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VALUE OF MERCHANTABLE TIMBER IN SCOTS PINE STANDS OF DIFFERENT DENSITIES

Differences in the intensity of silvicultural treatments, as well as natural tree mortality, insect damage and fungal disease can eventually lead to variable stand density even on sites of the same quality. In addition, the bigger the initial stand density, the smaller the crown and trunk volume of single trees. The objective of the research was a detailed analysis of the impact of stand density on the total stand volume and value of merchantable timber. The area studied was in Drawno Forest District, north-west Poland, on sites with sandy soil conditions typical for Scots pine (Pinus sylvestris L.*). The total volume of merchantable roundwood was measured on 20 sample plots (each covering an area of 0.5 ha) of which 19 were in 82-year-old stands and one in an 87-year-old stand. The stands were divided into three stand density groups (SDG), where the average number of trees growing per group was as follows: 547 (SDG I), 651 (SDG II) and 765 (SDG III). The volume of a single tree was calculated using diameter (DBH) and height measurement. A quality classification of all 6432 tree stems was carried out in accordance with the Polish Stan-*

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dard. Statistical analysis did not indicate that density influenced the total timber volume of the stands studied, which was recorded as an average of 323 m³·ha⁻¹. However, statistically significant differences in the value of merchantable timber were observed: the highest value of 100 m³ of merchantable timber was recorded in SDG I (€ 5118.87), 6 and 12% higher than in SDGs II and III (€ 4842.09 and € 4565.80, respectively). The results obtained suggest that in the final phase (the last two age classes), pine stands growing in Polish conditions should be maintained at a lower stand density.

Keywords: Scots pine (*Pinus sylvestris* L.), timber value, stand density, wood quantity and quality

Introduction

Timber production in stands is connected to silvicultural practices aimed at achieving optimal tree stand volume and quality when the trees are ready for final felling. Differences in the intensity of the silvicultural treatments and natural phenomena such as wind, fungi or insects, which lead to tree thinning, result in tree stands of varying densities at final age. This occurs despite identical initial spacing. The severe thinning of young stands, whether planned or not, leads to changes in light conditions and nutrient availability. The natural reaction of trees to better conditions and less competition is faster tree biomass growth [Borowski 1974], an increase in breast height diameter and tree height (in *Pinus larico* Poiret) [Picchio et al. 2011] and bigger radial growth (in *Pinus halepensis* L.) [Olivar et al. 2014]. However this can lead to faults in the structure of the timber [Bembenek et al. 2013; Stempski et al. 2011]. This is further confirmed by studies at an anatomical level: thinning can result in shorter tracheids in the wood of the remaining trees [Sława-Neyman et al. 1995]. According to Brazier [1977] and also Zobel and Jett [1995, after Macdonald, Hubert 2002], any factor that changes the growth pattern or form of a tree may result in a change in wood quality and properties. Tree growth patterns can be affected by silvicultural practice, site factors and the genetic quality of planting stock [Macdonald, Hubert 2002]. Better conditions for tree growth can also be created by establishing skid trails which positively affect annual ring widths and diameter increment [Yilmaz et al. 2010].

The aforementioned results of research indicating the influence of increased light on the development of individual trees, provided the basis for the hypothesis that in sites with a lower number of trees per hectare, single trees attain a larger diameter at breast height (DBH), and, as a consequence, greater volume. Timber value is related not only to quality but also thickness: the thicker the wood, the higher the value of 1 m³ ($d_{1/2} \leq$ 24 cm is rated as class I which has the lowest value, class II is $d_{1/2}$ = 25 − 34 cm, whereas $d_{1/2}$ > 35 cm is class III – the most expensive). Bearing this in mind, a further hypothesis was accepted: a tree stand of lower density will provide thicker and more expensive timber. It was also assumed that in the same habitat conditions, the production potential is also the same, that is, the production of biomass (total timber volume) would be similar. It was therefore accepted that silvicultural treatments would result in: 1) a higher number of trees per surface unit but a lower volume, or 2) a lower number of trees with a higher volume. The total volume of merchantable timber obtained from the two different methods would be the same.

