Chapter 8: Simulating Mortality From Forest Insects and Diseases

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Abstract

We describe methods for incorporating the effects of insects and diseases on coniferous forests into forest simulation models and discuss options for including this capability in the modeling work of the Interior Northwest Landscape Analysis System (INLAS) project. Insects and diseases are major disturbance agents in forested ecosystems in the Western United States, and over time, are responsible for major changes in forest composition and structure. Incorporating their effects into forest simulation models is difficult, especially the representation of large, episodic insect epidemics. Much empirical data on insect mortality is available for modelers, and an array of mortality models have been incorporated into indivdual tree growth simulators. Scaling these models to simulate epidemics on landscapes requires, among other things, parameters that describe the amplitudes and periodicities of pathogen/pest population cycles. Incorporating insect and disease effects into forest simulation models makes it possible to explore ways to minimize epidemic conifer mortality and secondary interactions with other disturbances. In addition, the inclusion of other resource goals and financial considerations makes it possible to analyze the costs and benefits of forest management activities that target stands with high risk of mortality. We discuss options for modeling insect and disease mortality within the INLAS project.

Keywords: Forest insects and diseases, forest stand simulation, tree mortality, landscape simulation.

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Introduction

Simulating the potential impacts of insects and diseases on forests like those in the Blue Mountains of northeast Oregon is challenging. Defoliators (Torgersen 2001), bark beetles (*Dendroctonus* spp.) (Hayes and Daterman 2001), mistletoe (*Arceuthobium* spp.) (Parks and Flanagan 2001), and root diseases (Thies 2001) all have unique population dynamics, epidemiology, and effects on forest vegetation. Interactions among these disturbance agents as well as with management activities and physical disturbances such as wildfire and windthrow are also significant. Collectively, insects and diseases are major determinants of forest composition and structure over time, and thus warrant serious attention in forest planning and landscape simulation efforts (Quigley et al. 2001). Previous federal and state planning efforts may have underestimated the potential effects of insects and diseases in projections of future forest conditions, which may have reduced the effectiveness of these plans (Gast et al. 1991).

In this paper, we review methods to model conifer mortality caused by major forest insects and diseases within the framework of landscape planning models such as those described in Ager (Chapter 3), Bettinger et al. (Chapter 4), and Hemstrom (Chapter 2). Much of this work involves integrating and parameterizing existing mortality and risk models implemented elsewhere, such as in the Forest Service Forest Vegetation Simulator (FVS) (Wykoff et al. 1982). However, major gaps exist in the area of modeling spatial spread rates data for some insect species, and the process of simulating the complex cycles of insect populations and disease centers on a large landscape is a challenge for any landscape planning effort. The following discussion treats forest insects separately from forest diseases. We focused on major pests in the Blue Mountains based on historical survey data (Gast et al. 1991) with the broad goal of summarizing existing tools, identifying major gaps, and proposing research and development to create a robust set of methods for modeling mortality caused by forest insects and diseases.

Extensive descriptions and reviews of insects and diseases and their effects on forest trees in the Blue Mountains can be found in Filip et al. (1996), Gast et al. (1991), Hayes and Daterman (2001), Parks and Flanagan (2001), Thies (2001), and Torgersen (2001). Aerial survey maps of insect infestations provide a detailed chronology of infestations over a 50-year period for the Blue Mountains (USDA FS 2003a).

Insect Mortality Models

Pertinent aspects of insect biology in the context of landscape planning models center on the dynamics of infestations and include the periodicity and amplitude of the infestation cycles, the spatial pattern of the initial infestation centers, and the resulting damage they cause in terms of mortality and reduced vigor. The divergent life histories of the major mortality-causing insects complicate an integrated modeling approach in landscape planning models.

