Evaluation of Risk Assessment of Mountain Pine Beetle Infestations

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ABSTRACT: *Decision support systems to aid the management of mountain pine beetles combine characteristics of the stand and beetle infestation to estimate risk of damage. Beetle infestation information is now available in a format amenable to the operational implementation of risk. In this study, an established risk rating system was evaluated to determine the utility of the values generated. For a study area located in British Columbia, Canada, global positioning systems were used to survey an infestation. The annual data was used to generate risk for a given year and to compare the ratings with survey data from the subsequent year. Under epidemic conditions, 30% to 43% of the stands rated as high risk were subsequently infested. Of the infested stands, 72% to 76% had a high risk rating. In general, the risk rating system accurately predicted risk in stands that were infested, but not all high risk stands were subsequently attacked. This highlights the difficulty of modeling processes that have a stochastic component. For operational contexts, the estimation of risk on an annual basis is sufficiently reliable to aid in the strategic planning of forest managers. West. J. Appl. For. 21(1):5–13.*

Key Words: Decision support, survey, mountain pine beetle, *Dendroctonus ponderosae*, epidemic, forest damage, global positioning systems, risk rating.

The mountain pine beetle (*Dendroctonus ponderosae* Hopk.) generally attacks mature stands of lodgepole pine (*Pinus contorta*), ponderosa (*P. ponderosa*), and whitebark pine (*P. albicaulis*), often causing extensive mortality. Infestations of mountain pine beetle are generally limited by host abundance and distribution, and suitably mild winter temperatures (Safranyik et al. 1974). The extent of the current epidemic in British Columbia, Canada, is increasing annually. The area infested is estimated at approximately 2 million ha in 2002 (Westfall 2003), over 4 million ha in 2003 (British Columbia Ministry of Forests 2003a), to over 7 million ha in 2004 (Westfall 2005). Decision support systems that incorporate movement of pests allow managers to fight outbreaks more efficiently (e.g., Hawksworth et al. 1995).

Decision support systems that aid managers in combating insect outbreaks must incorporate information on the pest locations and population. Traditionally, information regarding bark beetle infestations was available from aerial overview survey data and subsequent field visits (Van Sickle et al. 2001). However, each of these data sets had limitations precluding their use in the decision support systems. For instance, aerial overview survey data lacks spatial precision and often remained in an analog paper form. Field surveys had high precision and accuracy, however, were rarely done over large areas (Wulder et al. 2004). The operational adoption of helicopter-surveys with global positioning systems (GPS) point collection provides a reliable data set for large management units. It is only recently (2000) that the reliability of GPS, through the removal of selective availability, increased to levels required for unfettered operational usage (www.ngs.noaa.gov/FGCS/info/sans_SA/). An additional advantage of collecting GPS locations from a helicopter platform is the lack of interference with the GPS signals caused by the forest canopy.

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Identifying forest stands prone to attack by mountain pine beetle provides forest managers with information to assist in mitigation and management planning. We define risk as "the short-term expectancy of tree mortality in a stand as a result of mountain pine beetle infestation" (Shore et al. 2000). Areas identified as high risk can be targeted for sanitation harvesting or other mitigation activities. Risk rating systems for mountain pine beetle have been developed because susceptibility or hazard rating, which are based on stand characteristics, do not necessarily indicate a short-term likelihood of infestation under outbreak conditions (Shore and Safranyik 1992, Bentz et al. 1993). Stand risk is the combination of the host tree characteristics and the location and size of nearby beetle populations. Therefore, it indicates the short-term probability of loss of stand basal area. For example, stands close to high beetle populations may be rated as having high risk despite suboptimal stand characteristics. Risk rating systems may evaluate the impact of the beetle population based on the density of currently infested trees within the attacked stand (Munson and Anhold 1995, Chojnacky et al. 2000) or combinations of stand and landscape variables (Shore and Safranyik 1992). The incorporation of landscape-scale indicators of beetle population size in the Shore and Safranyik (1992) risk model allows for dispersal of beetles out of the earlier infested stands. This model was developed for environmental and insect conditions present in British Columbia, and the susceptibility component is commonly used by forest managers in the private and public sector.

Risk rating is often done informally by visually interpreting maps of areas infested by mountain pine beetle and a stand susceptibility map. The limitations to this type of informal approach include inconsistent interpretation among individuals or organizations, knowledge gaps (based on different background experience), and interpreter inexperience caused by time lags that often occur between epidemics. Some of these limitations can be addressed through formal definitions and standardized estimates of risk. The formal risk assessment compliments the local knowledge of experienced managers. This approach of informing managers, other stakeholders, and the general public has been successfully applied in the fire management context through the development of fire danger rating systems (Van Wagner 1987, Alexander et al. 1996).

In this study, an established decision support system was evaluated for operational use (Shore and Safranyik 1992). Digital forest inventory and beetle-impact survey data were integrated in standard GIS software for rating susceptibility and risk of mountain pine beetle infestation. The beetle impact data, collected over a 3-year period, provided an opportunity to generate risk in a given year and to compare it with attacks in the subsequent year. We used this technique to evaluate the likelihood of an attack in the next year.

