

INFLUENCE OF INITIAL DENSITY ON INVENTORY PARAMETERS OF UNTHINNED NORWAY SPRUCE STANDS

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Initial density to large extent determined the stand development thus is crucial to ensure efficient transfer of genetic gain in forestry. Lower density may reduce the stand establishment costs, but also impact the stem quality and standing volume. Very limited information exists about older sparse plantations, therefore aim of the study was to characterize the forest inventory parameters of low-density Norway spruce (*Pice abies* (L.) Karst.) stands. Data were collected in two planted, un-thinned, 47 year old, pure stands in central part of Latvia (56°N, 25°E) with initial density 600 and 1600 trees ha⁻¹, growing on fertile mineral soil. Even the sparsest stand (600 trees ha⁻¹) had standing volume that was not significantly different from the average in Norway spruce forests in similar conditions at the age of 80 years (294±28.8 and 318±18.7m³ha⁻¹, respectively), based on National Forest Inventory data. Mean height (21-22 m) and length of branch-free part (<1 m) as well as diameter of the thickest branch in bottom 2m of the stem (<2 cm) and proportion of trees with stem cracks (4%) was not affected by initial stand density. Mean breast height diameter decreased and lengths of dry-branch section increased with increasing initial stand density. The proportion of browsed trees was smaller in sparser stand (23% vs. 31%). Notably lower initial density of planted stands than currently required (2000 trees ha⁻¹) can be used while avoiding negative impact on forest inventory parameters.

Keywords: competition, growth, initial spacing, stem quality, target diameter

INTRODUCTION

Forest regeneration requires substantial effort and greatly affects the economic output from a certain area of forest land. Due to rising costs of this forest management activity, two opposite decision had become increasingly more common in recent decades: a) relying on natural regeneration, often delaying the first thinnings and thus losing out on radial growth of trees and stand (land expectation) value (Fahlvik, 2005); b) planting lower number of trees per ha with improved soils scarification and genetic value of the planting material (Dzerina et al., 2016). Efficient transfer of genetic gain into forestry can notably raise the value of the stands (Ahtikoski et al., 2018; Jansons, Gailis, 2011, Jansson et al., 2017). Also more homogenous stands with lower density (depending on management regime) have a better resistance against disturbance e.g. wind (Donis et al., 2018, Gardiner, Quine, 2000, McClain, 1994). Planted stands and increased intensity of the use of whole tree biomass does not present the threat to genetic diversity (Ruņģis et al., 2019) of forest ecosystem (Čakšs et al., 2018; Lībiete et al., 2017), but rather substantial gain for carbon sequestration (Kēniņa et al., 2018). Also planted stands with good management have additional height increment at young age (Katrevičs et al., 2018). Models, also ones including the genetic improvement component (Egbäck et al., 2017) can be used to predict the development of stands with different densities. However, the models are as good as the input data used for their development. Therefore empirical information from spacing (or precommercial thinning) trials is essential to test and fine-tune the models. Usually such trials include set of rather large densities (e.g. 3330-6660 trees ha⁻¹, Mangalis, 1960) or analyse the stands at rather young age e.g. spruces at the age of 24-33 years (Deans, Milne, 1999, Pfister et al., 2007), lodgepole pine at 23 years (Liziniewicz et al., 2011), jack pine at 25 years (Hébert et al., 2016). Analysis of a single 40-year-old low-density (400 trees ha⁻¹) plantation of silver birch clones growing on former agricultural land in the central Latvia was carried out. It was found, that trees had reached the target diameter for final harvest (27.7±5.5 cm) and stemood productivity was 5.25 m³ ha⁻¹ year⁻¹ (Zeltiņš et al., 2018). Similarly in a recent study in Latvia sparse Norway spruce trial (400 trees ha⁻¹) was assessed at the age of 50 years and data compared to National Forest Inventory (NFI) plots (Katrevičs et al., 2018). The results suggest a high productivity of such stand and notable impact of clone (genetics). Mäkinen et al. (2000) in a detailed study involving a limited number of Norway spruce trees have found, that increasing stand density (350 to 1600 trees ha⁻¹) results in decrease in radial increment, but it had no effect on height increment. Closer spacing produces higher standing basal area and volume than wider spacing, especially at young age (Gizachew et al., 2012). To improve the overall understanding of initial spacing on stand development, aim of the study was to characterize the forest inventory parameters of low-density Norway spruce stands. Results can be further used in the development of forest management recommendations.

