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# Dynamics of understory vegetation after restoration of natural characteristics in the boreal forests in Finland

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ABSTRACT

Restoration of boreal coniferous forests is used in Northern Europe to increase the natural variability of forest structure and to add coarse woody debris for red-listed dead-wood dependent species, mainly insects and fungi. In four protection areas of eastern Finland, we evaluated how three commonly used restoration methods (felling with chainsaw, storm simulation, and felling with burning) with two felling levels (20% and 40% of initial living stand volume) affect the vegetation dynamics. The aim was to assess whether the type and intensity of restoration lead to different stages in the plant succession which would reflect the effectiveness of the restoration methods in terms of simulating natural disturbances. The restoration treatments were conducted in 2006 on 43 experimental stands and 15 were set as controls. Understory vegetation cover was surveyed from 372 permanent 1 $m^2$ plots in 2005, 2007 and 2011. The data were analyzed with mixed effect models and multivariate methods. Burning most efficiently initiated natural vegetation succession. Despite the initial decline of nearly all plant functional types, pioneering species such as *Betula* spp. and *Populus tremula*, forbs, graminoids and pioneer mosses regenerated quickly and exceeded their pre-disturbance covers in 2011. Dwarf shrubs *Vaccinium myrtillus*, *V. vitis-idaea* and *Calluna vulgaris* recovered nearly to their initial levels, whereas *Empetrum nigrum*, forest mosses and lichens did not show any recovery in five years. Storm simulation increased species richness on the stand scale and promoted the regeneration of *Pinus sylvestris* in soil exposed by tree uprooting. Tree felling slightly decreased the cover of lichens on the lower felling level treatment. We generated a species response table illustrating the responses of dominant species to restoration methods in the course of the seven-year study. We conclude that the dominant restoration method, tree felling, could increasingly be replaced by burning and storm simulation which have faster and greater positive impacts on the forest ecosystem.



## 1. Introduction

The structure and dynamics of boreal coniferous forests are affected by natural disturbances varying in size and severity from large stand-replacing fires to single windblown trees, resulting in highly diverse and heterogeneous forests (Pickett and White, 1985; Esseen et al., 1997; Östlund et al., 1997). For thousands of years, fire was the main and most powerful disturbance until the late19th century, when wildfires were almost completely eliminated from Fennoscandia (Zackrisson, 1977; Wallenius, 2011). In Finland the annually burned area has been on average 500 ha during the last 30 years (Finnish Forest Research Institute, 2011). Fire exclusion together with commercial forest management has altered the forest structure by leading to a loss of structural variation within forest stands, a dramatic decrease in the volume of dead wood, and an increase in the density of the growing stock (Esseen et al., 1997; Östlund et al., 1997; Siitonen, 2001; Tonteri et al., 2013). The loss of forest naturalness and natural disturbance dynamics has caused hundreds of species, mainly dead-wood dependent insects and fungi, to become threatened (Siitonen, 2001; Rassi et al., 2010; Gärdenfors, 2010).

In order to halt the decline of forest species and habitat degradation, and hence to meet the targets of the Convention of Biological Diversity (CBD, 2010), the structural and functional diversity of boreal forests has been actively restored in Finland and increasingly in other Northern European countries (Similä and Junninen, 2012; Halme et al., 2013). In Finnish nature protection areas, over 16,000 ha of forests were restored from 2003 to 2011 and another

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13,000 ha will be restored by 2016 (Similä and Junninen, 2012). In Fennoscandia, the principal methods include different types of tree felling and controlled burning to increase structural variation and to create dead wood (Halme et al., 2013). Restoration felling is related to silvicultural thinning with the exception that the felled trees are left in the restored stand to create habitat for dead-wood dependent species.

Restoration research has primarily concentrated on investigating the responses of dead-wood dependent taxa, such as beetles (Toivanen and Kotiaho, 2007; Hekkala et al., 2014) and polypores (Olsson and Jonsson, 2010; Berglund et al., 2011; Pasanen et al., 2014). Much less attention has been given to the characteristic boreal forest vegetation, even though vegetation is an important driver of ecosystem functioning (Nilsson and Wardle, 2005; Wardle et al., 2012; Cardinale et al., 2013). It is crucial to understand the ecological consequences of the most common forest restoration methods on typical boreal forest vegetation, even though no specific goal has been set regarding the vegetation.

The dominant boreal forest vegetation is highly resilient and adapted to recurrent natural disturbances (Zackrisson, 1977; Rydgren et al., 2004). Prolonged absence of fire and other changes in the natural disturbance regime may affect the whole forest ecosystem and its functioning by altering the dominance and productivity of species and plant functional types (PFTs) (Reinikainen et al., 2000; Mallik, 2003; Wardle et al., 2003, 2004; MacKenzie et al., 2006). For example in Fennoscandia, a decline in the cover of dominant ericaceous dwarf shrubs *Vaccinium myrtillus, V. vitis-idaea* and *Calluna vulgaris* (Nieppola, 1992; Salemaa, 2000a,b,c) and an increase in the thickness and relative cover of the moss layer (Vanha-Majamaa, 2000a) have been observed, possibly caused by the change of forest use and the exclusion of fire. Other ericaceous dwarf shrubs, such as *Empetrum nigrum*, may become dominant without fire (Nilsson and Wardle, 2005), and an increase of its cover has been observed in Finnish National Forest Inventories from 1951 to 1995 (Vanha-Majamaa, 2000b). As a species with allelopathic effects it alters ecosystem function by, for example, reducing tree seedling establishment, microbial activity and decomposition rates (Zackrisson et al., 1997; Nilsson et al., 2000; Nilsson and Wardle, 2005).