Methods and Data

Study Area

The study area is a valley located between two epidemic beetle populations in central British Columbia, Canada. The study area was at the south end of the Nadina forest district, and north of Tweedsmuir provincial park (Figure 1). The valley runs south-east to north-west, and is bordered on the south by a large lake, and to the west and north by alpine/tundra land cover (Figure 1). This area overlaps three biogeoclimatic ecozones: the coastal western hemlock zone, the Englemann spruce-subalpine fir zone, and the subboreal spruce zone (British Columbia Ministry of Forests 2003b). The productive forest is dominated by fir (primarily *Abies lasiocarpa*), hemlock (*Tsuga* spp.), and pine (predominantly *Pinus contorta*, with *Pinus albicaulis* also present), with spruce (*Picea* spp.) as secondary species.

Application of the Risk Rating Model

Susceptibility

Risk rating is the combination of forest susceptibility and beetle population pressure. The susceptibility was based on the calculations presented by Shore and Safranyik (1992). Some modifications were required to enable standardized implementation and use of the rating system. One modification was the use of continuous equations rather than look-up tables. The equations are a model refinement that provides a more realistic distribution of susceptibility values. T.L. Shore and B.G. Riel (unpublished data) provided the equations, which resulted from their continued research and development work after the 1992 publication. The susceptibility model was also adapted to the variables available in Forest Inventory Planning (Forestry Incentives Program [FIP]) databases. Howse (1996) suggests an adaptation of the model to operate using available FIP variables. The FIP data does not contain the basal area of different species or the density (stems per hectare), which are required by the Shore and Safranyik (1992) model. The FIP adaptation replaced the percent of pine by basal area with the percentage of pine by stand volume. Furthermore, density was replaced using mean diameter as a surrogate. In addition to the forest characteristics captured in the FIP database, the latitude and longitude (in decimal degrees) and elevation (in meters) were from a 25-m digital elevation model before implementation.

The FIP database was developed primarily to maintain information on timber volume. The database was kept up to date by air photo interpretation as needed. The variables collected included dominant canopy species (up to four species), percentage of composition, stand age at time of survey, stand mean diameter, crown closure, site index, land type, and land position. Growth and yield models were applied to project the stand characteristics to a common date. Data quality issues include the inconsistencies of air photo interpretation between photo scales, people, or dates; different data collection standards (e.g., identification of trees at the genera level, i.e., *Picea* spp. or at the species level, i.e., *Picea glauca*); artificial stand boundaries created by map sheet edges; ephemeral water bodies; and possible inaccurate assumptions on the relationship between tree height and age. Specific to the calculation of susceptibility and risk, the most significant data quality problem was that

