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Tree and stand recovery after heavy diameter-limit cutting in Norway spruce stands

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ABSTRACT

Stand development after heavy diameter-limit cutting in spruce forests in southern Finland was addressed in this study. Tree diameter growth, regeneration and undergrowth, stand structure, and volume yield level were addressed with data from an experimental set of six stands. They were harvested once with a breast-height diameter limit of 21–23 cm and left to recover for 26–29 years until remeasured and studied. Spruce regeneration was abundantly present with an average of 5000 seedlings (height 3–129 cm) ha^{-1}. Additionally, there were some 500 saplings (diameter at breast height 0.1–4.0 cm) ha^{-1}, which included both the regeneration established and developed after the harvest and included seedlings and saplings that were already present before the harvest. Trees in all size classes reacted to partial release with accelerating diameter increment without substantial lag. Trees with a high initial diameter had a consistently higher average growth rate than smaller trees. The stands had recovered quite well and evolved into fully stocked stands with a high number of trees in the lower canopy layers, implicating good prospects for the application of sustainable single tree selection. The average stand volume growth was 4.9 m^3 ha^{-1} $year^{-1}$, which was close to the level achieved in single tree selection with spruce in the area. Heavy diameter-limit cutting had not resulted in the depletion or destruction of stands.

1. Introduction

In this article, we applied the definitions for the cutting and management methods as defined in The Dictionary of Forestry (Helms, 1998). In selection management methods, a multiaged stand structure is maintained by removing some trees in all size classes. In single tree selection, individual trees of all size classes are removed more or less uniformly throughout the stand, to promote growth of remaining trees and to provide space for regeneration. In diameter-limit cutting, all merchantable trees above a specific diameter limit are harvested, with or without the cutting of some or all cull trees. In principle and in definition, diameter-limit cutting is roughly identical to high-grading, which usually refers to an ultimately destructive form of the harvesting principle. Heavy high-grading gives no consideration to the condition and future of the remaining stand, and it tends to leave a residual stand composed of trees of poor condition, especially if the remaining smaller trees have been severely suppressed in a stand with a large standing volume.

This study was based on experimental diameter-limit cutting with two points of reference: Firstly, Sarvas (1944) concluded that the very low growth of high-graded spruce stands in Southern Finland was mostly attributable to low standing volume, but poor tree vigor and quality also played a major role in repeatedly and very heavily harvested middle-aged and older stands. This was a major point discrediting uneven-aged management in the Nordic countries from the 1950s until quite recently. Secondly, diameter-limit cutting acted as a proxy to very heavy selection harvesting, with the aim to contribute to research and practice with information from an ultimately inconsiderate treatment. The focus was on tree and stand response to harvesting in terms of tree increment, stand volume growth, and regeneration.

Contemporary studies focusing on diameter-limit harvesting in the Nordic area have not revealed such poor or outright catastrophic stand development and volume growth that Sarvas

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(1944) had encountered. Studies in comparable site and climatic conditions have shown rather more favorable stand developments and yield levels, while the treatments have been less drastic and destructive (Chrimes and Lundqvist, 2004; Lähde et al., 2001, 2010; Laiho et al., 2011; Pukkala et al., 2010; Lundqvist et al., 2013). Additionally, several studies on partial harvests resembling diameter-limit cutting or high-grading in northern and alpine conditions have shown variable stand development, growth, and regeneration patterns depending on treatments and sites (Lundqvist, 1994, 2004; Lundqvist et al., 2007; Øyen and Nilsen, 2002).

In single tree selection, a relatively high standing volume is often claimed to be necessary in order to sustain high volume production. This certainly is a very well-established relationship in even-aged management, hence seen as a cornerstone of all types of sustainable forestry. Indeed, higher volume production with higher standing volume has been shown in most studies with selection harvesting with spruce in the Nordic area, but the relationship has often been less pronounced (Lundqvist, 1989; Chrimes and Lundqvist, 2004; Lähde et al., 2002, 2010; Shanin et al., 2016 see also Lundqvist et al. (2007) for more studies in northern and alpine conditions). High volume growth with low standing volume would be economically very favorable while yielding higher interest rates on standing volume. Therefore Pukkala et al. (2010) concluded that the economically optimal postharvest basal area in single tree selection with spruce was 11.2–12.3 $m^2\,ha^{-1}$ on mesic *Oxalis-Myrtillus* (OMT) sites and 3.9–5.8 $m^2\,ha^{-1}$ on submesic *Myrtillus* (MT) sites (site types by Cajander, 1926). Similar levels (6.5–8.9 $m^2\,ha^{-1}$) were subsequently indicated by Pukkala et al. (2011, 2015). Tahvonen et al. (2010) found that the optimal density for the maximization of volume yield was 12 $m^2\,ha^{-1}$, but economically optimal solutions with 3–5% interest rates gave about 4 $m^2\,ha^{-1}$. Similarly Tahvonen (2011) calculated an optimum for the maximization of volume yield at 12.3–15.8 $m^2\,ha^{-1}$ and for the economic optimum at 2.2–8.7 $m^2\,ha^{-1}$, with most variation resulting from the interest rate. The simulated treatments have seemingly resembled high-grading in that trees were systematically removed simply based on diameter. However, impeccable vigor and response capacity has been assumed for the remaining smaller trees in the simulations, perhaps resulting in somewhat optimistic outcomes with very heavy harvesting.

