Biological Conservation 228 (2018) 70–78

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Deadwood enrichment combining integrative and segregative conservation elements enhances biodiversity of multiple taxa in managed forests

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ARTICLE INFO

Keywords:
Beech forest
Canopy cover
Deadwood
Integrative conservation
Multidiversity
Saproxylic species

ABSTRACT

Integrative management strategies that simultaneously aim for wood production and biodiversity conservation are considered crucial to protect biodiversity of forest species outside protected areas. In this study, we evaluated whether deadwood enrichment as an integrative strategy at a scale of 17,000 ha resulted in enhanced biodiversity of saproxylic and non-saproxylic taxa eight years after the implementation of the strategy. The strategy included active deadwood enrichment with harvest remnants, retention of deadwood, and nature forest reserves areas. The analysis was based on data on the occurrence of plants, fungi, beetles, true bugs and birds from directly before and after the implementation of the strategy. The implementation of the strategy resulted in an increase in the deadwood amount by an average of 90 ± 40 $m^3\,ha^{-1}$ (mean ± SE) over this period. While deadwood amounts doubled in production forests (+90%), they increased even more in nature forest reserves (+160%). Multidiversity (species density of all taxa) increased with an increase in deadwood amount; this was a result of an increase in the multidiversity of saproxylic species as the non-saproxylic multidiversity did not respond. Among single taxon groups, fungal and beetle species density responded positively to the increase in deadwood amount, especially when only saproxylic species were analysed. Importantly, this effect was not only found in the nature forest reserves, but also in the production forests. We thus conclude that active deadwood enrichment in production forests and nature forest reserves is a promising tool to rapidly promote the protection of forest biodiversity.

1. Introduction

Millennia of human activity have affected temperate forests in Europe and altered their structure considerably to optimize forests for timber production (Parviainen, 2005). During and after the Middle Ages the forest cover decreased strongly in Germany. The introduction of a sustainable silviculture in the middle of the 18th century stopped the deforestation (Röhrig et al., 2006). As part of this management, the extent of forests has increased but natural broadleaf tree species were largely replaced by conifers to promote timber production (Spielmann et al., 2013). The structure of the remaining broadleaf forests has been strongly altered and particularly the amounts of deadwood were reduced to, on average, < 10% of natural amounts (Müller and Bütler, 2010). Additionally, forests have become denser and darker due to an increasing growing stock (Schelhaas et al., 2003). Owing to these structural changes, managed forests across Europe harbour, in general, a lower biodiversity, especially of deadwood dependent species, compared to old-growth forests, or forests set aside for conservation, but with differences among taxa (Chumak et al., 2005; Paillet et al., 2010). The reduced availability of certain habitats, such as large-diameter deadwood and open forest habitats, has caused a decline in populations of species associated with these habitats and thus many of them are today classified as threatened (Berg et al., 1994; Nieto and Alexander, 2010; Seibold et al., 2015b).

One strategy to protect biodiversity of forest species is the establishment of forest reserves without timber production that develop according to natural forest dynamics (Bollmann and Braunisch, 2013). Such reserves can benefit a variety of species (Paillet et al., 2010), particularly species requiring high amounts of deadwood (Bässler and Müller, 2010). The protection of species exclusively in reserves has, however, been questioned because protected areas comprise only a small fraction of the overall forest area, and are usually small and

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https://doi.org/10.1016/j.biocon.2018.10.013
Received 19 November 2017; Received in revised form 27 September 2018; Accepted 8 October 2018

embedded in a matrix of production forests or non-forest habitats and are thus poorly connected (Abrego et al., 2015). Additionally, the development of old-growth features is a slow process if reserves are established in former production forests (Christensen et al., 2005; Paillet et al., 2015). The protection of species that depend on features such as deadwood may thus not be guaranteed in these reserves as populations may disappear before the required habitat structures are established by natural processes (Gossner et al., 2014; Müller et al., 2005). In contrast, with active deadwood management the deadwood amounts can increase even over short time periods (Doerfler et al., 2017). Therefore, conservation need not be restricted to forest reserves but should also include production forests (Gossner et al., 2013a; Seibold et al., 2017).

Integrative forest management strategies that include both biodiversity conservation and timber production aim to create and retain structures such as deadwood or canopy gaps known to benefit biodiversity (e.g. Bauhus et al., 2009; Fedrowitz et al., 2014). When pursued in large parts of the production forest matrix, these measures are thought to increase total habitat amount and thus population sizes of many species (Mason and Zapponi, 2016; Seibold et al., 2017).

In temperate European production forests, one of the most important components of such integrative strategies is the creation and retention of deadwood during regular management operations. In Germany, this strategy is increasingly applied and supported by governmental incentives. For example, the Bavarian State Forest Company, which manages 30% of the Bavarian forest (Bundeswaldinventur, 2012), has successfully applied this strategy in the northern Steigerwald forest since 2006. This resulted in a significant increase in deadwood amounts at the landscape scale (Doerfler et al., 2017). This particular strategy includes the intentional retention of tree crowns and parts of trunks after harvests, and preserving existing, naturally developed deadwood. These measures are complemented by the protection of small reserves (30–180 ha) that were created in the 1980s where deadwood naturally accumulates.

