Forest Ecology and Management 350 (2015) 81–86

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Stand development during 16–57 years in partially harvested sub-alpine uneven-aged Norway spruce stands reconstructed from increment cores

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ARTICLE INFO

Article history:
Received 6 February 2015
Received in revised form 19 April 2015
Accepted 21 April 2015
Available online 5 May 2015

Keywords:
Picea abies
Selections system
Ingrowth
Stand structure
Volume increment
Continuous cover forestry

ABSTRACT

Long term effects of partial harvests were studied in seven uneven-aged *Picea abies* (L.) Karst stands in northern Sweden, by reconstructing stand development from increment cores. All stands had been subjected to partial harvests 16–57 years before the inventory. Two 1000 m^2 circular plots were established in each stand. All trees with a diameter at breast height (1.3 m above ground) ⩾5 cm were mapped and calipered. Historic stand development was reconstructed backwards in five year intervals to the year of the previous harvest, using increment cores taken from randomly chosen sample trees in each 2-cm diameter class.

The pre-harvest stem density was restored in all stands but one, at the time of the inventory. Average ingrowth of survived trees was 13 stems ha^{-1} yr^{-1}, but no relation was found between annual ingrowth and standing volume. Only four stands had inversely *J*-shaped diameter distributions after harvest, but all seven stands did at the time of the final inventory. Standing volume was 34–88 m^3 ha^{-1} after harvest and 126–207 m^3 ha^{-1} at the final inventory, with an average volume increment around 3 m^3 ha^{-1} yr^{-1} for the whole observation period. Volume increment increased with standing volume in all stands but one. The shapes of the diameter–height curves were similar for all stands, irrespective of the time elapsed since the harvest. In conclusion, the results from this study indicate that the selection system is a sustainable silvicultural system in uneven-aged sub-alpine Norway spruce forests. These forests have high resilience and a capacity to recreate stable diameter distributions after rather harsh treatments.

1. Introduction

Swedish forestry has been completely dominated by even-aged forestry and clear-cutting since the early 1950s. However, during the last decade or so, interest in uneven-aged forestry has been steadily growing among the Swedish public. The public debate began to accelerate in 2012 after several articles in Swedish daily press, and critical books (e.g. Zaremba, 2012), causing both forest professionals and politicians to request more knowledge on uneven-aged forestry.

A major alternative to even-aged forestry is the selection system. This system requires and preserves uneven-aged stands with a diameter distribution in which number of trees decreases over dbh (diameter at 1.3 m), usually roughly resembling an inverted *J* (Liocourt, 1898). To maintain this stand structure and a high continuous production of stem wood, trees harvested or self-thinned must be replaced by ingrowth from below, i.e. saplings must develop into small trees that grow into the tree stratum, which means that there must be a more or less continuous recruitment of new seedlings establishing in the forest (Lundqvist, 1991). In Sweden, of conifer species only Norway spruce (*Picea abies* (L.) H. Karst.) is assumed to be able to regenerate under a dense stand, and thus possible to manage with selection system.

The average level of annual ingrowth in an uneven-aged stand is controlled by three factors; number of saplings below the ingrowth threshold, and the growth and mortality among them (Lundqvist, 1995). In most studies ingrowth has been monitored for less than two decades. These studies indicate that ingrowth past 5–9 cm dbh is about 7–15 stems ha^{-1} yr^{-1} (Lähde et al., 2002; Lundqvist, 2004; Lundqvist et al., 2007). However 10–20 years is a short observation period considering the fact that it usually takes 40–60 years for seedlings to reach a height of 1.3 m (Nilsen, 1988; Lundqvist, 1989; Lundqvist et al., 2007) and another few decades to reach 5–9 cm dbh. As a result, changes in any or all of these three factors (number, growth, mortality) today may affect ingrowth not only today, but also several decades in the future.

A classical feature of uneven-aged forests managed with the selection system is the inversely *J*-shaped diameter distribution

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http://dx.doi.org/10.1016/j.foreco.2015.04.021
0378-1127/

(Meyer, 1952; Nyland, 1996). Lundqvist (2004) and Lundqvist et al. (2007) reported that stands subjected to partial harvests maintained or even improved their inversely *J*-shaped diameter distribution 10–20 years after harvest, as expected. In contrast to this, Nilsen (1988) and Lundqvist (1993) suggested that Scandinavian multi-storied Norway spruce stands tend to change into bell- or bimodal-shaped diameter distributions or even two-storied structures several decades after partial harvests.

The shape of a diameter distribution is mainly a result of the relation between diameter and diameter increment, i.e. the gradual increase in diameter increment over diameter (observed by e.g. Mitscherlich, 1952) creates a diminishing number of trees in consecutively larger dbh classes (Prodan, 1949). A silvicultural system for uneven-aged forests, with continuously re-occurring partial harvests, therefore requires that the forest contain more small trees than large trees. In an attempt to quantify the area of Swedish forests that could potentially be managed by such a silvicultural system, Anonymous (1992) invented a simple definition for stands potentially suitable for uneven-aged forest management and applied it on data from the Swedish National Forest Inventory (NFI): For each NFI survey plot the diameter range from 0 to the largest tree calipered on the plot was split in four equally wide dbh classes (D1–D4), each class thus representing one quarter of the diameter range. If the quota between the stem number in each class and the class above (D1/D2, D2/D3, D3/D4) was larger than one, the plot was classified as being suitable for uneven-aged management. This structural definition was later termed 'full-storied' by Lundqvist (1992), and also slightly modified such that the quota D3/D4 was excluded and replaced with only a requirement that both classes must contain trees, and less so than D2. So far it has not been tested if boreal Norway spruce forests in Fennoscandia can maintain such a full-storied stand structure over several decades.

