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Effects of stump harvesting on soil C and N stocks and vegetation 8–13 years after clear-cutting ☆

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ABSTRACT

Effects of stump harvesting on coarse woody debris (CWD), soil and vegetation were investigated 8–13 years after clear-cutting of eight forest stands located at two sites, Honkola and Haukilahti, in Central Finland. Norway spruce (*Picea abies*) was the dominant tree species in the harvested stands. Four of the stands were subjected to mounding and four were stump-harvested. Logging residues were removed at harvest from all eight stands.

The amount of CWD remaining after stump harvesting was estimated from basal area of remaining stumps, diameter and length of logs and by weighing smaller pieces of dead wood. Moss and field layer vegetation cover was estimated by a point-intercept method and the diameter of young trees was measured to estimate basal area. Soil carbon and nitrogen stocks and pH were determined in the humus layer and down to 25 cm depth in the mineral soil. The degree of soil disturbance was visually assessed in the field.

Basal area measurements on remaining stumps suggested that about 75% of the stumps had been removed from the stump-harvested stands, which is a typical stump harvesting rate in Finland. The amount of remaining stumps and root biomass was significantly lower in stump-harvested stands than in stands where stumps had been retained, whereas differences between mounding and stump harvesting were not significant for the other types of CWD. Stump harvesting had no significant effect on the cover of field layer species, total moss cover or vegetation composition. Total stem density was almost twice as high in stump-harvested stands as in stands where stumps were not harvested, due to significantly higher stem density of *Betula pendula* Roth., whereas no effect was observed on the basal area of the other tree species. No significant treatment effect on soil carbon and nitrogen stocks or on degree of soil disturbance was detected, but the higher density of *Betula* indicates higher exposure of mineral soil during the years following stump removal. In conclusion, stump harvesting seems to promote natural establishment of *Betula* seedlings, but does not change tree productivity.

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1. Introduction

Tree stumps are a significant source of biomass and represent one of the few remaining possibilities to increase the use of renewable energy sources for bioenergy production in Sweden and Finland. At the same time, the sustainability of stump harvesting has been disputed. In particular, there are concerns about the climate benefits of using stumps for energy and the effects of stump harvesting on biodiversity (Walmsley and Godbold, 2010; Lattimore et al., 2013; Persson, 2013; Repo et al., 2015).

In Finland, stump harvesting started on a large scale in the year 2000. A recent estimate (for 2010) is that about 20,000 ha per year is stump-harvested in Finland (Juntunen and Herrala-Ylinen, 2011; Kellomäki et al., 2013). Stump harvesting for energy purposes started later in Sweden and since 2011 is restricted by Swedish FSC certification regulations to a total of 2500 ha per year in FSC-certified forests (Helmisaari et al., 2014). Knowledge gaps about environmental issues relating to stump harvesting are at present a major barrier to extending stump harvesting in practice.

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The main technique for extracting stumps in Sweden and Finland is currently the use of an excavator equipped with a hydraulic stump harvester head, e.g. the Pallari KH-160 device, which breaks up and splits stumps and coarse roots (Laitila et al., 2007, 2008). Stump lifting often creates pit-like cavities in the soil that are sometimes levelled by the excavator, but additional soil damage is caused by operations with both the excavator and the forwarder. The extent of soil damage caused by these operations depends on the physical stability of the soil, which varies with season, soil texture and groundwater level.

Site preparation is a normal practice following clearcutting in Sweden and Finland, with the aim of facilitating the establishment and growth of the new stand. Spot mounding is the most common method used to establish Norway spruce stands (Hallsby and Örlander, 2004; Rantala et al., 2010). Stump harvesting reduces, but does not exclude, the need for additional site preparation. Stump harvesting is therefore combined with site preparation (Laitila et al., 2008; Rantala et al., 2010). In contrast to site preparation techniques, stump harvesting removes coarse roots that augment the physical stability of soils, and therefore stump extraction can be expected to cause more severe soil disturbance than site preparation. Stump harvesting often increases the area of soil disturbance to 70–80%, in comparison with 25–50% for mounding (Kardell, 2010; Kataja-aho et al., 2012; Strömgren et al., 2012; Strömgren and Mjöfors, 2012; Saksa, 2013).

Previous studies on site preparation suggest that increased soil disturbance can increase the rate of soil organic matter decomposition (Johnson, 1992; Johansson, 1994; Lundmark-Thelin and Johansson, 1997; McLaughlin et al., 2000) and thereby deplete soil carbon (C) stocks. Other studies suggest that the impact of soil disturbance on soil carbon C varies and also depends on soil characteristics, the soil layers included in the study (Nordborg et al., 2006) and the intensity of soil disturbance (Johansson, 1994; Schmidt et al., 1996; Örlander et al., 1996; Mallik and Hu, 1997; Clarke et al., 2015).

