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# Influence of site conditions and silvicultural practice on the wood density of Scots pine (*Pinus sylvestris* L.) – a case study from the Doksy locality, Czech Republic

*Ondřej* SCHÖNFELDER[1], *Aleš* ZEIDLER[1]*, *Vlastimil* BORŮVKA[1], *Lukáš* BÍLEK[2]

[1]*Department of Wood Processing, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Prague, Czech Republic*

[2]*Department of Silviculture, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Prague, Czech Republic*

**Corresponding author: zeidler@fld.czu.cz*

**Abstract**

Schönfelder O., Zeidler A., Borůvka V., Bílek L. (2017): Influence of site conditions and silvicultural practice on the wood density of Scots pine (*Pinus sylvestris* L.) – a case study from the Doksy locality, Czech Republic. J. For. Sci., 63: 457–462.

After spruce, the Scots pine (*Pinus sylvestris* Linnaeus) is the second most important commercial coniferous tree species in the Czech Republic. However, we are finding out that awareness of the variability of properties, and possibilities to affect them, are noticeably small for this type of tree species in our conditions. The goal of this study is to primarily evaluate the importance of site conditions, silvicultural measures and other factors for the density of Scots pine wood in the Doksy locality in the Czech Republic. The Doksy locality is represented by three forest stands with different silvicultural history. Samples were taken from each stand, the basal and central parts of which were subsequently processed for test samples with dimensions of 20 × 20 × 30 mm. Wood density at 12% moisture content was ascertained in the test samples. The highest density value of 0.541 g·cm$^{-3}$ was reached in a stand that is regenerated using the shelterwood method with long regeneration period, and the lowest density value of 0.488 g·cm$^{-3}$ was recorded in a stand that was regenerated using the clear-cutting method. From a forestry perspective, it can be further stated that the wood density of Scots pine is also affected by the site conditions and position of samples in the trunk.

**Keywords**: shelterwood regeneration; clearcut; forest site; softwoods; physical properties; variability

After Norway spruce (*Picea abies* (Linnaeus) H. Karsten), the Scots pine (*Pinus sylvestris* Linnaeus) is the second most important commercial coniferous tree species in the Czech Republic. With the increasing biotic and abiotic damage to spruce forests, the importance of the pine will be increasing; however, we are finding out that we know very little about the properties of this tree species in the conditions of Central Europe. In terms of forest management, the pine currently covers 16.6% of the total area, whilst its natural representation in the tree species composition of the forest was 3.4%. The recommended representation of the pine in forest stands is in fact higher than the current state (Ministry of Agriculture of the Czech Republic 2016).

Forest owners and managers who want to acquire maximum profits from their forests need to understand not only the essence of growth and regeneration of forest stands, but also they must have the information about the quality of their wood (Jozsa,

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Middleton 1994). The quality of wood is a subjective concept to a certain extent, and it must always be understood in the relevant context (MacDonald et al. 2010). We usually understand it from the perspective of properties that are beneficial for the final use of wood.

Wood is a heterogeneous material and exhibits high variability of properties. The variability of pine properties can be observed between individual localities and trees, and even within a single tree (Tomczak et al. 2007; Kask 2015). Through the tree genotype, wood properties are largely influenced by altitude, climatic factors, by the surrounding environment and by silvicultural measures (Tsoumis 1991; Peltola et al. 2007; Jelonek et al. 2008, 2012; Tomczak et al. 2013; Roszyk et al. 2016). The variability of wood properties within a trunk is crucial for the final processing of wood.

The main indicator of wood quality is density, which largely affects other physical, and of course strength characteristics of wood (Kollmann 1951; Auty et al. 2014). It generally applies that the strength of wood increases with increasing density (Kimberley et al. 2015). Wood density decreases with the increasing height of the tree, and it increases in the horizontal direction from the pith to the periphery of the trunk (Požgaj et al. 1997). One of the causes of variability of wood properties in the horizontal direction is juvenile wood. Juvenile wood is generally defined as the wood zone in the middle of the trunk which takes up approximately 5 to 20 tree rings. In this zone, rapid and progressive changes occur in the structure of the wood, and it therefore has different properties compared to mature wood (Kretschmann et al. 1993). Another determining criterion that influences properties in the horizontal direction is the width of the tree ring. In pine wood, it is assumed that with increasing ring width, the proportion of late wood decreases, and consequently its density also decreases (Kask 2015).

