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The influence of tree species, stratum and forest management on beetle assemblages responding to deadwood enrichment

Andreas Floren [a,*], Tobias Müller [b], Marcus Dittrich [b], Matthias Weiss [c], Karl Eduard Linsenmair [a]

[a] Department of Animal Ecology and Tropical Biology, Biocenter, University of Würzburg, Am Hubland, 97074 Würzburg, Germany
[b] Department of Bioinformatics, Biocenter, University of Würzburg, Am Hubland, D-97074 Würzburg, Germany
[c] Institute of Entomology, University of South Bohemia, Branisovska 31, 37005 Ceske Budejovice, Czech Republic

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ABSTRACT

Deadwood harbours a diverse community of saproxylic beetles but has become rare as a result of intensive forest management. The lack of this key-resource has yet largely unmeasured consequences for the distribution of saproxylic species, their overall abundance and guild composition. In order to investigate these effects we established a large field experiment by enriching freshly cut beech and spruce deadwood of different size in the canopy and on the ground beneath beech and spruce trees in age-class and extensively managed forests. Flight Interception Traps (FITs) were used to collect attracted arthropods. Sampling was performed monthly from April to September and resulted in a total of 7542 beetles sorted to 371 species of which 5502 specimens (73%) and 180 species (49%) were saproxylics. All beetles as well as saproxylic assemblages taken separately showed substantial differences in species and guild composition between *Fagus* and *Picea* and the canopy-ground stratum but not between wood diameter classes. Indicator analysis identified 21 beetles indicative for beech and 27 species indicative for spruce. This assortment is largely supported by ecological data. In respect to vertical stratification 13 beetles (61.9%) were indicative for beech canopy but only 5 species (18.5%) for the spruce crowns. Difficult to interpret are results comparing forest management types. A respective effect was detected only in beech crowns. Forty-nine endangered species (13% of the total) were collected of which 76% were saproxylics (representing 80% of all endangered beetles).

1. Introduction

Managed forests differ from pristine forests in structural complexity, abiotic conditions and forest dynamics with the effect that the diversity of habitat types is greatly reduced (Bobiec, 2002; Brunet et al., 2010; Korpel, 1995; Londsdale et al., 2008). As a result, species diversity is also significantly reduced (Jacobs et al., 2007; Langor et al., 2008). To what extent this loss of biodiversity also affects ecosystem functioning is only scarcely investigated, however (Fischer, 2010). Such effects remain largely unmeasured but must be expected as the local loss of species results in an impoverishment of community and guild complexity which impacts on ecosystem processes like wood decomposition or the control of herbivore populations through predation (Jactel, 2009; Ulyshen, 2013).

In Germany around 98% of all forests are subject to a more or less intensive management regime securing high and constant wood production (Meyer and Schmidt, 2011). This has resulted in a significant shortage of deadwood which provides habitat to a rich and functionally diverse fauna of organisms (Köhler, 2000; Lemperiere and Marage, 2010; Londsdale et al., 2008). Deadwood has become widely scattered in forests due to different small scale management practices (Bobiec, 2002; Brunet et al., 2010; Schroeder et al., 2007) which has thus created a mosaic of areas varying greatly in deadwood amounts, from 1 to 10 m^3 per hectare in intensively managed stands (Müller and Bütler, 2010) to 60 and more cubic metres in more naturally managed forests (Brunet et al., 2010). Tree crowns appear to be especially affected. They receive special management attention as crown size crucially influences wood production and deadwood diminishes wood quality (Stark and Schmidt, 2008). Little is known, however, about how the lack of deadwood affects arboreal arthropods which occur in large numbers and in high diversity in the trees (Floren, 2008; Southwood et al., 2004). In our research we focus on beetles for which comprehensive ecological information is available allowing

* Corresponding author. Tel.: +49 (0)931 31 84376; fax: +49 (0)931 31 84352.
E-mail addresses: floren@biozentrum.uni-wuerzburg.de (A. Floren), Tobias.Mueller@biozentrum.uni-wuerzburg.de (T. Müller), marcus.dittrich@biozentrum.uni-wuerzburg.de (M. Dittrich), mattweis@t-online.de (M. Weiss), ke_lins@biozentrum.uni-wuerzburg.de (K.E. Linsenmair).

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an in-depth analysis of the factors determining their distribution and their functional relevance in ecosystems.

In order to directly measure the effects of deadwood on beetle assemblages we established a large field experiment in which we enriched large amounts of freshly cut deadwood in the canopy and on the ground beneath beech (*Fagus sylvatica* L.) and spruce trees (*Picea abies* L. Karst) in forest stands subjected to different management practices (Fig. S1). We installed Flight Interception Traps (FITs) next to the dead wood to collect the arthropods every month during the season. Here, we analyse how these assemblages react to the factors ''tree species'', ''vertical stratum'' and ''wood diameter class''. We also test whether low diverse and structurally uniform age-class forests can be distinguished from structurally more complex extensively managed forests.

