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Impact of windthrow and salvage-logging on taxonomic and functional diversity of forest arthropods

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ABSTRACT

Windthrow is recognized as the most important driver in European forest dynamics and its importance is likely to increase with climate change. Typically, windthrown timber is salvaged for economic and phytosanitary reasons. This markedly affects the natural development of the disturbed areas, in particular by removing important dead wood resources. For a sustainable and ecologically sound management of disturbance effects, more knowledge is needed on the impact of windthrow and salvage logging on animal species communities.

We monitored various arthropod taxa (spiders and insects) two and five years after the storm Lothar in 1999 in salvaged and unsalvaged windthrows as well as in adjacent intact forests. Basing on a comprehensive data set with 1276 species and 228,718 individuals, species diversity, abundance and community composition were compared. Species richness and abundance of most taxonomic and functional groups (pollinators, saproxylics and predators) in the windthrow habitats clearly differed from those in the intact forests. On average, twice as many species were present in windthrows as in the forest. Windthrows also supported more red-listed beetles (mainly saproxylics) than the intact forest and more habitat indicator species (mainly Heteroptera and Aculeata) were found in windthrow areas.

No difference in species diversity was found between salvaged and unsalvaged windthrows. However, similarity analyses showed that the communities of certain taxonomic and functional groups differed between the two salvaging treatments. A combination of unsalvaged and salvaged windthrows in intact forests increased local species richness approximately 2.5 times relative to that in the forests alone. Therefore after large-scale windthrows, a mosaic of salvaged and unsalvaged windthrow patches fosters high forest biodiversity levels.

1. Introduction

Disturbances rapidly alter the state of an ecosystem, creating landscape heterogeneity and distinctly impacting the system's trajectory (Turner, 2010). Windthrow is a typical abiotic disturbance that stochastically recurs at various spatial and temporal scales (Thom et al., 2013). In Europe, windstorms are the prime natural disturbance agent in forests, followed by fire and biotic agents (Schelhaas et al., 2003). The large-scale windthrows caused by the devastating winter gales Vivian and Wiebke (1990), Lothar (1999), Gudrun (2005) and Kyrill (2007) in Central and Northern Europe led to extensive discussions about the ecological and economic consequences of harvesting the fallen timber, i.e. of salvage logging. Windthrow in forests affects timber resources, the protective function of mountain forests and the silvicultural planning of forest managers.

1.1. Ecological consequences of windthrow

Large windthrows bring about drastic changes in a forest. The formerly closed-canopy habitat abruptly becomes open landscape. The loss of the dominant tree canopy leads to more sun exposure and favors herbaceous ground vegetation (Wohlgemuth et al., 2002). This dynamically developing habitat with multifaceted

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structures provides food and shelter for a great variety of organisms. Recent research has highlighted the ecological significance of windthrow as a natural component in the dynamics of forest ecosystems and as an important driver for biodiversity (Duelli et al., 2002; Bouget and Duelli, 2004; Gandhi et al., 2009). An obvious consequence of windthrow is that it creates ample supply of dead wood. This substrate is increasingly valued as an essential habitat for threatened saproxylic species, and has been singled out as an indicator for the sustainable stewardship of forests by the European Environment Agency (EEA, 2010). However, the lack of dead wood is still a limiting factor for many saproxylic taxa in most managed European forests. Primeval forests with large quantities of dead wood in various dimensions and decay classes support a specific fauna of saproxylic species (Müller et al., 2005; Gossner et al., 2013). In intensively managed forests, a number of saproxylic beetle species are threatened and are thus red-listed (e.g. Nieto and Alexander, 2010). The substrates that are most lacking are large-diameter logs in medium to late decomposition stages (Brin et al., 2011; Gossner et al., 2013; Seibold et al., 2015).

While the development of arthropod communities after wildfire has been in the focus of a considerable number of studies (e.g. Boulanger and Sirois, 2007; Moretti et al., 2010; Cobb et al., 2011; Elia et al., 2012), less research has been devoted to the short- and long-term responses of arthropod communities to windthrow (Bouget and Duelli, 2004). Most investigations to date have concentrated on the short-term reactions of specific insects, e.g. the dynamics of detrimental bark beetles in coniferous forests (e.g. Bouget and Noblecourt, 2005; Komonen et al., 2011; Wermelinger et al., 2013; Stadelmann et al., 2014) or other saproxylic beetles (Kopf and Funke, 1998; Wermelinger et al., 2002; Bouget, 2005; Gandhi et al., 2009). Others have compared unlogged windthrows with intact forest (Otte, 1989; Kenter and Funke, 1995; Bouget, 2005; Grimbacher and Stork, 2009). Most studies were carried out in coniferous forests.

