Modelling Spruce Bark Beetle Infestation Probability

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Abstract

Spruce bark beetle (*Ips typographus* L.) risk model, based on pure Norway spruce (*Picea abies* Karst.) stand characteristics in experimental and control plots was developed using classification and regression tree statistical technique under endemic pest population density. The most significant variable in spruce bark beetle infestation risk model was spruce basal area. Model, good enough for forest management practices, rate spruce stands to: a) stands of low bark beetle risk (probability of infestation p=20%) – basal area of spruce less than 17.8 m²/ha; b) stands of moderate bark beetle risk (p=55%) – spruce basal area greater than 17.8 but less then 46.9 m²/ha; c) stands of high bark beetle risk (p=83%) – spruce basal area greater than 46.9 m²/ha. Further model clarification need research under epidemic spruce bark beetle condition levels.

Key words: spruce bark beetle, *Ips typographus*, Norway spruce, *Picea abies*, risk, classification and regression tree model

Introduction

Spruce bark beetle *Ips typographus* (L.) is the most important pest in premature and mature stands of Norway spruce (*Picea abies* Karst.) in Lithuania and in the most of Europe. Spruce bark beetle damages in average few thousand hectares of spruce stands in Lithuania every year, heavy outbreaks are repeating every 8-10 years (Žiogas and Zolubas 1998). Most of bark beetle species are able to breed only in stressed or dying trees, but *Ips typographus*, in addition, can successfully colonize living trees, when population increase to epidemic level and large quantities of the pest can overcome defensible mechanisms of living tree by mass attack (Horntvedt *et al.* 1983). Therefore one of pest management objectives is to remove susceptible or bark beetle attacked trees as soon as possible to avoid population growth.

For vegetation management practices in European spruce forests, it is essential to assess the risk of *I. typographus* attacks in spruce stands. No suitable method exists to measure stand resistance to spruce bark beetle, thus a need exists to develop more tangible indicators of possible bark beetle attacks in spruce. For this purpose different approaches have been used to evaluate stand susceptibility, including GIS and regression analyses (Lexer 1995, Dutilleul *et al.* 2000, Wichmann and Ravn 2001). Soil nutrients, such as nitrogen, phosphorus, and magnesium, have a significant influence on spruce bark beetle attack rates (Nef 1994, Dutilleul *et al.* 2000). Stands determined to be more at risk were those neighboring windthrows subsequently harvested after the first beetle generation and those within 500 m of an old attack (Wichmann and Ravn 2001). The use of pheromone traps is not a reliable means of evaluating bark beetle risk in spruce stands (Weslien 1992, Lindelöw and Schroeder 2001). Lexer (1995) indicated several site and silvicultural characteristics; mainly water availability and slope seem to be related to attack probability. Physiological predictors at the single tree level (water status, nutrients, phenols, resin) may not be good parameters as stand level estimates of risk. No statistical relation seems to exist between forest decline symptoms and associated bark beetle attack (Prien *et al.* 1996). Because these factors are difficult to measure they are of limited use for applied forest management practices.

There are two traditional approaches for developing risk and hazard rating models to predict bark beetle infestation in a forest stand or potential tree mortality (Hedden 1981). One traditional approach is called biological. Under this scenario, numerous research studies and site evaluations have provided sufficient information to develop a rating system based on biological relationships. Such a system was developed by Schmid and Frye (1977) which provides the resource manager with a hazard rating for an Engelmann spruce, *Picea engelmannii* Parry ex Engelm., stands susceptibility to spruce beetle *Dendroctonus rufipennis* Kirby, attack. When rating a stand, 1-3 points are assigned to each of the four factors (physiographic location, average diameter of spruce over 25 cm, basal area and proportion of spruce in canopy) using one of three elements of risk for each of the four factors. The points are then added to obtain a cumulative stand risk value (low, medium or high). This is considered a biological system, because it was assembled based on knowledge accumulated from various studies. It is often assumed that because these systems are biologically based and constructed with the objective of wide applicability, they can be extrapolated to other areas with little modification. However, all biological hazard or risk rating models should be field validated for specific areas since local conditions may affect model outputs.

