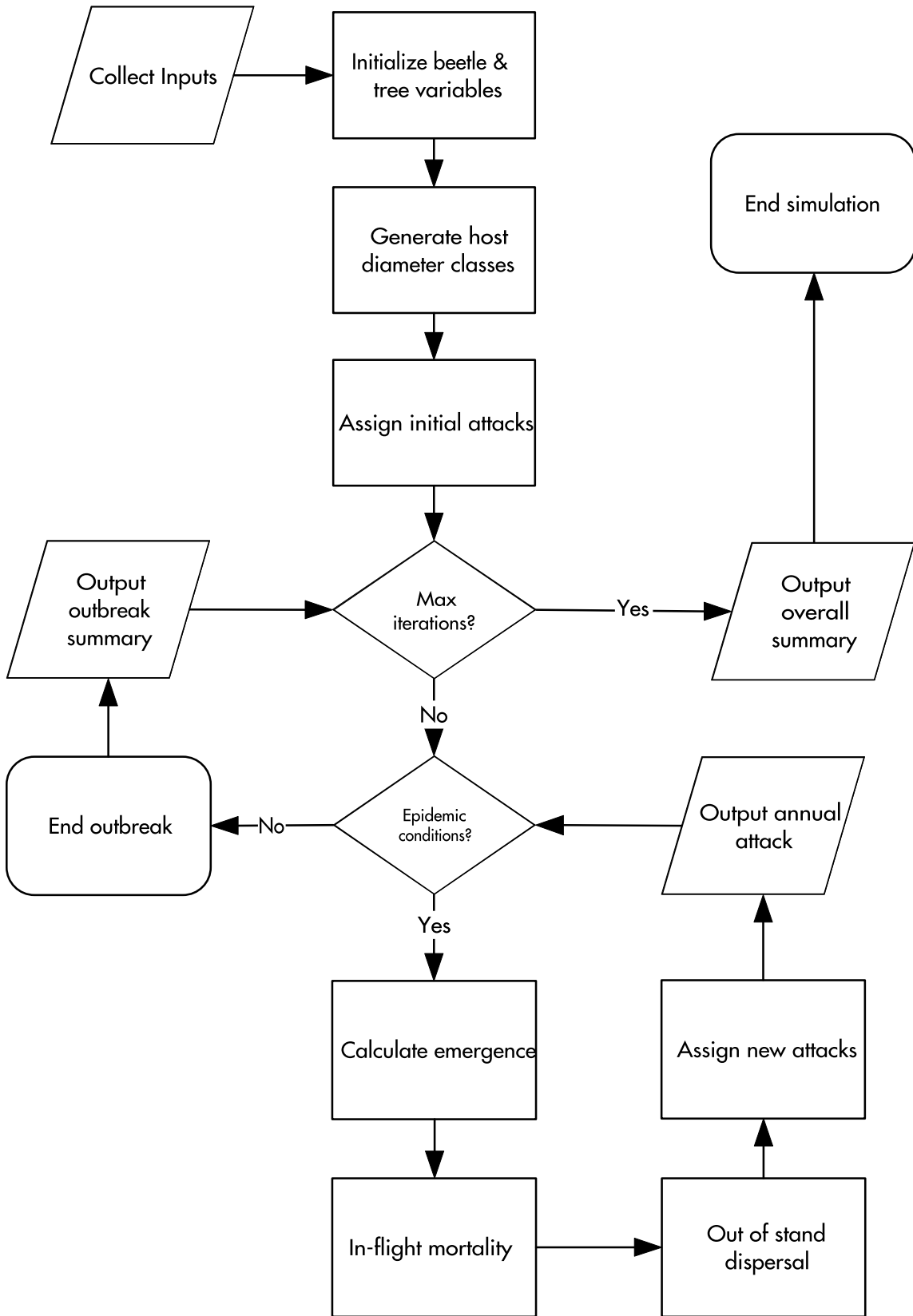


Figure 2. MPBSIM flow diagram.

