Effects of Management and Restoration on Forest Biodiversity: An Experimental Approach

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Abstract

To conserve biodiversity of boreal forests, many management and restoration actions have been undertaken during the last decades. However, research based knowledge about the impacts of the currently used practices are yet largely unavailable. Here we introduce two large scale experiments on the impacts of forest management and restoration on biodiversity of boreal forests. In the first experiment we concentrate on the effects of prescribed burning on species richness of two species groups, which are known to be largely dependent on the amount and quality of decaying wood: saproxylic beetles and polypore fungi. In the second experiment, we study the immediate surroundings of small forest brooks, which are defined as valuable habitats in the Finnish Forest Act. Our aim is to determine the effect of silvicultural practices conducted at the valuable habitats or in the vicinity of them on long term persistence of the special characteristics of these habitats. Our preliminary results indicate that preserving the characteristic features of valuable brook habitats will help to preserve the overall species richness of boreal forests.

Keywords: Boreal forest; prescribed burning; restoration; species richness; valuable habitat.

Introduction

Background

Conservation and economical utilization of natural resources forms a confrontation between the two, in which promotion of one unavoidably compromises the other. Last few decades have shown that excessive unsustainable utilization of natural resources causes extinctions and impoverishment of biodiversity (Meffe and Carroll 1997; Hanski 2000; Hanski and

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Ovaskainen 2002; Benton et al. 2003; Fahrig 2003). To conserve biodiversity, some practical actions have been undertaken, but research based knowledge about the impacts of the currently used management and restoration practices are still largely unavailable (Meffe and Carroll 1997; Noss 1999; Simberloff 1999; Yoccoz et al. 2001). Nevertheless, the best guarantee for successful sustainable management, restoration practises and conservation of biodiversity is to have scientific information based on controlled and replicated experimental research (Simberloff 1999).

Our research is based on controlled experiments comparing results in replicated treatments. We concentrate on two major issues of conservation of forest biodiversity. First, we study the effects of prescribed burning on species richness and the role of the amount and quality of decaying wood in preserving high species diversity. In these experiments, we study the species richness and abundance of beetles and polyporal fungi. Second, we study the importance of so called valuable habitats (see below) in conserving forest biodiversity and the effects of some silvicultural practices on the survival of species richness of these habitats. In these experiments, we study the species richness and abundance of vascular plants, mosses, polyporal fungi and polypore dwelling beetles. All our studies are conducted in the boreal coniferous forest zone in Finland.

The role of forest fire in conserving biodiversity

Forest fires are one of the most important disturbances of unmanaged boreal coniferous forests (Zackrisson 1977; Granström 1993; Zackrisson et al. 1996). Natural forest fires are effective in remoulding the age structure of the trees, increasing the proportion of deciduous trees, particularly birch and aspen (Wikars 1992), and they have an effect on soil decomposing and nutrient release (Wein 1983; Granström and Schimmel 1993; Zackrisson et al. 1996; Dahlberg et al. 2001). All of these effects contribute to the diversity of species the forests are able to maintain. During the last thousand years, boreal forests have burnt on average every 50 to 200 years (Zackrisson 1977; Engelmark 1984; Larsen and MacDonald 1998). However, during the 20th century, natural forest fires became rare due to effective fire suppression. Because of this, the diversity of species typically associated with burnt forests has decreased. Moreover, several forest species are now considered threatened or already extinct or they are likely to be extinct after a time lag (e.g. Ehnström et al. 1993, 1995; Höier 1995; Hanski 2000; Rassi et al. 2001; Hanski and Ovaskainen 2002).

Approximately 40 species of insects in Northern Europe are considered to be dependent on forest fires (Heliövaara and Väisänen 1984; Lundberg 1984; Wikars 1997). Majority of these species are beetles (*Coleoptera*), but there are also some true bugs (*Heteroptera*), flies (*Diptera*) and moths (*Lepidoptera*). Most of these species require burnt or decaying wood for their survival. They are mainly fungivores (feeding on fungi growing on decaying wood), saproxyls (feeding on decaying wood) or predators (Muona and Rutanen 1994). Typically these species survive in the area only few years after the fire (Wikars 1992). In addition to fire dependent species, there are several species that benefit from the warm microclimate and are most abundant in recently burnt areas. These species are not specialised to burned areas but survive best in warm, sun-exposed areas provided that suitable decaying wood is available.

