WOOD RESEARCH
64 (4): 2019
577-588

IMPACT OF SILVICULTURAL MEASURES ON THE QUALITY OF SCOTS PINE WOOD PART I. EFFECT OF REGENERATION METHOD

Ondřej Schönfelder, Aleš Zeidler, Vlastimil Borůvka
Czech University of Life Sciences Prague, Faculty of Forestry
and Wood Sciences, Department of Wood Processing and Biomaterials
Prague, Czech Republic

Lukáš Bílek
Czech University of Life Sciences Prague, Faculty of Forestry
and Wood Sciences, Department of Silviculture
Prague, Czech Republic

(Received April 2019)

ABSTRACT

This study deals with the influence of the silvicultural measures on selected mechanical properties of Scots pine (*Pinus sylvestris* L.) wood in the Czech Republic. Sample trees were selected at two different localities that are characteristic of Scots pine growth, and they represent two different Scots pine regeneration methods, namely the clear-cutting and shelterwood regeneration method. We tested compressive strength and impact bending strength. The density of the wood was also evaluated as a factor influencing strength characteristics. The shelterwood regeneration method shows higher values in most of the investigated characteristics (49.3 MPa for the shelterwood method and 44.6 MPa for the clear-cutting method in the case of compressive strength); however, these differences are not significant for the processing industry. Another positive effect of the shelterwood regeneration method is the even distribution of the properties within the trunk in radial direction in contrast to clear-cutting method.

KEYWORDS: Scots pine, silviculture, wood, mechanical properties, variability.

INTRODUCTION

The Scots pine (*Pinus sylvestris* L.) is the most wide spread and one of the most economically important evergreen trees in Europe (Kask 2015). Currently, the regeneration of new stands by planting seedlings is the most widespread method of growing Scots pine (Agestam et al.

1998). However, due to favourable environmental impacts, there is a growing interest in natural regeneration of stands. This method of regeneration of Scots pine stands is widely applied in the Scandinavian countries, but in Central Europe it is a marginal regeneration method (Bílek et al. 2018). Very little attention is paid to the influence of silvicultural practices on the quality of wood, in particular on the properties of wood, which are important from the perspective of the processing industry (Eriksson et al. 2006).

One of the criterions determining the use of wood in industry are the mechanical properties of wood. In particular, strength characteristics are closely related to wood density and are closely related to each other (Zeidler et al. 2015). Differences in mechanical properties can be found between individual trees of the same species as well as within a single tree, both in the radial (from the pith to the bark) (Horáček et al. 2017). The variability of properties in the trunk in the radial direction has been confirmed by many authors (Hautamäki et al. 2014, Kask 2015, Jelonek et al. 2008, Raiskila et al. 2006a). Generally, for conifers, it applies that the wood properties increase with increasing distance from the pith (Fernandes et al. 2017, Ivković et al. 2013, Nicholls and Brown 1973, Repola 2006). Factors contributing to this radial variability include, in particular, the annual ring width and the presence of juvenile wood in the trunk (Zeidler and Šedivka 2015, Zobel and Van Buitenen 1989). The presence of juvenile wood is cited as one of the main causes of horizontal variability, in particular in coniferous trees (MacDonald and Hubert 2002, Kretschmann et al. 1998). Juvenile wood is a zone in the middle of the trunk occupied by approximately 5 to 20 annual rings (Kretschmann et al. 1998). It shows a different structure (fiber length, fibril orientation in the cell wall) and chemical composition (Horáček et al. 2017) compared to mature wood. Another cause of the variability of wood properties in the radial direction is the thickness of the annual ring and the associated proportion of late wood (Požgaj et al. 1997, Kolmann 1951). Generally, for softwoods, it applies that with increasing annual ring thickness, the resulting wood properties are decreasing. The variability of properties in the trunk is primarily due to the relationship between the wood density and its strength (Horáček et al. 2017). The variability of wood properties between trees is around 5 - 20% and is much smaller than the variability of characteristics in the trunk. The variability between individual trees is mainly due to genetic properties, while variability within the trunk is caused by different trunk thickness and the number of annual rings (Horáček et al. 2017).