The aim of this research was a detailed analysis of the influence of tree density on the value of timber obtained from tree stands of different density.

Materials and methods

The research was carried out in pine tree stands in the lowlands of north-western Poland, in Drawno Forest District (E 15°50'–16°0', N 53°10'–53°13'). The habitat and the sandy soil conditions were typical for Scots pine (*Pinus sylvestris* L.). The average annual rainfall in the area analysed is 589 mm, the average temperature is 7°C, and the growing season lasts 200–220 days. The volume of merchantable timber was measured on 20 sample plots (each covering an area of 0.5 ha) of which 19 were in 82-year-old stands and one in an 87-year-old stand. The 20 plots were divided into 3 groups according to tree stand density: SDG I (6 stands), SDG II (10 stands) and SDG III (4 stands, table 1). The difference in the number of trees between SDGs was 104 and 116 (SDG II – SDG I = 104, SDG III – SDG II = 116, table 1).

Table 1. Stand characteristics by density group

Stand density group	Mean age (±SD) [years]	Mean density (±SD) [tree·ha^{-1}]	Mean DBH (±SD) [cm]	Mean height (±SD) [m]	Mean basal area (±SD) [m^2·ha^{-1}]	Mean volume of merchantable timber (±SD) [m^3·ha^{-1}]
I	82.8±2.0	547.0±46.8	27.04±4.8	22.61±2.01	32.2±2.9	333.8±37.5
II	82.0±0.0	651.2±27.9	24.76±4.76	21.52±2.11	32.2±2.9	321.6±47.9
III	82.0±0.0	767.5±48.9	22.43±4.6	21.01±3.19	31.3±3.2	308.8±32.4

The DBH of all the trees on the sample plots was measured (in two directions N-S and E-W) using callipers (accurate to 1 mm), and the height of 20% of the trees was recorded with a Haglof Vertex Laser (accurate to 0.1 m). The measurements were used to create a hypsometric curve (modelled using the Näslund function) on the basis of which the height of all the trees was calculated (table 1). The volume of a single tree was calculated using empirical models for pine [Bruchwald 1996] on the basis of the measured DBH and tree height. The timber quality was determined by quality and dimension according to the Technical Conditions for Softwoods [Technical... 2013] (Appendix A). The thickness class of the large-size timber was determined on the basis that each tree yielded a 10 m log, and according to the mid-diameter of the log, the timber fell into one of three classes:

- 1st thickness class (≤24 cm mid-diameter under bark),
- 2nd thickness class (>24 cm ≤35 cm mid-diameter),
- 3rd thickness class (>35 cm mid-diameter).

Timber below 19 cm mid-diameter under the bark was classified as pulpwood. Due to the low number of trees in the high quality classes, all the timber (for simplicity) was graded as C quality class (large-size wood – wood with a minimum top diameter of 14 cm under the bark, defined as sawmill wood). The value of the timber was calculated on the basis of the average net price of timber sold in the Drawno Forest District in 2013, as follows:

- sawmill wood 1st class thickness = €[5] 48.84 · m^3
- sawmill wood 2nd class thickness = € 56.94 · m^3
- sawmill wood 3rd class thickness = € 65.04 · m^3
- pulpwood = €[6] 38.12 · m^3

The Polish Principles of Silviculture [CILP 2012] in the analysed habitat recommend identifying 350–500 healthy trees per hectare at the early thinning stage. These are the trees which should remain until felling age and form the tree stand structure. An optimal value was thus accepted and the 20 tree stands in the study were categorised according to tree density:

- density group I (DGI) (≤600 n ha^{-1})
- density group II (DGII) (>600 ≤700 n ha^{-1})
- density group III (DGIII) (>700 n ha^{-1}).

Three SDGs were therefore determined, which included 6, 10 and 4 tree stands, respectively.

Statistical analysis was performed using R statistical software and agricolae packages [R Development Core Team 2012]. Normal distribution was analysed using the Pearson chi-square normality test. A one-way analysis of variance was performed on the tree stand volume and its value. A post hoc Tukey HSD test was carried out in cases where significant differences emerged. In total, 6432 trees across all the SDGs were analysed.