Landscape Level: SELES-MPB

To effectively simulate a mountain pine beetle epidemic, a landscape scale simulation is important. A spatially explicit simulation allows a better platform for evaluating mountain pine beetle impacts and comparing various management strategies. For these reasons the Spatially Explicit Landscape Event Simulator (SELES) was chosen as a platform to build a spatial landscape scale mountain pine beetle simulation model (Fall and Fall 2001). SELES is not a model, but a raster-based platform in which to build and execute spatially explicit landscape models (Fall and Fall 2001). Every SELES model consists of three components:

1. Raster layers. These are the landscapes on which the simulation is executed. Layers can be base maps, forest inventory, road networks, etc.
2. Global variables. Global variables describe the state of the system.
3. Landscape events. Landscape events are the dynamic models that operate on (sometimes modifying) the landscape (raster layers). Landscape events can communicate indirectly through modifying the landscape.

The spatio-temporal model of mountain pine beetle spread and impact which was developed consists of several landscape events, including a spatially explicit mountain pine beetle spread model, a spatial timber harvesting model, a spatial mountain pine beetle management model and an aspatial mountain pine beetle impact simulation. This model is referred to as SELES-MPB.

Model Integration

To provide a satisfactorily detailed projection of mountain pine beetle impacts and to evaluate management effectiveness, it is preferable to generate stand level details of mountain pine beetle impacts even in a landscape model. For this reason, MPBSIM has been linked with the SELES landscape model as a landscape event. Because the purpose of SELES-MPB is to simulate beetle impacts and management strategies on real landscapes with unique climate and topography, it is important that MPBSIM projects beetle development and survival consistent with those conditions. To do this, MPBSIM is calibrated for the specific landscape using the Safranyik model.

The Safranyik model is capable of utilizing recorded daily temperatures for projecting mountain pine beetle development and survival as influenced by climate. To calibrate MPBSIM, temperature data from several weather stations located within the landscape are collected and adapted as inputs to the Safranyik model. A number of simulations are performed in a variety of stand conditions using these temperature data, and the resulting development and survival rates are used to calibrate MPBSIM.

Once MPBSIM has been calibrated to the local landscape climate, it can now be incorporated into the landscape model using a loose coupling methodology (Chang 2001). This is accomplished by collecting a complete range of inventory data for the landscape in question and pre-running MPBSIM for as many conditions as possible at a large number of different initial beetle attack levels. In practice this can amount to well over one million different combinations. A variety of values and indicators are output and collated in a large table which includes stand information (number of stems per hectare, stand age, percent pine, site index) and beetle and beetle activity information (number of attacking beetles, number of dispersing beetles, number of beetles emerging next year, trees killed and tree volume killed). This table reflects MPBSIM's projection of mountain pine beetle activity for any condition that exists on the landscape (Fig. 3).