Tree-level mortality models for the major mortality-causing insects are all implemented in FVS extensions that are described in detail elsewhere (USDA FS 2003b) There are many case histories of modeling insect- and disease-caused mortality at the stand (e.g., Cameron et al. 1990, Gast et al. 1991; also see Hayes and Daterman 2001, Torgersen 2001), and to a lesser extent, landscape scale (Beukema et al. 1997, Eager and Angwin 1997, Graetz 2000, Smith et al. 2002). Landscape simulations are usually accomplished by imputing tree lists for stands where data are incomplete. Insect mortality models can be built ad hoc in FVS when no formal model exists by using the COMPUTE statements and the event monitor to trigger mortality on specific host trees when stand conditions meet an established susceptibility criterium. The existing FVS model extensions differ in their state of validation and complexity and require many parameters to trigger outbreaks and regulate the mortality. Recent efforts have focused on simulating multiple pests (e.g., Roberts 2002, Roberts and Weatherby 1997), examining interactions among pests (e.g., Eager and Angwin 1997), and modeling the spatial spread of insects (e.g., Smith et al. 2002). The use of the FVS Parallel Processor (Crookston and Stage 1991) vastly simplifies the modeling of insect spread among stands within the FVS system.

Modeling endemic insect mortality requires parameters that define stand and tree susceptibility and mortality rates among the tree type within the stand. Modeling epidemics implies a spatial extent beyond an individual stand, and additional parameters are required to control (1) triggering of an outbreak; and (2) duration, intensity, and frequency of occurrence (Roberts and Weatherby 1997). In the case of the westwide pine beetle model (Beukema et al. 1997), a spatially explicit model that considers stand contagion, parameters also are needed to control the rate of spread. Parameters needed to simulate insect epidemics are described individually below.

Determining Susceptibility Levels to Epidemic Events

Stand susceptibility models use stand attributes such as average size and density of host species and physical site factors including ecoclass, slope, aspect, and elevation in determining susceptibility to insect outbreaks. In a few cases, spatial information such as the distance to the nearest infestation also is considered (e.g., Shore et al. 2000). In FVS, stand susceptibility models can be built and implemented by using FVS COMPUTE statements that calculate relevant stand metrics (Roberts and Weatherby 1997).

Triggering an Outbreak

Outbreaks can be triggered as a function of susceptibility levels or by using assumptions about intrinsic insect population cycles (Monserud and Crookston 1982). The resultant mortality is dependent on other factors such as susceptibility levels and outbreak duration and intensity. Epidemic triggers can be regulated independently of endemic mortality by changing the probability of the two levels of mortality and associated intensity of the outbreaks. Some FVS model extensions have keywords that specify whether stands are part of widespread or local outbreaks. Assumptions that are tailored to specific insect pests are usually made about the interval between outbreaks and their duration. The outbreak is manifested in mortality if susceptibility conditions are appropriate. Roberts and Weatherby (1997) provide examples of simulating insect outbreaks by using the FVS extensions.

Duration of Outbreaks

Population dynamics, spread, and host availability affect duration of infestations. The FVS insect extensions have defaults for duration. For instance, the default for Douglas-fir beetle (*Dendroctonus pseudotsugae* Hopkins) pest extension (Marsden et al. 1994) is 4 years in the Blue Mountain variant. In the western spruce budworm (*Choristoneura occidentalis* Freeman) extension (Crookston et al. 1990, Sheehan et al. 1989), the duration is related to a hazard rating system where low hazard generates a 5-year, moderate a 10-year, and high a 15-year duration. Management activities that alter susceptibility after an outbreak begins can alter the duration. Mortality of the host also affects duration of outbreak.

Intensity of Outbreaks

Intensity is usually expressed as a function of the number of host trees killed by tree species and diameter class per FVS cycle. Some models such as the Western Spruce Budworm Extension can incorporate other types of damage like top kill and decreased growth from defoliation. Intensity is modeled in concert with spread rate among stands as part of simulating an epidemic. Damage is affected by using mortality functions in the FVS extensions, either within an FVS extension or within outside software.

Spread

At least two methods have been applied to simulate the spread of an insect epidemic. One approach uses Monte Carlo methods that simulate gradual growth of the infestation among the population of stands in the simulation (Roberts and Weatherby 1997). This approach does not consider stand contagion but rather uses random selection of stands that meet susceptibility criteria. The probability of an infestation can be changed in this process to alter the rate at which stands become infested. Multiple probabilities can be used in a similar Monte Carlo process to trigger low-level endemic mortality as well as large epidemics. A more sophisticated approach to insect spread that considers stand contagion was developed in the westwide Pine Beetle Model (Beukema et al. 1997, Smith et al. 2002). Stands are simultaneously simulated by using the FVS parallel processor, and stand-to-stand spread of beetles is simulated.