The aim of this study was to assess the impact of silvicultural measures and site conditions on the wood density value of Scots pine from the Doksy region in the Czech Republic. The variability of density in the horizontal and vertical position of the trunk was also analysed. The influence of the tree ring width on wood density was also evaluated.

Table 1. Average values of sample trees from selected stands

| Doksy region | Forest site type* | Silvicultural practice | DBH (mm) | Tree height (m) |
|---|---|---|---|---|
| Stand 1 | 0K | shelterwood | 169 | 13.0 |
| Stand 2 | 0K | clear-cutting | 187 | 18.1 |
| Stand 3 | 2K | clear-cutting | 204 | 21.6 |

*group of forest site types according to the Czech typological system (Viewegh et al. 2003)

## METHODS

The research was conducted in the Doksy study locality, of which the natural occurrence of Scots pine in the Czech Republic is typical. Extraction took place in three forest stands that are characteristic of the Doksy region and represent different silvicultural practices or site conditions (Table 1). Forest stands are owned by the Municipal Forests of the town of Doksy and are located in the Natural Forest Region PLO 18 (Severočeská pískovcová plošina and Český ráj), where average precipitation is 550 mm, the average temperature is between 7 and 8°C, according to the data from the nearest meteorological station, and the altitude reaches up to 450 m a.s.l. Seven sample trees were selected from each stand, from which test material was made. An important criterion for the selection of sample trees was the representation of characteristic individuals of the relevant stand, their vitality and absence of growth irregularities and defects. Stand 1 is characterized by the advanced understorey of pine that grows in the shade of parent trees. Sampled trees represent these individuals growing under the canopy of parent stand tended by regeneration fellings. Stands 2 and 3 were established on a clear-cut area, i.e. sampled trees have grown without the shelter of parent trees in a single-layered even-aged stand since the very beginning.

A total of 21 sample trees were felled in winter to assess wood density from the Doksy locality. To assess the vertical variability of wood density, two logs were cut out from individual sample trees in the direction from the base to the crown. A basal log was always cut out from the breast-height diameter area (in the middle of the section), and the central log was cut out at 1/3 of the height of the trunk only if the trunk had a diameter greater than 15 cm. The length of each section was 150 cm. In stand 1 the trunk did not have the required dimensions, and therefore the central log was not cut. A disc was cut out from each log so that a tree ring analysis could be carried out. In order to assess the variability in the horizontal plane of the trunk, a central plank was cut out from each log whose width allowed for test materials to be produced. The timber prepared in this way was interleaved and stored in a covered space with free air flow. When the wood moisture content dropped below 15%, the individual planks were cut lengthwise in the direction from the pith toward the cambium making laths of 20 × 20 mm in cross-section (Fig. 1). The material prepared in this way served as a basis for the preparation of test specimens. After final modifications, the test specimens had dimensions of 20 × 20 × 30 mm for physical tests. The examined physical property was the basic variable, i.e. density at 12% moisture content. The test specimens were stabilized in a conditioning chamber at 12% equilibrium moisture content in the environment with an air temperature of 20 ± 2°C and relative humidity of 65 ± 5%. A total of 1,636 specimens were tested for density. The quality of all the samples complied with the standard ČSN 49 0101 and they were free of irregular growth defects and compression wood.

The standard ČSN 49 0108 was used to evaluate density. Density was evaluated at 12% moisture content ($\rho_{12}$) according to Eq. 1:

$$\rho_{12} = \frac{m_{12}}{V_{12}} \left(\text{g·cm}^{-3}\right) \qquad (1)$$

where:

$m_{12}$ – mass of the specimens at 12% moisture content (g),

$V_{12}$ – volume of the specimens at 12% moisture content ($cm^3$).