To conserve viable populations of fire dependent species, we must ensure a continuum of burnt areas in time but also in space. Time and space interval for adequate fire continuum is not known, but it is likely that forest fires should occur more frequently than is the case today. Because natural forest fires seldom occur in Finland anymore, the distribution of fire dependent species has become highly fragmented, and is almost entirely dependent on silvicultural burnings and conservational restoration practices. To ensure the long term survival of fire dependent species in managed forests and thus maintain forest biodiversity, it is vital to determine the frequency of burning that is necessary to achieve this goal. To determine the adequate frequency of managemental burnings, information is needed about the colonisation and long term succession patterns as well as life history of fire dependent species.

The role of decaying wood in conserving biodiversity

Availability and diversity of resources are factors that strongly limit species richness and biodiversity (Begon et al. 1990; Meffe and Carroll 1997). In boreal forests, the limiting resource for a large variety of species representing several taxa is the availability of decaying wood (Kaila et al. 1994, 1997; Samuelsson et al. 1995; Martikainen et al. 2000). In Finland alone, there are at least 4000 species which are dependent on decaying wood (Siitonen 2001). Best known decaying wood dependent taxa are beetles (*Coleoptera*) and polypores (*Polypore*) (Speight 1989). Many old growth forest species are highly specialised on decaying wood of a particular tree species, on particular species of polypore or on particular degree of wood decay (Heliövaara and Väisänen 1984; Hansson 1992). Diversity of beetles has been noted to be particularly high in those areas that have had a prolonged and continuous supply of slowly decaying wood (Nilsson and Baranowski 1997; Martikainen et al. 2000). Many of the threatened beetle species in Finland live in old growth forests and most of them are dependent on decaying wood at some stage of their life cycle (Rassi et al. 2001).

Efficient forest management requires that injured trees and decaying wood are removed from the forest. It is likely that these managemental practises have contributed to the decline of biodiversity in forests (Simberloff 1999). Therefore, by implementing new management practises, in which some trees are injured and decaying wood is left into the forest, we may be able to stop the decline of forest biodiversity. Our objective is to determine the optimal number, size and species of trees that should be left to decay that is necessary to able colonisation and long term survival of species that are dependent on decaying wood.

Conservation of valuable habitats

In Finland, ensuring biological diversity of the forests is taken into account both in Forest Act and in the Nature Conservation Act. This is based on forming and maintaining protected areas, but also on sustainable forest management in commercial forests. In the Forest Act certain key biotopes have been defined as valuable habitats, where rare and demanding species are expected to occur. The valuable habitats are defined to be in a virgin state or in a state close to that and to display the permanent characteristics which are needed to preserve their characteristic species composition. To meet the criteria of the Forest Act the valuable habitats need to be relatively small (the average size is about 0.6 ha (Tenhola and Yrjönen 2000)) and clearly distinguishable from the surrounding habitats. In Finland, term valuable habitat includes habitats of special importance (Forest Act, Section 10), protected nature types (Nature Conservation Act) and other valuable habitats that are recommended to be preserved in good forest management. The purpose of the Forest Act is to develop ecologically, economically and socially sustainable utilization of forests.