The main objectives of this project are to answer the following questions: (1) To what extent do beetle assemblages, and saproxylic beetles in particular, differ between beech and spruce trees? As deciduous and coniferous trees differ most strongly in secondary compounds (Lassauce et al., 2012; Wagner et al., 2002) we expect beetle faunas to separate most clearly from one another. (2) Do assemblages show species and guild differences between the canopy and the lower vegetation? The extent of vertical stratification is still a focus of major debate (Bouget et al., 2011; Vodka and Cizek, 2013). Assemblages are expected to be more diverse near the ground due to a larger diversity of plants and more constant microclimatic conditions compared to the canopy (Unterseher and Tal, 2006; Vodka et al., 2009). (3) We also investigate whether deadwood diameter class contributes to species diversity as several studies reported (Brin et al., 2011; Lassauce et al., 2012; Lemperiere and Marage, 2010). (4) We expect that differences in local species pools in age-class forest and extensively managed forests impact species diversity and guild composition of the saproxylic beetle assemblages because their resource availability largely depends on management type.

2. Material and methods

2.1. Study area and sites

The study area is located in the biosphere reserve ''Schwäbische Alb'' in south-western Germany covering 85.000 ha. It has been selected within the frame of a large-scale and long-term research program, the 'Biodiversity Exploratories' (Fischer, 2010). Altitudes vary between 600 and 1000 m above sea level, annual precipitation lies between 800 and 1000 mm and the average temperature is between 6 and 8 °C. The landscape consists of a small-scale mosaic of grasslands and forests with beech (*F. sylvatica*) and spruce (*P. abies*) dominating. While *Fagus* occurs naturally in the area the non-native spruce trees were planted for economic reasons. Within this landscape eight forests were selected which were separated by maximum 20 km of open land or other forests. From each forest plot two conspecific trees of the dominating tree species, either two beeches or two spruces, were chosen for the deadwood enrichment experiment.

In order to identify possible management effects on the beetle fauna we distinguish conifer age-class forests (three forest stands), beech age-class forests (three forest stands) and extensively managed beech forests (two forest stands). Age-class and extensively managed forests varied greatly in the manner of forest stand cultivation which affects structural complexity and as hypothesised also the diversity of associated arthropods. Age-class forests, both for beech and spruce, are characterised by uniform tree species composition, forest structure and site conditions. In these even-aged forests, trees are usually about the same height with a single canopy layer. Forests are managed for efficient timber extraction which is carried out as clear cut of smaller or larger forest parts. In contrast, individual trees or small groups of trees are removed in extensively managed forests without further invasive management activities in order to restore structurally more complex beech stands (Brunet et al., 2010). Annual application of the single tree selection method should regenerate a forest with an all-aged stand structure (Wittwer et al., 2004).

2.2. The deadwood enrichment experiment

Freshly cut wood of beech and spruce in pieces of 1 m length were installed in the canopy of each tree with the help of a lifting platform early in February 2009 (Fig. 1). All wood was cut during the same felling operation in February 2009 in order to minimize variation in wood quality. The two study trees on each research plot were growing 50–150 m apart from each other. Three different sizes of deadwood (diameters 1–5 cm, 6–10 cm, 11–20 cm) were used for the experimental set up. The deadwood was held together with wire mesh and was fixed at the trunk with steel rope. Smallest size of deadwood was always placed in 22 m height, medium sized wood in 18 m and the largest wood diameter class in 16 m. Installation height was limited by the range of the lifting platform. Each size of deadwood contained about 0.2 m^3 so that the total amount was 0.6 m^3 per tree. In addition, three stacks of cut wood (each 1 m^3) of the same three sizes were piled up on the ground beneath one of the two study trees while the other was growing in short distance. Larger volumes of deadwood were used on the ground due to logistical reasons and to prevent vegetation from quickly overgrowing the wood. For reasons of comparability we also wanted to use the same type of FITs as those in the canopy. We used rarefaction statistics to directly compare samples in the canopy and near the ground. FITs were installed next to each deadwood bundle resulting in a total of nine samples per research plot. A collecting jar was mounted at the bottom of each FIT and filled with a 1.5% cupric-sulphate solution acting as a killing and conserving liquid. All traps were installed in March 2009 and emptied monthly from April to the end of September. The number of samples differs between studied plots due to losses of samples by either technical problems or vandalism. From all eight study areas 294 samples were collected representing 89% of the maximum 330 samples.

2.3. Sorting and identification of arthropods

Beetles were separated from all FIT samples in the lab and identified to the species level by specialists. Guild assortment followed (Köhler, 2000) distinguishing zoophages, xylophages and mycetophages. Species indexed on the 'Red-list of endangered species in Germany' were identified following (Geiser, 1998). Voucher specimens are stored in the collection of the first author.

2.4. Statistical analysis

All statistical analyses were performed in R (R Development Core Team 2011) using the packages 'vegan' (Oksanen, 2011), 'ade4' (Chessel and Dufour, 2012) and 'labdsv' (Roberts, 2013). The saproxylic beetles of all traps were summed for the analysis over all months. Similarity of beetle assemblages was analysed by canonical correspondence analysis (CCA) aiming at identifying the significance of the recorded environmental variables tree species, stratum, wood diameter class and forest management. Alpha diversity was calculated as exp. Shannon diversity which calculates an 'effective number of species' (Jost, 2006). Rarefaction statistics (sample- and individual based) were computed to allow direct comparison of diversity between unevenly sampled species pools.