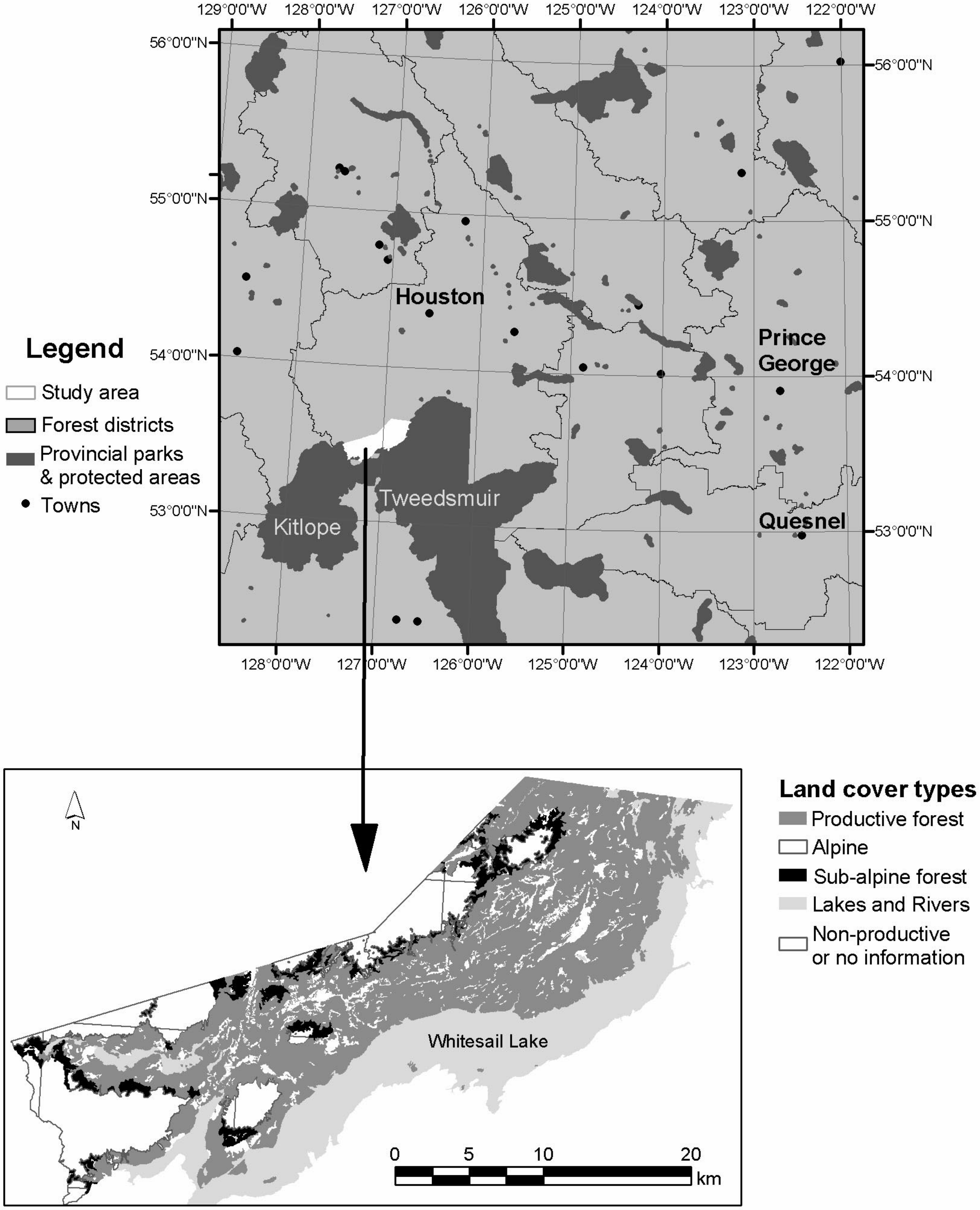

Figure 1. Study area in central British Columbia, Canada.

the characteristics of the entire stand did not necessarily apply to pine component.

Beetle Pressure

Beetle pressure was calculated for each stand based on helicopter survey data. Provincial forest managers have used point aerial surveys to monitor mountain pine beetle infestations in the area since 1995. Aerial surveys most often capture trees with red foliage that represent the locations of killed trees in the previous year. Some trees can remain red for several years. These older attack areas were not included if they could be distinguished by darkening foliage color. During aerial surveys, clusters of infested trees were identified visually and a GPS recorded the location of the cluster centroids. For each cluster, the number of infested trees was estimated and the pest species was recorded. The maximum area represented by a point was 0.031 km^2, equivalent to a circle with a radius of 100 m (Nelson et al. 2004).

Although a single point identified a cluster of trees, the total area, size, shape, and compactness of clusters will vary and also depends on the surveyor. Survey accuracy may have been influenced by operational factors such as weather conditions, surveyor experience, and speed or flying height of the aircraft. Aircraft movement, shadow, view angle, and

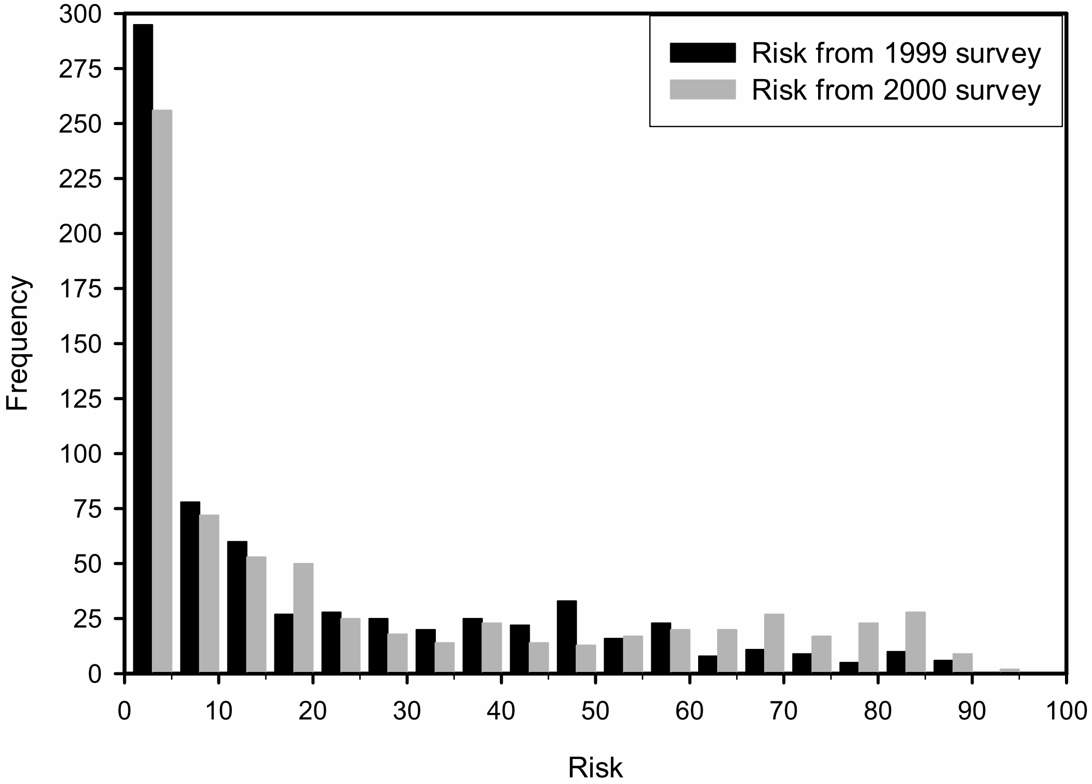

Figure 2. Distribution of risk rating for all susceptible stands for 1999 and 2000.