Disease Mortality Models

The major tree diseases in the Blue Mountains are root disease and dwarf mistletoe. Although dwarf mistletoe is primarily modeled as causing growth reduction, root disease is simulated as causing mortality. Principal root diseases include Armillaria root disease caused by *Armillaria ostoyae*, laminated root rot caused by *Phellinus weirii* (Murr.) Gilb., Annosus root disease caused by *Heterobasidion annosum* (Fr.) Bref., and black stain root disease caused by *Leptographium wageneri* Kendrick M.J. Wingfield. Extensive reviews of these diseases and their occurrences in the Blue Mountains can be found in Hagle and Goheen (1986), Hessburg et al. (1994), Campbell and Liegel (1996), Filip et al. (1996), and Thies (2001). Fundamental differences in the biology between insects and diseases call for different modeling methods. Although contagion is a factor with diseases, the spread is too slow to consider as part of a landscape process (e.g., 2 feet per year). Diseases can be modeled as endemic mortality, meaning that the mortality is chronic, not episodic, and mortality is an intrastand or intrapolygon, rather than an interstand or interpolygon process. In contrast to disease, the most important component in simulation models for insects is the relationship between mortality and management activities. High levels of management activities can bring about more infections and mortality (Thies 2001), whereas in insect pests, management is largely viewed as a way to reduce spread.

As with insects, extensive modeling capability for diseases exists in FVS (Frankel 1998, Hawksworth et al. 1995). The western root disease model in FVS simulates the effects of Armillaria root disease, laminated root rot, and Annosus root disease (Frankel 1998). Considerable effort is required to build keyword files and calibrate these models for application on large landscapes. Management to control diseases (e.g., boron treatments) can be simulated with FVS extensions. Given the slow rate of disease spread, many of the concerns with insect pests in terms of interstand spread and cyclical epidemics are not an issue with diseases.

Insect and Disease Risk Models

The previous discussion focused on the modeling of tree mortality from insects and diseases. Depending on the overall objectives, the insect and disease considerations in landscape planning can often be addressed by using only measures of infestation or infection risk rather than predicting actual tree mortality. Risk models measure the long-term outlook for the effects from pests and offer a relatively simple approach to characterize forest conditions in terms of a latent potential to experience mortality, and are often used when tree-level mortality modeling is not practical. Numerous risk rating models for insects and diseases have been developed and widely applied in coniferous forests in the intermountain West and elsewhere (see Hayes and Daterman 2001, Hessburg et al. 1994, Lehmkuhl et al. 1994, Steele et al. 1996). These models are typically used in watershed or National Environmental Policy Act (NEPA)-related analysis to help identify susceptible stands and assign treatment priorities. Most models output categorical values that measure relative risk, and a few quantify risk in probabilistic terms. Risk assessments are used to identify treatment priorities to reduce hazards from infestations or epidemics. Many, but not all of the models, have been tested through field validation and are published with accompanying software. Risk models have been added to FVS as event monitor applications for the mountain pine (*Dendroctonus ponderosae* Hopkins) and spruce (*D. rufipennis* (Kirby)) beetle. There is also integrated pest risk software that calculates multiple insect and disease risk ratings (Ager 1996, Hessburg et al. 1994, Scott et al. 1998).

Data requirements for the risk models differ ranging from coarse photointerpreted stand characteristics such as canopy closure to detailed stand metrics such as the basal area of host species within a specific diameter range. In addition, many models require physiographic inputs like slope, aspect, elevation, and other physical attributes. A number of risk models have subcomponents that independently measure risk from susceptibility to better assess probability of mortality.

Although risk models offer a rapid way to address insect and disease considerations in landscape planning projects, their shortcoming is that they generally do not consider population levels and cycles, and therefore only measure the longer term risk of an infestation and mortality.