The aim of this work is to assess the impact of the application of the shelterwood regeneration method and clear-cutting regeneration method on selected physical and mechanical characteristics of Scots pine wood from the Czech Republic. The evaluation criteria determining the impact of the regeneration method were wood density, impact bending strength and compressive strength of wood. The variability of these wood properties in the trunk in the horizontal plane was also analysed. The influence of density on the strength characteristics was also evaluated.

MATERIAL AND METHODS

Materials

Sampling was carried out in two different localities, which are representative of the growth of Scots pine in the Czech Republic (Fig. 1). At each locality, two stands were selected that represent different habitats and different regeneration methods (Tab. 1).

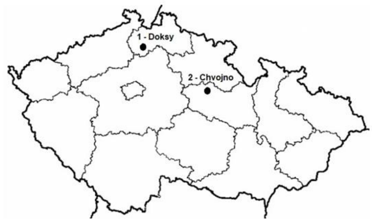


Fig.1: Location of study areas in the Czech Republic.

Tab. 1: Stand and site characteristics.

Locality	Regeneration method	Tree height (m)	DBH (mm)	Forest site type*
1 Doksy	Shelterwood	13.0	169	0K
	Clear-cutting	18.1	187	0K
2 Chvojno	Shelterwood	15.2	205	2I
	Clear-cutting	21.7	224	2I

DBH – diameter at the breast height

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

A total of 7 sample trees were taken from each stand. A total of 28 sample trees were taken from which the test material was made. An important criterion for the selection of samplers was the representation of characteristic individuals for a given stand, and the absence of growth irregularities and defects.

Methods

A 120 cm long section from the trunk base region was taken from each sample trees. Along with the sections, discs were cut off at the collection point so that annual ring analyses could be carried out. The sections were taken from the forest stands for subsequent cutting on a band saw, and the planks were stored and left to dry naturally. The subject of further processing was a central plank that allows for the evaluation of the distribution of properties over the trunk diameter, which was subsequently used for the production of test specimens. The test material was used for the production of test specimens for physical and mechanical tests. The test specimens for the physical tests were 20 x 20 x 30 mm (radial x tangential x axial). The physical property examined was density. The wood compressive strength was determined on the same specimens as the wood density and specimens for impact bending strength had dimensions of 20 x 20 x 300 mm (radial x tangential x axial). The test specimens in the air-conditioning chamber are air-conditioned to an equilibrium moisture of 12%, in conditions with an air temperature of 20°C (± 2°C) and a relative moisture content of 65% (± 5°C). All of the samples comply with quality standard ČSN 49 0101 and do not have irregularities, growth defects or pressure wood.

Standard ČSN 49 0108 was used to evaluate wood density. The number of test samples for wood density was 1268. The density (ρ) was determined according to the following Eq. 1:

$$\rho = \frac{m}{V} \quad (\mathrm{g{\cdot}cm^{-3}}) \qquad (1)$$

where: m - the weight of the specimen (g),
V - the volume of the specimen (cm^3).

Compressive strength was determined by means of universal testing machine Tira 2850 (Tira GmbH, Schalkau, Germany). Compressive strength (σ) was evaluated on 733 specimens. The test was determined in accordance with standard ČSN 49 0110.

$$\sigma = \frac{F}{a \cdot b} \quad \text{(MPa)} \qquad (2)$$

where: *F* - the maximum load force (N),
a and *b* - the cross-sectional dimensions of the specimen (mm).

Another investigated characteristic is impact bending strength. Charpy's hammer (CULS, Prague, Czech Republic) was used for this determination. The hammer impact direction was tangential. The number of test samples used for impact bending strength was 536. Impact bending strength (A) was determined in accordance with standard ČSN 49 0117.

$$A = \frac{Q}{a \cdot b} \quad (\text{J}\cdot\text{cm}^{-2}) \qquad (3)$$

where: *Q* - the consumed power to break the specimen (J),
a and *b* - the cross-sectional dimensions of the specimen (cm).