weather conditions, can result in over- and underestimated attribute values. The positional accuracy of GPS points is impacted by GPS instrumentation, aircraft movement, sighting angles, and surveyor biases.

Spatial location and attribute (the number of estimated killed trees) uncertainty of points was assessed and incorporated before analysis. Surveyors operating in the Morice forest district have suggested that the spatial error of points,

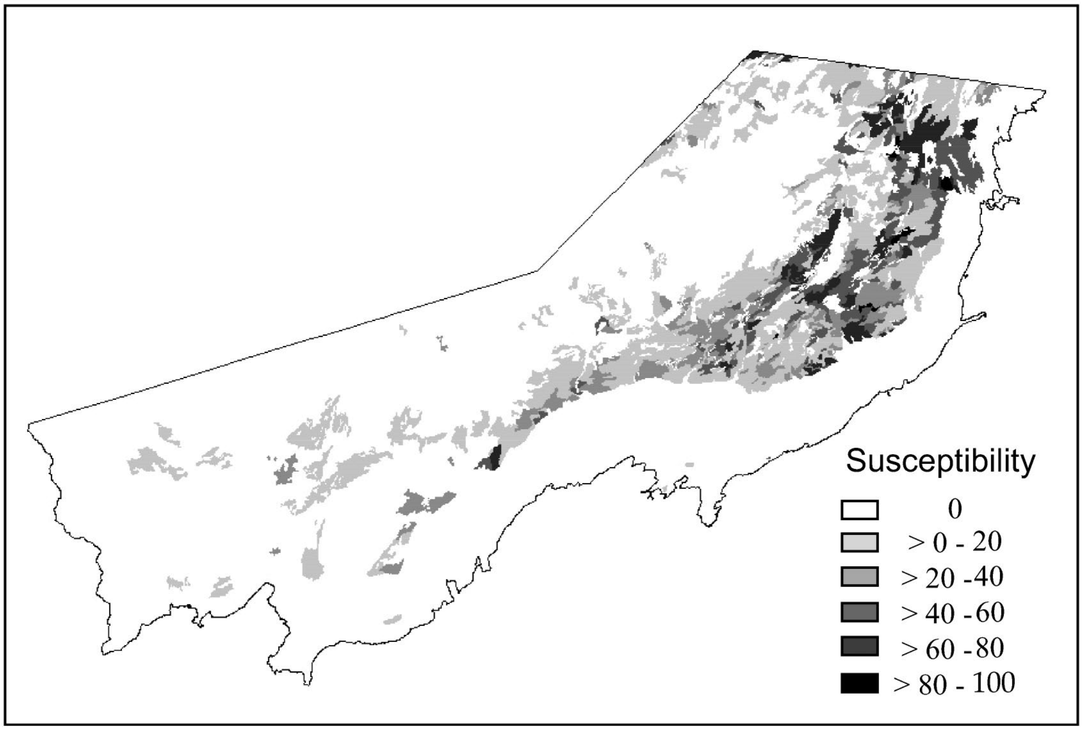

Figure 3. Susceptibility to mountain pine beetle attack over the Morice Forest District study area.

