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Spatial Distribution of Mountain Pine Beetle in the Morice Timber Supply Area in Western British Columbia between 1995 and 2002

The mountain pine beetle (*Dendroctonus ponderocae* Hopkins; MPB) is an aggressive bark beetle, one that typically kills host trees in order to successfully reproduce (Logan et al., 1998). Lately, outbreaks of the mountain pine beetle in British Columbia (Canada) have been of spectacular proportions. Beetle populations are increasing exponentially resulting in host tree mortality that is both intensive (often in excess of 80% mortality) and extensive (sometimes thousands of acres) causing the loss of millions of cubic meters of wood. In addition, sever mountain pine beetle outbreaks can also result in forest successional changes, increased risk of fire, changed watershed quality, wildlife composition, and disturbed recreational values (Carroll & Safranyik, 2003). Consequences of mountain pine beetle occurrence are, therefore, both economically important and ecologically significant (Logan et al., 1998).

Although considerable scientific research and financial resources have been devoted to the mountain pine beetle, and a great deal of knowledge exists regarding its ecology and spatial impacts, some of the most basic questions concerning landscape level, spatial dynamics of the mountain pine beetle outbreaks remain unanswered. Perhaps one reason for the lack of synthesis and predictive power is the marginal treatment of spatial dynamics in outbreak theories (Logan et al., 1998). The current knowledge of the mountain pine beetle is usually based on stand- or fine-scale research and little work is devoted to explain if processes governing spread of the beetle operate similarly at the landscape level (Nelson et al., 2006). Spatial analysis and modeling of the mountain pine beetle activity at landscape level-scale is important for answering various management questions and it permits evaluation of management strategies at appropriate level of detail.

Factors affecting the spatial dynamics of mountain pine beetle outbreaks were investigated in this research. The objectives of the research were (i) to determine the extent to which the large-scale spatial patterns of mountain pine beetle occurrence can be influenced by climate, forest characteristics and topography, (ii) and to determine which of these factors are most important for spread of the mountain pine beetle over the eight researched years (1995 to 2002) in the Morice Timber Supply Area (TSA) in Western British Columbia. The statistical evaluation of the influence of climate, forest characteristics and topography on the frequency of mountain pine beetle infestations was carried out using classification and regression tree model (CART). CART is a logical model represented as a binary (two-way split) tree that shows how the value of a target variable (dependent variable) can be explained by a set of predictor variables (independent variables) (Moisen & Frescino, 2002). The tree is called classification tree if the target variable is qualitative and regression tree if the target variable is quantitative. CART models provide a nonparametric alternative to regression techniques. This means that CART models do not rely on priori hypothesis about the relationship between independent and dependent variables (Thuiller et al., 2003). In classical regression technique the relationship between the predictor and target variables is pre-specified (e.g. straight line, quadratic), and the test is performed to prove or disprove the relationship. CART assumes no such relationship and it is primary a method of constructing a set of decision rules on the predictor variables (Prasad et al., 2006). During the CART analysis binary recursive partitioning is conducted where the data are successively broken into left and right branches with the splitting rules defined by the single explanatory variable (Moisen & Frescino, 2002).

Several sets of classification and regression trees were calculated for each of the investigated years and two analysis procedures were employed. In the first procedure (A), all mountain pine beetle presence observations were included in the analysis and in the second procedure (B), only mountain pine beetle observations in stands with more than 1% of pine were included in the analysis. Additionally, presence-absence, count and average magnitude data were used as dependent variables in each of the two procedures.

