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# Impacts of shelterwood logging on forest bryoflora: Distinct assemblages with richness comparable to mature forests

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ABSTRACT

Shelterwood (SW) cutting is a silvicultural method for establishing natural tree regeneration. It is considered to be less destructive for forest biodiversity than intensive harvest methods. In boreal forests, bryophytes are an important taxonomic group, but are vulnerable to changes caused by intensive forest management. To date, the effect of SW cutting on bryophytes has been insufficiently tested, particularly if the entire cutting cycle and different forest-type groups are included. Bryophyte assemblages and forest structural features were surveyed at the stand scale in 30 dry and fresh boreal study sites to test which factors influence bryophyte species richness and composition in SW cuttings as compared to mature managed forests. Total species richness of bryophytes was generally higher in mature forests (123 species) compared to SW cuttings after the first (96 species) and final (90 species) stages of the cutting rotation, but the mean stand scale richness was similar among SW cuttings and mature stands. Independent of the management, a higher number of deciduous trees favoured richness of mosses and liverworts, the latter also positively influenced by the volume of well-decayed logs. Bryophyte assemblages of the first and completed SW cut sites were similar, but distinct from those of mature forests. This pattern also held if mosses and liverworts were analysed separately or if assemblages of the same substrate type (i.e. live trees, stumps, dead wood) were compared between management treatments. The general impact of SW cutting on bryophytes was mild in dry boreal sites, but destructive for species of conservation concern in fresh boreal sites. Retaining a higher density of coniferous and deciduous trees during the SW rotation, as well as careful retention of dead wood legacies (snags and logs), is critical to support bryophyte assemblages in SW post-cut sites.

## 1. Introduction

It has been shown that intensive forest management methods, such as clear-cut harvesting, cause drastic changes in abiotic conditions in forest ecosystems, resulting in modified and impoverished communities of forest biota (Pawson et al., 2006). As a result, silvicultural alternatives have received more and more attention globally (Puettmann et al., 2015) and sustainable management of production forests has been one of the major goals of modern forestry (MCPFE, 2003). Bryophytes, being poikilohydric organisms, are a group of the taxa that are notable for their sensitivity to changes caused by intensive forest management practices. Numerous studies have reported a decline in abundance and/or changes in species composition, particularly of liverworts, following intensive harvest (Fenton and Frego, 2005; Shields et al., 2007; Halpern et al., 2012; Dynesius, 2015), mainly because of their dependence on a moist microclimate and the availability and diversity of woody substrates (McGee and Kimmerer, 2002; Lõhmus et al., 2007; Müller et al., 2015). However, retention of woody legacies can mitigate the impact of cutting disturbances (Lõhmus and Lõhmus, 2008; Pharo and Lindenmayer, 2009) and different harvesting methods can have different influences on bryophytes (Arseneault et al., 2012). One method considered to be less destructive than clear-cutting on the forest flora is shelterwood (SW) logging (Hannerz and Hånell, 1993, 1997). The latter involves a series of partial cuttings, where new trees start to grow beneath the protection of older shelter trees. The essential characteristic of this method is that the new stand is established naturally or artificially before the last of the old stand is removed (Wenger, 1984). SW logging can be laid out uniformly throughout a stand, or in groups or strips which extend through the whole stand. In European boreal and hemiboreal coniferous forests, a SW cycle (consisting of two or three partial cuttings) is usually completed within 10–20 years. The time of the next cutting depends on the establishment of natural

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regeneration (Lieffers et al., 2003). In pine forests, usually 100–200 trees $ha^{-1}$ are retained after the first step and 100 or fewer trees $ha^{-1}$ after the second step (Béland et al., 2000; Nilsson et al., 2002; Laas and Väät, 2004). SW logging differs from seed tree systems in that it retains a higher number of seed trees to achieve natural regeneration (Valkonen, 2000; Lieffers et al., 2003) and, unlike selection cutting where forest cover is permanent and includes different age classes, SW logging forms an even-aged stand structure (Lieffers et al., 2003).

Although the main aim of SW logging is the establishment of new tree regeneration, its application could also support the survival and recolonization of a bryoflora characteristic of mature forests. This is because the transition from a closed canopy phase to an open canopy phase is gradual, and new regeneration that provides shade is already present when the last trees are removed. It is known that following clear-cut and partial harvest practices, bryophyte communities that depend on dead wood and/or the bases and stems of living trees experience bigger changes than those on other substrates (Caners et al., 2013; Dynesius, 2015). However, harvesting also induces a pronounced shift in forest floor bryophyte communities, with the greatest change related to forest floor disturbance (Fenton et al., 2003; Dovčiak et al., 2006). Soil scarification is often used in SW logging to improve seedbed germination and increase soil moisture availability; therefore, changes in forest floor bryophyte communities can be expected after SW logging. Bryophytes are generally important in boreal forests for regulating soil moisture and temperature, and for affecting ecosystem C and N storage (Vanderprooten and Goffinet, 2009; Turetsky et al., 2010; Rousk et al., 2013). Thus, it is necessary to compare changes in the mature forest flora during the entire SW logging cycle in order to test how the SW logging regime affects the mature forest bryophyte species in the short- and long-term. To our knowledge, no such studies have been undertaken.

