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Spruce bark beetles (*Ips typographus*, *Pityogenes chalcographus*, Col.: Scolytidae) in the Dinaric mountain forests of Slovenia: Monitoring and modeling

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ABSTRACT

In this paper, we analyze the phenology of spruce bark beetles (*Ips typographus* and *Pityogenes chalcographus*) in the Dinaric mountain forests of southwestern Slovenia. The study of *I. typographus* took place from 1986 to 2000, while that of *P. chalcographus* took place from 1993 to 2000 in an area characterized as a Dinaric Fir-Beech forest community (*Abieti-Fagetum dinaricum*) on the Karst plateau (447–751 m above sea level). On the studied area Norway spruce (*Picea abies*) has been planted between 60 and 90 years ago on approximately 1000 ha. Frequent catastrophic weather conditions are characteristic for this area, followed by an increased trophic capacity of the forest for the various bark beetle species. The population density of spruce bark beetles was monitored at five locations at varying exposures using commercial pheromones (Pheroprax® and Chalcoprax®) in traps under the trade name Theysohn. Both species studied (*I. typographus* and *P. chalcographus*) have a relatively high abundance and have two main generations per year; both species may also produce two sister generations. Data on some environmental factors as well as data on bark beetle catches have been collected and then analyzed to model the dependence of spruce bark beetle catches on the environmental factors. The machine learning methodology of liner regression as well as model tree induction was used for this purpose. The following attributes were used to analyze the occurrence of both species of bark beetle: position (NW, NE, W, E, N and S), age of pheromone, number of days since last monitoring, average monthly temperature, monthly precipitation, month and previous number of bark beetles. There was a strong correlation between a high population density of *I. typograpus* and Northeast (NE) and position and a high density of populations of *P. chalcographus* and West (W) and North (N) positions.

1. Introduction

Slovenia lies in the southern part of central Europe. Its mesoclimatic, topoclimatic and microclimatic conditions are affected by the swiftly changing relief of the terrain. In Slovenia the mixture of influences from both Mediterranean and continental climates felt over the small territory.

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In southwestern Slovenia, the area around Postojna, the lowest geographical point of entry from the Mediterranean into central Europe, often exhibits extreme weather conditions, such as sudden changes in temperature and sleet, which fells large numbers of trees (Orožen-Adamič, 1987). Trees are frequently downed due to wind and snow in this area and between 1948 and 1998 this has happened 15 times (Forest Management Plan for the FU Planina 1960, 1965, 1971, 1977, 1993 and 2001). This region was chosen for our study of the phenology and ecology of spruce bark beetles.

In Slovenia as one of the most forested countries in Europe, forests cover from 57 to 60% of the country (Hočevar, 2003), or 1,227,832 ha. The last inventory of Slovenian forests showed that deciduous forests cover around 39%, conifer forests around 22% and mixed forests around 39%. The percentage of conifers in the wood stock is approximately 48%. Norway spruce (*Picea abies* (L.) Karst.) makes up around 33% of conifer forests or 34% of the surface area of Slovenia, although its natural habitat only covers around 8% of the country. Its frequent occurrence on unnatural habitats (National Forest Development Programme, 1995) is linked to damages to Norway spruce due to abiotic factors (mechanical instability, failure to thrive, etc.) and biotic factors (mostly spruce bark beetles).

Even in the 17th century the multiplication of bark beetles had caused large-scale damage in central Europe (Staack, 1985). In the 20th century, the ecology and economic importance of bark beetles (*Ips typographus* (L.), *Pityogenes chalcographus* (L.) and *Cryphalus piceae* (Ratzeb.), etc.) were studied for very pragmatic reasons and emphasis was placed on controlling them (Escherich, 1923; Nüsslin and Rhumbler, 1927). In European forests with a large percentage of conifers on non-arable land, natural stands, bark beetles represent the primary harmful biotic factor to these hosts (Vité, 1989; Eidmann, 1992).