If it is true that single tree selection thrives under heavy cutting (Lähde et al., 2002), it must logically result from a substantial response to partial release of trees in the lower canopy layers if their vigor and physiological response capacity is supported with repeated intensive harvesting of the larger trees. However, there is still very little empirical evidence to support the proposition regarding single tree selection with Norway spruce in the area. Lähde et al. (2002) stated empirical support for the hypothesis, but it was based just on stand-level volume growth in selection and low thinning treatments. The growth and response of individual trees has not been examined in this context. Eerikäinen et al. (2007, 2014) modeled the development of seedlings and saplings in spruce selection stands, but the details of response were not explicitly focused on.

Additionally, the establishment and maintenance of a sustainable single tree selection structure requires repeated regeneration and the maintenance of a reserve of vigorous undergrowth and smaller trees. The regulation of stand structure and density is obviously one of the keys for promoting the smaller trees, but research in the Nordic area has not produced conclusive results on the matter (Chrimes, 2004; Chrimes and Nilson, 2005; Eerikäinen et al., 2007, 2014; Lähde et al., 2002; Laiho et al., 2014; Lin et al., 2011; Lundqvist, 1989, 1991, 1993, 2004; Lundqvist and Fridman, 1996; Lundqvist et al., 2007; Nilson and Lundqvist, 2001; Øyen and Nilsen, 2004).

The purpose of this study was to examine stand development after heavy diameter-limit cutting throughout a long recovery period without further disturbance. We used research results from high-grading, as a particularly destructive form of diameter-limit cutting, and sustainable single tree selection in comparable conditions as points of reference. We hypothesized the following:

- tree growth response to partial release would be slow, involving a relatively long (5–10 years) period of stagnant growth,
- stand volume growth for the period would be substantially faster than in high-grading, approaching that of single tree selection,
- stand volume growth would be positively correlated with postharvest standing volume,
- regeneration (the number of seedlings and saplings) would be at comparable levels with single tree selection.

2. Material and methods

The study was conducted on permanent experimental plots that had been established as a part of a larger experimental set representing various even-aged and uneven-aged management regimes. Plots were located in the experimental forests of Natural Resources Institute Finland (Luke) at ten locations around southern Finland with 0–2 replications of each treatment per location. For the experiment in general and the diameter-limit cutting, too, late-middle age spruce forests were selected on the submesic *Myrtillus* (*MT*) or the mesic *Oxalis* – *Myrtillus* (*OMT*) site types (Cajander, 1926). The dominant tree species was Norway spruce (*Picea abies* Karst), with Scots pine (*Pinus sylvestris* L.) and silver and pubescent birch (*Betula pendula* Roth and *B. pubescens* Ehrh.) and European aspen (*Populus tremula* L.) as codominants with various proportions. A number of other broadleaf species occurred in minuscule amounts. Later on the experimental set was dismantled and the treatments were maintained, studied and reported rather independently from each other.

The stands were not managed after the initial treatment, because the treatment was considered redundant until now. Originally there were four locations with eight high-grading stands in the experimental set. One stand was excluded from this study because it had been harvested twice (unlike the rest with one harvest). One stand was excluded because its site conditions were too divergent, with distinctive peatland characteristics. Thus there were 3 locations (Lapinjärvi 60°30′N, 27°20′E, Padasjoki 61°20′N, 25°00′E and Suonenjoki 62°40′N, 27°10′E) with six stands in our material (see Fig. 1). The distance between stands within a location varied between 0.5 and 20 km. One (3 Lap12) was an *OMT* site, the rest were *MT*. In addition, all plots were heavily dominated by spruce. The average proportion of spruce stemwood volume was 81% (range 71–92%) at the end of the observation period (no data for the beginning of it).

The diameter-limit harvests were carried out in 1984–87 (Table 1). Trees above a predetermined diameter (d, diameter at breast height) limit of 21 or 23 cm were harvested if they yielded at least some sawlog-quality timber. Some trees that were not sawlog quality (with defects, deformations) were also retained, but they were very few and far between. Tree felling and bucking was carried out manually using chainsaws, and transportation with forwarders on four meter-wide strip roads about 20 m apart from each other.

Stand size was 1½–2 ha. In each stand, one experimental plot of 40 m ∗ 40 m was placed in its central part with good average representation of the stand in terms of site and structure (Fig. 2). All measurements were conducted on the plot. Before a harvest in