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Effects of forest restoration by fire on polypores depend strongly on time since disturbance – A case study from Finland based on a 23-year monitoring period

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ABSTRACT

Fire is increasingly used in management and restoration of forest ecosystems, in order to rehabilitate habitat structure and to create habitats for species dependent on forest fires and dead wood. However, information on the impacts of fire on saproxylic species is scanty, and long-term studies on the effects are almost totally lacking. Here we present results from a long-term field study conducted in eastern Finland in 1988–2011. Two pine-dominated boreal forest stands, a seminatural and a managed one, were intentionally burnt in 1989. We inventoried polypores 1 year before the fire, in the year of burning, and 1, 2, 6, 13 and 22 years after the fire. The short-term effects of fire were destructive for polypore communities. However, species numbers recovered to the pre-fire level 6 years after the fire. After 13 years, the number of species was clearly higher than before the fire, due to the large input of fire-killed dead trees. The number of red-listed species was strikingly high (18 species) in the seminatural stand 13 years after the fire including several species which have earlier been considered as old-growth forest indicators, and remained at high level (17 species) still 22 years after the fire. The number of red-listed species was much lower in the formerly managed stand (6 and 8 species, respectively). We conclude that burning of stands can be a very effective method to create habitats for red-listed polypore species, at least if the stand is located close to high-quality source areas and contains a sufficient amount of large-diameter trunks of different tree species.

1. Introduction

Fire is one of the most important disturbance factors in boreal forests under natural conditions. Wildfires create landscape mosaics consisting of stands at different successional stages, affect stand structure and dynamics, and produce large amounts of dead wood by causing tree mortality (Johnson et al., 1998; Jonsson and Siitonen, 2012; Niklasson and Granström, 2000; Shorohova et al., 2009). A large group of organisms in boreal forests, mainly consisting of invertebrates and fungi, are dependent on or favored by fire (Dahlberg, 2002; Saint-Germain et al., 2004; Wikars, 1992). These so-called pyrophilous species occur mainly in recently burnt sites and at site types where natural fire frequency is the highest such as dry pine forests. Studies on the effects of fire on post-fire fungal succession have concentrated on ground-dwelling fungi (Horikoshi et al., 1986; Moser, 1949; Petersen, 1970; Vásquez Gassibe et al., 2011; Zak and Wicklow, 1980). According to these studies, there are several strictly fire-dependent species, especially in Ascomycetes, which usually emerge very soon after fire. Most fire-dependent macrofungi seem to be soil and litter saprophytes. For example, in Sweden a total of 40 macrofungal species have been reported as fire-dependent, and of these 32 are soil and litter saprophytes (Dahlberg, 2002).

During the last century, modern forestry and other land-use forms coupled with efficient fire suppression have replaced fire as the main disturbance factor in large regions in the boreal and temperate zones. This change from natural to human-caused disturbance dynamics has greatly affected forest composition and structure and, consequently, also biodiversity. In some regions, numerous organisms dependent on fire have declined and become threatened because of lack of fires (Kouki et al., 2012; Wikars, 2001). For instance, reduction of burnt forest areas (including other young stages of natural succession) has been identified as the main cause of threat to eight regionally extinct and 68 threatened species in Finland (Rassi et al., 2010). In other regions, such as in several types of coniferous and mixed forests in North America,

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the fire regime has shifted to the other direction, so that fires are less frequent but larger and more intensive than in the past (Allen et al., 2002; Fulé et al., 2012). The altered fire regime may have severe negative effects on biodiversity (Driscoll et al., 2010). A general, widely applicable objective of fire management is to avoid population extinctions within a defined management area due to the effect of an adverse fire regime. Prescribed burning can be used to reduce fire loads and risk of uncontrolled wildfires, but also to restore habitats for fire-dependent and dead-wood inhabiting species.

Polypores are principle decomposers of dead wood in boreal and temperate forests (Boddy, 2001). Besides providing the basic ecosystem services, wood decomposition and nutrient cycling, they provide habitats for many other saproxylic forest species (Siitonen, 2012; Stokland and Siitonen, 2012). Many polypore species have declined owing to intensive forest management which has caused loss of old-growth forests and reduced the amounts of decaying wood (Lonsdale et al., 2008; Junninen and Komonen, 2011a).

