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Is shelterwood harvesting preferable over clear-cutting for sustaining dead-wood pools? The case of Estonian conifer forests

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ABSTRACT

Shelterwood is commonly assumed to be a more nature-friendly silvicultural system than clear-cutting. However, dead-wood pools – a key characteristic of natural forest – have been seldom compared between these systems. We investigated how shelterwood harvesting influences the dynamics of different dead-wood fractions in Estonia, where the predominant forestry model is clear-cutting based but 'seminatural' (using native tree species and, to a significant extent, natural regeneration). We measured dead-wood pools in 49 Scots pine-dominated stands (representing all shelterwood harvesting stages), and in 11 pine-dominated and 10 Norway spruce-dominated stands as before-after experiments (1st stage only). We analysed dead-wood amounts in relation to site conditions and the proportion of timber harvested, and we compared the shelterwood impacts with published estimates from Estonian clear-cuts. Fine woody debris (5–9.9 cm) increased with the harvest. The volume of coarse woody debris was 19–27 $m^3\,ha^{-1}$ in uniform shelterwood stands in pine forest (0–25 years after the first harvest); 63 $m^3\,ha^{-1}$ in strip shelterwood stands in spruce forest (immediately post harvest). In before-after experiments, post-harvest dead-wood amounts depended on fraction and harvesting intensity, which determines the balance between the input of new debris (logs; stumps) and the loss of pre-existing standing and downed dead trees. After the first shelterwood harvesting, dead-wood pools remained relatively stable, which contrasts with the large fluctuations after clear-cutting. In the long term, however, shelterwood did not sustain generally larger dead-wood pools than the clear-cutting system in seminatural forestry setting. The issue to be resolved in both types of regeneration cuttings is the near-complete loss of standing dead trees, which probably requires new harvesting techniques.

1. Introduction

A major aim of sustainable forest management is to reduce the environmental impacts of timber harvesting (United Nations, 1992). Shelterwood silvicultural systems were historically designed to promote natural tree regeneration under the protection of older (shelter) trees before their removal. This can be achieved by harvesting either individual trees (uniformly or irregularly), tree groups or strips during 2–3 entries (Matthews, 1989). The strip shelterwood is preferred in spruce forest, because windthrow risk is higher in uniform shelterwood (Holgén and Hånell, 2006). The interval between shelterwood harvests (stages) depends on tree species, regeneration success, and it can be between 3 and 20 years (Matthews, 1989).

In temperate Europe, shelterwood has been considered a more nature-friendly silvicultural system than clear-cutting (e.g. Brang et al., 2014), although the benefits depend on the intensity of shelterwood management (Brunet et al., 2010). In principle, natural regeneration helps to retain local gene pools of the trees, and the typically high seedling densities ensure a high selection potential (Fady et al., 2016). Gradual removing of shelter trees also helps to retain forest vegetation better than abrupt clear-cutting (e.g. Hannerz and Hånell, 1997; Tullus et al., 2018).

It is less clear whether shelterwood systems have advantages over clear-cutting in terms of dead wood pools. Promoting silvicultural systems that maintain more natural-like dead wood pools is an important task because the amount and composition of dead wood are major factors for forest biodiversity and a key indicator of sustainable forest management (e.g. Stokland et al., 2012; Forest Europe, 2015). Many studies have shown that, in general, intensive forest management decreases total dead wood pools (Siitonen, 2001; Hahn and Christensen, 2004), and some fractions are particularly vulnerable to removal or suppression: e.g. snags (Wisdom and Bate, 2008; Perry and

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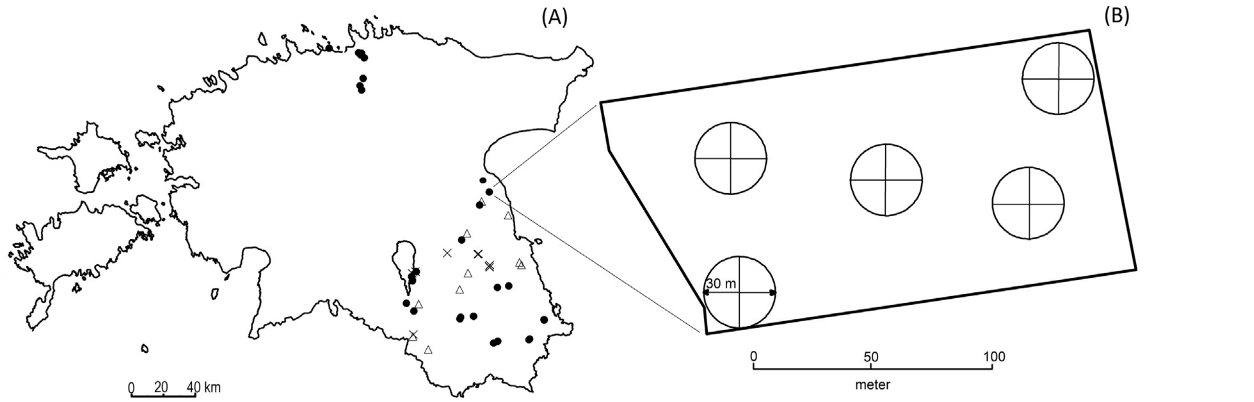

Fig. 1. Locations of the shelterwood study plots in Estonia by setup (A): uniform shelterwood cuts (initial cut 3–25 years ago; N = 49) – filled circles; "before–after experiments" in pine forests (N = 11) – crosses; "before–after experiments" in spruce forests (N = 10) – triangles. The subgraph (B) illustrates a 2-ha study plot with sampling circles and transects inside the circles.