The basic principles of controlling bark beetles in central Europe were set by German entomologists, with domestic researchers in Šlander (1951) and Titovšek (1994) (Jurc, 2003) following their lead. An integrated system of controlling the most important spruce bark beetle species (*I. typographus* and *P. chalcographus*) with the use of pheromone traps has been used in Slovenia since the 1980s, and in the environs of Planina since 1985. At first domestically produced pipe traps using the Pheroprax® pheromone were used, then after a few years (in the environs of Planina in 1987) Theysohn traps using commercial pheromone dispensers (Pheroprax® and Chalcoprax®) began to be used (Perko, 2002). Due to the great dangers associated with the multiplication of bark beetles, the Act on forests (1993) forbids leaving felled and unstripped trunks of conifer trees in the forest and impels the use of sanitary fellings.

On the other hand, the Act on forests (1993) prescribes how to preserve the productiveness and biodiversity of the forest. The biodiversity of the forests is preserved and increased by planned leaving of dead and dying wood biomass, which is the habitat for saprophytic species of invertebrates, fungi and microorganisms (Speight, 1989). In Slovenia, the prescribed amounts of left wood biomass in the forest varies between 0.5 and 3% depending on the wood stock in the stands. The cited regulation increases the number of habitats suitable for primary saprophytes, a group represented mostly by bark beetles (Lindelöw and Schroeder, 2001; Hedgren, 2002). When this regulation is implemented where there are frequent wind breaks and snow breaks, as well as hot, dry summers, higher densities of bark beetle populations and greater damage to the forests can be expected.

Data on sanitary fellings in Slovenia are available from 1985 and show fellings due to abiotic (catastrophic weather conditions: wind, sleet and snow, fires, emissions and landslides) and biotic factors (insects, diseases-fungi and game). In the past 18 years in Slovenia, the greatest numbers of sanitary fellings were carried out due to catastrophic weather conditions (42% or 5,069,307 m^3), followed by fellings due to other reasons (24% or 2,863,105 m^3) and insects (19% or 2,233,303 m^3) (Statistical Yearbook of the Republic of Slovenia, 1998, 2002; Annual Reports-Slovenian Forest Service, 1995–2002; Jurc et

Table 1 – Sanitation cutting of spruce, fir and pine due to bark beetles from 1945 to 2002 (Statistical Yearbook of the Republic of Slovenia, 1998, 2002; Titovšek, 1994; Annual Reports-Slovenian Forest Service, 1995–2002)

Year	Region	m^3
1945–1952	Majority of the Slovenian territory	273,000
1983–1985	Regional gradation, Gorenjska region (spruce bark beetles: *Ips typographus*, *Pityogenes chalcographus*)	500,000
1991–1992	Majority of Slovenian territory	174,783
1994	FMR[a] Maribor, Kranj, Ljubljana, Celje (spruce bark beetles: *I. typographus*, *P. chalcographus*), FMR Kočevje (fir bark beetles: *Pitykteines spinidens*, *P. curvidens*, *Cryphalus piceae* and spruce bark beetles)	116,700
1995	FMR Ljubljana, Kočevje, Maribor, Bled, Kranj (spruce and fir bark beetles)	164,000
1996	Majority of Slovenian territory	88,000
1997	Majority of Slovenian territory	81,000
1998	Majority of Slovenian territory	166,700
1999	FMR Bled, Kranj, Ljubljana Kočevje (spruce and fir bark beetles)	102,500
2000	FMR Kranj, Bled	118,843
2001	FMR Ljubljana, Novo mesto (fir bark beetles: *Pitykteines spinidens*, *P. curvidens*, *Cryphalus piceae* and spruce bark beetles: *I. typographus*, *P. chalcographus*)	132,732
2002	FMR Kočevje, Ljubljana, Novo mesto (fir bark beetles: *Pitykteines spinidens*, *P. curvidens*, *Cryphalus piceae* and spruce bark beetles: *Ips typographus*, *Pityogenes chalcographus*)	169,382

[a] Forest management region.

al., 2003). Data on felling of trees in forests due to insects (particularly bark beetles) have been recorded from 1945 onward. Table 1 shows sanitary fellings due to insects for various areas of Slovenia.

Larger scale sanitary fellings due to bark beetles were carried out in 1986/1987 and 1993/1994, while larger scale sanitary fellings due to catastrophic weather conditions were carried out in 1986, 1995/1996 and 1996/1997. Fellings due to insects have increased since 1999 (1999: 102,590 m^3, 2000: 118,843 m^3, 2001: 132,732 m^3 and 2002: 169,382 m^3 of wood). In 2001 and 2002, fir bark beetle (*Pitykteines spinidens* (Reit.), *P. curvidens* (Germar), *C. piceae* (Ratzeb.)) and spruce bark beetle (*I. typographus* (L.) and *P. chalcographus* (L.)) populations increased, mostly in the south and southwestern parts of Slovenia (Jurc et al., 2003).