Several recent studies have explored the effects of wildfire or prescribed burning on wood-inhabiting species, including saproxylic beetles (Hyvärinen et al., 2009; Saint-Germain et al., 2004; Toivanen and Kotiaho, 2007a) and wood-decaying fungi (Junninen et al., 2008; Olsson and Jonsson, 2010; Penttilä and Kotiranta, 1996). However, all these studies have only followed the short-term effects (1–5 years) of fire on species assemblages. According to these studies, the short-term effects on saproxylic beetles are generally positive, i.e. burnt sites have higher species richness and higher numbers of rare and red-listed species, whereas the short-term effects on wood-decomposing fungi appear to be negative. The only studies in which the more long-term (29 and 16 years, respectively) changes in saproxylic beetle assemblages were investigated are not experimental follow-up studies but retrospective chronosequence studies (Boulanger and Sirois, 2007; Toivanen and Kotiaho, 2007b). Knowledge on the long-term effects of fire on wood-decaying fungi seems to be almost totally lacking. A recent study by Kurth et al. (2013) explored long-term changes in communities of wood-inhabiting fungi in a 32-year chronosequence study based on wood samples and molecular identification of fungi. However, there were very few polypores and other species belonging to Basidiomycota in the species assemblages they found.

The aim of this study was to describe both the short-term effects of fire on wood-decaying fungi, and the long-term (>20 years) changes in species composition, and particularly in the occurrence of red-listed species. In addition, the aim was to explore how the amount and quality of dead wood affect the post-fire fungal succession.

2. Materials and methods

2.1. Study area and study sites

The study area is situated in Patvinsuo National Park in eastern Finland close to the Russian border. The area lies in the middle boreal zone, just next to the border between southern and middle boreal zones. Climate in the area is slightly continental. The extent of the national park is about 100 km^2 and it is characterized by large peatlands and pine-dominated forests. Before the park was established in 1982, part of the area had been managed for forestry purposes. Consequently, at the moment 48% of the forests in the park are young or middle-aged, previously managed stands, but there are also large tracts of old-growth forests within the park.

Two separate forest stands were used in the study. The first stand was close to natural state, the other one had been previously managed. Hereafter we refer to these stands as "seminatural" and "managed". Both were small (about 1 ha), pine-dominated (*Pinus sylvestris*) forest islands surrounded by open peatlands and located about 200 m from the closest edge of a larger old-growth forest and 4 km from each other. Both stands were burnt in 1989. To our knowledge, this was the first time when standing forest was burnt for restoration purposes in Europe.

In the seminatural stand, only some medium-sized pines had been selectively cut several decades before the fire. Most of the dominating pines were about 100 years old, but there were also dozens of large, 200- to 300-year-old pine individuals. Norway spruce (*Picea abies*) and birches (*Betula pubescens, B. pendula*) occurred as admixed tree species. Before the fire, the total volume of living trees was about 200 m^3/ha and the volume of dead trees about 40 m^3/ha. Most dead trees were large fallen pines and spruces, with some fallen birches and some large, dead standing pines.

The managed stand had been logged before the national park was established, and the dominant pines were 40 years old. Some old, living pines had been left as seed trees in the logging. A few large birches and groups of small-diameter grey alders (*Alnus incana*) occurred as admixed tree species. Before the fire, the total volume of living trees was about 75 m^3/ha and the volume of dead trees 10 m^3/ha. The volume of dead wood was mainly composed of a few large fallen pines.

Burning of the stands took place on the 26–27th June in 1989. In both stands, the ground layer burnt almost completely, except for a few patches that remained unburnt in the seminatural stand.

Almost all living spruces and birches and most of the living pines were killed by the fire. The survival probability of pines increased with tree diameter and was > 50% in trees that were over 20 cm in diameter, and > 80% in trees that were over 30 cm in diameter (Kolström and Kellomäki, 1993). Of the pre-fire dead wood, most of the barkless pine snags burnt from the base and fell. Most lying trees burnt strongly (seminatural stand) or very strongly (managed stand). Fallen pines and spruces burnt more strongly than birches.

2.2. Inventory of polypores

Polypores were surveyed in both stands one year before the fire (in 1988), in the year of burning, and 1, 2, 6, 13 and 22 years (in 2011) after the fire. The inventories were carried out during September–October when the detection probability of annual species is at its largest. In every inventory, all dead and living trees with a minimum diameter of 5 cm within the whole stands were checked for polypore fruiting bodies. One or several fruiting bodies of a species per one substrate unit (or several units originating from the same tree) were counted as one record. Abundance of each species in each inventory was the sum of its records. Dead perennial fruiting bodies were excluded from the data and further analyses. The nomenclature of polypores follows Kotiranta et al. (2009) and the classification of red-listed species Kotiranta et al. (2010).

In every inventory, all trees with polypore fruiting bodies were measured. The host-tree variables included tree species, diameter, length of pieces of trees, decay stage (five classes after Renvall 1995) and degree of burn (six classes according to Penttilä and Kotiranta 1996). In 2002 and 2011 (13 and 22 years after the fire) also 'empty' trees without any polypore fruiting bodies were recorded and measured, to enable calculation of total dead-wood volume. In the pooled data of 2002 and 2011, the total numbers of inventoried substrate units were 2283 in the seminatural stand and 2129 in the managed stand. The diameter distribution of entire dead trees differed between the two stands, so that the proportion of large-diameter trees was higher in the seminatural than in the managed stand (Fig. 1).