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Forest management regulates temporal change in the cover of boreal plant species

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ABSTRACT

We analysed the driving forces of temporal change in the cover of boreal forest plant species in Finland over 21 years (1985–2006). Our study focused on the effects of forest cuttings of different intensity, i.e. regeneration cuttings (RC) and intermediate cuttings (IC), on 11 common understory species (including vascular plants, mosses and lichens) and their recovery after cuttings. General linear models (LM) were applied in modelling the change in the cover of plant species. The plant species displayed contrasting responses to RC and IC in accordance with their light demand, which also accounted for their recovery rate after cutting disturbance. After RC of old forest, shade and semi-shade tolerant species (herb *Oxalis acetosella*, moss *Hylocomium splendens*, dwarf shrub *Vaccinium myrtillus*) decreased strongly in cover (>70%) and recovered relatively slowly, but increased (40–100%) after IC. Species adapted to semi-light conditions (mosses *Dicranum polysetum* and *Pleurozium schreberi*, dwarf shrub *Vaccinium vitis-idaea*) decreased rather strongly (20–60%) after RC, but recovered relatively fast, reaching their old-forest cover level at a stand age of ca. 30 years. These species also increased after IC. In contrast, light-demanding species (dwarf shrubs *Empetrum nigrum* and *Calluna vulgaris*, grass *Deschampsia flexuosa*) increased after RC and decreased after IC. *Cladina* lichens decreased across the country. In general, early successional light-demanding species increased and late successional shade-tolerant species decreased after RC. IC favoured all but the most light-demanding species. Species-specific responses to cuttings showed considerable variation within plant functional groups (e.g. dwarf shrubs, herbs, mosses). Cuttings determined the principal change in vegetation, while only slight signals of the effect of climate warming were found in few species. The legacy of forest management deserves special attention when e.g. tracking the effect of global change on vegetation.

1. Introduction

Boreal forests constitute the world's largest terrestrial biome, accounting for nearly one third of the world's forested area (Apps et al., 1993). In this biome, understorey vegetation plays a significant role in biodiversity, nutrient cycling and the carbon sequestration. The abundance and composition of understorey vegetation reflects the combined effect of resource availability, biotic interactions (e.g. competition for light and nutrients), and regeneration processes (Tilman, 1985; Grime, 2001) which are in turn controlled by climate and edaphic conditions. Understorey vegetation undergoes constant change, driven by successional processes and natural and anthropogenic disturbance regimes, of which tree cuttings concern all forests subject to forestry.

In Finland, 76% (23 million ha) of the land area is covered by forests, while circa 91% of the forested area is managed for forestry purposes (Peltola and Ihalainen, 2012). Consequently, forest regeneration areas, sapling stands and thinned stands are representative of abundant human-influenced habitats in the Finnish landscape. The current, conventional forest management practices generally applied in Nordic countries seek to optimise timber production and management costs during the rotation period of a stand. A rotation period begins when a new forest stand is established and ends after several decades, when most of the trees are harvested (Regeneration cuttings, RC). RC include several harvesting practices, of which clear-cuttings are the most intensive. After RC, soil is usually mechanically prepared to aid either natural regeneration or artificial regeneration by seeding or planting. During the rotation period, the forest is usually managed by 1–3 intermediate cuttings (IC) in which 25–30% of the current growing stock in the stand is removed in order to direct the growth of the stand in favour of the most valuable trees. Each cutting treatment

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constitutes a sudden disturbance of the natural succession of the forest vegetation and changes tree canopy closure, which affects the environmental conditions of understorey plants.

Cutting regimes change the environmental conditions of understorey vegetation, resulting in the increased gain of solar radiation, greater fluctuation of air and soil temperatures, and changes in hydrological conditions (Prevost and Raymond, 2012; Schelker et al., 2013). In addition, mechanical damage caused by felling machinery, logging residues and possible soil preparation of the site affect the forest understorey. Earlier studies on the response of understorey vegetation to clear cuttings and other major harvesting regimes tend to show a decrease in the cover of many understorey species after harvesting. Such a response has been reported e.g. in the case of bilberry (*Vaccinium myrtillus*; Atlegrim and Sjöberg, 1996; Bergstedt and Milberg, 2001; Hedwall et al., 2013) and some late successional vascular plants, mosses and liverworts (Jalonen and Vanha-Majamaa, 2001; Uotila and Kouki, 2005). In contrast, early successional species, such as fireweed (*Epilobium angustifolium*) have clearly benefited from regeneration cuttings, while some species have shown no response to logging (Bergstedt and Milberg, 2001). The intensity of cutting has also been shown to affect understorey plants (Bergstedt and Milberg, 2001). However, studies on the response of understorey species to less intensive disturbance, such as thinnings, are relatively scarce (Widenfalk and Weslien, 2009) and, with a few exceptions (Bergstedt and Milberg, 2001; Miina et al., 2010; Hedwall et al., 2013), are mainly based on case studies. In addition to cuttings that affect forest vegetation primarily at local scale, combination of large scale factors such as climate change (Hughes, 2000) and atmospheric deposition of nitrogen (Dirnböck et al., 2014) may cause changes in forest vegetation, either directly or indirectly via changes in the tree layer (Hedwall et al., 2015; Verheyen et al., 2012).