We used an A3 Epson GT-15000 scanner (Epson, Japan) and resolution of 800 dpi to scan the disk for tree ring width analysis. The NIS-Elements AR Image Analysis Software (Version 4.11, 2014) was employed to measure the width of tree rings.

To assess the statistical significance of individual impacts, the multifactor ANOVA tests (Fisher *F*-test) and Duncan's multiple comparison tests were used. The level of significance α = 0.05% was used for all statistical analyses. The evaluated factors were vertical position (along the height of the trunk), horizontal position (distance from the pith), and silvicultural measures and site conditions. Statistical analyses were carried out using the STATISTICA program (Version 13, 2016).

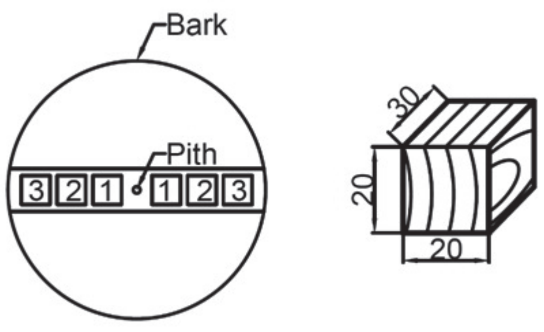


Fig. 1. Tree sampling and the test sample description (dimensions in mm)

Table 2. Descriptive statistics – comparison of density in individual stands

| | Stand 1 | Stand 2 | Stand 3 |
|---|---|---|---|
| Mean (g·cm$^{-3}$) | 0.541 | 0.529 | 0.488 |
| Median (g·cm$^{-3}$) | 0.534 | 0.528 | 0.477 |
| Coefficient of variation (%) | 7.9 | 10.9 | 17.1 |
| Standard deviation (g·cm$^{-3}$) | 0.0428 | 0.0581 | 0.0836 |
| Number of specimens | 342 | 556 | 738 |

## RESULTS AND DISCUSSION

A difference in density on different sites (forest type groups 0K and 2K) was observed between stands 2 and 3, which were regenerated on a clear-cut area. The descriptive statistics of individual stands are shown in Table 2. Table 2 shows that the average value of pine wood density at 12% moisture content reaches 0.529 g·cm$^{-3}$ for stand 2, and 0.488 g·cm$^{-3}$ for stand 3. An analysis of variance of the examined stands revealed that the wood density of Scots pine differs significantly, $P < 0.05$ (Fig. 2). Stand 2 shows higher density values than those indicated by many authors (Lexa et al. 1952; Požgaj et al. 1997; Wagenführ 2002; Fellner 2007). Conversely, the wood density of stand 3 is comparable with literature (Novák 1970; Šimůnková, Kučerová 2000), but the variability of density is high. Jelonek et al. (2005), Tomczak and Jelonek (2013), and Hautamäki et al. (2014) reported dif-

