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Resilience of understory vegetation after variable retention felling in boreal Norway spruce forests – A ten-year perspective

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ABSTRACT

We studied the ten-year response of understory vegetation and lichens in mature boreal Norway spruce forests to five felling treatments in southern Finland. The stand level treatments represent a range in intensity of overstory removal: clear felling (CF) with site preparation and planting, retention felling (RF) (7% of stand volume retained) with site preparation and planting, gap felling with site preparation (GFs) (50% retained) and without planting, gap felling (GF) (50% retained) without site preparation or planting, and selection felling (SF) (67% retained) without site preparation or planting. Disc trenching was used for site preparation. Vegetation was sampled before and 1, 2, 3 and 10 years after the treatments. Both species cover and number decreased significantly immediately after all treatments. The resistance of understory vegetation, defined as the amount of change in the community structure caused by the treatments, increased in the order CF < RF < GFs < SF < GF. The dynamics of vascular plants depended on the felling intensity. The dynamics of non-vascular species depended both on the felling intensity and site preparation. CF and RF caused almost similar effects on understory vegetation composition. Local extinctions of mosses and liverworts were caused especially by CF and RF. However, even with 67% retention, 18 bryophyte species were lost during the study period. Loss of bryophyte species was higher after SF than after GF treatments, suggesting that aggregated retention is better for maintaining bryophyte species in felling areas. The resilience of understory vegetation increased in the order CF < RF < GFs < GF < SF. The abundance of mosses, liverworts and dwarf shrubs had not recovered ten years after treatments. Herb species were the most resilient compared to other species groups. We conclude that in intensively managed forest landscapes, GF and SF can be recommended as alternatives to CF to better maintain understory diversity on the stand level. However, the aim with GF and SF treatments was to further harvest the stands. Subsequent removal of the residual stands may cause substantial changes in understory vegetation for the whole treatment area. To protect late-successional bryophytes in felling areas in mesic spruce forests, high levels of retention and minimizing soil disturbance would be required.

1. Introduction

Intensive forestry based on clear felling, often with heavy site preparation, has been practiced in Fennoscandia since the 1950s. Despite current existing alternative felling methods, clear felling is still the prevailing final felling method with a minimum number of retention trees per ha ranging from five in Finland to ten in Norway and Sweden (Gustafsson et al., 2010; Finnish statistical yearbook of forestry, 2014). Consequently more than 90% of all productive forest land in Finland and Sweden is represented by structurally simplified, even-aged and even-structured stands (Gustafsson et al., 2010). Intensive forestry has been shown to affect biodiversity and ecosystem functions, which has been reflected in the long-term changes in understory vegetation (Reinikainen et al., 2000; Uotila and Kouki, 2005; Hedwall et al., 2013; Tonteri et al., 2016).

The ecological impact of clear felling on boreal forests vegetation is well known in general (Reinikainen et al., 2000) and in spruce forests in particular (Uotila and Kouki, 2005). After clear

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felling, solar radiation, temperature amplitudes and wind velocity increase, whereas humidity decreases (Chen et al., 1993; Heithhecker and Halpern, 2007). These changes in microclimatic conditions lead to changes in understory vegetation. After clear felling, cover and richness of bryophytes, especially liverworts, decrease remarkably in several vegetation types (Jalonen and Vanha-Majamaa, 2001; Fenton et al., 2003; Dovčiak et al., 2006; Liu and Bao, 2014), with slow recovery afterwards (Dynesius and Hylander, 2007; Dynesius, 2015). In boreal spruce forests, many studies have shown that especially bryophytes are sensitive to harvesting (e.g. Rydgren et al., 2004; Åström et al., 2007; Dynesius et al., 2008). The change in microclimatic conditions affects understory vegetation leading to a shift from late-successional species to early successional, light-demanding species, sometimes causing local extinction of some understory species (e.g. Fenton et al., 2003).

The role of site preparation after clear felling has not always been addressed in ecological studies, even though it can cause even more drastic changes than canopy removal, affecting e.g. coarse woody debris (CWD) (Hautala et al., 2004) and epixylic species (Hautala et al., 2009). In general, the effects of site preparation on understory vegetation depend on its severity (Haeussler et al., 1999, 2004). It has been shown that the vegetation changes after site preparation differ from changes caused by felling only, and that the effects are long-lasting (Bergstedt et al., 2008). Removing soil organic layer causes a shift from residual and resprouting understory species to ruderal species regenerating from seeds and spores (Haeussler et al., 2002). Higher percent cover of grasses and annual herbs has been observed after site preparation (Peltzer et al., 2000). After mounding, the understory vegetation has been found to be more resilient than with higher severity site preparation methods (Haeussler et al., 2004). In Finland, the annual area of site preparation is currently between 100,000 and 125,000 ha, and the cumulative site preparation area since the 1950s is between 5 and 6 million ha. The use of site preparation methods has changed during the last decades. Until the year 2005 disc trenching was the most common site preparation method, but after that, mounding became more common (Finnish statistical yearbook of forestry, 2008).