The relationship between standing volume and volume increment in uneven-aged Norway spruce stands has been studied several times over the years. Most researchers have found a positive relationship, e.g. Näslund (1942), Lundqvist (1994), Lähde et al. (2002), Chrimes and Lundqvist (2004), and Lundqvist et al. (2007), but e.g. Øyen and Nilsen (2002) and Lundqvist (2004) found no relationship at all. Common for all these studies is that they only covered a relatively short time period, usually only the first 10 years after harvest, which means that a large part of the period studied was affected by what was in essence a thinning effect. Heavy thinnings are known to significantly reduce volume increment in uneven-aged Norway spruce forests (e.g. Näslund, 1942), which means that the positive relation could be a temporary effect, caused primarily by thinning strength and not by the size of the residual growing stock. Thinnings also increase the wind load on remaining trees, and increasing wind load may temporarily reduce height growth (e.g. Meng et al., 2008), thus causing a temporary reduction in volume increment. Studying effects of standing volume on volume increment, therefore, require long observation periods, and preferably stands on similar sites but with differences in standing volume.

In the absence of long time series of records from permanent sample plots or other continuously monitored forest stands, one way to study stand dynamics over long time periods is to reconstruct stand development from increment cores. In this study we reconstructed stand development from increment cores of living trees in seven uneven-aged Norway spruce stands, which had all been subjected to partial harvests in the past.

A major problem when reconstructing stand development from increment cores is that one usually has to base calculations of stem volume on some assumption about the historic height-diameter relationship in the stand. Uneven-aged spruce stands that are managed so that there are only moderate fluctuations in stand density usually have very stable height-diameter relationships (e.g. Mitscherlich, 1952; Shütz, 2001; Pretzsch, 2010). However, if such stands are subjected to heavier partial harvests there may be drastic changes in the height curve, changing from the normal curved shape to an almost linear shape (Lundqvist, 2004). Not accounting for this could cause an overestimation of annual volume increment of as much as 20% over a 20 year period (Lundqvist, 2004). To account for this we chose stands with a large span in the time since the last harvest.

The hypotheses were: (1) pre-harvest stem numbers will be restored and then maintained for several decades, (2) the diameter distributions will develop toward or remain roughly inversely *J*-shaped after the harvests, and will spontaneously strive toward being "full-storied", (3) the height curves will change from almost linear 15–20 years after harvest to the typically curved shape when stand density increase over time, and (4) stand volume increment will be positively correlated with standing volume throughout the observation period.

2. Material and methods

To find stands suitable for the study, the local forest authority in Vilhelmina was contacted, who then provided historical records of partial harvests in the area. Based on the records, 25 stands were selected for field inspection, with the aim of getting a good representation of the possible time span. All stands were visited in the summer of 1993, and rough estimates of standing volume, vertical structure, size distribution and field vegetation, were noted. Stands that were more single-storied than multi-storied were excluded, and also stands with small standing volume. The remaining 13 stands were sorted based on time elapsed since last harvest, and finally eight of them were chosen for the study. They were perceived to have similar standing volume and site conditions, and were well distributed on a time scale from 1937 to 1978. Field work was planned for the next autumn, but when the field crew reached one of the stands, partially harvested in 1947, it had been clear-cut during the winter, so only seven stands remained for the study.

All seven stands had been subjected to partial harvests in the past. They were situated in the north of Sweden, in the county of Västerbotten. Four of the stands were located at Granliden (Lat. 64.8°N, Long. 16.0°E) 40 km WNW of Vilhelmina and three of the stands at Eriksberg (Lat. 65.0°N, Long. 15.8°E) 60 km NW of Vilhelmina, both groups at about 400–540 m a.s.l. (Table 1), which is about 150–250 m below the coniferous tree line in the area. The time elapsed since last harvest varied from 16 to 57 years. The stands are henceforth referred to as Hxx, where xx denote the year of the last harvest.

All stands were dominated by Norway spruce (*P. abies* (L.) H. Karst.), constituting more than 90% of standing volume, with a small addition of birch (*Betula pendula* Roth and *Betula pubescens* Ehrh), Rowan (*Sorbus aucuparia* L.), and Willow (*Salix caprea* L.). The soil was moraine, soil moisture was mesic, and ground vegetation dominated by *Vaccinium myrtillus* L. and mosses, e.g. *Pleurozium schreberi* and *Hylocomium splendens* in most stands, but in two stands there were occasional herbs, indicating slightly better site productivity. Site index, estimated from site properties according to Hägglund and Lundmark (1981), was 13–17 (top height at 100 year total age in an even-aged stand on the same site), corresponding to a site productivity of about 2.0–3.3 $m^3\ ha^{-1}\ yr^{-1}$.

In each stand two 1000 m^2 circular plots (plots A and B) were inventoried, with a minimum distance of 100 m between plots. All trees with d_{bh} (diameter at breast height, 1.3 m above ground) $\geqslant$5 cm were mapped and calipered. All stumps deemed to be from