The active creation of deadwood has been shown to promote the diversity of saproxylic, i.e., obligatorily dead-wood dependent, taxa (Gossner et al., 2013b; Jonsell et al., 2004; Lassauce et al., 2011; Seibold et al., 2015a) and it is similarly effective in stands with previously low and high deadwood amounts, at least for saproxylic beetles (Seibold et al., 2017). The creation of deadwood, however, may also affect non-target organisms, i.e. taxa not obligatorily dependent on deadwood. Non-saproxylic taxa have been shown to respond positively but also negatively to experimental deadwood enrichment (Seibold et al., 2015a). For example, birds have been repeatedly shown to profit from an active creation of standing deadwood stems (snags) that are used as breeding sites or for foraging (e.g. Brandeis et al., 2002; Kroll et al., 2012). The effect of deadwood enrichment on plants is rarely studied. However, it was shown that for single species, such as *Gymnocarpium dryopteris* (L.) *Newman* or *Lycopodium annotinum* (L.), deadwood can be an important habitat, especially in old growth mountain forests (Dittrich et al., 2014) as deadwood for example facilitates the growth of tree seedlings (Zielonka and Niklasson, 2001). Some species groups however profit from deadwood removal during post-disturbance salvage logging (Thorn et al., 2018). These are commonly associated with open habitats including a number of spiders and carabid beetles (Thorn et al., 2018).

Therefore, the response of species to deadwood development in forests can also be linked to changes in abiotic conditions mediated by changes in the canopy, because the death of a tree usually leaves a gap in the canopy. Non-saproxylic taxa, such as plants, are positively influenced by creation of canopy gaps because of increased light availability (Beudert et al., 2015). For saproxylic taxa, increased light availability may also have an effect as it increases the exposure of deadwood to sunlight. Sun-exposed deadwood promotes, for instance, a higher diversity of saproxylic beetles, as well as different beetle communities than deadwood under shady conditions (Gossner et al., 2016; Lindhe et al., 2005; Seibold et al., 2016). Additionally, fungal richness might increase with deadwood enrichment combined with sun exposure (Brazee et al., 2014). However, sun exposure can also have negative effects, e.g., on species numbers of saproxylic fungi (Bässler et al., 2010). Since management can influence the size and dynamic of canopy gaps (Boncina, 2000), it is important to consider potential effects of the canopy openness when evaluating deadwood enrichment.

Existing evaluations of deadwood enrichment strategies in temperate European forests are mostly based on experimental treatments (Seibold et al., 2015a). The drawback of experiments is that they are often implemented on a small spatial scale and that their documentation often focuses on single taxonomic groups. The evaluation of the success of deadwood enrichment for increasing biodiversity on a landscape scale is still lacking. In this paper, we evaluate the effects of an integrative forest management strategy, applied by the Bavarian State Forest Company (BaySF, 2016), that aims at increasing deadwood amounts to support biodiversity. The strategy is implemented by active deadwood enrichment with harvest remnants and the passive retention of deadwood combined with nature forest reserves as segregative element. Based on an assessment of deadwood enrichment before and after the implementation of the strategy (Doerfler et al., 2017), we measured changes in diversity of five taxonomic groups, i.e. plants, true bugs, birds, beetles and fungi, that span a range of trophic levels and differ in their association with deadwood. These measurements were taken on 68 plots directly before and eight years after the implementation of the strategy. We tested the following hypotheses:

(i) Deadwood enrichment promotes overall biodiversity
(ii) Responses are most pronounced in saproxylic taxa, but neutral or even negative for non-saproxylic taxa
(iii) Canopy openness promotes saproxylic and non-saproxylic biodiversity.

2. Methods

2.1. Study area and conservation strategy

The study area is part of the northern ‘Steigerwald’ in southern Germany (Bavaria) (N 49° 50′ 53 E 10° 29′ 41). Elevation ranges from 300 to 450 m, mean annual temperature is 8.2 °C and mean annual rainfall is about 850 mm (Lischeid, 2001). The study was conducted in the forestry department Ebrach (17,000 ha), which belongs to the Bavarian State Forest Company. The managed area covers 16,494.2 ha (97% of the total forestry department). The remaining area (3%) is designated as six forest nature reserves, in which all management activities have stopped. The two first reserves were established in 1978, followed by two more reserves in both 1998 and 2010. Today, the sizes of the reserves range from 28 to 183.4 ha, due to extensions of the areas of the oldest reserves.

The main harvesting practice in this department is shelterwood cutting and single tree harvests. In 2006, the forest management was reformed with two major components: abandonment of clear-felling and a focus on tree species native to Germany: European Beech (*Fagus sylvatica* L.), Sessile oak (*Quercus petraea* (Mattuschka) Liebl.), Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) H.Karst.). Additionally, a conservation strategy was implemented that aims to increase deadwood amount to 20 $m^3 ha^{-1}$ in broadleaf stands older than 100 years, and 40 $m^3 ha^{-1}$ in broadleaf stands older than 140 years (Doerfler et al., 2017). These goals are pursued by an active enrichment via retention of harvest remnants including logs, snags, branches and stumps (without the definition of a minimum diameter) and by passive enrichment, i.e., naturally developed deadwood, such as snags or windblown trees, are retained. For the active enrichment, a strong focus is on the preservation of crowns as harvest remnants, wherefore felled stems are cut at the first strong branch (~ > 15 cm diameter) and the upper part, including the stem and branches remains in the forest. Additionally, the lower part of the stem remains in the