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Spatial interactions between storm damage and subsequent infestations by the European spruce bark beetle

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ABSTRACT

Disturbances such as storm damage and bark beetle infestations are key factors for the development of forest ecosystems. Infestations of the European spruce bark beetle (*Ips typographus*), which is the most devastating biotic disturbance agent in forests of central Europe and Scandinavia, are often triggered by storm damage. However, our understanding of spatio-temporal bark beetle dynamics at fine scales is still limited. In order to assess future risks of *I. typographus* infestations, we analyzed spatial interactions of the infestation pattern in a 180 km^2 study region in central Switzerland. We computed neighborhood characteristics of bark beetle dispersal and fitted Poisson models to the spatial point patterns of bark beetles and storm damages. Infestations of *I. typographus* were found to be clustered at short distances (<500 m). In contrast, the spatial distribution of storm damages followed an inhomogeneous Poisson distribution that was explained by environmental covariates. Increasing topographic exposure, south- and west-facing slopes as well as increasing proportions of Norway spruce enhanced the probability of storm damage and bark beetle infestations. Our study is a contribution towards quantifying important ecological drivers in a spatially explicit manner that helps assessing predisposing factors for future bark beetle infestations.

1. Introduction

Disturbances such as storm damage and bark beetle infestations affect the development of forest ecosystems and are therefore key factors in forest dynamics and long-term succession (Ayres and Lombardero, 2000; Dale et al., 2001). For example, recent infestations of host trees by the mountain pine beetle (*Dendroctonus ponderosae* H.) have caused 6–11 million ha of pine mortality in British Columbia and the western United States (Meddens et al., 2012), resulting in a carbon feedback from the forest biome to the atmosphere that may foster climate change (Kurz et al., 2008). Thus, bark beetles are considered one of the most important biotic disturbance agents in forest ecosystems (Dale et al., 2001; Schelhaas et al., 2003; Raffa et al., 2008). While the outbreak of mountain pine beetles in British Columbia was mainly driven by elevated summer temperatures, mild winters, drought and ample supply of susceptible host trees (Raffa and Berryman, 1983; Logan and Bentz, 1999; Heavilin et al., 2007), large-scale outbreaks of the European spruce bark beetle (*Ips typographus* L.) are typically triggered by windstorms (Bouget and Duelli, 2004; Marini et al., 2013; Wermelinger et al., 2013) often in combination with weakening of the host trees, drought and heat (Rouault et al., 2006).

While bark beetles are responsible for 8% of forest damages in Europe, storm damage is the most significant disturbance causing up to 53% of total damage (Schelhaas et al., 2003). Roughly 60% of the sanitation fellings in Swiss forests are due to storm damage (Schelhaas et al., 2002). Storm damage is observed most often in mature Norway spruce dominated forests that are exposed to the main wind direction (e.g., west-facing slopes, hilltops), whereby damage is expected to increase with stand height (cf. Dobbertin, 2002; Mayer et al., 2005; Schütz et al., 2006; Schmidt et al., 2010; Valinger and Fridman, 2011). As a consequence of storm damage to Norway spruce stands, the surrounding stands are typically infested in subsequent years (Schroeder, 2010; Stadelmann et al., 2013a), resulting in a distinct spatial infestation pattern in the surrounding area (Wichmann and Ravn, 2001; Schroeder, 2010).

Spatio-temporal patterns of bark beetle infestations are often analyzed using a range of statistical methods (e.g., Aukema et al., 2006; Chapman et al., 2012; Chen, 2013). In particular, the analysis

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of the spatial pattern of locally distinct bark beetle infestations, including the underlying processes and neighborhood effects between bark beetle infestations, often relies on point pattern analysis (for reviews cf. Perry et al., 2002; Wiegand and Moloney, 2004; Illian et al., 2008). A spatial point pattern consists of observed points in an observation window. The pattern can be described by first-order statistics that include the intensity λ (i.e., the density of observations) of a point process, its large-scale variation and nearest neighbor distances. Second-order statistics include neighborhood characteristics such as Ripley's K-function (Ripley, 1976, 1981) that provide information on the correlation of points over a range of spatial scales, which allows for the detection of randomness, clustering or dispersion at any given scale. To date, most point pattern analyses of bark beetle infestations have been restricted to second-order statistics (Kautz et al., 2011, 2013; Colombari et al., 2013). However, recently developed methods allow for a more comprehensive analysis of point patterns, which additionally consider environmental covariates that explain their spatial distribution (Baddeley and Turner, 2005). We took advantage of these recent developments for the analysis of a fine-scale dataset of storm damages and bark beetle infestations.

The overall goal of this study was to increase our understanding of the environmental factors that influence the spatial pattern of bark beetle infestations and storm damage. We used a survey dataset containing records of >1600 bark beetle infestations and >500 storm damages. Specifically, the following questions were addressed: First, at what spatial scale do neighborhood interactions occur between bark beetle infestations of the current year and storm damage or bark beetle infestations of the previous year? And second, which environmental variables explain the observed spatial point patterns of storm damages and bark beetle infestations? Answering these questions will improve the basis to assess future infestation risks of the European spruce bark beetle in a spatially explicit manner.