Thill, 2013), large trunks, and wood in advanced stages of decay (Siitonen et al., 2000; Lõhmus and Kraut, 2010). Although harvesting events can also create substantial amounts of dead wood on site, that supply does not last long and it typically contains much fine debris, while well-decayed coarse woody debris (CWD) is mostly lost (Montes and Cañellas, 2006; Lõhmus et al., 2013).

Both in shelterwood and in other silvicultural systems, dead wood pools can be expected to vary depending on harvesting intensities and the time-frame considered. After the first harvest entry, the amounts of logging waste and stumps are usually smaller than after clear-cutting, but additional amounts are created during the subsequent entries (Vanderwel et al., 2009). If the retained shelterwood stock becomes prone to windthrow, fallen trees may increase in abundance. Fallen trees may be soon harvested however, e.g. during the next shelterwood entries, salvage logging (in case of extensive damage) or removals for fuelwood. Such additional tree removals might explain why some shelterwood systems have very little dead wood (e.g. Brunet et al., 2010). In clear-cutting systems with green-tree retention, tree deaths are less frequent but, in principle, that new dead wood is not removed (e.g. Gustafsson et al., 2012). Dead-wood pools are also vulnerable to mechanical site preparation (scarification) for regeneration (Hautala et al., 2004). Because scarification is a common practice in the shelterwood system, its relative habitat quality may depend on whether it is compared to clear-cutting systems with (e.g. Kruys et al., 2013) or without similar treatment (e.g. Lõhmus et al., 2013).

In this paper, we describe the dead wood supply of a shelterwood system in Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) stands in Estonia. These two conifers comprise major commercial tree species in the country's predominantly clear-cutting based forestry; the conifer rotations are 60–130 years depending on tree species and site fertility. However, a distinct feature of the Estonian clear-cutting system is frequent use of natural regeneration, i.e. mostly dense deciduous regrowth. This, combined with less intensive thinning practices, has favoured natural development of diverse dead wood and supported dead-wood inhabiting species in the recent past (e.g. Lõhmus and Kraut, 2010; Lõhmus et al., 2016). Although shelterwood harvests only form 7% of the total final felling area in the last years (Estonian Environment Agency, 2017), the Estonian legislature specifically prescribes using shelterwood, instead of clear-cutting, in areas with environmental restrictions.

We address two goals. First, we use original field data for exploring three central questions about dead-wood input, loss, and diversity in the shelterwood system. (i) Can the repeated input of dead wood from subsequent harvest entries alleviate dead wood shortage, especially of CWD, that is characteristic of mid-aged post clear-cut stands? (ii) How extensive is the loss of biologically important well-decayed CWD due to repeated disturbance by felling machines and scarification (cf. Perry and Thill, 2013)? (iii) How much dead wood, and which kind, is added by pre-commercial thinnings that remove the relatively dense undesired natural regeneration after shelterwood? Our second goal is to compare dead wood amounts and dynamics in shelterwood (original data) and clear-cutting systems (published data: Lõhmus and Kraut, 2010; Lõhmus et al., 2013; Sellis, 2014). As indicated above, such comparisons depend on the harvest approaches used, but the broad question is whether clear-cutting with much legacies (such as practiced in Estonia; Lõhmus et al., 2013) can be better than shelterwood for wood-inhabiting species. The answer would contribute to an understanding whether increasing the share of shelterwood among final fellings might be warranted.

2. Methods

2.1. Study areas

The study was carried out in Estonia – a lowland country in the European hemiboreal vegetation zone. The long-term average annual precipitation is 650 mm; the average temperature is 17.0 C in July and −6.7 C in January. The 70 study plots were located in south-eastern and northern parts of the country and comprised three setups (Fig. 1A).

One setup included 49 uniform shelterwood (hereinafter "shelterwood") plots, which represented three stages (Fig. 2, see also Appendices A and C) : (I) the first (regeneration) harvest only (N = 27; age range 3–19 years since the harvest); (II) two harvests of a three-stage shelterwood (10–15 years after the first harvest; N = 12), and (III) finalized shelterwood harvest in 2–3 stages (11–25 years after the first stage; N = 10). The harvests had been performed with chainsaws (earlier years) or harvesters (recent years); the logs had always been transported using forwarder tractors. Twenty-seven plots had been scarified after the harvest. The information about harvest times was obtained from the database of the State Forest Management Centre. Based on soil moisture and fertility conditions, the shelterwood plots were classified into two broad types of forests that are common in Estonia. 'Dry forests' included nutrient-poor Scots pine dominated stands on dry to moist mineral soil: *Cladonia* (N = 2), *Vaccinium vitis-idaea* (N = 22), *Vaccinium myrtillus* (N = 5) and *Oxalis–V. vitis-idaea* (N = 8) site types (Lõhmus, 1984). '*Oxalis*-type forests' included pine or Norway spruce dominated productive forests of *Oxalis* (N = 6) and *Oxalis–V. myrtillus* (N = 6) site types.

We had two "before-after" (BA) experimental setups: pine-dominated and spruce-dominated stands, which were measured before and 0–2 years after the first shelterwood harvesting. In all these plots, the ground was scarified after the harvest. The 11 pine-dominated plots represented uniform shelterwood cutting in *Oxalis–V. myrtillus* (4), *Oxalis–V. vitis-idaea* (3) and *Vaccinium vitis-idaea* (4) site types. The 10