Another traditional approach is an empirical hazard or risk-rating modelling. In this scenario little information is available about the factors that may affect stand susceptibility for a particular bark beetle species. To develop empirical models, a site-specific study is undertaken where representative study areas are selected, intensively sampled, and associated with some level of bark beetle mortality or occurrence. An example of such a system was developed to estimate the probability of infestation by roundheaded pine beetle *Dendroctonus adjunctus* Blandford in ponderosa pine, *Pinus ponderosa* Laws, stands (Negron *et al.* 2000). Due to the empirical nature of these models, extrapolation to other areas needs to be done with caution. Even so, suitable methodology is available to develop models for other bark beetle species with a limited amount of research resources required.

Little is known about site or forest conditions associated with *Ips typographus* populations in Lithuania and many neighboring countries with the exception of a recent study in Poland. Hilszczański *et al.* (2006) developed an empirical model for *Ips typographus* and Norway spruce in northeastern Poland. Because developing a biological system that would be applicable to a larger geographical area may be difficult with the lack of available information and resources, an empirical approach may be more appropriate for model development in Lithuania. The objective of this study was to develop a spruce bark beetle risk model, based on easily measured tree or site characteristics using temporary fixed radius plots as the experimental unit.

Materials and methods

The study was conducted at endemic (non-outbreak) population level of *Ips typographus* during 2000-2002. Fixed radius plots were established in 80-100 year old spruce stands (over 80% spruce) around one or more spruce trees infested by spruce bark beetle. Control plots were established 75 m from an infested plot at random directions within the same stand. Ninety-two paired plots (infested and control) were established throughout Lithuania in spruce forests.

The following data were collected in each plot for all trees greater than 8 cm diameter at breast height: tree species, tree status (alive or spruce bark beetle attacked), diameter and tree height. Calculated values of mean tree diameter, mean height, mean tree number, basal area, Reineke's stand density index ($\sum(dbh/25)^{1.6}$, Long and Daniel 1990), for all tree species and for spruce only, were included in the analysis.

A statistical method called Classification and Regression Trees (CRT) was used to rank variables and calculate their breakdown values that would split the data set into homogenous groups of reduced variance (Breiman *et al.* 1984). The splits on these variables were used to classify experimental plots into infested or uninfested. Classification Tree methods are nonparametric and nonlinear, and are particularly well suited for tasks, where there is often little a priori knowledge nor any coherent set of theories or predictions regarding which variables are related and how. Multi-response permutation procedures (Mielke *et al.* 2001) were used for paired comparisons between infested and uninfested plot characteristics.

Results

Larger mean diameter, higher spruce basal area, and higher stand density index for spruce trees were observed in infested plots compared to uninfested plots ($p<0.05$). No differences were observed for any of the other plot variables, same as for all variables when all tree species in the plot were included (Table 1).

Table 1. Descriptive statistics of experimental plots

	control plots		infested plots		p
	mean	std. dev.	mean	std. dev.	
mean diameter (cm), all species	26.8798	5.5110	27.8221	5.3006	0.0931
mean diameter (cm), spruce	26.2147	6.2587	27.6277	6.1425	0.0215
mean height (m), all species	20.4372	3.4969	20.5392	3.6651	0.7595
mean height (m), spruce	19.8947	3.8627	20.4231	3.7925	0.1674
basal area (m²/ha), all species,	35.5470	14.5841	37.0291	14.7218	0.4205
basal area (m²/ha), spruce	25.5116	10.9058	29.9657	11.7996	3.24E-04
density index, all species	647.4897	236.2283	667.0510	240.2758	0.6189
density index, spruce	472.9714	179.7441	546.1012	194.3640	5.62E-04
tree number (trees/ha), all species	561.8280	223.111	546.2366	212.2869	0.6632
tree number (trees/ha), spruce	430.6452	163.655	459.6774	175.7921	0.1660

The most important classification variable, ranked by CRT procedures, appeared to be spruce basal area (m^2/ha). The most simple and straightforward model includes this one variable with two nodes (risk probability levels), which classified spruce stands in two categories (Figure 1). Stands with basal area larger