Landscape Modeling Systems

State transition models of landscape vegetation (Hemstrom et al. Chapter 2) use discrete vegetation classes and transition probabilities to model change from succession, management, and disturbance (Kurz et al. 2000). In contrast to tree-level growth models like FVS, the growth and mortality of individual trees is encapsulated in the transition probabilities. The use of states and transitions reduces the complexity of landscape simulations, although there remains a significant challenge to estimate and validate transition probabilities. There are several case studies using a state and transition approach to modeling forest landscape change by using the Vegetation Dynamics Development Tool (VDDT) and the Tool for Exploratory Landscape Analysis (TELSA) (Kurz et al. 2000). A prototype TELSA model built for the Upper Grande Ronde considered insect mortality from spruce budworm and Douglas-fir beetle; and spruce beetle and mountain pine beetle in ponderosa (*Pinus ponderosa* Dougl. ex Laws.) and lodgepole pine (*P. contorta* Dougl. ex Loud.). Insect epidemics were simulated, and mortality was represented by changing the vegetative state of infested stands based on host mortality. Parameters for simulating epidemics were obtained from data on historical infestations including USDA Forest Service, Pacific Northwest Region aerial survey maps (USDA FS 2003a) and other historical information (e.g., Gast et al. 1991). Pertinent information for each insect vector included periodicity of outbreaks and the percentage of host type infested during an outbreak. Initial results from this model show how different management scenarios change future extent and severity of insect epidemics and the effects of alternative forest management schedules.

Alternatives to the state and transition approach are stand-level models that use individual-based tree growth models to simulate multiple stands on a landscape. Incorporating insect- and disease-caused mortality into these models is relatively straightforward. For instance, a simple landscape simulation with insect and disease mortality can be built by simulating all the stands in a landscape with FVS and FVS pest extensions (Roberts and Weatherby 1997). This approach can be enhanced to consider spreading of infestations by using the FVS parallel processing extension, as in the westwide pine beetle model (Smith et al. 2002). When combined with the array of other FVS extensions and postprocessors (USDA FS 2003c), the multistand approach of using FVS and the parallel processing extension provides a flexible system that can address a variety of scenarios.

More complex are the stand-alone optimization models such as the Simulation and analysis of forests with episodic Disturbances (SafeD) model (Bettinger et al. Chapter 4, Graetz 2000, Wedin 1999), which derive their growth equations from FVS code but do not have direct linkages to FVS and the pest extensions. In SafeD, insect and disease mortality was modeled as an endemic process as part of stand growth (Wedin 1999), and epidemic or periodic mortality from insects or diseases was not considered.

Research Approach

Options for Different Modeling Frameworks

Each of the methods (FVS-related software, state transitions models, landscape simulation/optimization models) for simulating vegetation change for the INLAS project requires different amounts and kinds of development to enable modeling of insect and disease mortality. The major tasks required to incorporate insect- and disease-caused mortality by using FVS-related software approach (Ager Chapter 3) involve issues of local calibration and experience to run the FVS extensions for Douglas-fir beetle, western spruce budworm, Douglas-fir tussock moth (*Orgyia pseudotsugata* McDunnough), and mountain pine beetle on lodgepole pine. Additionally, ad hoc models for mountain pine beetle on ponderosa pine, western pine beetle (*D. brevicomis* LeConte) on ponderosa pine, and spruce beetle on Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), such as those illustrated by Roberts and Weatherby (1997) for ponderosa pine, need to be evaluated on local stand conditions. A major part of this work will be estimation of parameters for epidemic lengths, periodicities, and spread rates for Blue Mountain conditions. For INLAS, we will experiment with FVS insect extensions in concert with the development of FVS-related landscape simulation tools.