Due to the high percentage of spruce in non-natural stands, evident changes in climatic conditions (Kajfež-Bogataj, 2001), and the cited legal regulation to leave wood biomass in the forest, laic public expect increased damages to spruce forests due to spruce bark beetles. Therefore, it would be desirable to clarify the effects of certain ecological factors in order to better understand the development of important species of spruce bark beetles (*I. typographus* and *P. chalcographus*). We have used modeling ("machine learning") to correlate the catch of two important bark beetles species (*I. typographus* and *P. chalcographus*) in pheromone traps with various ecological parameters. This enables us to clarify the effects of certain ecological factors on the development of spruce bark beetles.

2. Materials and methods

2.1. *Research area*

The research area was Forestry Unit (FU) Planina, covering 618 ha. This area is found in the southwestern part of Slovenia on the Karst plateau (447–751 m above sea level (m.a.s.l.)). The substrate is limestone and dolomite, and the soil is chromic cambisols and rendzic leptosols. The unit is found on land dominated by Dinaric Fir-Beech forests (*Abieti-Fagetum dinaricum*). After using this stand exclusively for hunting for 50 years, the stands began to be cut down due to age in 1895. From 1910 to 1960 Norway spruce (*P. abies*) was planted for economic reasons. The saplings later used in the forest were raised in local tree nurseries from seeds of unknown provenance. These spruce tree stands are now 60–90 years old and form a continuous complex covering 1000 ha (FMP, 1960, 1965). Sampling took place at five locations, with coordinates described in Table 2.

Table 2 – The sampling locations

Location	Coordinate X	Coordinate Y	Distance from first location (m)
First	14.250832	45.799067	–
Second	14.251562	45.821337	2443
Third	14.269895	45.820835	2842
Fourth	14.276249	45.833478	4289
Fifth	14.281562	45.832544	4418

2.2. *Materials*

This study is based on tracking data on caught spruce bark beetles using Theysohn pheromone traps with commercial pheromones Pheroprax® and Chalcoprax®. For *I. typographus* the population density was tracked between 1986 and 2000 and for *P. chalcographus* between 1993 and 2000.

The placement and replacement (exchange) of pheromones in the traps took place at different times. The reasons for this were the weather conditions and different objective obstacles, which occurred during long research period. For *I. typographus* the placement took place in the period from April 9 to 26 every year; the first exchange took place from May 11 to June 29; the second exchange from July 3 to September 9; the third exchange only from 1996 to 2000 from August 2 to September 9 and the fourth exchange only on September 6 2000. For *P. chalcographus* the placement of pheromone into the trap took place in the period from April 16 to May 12 every year; the first exchange from May 24 to June 23; the second exchange from June 28 to August 8; the third exchange from August 2 to September 1 and the fourth exchange only once on September 6, 1999. The quantification of catches took place periodically (usually once per week) by counting catches, or by measuring volume of the catches if the catch were greater than 500 individuals per trap. The method of measuring was according to Chaloupek et al. (1988) (38 individuals/ml for *I. typographus* or 580 individuals/ml for *P. chalcographus*). All together 1134 samples for species *I. typographus* and 768 samples for species *P. chalcographus* were taken. To clarify the effects of weather we have used meteorological data (average monthly temperature and average monthly precipitation) from the nearest weather station Postojna, which is 7105 m faraway from the center of the plateau (Meteorological data, Postojna, 1986–2000).

2.3. *Modeling*

2.3.1. *Methodology of modeling: regression trees induction*

Regression trees are a representation for piece-wise constant or piece-wise linear functions. Like classical regression equations, they predict the value of a dependent variable (called class) from the values of a set of independent variables (called attributes). Data represented in the form of a table can be used to learn or automatically construct a regression tree. In the table, each row (example) has the form (x_1, x_2,..., x_N, y), where x_i are values of the *N* attributes (e.g. site characteristics, such as monthly precipitation, average monthly temperature, etc.) and y is the value of the class (the number of bark beetle individuals in our case).