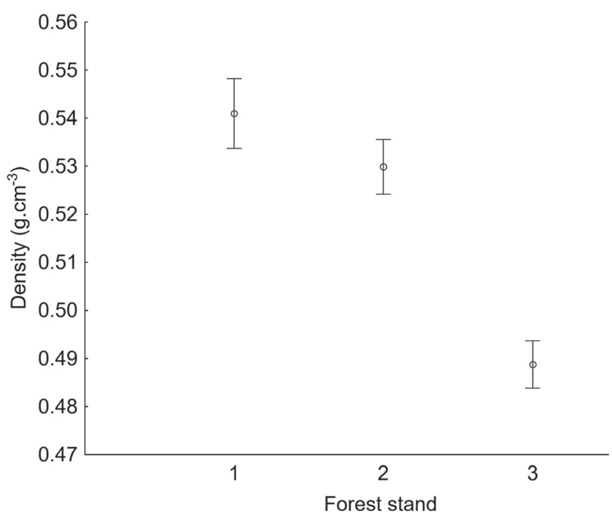


Fig. 2. Impact of site and silvicultural practice on wood density

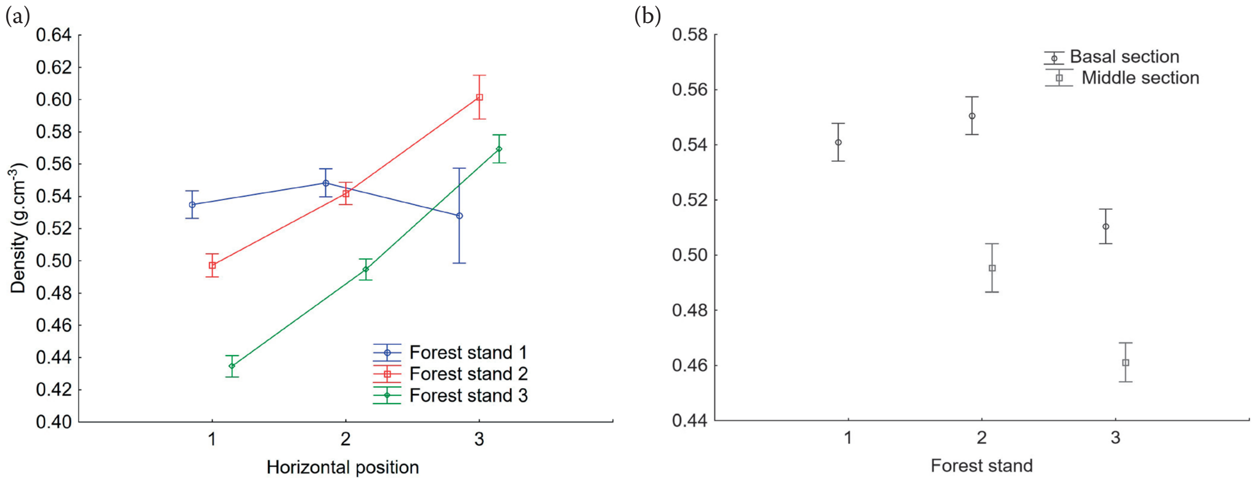


Fig. 3. Impact of the horizontal (a), vertical (b) position on the wood density of individual stands

ferent results of pine density in various sites. This phenomenon was confirmed by Tsoumis (1991), who stated that site conditions may significantly affect density.

The monitored differences in density depending on silvicultural measures were observed between stand 1 and stand 2. These stands are found in the same site conditions (forest type group 0K), and it is therefore possible to monitor differences in properties caused by different regeneration methods used. A statistically significant difference ($P < 0.05$) in density values was confirmed between the investigated stands. Higher average density values of 0.541 g·cm$^{-3}$ were obtained in stand 1, which is regenerated using the shelterwood method, and conversely, lower values of 0.529 g·cm$^{-3}$ were shown in stand 3, which was regenerated using the clear-cutting method. Low values of wood density for planted pines were also reported for example by Eriksson et al. (2006) and Mederski et al. (2015).

The density variability in the horizontal direction is shown in Fig. 3a and Table 3 with the average density values in individual sections. The density variability in the horizontal direction for stands 2 and 3 demonstrated a clear trend of increasing the value in the direction from the pith to the bark, similarly to what was stated by Nicholls and Brown (1973), Fritts et al. (1991), and Ivković et al. (2013). A statistically significant difference ($P < 0.05$) was demonstrated between these stands in individual positions. Sample trees from stand 1 grew in the shade. For this reason they show low annual increments at the early stages of growth. After the regeneration felling in 2008, there was a sudden significant increase in the thickness of the tree ring of the understorey individuals. This trend was described by Eriksson et al. (2006).