Several alternative continuous cover forest management options and practices have been proposed and adopted in the past few decades (Pommerening and Murphy, 2004). Variable retention (green tree retention) has been defined as a method, in which trees are retained to meet ecological objectives such as maintaining structural heterogeneity and protecting biological legacies (Mitchell and Beese, 2002). In variable retention, depending on the amount and pattern of retention, the changes in environmental conditions are not as drastic as after clear felling, and late-successional species have better chances to survive.

During the last decades, integration of conservation measures into forest management through variable retention felling to promote biodiversity has taken place starting in North America (Franklin, 1989; Aubry et al., 1999; Beese and Bryant, 1999; Monserud, 2002) and has been followed by some experimental studies in Fennoscandia (Vanha-Majamaa and Jalonen, 2001; Bergstedt et al., 2008; Hautala et al., 2009; Gustafsson et al., 2010; Johnson et al., 2014). Its ecological (Rosenvald and Lõhmus, 2008; Gustafsson et al., 2010; Johansson et al., 2013) and economic (Knoke, 2011) aspects have been reviewed. The level and spatial pattern of overstory retention, together with rotation age, are fundamental elements of forest structure that can be altered to target specific ecological objectives (Franklin et al., 1997; Koskela et al., 2007).

Since the implementation of variable retention fellings, their effects on understory vegetation have been studied in large-scale experiments, especially in North America (e.g. Aubry et al., 1999; Halpern et al., 2012), but also in Fennoscandia (Jalonen and Vanha-Majamaa, 2001; Johnson et al., 2014). As the variable retention methods have been practiced and studied for less than 20–25 years, the results concentrate mainly on short-term effects during early secondary succession (Jalonen and Vanha-Majamaa, 2001; Halpern et al., 2005, 2012; Macdonald and Fenniak, 2007; Kruys et al., 2013).

Studying the dynamics of the response of understory vegetation communities to variable retention will allow estimating the community-level resistance (the amount of change caused by a disturbance), and resilience (the speed with which a system returns to its pre-disturbance level following a disturbance) (Pimm, 1984). The distances between pre- and post-disturbance samples in ordination space can be used to quantify the relative resistance and resilience of forest communities (Halpern, 1988). The resistance of understory vegetation can be estimated immediately after felling, whereas a longer time period is needed to study its resilience.

Results both in North-America and Fennoscandia have shown that 15–17% retention is insufficient to retain the abundance and diversity of plant species characteristic to late-successional stages, and the changes are reduced at higher levels of retention (Craig and Macdonald, 2009; Halpern et al., 2012; Johnson et al., 2014). Earlier studies on the effects of variable retention on different species groups have shown, e.g., that vascular plants are more resilient than bryophytes (Halpern et al., 2012), and that among bryophytes, especially liverworts are sensitive to felling (Nelson and Halpern, 2005). Retention pattern has been shown to have little effect on the magnitude of decline in the bryophyte cover and species' frequencies (Dovčiak et al., 2006). Götmark et al. (2005) found no evidence that partial cutting causes herb species losses in broadleaved forests in Sweden. In conifer forests in Alberta, Canada, Macdonald and Fenniak (2007) found that herb richness and diversity were not significantly different in any other treatment than clear felling, suggesting that herbs are relatively resistant to felling.

This study is a part of a larger experiment, "Biodiversity and regeneration of Norway spruce forests (MONTA)". Started in 1995, the experiment has been used to study the effects of five different felling methods with variable overstory retention on diverse groups of organisms in southern Finland (Koivula, 2002; Matveinen-Huju and Koivula, 2008; Siira-Pietikainen and Haimi, 2009). The practical aim of the experiment was to develop alternative forest management practices to create structures needed for preserving and restoring biodiversity in originally even-structured spruce stands, and at the same time ensure timber production. With this paper, the authors aim to give a general description of how understory vegetation changes and develops after variable retention with and without soil disturbance. We examined understory vegetation response to the variable overstory removal and related this response to direct and indirect effects of felling, including ground disturbance (site preparation), for ten years on permanent sample plots.

Our objective was to examine the understory vegetation response to variable retention felling and site preparation in mature boreal spruce-dominated forests. Specifically, the objective was to examine the dynamics of understory vegetation at different levels: whole community, different species groups, and individual species. We hypothesized that (i) the vegetation response in terms of changes in both species cover and composition depends on the intensity of felling, so that (ii) the resistance and resilience are higher with higher levels of retention, (iii) understory vegetation extinctions vary as a function of the treatments and their characteristics (the gradient in felling intensity or the presence/absence of ground disturbance), (iv) site preparation increases the negative effects of felling on understory vegetation and (v) that resilience will be greater for vascular plants than for bryophytes; especially