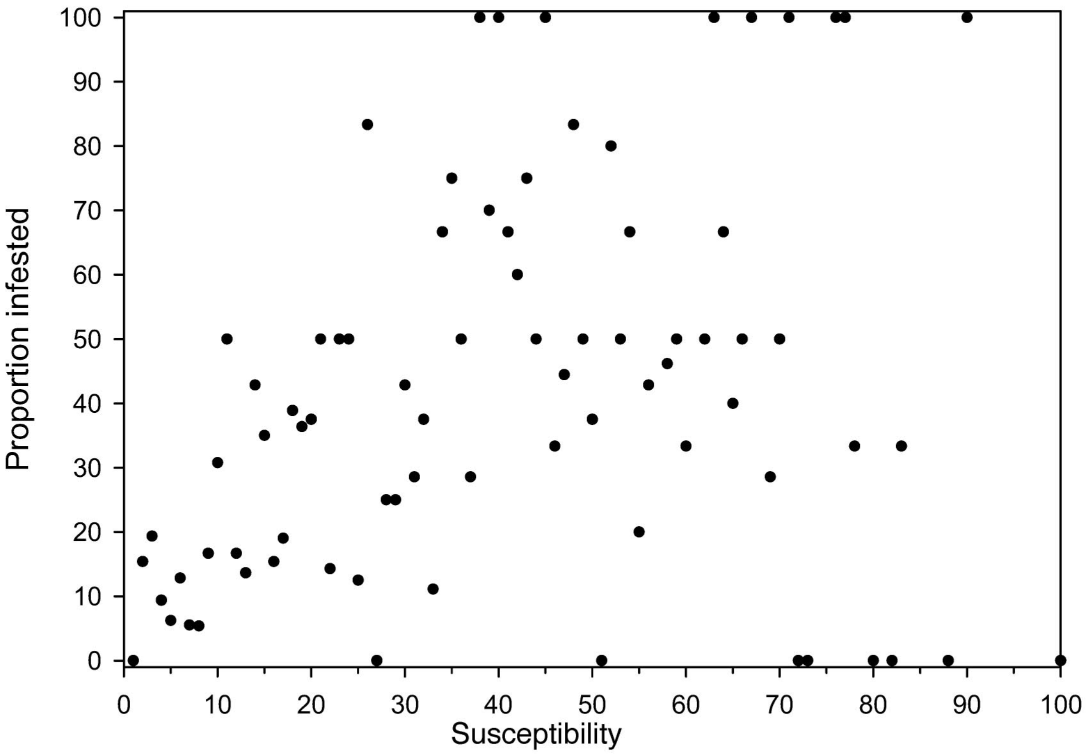

Figure 4. Proportion of stands with a given susceptibility ranking that were infested in 2000. (Susceptibility values were converted to integers.).

or cluster centroids, was approximately ±25 m (Nelson et al. 2004). For each point, 100 values were drawn from a normal distribution, scaled between ±25 and added to the *x* and *y* locations of each point. The 100 drawn values were

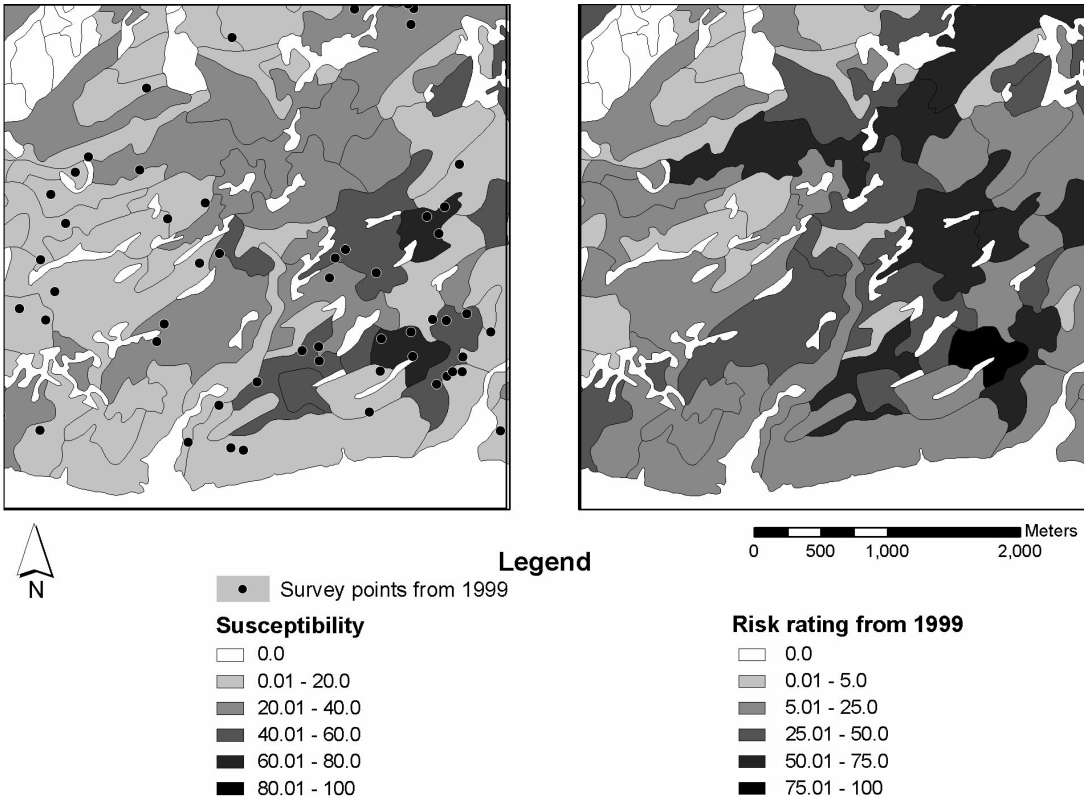

Figure 5. Example of subarea illustrating integration of susceptibility and beetle points resulting in an annual risk rating.