The regression tree analysis used with the second procedure and the count data proved to be the most powerful in establishing the relationships between the mountain pine beetle occurrence and independent variables. Out of 40 independent variables used in each year's analysis, the regression tree models retained 5-7 variables related to weather, stand age and composition, elevation and focal sum. Although weather plays a very important role in the mountain pine beetle infestation outbreaks, the weather variables were not represented in the analysis as extensively as expected, probably because of the small number of weather stations available for the analysis (data quality). The mountain pine beetle occurrence was associated with relatively warm falls, springs and winters, and high average precipitation. Variables describing forest characteristics (forest age, and stand composition) were represented somewhat better, although the accuracy of these variables is questionable because of the infrequency of the forest inventory updates. The beetle was associated with stands where pine is a dominated or secondary species and stand age was between 120 and 200 years. Elevation and focal sum were the variables that formed the greatest number of splits and seemed to be the most important in the mountain pine beetle modeling process in the Morice TSA between 1995 and 2002.

In areas with more extreme topographic relief and where conditions are considered marginal for the establishment of a mountain pine beetle population (Amman, 1973; Logan & Powell, 2001), topographic attributes such as elevation, may have a stronger influence on the efficiency of beetle infestations (Wulder et al., 2006). In this research, elevation was depicted as one of the most important explanatory variables in the mountain pine beetle modeling. Historically, the occurrence of the mountain pine beetle in British Columbia was associated with elevations up to 800 m. However, in the Morice TSA between 1995 and 2002, the mountain pine beetle occurred on elevations from about 550 m to about 1300 m. The regression trees showed generally that the beetle occurred on lower elevations (up to 700-900 m) in years when the magnitude of the mountain pine beetle infestation was lower (1995, 1999 and 2000) and on higher elevations (above 1000 m) in years when the infestation covered vast areas of the Morice TSA (1997, 2001 and 2002). Occurrence of the mountain pine beetle at higher elevations has typically been considered limited due to a lack of sufficient thermal energy to complete the life cycle in a single year (Amman, 1973). However, increasing temperatures observed in the past three decades in British Columbia may be invalidating to the effect of elevation, as successful mountain pine beetle populations are currently being observed in pine ecosystems previously not suitable for the beetle (Carroll et al., 2004).

There is a variety of factors that drive the spatial dynamics of a mountain pine beetle population, for example, their dispersal and aggregation. Spatial dynamics typically play a central role in the community dynamics of highly mobile insects such as mountain pine beetle (Besinger et al., 2000). In the second procedure (B) of the analysis a new independent variable (focal sum) was introduced. This variable describes the spatial distribution of the mountain pine beetle occurrence one year before the analyzed year. Focal sum was the most important variable (formed the greatest number of splits) in the regression tree modeling in the second procedure and its spatial arrangement could be attributed to the dispersal and aggregation of the mountain pine beetle.

To coordinate their mass attacks, mountain pine beetles have evolved a chemical communication system based on diffusible aggregation and anti-aggregation (Borden et al., 1987). Aggregation feedback driven by pheromones has the potential to attract large numbers of mountain pine beetle. Besinger et al. (2000) found that beetle movement is directed about 31 times more strongly by pheromones than by random redistribution. Over-colonization, on the other hand, is avoided via an anti-aggregation force of the pheromone communication system (Borden et al., 1987). The mechanism of aggregation and anti-aggregation of the mountain pine beetle mass attack might also be present in larger, landscape-level scale. In the regression trees, the beetle presence was associated with the previous year's focal sum between 2.5 and 5.5, and the beetle absence was associated with focal sum less than 1.5. This finding might imply that the beetles are attracted to the areas already colonized by other beetles, therefore responding to the aggregation forces. On the other hand, no beetle presence was modeled on the focal sum greater than 5.5, suggesting that the beetles are not attracted to over-colonized areas, therefore responding to the anti-aggregation forces.

Given these types of analyses performed over large regions and over relatively long periods of time, the accuracy issues limit or impair our ability to build a single model that can explain the mountain pine beetle occurrence through time. However, as my research shows, coarse, landscape-level, topographical, environmental and weather variables can enable researchers to determine the range of values that allows the prediction if the mountain pine beetle occurrence in studied region. Despite many uncertainties stemming mainly from the quality of the data, the CART modeling method proved to be useful in analyzing and explaining the hierarchical relationships between dependent and independent variables used this research.