The habitats of special importance are listed in the Section 10 of the Forest Act. The list includes the immediate surroundings of boreal springs, brooks and rivulets, small lakes, grass-and-herb-rich hardwood-spruce swamps, fern-rich hardwood-spruce swamps, eutrophic fens located south of the Province of Lapland, fertile patches of herb-rich forest, heathland forests on undrained peatlands, gorges and ravines, cliffs and underlying forest stands, sandy soils, exposed bedrock, boulder fields, sparsely treed mires and alluvial forests with poorer wood yield than nutrient-poor mineral soils. In these habitats endangered and rare species are assumed or, in some cases, known to occur. In habitats of special importance, some forestry operations are prohibited (e.g. clear-cutting) but some gentle operations are allowed (e.g. single felling and gentle logging). There is no systematic empirical information on whether the valuable habitats harbour more species than other habitats or whether the area of a valuable habitat is large enough to allow long term survival of populations. Therefore, our first aim is to determine whether there are more species in valuable habitats than in control habitats. The second aim is to determine experimentally the effect of some silvicultural practices conducted in the valuable habitats or in the vicinity of them on long term survival of species richness of the habitats.

Description of the conducted and planned experiments

The effect of fire combined with the amount and quality of decaying wood on the species richness of beetles

Our main burning experiment was established during the winter 2001-2002 at Evo, Southern Finland in collaboration with the University of Helsinki and Finnish Forest Research Institute. We selected 24 two hectare plots of 80-years-old forest. The main tree species of these areas is Norway spruce (*Picea abies*) with some birch (*Betula spp.*) and Scotch pine (*Pinus sylvestris*). During the winter 2001–2002 the areas were harvested such that the volume of standing trees in each treatment area was set to 50 m^3 / hectare. Cut down trees were left to the harvested areas such that the volume of cut down wood was 5m^3, 30m^3 or 60 m^3 per hectare. The control areas were not harvested. Each treatment and control was replicated six times out of which three were burnt and three were left unburnt during the summer 2002.

From each of the 24 experimental areas, we collect beetles with window traps. Immediately after the burning in 2002, when the areas had cooled enough to allow moving on them, we settled 10 window traps on each area. The setup consists of five freely hanging traps and five traps attached to standing trees. In 2002, the trapping season begun in June and lasted until the end of September. To study the short-term colonization patterns in detail, the traps were emptied weekly. In 2003, the beetles were trapped from mid May to the end of September. Initially, our aim is to follow the colonisation and diversity of beetle fauna on these areas for three years (until the end of 2004), but a long term, at least 20 year monitoring will also be established on this experimental design.

Different beetle species require decaying wood of a different tree species as their food resource. However, when the wood has burnt the specialisation is reduced (Wikars 1997). With the window traps that were attached to standing trees in the experimental setup described above, we will determine the effect of the species of a decaying standing tree on the number and diversity of beetles. In each area the five window traps are allocated such that three of them are on spruce (main tree species on all areas) and two on birch. In the unburnt plots, the experimental trees were damaged during spring 2002 so that they have started to decay. Comparing the catch from traps on different tree species and between burnt and unburnt trees, we obtain valuable information about the importance of the quality of the reserve trees on the abundance and species richness of beetles.

In this experiment, we will also study the distribution and abundance of polypore fungi and beetles living in the fruiting bodies of the polypores. In spring 2005, we will collect samples from three common species of polypores (*Fomes fomentarius*, *Fomitopsis pinicola* and *Trametes spp*.) from our study plots. Sampled polypores will be brought into the laboratory and emerging insects will be collected and identified.

Based on our results we will be able to directly measure the effects of prescribed burning on abundance and species richness of beetles and estimate the optimal amount and quality of decaying wood for maintenance of species richness. We can also give managemental recommendations about prescribed burning and the quality and quantity of decaying wood that should be saved.

The effect of forest fire on the risk of forest damage by bark beetles

The most abundant beetle species dispersing to burnt forest are bark beetles (*Scolytidae*), the larvae of which forage in dying or damaged trees. Some bark beetle species (e.g. *Ips typographus*) are also known to attack healthy trees and they can be considered a risk for commercial forestry. Our burned study plots as well as unburnt plots offer a very suitable habitat for bark beetles because of the large amount of recently died trees. Therefore, a dramatic increase in population sizes of bark beetles can be expected and there may be an increased risk of forest damage also in the surrounding, healthy forests.