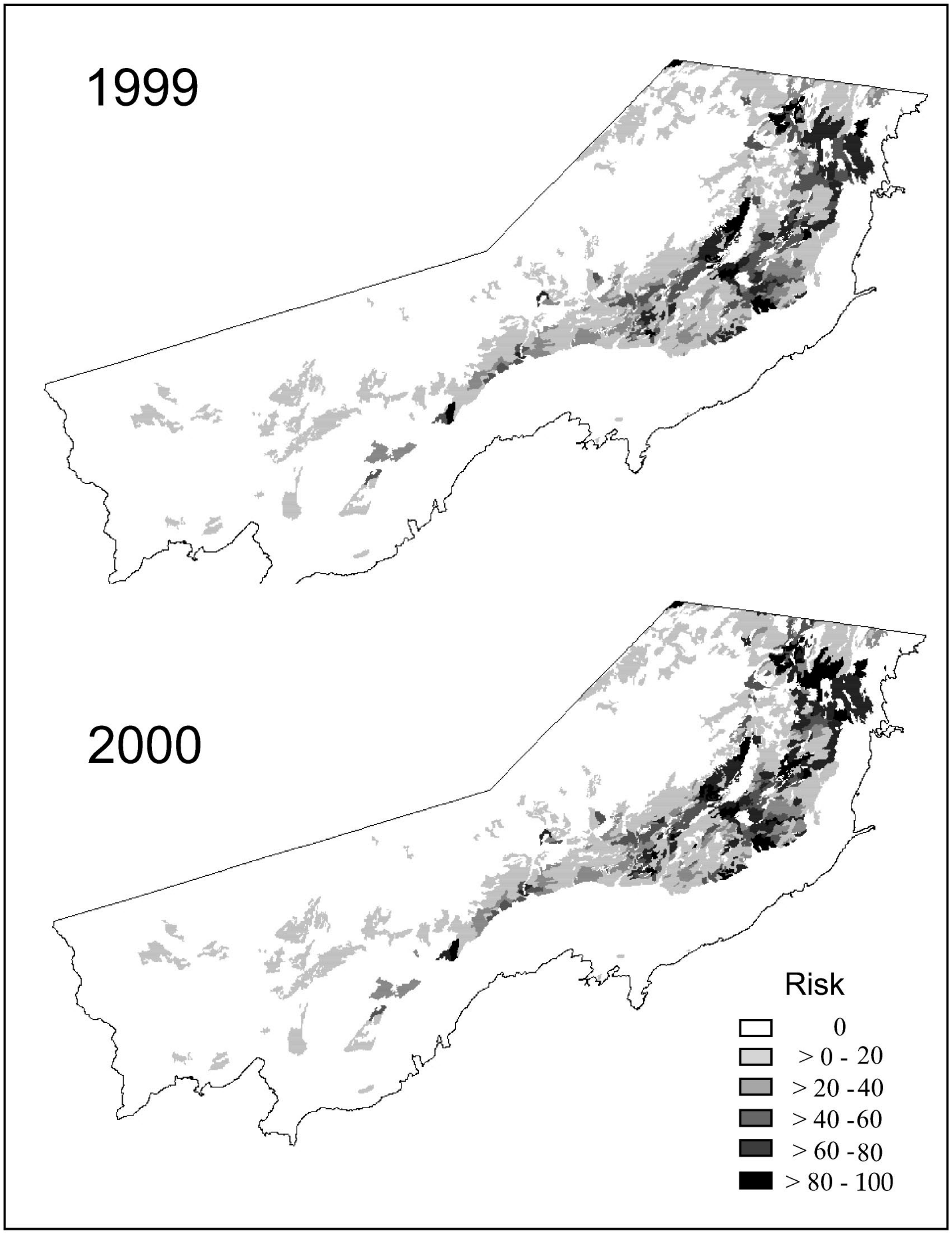

Figure 6. Spatial distribution of risk rating of all stands for 1999 and 2000.

Table 1. Predicted risk based on 1999 survey and actual infestation in 2000.

Predicted risk from 1999	Stands with 2000 infestation	Stands with no infestation	Sum	True positive (users accuracy)
High (>5)	176	230	406	43% (176/406)
Low (>0 ≤5)	22	273	295	93% (273/295)
Null (0)	35	1,189	1,224	
Sum	233	1,692	1,925	

Table 2. Predicted risk based on 2000 survey and actual infestation in 2001.

Predicted risk from 2000	Stands with 2001 infestation	Stands with no infestation	Sum	True positive (users accuracy)
High (>5)	132	313	445	30% (132/445)
Low (>0 ≤5)	19	237	256	93% (237/256)
Null (0)	32	1,192	1,224	
Sum	183	1,742	1,925	

Table 3. Agreement between prediction of risk and presence of attacked trees in the following year.

Year used to evaluate risk	Proportion of infested stands in high-risk category	Proportion of high-risk stands infested	Proportion of uninfested stands in low-risk category	Proportion of low-risk stands not infested
1999	76%	43%	86%	93%
2000	72%	30%	82%	93%

averaged together to incorporate spatial uncertainty in the point locations.