In order to assess the variability of wood properties, it is necessary to take into consideration in which part of the trunk the wood is located. It is evident from Fig. 3b and Table 3 that wood density in the basal part of the tree shows higher density values than those in the middle part. A statistically significant difference ($P < 0.05$) was found between individual sections. No significant difference in density ($P = 0.066$) was found between stands 1 and 2 at the base part. Stand 3 indicates a lower density value in all sections than the other stands. Higher density values in the basal part of the trunk were described for example by Tsoumis (1991), Požgaj et al. (1997), Repola (2006), and Riesco Muñoz et al. (2008).

The tree ring analysis is shown in Fig. 4. It is evident from the image that stands 2 and 3 have the widest tree rings in the part closest to the pith. With increasing distance from the pith, the width of the tree rings shows a decreasing tendency until it essentially stabilizes (Tomczak et al. 2007).

Table 3. Mean density variability within a trunk

| | Density variability (g·cm$^{-3}$) | | | | |
|---|---|---|---|---|---|
| | vertical | | horizontal | | |
| | basal section | middle section | 1st position | 2nd position | 3rd position |
| Stand 1 | 0.541 | – | 0.535 | 0.548 | 0.528 |
| Stand 2 | 0.551 | 0.495 | 0.497 | 0.542 | 0.602 |
| Stand 3 | 0.511 | 0.458 | 0.435 | 0.495 | 0.569 |

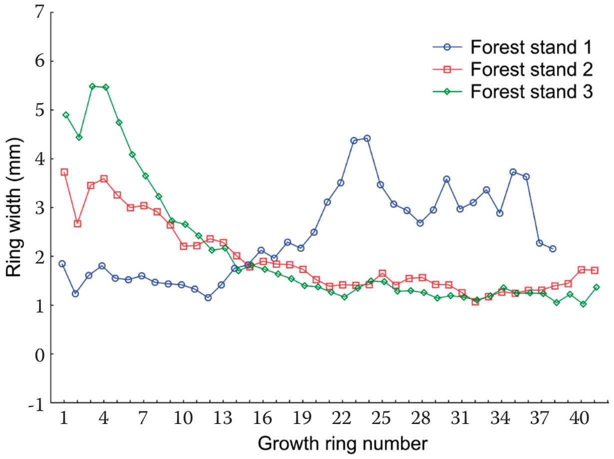


Fig. 4. Tree ring analysis of the basal section

Stand 1 indicates a completely opposite trend. This trend largely copies the horizontal course of density, wherein the density decreases with the increasing width of the tree rings, similarly to what was stated by Mörling (2002) or Ivković et al. (2013), as mentioned earlier.

Table 4 shows a comparison of our results with those of the authors who investigated the density of Scots pine wood in the region of Central Europe. In most cases, the investigated pine wood density from the Doksy region shows higher density values when compared to these authors.

## CONCLUSIONS

The aim of this study was to primarily evaluate the impact of silvicultural measures and site conditions on the wood density of Scots pine from the Doksy region in the Czech Republic. In most cases, the investigated pine wood density from the Doksy region reaches higher density values when compared to the results of other authors (Lexa et al. 1952; Novák 1970; Wagenführ 2002), who investigated the density of Scots pine in neighbouring territories. Given the fact that wood density significantly affects the mechanical properties of wood, it can be presumed that pine, which grows on natural pine sites in the study locality, achieves high wood qualities for final use. Forest site was proven to be a significant factor that affected wood density. Silvicultural practice was also proven to have an impact on wood density; the shelterwood method with long regeneration period indicates a more even distribution of density along the radius of the trunk. With regard to the final processing of wood, it is necessary to take into consideration which part of the tree the wood comes from – wood with greater density is found more in the basal part of the tree than in the middle part. Pine wood plays an important role in the wood processing industry in the Czech Republic, and it will be increasing in the Czech Republic the more it is planted.

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Table 4. Comparison of the wood density of Scots pine with various authors

| | Measured values | Wagenführ (2002) | Novák (1970) | Lexa et al. (1952) |
|---|---|---|---|---|
| Density ($g\cdot cm^{-3}$) | 0.488–0.541 | 0.510 | 0.470 | 0.510 |

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