In this study, we analysed the driving forces behind temporal change in the cover of understorey vegetation, including vascular plants, mosses and lichens. Besides cutting effects and changes in forest structure, we also explored the effect of climate warming and background nitrogen and sulphur deposition on the vegetation change. The study was based on a geographically extensive vegetation survey conducted in forests on mineral soils in Finland, initially surveyed in 1985–86 and resurveyed in 2006. Our focus was on analysing the effects of forest cuttings of varying intensity (regeneration cuttings (RC) and intermediate cuttings (IC)), on 11 common forest plant species belonging to different functional groups and their rate of recovery after cuttings. According to the sequence of the species optima along the light gradient (estimated based on the canopy cover in uncut forests), we predict that the response of various species to forest cuttings is strongly dependent on their tolerance/sensitiveness to light intensity.

We will test the following hypotheses:

1. The intensity of cuttings is reflected by the magnitude of change in the cover of plant species.
2. Ground layer mosses are more sensitive to cuttings than vascular plants.
3. Plant species with high tolerance of intense light and drought recover faster from disturbance due to cutting than shade-tolerant species. Species that are adapted to intermediate light intensity benefit from stand thinnings.

2. Material and methods

2.1. Vegetation survey and inventory of environmental variables

Understorey vegetation was surveyed on a systematic network of 443 sample plots established on mineral-soil sites in 1985–86 and resurveyed on the same plots in 2006 (Fig. 1). These sample plots are a subset of the pan-European UN-ECE ICP Forests extensive monitoring plot network (Level I; Lorenz and Fischer, 2013), as well as part of a systematic sampling network of 3000 permanent plots established in connection with the 8th Finnish National Forest Inventory (NFI; Reinikainen et al., 2000). The survey performed in 2006 was part of the BioSoil project carried out under the Forest Focus scheme (Regulation (EC) Nr. 2152/2003).

Plant species were identified and their percentage cover was visually estimated on four 2 m^2 permanent sampling quadrats on circular 400 m^2 plots. In the data analysis, species abundances on the four sampling quadrats were averaged for each plot.

For the analysis, we chose species or genera in the field and ground layers which are common or dominant, belong to different functional groups and are important indicators of plant communities: heather (*Calluna vulgaris* (L.) Hull), wavy hair-grass (*Deschampsia flexuosa* (L.)Trin.), crowberry (*Empetrum nigrum* L.), wood-sorrel (*Oxalis acetosella* L.), chickweed wintergreen (*Trientalis europaea* L.), bilberry (*Vaccinium myrtillus* L.), cowberry (*Vaccinium vitis-idaea* L.), reindeer lichens (*Cladina* Nyl. spp.), wavy broom moss (*Dicranum polysetum* Sw.), step moss (*Hylocomium splendens* (Hedw.) Schimp.) and red-stemmed feathermoss (*Pleurozium schreberi* (Willd. ex Brid.) Mitt.) (Table 1). Further on, the first four letters of the genus and species names are used as abbreviations for each species.

The inventoried sample plots were situated in both unmanaged and managed stands. The stands were divided into groups using factor **cutting** which combines both the cutting type and the time since cutting, adding up to a total of 8 levels in the cutting factor (Table 2). All cuttings that took place between regeneration cuttings (RC), most of which were thinnings, were classified as intermediate cuttings (IC).

When forming the 2-level factor **zone**, we applied subzones of the boreal zone outlined in Ahti et al. (1968). In the case of *Clad* spp. and *Empe nigr*, the hemiboreal, southern boreal and middle boreal subzones were combined to form the zone 'South', leaving the northern boreal subzone as the zone 'North' (Fig. 1), as the species were expected to show a deviating pattern in northern boreal subzone because of reindeer grazing in the case of *Clad* spp. and due to the dominance of different subspecies in the case of *Empe nigrum* (ssp. *hermaphroditum* in North, and ssp. *nigrum* in South). For other species, the hemiboreal and southern boreal subzones were combined to form the zone 'South' and the middle boreal and northern boreal subzones were merged to form 'North'. A total of 24% of the plots represented young succession stages after RC, 55% were in the mid-successional stages managed by ICs and 21% had been uncut for the last 30 years by 2006.

The forest site type was determined on the basis of understorey vegetation (Cajander, 1949). In order to form a factor **site type**, herb-rich sites and mesic sites were merged to form a factor-level 'Mesic' site type, whereas sub-xeric sites, xeric sites and barren sites were combined to form a level 'Xeric' site type. Division of the sample plots into two site types also roughly groups the plots according to the dominant tree species: the mesic sites are mainly Norway spruce (*Picea abies*) dominated with a variable mixture of Scots pine (*Pinus sylvestris*) and broadleaved species (mostly *Betula* spp.), while the xeric sites are mainly dominated by Scots pine and the proportion of other tree species is low.

The stand age was estimated using increment core from one sample tree representing the dominant canopy layer. The total basal area (BA) of the tree stand and the proportions of Norway spruce, Scots pine and broadleaved trees of the total BA were estimated using measurements of stem diameter at breast height according to the field instructions of the NFI. The crown cover of trees higher than 1.5 m and the crown cover of shrubs (including shrubs height >0.5 m and trees 0.5–1.5 m) were estimated visually.