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Induction and Spread of a spruce bark beetle outbreak in the Wilderness Area Dürrenstein, Austria

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Abstract

Mass outbreaks of the spruce bark beetle *(Ips typographus*) currently represent the largest threat to spruce dominated forests in Central Europe. Besides the high reproductive capacity and the aggressiveness of the beetle itself, climatic conditions affect the number of possible generations per year, and thus the occurrence of high population densities of the insect. The aim of this study was to investigate the uninterrupted influence of microclimatic site and stand conditions on the dynamics of population densities of the spruce bark beetle in a valley end of the Wilderness Area Dürrenstein (IUCN Cat.1).

A retro perspective analysis of the areas infested by the beetle during the years 2003-2011 was done regarding climatic conditions (temperature, irradiation, and precipitation) as well as stand and site related predisposition factors. The results show that high amounts of trees killed by bark beetles only occurred after extreme events (e.g. avalanche or wind throw) and that there was no direct or delayed relationship between temperature conditions and new infestations. South facing slopes showed higher predisposition and were infested earlier than east, west or north facing slopes. The site variables geomorphology and snowbreakage, as well as the stand variables proportion of spruce, stand age and storm hazard were crucial for the study sites predisposition towards bark beetle infestations.

In 2012, spruce bark beetles marked with fluorescent powder were caught in pheromone traps to examine the beetles' dispersal (flight direction and distance). Most beetles were found in south-western direction and within 100 m (>50%), 93% within 500 m. Very few individuals (<0.2%) managed to fly over a 1500 m high mountain ridge and were found in pheromone traps up to 5 km away from their hatching site.

The areas predicted temperature increase of +1.1° to +2°C (2021-2050) and +3° to +3.9°C (2050-2071) will severely influence the development of *Ips typographus* from currently a univoltine development at higher elevations to a mulivoltine development in future. This may have a significant effect on beetle's population growth and trigger longer, more intense, and larger epidemics.

Keywords

Ips typographus, dispersal, voltinism, predisposition , protected area,

Introduction

Mass outbreaks of the spruce bark beetle (*Ips typographus*) currently represent the largest threat to spruce dominated forests in Central Europe. Besides the high reproductive capacity and the aggressiveness of the beetle itself, climatic conditions affect the number of possible generations per year, and thus the occurrence of high population densities of the insect.

The presence of large amounts of potential breeding materials are essential in order for mass outbreaks of the spruce bark beetle to occur and this often occurs after storms, snowbreakage or avalanche events. If these are followed by warm and dry weather conditions, a rapid population increase of the beetle can be triggered. Apart from the beetles' high reproductive capacity, climatic conditions mainly influence the development and the number of generations per year. In order to estimate the risk of bark beetle outbreaks and to initiate control measures in good time, it is necessary to have knowledge about the vulnerability of the stands and sites towards disturbances through extreme weather events (predisposition). It is also crucial to have knowledge on the possible numbers of beetle generations per year (voltinism of the beetle) as well as about their dispersal behaviour.

Without protective forestry measures mass outbreaks of the spruce bark beetle can lead to eruptive dimensions as can be seen upon the example of the Bavarian Forest National Park. Debates revolving around the conservation of natural heritage on the one hand and the protection of economically valuable natural resources on the other hand are ongoing in the Dürrenstein area and many other areas close to protected areas such as National Parks. Managers of adjacent forests are worried about possible "germ herds" which are harboured in the Wilderness and threaten to weaken or even destroy their harvest. It is extremely important to communicate and prove the real situation by means of thorough research. The unique study site in the Wilderness Area Dürrenstein enabled detailed research of an undisturbed bark beetle outbreak.

The aim of this study was to investigate the influence of microclimatic site and stand conditions on the population density, voltinism and dispersal behaviour of the spruce bark beetle *Ips typographus*. Initial predisposition of a secondary spruce forest was calculated and compared to the actually infested areas during a time period of nine years. Climate change scenarios were implemented upon the study area to simulate the possible development of the spruce bark beetle in the future.

Materials and methods

The research was carried out in a valley end of the Wilderness Area Dürrenstein (IUCN Cat.1) which is located in the eastern part of the northern limestone Alps, near to the border between the provinces Lower Austria and Styria. The area covers 2.400 ha and encloses the largest remainder of primary forest in Central Europe. A large area of the Wilderness Area also consists of secondary spruce forests which are slowly transforming naturally. In a valley end of one of these forests a bark beetle infestation, undisturbed by protective forestry measures, has been monitored since 2003. Storms, snowbreakage, as well as avalanche events have allowed massive amounts of potential breeding material to accumulate, giving a unique opportunity to survey the processes involved in the dynamics of a spruce bark beetle outbreak.

