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Spatio-temporal infestation patterns of *Ips typographus* (L.) in the Bavarian Forest National Park, Germany

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ABSTRACT

The Bavarian Forest National Park in Germany has experienced infestations of bark beetle (*Ips typographus* L.) since the 1980s, resulting in considerable ecological loss due to the destruction of almost 5800 ha of spruce forests. Although there have been numerous investigations on the physiology and ecology of the bark beetle, until now the spatio-temporal infestation and dispersal dynamics of the bark beetle over a longer period have still not been satisfactorily understood. The understanding of the structure and the dispersal of bark beetle infestations is however of significant importance for forest management systems in order to predict the risk of outbreaks, especially in the face of climate change.

The aim of this investigation was therefore (I) to analyse and describe the long term spatio-temporal infestation patterns of *I. typographus* in the Bavarian Forest National Park, Germany on the landscape scale, (II) to conduct investigations on spatio-temporal shifts of the focal points of bark beetle infestations from 1988 to 2010 and (III) to compare the quantitative spatio-temporal infestation patterns obtained at the landscape level with the dispersal patterns of the spatially explicit agent-based simulation model (SAMBIA) for *I. typographus* (Fahse and Heurich, 2011).

The results of the study show that a shift in the infestation pattern of *I. typographus* from 1988 to 2010 occurs at different time intervals both undirectionally as well as directionally. Furthermore, the dispersal pattern of the bark beetle was recorded quantitatively and described extensively over a period of 23 years on the landscape scale.

The quantification of the presence and dispersion pattern of *I. typographus* in the Bavarian Forest National Park allows us to gain a better understanding of the distribution pattern of the bark beetle on the landscape scale. In this way, both the pattern and structure of infestation patterns obtained for *I. typographus* serve as: (a) a basis for the criteria to improve the parameters of spatio-temporal simulation models, (b) a better understanding of the bark beetle pattern and existing processes such as disturbance patterns or damage patterns in the food web of spruces due to climate change, (c) a test for the hypotheses on the relationships between the presence of bark beetle and relevant habitat variables as well as (d) the compilation of forecast models on the dispersal of bark beetle. These predictions can help with the implementation of specific management strategies to prevent the dispersal of bark beetle.

1. Introduction

The Bavarian Forest National Park is the oldest National Park in Germany. The management principle for the National Park is the so-called natural process principle: nature within the park should be given the opportunity to take its own course as much as possible without human intervention. In fact, since 1970 a habitat has been created that acts as a unique refuge for many plant and animal species.

The severe thunderstorms that struck in 1983 and 1984 blew down many of the old tree stands, destroying a total area of 173 ha. Following the National Park's principle, the trees that had fallen within the nature zone of the National Park were left to take a natural course as was the outbreak of bark beetle. In the years that followed the bark beetle population increased dramatically so that even healthy trees became infested and died off. Following an initial fall in the activity of the bark beetle at the end of the eighties, unfavourable weather conditions in the early nineties (Heurich et al., 2001) resulted in annual increases in the area of ancient spruce stands dying off from 1992 onwards (slowly at first,

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but then escalating). Even until this day there have always been local infestations in the park which then spread to larger areas (Heurich et al., 2001; Nationalparkverwaltung Bayerischer Wald, 2001; Heurich, 2009).

In Europe there are around 154 species with different bark beetles infesting different tree species. The bark beetles that are found in the Bavarian Forest National Park are the spruce Ips (*Ips typographus*) and the six-toothed spruce bark beetle (*Pityogenes chalcographus*), both of which infest spruce trees (Heurich et al., 2001). Bark beetles are considered to be secondary pests, meaning that they only find favourable living conditions in weakened or dying trees. Storms and hurricanes (Coulson et al., 1999; Schroeder et al., 1999), snow, emissions or drought resulting from extreme weather events are known to weaken spruce trees that can then serve as ideal breeding grounds for the bark beetle, eventually leading to infestations under favourable weather conditions and sufficient breeding material (Netherer and Schopf, 2009).

Numerous investigations have already been conducted on the dispersal pattern of the bark beetle: in North-America (Powers et al., 1999; Negron et al., 2000; Klutsch et al., 2009), in Canada (Aukema et al., 2006; Wulder et al., 2006; Coops et al., 2009), in Slovenia (Jurc et al., 2006), in the Czech Republic (Svoboda and Pouska, 2008) in Poland and in Slovakia (Grodzki et al., 2003) in France (Gilbert et al., 2005) as well as in Germany (Heurich, 2001; Müller et al., 2009; Kautz et al., 2011; Lausch et al., 2011). Netherer and Schopf (2009) showed for example that global warming, temporal and spatial dynamics as well as the pattern, frequency and population dynamics can all alter the dispersal of the bark beetle. According to them, an increase in temperature can lead to a change in the number of generations per year, survival during the winter period as well as an increase in the susceptibility of the host vegetation. Baier et al. (2007) and Aukema et al. (2008) were able to prove a shift in the flight activity and dispersal for *I. typographus*. Investigations conducted by Jönsson et al. (2009) proved a change in development, reproduction rate, diapause and winter mortality of bark beetles.