Results and discussion

Despite a large difference in tree density, similar volumes within the analysed stands were observed. Statistical analysis did not indicate the influence of density on the volume of the analysed stands (ANOVA, $p = 0.661$), the mean volume of which was 323 $m^3 \cdot ha^{-1}$ (ranging from 283 to 394 $m^3 \cdot ha^{-1}$). This result confirmed the hypothesis that habitat conditions ultimately lead to optimal production ie. the same total volume of merchantable timber, though consisting of a different number of trees.

[5] € = 4.1974 PLN in accordance with the average exchange rate archive of the National Bank of Poland – table A, 2013.

[6] Prices obtained in Drawno Forest District.

The analysed SDGs can therefore be regarded as uniform in terms of volume. Per 100 m^3 of merchantable timber, the Pearson chi-square normality test revealed that the tested data group featured normal distribution (p = 0.4337). Furthermore, all the SDGs revealed homogeneity of variance.

The mean value of 100 m^3 of merchantable timber across the studied stands was € 4870 (min. 4418, max. 5240, standard deviation 248, n = 20). There was a clear difference in the mean value of 100 m^3 of merchantable timber between the stands: 6% higher in SDG I when compared to SDG II, and 12% in comparison with SDG III (table 2).

Table 2. Value of 100 m³ timber

Stand density group	Value of 100 m^3 timber [€]	Standard deviation	Number of stands in group [n]
I	5118.87	112.76	6
II	4842.09	188.83	10
III	4565.80	179.94	4

One-way variance analysis revealed significant differences in the mean total tree value between SDGs (p = 0.000343). The post hoc Tukey HSD test revealed that all the average values of the tree stands differed significantly between the groups (α = 0.05). Tree value and the frequency of occurrence in the defined stands indicated significant differences between the groups, in particular between SDG I and SDG III (fig.1).

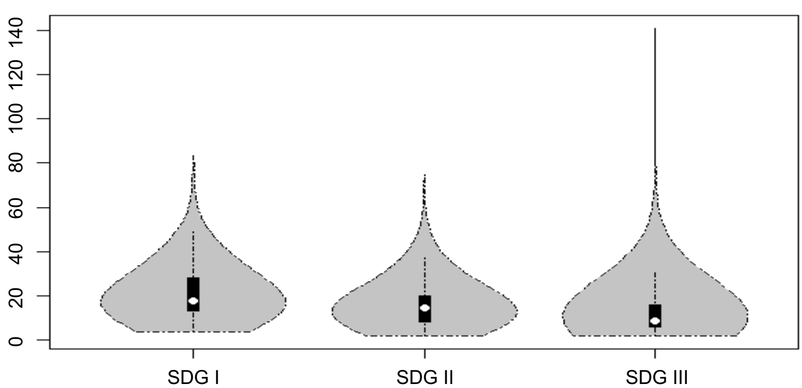

Fig. 1. Vioplot of single tree values (in €) in the SDGs showing the frequency of data groups; it presents a symmetrical reflection of kernel density estimation. The centre of each violin contains a boxplot. From the top: the number of trees increases as the value of a single tree falls to a certain point, then the number of trees decreases alongside the fall in the value of single trees

SDG I contained the smallest number of low-value trees, though a single tree here was still significantly more expensive (min. = € 3.36) than in SDG II or III

(€ 1.66 and € 1.57, respectively). The high median (€ 17.71) in SDG I indicated that there was a low incidence of the cheapest trees (white dot in fig. 1). Furthermore, the widest point in SDG I, the highest of all the three groups, indicated that the most frequently occurring trees were more expensive than in SDG II and III. In SDG I and II, the increase in the number of trees together with the increase in value was more dynamic than in SDG III (lower section of the plots). It is worth noting that the maximum value of € 141.26 was in SDG III. This should be regarded as an outlier – it is likely the tree developed under specific micro-habitat conditions with significant access to light. At the same time, this indicated the potential which may be exploited in the management of tree stands of lower density. Once this outlier had been removed, the plot clearly showed all the adverse parameters of SDG III, including the lowest maximum value (€ 65.04, fig. 2).