1.2. Salvaging effects

Only limited data are available on the effects of salvage logging on the insect fauna. Usually, windthrows are salvaged for economic as well as for phytosanitary reasons. Apart from eliminating important resources for saproxylic species, salvage logging also alters surface structure, soil, microclimatic and vegetational conditions in the logged areas. While some findings on specific taxa in spruce forests have been published (Otte, 1989; Kenter et al., 1998; Duelli et al., 2002; Thorn et al., 2014), no results are available to date based on consistent data sets across multiple taxonomic and functional groups of arthropods or for non-coniferous forests.

With climate change, large-scale storms are likely to become more frequent and/or more severe (Fuhrer et al., 2006; Usbeck et al., 2010). Thus, forest managers will be faced more often with making a decision about salvage-logging windthrows, taking into consideration both economic and ecological aspects. Moreover, the pressure to salvage windthrown timber will increase because with promoting non-fossil fuels the damaged and low-quality timber and slash is now increasingly exploited as energy wood. Therefore, comprehensive knowledge is needed particularly on the effect of salvage-logging on biodiversity. However, studies in windthrows are not easily-planned experiments with sufficient replicates in space and time, and the abiotic and biotic properties often differ even between windthrows that were caused by the same storm.

1.3. Goal of this study

This article focuses on the effects of windthrow per se, as well as of salvage logging, on arthropod α- and β-diversity by comparing the composition of various taxonomic and functional arthropod groups. We used three case studies from different forest types, each with salvaged windthrows, unsalvaged windthrows and intact stands and from two sampling years. Specifically, we applied generalized linear mixed models to evaluate the effects of these three treatments on species richness, abundance and diversity of six taxonomic and three trophic groups. Moreover, we calculated Bray-Curtis similarities to compare community compositions and used IndVal analyses to identify indicator species for the treatments.

2. Materials and methods

2.1. Study sites and treatments

Studying ecological effects of natural disturbances such as severe storms have to rely on real situations that often do not meet all statistical requirements of specifically designed experiments and thus have case-study character. Hence, the windthrow areas caused by the devastating storm "Lothar" on 26 December 1999 had to meet the following minimal requirements: complete tree blowdown, similar elevation, nearby control forest, salvaged and unsalvaged plots available, and contracted agreement that these plots remain unchanged for long-term research for at least two decades. Three locations could be selected on the Central Plateau of Switzerland (Table 1): Sarmenstorf (Canton Aargau) with a beech (*Fagus sylvatica* L.) forest, Messen (Canton Solothurn) with a spruce (*Picea abies* [L.] Karst.) forest and Habsburg (Canton Aargau) with a mixed forest. The mixed forest was approx. half coniferous (mainly spruce with some *Pinus sylvestris* L., *Larix decidua* Mill. and *Abies alba* Mill.) and half broad-leaved (mainly beech with some *Acer pseudoplatanus* L.). At each location, we selected a triplet of treatments, i.e. an unsalvaged windthrow, a salvage-logged windthrow, and an intact control forest. In the unsalvaged plots, no timber harvesting or regeneration planting was carried out. In the salvage-logged windthrow plots, the timber was harvested, but the stumps and small branches were left on site and some regeneration planting was done. The intact forest plots unaffected by windthrow served as control treatment. In each location, the three treatment plots were close to each other (a few 100 m, one control forest 3 km) to keep site conditions and stand structures as similar as possible. In each treatment plot, dead wood was classified as either CWD (coarse woody debris) or FWD (fine woody debris). CWD has a mean diameter >10 cm and included upright snags and stumps, while FWD is between 1 and 10 cm diameter. The volume was estimated with the fixed-area-plot sampling method (Harmon and Sexton, 1996).

The arthropod communities in these study sites have been monitored since 2001. Here we present the results of the sampling campaigns two and five years after the windstorm.

2.2. Insect sampling design

In each treatment plot, three flight interception traps were set up approximately 100 m apart from each other, and five pitfall traps were distributed in the same way according to a design used in other similar studies (Müller and Brandl, 2009; Stenbacka et al., 2010). The flight interception trap consisted of a wooden frame supporting a yellow plastic funnel (43 cm in diameter) with two acrylic glass panes (50 × 43 cm each) mounted crosswise on top of the funnel (Duelli et al., 1999). The funnels were closed with a rubber stopper and filled with water spiked with 0.5% Rocima GT (Acima, Buchs, Switzerland) as a bactericide and detergent. The pitfall trap consisted of a plastic funnel (15 cm in diameter) screwed to a bottle filled with an aqueous 4% formaldehyde solution (Duelli