MATERIALS AND METHODS

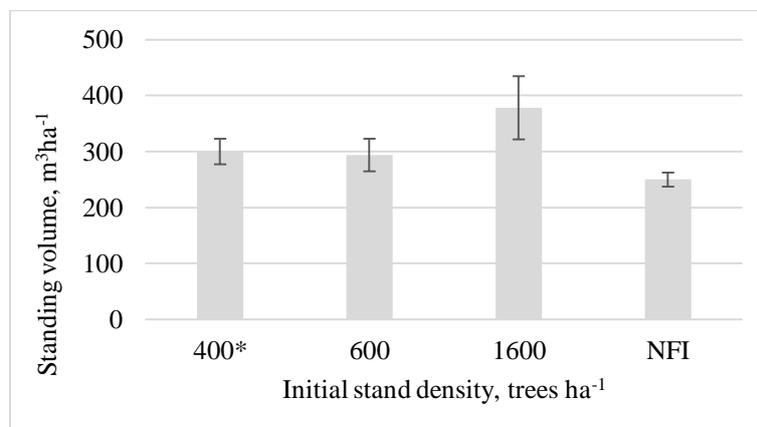
Material was collected in two 47 year old, pure Norway spruce stands in central part of Latvia (56°N, 25°E). According to data of Latvian Environment, Geology and Meteorology Centre, the climate is maritime, mild, 30-years mean air temperature in July and January is 18 and -6 °C, respectively. Annual sum of precipitation varies between 700 and 800 mm. Soil was prepared in rows and stands were established by planting, with initial density 600 and 1600 trees ha⁻¹. No thinning had been done before the measurements. Measurements were carried out in rectangular plots within the stand of size 0.35-0.4 ha, trees in outer border rows of the stands were not measured to avoid edge effect. Stands were located on fertile mineral soil with normal moisture regime, *Oxalidos* forest type, where highest productivity of Norway spruce can be observed.

Allogometric parameters of trees measured included height (H, ±0.1 m), breast height (1.3 m) diameter (DBH, ±0.1 cm), height to the forest living branch, not separated from the next living branches by more than one branch whorl (crown base, ±0.1 m), diameter of the thickest branch in bottom 2m of the stem (mm), browsing damages: lowest and highest point of the scar (cm) and length of the stem cracks. Additionally, occurrence of the dry trees (results of self-thinning) was recorded. Stem volume was calculated based on Liepa (1996). Significance of differences was tested by ANOVA, 95% confidence interval was used show the variation throughout the manuscript. Data from low density stand, presented by Katrevičs et al. (2018) was used for comparison. Similarly, data from pure (at least 80% of the standing volume) Norway spruce stands on fertile mineral soil with normal moisture regime – altogether 31 plot with size 400 to 500 m² – were used. Source of these data was National forest inventory (NFI) dataset. In these stands initial density is not known, rather assumed as it was in accordance to normative at that time (4000-7000 trees ha⁻¹) and management history is not known.

RESULTS AND DISCUSSION

Survival had been better in stand with lower density (600 trees ha⁻¹), than in the stand with higher (1600 trees ha⁻¹), indicating notable effect of self-thinning. Even so, there were almost two-fold difference between the stands in the actual density at the time of the measurement: 451 and 883 trees ha⁻¹, respectively. Also the stands in traditional forest management, that were rather dense initially (4000-7000 trees ha⁻¹), currently had the density of 526 trees ha⁻¹ on average, as shown by National forest inventory (NFI) data.

Standing volume in stands with low initial density (400-600 trees ha⁻¹) was slightly (on average by 47m³), but statistically significantly larger than that in the Norway spruce stands with notably larger initial density (and un-known management history), represented in dataset of National forest inventory (Figure 1). It was not different than the average standing volume in Norway spruce stands approximately 30 years later – at the cutting age in accordance to the current legislation in Latvia (318±18.7m³ha⁻¹). However, it was significantly lower than that in the stand with initial density 1600 trees ha⁻¹, indicating, that the biomass production had not been maximized in low-density stands. Similar results were found in young *Pinus contorta* stands in southern Sweden, where yield of low density (625 trees ha⁻¹) plantations was considerably lower than that of higher density (1250 trees ha⁻¹): 35-40 and 59-92 m³ha⁻¹, respectively, at the age of 23 years (Liziniwicz et al., 2011). Based on the chronosequence approach, Zālītis et al. (2006) concluded, that early thinning (mean height of the stands 2-5 m) to density 1500-2000 trees ha⁻¹ had resulted in notable increase of standing volume in stands at the age of 50 years: thus have found a similar trend, as in our study, when comparing the with the initial density 1600 trees ha⁻¹ and NFI dataset.