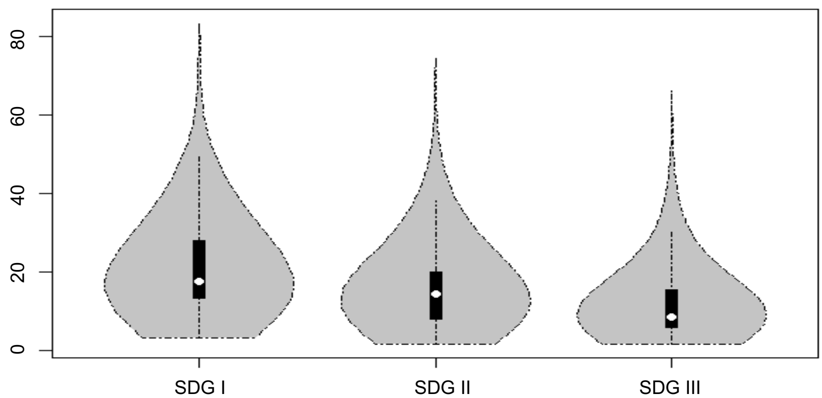

Fig. 2. Vioplot, frequency of data groups (in €) after the removal of the outlier (€ 141.26) from SDG III

Therefore – from the perspective of the round timber producer – in order to achieve a maximum profit from harvesting, the tree stand should be of a lower density (less than 600 trees per hectare) in the final growth phase (IV/V age class). Such management would also lead to greater income from more intensive pre-commercial thinning. It is important to bear in mind the local conditions affecting the growth and development of tree stands: habitat fertility, climate and phenotype. Research carried out in Finland [Ikonen et al. 2003] showed that in a 100-year-old, unthinned and very dense pine tree stand (995 trees per hectare), a stand yield of a higher value (€ 19 196 ha^{-1}) was achieved in comparison with a heavily-thinned stand (390 trees per hectare, € 13 369 ha^{-1}). These studies were carried out during the same period of time. However, other studies performed on Finnish pine and spruce stands indicated a reverse dependency – increases in: 1) the initial stand density and 2) the thinning intensity could be beneficial for energy wood production, timber and carbon stock enhancement, as well as to reduce CO_2 emissions for energy wood production [Alam et al. 2012].

It should also be noted that timber value in this study was determined on the basis of 10 m lengths. As the study by Porter [2012] indicated, timber cut-to--length can lead to an increase in the share of more expensive thickness classes (2nd and 3rd thickness classes) and, as a result, an increase of 6–15% in timber value. This also points to the additional potential which may be exploited in the case of growing trees with a larger DBH (managing tree stands of lower density).

More intensive thinning may cause a higher risk of injuries on the remaining trees. This could lead to the appearance of scars – defects which are taken into consideration during grading, not only in pine (scars seriously degrade beech sawmill wood, particularly the most valuable butt logs [Karaszewski et al. 2013a, 2013b]). Apart from defects, logging injuries have been identified as one reason for tree growth reduction [Vasiliauskas 2001]. However, some studies analysing the effects of injuries 10 years after treatment, found no negative consequences on pine growth (*Pinus laricio* Poiret) [Picchio et al. 2011]. As the aforementioned authors suggested, a deeper knowledge on the long-term effect of logging damage is needed.

Finally, a further point also worth highlighting is that SDG I featured a higher than average tree height in comparison to the tree heights in SDG II and III: by 5 and 8%, respectively (table 1). This is particularly interesting as trees growing in a higher density compete for light and growth, and therefore tend to focus on achieving height. However, it seems that in older tree stands (5th age class), crown volume is of greater influence. Trees with a bigger crown have greater volume and therefore the production of assimilates will also be higher. This positively affects growth in terms of both thickness and height.