Stand-alone landscape optimization models such as those described by Bettinger et al. (Chapter 4) pose a larger problem within the context of INLAS. Although modeling **endemic** mortality can be accomplished by using mortality functions derived from the literature, modeling epidemics in stand-alone optimization models will require substantial work and is probably beyond the scope of this project. A first step would be converting FVS insect extensions to run within other stand-alone programs. Parameters are then needed for epidemic lengths, periodicities, and spread rates for Blue Mountain conditions. With this accomplished, epidemics could be simulated much like wildfire as described by Bettinger et al. (Chapter 4), where simulations are stopped each decade to run the FARSITE fire model (Finney Chapter 9). Insect mortality could be simulated every cycle, with epidemic parameters carrying over from cycle to cycle. Supporting epidemic parameters described above, including spread rate, intensity, and duration, are needed. An alternative that would take advantage of many of the FVS insect and disease models could be achieved by using the pest extensions in FVS to process tree lists from a stand-alone optimization model at each cycle. Specifically the Douglas-fir beetle, western spruce budworm, and western pine beetle can be applied to tree lists generated by SafeD and used to trigger single-cycle tree damage and mortality. Components of the FVS insect and disease models that consider more than one cycle would need to be incorporated into the optimization model. For instance, the scheduling of periodic outbreaks could be implemented by writing the appropriate keyword files for FVS. The integration of insect and disease mortality into forest simulation/optimization models would provide a way to explore how different landscape goals are affected by these disturbance agents. Both stand and landscape goals can incorporate financial or other considerations to allow the estimation of the marginal cost of reducing insect and disease effects. Landscape goals also can be combined into multiobjective goals. For instance, stand goals would minimize susceptibility, whereas landscape goals could alter the spatial arrangement of susceptible stands to minimize spread (see Bettinger et al. Chapter 4). Landscape planning models can explore alternative scenarios by applying management activities targeting specific insect pests. Results from simulations could be applied by forest managers, pest management practitioners, and researchers concerned with landscape planning and simulation.

State and transition models require specific transitions to represent mortality of the different insect and disease agents (Hemstrom et al. Chapter 2). Like the other modeling approaches, the major part of this work is estimating characteristics of epidemics for Blue Mountain conditions. We discuss approaches to estimating these parameters below.

Estimating Parameters for Insect Epidemic Cycles

As mentioned earlier, a key component of any effort to model insect and disease mortality is parameters that describe the lengths, periodicities, and spread rate of epidemics for each insect of concern for local conditions. This section presents the result of a preliminary work to quantify these parameters by using data on past infestations. Although ultimately the size of epidemics is dependent on host type availability and secondary factors that influence epidemic growth (e.g., weather, spatial patterns of host, natural disturbance), realistic values must be used for epidemic cycles.

The importance of host availability and other factors is illustrated with historical conditions in the Blue Mountains. For example, it is assumed that the large historical outbreaks of western pine beetle have not been repeated in recent times owing to a decrease in large-diameter ponderosa pine. In contrast, infestations by defoliators have increased with the extent of defoliator host type (e.g., true firs) (e.g., Powell 1994). Spruce beetle epidemics are often triggered by wind events that result in a large number of downed spruce (e.g., Gast et al. 1991). Another example is Douglas-fir beetle, where trees weakened during defoliator outbreaks seem especially susceptible to Douglas-fir beetles (e.g., Wright et al. 1984). Hence, bark beetle activity is often observed after several years of budworm or tussock moth defoliation in the Blue Mountains.

Despite the dependence of outbreak size on host and other factors, we tried to gain some preliminary insight into the spatiotemporal patterns of insect epidemics by surveying historical outbreaks. For instance, it would be of interest to know how epidemics are manifested in terms of the numbers of individual infestation sites and the average size. Using data from the annual Aerial Insect Detection Survey conducted by the USDA Forest Service Pacific Northwest Region and Oregon Department of Forestry, we summarized and examined patterns of past insect infestations in the Blue Mountains. Additional information was obtained from Gast et al. (1991). These data clearly show the difference between epidemic and endemic infestations, and that endemic levels for one insect may exceed endemic levels for others (table 6, fig. 26). Bark beetles have relatively active endemic populations in the Blue Mountains compared to defoliators, and the acres affected during an epidemic range from a twentyfold to thirtyfold increase for some species, whereas others can cause a onefold to several hundredfold increase. Endemic levels of defoliators are so low that damage is not visible. Clearly, the defoliator cycles are high amplitude, and in the case of spruce budworm, have a long cycle. Although epidemics were characterized by increases in both infestation size and number of sites, the latter appears more important than the former. For instance, the individually mapped beetle infestations are all about 1.5 to three times larger for the epidemic versus endemic periods, whereas the number of polygons increased by an average of six times. We note that this difference could be an artifact of the mapping procedure. Also, the spatial arrangement of host stands could account for a major component of the size versus number contrast.