The spruce bark beetles dispersal was studied after infested logs (12x 1,5 m) had been covered with fluorescent powder in May, 2012 and emerging beetles marked themselves. A total of 23 pheromone traps were placed around the hatching site at distances between 50 m and 7 km. The traps were emptied at least once a week. The total number of caught beetles was assessed and marked beetles were determined by looking at the catches under UV light.

A camera (Type: AXIS – 1347, MP 5 Resolution), taking one photo per minute, was placed directly above the emerging site to monitor beetle activity. A climatic station located next to the emerging site recorded temperature, precipitation, wind direction and wind speed. The photo taken at noon each day was compared to the previous day's photo concerning general beetle activity, new boring holes, sawdust and out-boring beetles. Beetle activity was examined in accordance to temperatures, precipitation and wind speed during the beetles' potential swarming time. On behalf of the climatic data, the phenology model PHENIPS (Baier et al. 2007) calculated *Ips typographus* developmental stages and enabled an insight into the beetles activities without being in the field.

The number of infested trees during the years 2003-2012 was analysed in accordance to the factors influencing the beetles' development (temperature, precipitation and potential breeding material through storms and avalanche events). The areas initial predisposition towards bark beetles was assessed by the Predisposition Assessment Model (PAS) (Netherer & Nopp-Mayr 2005).

The regional climate models PROMES, RegCM3 and Aladin were used to simulate the potential voltinism of *Ips typoraphus* under changing climate conditions for the periods 2021-2050 and 2071-2100.

Results

A total of 1478 spruce bark beetles marked with fluorescent powder were caught in the eleven pheromone traps in the "Hundsau" area. This represents a capturing rate of approximately 22% of the emerged and marked beetles. More than 50% of all marked bark beetles were recaptured within a radius of 100 m from the emerging site, predominantly in south-western direction; 93% were recaptured within a radius of 500 m. Very few marked beetles (<0.2%) managed to overcome the height difference of 600-700 m and flew over the mountain ridge where they were trapped at distances up to 5 km from the emerging site (Figure 1).

Beetle activities were significantly correlated with diurnal mean and maximal temperatures and significantly negatively correlated with precipitation during potential swarming times in the afternoon. Wind speed had no direct effect on outboring activities.

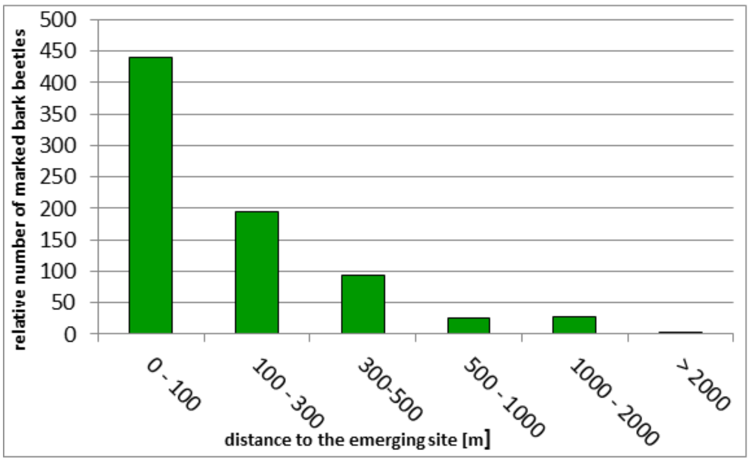

Figure 1: Distances of the pheromone traps to the emerging sites (m).

The results of the retrospective analysis show that high amounts of trees killed by bark beetles only occurred after extreme events such as the avalanche in 2009, after which massive amounts of potential breeding material was available. New infestations were mostly found within 500 m of preyear infestations. If precipitation in April was high, significantly fewer trees were infested in the course of the year. No direct or delayed relationship between temperature conditions during the vegetative period or the calculated number of potential generations and new infestations of trees was found. Even the exceptionally warm summer of 2003 did not result in a rise of the beetles' population density.

Of the 3788 examined grid cells, 4% were in the class with no predisposition, 10% were classified as low, 29% were classified as having moderate predisposition and 57% were classified as highly predisposed towards an attack by *I. typographus* (Figure 2).