Conclusions

The research results and proposed division of tree stands into 3 groups of different densities indicated that silvicultural practices in pine tree stands on soils typical for Scots pine (*Pinus sylvestris* L.) should lead to approximately 550 trees per hectare in stands entering the 5th age class. Such a number of trees means the stability of the tree stand can be maintained and it also results in an increase in timber value. A larger number of trees per hectare does not increase the total volume of timber in a stand, but rather leads to a decrease in the value of merchantable timber.

In the analysed pine stands, there was no impact of the tree density (from 476 to 836 per ha^{-1}) on the volume of merchantable timber and this was statistically proven. Timber from stands of low density had a higher value (€ 5118.87 per 100 m^3), 6 and 12% higher in comparison to the timber from SDG II and SDG III (€ 4842.09 and € 4565.80 per 100 m^3, respectively).

The higher timber values in the lower density tree stands were not due to increased total timber volume per hectare but rather from the greater thickness of the individual trees for which there was more demand due to the versatility of such timber.

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List of standards

Directive no. 72 approved by General Director of the State Forests [2013]: Technical conditions for softwoods

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Appendix A. Guidelines for sawmill softwood grading in Polish conditions

<table>
<tr><td colspan="2" rowspan="2">Characteristics</td><td colspan="4">Classes</td></tr>
<tr><td>WA0</td><td>WBO</td><td>WC0</td><td>WD</td></tr>
<tr><td colspan="2">Minimum top diameter (dt)</td><td>22 cm</td><td colspan="3">14 cm</td></tr>
<tr><td colspan="2">Length</td><td colspan="4">from 2.7 m to 14.0 m – interval every 10 cm</td></tr>
<tr><td colspan="2">Minimal length of butt log without defects or with permitted defects</td><td colspan="2">4 m</td><td colspan="2">without limit</td></tr>
<tr><td rowspan="3">Knots</td><td>uncovered</td><td colspan="2">permitted to 2 cm,
not permitted in pine and larch</td><td colspan="2">permitted</td></tr>
<tr><td rowspan="2">covered knots</td><td colspan="2">to 1 cm high not taken into account, higher</td><td colspan="2" rowspan="2">permitted</td></tr>
<tr><td>not permitted</td><td>permitted on 1/2 of circumference</td></tr>
<tr><td rowspan="3">Shakes</td><td>end shake</td><td>permitted to 1/5 of face diameter</td><td>permitted to 1/3 of face diameter</td><td colspan="2">permitted</td></tr>
<tr><td>check</td><td>permitted of width to 3 mm</td><td colspan="3">permitted</td></tr>
<tr><td>deep crack and traversing crack</td><td colspan="3">not permitted</td><td></td></tr>
<tr><td colspan="2" rowspan="2">Sweep</td><td colspan="4">permitted when grading logs of 2.7 m in length with sweep of</td></tr>
<tr><td>2 cm/m</td><td colspan="2">3 cm/m</td><td>5 cm/m</td></tr>
<tr><td colspan="2">Spiral grain</td><td>permitted to ≤5 cm</td><td colspan="3">permitted</td></tr>
<tr><td colspan="2">Scars</td><td colspan="2">permitted, not in spruce</td><td colspan="2">permitted</td></tr>
<tr><td rowspan="2">Stain</td><td>blue stain</td><td colspan="2">not permitted</td><td>permitted to 1/2 of sapwood area</td><td>permitted</td></tr>
<tr><td>brown streak</td><td colspan="3">not permitted</td><td>permitted</td></tr>
<tr><td rowspan="3">Rot</td><td>inner</td><td colspan="2">not permitted</td><td>permitted on one face to ≤1/5 of diameter</td><td>permitted on one face to ≤1/3 of diameter</td></tr>
<tr><td>soft rot</td><td colspan="3">not permitted</td><td>permitted</td></tr>
<tr><td>outer</td><td colspan="2">not permitted</td><td>permitted on 1/4 of circumference to 1/10 of diameter</td><td>permitted</td></tr>
<tr><td colspan="2">Insect attack</td><td colspan="3">not permitted</td><td>permitted</td></tr>
<tr><td colspan="2">Foreign bodies</td><td colspan="3">not permitted</td><td>permitted</td></tr>
</table>