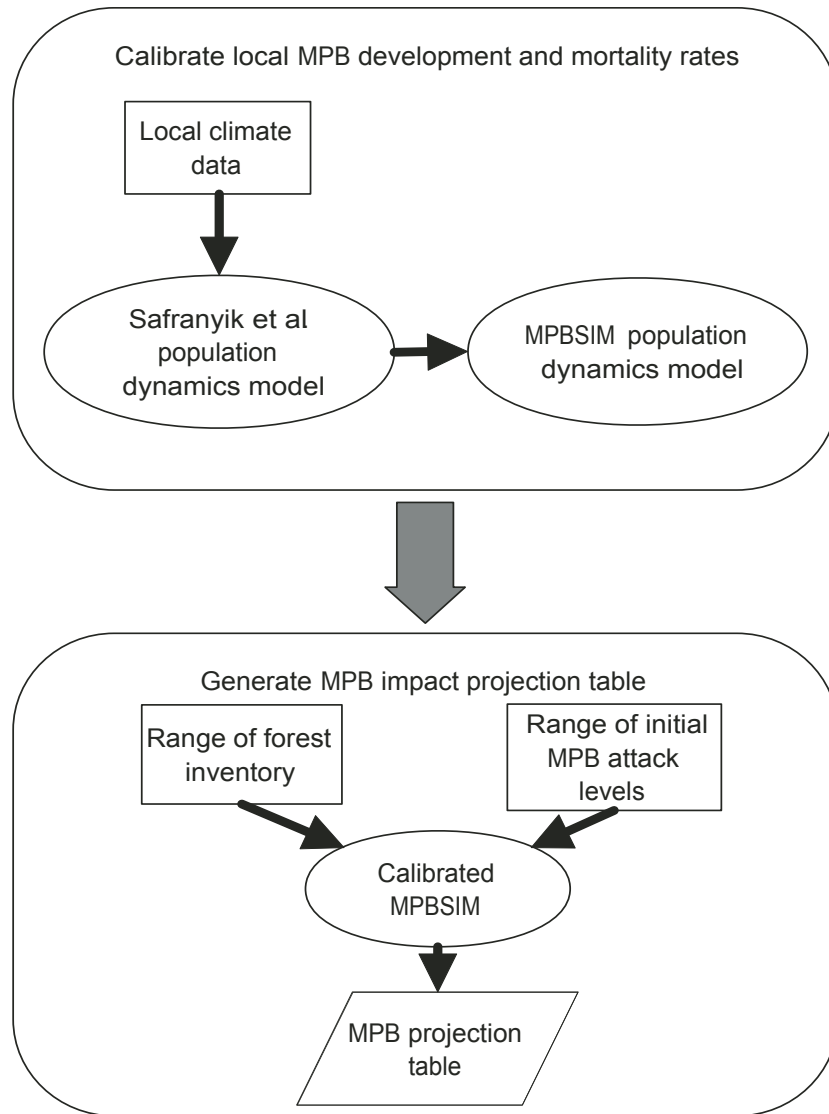


Figure 3. MPBSIM Calibration and table generation for SELES-MPB (MPB = mountain pine beetle).

The MPBSIM generated table is integrated into SELES-MPB as a landscape event, along with the spatial harvesting model and management model (Fig. 4). These landscape events do not directly communicate with each other, but can impact each other by making changes on the landscape (spatial landscape layers).

This modelling approach has been successfully applied in several districts within the provinces of BC and Alberta (Fall et al. 2001; Fall et al. 2002a; Fall et al. 2002b).