Multi-factor ANOVA tests (Fisher's F-test) and Duncan's multiple comparison tests were used to evaluate the statistical significance of each factor. The significance level of $\alpha = 0.05$ was used for all statistical analyses. The evaluated factors were the regeneration method and locality. The impact of the horizontal position in trunk was also evaluated.

A linear regression model was used to assess the effect of density on strength characteristics. Statistical analyses were performed using program STATISTICA 14 (Statsoft Inc., USA).

RESULTS AND DISCUSSION

The impact of silvicultural measures on the strength characteristics of wood was investigated between the stands where the shelterwood and clear-cutting regeneration methods were applied. Both regeneration methods were applied in stands that are close to each other at the same forest locality type and can therefore be compared to each other. Wood density, impact bending strength and compressive strength reached higher values in all of the renewed localities in stands regenerated using the shelter wood method (Figs. 2 and 3, Tab. 5). Although all of the examined characteristics are higher for the shelter wood regeneration method, this difference is completely irrelevant from a processing point of view. Statistically significant differences caused by silvicultural measures were only found in compressive strength at both localities ($P<0.05$). For wood density and impact bending strength, the statistically significant effect of silvicultural measures on the properties of wood did not occur ($P>0.05$), see Tab. 2 - 4. Many studies have reported that the natural regeneration of pine stands or stands with a small planting span is necessary for the production of wood with high wood mass quality (Agestam et al. 1998, Herman 1962, Ekö and Agestam 1994, Auty and Achim 2008). Zobel and van Buijtenen (1989) conducted a study in which they worked with Scots pine spacing of 0.75 x 0.75 m to 3.00 x 3.00 m. They found that trees with a higher planting span had reduced wood density. Furthermore, an increased proportion of juvenile wood was recorded in sparsely planted pines. Persson (1975) found the same results in Norway spruce as Zobel and van Buijtenen (1989) found in Scots pine.

Agestam et al. (1998) states that the greater spacing of planted trees leads to lower quality of produced wood compared to naturally renewed stands.

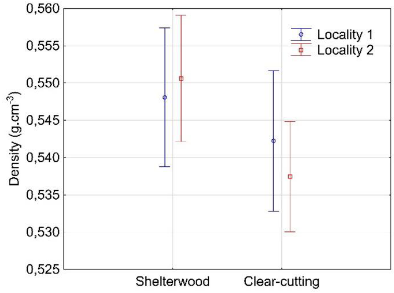
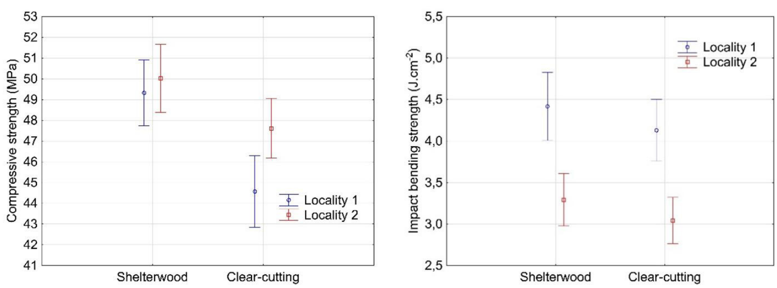


Fig. 2: Impact of regeneration method on wood density.

Tab. 2: Duncan's multiple range test for density.

MS = 0.00367 DF = 1264	L1 S	L1 C	L2 S	L2 C
L1	S			
L1	C	0.335		
L2	S	0.687	0.209	
L2	C	0.108	0.444	0.053

* Values are significant at $p < 0.05$. Error: Between MS = mean squares, DF = degrees of freedom. L = Locality, S = Shelterwood, C = Clear-cutting.



(a) (b)

Fig. 3: Impact of regeneration method on compressive strength (a) and impact bending strength (b).

Tab. 3: Duncan's multiple range test for compressive strength.

MS = 5,531,000 DF = 729	L1 S	L1 C	L2 S	L2 C
L1	S			
L1	C	0.000*		
L2	S	0.544	0.000*	
L2	C	0.138	0.008*	0.047*

* Values are significant at $p < 0.05$. Error: Between MS = mean squares, DF = degrees of freedom. L = Locality, S = Shelterwood, C = Clear-cutting.