Although the biology and ecology of the spruce Ips (*I. typographus*) has been investigated extensively (Wermelinger, 2004), until now there has been no satisfactory understanding in terms of its long-term spatio-temporal dispersal dynamics in forests on the landscape scale.

In many of the investigations covering dispersal dynamics only a short time frame of bark beetle dispersal was modelled as a result of insufficient data e.g. Powers et al. (1999) and Gilbert et al. (2005). Although Grodzki et al. (2003) and Jurc et al. (2006) were able to conduct analyses of bark beetle dispersal over a period of 7 and 11 years respectively, the presence/absence data, which they provided was point data as opposed to area data, as it is difficult to conduct a thorough analysis that covers entire areas.

Therefore the aims of this research were (I) to conduct investigations on the spatio-temporal shift in focal sites of bark beetle infestations from 1988 to 2010, (II) to analyse and describe long-term spatio-temporal infestation patterns of *I. typographus* (L.) in the Bavarian Forest National Park on the landscape scale and (III) to compare spatio-temporal infestation patterns obtained on the landscape level with the dispersal patterns of a spatially explicit agent-based simulation model (SAMBIA) for *I. typographus* (L.).

2. Data and methods

2.1. The study area

The study area known as the Rachel Lusen Region (Lat. E13°23′, Long. N48°53′) covers approximately 130 km^2 of the Bavarian National Park, from approx. 700 m above sea level to approx. 1450 m. The Bavarian Forest National Park was established in 1970 and has boasted a relatively natural state since 1972. Outbreaks of *I. typographus* (L.) have occurred from 1992, initially at higher elevations and peaking around 1996 and 1997 but continuing to this day. From 1988 to 2010 a total of 5800 ha of the naturally occurring Norway spruce stands died off because of *I. typographus* infestations (Fig. 1).

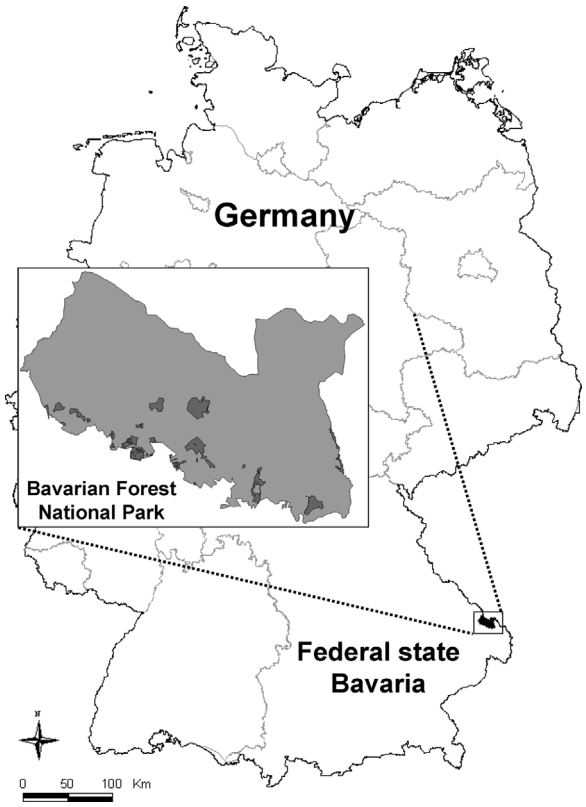

Fig. 1. Location of the study area – The Rachel-Lusen Area of the Bavarian Forest National Park, Germany.

2.2. Collecting presence/absence data on I. typographus

To document the extent and the impacts of bark beetle dispersal, flight campaigns have been carried out in the National Park since 1988. The methodology behind taking, processing and interpreting the aerial images has been described in detail by the Bavarian Forest National Park administration (2002). Every year 267 CIR aerial images were taken per flight campaign with a geometrical resolution of 20 cm, corresponding to a total of 147 gigabytes of data. Two CIR flight campaigns were conducted every year with the first campaign in June/July of every year. Trees infested by bark beetle can only be recognised from the beginning of August, therefore conducting campaigns in June/July enables a documentation of any additional dead wood that has occurred since the previous year. The second campaign is then carried out in September/October of every year. With the help of these aerial images the current status of how much dead wood has accumulated can be documented in the year of investigation. Colour infrared stereo aerial images were taken at scales between 1:10,000 and 1:15,000. Up to the year 2000 the images were mapped using a stereoscope and transparent slides, drawn onto maps and finally digitalised (Nüsslein et al., 1999). From the year 2001 onwards, aerial images were scanned with a photogrammetric scanner at a