A similar approach was used to incorporate attribute uncertainty. Uncertainties in the aerial estimates of number of trees attacked were quantified using field data (Nelson et al. 2004). Most errors were small (74.6% of errors ± 5 trees), however, only 28% of points had the correct attributes values. The correct attributes could be simulated using the distribution of field attributes, which was of gamma form. For each point, 100 values were drawn from a two-parameter gamma distribution fitted to the field values (Nelson et al. 2004). The drawn attribute values were averaged together, providing an estimated attribute value that incorporates uncertainty. These adjusted points were used to calculate beetle pressure.

Calculating Risk

The Shore and Safranyik (1992) model for calculating beetle pressure was based on the number of infested trees inside the stand within 3 km of the stand, and the distance between the stand and closest infestation. For example, a stand that contained less than 10 infested trees, with 900 to 9,000 infested trees nearby and infested trees within the stand had a beetle pressure index of 0.8. If instead, that stand contained no infested trees, and the closest infestation was between 1 and 2 km away, the beetle pressure index dropped to 0.6. The distance-interval of 1 km was developed based on professional judgment and experience (Shore and Safranyik 1992). The susceptibility (S) and the beetle pressure (B) were combined in the calculation of risk (R) (Shore and Safranyik 1992):

$$R = 2.74(S^{1.77}e^{-0.0177S})(B^{2.78}e^{-2.78B}). \qquad (1)$$

The risk index was calculated annually based on the changing beetle pressure, for 1999 and 2000, after outbreak conditions appeared in the study area.

Agreement between Modeled Risk and Subsequent Attack

The correspondence of the risk predictions to actual infestations were evaluated as simple categories and as continuous variables. A comparison was done where the risk prediction from one year was compared with the presence or absence of infestation in the following year. A simple classification was used to designate low and high

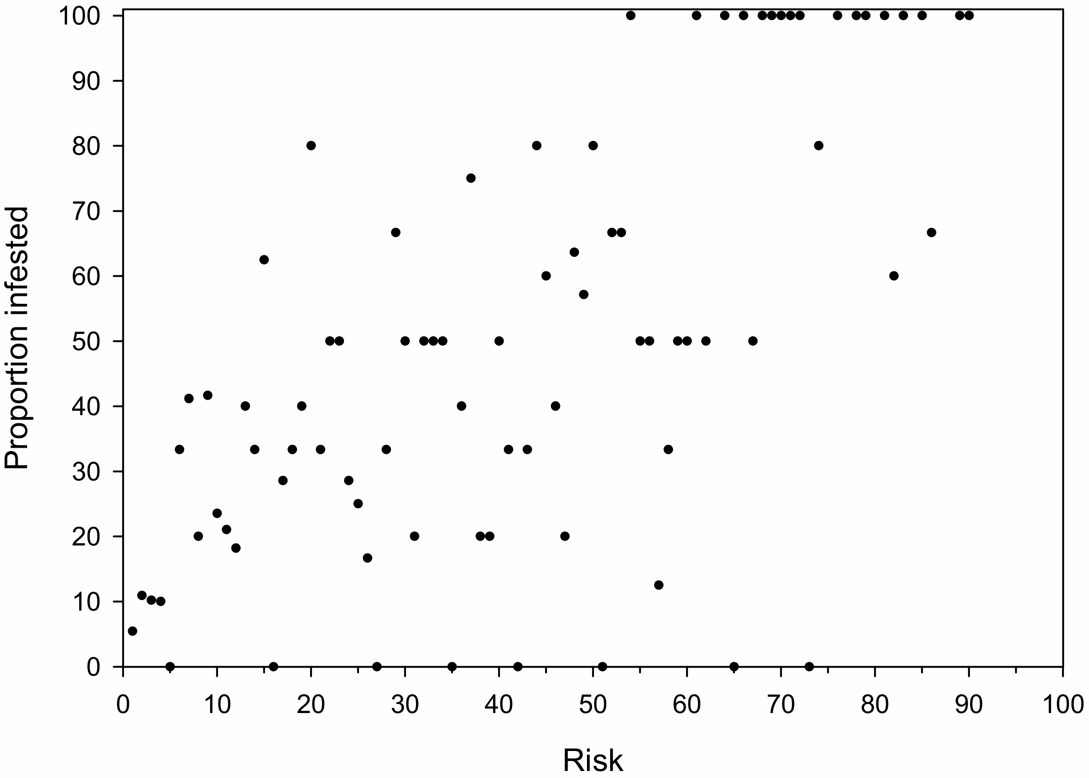

Figure 7. Proportion of stands with a given risk rating (converted to integers) that were subsequently infested. Risk calculated from 1999 and infestation from 2000.

Table 4. Logistic regression coefficients and significance test results for the risk rating system.

Year used to evaluate risk	Parameter	Estimate	Standard error	Wald chi-square
1999	Intercept	−2.02	0.14	205[a]
	Slope	0.047	0.0043	121[a]
2000	Intercept	−2.10	0.15	195[a]
	Slope	0.0261	0.0033	64.5[a]

[a] Probability less than 0.01.

risk; low risk was defined as a rating from 0 to 5, and high risk as greater than 5. The risk threshold was based on a natural break in the distribution of risk (Figure 2). Furthermore, we evaluated if increasing risk implied increasing probability of infestation using logistic regression. The sample size used for the logistic regression was the 700 susceptible polygons, of which 233 were infested in 2000 and 183 were infested in 2001.