Tab. 4: Duncan's multiple range test for impact bending strength.

MS = 5,531,000 DF = 532		L1 S	L1 C	L2 S	L2 C
L1	S				
L1	C	0.295			
L2	S	0.000*	0.000*		
L2	C	0.000*	0.000*	0.317	

* Values are significant at $p < 0.05$. Error: Between MS = mean squares, DF = degrees of freedom.
L = Locality, S = Shelterwood, C = Clear-cutting.

Tab. 5: Descriptive statistics–comparison of the regeneration method on the investigated properties.

Site	Property	Shelterwood			Clear-cutting		
		Mean ± SD	Min	Max.	Mean ± SD	Min.	Max.
Locality 1	Density ($g{\cdot}cm^{-3}$)	0.548 ± 0.043	0.438	0.699	0.542 ± 0.052	0.371	0.658
	Compressive strength (MPa)	49.3 ± 5.7	35	68	44.6 ± 11.1	26	72
	Impact bending strength ($J{\cdot}cm^{-2}$)	4.4 ± 1.3	1.9	7.6	4.1 ± 1.6	1	8.3
Locality 2	Density ($g{\cdot}cm^{-3}$)	0.550 ± 0.052	0.449	0.741	0.537 ± 0.070	0.381	0.701
	Compressive strength (MPa)	50.0 ± 6.4	35	63	47.6 ± 7.8	28	64
	Impact bending strength ($J{\cdot}cm^{-2}$)	3.3 ± 1.2	0.6	7.1	3.0 ± 1.7	0.7	6,9

In terms of processing and final use of wood, it is necessary to be aware of the distribution of wood properties over the trunk cross-section, i.e. from the trunk pith to the cambium (Fig. 4 and 5). It is very evident that stands regenerated via the clear-cutting regeneration method show the lowest strength value in the juvenile wood zone, and the density and strength of the wood grows towards the trunk perimeter. This trend is described by many authors (Ivković et al. 2013, Nicholls and Brown 1973 and Fritts et al. 1991). In contrast, stands regenerated via the shelterwood method show higher values of the investigated properties in the centre of the trunk compared to the clear-cutting method. As mentioned above, Zobel and van Buijtenen (1989) have found an increasing proportion of juvenile wood in the trunk with increasing spacing between growing trees, thus explaining the higher values of properties in the centre of the trunk for stands regenerated via the shelterwood method. Furthermore, stands regenerated via the shelterwood method at both localities show a uniform distribution of properties along stem radius, regardless of the position in the trunk.

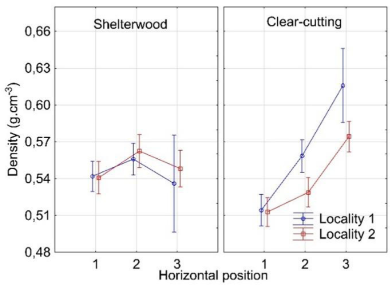


Fig. 4: Impact of regeneration method on the density distribution in the trunk in the radial direction.

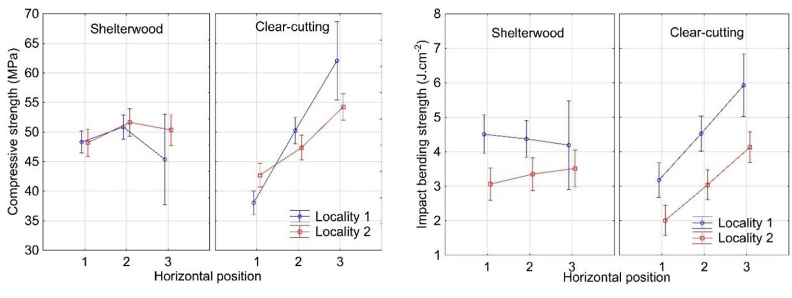


Fig. 5: Impact of regeneration method on the distribution of compressive strength (a) and impact bending strength (b) in the trunk in the radial direction.

