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Logging residue removal after thinning in Nordic boreal forests: Long-term impact on tree growth

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ABSTRACT

The aim of this study was to determine the effect of whole-tree harvesting (WTH) on the growth of Scots pine (*Pinus sylvestris L.*) and Norway spruce (*Picea abies* (L.) *Karst.*) as compared to conventional stem harvesting (CH) over 10 and 20 years. Compensatory (WTH + CoF) and normal nitrogen-based (CH + F or WTH + F) fertilisation were also studied. A series of 22 field experiments were established during 1977–1987, representing a range of site types and climatic conditions in Finland, Norway and Sweden. The treatments were performed at the time of establishment and were repeated after 10–13 years at 11 experimental sites. Seven experiments were followed for 25 years.

Volume increment was on average significantly lower after WTH than after CH in both 10-year periods in the spruce stands. In the pine stands thinned only once, the WTH induced growth reduction was significant during the second 10-year period, indicating a long-term response.

Volume increment of pine stands was 4 and 8% and that of spruce stands 5 and 13% lower on the WTH plots than on CH during the first and the second 10-year period, respectively. For the second 10-year period the relative volume increment of the whole-tree harvested plots tended to be negatively correlated with the amount of logging residue. Accordingly, the relative volume increment decreased more, the more logging residue was harvested, stressing the importance of developing methods for leaving the nutrient-rich needles on site.

If nutrient (N, P, K) losses with the removed logging residues were compensated with fertiliser (WTH + CoF), the volume increment was equal to that in the CH plots. Nitrogen (150–180 kg ha^{-1}) or N + P fertilisation increased tree growth in all experiments except in one very productive spruce stand. Pine stands fertilised only once had a normal positive growth response during the first 10-year period, on average 13 m^3 ha^{-1}, followed by a negative response of 5 m^3 ha^{-1} during the second 10-year period. The fertilisation effect of WTH + F and WTH + CoF on basal area increment was both smaller and shorter than with CH + F.

1. Introduction

Forest biomass is increasingly being used as an energy source. Forest bioenergy sources include logging residues and small-size or inferior-quality tree stems that are normally not harvested in conventional harvesting and stumps. In Finland the National Forest Program has set a target to double the annual domestic use of forest chips from 4.6 (in 2008) to 8–12 mill. m^3 by the year 2015, amounting to half of the annual estimated forest chip harvesting potential of 16 mill. m^3 (Ylitalo, 2007). In Norway the government has proposed to increase the use of bioenergy with 14 TWh before 2020 (St. meld. nr. 34 2006–2007). This means a doubling of the current production, and most of this increase is expected to come from forest biomass. Langerud et al. (2007) estimated the annual potential from harvesting residuals (branches and tops) in Norway to be 2.7 mill m^3. The proportion of biofuels used in the Swedish energy system has steadily increased, from a little over 10% of the total energy supply in the 1980s to 20% in 2008. A major part of the biofuels are domestic, and originating from the forest, industrial forest residues being the primary bioenergy source (Egnell, 2011).

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Since the nutrient demand of a tree stand is high at the thinning stage (Mälkönen, 1974), such stands may be rather sensitive to nutrient removal with logging residues (Jacobson et al., 1996). At the stage when Scots pine and Norway spruce stands are thinned, the tree crown contains about one third of the dry matter but two thirds of the total amount of nutrients (Mälkönen, 1976). In Nordic long-term experiments, up to 10,000 kg C ha^{-1} and 130 kg N ha^{-1} was removed with logging residues at the first thinning (Jacobson et al., 2000), and these values could be even higher depending on the thinning intensity. The removal of logging residues may cause a long-term reduction in soil nutrient availability for the remaining tree stand, but the effects are site- and practice-specific (Raulund-Rasmussen et al., 2008; Lattimore et al., 2009). Olsson et al. (1996) reported that leaving logging residues on the site decreases the organic layer C/N ratio, improving site fertility.

The 10-year results of the Nordic thinning experiment series showed that whole-tree harvesting (WTH) in thinnings caused a reduced tree volume increment in Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) *Karst.*) stands by 5% and 6%, respectively, and it was suggested that the reduction was a result of a reduced nitrogen (N) supply (Jacobson et al., 2000).