Restoration mimics natural disturbances, but response of understory vegetation will depend upon the method used and its intensity (Schimmel and Granström, 1996; Haeussler et al., 2002; Rydgren et al., 2004; Wang and Kemball, 2005; Hollingsworth et al., 2013). Tree felling creates openings in the canopy cover and increases light penetration on the ground, and may increase the total vegetation cover and the diversity of the understory vegetation (Thomas et al., 1999; Burke et al., 2008). A disturbance that exposes the soil, such as tree uprooting, creates important 'windows of opportunity' for seed-dispersing conifers (e.g. *Pinus sylvestris*) and pioneers, such as *Betula spp.* and fast growing graminoids (Eriksson and Fröborg, 1996; Hautala et al., 2001). Boreal fires are highly variable in the intensity and ecological effects (Schimmel and Granström, 1996, 1997; Vanha-Majamaa et al., 2007). Species richness and cover may either increase (Peltzer et al., 2000; Marozas et al., 2007; Laarmann et al., 2013) or decrease temporarily (e.g. Halpern and Spies, 1995; Schimmel and Granström, 1996; Wang and Kemball, 2005). Severe fire shifts the species assemblage towards early successional stages by removing late-successional forest species such as dwarf shrubs and forest mosses and increasing the proportion of seed- and spore-dispersing pioneer species, whereas light intensity fire may accelerate the growth of sprouting species (Schimmel and Granström, 1996; Wang and Kemball, 2005).

We present a seven-year experimental study on the effects of the most commonly used forest restoration methods in Finland on understory vegetation. The study is part of a large-scale series of before-after-control-impact field experiments investigating the outcome of forest restoration methods on the biodiversity and structure of boreal coniferous forests. The aim of the present study is to evaluate whether the method and intensity of restoration lead to different stages in the successional pathway which would reflect the effectiveness of the restoration in terms of simulating natural disturbances. To our knowledge this is the first study that concentrates on the relationship between boreal forest vegetation dynamics and restoration as a disturbance factor and compares the impacts of restoration methods of different type and intensity on plant communities, PFTs and species, and separately on stand and plot scale.

Our hypotheses were that: (1) restoration felling will result in only slight stand scale changes in vegetation cover and composition, (2) soil disturbance caused by tree uprooting and burning will increase species richness on stand scale, (3) burning will shift species composition towards early successional phases more efficiently than less intensive restoration treatments. Accordingly, the higher the proportion of the burned ground, the more efficiently early successional species colonize and fire-sensitive species disappear.

## 2. Material and methods

### 2.1. Study area and study design

The study was conducted in four Natura 2000 protection areas (called hereafter study areas) in eastern Finland (Fig. 1 and Table 1). Oulanka and Pahamaailma belong to the northern boreal vegetation zone, and Elimyssalo and Lentua belong to northern parts of the middle boreal vegetation zone (Ahti et al., 1968). Prior to the treatments the forests were mainly dominated by *Pinus sylvestris* L. with the exception of Oulanka, a mixed-wood forest containing mainly *Picea abies* L. and *Betula pubescens* Erhr. The understory vegetation was dominated by ericaceous dwarf shrubs *Vaccinium vitis-idaea* (L.), *V. myrtillus* (L.) and moss *Pleurozium shreberi* (Brid.)Mitt.. The forests had been managed earlier and they lacked characteristics typical to a natural forest, for example dead wood, diverse tree size and species composition and/or random spatial distribution of trees.

### 2.2. Restoration treatments and sampling design

The restoration treatments included two felling treatments (F1 and F2), one storm simulation treatment (S1, only in Lentua), and two felling treatments combined with subsequent burning (FB1 and FB2). All the restoration treatments were carried out on larger (6.7–29.2 ha) areas, hence experimental stands are random samples of the treatments. However, due to practical reasons arising from the management of the Natura 2000 areas, a fully factorial experiment could not be carried out across the restoration treatments and study areas (Table 2). In the treatments F1, S1, and FB1, 20% of the initial volume of randomly selected living trees was felled. In the treatments F2 and FB2, the proportion of felled trees was 40%. Trees were cut down from the base of the tree trunk with a chainsaw, except for the storm simulation treatment S1, in which trees were uprooted by an excavator to expose patches of mineral soil on the ground. Higher proportion of felled trees in FB2 aimed at greater ecological responses as compared to FB1. The measured responses other than vegetation were the height of the scorched tree trunks and the proportion of the burned ground on vegetation plots. In the burning treatments, trees were felled in February–March 2006 and burnings took place in late June–early July 2006 at the time of high fire escape risk, when fires occur also naturally. In the felling and storm simulation treat-