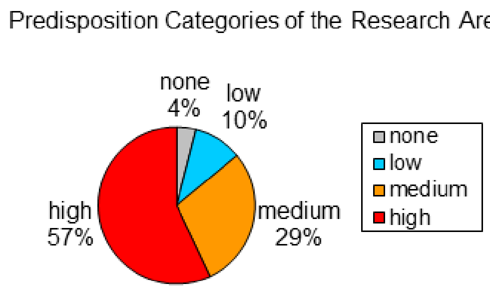

Figure 2: Percentages of predisposition categories in the research area

Of the total area of the Wilderness Area Dürrenstein the south facing slopes were in notably higher predisposition classes and were also preferably infested compared to north facing slopes. A rate of 11% of the 3788 grid cells (30x30m) were infested by the spruce bark beetle during the period between 2003- 2011. Grid cells were preferably infested where the predisposition model PAS calculated a high risk level due to high percentages of spruce trees (>50%), stand age (60-100 years), geological position (hill or mountaintop, middle slope) as well as high vulnerability towards storms and snow breakage (Figure 3).

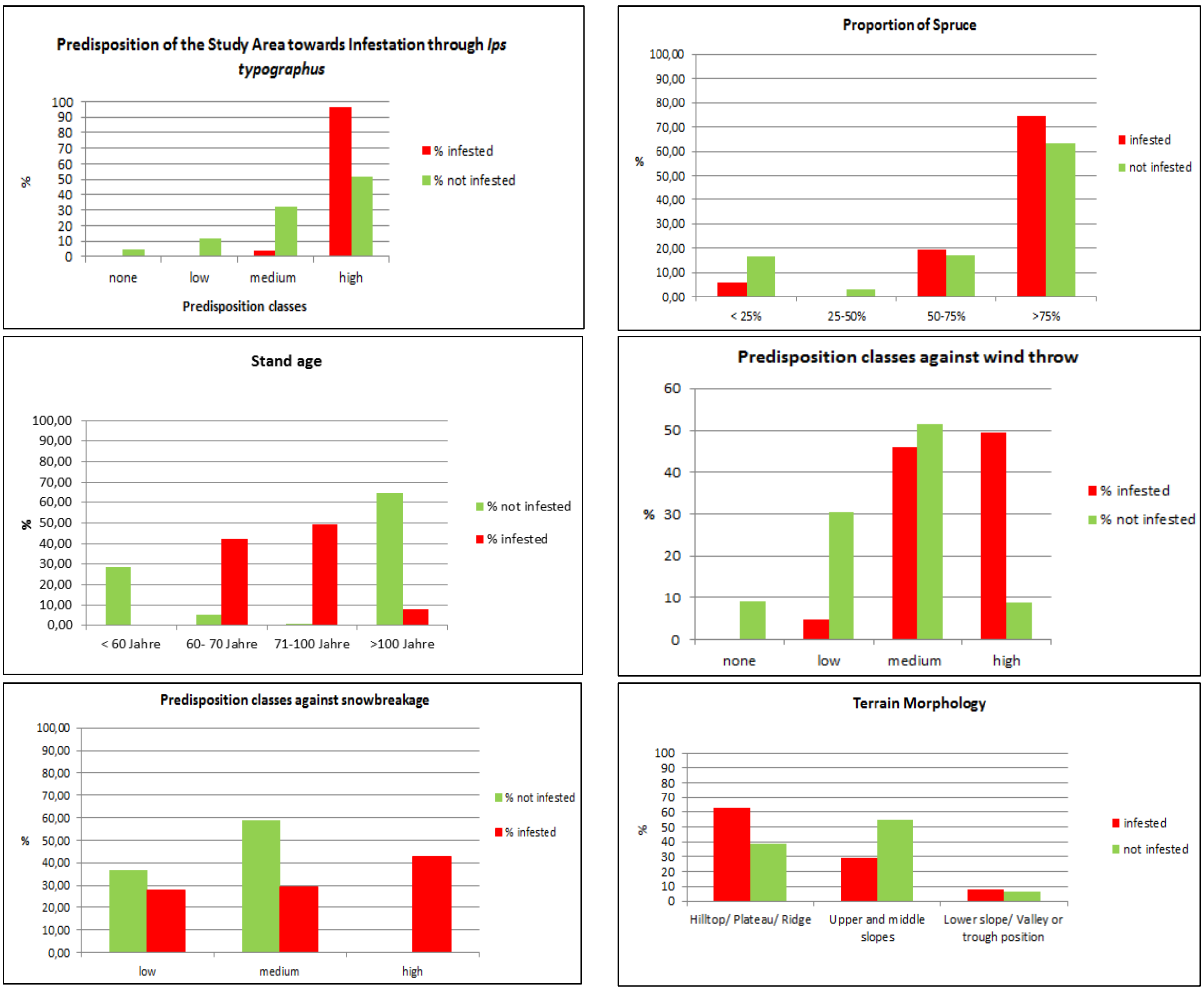

Figure 3: Relative percentages of infested and not infested grid cells in accordance to their predisposition towards infestation by *I. typographus*, proportion of spruce, stand age, terrain morphology as well as predisposition classes towards wind throw and snowbreakage.

