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Initial effects of restoring natural forest structures in Estonia

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ABSTRACT

The legacy of structural homogenization due to forest management for commercial products is a loss of biodiversity. A common policy in many European countries is to increase forest diversity by converting managed forests to more natural conditions. The aim of this study was to provide an early evaluation of the effectiveness of different restoration treatments to rehabilitate managed stands in order to increase their naturalness. Restoration treatments were imposed on 30–60 years old conifer plantations including gap creation with and without added deadwood, added deadwood without gaps, gaps plus overburning, and controls. We sampled stand structure, understory vegetation and beetles before and after treatments on 50 circular permanent plots. Diversity of different groups responded differently to treatments with understory vegetation diversity increasing the most in gaps with burning, lichens in gaps without burning and bryophytes with the addition of dead wood. Increased beetle abundance and greater species diversity was a direct effect of changed light conditions inside the canopy. Gaps with overburning had the greatest recruitment of tree seedlings. Stands that were homogeneous pre-treatment increased in heterogeneity in structural conditions and microclimatic conditions after treatments and therefore richness and abundance of different species groups increased.

1. Introduction

Ecological restoration aims to return degraded ecosystems to an idealized natural state as before anthropogenic intervention, with similar species diversity, composition and structure (SERI, 2004; Stanturf and Madsen, 2002). Rehabilitation of a degraded forest stand aims to restore naturalness in terms of stand structure, species composition or disturbance regimes (Bradshaw, 2002; Stanturf, 2005). Rehabilitation at the landscape scale can be used to complement conservation efforts in protected areas in order to enhance habitat quality and quantity, to improve connectivity between fragmented areas and to create buffer zones between reserved and managed forest areas (Kuuluvainen et al., 2002).

The ultimate goal of restoration is to create a self-maintaining ecosystem that is resilient to perturbation without further assistance (Urbanska et al., 1997). Integrated approaches are suggested to measure restoration success including examining vegetation characteristics, species diversity and ecosystem processes (Ruiz-Jaen and Mitchell Aide, 2005). The main aim of restoring forest naturalness is to initiate natural processes in forests that have been heavily influenced by human manipulation, to monitor these processes going forward, including monitoring of important inter-related processes of stand regeneration, small-scale disturbances and tree mortality (Kuuluvainen, 2002; Beatty and Owen, 2005). Intervention at the stand regeneration phase can be the basis for diversification and dynamics of forests (Vodde et al., 2011). Small and large disturbances generate different possibilities and scales for successional development. Tree mortality, for example is a natural process with many causes and high spatiotemporal variability (Laarmann et al., 2009). Gap formation in natural and semi-natural forests is dependent on mortality processes that also add deadwood structure to forests. Quality of coarse woody debris is a key structural component of unmanaged forests and plays an extremely important role in ecosystem function and biodiversity conservation (Lilja-Rothsten et al., 2008; Köster et al., 2009).

One common effect of forest management to produce commercial products is structural homogenization and compositional simplification over time (Halpern and Spies, 1995). The legacy of such landscape homogenization is a loss of biodiversity; forest policy in many European countries has been to increase forest diversity by converting managed forests to more natural states (Fries et al., 1997; Lõhmus et al., 2005). In Estonia, it can be seen as reversing the trend in forest management from cultivated, even-age coniferous forests of Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) toward more complex structures that include special attention to spatial and quality properties of deadwood in forest stands (Laarmann et al., 2009; Lõhmus and Kraut, 2010; Paal et al., 2011; Liira et al., 2011).

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Ensuring the sustainable dynamics processes for sustaining or steadily increasing forest biodiversity and structural complexity may be expected from either allowing natural disturbance processes to operate (Franklin et al., 1997; Kangur et al., 2005; Shorohova et al., 2009) or by attempting to emulate disturbance processes by management intervention (North and Keeton, 2008; Long, 2009) although, management actions may never fully mimic natural disturbance regimes (Lindenmayer and Franklin, 2002). Restoration involves rehabilitating stands using a set of silvicultural treatments to speed up the development of structural complexity including thinning, creating snags or cavities, enhancing recruitment of woody debris and where necessary under-planting with desired species. Forest stands with high spatial heterogeneity (indicated by a large number of gaps) are typically a result of continuous moderate-intensity canopy disturbances (Lerzman and Fall, 1998; Bradshaw et al., 2011). Many non-traditional approaches can be taken in thinning for designing multispecies and multi-storeyed stands that mimic such a moderate-intensity disturbance regime (Coates and Burton, 1997; Fulé et al., 2005; Keeton, 2006; Vanha-Majamaa et al., 2007; Felton et al., 2010).

The aim of this study was to examine the early effects of treatments that targeted restoring naturalness in Estonian hemiboreal protected forests. Study questions we addressed were: (1) what were the initial effects of restoration treatments on biological diversity and (2) were there significant differences on assemblages of understory and beetle diversity and abundance of deadwood between restoration treatments? To address these questions we focused on detection of small changes at an early stage after restoration treatments.