Unlike classical regression approaches, which give one single equation for a given set of data, regression trees partition examples into axis-parallel rectangles and fit a model to each of these partitions. A regression tree consists of inner nodes that test the value of a certain attribute, and a model for predicting the class in each leaf. To predict a class the model contains a linear equation or just a constant factor. Trees that have linear equations in the leaves are also called model trees.

Given a new example, for which the value of the class should be predicted, the tree is interpreted from the root.

In each inner node, the prescribed test is performed to classify the example into the corresponding (left or right) subtree. When the selected node is a leaf then the value of the class for the new example is predicted according to the model in the leaf.

Tree construction proceeds recursively starting with the entire set of training examples (entire table). At each step, the most discriminating attribute is selected as the root of the (sub)tree and the current training set is split into subsets according to the values of the selected attribute. For discrete attributes, a branch of the tree is typically created for each possible value of the attribute. For continuous attributes, a threshold is selected and two branches are created based on that threshold. Technically speaking, the most discriminating discrete attribute or continuous attribute test is the one that the most reduces the variance of the values of the class variable. For continuous attributes, the values of the attribute that appear in the training set are considered as thresholds. For the subsets of the training examples in each branch, the tree construction algorithm is recursively called. Tree construction stops when the variance of the class values of all examples in a node is small enough (or if some other stopping criterion is satisfied). Such final-nodes are called leaves and are labeled with a model (constant or linear equation) for predicting the class value.

An important mechanism used to prevent trees from overfitting data is tree pruning. Pruning can be employed during tree construction (pre-pruning) or after the tree has been constructed (post-pruning). Typically, a minimum number of examples in branches can be prescribed for pre-pruning and confidence level for the error estimates in the leaves for post-pruning.

A number of systems exist for inducing regression trees from examples, such as CART (Breiman et al., 1984) and M5 (Quinlan, 1992). M5 is one of the most well known programs for regression tree induction. We used the system M5′ (Wang and Witten, 1997), a re-implementation of M5 within the software package WEKA (Witten and Frank, 1999). The parameters of M5′ were set to their default values, except where described differently in this text.

2.3.2. Presentation of models (regression trees)

We have analyzed two datasets, for the species *P. chalcographus* and *I. typographus*, respectively. For each of them we built a linear regression equation and a model tree. In both cases the same attributes were used:

Table 3 – The linear equation for the six-toothed spruce bark beetle species *P. chalcographus*

number_beetle	= 3986.0957 if position ∈ {W, N}
	+ 192.6733*age_pheromone
	+ 1594.0956*avg_monthly_temp
	− 990*month
	+ 0.2591*previous_number_beetle
	− 13243.9166

Table 4 – The linear equation for the eight-toothed spruce bark beetle species *I. typographus*

number_beatle	= 274
	+ 4.65 if position ∈ {N, S, W, NE}
	+ 35 if position ∈ {S, W, NE}
	+ 16.6 if position ∈ {W, NE}
	+ 93.4 if position ∈ {NE}
	+ 11.1*age_pheromone
	− 3.67*days_since_last_control
	+ 13.5*avg_monthly_temp
	− 0.259*monthly_precipitation
	− 44.9*month
	+ 0.345*previous_number_beetle

- position (the position of the slope where the samples were taken);
- age_pheromone (the age of the bait);
- days_since_last_control (the time since last control, since it was not always exactly 7 days);
- avg_monthly_temp (average monthly temperature from a nearby weather station);
- monthly_precipitation (from a nearby weather station – only monthly data was available);
- month (month of the sampling);
- previous_num_beetle (the number of spruce bark beetles at last control).

Other attributes like the rate of weather damaged trees and more precise weather data could improve results, but were not available.

The linear equations for *P. chalcographus* and *I. typographus* are presented in Tables 3 and 4, respectively.

The model trees for species *P. chalcographus* and *I. typographus* are given in Figs. 1 and 2, respectively. The accuracy of all models was estimated using 10-fold cross-validation.