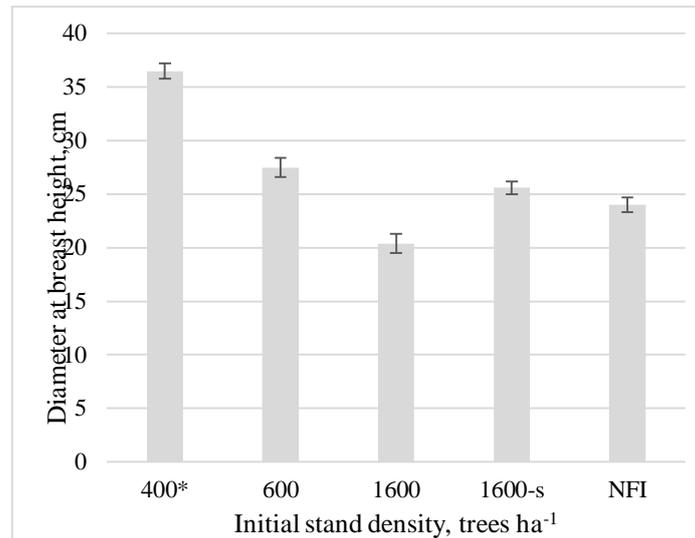
*Data from Katrevičs et al., 2018

NFI – data from National forest inventory

Figure 1. Standing volume in Norway spruce stands with various initial density

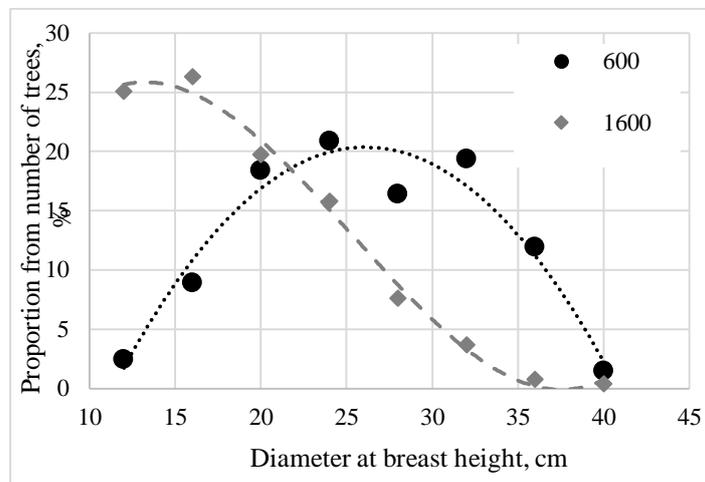
Initial stand density had significant influence on average breast height diameter of the trees: in low density stand it was considerably – on average by almost one third or 7.1cm – larger than on higher density (1600 trees ha⁻¹). Shape of

diameter distribution in the denser stand suggests, that it is strongly influenced by competition and large portion of small dimension alive spruces are present (Figure 3). Therefore its mean diameter is even smaller than that in stands with traditional management and high initial density (Figure 2), where most likely several thinnings had been carried out in past. Selection of largest trees with density corresponding to that in low-density stand (denoted as “1600-s” in Figure 2) ensure a significantly higher diameter, but still not as high as in the sparse stand. Trend of increase in mean tree diameter as the stand density decreases, are similar as reported in other studies of younger stands: at the age of 24-33 years for spruces (Deans, Milne, 1999, Pfister et al., 2007) and at the age of 23 years in for lodgepole pine in southern Sweden (Liziniewicz et al., 2011). In plantations of Norway spruce with rather high initial density (3330-6660 trees ha⁻¹) and unknown management regime, at the age of 45-51 years (density 1729-1835 trees ha⁻¹) mean diameter (17.9-18.6 cm) was slightly lower than that in denser stand of our study (Mangalis, 1960). It indicates a strong influence of self-thinning.