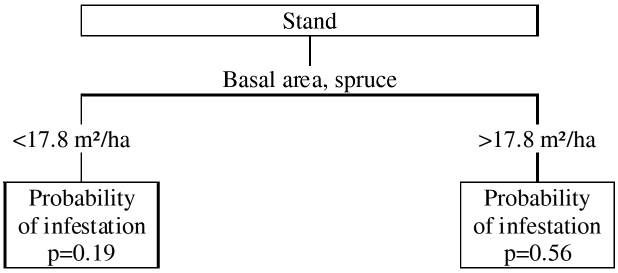

Figure 1. *Ips typographus* infestation risk model with one variable and two terminal nodes (misclassification rate=0.38, residual mean deviance=1.313)

than 17.8 m^2/ha exhibit increased susceptibility with a probability of infestation of 0.59. Stands with less basal area are less susceptible with a probability of infestation of 0.20. However, using only two spruce stand categories in risk rating is insufficient to measure overall risk.

Model with one variable and three terminal nodes separate spruce stands into three categories (Figure 2):

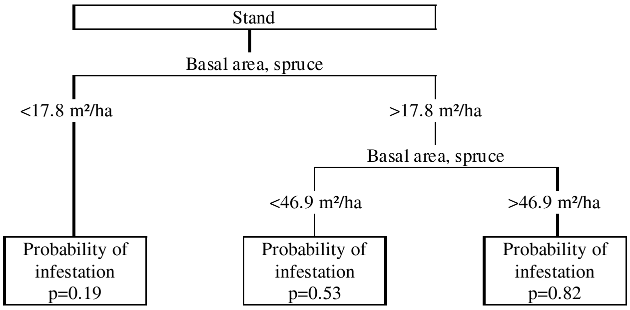

Figure 2. *Ips typographus* infestation risk model with one variable and three terminal nodes (misclassification rate=0.38, residual mean deviance=1.288)

- stands with low bark beetle risk (probability of infestation p=0.20) – basal area of spruce less than 17.8 m^2/ha;
- stands with moderate bark beetle risk (p=0.55) – spruce basal area greater than 17.8 but less then 46.9 m^2/ha;
- stands with high bark beetle risk (p=0.83) – spruce basal area greater than 46.9 m^2/ha.

This model is more accurate, with an acceptable residual mean deviance, but the misclassification rate is no better than the model with one variable and two terminal nodes.

Another stand variable, which contributed to model relevance, was stand density index, calculated using tree number in the plot and tree diameter (Long and Daniel 1990). The model with two variables and four levels of spruce bark beetle risk (Figure 3) has lower residual mean deviance and a lower misclassification rate than the two previous models and can be used as a decision tool for forest practices. It is possible to proceed constructing models with more variables and add more risk levels, describing some of the observed relationships. However, these models may be too complex for general field use.

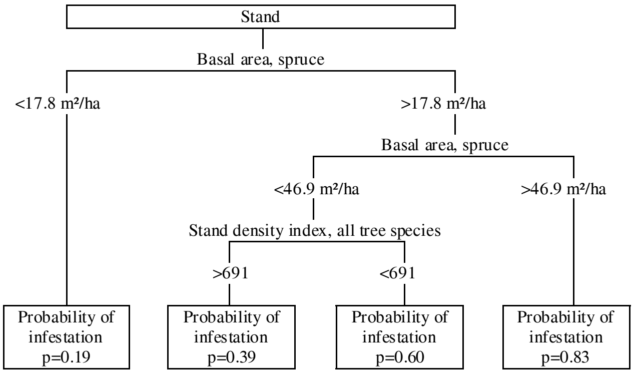

Figure 3. *Ips typographus* infestation risk model with two variables and four terminal nodes (misclassification rate=0.34, residual mean deviance=1.264)

Discussion

The spruce basal area was the most significant variable (as ranked by CRT procedures) in spruce bark beetle infestation risk models. Tree species composition in the stand can have particular influence as was found in similar study in Poland (Hilszczański *et al.* 2006), but our test plots were established in spruce stands with over 80% trees of host type, therefore, in this study tree species composition was not likely to be a factor.

The most straightforward model with one variable and two stand risk levels is simple and easily understandable for forest managers, but it lacks sensitivity for decision making. Seventy percent of the control plots and 88 percent of the infested plots of this study fall into the “susceptible” stand category, exhibiting an overestimation of risk. This model cannot effectively recognize stands most at risk, where management activities should be taken immediately.