For species *P. chalcographus* the model trees are more accurate than the results of linear regression (Pearson regression

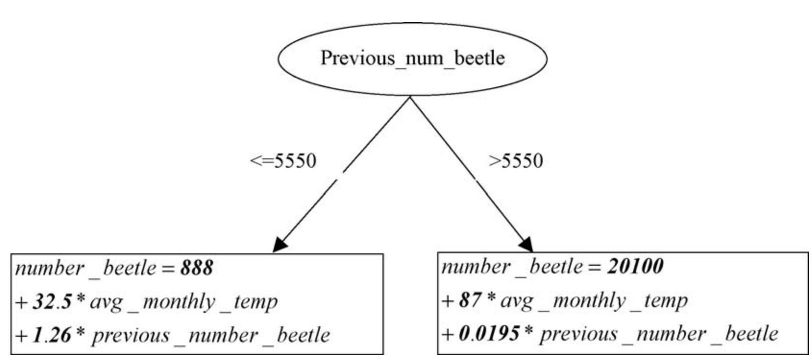

Fig. 1 – The model tree for spruce bark beetle species *P. chalcographus*.

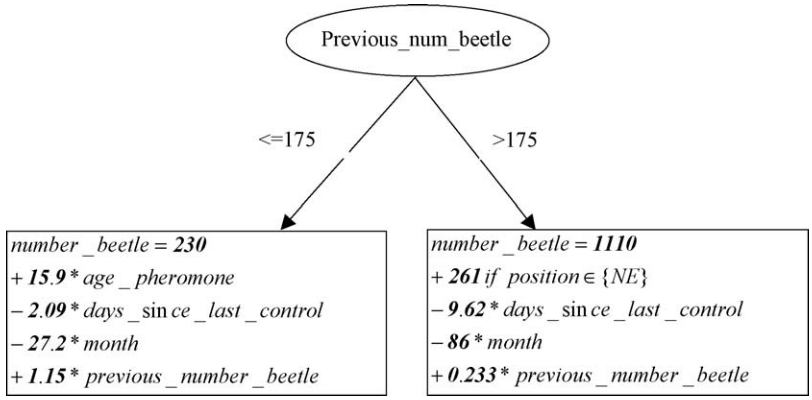

Fig. 2 – The model tree for spruce bark beetle species *I. typographus*.

coefficient $r = 0.37$ versus 0.44), and if we allow larger trees a correlation coefficient greater than 0.5 can be achieved.

For species *I. typographus* the model trees have the same accuracy as the linear regression. Building larger trees does not lead to an increase in predictive accuracy.

3. Analysis of results and discussion

3.1. *Overview and comparison of the data*

An analysis of the catches revealed two maximums in the number of caught individuals of both species *I. typographus* and *P. chalcographus*, thus showing that both species produce two generations per year.

The maximum number of the first species appears in different years at different times, e.g. the two maximum for 1998 were found on May 13 and June 7, in 1999 on June 3 and July 22 and in 2000 on June 10 and August 26. The first maximum represents the winter generation, while the second maximum represents mostly individuals from the summer generation. *I. typographus* may also have two sister generations. Some Swiss researchers have cited data that the days of appearance and the maximums in the numbers of the first and second generations of *I. typographus* in a 3-year study were almost the same (Zuber and Benz, 1992). In 1998, which was also the year with the highest catch in the entire study period, *P. chalcographus* had the first maximum on June 8 (winter generation) and, even more distinctively, a second maximum on July 6 (summer generation).

The number of specimens caught in the traps shows the relative abundance of the populations of spruce bark beetles in the FU Planina and it was compared with the available data for spruce bark beetles in Slovenia overall. Approximately 13,535 *I. typographus* were caught per trap in our research areas in 1998 (the most were caught on fifth location with 22,004 individuals per trap). In the other parts of Slovenia very high average caughts per trap were recorded in FMR Celje (21,763 individuals in 1987; Cimperšek, 1988), and on Kranjsko polje (18,965 individuals in 1989; Pavlin, 1992). A 12-year study beginning in 1980 tracking the population density of *I. typographus* in Norway shows fluctuations in population density from approximately 4000 to 10,000 individuals per trap until 1990 to up to approximately 20,000 individuals in the mid-1990s (Bakke et al., 1995). In Sweden, the number of *I. typographus* individuals per trap from 1995 to 2000 fluctuated between approximately 10,000 and 44,000 (Lindelöw and Schroeder, 2001). Data from the southeastern Alps shows that in the period from 1996 to 2001 average catches of *I. typographus* fluctuated between 4000 and 20,000 individuals per trap (Stergulc and Faccoli, 2003).

