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Early assessments are reliable indicators for future volume production in Norway spruce (*Picea abies* L. Karst) genetic field trials

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ABSTRACT

Early height measurement has commonly been used as a selection criterion in the Norway spruce breeding program in Sweden when the main breeding goal is to increase timber production per unit area. The aim of this study was to compare differences in early height with differences in stand yield at the time of the first commercial thinning in improved (IM) and unimproved (UNI) stands of Norway spruce. The study was based on ten field trials established in southern and central Sweden. The results showed that IM material produced, on average, 27.5% more volume per hectare over the first half of the rotation compared with UNI material. The early differences in height measured at an age of between 3 and 6 years were on average 17.7% greater in the IM trees. There was substantial variation in the average volume difference between IM and UNI between the trials, but the number of trials studied renders the results reliable. This study indicates that for improved Norway spruce at the middle of the rotation age growing in southern and central Sweden, volume production per hectare is greater than expected volume predicted from early height measurements.

1. Introduction

An important goal of the Norway spruce (*Picea abies* L. Karst) breeding program in Sweden is to increase the yield per unit area at rotation age in order to satisfy the increasing demand from industry (Berlin et al., 2009; Jansson, 1998). An increase in volume production can be realized by selecting genotypes whose offspring will grow well in operational plantations for the whole duration of the rotation (Egbäck et al., 2012). The rotation age for Norway spruce in southern Sweden varies between 45 and 70 years depending on site quality. In operational breeding, selection of the best genotypes and prediction of genetic gain is usually carried out early in the rotation, at approximately 20% of the duration of the rotation, to avoid delays in implementing improved material. One problem associated with the relatively early selection of improved genotypes is that correlation estimates between early and later measurements of the same trait, and between different traits measured early and late (e.g. height at six years and volume at the end of the rotation), are not always high (Rehfeldt et al., 1991). The stability of genetic gain over time is crucial information in determining appropriate stand management practices and in sustainable forest planning when volume production is the desired outcome. To date, such research in Sweden has been scarce, and there is a need for studies that focus on the long-term performance of improved plant material.

In Norway spruce grown in central and northern Sweden, Westin and Sonesson (2005) reported a genetic correlation of 0.5 between early height and volume production in 11 trials around 60 years in age. However, the variation among experimental sites was high. For Scots pine (*Pinus sylvestris* L.) in Sweden, Jansson (2007) found that the average difference for height between improved and unimproved material at the age of nine was 10.5% while at the age of 30, the difference in volume production was 11.7%. Based on the results of experimental trials on Scots pine, Jansson (2007) and Marklund (1981) suggested a value of 0.7 as the genetic correlation between early height measurement and volume production at rotation age for other species. However, this correlation has not been validated in the case of Norway spruce grown in Sweden. For other tree species, outside Sweden, it has often been found that relative differences in volume production later in the rotation were greater than those estimated from early assessments of height or diameter (Carson et al., 1999; Gould et al., 2011; Weng et al., 2008). However, there was considerable variation in the experimental design, the material tested and the way in which the comparisons were carried out.

In Sweden, evaluation of the genetic gain resulting from selection has been usually based on results from single-tree plot trials in which all varieties tested are distributed randomly across the experimental area. Moreover, genetic gain has been calculated for individual genotypes at

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the tree level whereas the desired trait is often expressed as yield per unit area. Single-tree plot design has been considered inappropriate as a way of estimating volume production per unit area, since inter-tree competition may result in overestimation of additive genetic variances leading to bias in the estimation of genetic gain (Foster, 1989; Magnussen and Yeatman, 1987; Namkoong et al., 1972). Block-plot designs have traditionally been used in evaluating the effects of silviculture measures on volume production, and this type of design has also been recommended for estimating genetic gain in volume production (Pretzsch, 2009; Vergara et al., 2004; White et al., 2007; Zobel and Talbert, 1984). However, due to the high costs of establishment and management, such experiments have seldom been established in Sweden or elsewhere.

The expected genetic gain realized for the third round of Norway spruce seed orchards in Sweden, established from genetically selected and tested plus-trees, has been calculated to be, on average, 25% more volume per unit area compared to seeds collected in unimproved stands (Rosvall et al., 2001). In 30-year-old Scots pine, Jansson (2007) found 12% difference in volume per unit area between control-pollinated progenies of phenotypically selected plus-trees and unimproved material. In the same study, selection of 25% of the best-growing trees led to a 25% realized gain in volume. For phenotypically selected plus-trees of Scots pine, the genetic gain in volume by the end of the rotation has been estimated at between 8.3 and 10.7% (Andersson et al., 2006). For Scots pine in Finland, Haapanen, et al. (2016) found that stands established from progenies tested plus-tree material yielded 23.9% more volume than stands from unimproved seed planted as seedlings.