The model with one variable and three spruce stand risk levels is suitable for field use, but requires further development. The high-risk breakpoint at a spruce basal area of 46.9 m^3/ha refers to a high value of relative stand density index (approximately 1.3), used in Lithuania. A relative stand density index of value 1 corresponds to basal area of the normal stand (canopies completely closed) of the same age and site (Repšys 1994). In our test plots relative stand density index could have been underestimated due to understory spruce with diameter over 8 cm, which were included in model building. Relative stand density index includes only trees in the larger diameter classes or trees found in the main canopy of the forest. The additional understory evaluation decreases the models applicability, thus requiring further refinement and classification.

The stand risk-rating model with two variables and four stand risk levels, is of sufficient sensitivity, and has an appropriate misclassification rate and residual mean deviation. Development of bark beetle risk models increasing number of terminal nodes result in complicated output increase difficulty to use. Even though, model validations at different bark beetle population densities, *i.e.* including some pest characteristics, are of particular interest.

The principle problem using the model with two variables is that one variable is not easily obtained. Reineke's stand density index, modified by Long and Daniel (1990), is not calculated in regular forest inventory procedures in Lithuania. Instead, relative stand density index, a ratio of observed basal area to that of a normal stand (Repšys 1994), is used. The importance of stand density index was shown in the study conducted in Poland (Hilszczański *et al.* 2006) where the lower index was associated with a higher probability of infestation. This indicates that insect does not preferentially prefer shaded environment, rather southern exposures and sunlit trees were preferably attacked by *Ips typographus*, especially after abrupt increases in solar radiation levels (Lobinger and Skatulla 1996, Jakuš 1998). The apparent contradiction of the higher infestation risk in stands with lower stand density index opposed to stands with greater spruce basal area can be explained by observing that *Ips typographus* prefer taller and larger in diameter spruce trees (Zolubas 2006). Those trees positively contribute to basal area value but decrease Reineke's stand density index, where number of trees is considered.

Single tree characteristics may be critical to bark beetle choice (Zolubas 2006), at least under an endemic spruce bark beetle population level. Similarly, it was found that beetles breeding in intermediate trees (Kraft class 3) appear to produce more progeny than beetles in other trees (dominant, co-dominant and suppressed, Mattanovich *et al.* 2001). Parameters associated with these colonized trees, due to the small number found in our experiment, have attributed little to evaluated stand variables. Subsequently, single tree characteristics in high-risk stands should be evaluated when looking for damaged trees and assessing spruce stands to determine management options.

Rather high misclassification rate and residual mean deviance of models could be caused by presence of high share of intact spruce trees in infested plots, *i.e.* not all spruce trees in infested plot were colonized by *I. typographus*, just one or few. Therefore research should be expanded in high bark beetle population conditions or in pockets of infestation when groups of trees are successfully attacked, and where all trees in test plot shall be bark beetle killed.

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МОДЕЛИРОВАНИЕ ВЕРОЯТНОСТИ ПОВРЕЖДЕНИЯ ДРЕВОСТОЕВ ЕЛИ ЖУКАМИ КОРОЕДАМИ

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Модель риска жуков короедов была разработана статистическими методами классификационных и регрессионных деревьев, используя таксационные характеристики еловых древостоев в экспериментальных и контрольных участках при невысокой численности популяции короеда типографа (*Ips typographus* L.). Наиболее существенной переменной оказалась сумма поперечных площадей сечения ели. Модель, достаточно пригодна для использования в практике, подразделяет древостои на: а) небольшого риска (вероятность повреждения короедом типографом p=20%) – с суммой поперечных площадей сечения ели менее 17.8 mI/ha; б) умеренного риска (p=55%) – с суммой площадей сечения от 17.8 до 46.9 mI/ha; в) высокого риска (p=83%) – с суммой поперечных площадей сечения ели выше 46.9 mI/ha. Требуется дальнейшее усовершенствование модели при высоких (эпидемических) уровнях популяций короеда типографа.

Ключевые слова: короед типограф, *Ips typographus* L., древостой ели, *Picea abies*, модель классификационных и регрессионных деревьев