The number of individuals of the species *P. chalcographus* reached a maximum in FU Planina in 1998, when 815,155 individuals were caught on fourth location. In 1998, 581,222 individuals per trap on average were caught at our research locations, which is much more that anywhere else in Slovenia (on Kranjsko polje the average yearly catch per trap was 122,705; Pavlin, 1992), but less than in neighboring Austria (773,300 individuals; Wuggenig, 1988).

The variation in the numbers of caught individuals of both species of bark beetles per trap at our locations is linked to the size of local populations of bark beetles (Bakke and Strand, 1981). The relatively high abundance of populations of the species *I. typographus* and *P. chalcographus* on our research locations can be explained by frequent catastrophic weather events, which have ensured suitable trophic material for the spruce bark beetles (Chronicle of FU Planina, catastrophic weather conditions in years 1948, 1951, 1952, 1965, 1966, 1967, 1969, 1986, 1987, 1988, 1992, 1993, 1996, 1997, 1998). The freshly damaged and devastated trees caused by catastrophic weather conditions are a suitable habitat for phleophagic bark beetles. Trees mechanically destabilized due to these catastrophic weather conditions also represent a potential habitat for these species (Weslien, 1992; Flot, 2001; Christiansen and Bakke, 1997; Gall and Heimgartner, 2003).

Another reason for the higher bark beetle population density is that the Norway spruce found in FU Planina are on a non-natural stands, as well as at a lower height above sea level than normal.

We wanted to determine the dependence of the population of two species of bark beetles on available ecological variables. Two models were built. A linear equation was built using linear regression and a model tree was built using M5′.

3.2. *Modeling and analysis of factors affecting the population of P. chalcographus*

The linear equation seen in Table 3, resulted from linear regression, has a correlation coefficient of 0.37. It was estimated for new data using 10-fold cross-validation. It suggests that W and N positions are the ecological factors which most contributes to increased population of *P. chalcographus*. Precipitation also supports increase in population. The number of bark beetles falls with the month and the age of pheromone.

The model tree is given in Fig. 1. This model, with correlation of 0.42, reveals the importance of average monthly temperature and the previous number of bark beetles for *P. chalcographus*. The interpretation of the model tree is in agreement with the ecology of *P. chalcographus*, which needs higher temperatures for development and a greater number of individuals in the previous generation to produce more descendants.

3.3. *Modeling and analysis of factors affecting the population of I. typographus*

The linear equation seen in Table 4 (with correlation of 0.44) shows that NE position influence strong increase the number of bark beetles, while the current number of bark beetles rises with average monthly temperature, previous number of bark beetles and the age of the pheromone. Other authors have also noted that the intensity of flight positively correlates with temperature (Botterweg, 1982; Lobinger, 1994). The number of bark beetles falls with the month, monthly precipitation and with the number of days since the last control. Similar findings hold also for the model tree (Fig. 2; correlation of 0.42).

3.4. *Discussion on the models*

The results of the modeling show an important correlation between the abundance of species *I. typographus* and *P. chalcographus* and the position: NE position were linked with strong increase of the number of *I. typographus* individuals, while W and N positions increase the number of *P. chalcographus* individuals. The greater number of individuals caught per trap is linked to the stronger presence of those individuals in the environment, in our case in the spruce stands, where the traps were laid (Bakke and Strand, 1981). The results of other studies have shown a greater catch of species *I. typographus* particularly in western and eastern positions, whereas catches at southern and northern positions are minimal (Zumr, 1991; Jakuš et al., 2003).

Our results are related to the findings of Christiansen and Bakke in Norway (1988), who mention the greater sensitivity and susceptibility of Norway spruce on natural stands in northern and eastern positions. They relate this to the shallow roots in shady exposures, which is linked to the high level of water at these exposures, thus making these stands are more sensitive to drought stress. On the other hand, trees with a southern exposure are more resistant to drought stress due to many years of adaptation to a drier environment by developing deeper roots. Similar findings were made by Worrell (1983). Results of studies on the phenology and ontogeny of root systems of spruce, and their biological adaptation to environmental factors, have confirmed the above (Puhe, 2003).