In this study, we compared the results of early assessments of height and diameter in tests on Norway spruce clones with volume production per unit area after 23–36 years, which is about half way through the rotation. The hypothesis tested was that early superiority for height or diameter of improved material results in an increased volume production per unit area at a later stage, compared with unimproved material. We studied the effects of differences between height and diameter assessed at ages 6–15, on realized yield per unit area at the time of the first thinning (at an age of 25–30 years). As contrasting material, we used rooted cuttings of selected Norway spruce clones and unimproved seedlings from 10 block-plot field trials.

2. Materials and methods

2.1. Description of material

The material used for this study was obtained from ten field trials on Norway spruce clones established in southern and central Sweden between 1981 and 1990 (Fig. 1, Table 1). In eight of the field trials, the clones were selected from different commercial seedling stocks or progenies from founder populations aimed at the regions where the experiments were established; in the two remaining trials, Lugnet and Rådahöjden, the clones were selected from the progeny of full-sib crossings between selected plus-tree parents with known origin (treatment – IM). The origins of the selected materials differed between experiments and details are presented in Table 1. Primary selection of the seedlings was based on height performance in the nursery at age 3–4 years. Selected seedlings were clonally propagated using rooted cuttings and secondary nursery selection of the best-growing clones was performed on the basis of three-year height. Rooted cuttings from the clones selected were planted in field trials, after selecting the field trial site according to the combination of spring and autumn phenology observed there, which was recorded in the nursery e.g. Hannerz (1992).

All field trials used a Latin square design, in which all plots except for one in each row and each column consisted of clones in a single-tree plot design. In each trial, the remaining plot in each row and column was planted with seedlings from unimproved seedling stocks (treatment – UNI) (Fig. 2). There were between six and nine replicates of each genotype mix composition within each field trial.

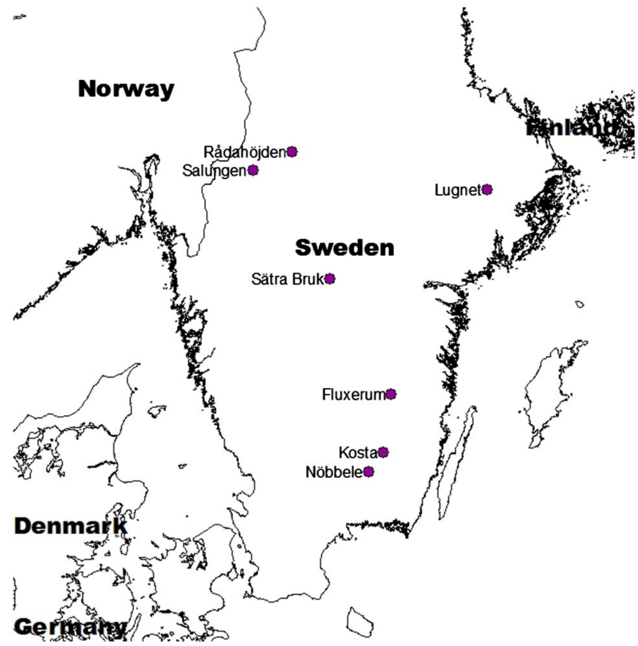

Fig. 1. Locations of experimental sites used in the study. There were three experiments in Fluxerum and two experiments in Sätra Bruk.

The origins of the unimproved material varied between experiments; they included Belarus (Minsk, "M" – 53°91′N, 27°54′E and Vitebsk, "V" – 55°22′N, 30°28′E), Romania (Moldovita, "Mo" – 47°68′N, 25°54′E, Pojorita "Po" – 47°52′N, 25°46′E) and Sweden (provenances Emmaboda – 56°63′N, 15°52′E, Lekvattnet – 60°21′N, 12°70′E). These provenances were selected on the basis of contemporary recommendations for use in the Swedish forestry sector. The UNI plots had different compositions in the experiments studied (Table 1). The UNI plots were therefore regarded as one treatment in this study, i.e. calculations were not divided according to separate provenances. None of the 10 field trials had been thinned at the time when the last assessment was carried out.

2.2. Field inventories

Measurements were carried out in all 10 experiments at least once at one early stage, usually between six and twelve years after establishment. In some trials, later measurements were also carried out (Table 1). In all trials, height and/or diameter at breast height (1.3 m) were measured. Instances of deterioration in quality, e.g. double tops, spike knots, were also recorded but were not taken into account in this study.

For the current study, new measurements of diameter at breast height (D) for all trees within each experiment were done in 2016.

After measurements of diameter, sample trees were selected for measurement of height (H). Approximately 20 sample trees were selected for each type of material used as comparison (UNI) and ~30–40 trees were selected for the clones (IM). Out of all sample trees, 25% were selected as dominant trees, i.e. trees with the greatest diameter, while the other were selected randomly from all living trees (Karlsson et al., 2012). In order to reduce edge effects, no sample trees were selected from the outermost rows within sub-plots.

Height-diameter relationship were estimated, separately for the IM and UNI treatments, according to the model developed by Näslund (1936):

$$HT = 1.3 + \frac{D^3}{(a + b\cdot D^3)}$$

where HT is height, D is diameter at breast height, a and b are