In spring and summer 2003, we studied the colonization of bark beetles to our study plots and the dispersion of them to the surrounding forests. The experimental setup consisted of a straight line of six free-hanging window traps deposited at right angle to the border of the study plot. One of the traps was settled 25 meters inside the treated study plot, one at the border of the plot and four to the surrounding forest, at the distances of 25, 50, 75 and 100 meters. Our aim is to study how the abundance of bark beetles depends on the amount of decaying wood and whether there is a difference between burnt and unburnt plots. In addition, this study will yield information on the distribution and abundance patterns of bark beetles in the healthy forests outside the study plots.

On the basis of these experiments we will be able to estimate the negative effects of restoration tools, particularly the effect of prescribed burning and increasing the amount of decaying wood on the risk of forest damage.

The succession of beetle fauna on old silvicultural burnings

In addition to the long term experimental monitoring of the succession of beetle diversity, we have studied the succession of beetle species assemblages on old silvicultural burning areas. The aim of this study is to complement the long term monitoring experiment by providing information on long term species succession with a short term study and to determine how long after the fire the burnt areas remain a suitable habitat for fire dependent beetle species. This study was conducted during the summer 2002 in Evo. We selected 20 silvicultural burning areas and 20 clear-cut areas, age of the areas ranging from 2 to 18 years. Methods of beetle capturing were the same as in our main experiment: 5 free-hanging window traps and 5 window traps attached to standing trees were settled on each area. Aim of this study is to determine how long after the fire the burnt areas remain a suitable habitat for fire dependent beetle species. Using information from this study we will be able to estimate the minimum frequency of managemental burnings in a given area that is necessary to maintain viable populations of fire dependent species.

Importance of valuable boreal brook habitats in conserving species richness

In spring 2002, we selected 20 areas containing a valuable brook habitat from boreal coniferous forests in Central Finland. These study forests are administered by the Finnish Forest and Park Service and by the forest industry enterprise UPM. From each of the 20 areas we selected three 0.1 hectare forest plots: one within the valuable brook habitat, one along the same brook but outside the protected habitat and one from the nearby forest. From each 0.1 hectare plot we determined the amount and quality of dead wood and the species richness of polypore fungi and epiphytic mosses. We counted all dead wood larger than 5 cm in diameter, identified the tree species, and measured base diameter, length of the tree and the decay stage. Based on the base diameters and the lengths of the trees we calculated the overall volume of the dead wood. The decay stage was classified on seven categories. All polypore fungi having a perennial fruiting body were identified and counted. All mosses growing on tree trunks at 50 to 250 cm height were collected and identified.

The experimental design of this study is paired because there was likely to be differences between the study areas depending on environmental factors not measured in our experiment. In the statistical analysis, we used nested and mixed model analysis of variance.

The effect of silvicultural practices on species richness of valuable forest habitats

The valuable habitats in our experiment are the immediate surroundings of boreal forest brooks and rivulets. In the Forest Act, the concept “immediate surroundings” is inadequately defined and it is poorly known how large areas of virgin forest around the brooks are needed to preserve the species composition of these valuable habitats. In our experiments, our aim is to study the importance of the width of a buffer zone on the biodiversity of the forest brooks.

At our study brooks, the surrounding forests are mature boreal coniferous forests, the main tree species being Norway spruce (*Picea abies*) with some birch (*Betula spp*.) and Scotch pine (*Pinus sylvestris*). In forestry terms, the forests are in the state of final felling. As a treatment, the buffer zone is created by clear-cut felling adjacent to the valuable habitat. The width of the buffer zone along the valuable habitat (the forest left between the brook and the clear-cut) will be 10 metres or 30 metres. In control areas, no clear-cut will be done. The length of our study section along each book will be 60 metres.

Before felling, the ecological variables as well as variables describing the tree stand will be measured. Also environmental factors affecting the habitat, such as temperature, light, moisture and water quality, are measured. Ecological variables included are vascular plants, mosses, polypore fungi and beetles inhabiting polypore fungi. In case of some polypore species, fruiting body samples will be collected and beetles living in the polypore will be reared. The plants and mosses will be monitored from one meter wide study lines which are drawn orthogonally from the brook to the edge. There will be three study lines at each study area. Every square metre of the line will be examined separately. In each square, plant and moss species will be identified and the percentage of coverage of each species will be noted.