Carbon balance at the ecosystem scale is a crucial component of the climate impact of using stumps for energy, and both direct and indirect effects can be identified. The direct effect is an inevitable reduction in CO_2 emissions from forest soils due to the lower amounts of dead organic matter (i.e. stump and root biomass) left on-site after stump harvesting (e.g. Repo et al., 2011; Palviainen and Finér, 2015). In managed forests the most important indirect effects include potential changes in soil organic matter decomposition rate or changes in litter production during the following rotation period.

Possible indirect effects of stump harvesting on soil C dynamics have been studied by e.g. field measurements of CO_2 emissions from soil. Strömgren and Mjöfors (2012) and Strömgren et al. (2012) observed a small short-term increase in CO_2 emissions after stump harvesting compared with site preparation. Grelle et al. (2012) found that after three years, the CO_2 emissions estimated by eddy covariance measurements were equally high in stump-harvested plots and in plots with intact stumps. However, long-term studies are needed to monitor the dynamics of CO_2 emissions and soil C pools.

Hyvönen et al. (2012) used data from long-term slash (tops and branches) harvesting experiments to predict the C dynamics in four coniferous stands. The simulations, which only included direct effects of harvesting slash and stumps, showed that stump harvesting in combination with slash removal initially resulted in a strong reduction in soil C pools, an effect which was more pronounced in low-production than in high-production systems. The duration of the lowered soil C storage effect after intensified biomass harvesting is not empirically known. A soil C investigation 25 years after experimental stump and slash harvesting did not show any persistent differences in soil C stores between the treatments over time, as remaining stumps and logging residues continued to decompose and the regenerating stand produced litter, building up the soil C stocks (Strömgren et al., 2013). Karlsson and Tamminen (2013) studied the effect of stump and slash removal (no site preparation was used) in a trial on the west coast of Finland 33 years after final harvest. They found that the organic layer was thinner after stump and slash harvesting than after only slash harvest, but observed no other effects of stump harvesting on the carbon and nutrient stocks in the organic layer and the 0–10 cm mineral soil layer.

In addition to the uncertainties about the climate benefits, the impact of stump harvesting on biodiversity has been mentioned as a particularly challenging issue. Recent studies have focused on organisms associated with stumps and other coarse woody debris (CWD) (e.g. Caruso and Rudolphi, 2009; Persson, 2013; Persson et al., 2013), whereas observations on changes in the diversity of understorey vegetation are relatively few (e.g. Kardell, 2010; Andersson, 2012; Tarvainen et al., 2015). Clearcutting alone is reported to cause significant disturbance to the late successional understorey vegetation of forests (Palviainen et al., 2005). The additional disturbance of stump harvesting causes further damage to the understory vegetation, but also creates potential sites for establishment of pioneer flora. However, there are only a few studies on tree seedling establishment. In one such study by Saksa (2013), the number of birch seedlings was higher after stump harvesting than after mounding, but there was a large variation between regeneration areas. Kardell (2010) found no differences in tree biomass production between stump-harvested and control plots in a study including nine field trials across Sweden over 27 years. Another Swedish experimental series including four trials showed site-specific effects on tree biomass 25 years after final felling (Strömgren et al., 2013). Stump harvesting increased the C stocks in the biomass of *Pinus sylvestris* at a site in northern Sweden, whereas a decrease in C stocks was only observed following stump and slash in Norway spruce, *Picea abies* (L.) Karst., stands in central Sweden.

The aim of the present study was to compare the effects of stump harvesting and site preparation (mounding) on soil C and nitrogen (N) stocks, young trees, field layer vegetation and the amount of CWD in forest stands 8–13 years after harvesting. This stand age was chosen for the study since there is a general lack of knowledge on stump harvesting effects beyond a few years of it taking place. The study was carried out in Central Finland and compared eight clearcut stands of Norway spruce, four with and four without stump removal. Logging residues were harvested in all stands and the stands were planted with Norway spruce seedlings after site preparation.

Based on the previous studies mentioned above, our starting hypotheses were that 8–13 years after stump harvesting, we would still be able to detect (i) a decreased amount of CWD, (ii) increased soil disturbance, (iii) higher abundance of pioneer species and lower abundance of late successional species and (iv) decreased soil C and N stocks.

2. Materials and methods

2.1. Study sites and design

Eight clearcut stands of Norway spruce (*P. abies* (L.) Karst.), four with and four without stump harvesting, were compared. The stands were located at two sites, Honkola (61°09′N, 23°25′E) and Haukilahti (61°48′N, 24°48′E), near the city of Tampere in Central Finland. The two clearcut stands in Honkola were located approximately 300 m apart, while the six clearcut stands in Haukilahti were located within a 4 km × 4 km area. Clearcut stands were selected to obtain similar site productivity, soil type and moisture

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