Results and Discussion

Susceptibility ranged from zero to 100 over the study area. Stands with no susceptibility were nonforested areas and fir stands (Figure 3). Low susceptibility ratings resulted from nonoptimal stand characteristics such as small diameters and/or high elevations. Across the landscape, susceptibility increased toward the lake and in the eastern part of the valley (recall Figure 1 for broad land cover of the land base).

There was a tendency for stands of higher susceptibility to be infested (Figure 4). However, low susceptibility stands were also infested, and high susceptibility stands remained uninfested as of 2001. These results were expected, as the susceptibility ratings relate the potential loss of timber volume over the course of an epidemic (Shore and Safranyik 1992). This has been verified as a strong relationship between susceptibility and basal area killed in a previous epidemic (Shore et al. 2000). Close proximity of high beetle populations can result in trees being attacked even if the stands are less than optimal habitat for the beetles (i.e., low susceptibility).

The risk rating for each stand was based on the susceptibility and beetle pressure (Figure 5). Therefore, any stands with zero susceptibility also had zero risk. The distribution of risk was skewed, with the majority of the susceptible stands in most years falling into the 0.01 to 5 class (Figure 2). More stands had a risk rating from 60 to 90 in 2000 compared with 1999 as the mountain pine beetle population increased within the study area. Furthermore, visual inspection of risk reveals that across the landscape in general it was higher in 2000 than in 1999 (Figure 6).

A simple evaluation of the risk rating system was performed by comparing the risk rating from one year versus the presence or absence of infestation in the following year. In 1999, 406 of the 1925 stands were rated as high risk versus 295 stands with low risk (Table 1). Many of the stands (1,224) had no risk because of zero susceptibility. The majority of the stands with detected infestation in 2000 had a high risk rating, and most of the stands with no infestation in 2000 had a low or no risk rating. The trend of risk rating from 2000 was quite similar to that of 1999 (Table 2). The incidence of corresponding predicted risk and actual infestation had a similar pattern in 2000/2001 as in 1999/2000, except the true positive rate for high risk stands infested dropped from 43 to 30%.

A high proportion of the infested stands were evaluated to be at high risk (Table 3; >70%). However, less than one-half of the stands evaluated as high risk in each year were detected as infested in the subsequent year (43 and 30%). Most of the uninfested stands corresponded to the low-risk class (>80%). High correspondence was also found in that most low-risk stands were not infested (>90%). The necessity of an adequate number of infested stands for accurate risk rating reinforces the importance of susceptibility rating at low beetle population levels. There is an element of randomness to the movement of beetles across a landscape, making predictions of future attack locations difficult to predict (Logan et al. 1998). At low levels of infestation, it becomes more important to manage the forest for susceptible characteristics than to manage the beetles (Safranyik et al. 1974, Whitehead et al. 2001).

The tendency for infested stands to be high risk is also seen when comparing the continuous distributions of the population at risk with the subset that was detected as infested in the subsequent year. The proportion of infested stands appeared to increase as risk increased, especially when risk was greater than 60 (Figure 7). This relationship was tested using logistic regression. The logistic regressions showed the probability of infestation increased as the risk rating increased (Table 4).

In this study, we evaluated the operational utility of the Shore and Safranyik (1992) susceptibility and risk rating system for mountain pine beetle using digital data sets. Stand susceptibility and risk were successfully evaluated using standard GIS software. This formal approach produced consistent results that were subsequently tested for predictive ability. The criteria for successful prediction was the simple presence or absence of red-attack trees in a stand in the following year. However, beetle biology indicates that dispersal rates and directions will vary from year to year (Safranyik et al. 1989), so that high risk stands could become infested 2 or 3 years after being evaluated to have high risk. The simple presence or absence of infestation was the best response variable available to test the definition of risk as “the short-term expectancy of tree mortality in a stand as a result of mountain pine beetle infestation” (Shore et al. 2000). The percentage mortality has been used to evaluate ratings based on stand characteristics only (defined as susceptibility for our study; Bentz et al. 1993, Shore et al. 2000). Future research may compare risk rating with the percentage mortality if multiyear field surveys are available.

Conclusions

The adoption of GPS in aerial surveys of forest health provides more complete data for implementing decision support systems. Furthermore, estimating risk adds useful and consistent information to the forest management process. The results of this study are intended to create an operational confidence in the risk estimates generated by the Shore and Safranyik (1992) model when beetle populations are at incipient levels and increasing. The risk estimates are a relative, and not an absolute measure. As a result, the modeled risk outcomes need to be considered by an experienced interpreter of beetle population dynamics and the local environment. The results of this study illustrated that the likelihood of infestation increased as the risk rating increased. The ability to generate risk values for an entire forest management area and to populate the forest inventory with the results is a practical option for forest managers.

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