After the first year measurements, the treatments described above will be conducted. Control areas will not be felled. The first year measurements will be a dependent control for each area, and the control area will be an independent control. In the first stage, the monitoring will be carried out yearly for four years. However, because the changes in the species composition are likely to proceed slowly, long-term monitoring will be formed and the monitoring will be carried out for at least 20 years.

Table 1. Nested ANOVA for the volume of decaying wood.

Source	SS	df	MS	F	Sig.	eta^{2} [b]
Area	16.5–E10	19	8.7–E09 [a]	2.678	.004	.538
Treatment(Area)	14.0–E10	39	3.6–E09	2.956	.000	.042
Error	315.9–E10	2598	1.2–E09			

[a] Error term for the area has been calculated using Satterwaithe approximation
[b] eta^2 = proportion of variance explained

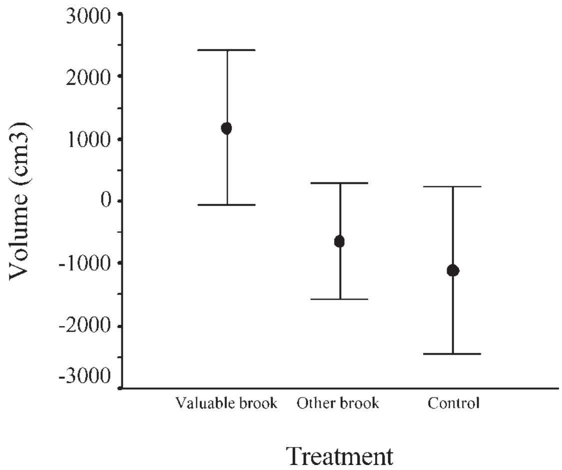

Figure 1. Volume (mean ± SE) of decaying wood at valuable brooks, other brooks and at control plots. For the figure the volume of decaying wood is standardised to mean of zero.

Preliminary results and discussion on the importance of valuable boreal brook habitats in conserving species richness

Decaying wood

The volume of decaying wood varied between the study areas but there was also a significant effect of the treatment (Table 1). However, the effect of treatment was small explaining only about 4% of the variation, while the difference between the areas explained about 54% of the variance. Although the variance is great and the difference between the treatments is only around 0.2 m^2 per hectare, the volume of decaying wood is greatest on the valuable brook habitat (Figure 1).

In addition to the volume of decaying wood also the quality measured as decay stage was significantly affected by the treatment, while there was no significant difference between the areas (Table 2). The decay stage of the dead wood was highest in the valuable habitats (Figure 2).

Table 2. Nested ANOVA for the decay stage of the dead wood.

Source	SS	df	MS	F	Sig.	eta^2
Area	227.83	19	11.991[a]	1.654	.088	.435
Treatment(Area)	323.45	39	8.293	7.613	.000	.103
Error	2829.31	2597	1.089			

[a] Error term for the area has been calculated using Satterwaithe approximation

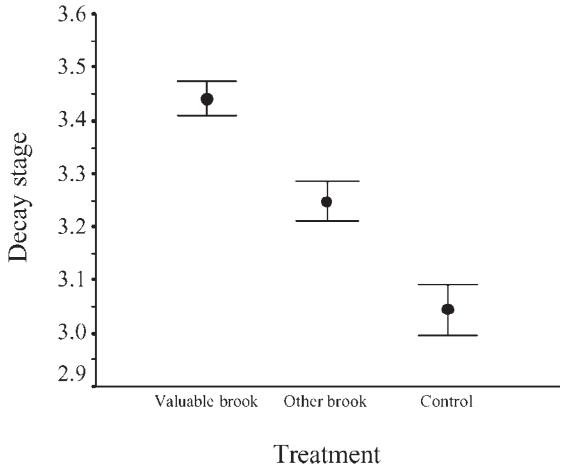

Figure 2. Decay stage (mean ± SE) of the dead wood at valuable brooks, other brooks and at control plots.