Table 6—Summary of aerial survey insect damage surveys showing population parameters[a]

Species	Population status	Average duration	Average periodicity	Number of polygons	Proportion of years	Average mapped unit	Total area
		– – – – – Years – – – – –			*Percent*	*– – – – Acres – – – –*	
Douglas-fir beetle	Endemic			108	43.75	70	7,560
	Epidemic	8	15	661	65.25	265	175,165
Fir engraver beetle	Endemic			137	79.20	190	26,030
	Epidemic	5	20	951	21.80	257	244,407
Western pine beetle	Endemic			108	75.00	143	15,444
	Epidemic	4	16	299	25.00	364	108,836
Mountain pine beetle in lodgepole pine	Endemic			68	70.80	200	13,600
	Epidemic	9	63	749	29.20	561	420,189
Mountain pine beetle in ponderosa pine	Endemic			216	78.70	154	33,264
	Epidemic	5	14	986	21.30	315	310,590
Spruce beetle	Endemic			23	85.40	225	5,175
	Epidemic	6+	Variable: disturbance-related	129	14.60	348	44,892
Douglas-fir tussock moth	Endemic			0	81.10	0	0
	Epidemic	3	9	353	18.90	557	196,621
Western spruce budworm	Endemic			0	56.60	0	0
	Epidemic	12	36	583	43.40	4,858	2,832,214

[a] Data were obtained between 1954 and 2001 and pertain to all forested lands in the Blue Mountains province. Low damage (BS-L and BS-1) for western spruce budworm were not included because they do not generally indicate host mortality.