2. Materials and methods

2.1. Study design

The study was carried out in Estonia (lat. 58–259N, long. 26–209E), which is situated in the hemiboreal vegetation zone (Ahti et al., 1968). The climate varies from maritime to continental. Annual average precipitation ranges from 600 to 700 mm. Mean temperature ranges from 16.3 to 17.4 °C in July and from −2.0 to −7.4 °C in February. Forests cover 51% of the land area of the country and the terrain is flat. Forests under some form of protection are 26% of the total forest area; about half of them are situated in nature protection areas (Yearbook, 2010).

The study was connected to the LIFE-Nature project "Protection of priority forest habitat types in Estonia" where one of the purposes was naturalness restoration on recently designated protected areas that had a low-level of naturalness and diversity. Stands requiring restoration that were selected included plantations, middle-aged (30–60 years old), normally or densely stocked, pure coniferous (*P. sylvestris* or *P. abies*) stands growing on mineral soils. Restoration treatments were implemented altogether on 350 ha in seven nature protection areas in Estonia according to existing management plans. For monitoring the restoration process, in 2004 50 permanent sample plots (PSPs) were established in 23 forest stands with total area of 78.1 ha (Korjus, 2005).

The 50 restoration treatment plots were divided into 27 with interventions and 23 without interventions designated as control plots (Table 1). Plots were established before treatments, re-measured after treatments and then re-measured after 3 years. In the 27 forest stands studied there was at least one treated plot and one control plot. Four stands had two treated plots and one stand had three treated plots.

The primary treatment was to create gaps (72–1463 m^2) by removing overstory trees; gaps were defined as an opening in the forest canopy extending vertically through all layers down to 2 m above ground (Brokaw, 1982). Our treatments were a single gap (G) with four installations; a gap with added dead wood (GDW) with 17 installations; and four installations with low intensity fire from burning branches and needles at the end of summer within a gap (GB). Intentional burning in the forest is usually not allowed in Estonia, even for research purposes. Other treatments included two installations with added dead wood but no overstory manipulation (DW) and 23 controls with no manipulation (C).

The PSP were established as a circular layout with a radius ranging between 15 and 25 m. The PSP radius varied depending on forest density and age structure, following the rule that every plot needed to include at least 100 main canopy trees before treatment. On each plot before treatment the tree coordinates were determined by measuring azimuth and distance from plot cente. Diameter at breast height (DBH) of each tree larger than 4 cm was measured. For every fifth tree the total height and height to crown base were measured.

Mortality was calculated for the 3 year period after treatments. The cause of mortality of each dead tree was categorized into (a) density dependent mortality; (b) wind damage; (c) game damage; (d) insect attacks; (e) fungi and diseases; (f) others (Laarmann et al., 2009).

Regeneration establishment was recorded in newly established measurement plots on each treatment plot in 2008. Five 25 m^2 subplots were established on each treatment plot. Subplots included one in the center of the treatment plot and the other four subplots were each located 10 m from the plot center in cardinal directions. All seedlings in each subplot were counted by tree species and the two tallest seedlings of each species were selected for height measurement.

We used a crown shape model (Lang and Kurvits, 2007) to reconstruct crowns for gap size estimation. Based on the methods of Green (1996) we used sixteen distance/direction coordinates as a polygon to estimate the gap area, which is more accurate (Zhu et al., 2009) than the widely used method of Brokaw (1982).

Biodiversity in a given area is usually evaluated through surveys of species richness in different taxonomic groups (Terradas et al., 2003; Liira and Sepp, 2009). Data on understory vegetation were collected before, immediately after and 3 years after treatments. Herbaceous species and mosses were surveyed using a step-line intercept method (Jõgiste et al., 2008). On each PSP a permanent quadrate (5 × 5 m) was located 4 m from the center of the PSP in the north direction. Within the quadrate, species were recorded on step-line, where after each step a 10 × 10 cm square was described, resulting in total 100 squares. Lichens were inventoried on selected host material before treatment and measured 1 and 3 year after treatments (Jõgiste et al., 2008). Lichens sampling was done on: (1) 5 randomly selected main canopy trees (dominating tree species), (2) all trees from co-dominating tree species on the plot, (3) five standing dead trees or/and snags (diameter > 10 cm), (4) from three different fallen logs and (5) from three different decaying stumps and root mound.

Beetle diversity was inventoried with flight-intercept traps on the treatment areas. Beetle diversity was not monitored on control plots as forest stands are quite small (1–2 ha) in Estonia and control plots are close to treatment plots. Therefore any treatment in a stand influences beetle fauna also on control plot and control plot does not represent an area without treatment. In total 22 traps were set out and beetles were collected six times (every 2 weeks) during the summer of the pre-treatment year and in years one and three after treatment. 82% of the all beetles collected were identified to the species level.

2.2. Data analysis

Biodiversity was calculated using the coverage data per species and the total coverage by species group using Shannon–Wiener