Table 3. Mixed model ANOVA for the number of moss species.

Source	SS	df	MS	F	Sig.	eta^2
Area	62.583	19	3.294	1.267	.260	.388
Treatment	19.900	2	9.950	3.828	.031	.168
Error	98.767	38	2.599			

Our results imply that the surroundings of brooks which are conserved by the Forest Act contain larger volumes of decaying wood than the nearby forests and other brook habitats. Although the differences were statistically significant they were relatively small: the mean difference between conserved brook habitats and control forests was only about 0.2 m^3 decaying wood per hectare. However, the average decay stage was highest at valuable brook habitats. This difference in the quality of decaying wood may be of importance for the diverse species community inhabiting decaying wood in boreal forests.

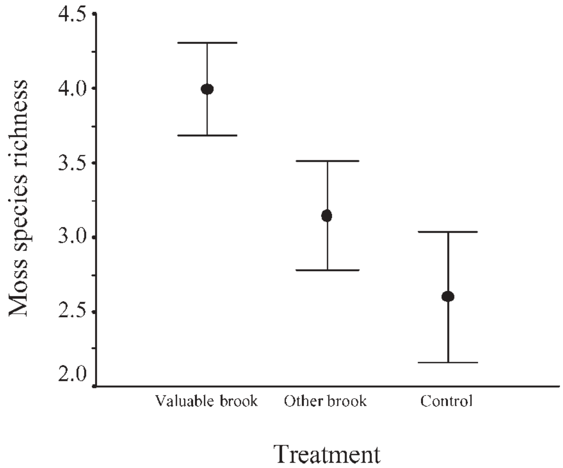

Figure 3. Species richness of mosses (mean ± SE) at valuable brooks, other brooks and at control plots.

Table 4. Mixed model ANOVA on the number of polypore species.

Source	SS	df	MS	F	Sig.	eta^2
Area	73.667	19	3.877	2.231	.017	.527
Treatment	6.633	2	3.317	1.909	.162	.091
Error	66.033	38	1.738			

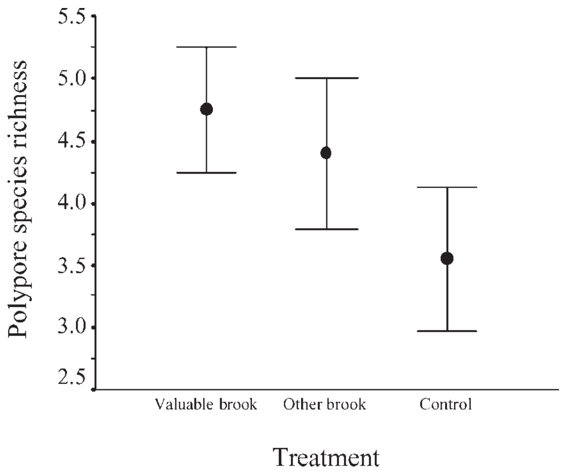

Figure 4. Species richness of polypores (mean ± SE) at valuable brooks, other brooks and at control plots.

Mosses and polypores

The species richness of mosses did not vary across study areas but there was a significant effect of the treatment (Table 3). The valuable brook habitats were most species rich while control areas were most species poor (Figure 3).

There were differences in species richness of polypores across the study areas but no significant effect of the treatment (Table 4). However, there was a tendency of the same direction as in mosses and decaying wood: valuable habitats had higher species richness than control habitats (Figure 4).

The species richness of epiphytic mosses was highest at the valuable brook habitats and smallest at control forest. Similar tendency, although not statistically significant, was found in the species richness of polypore fungi. Concerning these taxa, it seems that preserving the characteristic features of valuable brook habitats may help to preserve the overall species richness of boreal forests. This poses new challenges to silviculture: in the future it will be crucial for managers recognize the special characters that make a valuable habitat. Our ongoing studies are aimed to help in this task and to give answers to the question of what are the most important characteristics of valuable habitats that allow the occurrence of higher species richness.

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