Projected changes of mean air temperatures from April to October for the period 2021-2050 are most pronounced for RCM PROMES, intermediate for the model Aladin, and least for RegCM3. For the period 2071-2100 mean air temperature increases by 3.91°C and 3.04°C for the two RCMs Aladin and RegCM3. The comparison of the observed gridded mean temperature in 1991-2009 (present-day climate) with the climate normal period revealed an increase in air temperature of 0.92°C for the region Wildalpen/ Hochschwab. For the winter months December- February the model Aladin calculates a temperature increase of 1.22°C for 2021-2051 and 1.98°C for 2071-2100 (Table 1).

Table 1: Deviations between observed (E-OBS) and projected (RCMs Aladin, PROMES and RegCM3) mean air temperature and mean precipitation sum from April- October.

Differences of the mean temperatures from April - October (°C)			
	Mean	**Max.**	**Min.**
E-OBS (1991-2009) - (1961-1990)	**0,92**	**1,06**	**0,81**
Aladin (2021-2050) - (1961-1990)	**1,62**	1,70	1,56
PROMES (2021-2050) - (1961-1990)	**2,03**	2,05	2,00
RegCM3 (2021-2050) - (1961-1990)	**1,14**	1,15	1,12
Aladin (2071-2100) - (1961-1990)	**3,91**	4,00	3,81
RegCM3 (2071-2100) - (1961-1990)	**3,04**	3,07	2,98

The modell Aladin prognoses an increase of precipitation for 2021-2051 and a decrease for 2071-2100. The modell RegCM3 prognoses an increase for both time periods (Table 2).

Table 2: Differences between observed (E-OBS) and prognosed (Aladin, PROMES, RegCM3) precipitation rates during the winter months (December-Febuary).

Differences of the mean precipitation from April - October (%)			
	Mittel	**Max.**	**Min.**
Aladin (2021-2050) - (1971-1999)	**4,41**	5,72	3,05
RegCM3 (2021-2050) - (1971-1999)	**3,8**	5,02	3,2
Aladin (2071-2100) - (1971-1999)	**-8,94**	-7,31	-11,56
RegCM3 (2071-2100) - (1971-1999)	**3,29**	4,48	2,21

Calculations from the climate models indicate that the former predominately univoltine development of the spruce bark beetle will shift to bi-/multivoltine development. The inter-annual variability of successful established generations will also decrease. In comparison to the climate normal period, a change in potential as well as actual generation development can be detected.

Discussion

More than 50% of all marked and captured bark beetles were recaptured within a radius of 100 m from the emerging site. This finding corresponds with other recapture experiments such as ZUMR (1992). Most beetles were caught in south-western direction. Former studies assign tree exposition to the south and west to have higher attack probabilities (BLACKWELL 2011, LEXER 1995). Under epidemic conditions, 90% of new infestations are found to occur within 500 m of an old attack (WICHMANN & RAvn 2001, KAUTZ et al. 2011). This corresponds to the findings in our study, where 93% of the marked beetles were captured within a radius of 500 m. As only few beetles (<0.2%) managed to overcome the mountain ridge with the height difference of 600-700m, mountain ridges and valley ends can have a natural barrier effect.

The Predisposition Assessment Model (PAS) appears to be a reliable tool for assessing susceptibility towards bark beetles as 100% of the infested grid cells were in the medium or high predisposition class. A spruce percentage of over 50% is significantly correlated with infestation.

If the climate scenarios prove to be right, another shift towards multivoltine developments might take place. Together with increasing amounts of extreme weather events this can have significant effects on population growth and trigger longer, more intense, and larger epidemics (BAIER et al. 2011).

Conclusion

Using fluorescent powder to mark infested logs proved to be a good method of surveying *Ips typographus* flight dispersal. An undisturbed bark beetle infestation in a protected area does not necessarily pose a threat to adjacent managed forest stands as only 7% of the beetles flew further than 500 m and mountain ridges as well as valley ends can have a natural barrier effect. The predominant swarming direction as well as infestation direction of *I.*

typographus was south-west. The predisposition model PAS is a reliable tool for assessing susceptibility towards bark beetle attacks. If climate scenarios are correct then more intense, longer, and larger epidemics of the spruce bark beetle can be expected in future.

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