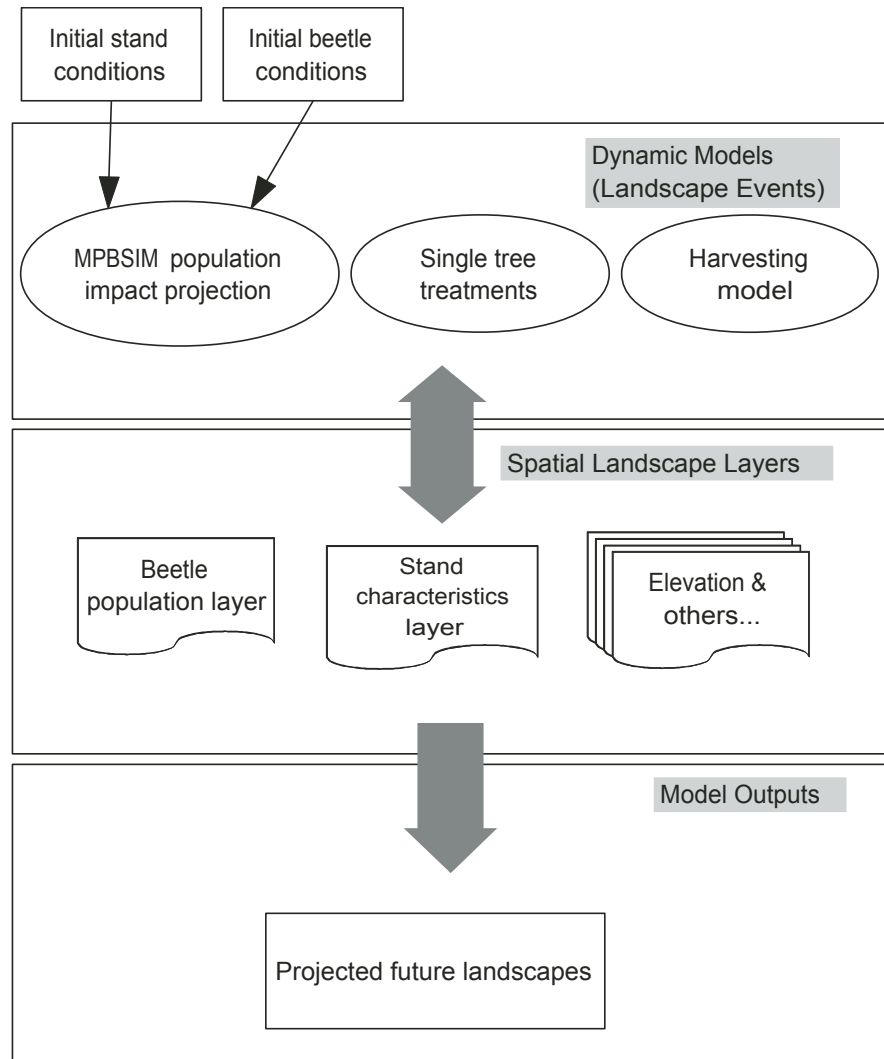


Figure 4. Overview of SELES-MPB.

Conclusions

Modelling mountain pine beetle activity at different scales is important for answering different management questions. Integrating models of different scales allows for a more detailed simulation of impacts and permits evaluation of management at appropriate levels of detail. The loose coupling approach of model integration used in SELES-MPB is a general method that could be used to integrate other models of different scales, whether they are simulations of mountain pine beetle activity or other landscape disturbance agents.

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Literature Cited

- Chang, K. 2001. Introduction to Geographic Information Systems. McGraw-Hill. Boston. 348 p.
- Fall, A.; Fall, J. 2001. A domain-specific language for models of landscape dynamics. *Ecological Modelling* 141(1-3): 1-18.
- Fall, A.; Eng, M.; Shore, T.; Safranyik, L.; Riel, B.; Sachs, D. 2001. Mountain Pine Beetle Audit Project: Kamloops Forest District Landscape Model. Report to Forest Practices Branch, BC Ministry of Forests.
- Fall, A.; Sachs, D.; Shore, T.; Safranyik, L.; Riel, B. 2002a. Application of the MPB/SELES Landscape-Scale Mountain Pine Beetle Model in the Lakes Timber Supply Area. Report to Forest Practices Branch, BC Ministry of Forests.
- Fall, A.; Sachs, D.; Shore, T.; Safranyik, L.; Riel, B. 2002b. Application of the MPB/SELES Landscape-Scale Mountain Pine Beetle Model in the Lignum IFPA. Report to Lignum Ltd.
- Safranyik, L.; Shrimpton, D. M.; Whitney, H. S. 1974. Management of lodgepole pine to reduce losses from the mountain pine beetle. *Can. For. Serv., Pac. For. Cen., Tech. Rep. 1.* 29 p.
- Safranyik, L.; Barclay, H.; Thomson, A.J.; Riel, W.G. 1999. A population dynamics model for the mountain pine beetle, *Dendroctonus ponderosae* Hopk. (Coleoptera: Scolytidae). *Can. For. Serv., Pac. For. Cen. Inf. Rep. BC-X-386.* 35 p.
- Thomson, A.J. 1991. Simulation of mountain pine beetle (*Dendroctonus ponderosae* Hopkins) spread and control in British Columbia. *Can. For. Serv., Pac. For. Cen. Inf. Rep. BC-X-329.* 18 p.
- Unger, L. 1993. Mountain pine beetle. Forest pest leaflet No. 76. *Can. For. Serv., Pac. For. Cen.* 7 p.
- Wood, S.L. 1963. A revision of bark beetle genus *Dendroctonus* Erichson (Coleoptera: Scolytidae). *Great Basin Naturalist* 23: 1-177.