The overall diversity of bryophytes in boreal forest ecosystems varies considerably between forest types (Frisvoll and Prestø, 1997; Vellak and Ingerpuu, 2005). In addition, forest site type affects the magnitude of changes in understorey vegetation communities after harvesting practices, with the changes being smallest in forest site types characterized by low soil moisture and soil fertility (Lõhmus, 1970). Therefore, forest site type, as determined by the gradients of soil richness and moisture, needs to be considered when analysing the effect of harvesting practices on understorey vegetation.

In the current study, stand scale bryophyte floras were compared between mature managed forests and cut sites at either the first or final cut of the rotation in uniform SW cuttings. Study sites were selected from dry and fresh boreal forest types in hemiboreal Estonia. The questions under investigation were: (i) does stand scale bryophyte species richness and assemblage composition (and separately of mosses, liverworts and species of conservation concern) differ between management treatments (i.e. SW cut stages compared to mature forests)?; (ii) does the potential cutting impact depend on forest group type (i.e. dry vs fresh boreal)?; (iii) which forest structural features are linked with the observed patterns?; and (iv) do bryophyte assemblages on the same substrate type (e.g. bark of live trees, logs, stumps, ground) differ between management treatments?

The hypothesis tested were: (1) SW logging has a mild impact on bryophyte richness and assemblage composition; (2) the impact of SW logging is more pronounced for liverworts than for mosses; (3) the magnitude of the change in bryophyte communities after SW cutting is higher in fresh than in dry boreal forests; (4) within substrate type, SW practices have differential influences on bryophyte assemblages as compared to mature stands.

## 2. Materials and methods

### 2.1. Study area

The study was undertaken in Estonia in the hemiboreal forest zone and the northern temperate climatic zone. The long-term (1981–2010) average temperature in Estonia is 6.0 °C, with July being the warmest (17.4 °C) and February being the coldest (−4.5 °C) month, average annual precipitation is 672 mm (http://www.ilmateenistus.ee/kliima/kliimanormid). We focused on two forest type groups (sensu Paal, 1997): (i) dry boreal forests where the overstorey is formed by Scots pine (*Pinus sylvestris* L.) and the understorey vegetation is fairly species-poor, with dwarf-shrubs as dominants and a continuous cover of bryophytes; within this forest group, our study sites represent mainly the *Vaccinium vitis-idaea* site type, (ii) fresh (also called as mesic) boreal forests, where the overstorey is formed by Norway spruce (*Picea abies* (L.) Karst.) or by a mixture of spruce and pine, the understorey is diverse and bryophyte cover is continuous; within this forest group our study sites represent mainly *Oxalis* and *Oxalis-Vaccinium myrtillus* site types.

Within each forest type group (hereafter referred as forest site types), an equal number of stands per management treatment (n = 5) were chosen in mainland of Estonia, resulting in 10 mature forest stands (some earlier thinned or sanitary cut), 10 stands where the first stage of the shelterwood (SW) logging rotation had been completed (SW1) (5–9 years ago, on average 6.6 years), and 10 stands where the entire SW cutting cycle was completed (SWF) (4–14 years ago, on average 15,6 years since the first SW cutting) (Suppl. Table A1). Compared to pre-harvest conditions, an average of 42% of tree volume (56% of trees) was cut in SW1, and 90% of tree volume (95% of trees) in SWF. The age of the canopy trees in mature forests was, on average, 40–50 years younger than that of legacy live trees in SW stands, but this reflects the common practice in Estonia where SW is usually performed in overmature stands. The majority of the stands was located in the southern and eastern part of Estonia (Fig. 1) and soil scarification in SW stands was only performed after the first cut.

### 2.2. Data collection

In each stand, a 2 ha plot was delineated on the map without prior knowledge of the bryoflora. In five SW stands, the area managed by SW logging was slightly smaller in size (see Suppl. Table A1) and was included in full.

In mature managed forests within each study plot, forest structural characteristics were surveyed along four 50 m-long straight, spaced-out sampling lines. This included a description of (a) live trees of ≥10 cm diameter at breast height (DBH) within a corridor of 2 m to both sides of the line; (b) standing dead trees ≥1.0 m tall and of DBH (or top diameter) ≥10 cm as well as (c) tip-up mounds of uprooted trees, elevated ≥30 cm, within corridor of 5 m to both sides of the line; (d) lying deadwood of ≥10 cm diameter (i.e. coarse woody debris, CWD) at intersections with the line; (e) fine woody debris (FWD, 0.3–0.9 cm in diameter) at six 1-m sections established at 10-m intervals along the line.

Decay stage (a five-point scale) of standing dead trees was assessed at breast height and decay stage of logs and fine woody debris was recorded at the intersection within the line. For more details of the method, including measurement of the height of live trees, see Lõhmus and Kraut (2010).

In SW stands, forest structural characteristics were described within study circles (r = 15 m, with area 707 $m^2$) established in the plots. The number of study circles varied between three to five, depending on the size of study area. Diameter at breast height (DBH) of all living trees having DBH ≥ 10 cm was measured within each study circle. In addition, the height of at least 20 trees of each species was measured in each plot, and a logarithmic regression model was developed to calculate the