*Data from Katrevičs et al., 2018
NFI – data from National forest inventory

Figure 2. Diameter at breast height in Norway spruce stands with various initial density



Trendlines included only for increased visibility of the differences between stands

Figure 3. Tree distribution in diameter at breast height classes in Norway spruce stands with various initial density

Tree height was not much affected by the difference in initial stand density (Table 1) as expected. It was slightly higher in stand in the same forest type and with even lower initial density (Katrevičs et al., 2018). This difference can be explained by tree breeding effect: notable genetic gains in height growth had been reported in the Baltic Sea region countries (Haapanen et al., 2016; Jansons et al., 2006, 2015; Jansson et al., 2017) and in the sparse Norway spruce stand in Latvia, that consisted of grafted first generation plus-trees (Katrevičs et al., 2018).

Height of first living branch was notably (by 4.2m) and significantly lower in stand with lower density, as was the crown ratio. Due to the larger space between the trees, also crown width was by one third larger, differences were statistically significant. It lead to shorter section of the trunk without green branches, however, that cannot be considered an improvement of stem quality – the dry-branch section was longer in the denser stand. It was because of the slow process of decay of the branches and healing over of the branch wound for Norway spruce (Baders et al., 2017). Very slow natural pruning was reported in studies of Norway spruce: branch-free part on average was only 0.3±0.07 m in 45

stands at the age of 20 to 28 years (Baders et al., 2017) and 0.5 to 1m in 10 stands at the age of 24 to 47 years (Mangalis, 1960). Thus, limited influence of stand density (if it is not very high) on natural pruning can be observed. It is consistent with the results of analysis of diameter of the thickest branch in bottom 2m of the stem: no significant differences were found between the stands in our study and in both the diameter was below 2 cm (Table 1).

Table 1. Forest inventory parameters in Norway spruce stands with various initial density

Tree parameters	Initial stand density, trees ha ⁻¹		
	400*	600	1600
Tree height, m	25.1±0.3	22.2±0.4	22.6±0.4
Height of first living branch, m	6.3±0.3	7.9±0.3	12.1±0.3
Crown ration	0.75±0.01	0.66±0.01	0.50±0.02
Branch diameter, mm**	-	15.4±4.0	13.2±3.1
Crown width, m	-	2.4±0.1	1.8±0.2
Tree stem volume, m ³	1.31±0.06	0.65±0.04	0.43±0.03

*Data from Katrevičs et al., 2018

**diameter of the thickest branch in bottom 2m of the stem

Similarly, both stand did not differ in the mean length of browsing damages: it was 0.5±0.07 m in stand with density 600 trees ha⁻¹, and 0.6±0.15 m in stand with density 1600. The proportion of browsed trees was smaller in sparser stand (23% vs. 31%). Only few trees (4%) had stem cracks wit length from 0.15 to 1.5 m (average 0.6±0.1 m) in both stands. The study by Zeltniš et al. (2018) found slight tendency of larger trees being more prone to cracks and much larger portion of trees with stem cracks (23.5%) in a 35-year-old provenance trial. The differences in proportion of affected trees between the studies are most likely explained by the cause of stem cracks – prolonged severe drought event (Persson, 1994) – that evidently has not occurred in location of our stands.

CONCLUSIONS

Standing volume of untinned Norway spruce stands with low initial density (400-600 trees ha⁻¹) was significantly (on average by 47 m³) larger than that in similar stands with notably larger initial density and traditional management regime, represented in dataset of National forest inventory (297±25.7 and 250±12.5 m³ha⁻¹, respectively); it was even higher in un-thinned stand with density 1600 trees ha⁻¹: 378±56.7 m³ha⁻¹. Height was unaffected by initial stand density, but mean breast height diameter decreased with increasing initial stand density. Largest trees (total stem volume 282 m³ha⁻¹) in stand with density 1600 trees ha⁻¹ had only slightly, but significantly smaller DBH than the mean in sparse stands: 25.6±0.6 and 27.5±0.9 cm, respectively. Stand density had no significant impact on presence browsing damages and stem cracks as well as on diameter of the thickest branch in bottom 2m of the stem. Results suggest, that the initial density lower than currently practiced could boost the diameter growth and thus reduce the time, when target diameter is reached. The optimum density presumably is above 600 trees ha⁻¹, to have larger standing volume, but below 1600 trees ha⁻¹, to ensure diameter growth, or this density with one thinning.

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