2. Materials and methods

2.1. Study area

The Napf region is located in central Switzerland in the transition zone between two biogeographic regions, i.e., the Swiss Plateau and the northern Swiss Alps (Fig. 1a). The study area extends over roughly 180 km^2 of rolling hills ranging in elevations from 598 to 1404 m a.s.l. The annual mean temperature at the weather station (WGS84 coordinates: 47°0.279′N/7°56.403′E; 1404 m a.s.l.) on the top of mount Napf amounts to 5.3 °C with a precipitation sum of 1708 mm (reference period 1981–2010, MeteoSwiss). The landscape is shaped by traditional agriculture that led to a complex mosaic of 50% forests and roughly 50% meadows plus some small villages and settlements (Fig. 1b). The forests in the Napf region are 'protection forests' (i.e., forests that protect human infrastructure against natural hazards such as avalanches, rockfall and landslides). In such 'protection forests', forest management endeavors to sustainably maintain the protective function against these hazards; thus forest practices such as clear-cutting are excluded. According to national guidelines, multi-layered stands are promoted using selective thinning (NaiS, cf. Frehner et al., 2007). The proportion of Norway spruce (*Picea abies*) ranges from 11% to 79% (mean: 35%), as derived from a simulation of the proportional basal area (Meier et al., 2010). The storm Lothar struck this region in December 1999 and caused 452 incidences of storm damage, which initiated mass infestations by *I. typographus* in the subsequent years (Figs. 1b and 2).

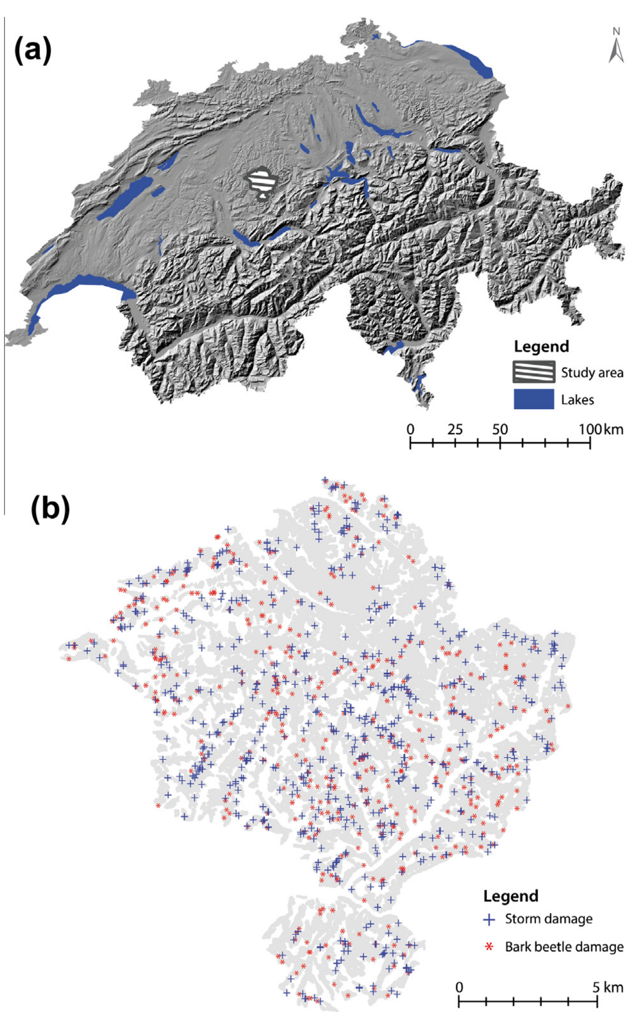

Fig. 1. (a) Map of Switzerland with the study area indicated by the hatched polygon. (b) Map of the study area with point patterns of damage by the storm Lothar in 1999 and subsequent bark beetle infestations in the years 2000–2002. The forest polygons (grey) are reproduced by permission of swisstopo (JA100120).

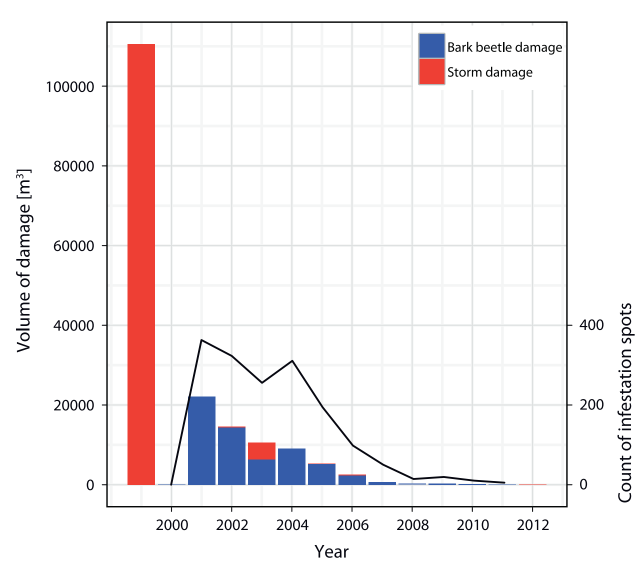

Fig. 2. Bar plot of bark beetle and storm damages in the years 1999–2012. The black line indicates the count of bark beetle infestation spots.