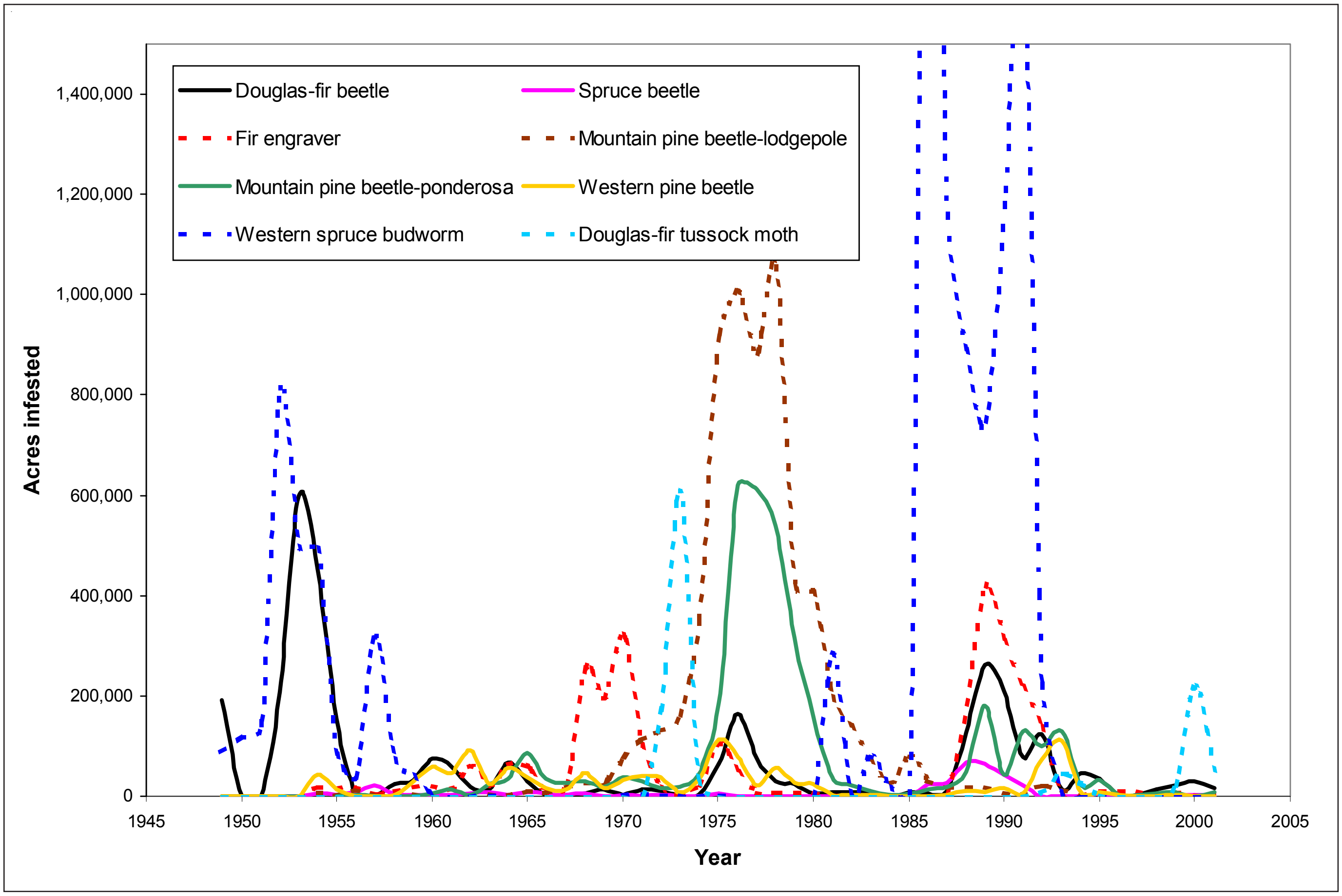

Figure 26—Acres infested with major insect pests as derived from aerial survey information and Gast et al. (1991). Peak values of about 3 million acres for western spruce budworm were truncated to improve visibility of other data. Budworm damage codes for low damage (BS-L, BS-1) were omitted.

At a minimum, table 6 and figure 26 illustrate qualitative features of insect infestations and illustrate the stochastic nature of this particular natural disturbance. In addition, the data show the relative importance of modeling spatial spread and contagion among the various insect pests. Defoliators like western spruce budworm that are capable of rapid spread over very large areas probably do not warrant detailed modeling of spread because most or all host are infested over a short period. In contrast, insects that have longer infestations per area affected (i.e., broad peaks, such as mountain pine beetle in lodgepole pine and fir engraver beetle [*Scolytus ventralis* LeConte in true fir]) show longer infestation periods per total acres infested, suggesting constraints to spreading are regulating these infestations more than in the western spruce budworm. Here, more detailed spread models might be warranted.

It should be noted that the data show population status data for the Blue Mountains as a whole, and it is possible to have localized epidemics that result in significant damage. Douglas-fir tussock moth epidemics have characteristically developed in several discrete and different areas within the Blue Mountains over the last century. However, in most cases, epidemic populations of various insects and associated damage develop concurrently or occur over large areas within the Blue Mountains.

One additional factor that must be considered with these data is that aerial survey sketch mapping has evolved over the years as new technology has been developed. For example, this new technology has allowed more accurate portrayal of discrete pockets of infestation, whereas in the early days of surveying, these were grouped in large polygons; thus, polygons have decreased in size and increased in number.

Proposed Work

The goal of incorporating insect and disease mortality in landscape simulation models in the context of INLAS is to better understand the long-term interactions of insects, disease, management, and other disturbances, and forest succession. Through the INLAS project, we will continue to investigate the historical epidemic data and try to produce parameters for each of the major insect pests. Work on diseases will probably be minimal given their relatively minor effect on mortality. We will explore methods to assess uncertainty in the insect epidemic data. Given a set of reasonable parameters, epidemics will be simulated by using the simulation framework described in Ager (Chapter 3) for the INLAS project area. These simulations will use the FVS pest extensions and will be completed for a set of management scenarios (Barbour et al. Chapter 1). The outputs will provide the data to examine how long-term levels of insect mortality might be affected by different intensities and kinds of forest management at the subbasin scale.

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Metric Equivalents

When you know:	Multiply by:	To find:
Acres	0.405	Hectares
Feet	.3048	Meters

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