Newer research emphasizes the difference between the influence of drought (which frequently coincides with high temperatures) on the predisposition of host plants to bark beetle attack and on the ecology of bark beetles (Botterweg, 1982; Lobinger, 1994). These studies have determined that weather conditions have a greater influence on the ecology of bark beetles than on physiological changes in the host (limiting growth and photosynthesis) (Reeve et al., 1995; Christiansen and Bakke, 1997). Studies of populations of *I. typographus* and *P. chalcographus* in the forests of northern Germany show that *I. typographus* prefer to brood their young in the colder internal parts of the stand during very hot summers. The edges of stands, as well as southern positions, are an unsuitable habitat for bark beetles (Niemeyer, 1997). The results of our studies may help to clarify the effects of microecological factors on populations of the above species of bark beetles in southern positions and partially on the status of hosts in northern positions.

4. Summary

In this paper we analyze data on the population density of spruce bark beetles (Scolytidae: *I. typographus* and *P. chalcographus*) in Dinaric forests in southwestern Slovenia. Research on the species *I. typographus* took place from 1986 to 2000, while that on *P. chalcographus* between 1993 and 2000 on land dominated by Dinaric Fir-Beech forest community (*Abieti-Fagetum dinaricum*), where the substrate is limestone and dolomite and the soil is chromic cambisols and rendzic leptosols. These forests are man-made stands of 60–90 year old spruce trees in a continuous 1000 ha large complex. The research area is on the Karst plateau (447–751 m.a.s.l.), which forms a natural passageway from the Mediterranean to Alpine climate, meaning that there are therefore frequent catastrophic weather conditions in this area (Chronicles of FU Planina, catastrophic weather conditions in years 1948, 1951, 1952, 1965, 1966, 1967, 1969, 1986, 1987, 1988, 1992, 1993, 1996, 1997 and 1998). The population density of spruce bark beetles were monitored at five locations with varying exposures using commercial Theysohn traps using pheromones Pheroprax® and Chalcoprax®. Placement of the pheromone Pheroprax® in traps for *I. typographus* took place from April 9 to 26 each year; while placement of the pheromone Chalcoprax® in the traps for *P. chalcographus* took place from April 16 to May 12 each year; the pheromones were exchanged up to four times in one vegetation season and catches were quantified periodically. Quantification of catches showed that both species have two main generations per year, and both species have the possibility of producing two more sister generations. The maximum numbers of the *I. typographus* appear in different years at different times, e.g. the two maximum for 1998 were found on May 13 and June 7, in 1999 on June 3 and July 22 and in 2000 on June 10 and August 26. In 1998, which was also the year with the highest catch in the entire study period, *P. chalcographus* had the first maximum on June 8 (winter generation) and, even more distinctively, a second maximum on July 6 (summer generation).

The number of individuals caught in the traps shows the relative abundance of the populations of spruce bark beetles in the FU Planina compared with the available data for spruce bark beetles in Slovenia overall. Approximately 13,535 *I. typographus* were caught per trap in our research areas in 1998 (the most were caught on fifth location with 22,004 individuals per trap). The number of individuals of the species *P. chalcographus* reached a maximum in 1998 on fourth location, where 815,155 individuals were caught. In 1998, an average of 581,222 individuals were caught per trap at our research locations, which was much more than elsewhere in Slovenia. The catch of both species of bark beetles was large compared with other similar studies in Slovenia.

Some ecological factors were correlated to data on the catch of bark beetles and analyzed using modeling. We used the modeling approach of model tree induction system M5′ within the software package WEKA. The following attributes were used to analyze the appearance of both species of bark beetle: position (NW, NE, W, E, N and S), age of pheromone, number of days since last control, average monthly temperature, monthly precipitation, month and the previous number of bark beetles. We determined a strong correlation between the appearance of *I. typographus* and the Northeast (NE) positions as well as a correlation between the appearance of *P. chalcographus* and the West (W) and North (N) positions. This phenomenon can be explained by the adaptation of spruce to extreme conditions at southern exposures. At the N, NE and W positions individual trees are more sensitive to drought and mechanical destabilization of the root system (due to catastrophic weather conditions) and are therefore more prone to attack by bark beetles.

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