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# Retention forestry and prescribed burning result in functionally different saproxylic beetle assemblages than clear-cutting

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ABSTRACT

In fire-susceptible boreal forests, clear-cutting has been justified as being a harvesting regime that mimics natural stand-replacing dynamics, despite obvious differences in its biological legacies. Prescribed burning and retention forestry are commonly applied to better maintain naturally occurring legacies, but the community-level effects of different disturbances on the functional characteristics of biota remains still largely unknown. In this study, we investigated the effects of prescribed fire, clear-cutting and retention forestry on the functional properties of saproxylic beetle assemblages in Eastern Finland, using stand-level data from a before-after field experiment with four levels of tree retention (0, 10 and 50 $m^3$ $ha^{-1}$ and control) and prescribed burning. We analyzed the functional-phylogenetic diversity and a set of species traits that link species to resources. The data include 377 beetle species and 38 549 individuals. Functional-phylogenetic diversity decreased from a random to a clustered pattern after burning and logging with retention trees, indicating environmental filtering of both processes. These effects became more pronounced with increasing logging intensity. Species-level traits that were favored by burning and tree retention were connected to open-habitat conditions and fresh dead wood, whereas clear-cutting revealed a random pattern without reference to specific resources. Our functional approach thus shows that clear-cutting does not mimic the dynamics of wildfire, but leads to different functional composition of species assemblages. Therefore, prescribed burning or wildfire should be incorporated and sufficient amount of trees retained in forest management to conserve functional processes and natural composition of saproxylic species assemblages in boreal forests.



## 1. Introduction

Since the early-1900s, prevention of natural disturbances in forests has been efficient in many regions, and clear-cut harvesting has become the dominant stand-replacing forest disturbance. Although some authors have proposed clear-cutting as a harvesting system that closely mimics natural dynamics, particularly in boreal forests with fire-dominated, stand-replacing dynamics (Parviainen and Seppänen, 1994; Mielikäinen and Hynynen, 2003), several studies have documented major differences in biological legacies, e.g. dead trees, between natural stand-replacing disturbances and clear-cutting (e.g. Franklin et al., 2000; Kouki et al., 2001; Swanson et al., 2011). The loss and fragmentation of such biological legacies due to large-scale application of clear-cutting with accompanied planting or seeding, pre-commercial thinning and removal of damaged and dead trees in managed forests (Kouki et al., 2001; Swanson et al., 2011) have been identified as serious threats to biodiversity (Tikkanen et al., 2006; Rassi et al., 2010; Stokland et al., 2012; Anonymous, 2015). Moreover, biodiversity loss may seriously alter ecosystem functioning, in turn having profound consequences on critical ecosystem processes, such as decomposition rates of woody biomass or carbon and nutrient cycling (Hooper et al., 2012; Tilman et al., 2014).

To counter these negative impacts, forest management has begun to adopt new techniques that are believed to complement rare habitat types and support threatened species, such as prescribed burning and green-tree retention. Burning supports species associated with charred or dead wood and early-successional habitats (e.g. Hyvärinen et al., 2009; Johnson et al., 2014), while green-tree retention – commonly known as retention forestry – has been

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developed as a universal concept of mitigation and has been proposed as a means to sustain continuities of ecosystem structures, functioning, and species composition in post-harvest forests (Franklin et al., 1997; Gustafsson et al., 2012; Lindenmayer et al., 2012; Fedrowitz et al., 2014). Prescribed burning and retention forestry target particularly the conservation of saproxylic species, i.e., species directly or indirectly dependent on dead or dying wood, as both methods directly (fire) or indirectly (retention forestry) contribute to the amount and continuity of large-sized dying and dead wood (Heikkala et al., 2014). Positive effects of prescribed burning have been shown for pyrophilous and saproxylic species if the amount of burned wood is sufficiently high (e.g. Wikars, 1997). The potential positive effects of retention trees for saproxylic species include, e.g., maintaining the quality of coarse woody debris through a sheltering effect against extreme wind, sunlight, temperature and moisture variation (e.g. Barnes et al., 1997); increasing dead wood by wind-caused falls and deaths of retention trees (Hautala and Vanha-Majamaa, 2006; Heikkala et al., 2014); and by allowing retention trees to become old and senescent (Hautala et al., 2004; Widerberg et al., 2012). Moreover, both fire and harvesting modify habitat conditions and the quality of dead wood regarding, e.g., sun-exposure or decay stage, and thus affect the available niche space for saproxylic species (Azeria et al., 2012; Mouillot et al., 2013).

