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Restoration potential of native forests after removal of *Picea abies* plantations

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ABSTRACT

Coniferous plantations may reduce biodiversity and homogenise environmental conditions but there is a lack of knowledge on the restoration potential of such sites. We assess whether first generation plantation impacts on soil and biodiversity are reversible. The study was carried out in western Norway and we compared species composition, alpha and beta diversity of vascular plants and bryophytes, and soil conditions on five sites of 4-year old wind-felled clearings and adjacent, remnant Norway spruce (*Picea abies*) plantations. Local native birch (*Betula pubescens*) forests provided a reference point for assessing the restoration potential of the Norway spruce plantations. We found that species composition in the wind-felled clearings quickly developed similarities to the local birch forests. A rise in humus pH, calcium concentrations and available nitrogen (total N in percentage of loss on ignition), indicates that one rotation of Norway spruce plantations has not imposed long-term impairment of soil conditions. After removal of the plantation tree layer, mean species number per plot (alpha diversity) increased for vascular plants but remained unchanged for bryophytes. Heterogeneity, in terms of beta diversity, and the variance of some soil elements (calcium and magnesium) increased, and beta diversity trends were similar for both vascular plants and bryophytes. During the course of succession, we predict that species composition and vascular plant alpha and beta diversity in wind-felled clearings of Norway spruce plantations may stabilise at levels similar to native birch forests.

1. Introduction

Coniferous plantation trees are often non-native, and extensive plantations of introduced conifers are found in the Southern Hemisphere and in Europe (Richardson and Rejmánek, 2004; Carrillo-Gavilán and Vilà, 2010; Simberloff et al., 2010). Plantation species have been shown to change and homogenise local environmental conditions (Augusto et al., 2002; Magura et al., 2005) and to reduce and homogenise native plant diversity (Hill, 1979a; Vellend et al., 2007) and are hence considered as potential "ecosystem engineers" (sensu Jones et al., 1997). Norway spruce (*Picea abies*) is the most important plantation species throughout northern and central Europe (Augusto et al., 2002; Spiecker, 2003; Richardson and Rejmánek, 2004; Øyen and Nygård, 2007). It is common in plantations far beyond its natural range; in particular, its western border has expanded considerably (Spiecker, 2000). Norway spruce has many characteristics of an ecosystem engineer: shade from dense even-aged monocultures may dramatically reduce understorey plant richness (Hill, 1979a; Kirby, 1988) and its litter decomposes slowly and acidifies the soil to a greater extent than for pine and deciduous trees (Nihlgård, 1971; Horntvedt, 1989; Cannell, 1999). The overall impact of Norway spruce plantations on soil and biodiversity may be greater than the planted area suggests as plantations are often located on relatively productive and potentially species-rich sites (Gjerde, 1993; Øyen and Nygård, 2007). In recent years, increased emphasis has been put on restoring native woodlands on sites with coniferous plantations (Zerbe, 2002; Spiecker, 2003), yet little is known about the restoration potential of such sites (Zerbe, 2002). Clear-felling represents a severe perturbation of the ecosystem, yet it holds potential for facilitating restoration of the native forest vegetation (Heinrichs and Schmidt, 2009). Removal of the tree layer induces great changes in light-availability, temperature, wind-exposure, precipitation, soil chemistry and hydrology (Braathe, 1956; Nihlgård, 1970; Likens et al., 1978; Atlegrim and Sjöberg, 1996), and vegetation and soils are disturbed by forestry machines. The many changes result in an unstable ecosystem, with little control on export of water and soil

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nutrients (Likens et al., 1978), and it is difficult to predict short- and long-term changes in biodiversity (Schoonmaker and McKee, 1988; Esseen et al., 1997). Shade- and moisture-demanding species that grow in the forests are often reduced (Hannerz and Hånell, 1997), new species may enter the clearings via seeds dispersed by forestry machines, animals and wind, from propagule banks within the soil, and by vegetative spread from adjacent vegetation (Grime et al., 1988; Jonsson, 1993; Rydgren and Hestmark, 1997; Zamora et al., 2011). With respect to the restoration potential, a key question is whether plantation effects prevail or if the felling-initiated succession progresses towards pre-plantation conditions of native forest communities.

Bryophytes form a high proportion of understorey vegetation and terrestrial biodiversity at high latitudes and in oceanic regions (Esseen et al., 1997; Mutke and Barthlott, 2005), and are of conservation concern (Nelson and Halpern, 2005; Frego, 2007). Bryophytes differ from vascular plants in size, microhabitat, reproduction, and water and nutrient uptake (During, 1979; McCune and Antos, 1981). For instance, bryophytes are often sensitive to changes in moisture conditions, and they might therefore be expected to differ from vascular plants in their response to severe environmental perturbations such as clear-felling (Lee and La Roi, 1979; Carleton, 1990). Dominant forest-floor bryophytes (e.g. *Sphagnum*, *Polytrichum*, feather mosses) may play important roles in the successional dynamics as they are able to suppress establishment and growth of vascular plants by reducing access to light, water, nutrients and space (Grime et al., 1990; Økland et al., 2004). This effect could be enhanced in coastal/oceanic climates with long, moist growing seasons (Økland et al., 2004). While species richness of brypohytes sometimes covaries with vascular plant richness (Fensham and Streimann, 1997; Pharo et al., 1999; Ingerpuu et al., 2001), the patterns in species turnover are often poorly correlated (Nekola and White, 1999; Pharo et al., 1999; Sætersdal et al., 2004). This suggests that the community composition is governed by different external or intrinsic drivers, and we explore this by comparing successional dynamics in the bryophyte vs. higher plant communities following clear-felling.