The aim of this study was to determine the effect of whole-tree harvesting (WTH) on the growth of Scots pine and Norway spruce as compared to conventional stem harvesting (CH) over 10 and 20 years. Seven out of the studied 14 Finnish stands, together with four Swedish and four Norwegian stands, belong to the Nordic experiment series, the 10-year results of which were published by Jacobson et al. (1996, 2000). This study lengthens the time span and enlarges the material of the previous studies. Normal fertilisation (F) and so called compensatory fertilisation (CoF) with (CH + F) and without (WTH + F/CoF) logging residues were also studied.

Nitrogen is the main nutrient limiting growth on mineral soils in the Nordic countries (e.g. Kukkola and Saramäki, 1983). Our main hypothesis was that WTH decreases tree growth in relation to CH, and this change depends on the amount of nutrients, especially nitrogen, removed in logging residues. Also, we hypothesized that the growth reduction after WTH can be prevented by compensatory fertilisation.

2. Material and methods

2.1. Sites and stands

Field experiments were established during 1977–1986 in Scots pine and Norway spruce stands that had reached the first thinning stage. The stands represent a wide range of climatic conditions and site types (Fig. 1, Table 1). The mean stand age was 44 years at first thinning, ranging between 24 and 71 years (Table 2). Most of the experiments are situated in the humid continental region with long-term (1961–1990) mean annual effective temperature sums (threshold +5 °C) between 1010 and 1380 d.d. (degree days). Two experiments were situated in northern Finland and Sweden in

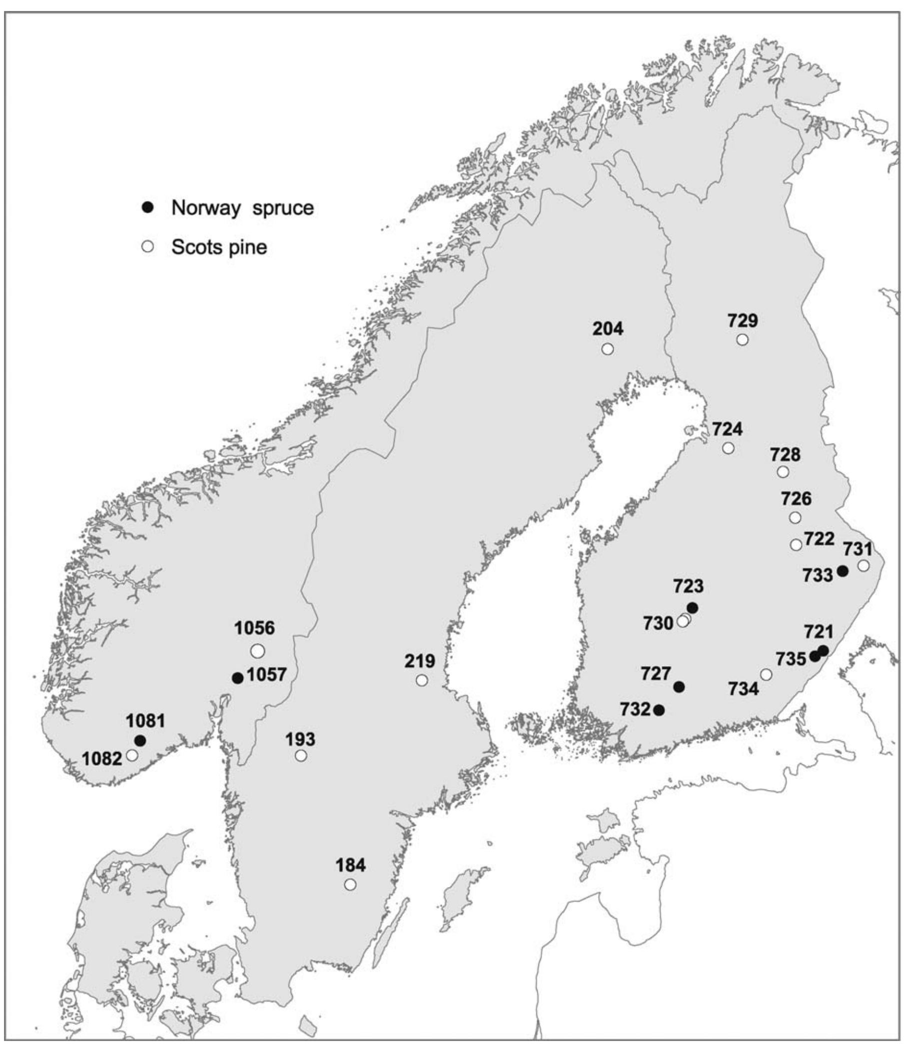

Fig. 1. Location of the experiments in Scots pine (white symbols) and Norway spruce (black symbols) stands.