Among saproxylic taxa, beetles comprise a large portion of biodiversity and contribute significantly to ecosystem functioning through the decomposition of wood (Schowalter, 1992; Angers et al., 2012; Jacobs and Work, 2012; Ulyshen, 2014) and thus by promoting post-disturbance recovery of vegetation (Cobb et al., 2010). However, due to the shortage of dead wood in Fennoscandian managed, clear-cut originated forests, hundreds of beetle species are threatened today (Rassi et al., 2010; Anonymous, 2015). Earlier research on saproxylic organisms and beetles in particular have demonstrated strong impacts of prescribed burning, clear-cutting and retention forestry on their richness and species-specific abundances (e.g. Hyvärinen et al., 2005; Saint-Germain et al., 2005; Boucher et al., 2012). These analyses have revealed higher abundance of threatened and pyrophilous species at stands subject to prescribed burning or retention forestry than at clear-cut stands (Hyvärinen et al., 2006b). Furthermore, community analyses, based on species occurrences, have indicated that these differences may be accompanied by changes in the assemblage composition (Saint-Germain et al., 2004; Hyvärinen et al., 2005; Cobb et al., 2011). While these sorts of evaluations coarsely reveal treatment-caused assemblage shifts, they do not directly provide information on the driving mechanisms behind these changes. Such information can be obtained, however, through an approach that links species traits to forestry-caused structural changes in forests. These sorts of approaches are rapidly gaining appreciation in conservation where the paradigm is shifting from focusing on single rare species to complete communities (Devictor et al., 2010; Cadotte et al., 2011). To meet this claim for forest conservation, it is crucial to understand how forest management strategies affect the functional structure of species assemblages (Gossner et al., 2013; Bässler et al., 2014; Seibold et al., 2015).

In the present paper we apply a functional-phylogenetic approach (Cadotte et al., 2013) based on two biological traits and four traits that describe required resources to evaluate effects of fire and logging on the functional composition of saproxylic beetle assemblages. While we acknowledge that not all traits studied here are functional, they nevertheless link species to the impacts of forestry on habitat conditions, particularly related to dead wood and microclimate (Gossner et al., 2013; Thorn et al., 2014; Seibold et al., 2015). Our data originate from a large-scale, replicated field experiment conducted in the boreal zone of Eastern Finland. The experiment represents a stand-level, before-after-control-impact design with prescribed fire and four levels of harvesting intensity, including clear-cutting, two levels of tree retention and an unlogged control.

We expected that prescribed fire and logging would cause environmental filtering by selecting specific traits that allow to cope with habitat conditions resulting from treatments and thus lead to a reduction in the total trait diversity of the local community (Azeria et al., 2012; Mouillot et al., 2013). Specifically, we put forward the following hypotheses regarding single traits. Prescribed burning should favor species that (1) require large pieces of dead wood objects and (2) are large bodied, as fire produces vast quantities of large snags and logs (Siitonen, 2001) and large species cannot occupy very small pieces of wood. With increasing harvesting intensity, we predicted a decrease in species that (3) require large dead-wood objects and (4) are large, as their required resources are removed and small-sized logging residues are produced in harvesting operations (Hautala et al., 2004). Moreover, increasing logging intensity should favor species that benefit from (5) well-illuminated conditions and (6) the logging-caused increase in the diversity of flowering plants (Jalonen and Vanha-Majamaa, 2001; Pykälä, 2004; Johnson et al., 2014). Finally, (7) specialists that reproduce on fresh dead wood and other substrates that are formed in fires and logging operations should increase with prescribed burning and increasing logging intensity (e.g. Moretti et al., 2010).

## 2. Methods

### 2.1. Study area and experimental design

The study area was located in the municipalities of Lieksa and Ilomantsi in Eastern Finland (63°10′N, 30°40′E), in the southern part of the middle-boreal vegetation zone (Ahti et al., 1968). A total of 24 stands, each 3–5 ha, were randomly assigned to an area of 20 km × 30 km (Appendix A, Fig. A1). These stands were Scots pine (*Pinus sylvestris* L.) dominated forests with dominant canopy trees being approximately 150 years old, and had not been subject to intensive forestry previously. Pre-treatment conditions of the stands are described in Hyvärinen et al. (2005).

The experiment was set up as a two-factorial design, combining prescribed burning and four levels of harvesting; clear-cutting, 10 and 50 $m^3$ $ha^{-1}$ retention, and unharvested control, and followed the before-after-control-impact (BACI) principle (Green, 1979). Each harvesting treatment was replicated six times and half of them were subsequently burned. The stands were harvested during the winter of 2000/2001 and burning was conducted during two consecutive days in late June 2001; for details, see Hyvärinen et al. (2005). Retained trees were mostly left in circular groups of 15–30 m in diameter. The retention level of 10 $m^3$ $ha^{-1}$ was chosen so as to be comparable (albeit slightly higher) with current guidelines and industry-certification regulations in Fennoscandia. The higher retention level, 50 $m^3$ $ha^{-1}$, was chosen so as to roughly correspond with the dead-wood volume that can maintain the diversity of saproxylic beetles in mature forests (Martikainen et al., 2000).

### 2.2. Beetle sampling

We sampled beetle communities in the years 2000 and 2002, i.e., one year before and one year after the treatments. As we were interested in beetle assemblages at the stand level, we used flight-interception traps that efficiently reflect beetle diversity at the stand level (Wikars et al., 2005; Hyvärinen et al., 2006a; Sverdrup-Thygeson and Birkemoe, 2009). We used a total of 240 traps (ten per stand) in each study year from mid-May to early