The first aim of this study is to assess whether plantation impacts on the soil and biodiversity of western Norwegian woodlands are reversible. Our reference point is data from local native forest vegetation (Odland, 1981) and we compare soils and vegetation of Norway spruce plantations and adjacent wind-felled clearings 4 years after removal of the tree layer, and hypothesise (H_A tested vs. H_0 of no change): (i) higher species richness and a community composition more similar to natural woodland habitats, and (ii) increased heterogeneity in plant communities and soil parameters. The second aim is to assess whether the successional trends differ between understorey vascular plants and bryophytes. We expect: (iii) slower increase in bryophyte species richness after wind-felling and subsequent clearing, and (iv) similar effects on beta diversity in bryophytes and vascular plants following clear-felling (i.e. they respond similarly to environmental heterogenisation).

2. Materials and methods

2.1. Study area

The study was carried out within two adjacent municipalities, Volda and Ørsta (Fig. 1), western Norway (62 °10′N, 6 °9′E). Climate is oceanic, with July and January mean temperatures of 14 °C and −0.3 °C, respectively (Aune, 1993), a relatively long growing season (~200 days above 5 °C) and annual precipitation of ~1900 mm (Førland, 1993). Bedrock consists of gneiss (Tveten et al., 1998a, 1998b). The area is in the south-boreal vegetation zone (Moen, 1998), with native forests dominated by *Betula pubescens* with a

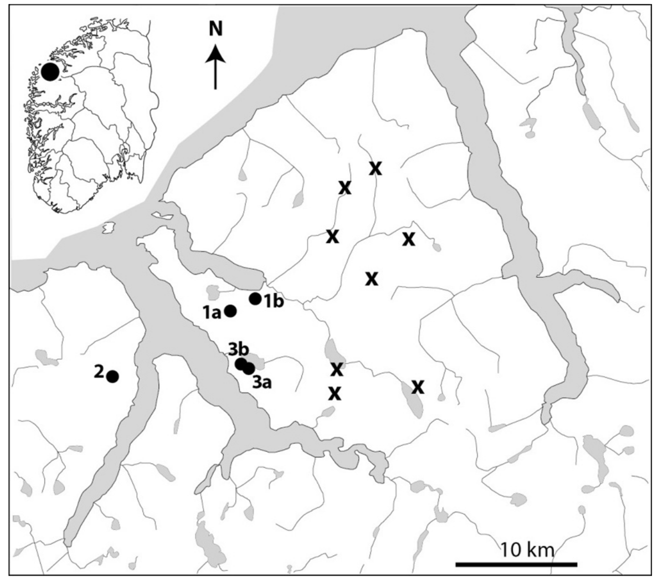

Fig. 1. Map showing the study area in the municipalities of Ørsta and Volda, in the county Møre og Romsdal, western Norway. ● = Study sites (1–3) from pairs of Norway spruce plantations and wind-felled clearings in Ørsta (site 1) and Volda (sites 2–3). **x** = Areas where native birch forests are investigated in Ørsta.

Vaccinium myrtillus, *Chamaepericlymenum suecicum* or fern understorey (e.g. *Gymnocarpium dryopteris*, *Phegopteris connectilis*, *Oreopteris limbosperma* and *Dryopteris filix-mas*) (Odland, 1981). The native forests have been heavily influenced by anthropogenic activity, such as grazing (Odland, 1981), but grazing pressure has been reduced in recent decades and secondary deciduous forests are now expanding (Gjerde, 1993). *Pinus sylvestris* is the only native coniferous tree species in this region (Gjerde, 1993; Farjon, 2008), but large-scale afforestation of western Norway took place in the late 1950s and early 1960s (Øyen and Nygård, 2007). Norway spruce is the most common plantation species, and by 2005 Norway spruce covered 165,000 ha in western Norway (Øyen and Nygård, 2007).

The investigated Norway spruce plantations are 40–60 years old and of first generation. Prior to plantation, the investigated sites were formerly grazed and mostly dominated by birch forests and encroaching juniper (*Juniperus communis*). The Norway spruce plantation forests had a well-developed bryophyte layer (cover 25–50%), dominated by feather mosses (*Hylocomium splendens* and *Thuidium tamariscinum*) and *Rhytidiadelphus loreus*, and many other bryophyte species were common in the different forests. A shrub layer was generally lacking and the field layer was poorly developed (5–10% cover), but small ferns were commonly found together with sterile *Avenella flexuosa*, *V. myrtillus*, *Oxalis acetosella*, *Anemone nemorosa* and *Luzula pilosa*, for example. Appendix A presents a complete species list of the investigated vegetation types.

2.2. Sampling

This paper combines data from native birch forests that were investigated by Odland in 1979 (Odland, 1981) and data collected by Saure within first generation Norway spruce plantations (hereafter spruce plantations) and adjacent (i.e. on the same site, either parallel to, or below the remnant spruce plantations) wind-felled clearings (Fig. 1). The wind-felled clearings resulted from a storm over New Year 1991/1992, which felled about 30,000 m^3 of spruce plantations in Ørsta/Volda (Table 1 and Fig. 1). The wind-felled clearings and adjacent plantations were investigated by Saure in summer 1996 and 1997, 4 years after windthrow and mechanical