The different method of distributing properties in the horizontal direction is due to the effect of the applied methods on the course of widths of annual rings in this direction. Fig. 5 clearly shows that stands regeneration via the clear-cutting renewal method at all localities have the widest annual rings in the area closest to the pith. With increasing distance from the pith, the width of the annual rings is presented by a downward trend. In contrast, stands regenerated via the shelterwood method show low annual growth in the centre of the trunk, and after the release of the maternal stand, the annual ring width suddenly increases. The course of annual rings widths of individual stands is very much related to the resulting properties, which are in strong correlation to each other (Kask 2015, Raiskila et al. 2006b) and, to some extent, explain the horizontal course of strength characteristics.

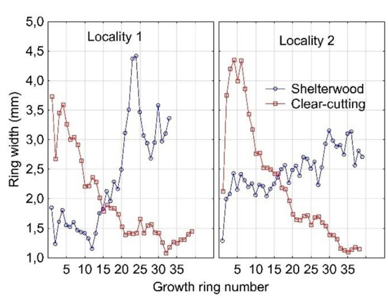


Fig. 6: Layout of annual ring width depending on the applied method.

Since wood density is seen as one of the most important indicators of wood quality, it is important to be aware of the relationship between mechanical properties and wood density. The strongest correlation was found in impact bending strength for stands regeneration via the clear-cutting method (R = 0.70) at Locality 1 and is shown in Fig. 7. The stand regenerated via the shelter wood regeneration method shows the highest correlation in compressive strength (R = 0.68) at Locality 2 (Tab. 6).

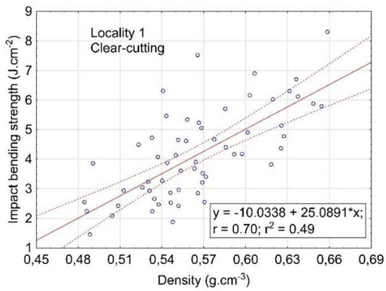


Fig. 7: Dependence of compressive strength on density.

Tab. 6: Dependence of strength characteristics on wood density.

Site	Forest stand	Property	Equation	R
Locality 1	Shelterwood	Compressive strength	y = 17.9446 + 57.7923*x	0.43
		Impact bending strength	y = 2.1885+3.9928*x	0.13
	Clear-cutting	Compressive strength	y = -8.4779 + 100.8647*x	0.48
		Impact bending strength	y = -10.0338 + 25.0891*x	0.70
Locality 2	Shelterwood	Compressive strength	y = 1.3905 + 89.8576*x	0.68
		Impact bending strength	y = -0.0277 + 5.8747*x	0.26
	Clear-cutting	Compressive strength	y = -0.505 + 92.8486*x	0.68
		Impact bending strength	y= -3.4923 + 11.855*x	0.53

The average density and strength characteristics are shown in Tab. 7. By comparing these results with literature, we can state that in the majority of cases, slightly lower mean compressive strength values were achieved than those specified in certain literature. Locality 1 shows impact bending strength values comparable to literature. On the other hand, somewhat lower impact bending strength values were achieved at locality 2. With regard to density, the results obtained oscillate around the mean value that it indicates (Novák 1970).

Tab. 7: Comparison of Scots pine wood values to literature.

			Density ($g\cdot cm^{-3}$)	Compressive strength (MPa)	Impact bending strength ($J\cdot cm^{-2}$)
This study	Locality 1	Shelterwood	0.548	49.3	4.4
		Clear-cutting	0.542	44.6	4.1
	Locality 2	Shelterwood	0.550	50.0	3.3
		Clear-cutting	0.537	47.6	3.0
Wagenführ (2002)			0.510	55.0	4.0
Novák (1970)			0.540	55.0	4.0
Požgaj et al. (1997)			-	49.9	4.6

CONCLUSIONS

1. The significant impact of the shelterwood method regeneration was reflected in the uniform distribution of properties over the trunk radius, regardless of position. Compared to the clear-cutting method, which produces wood with significant trunk width variability, the wood produced via the shelterwood method is quite homogeneous.
2. A statistically significant difference was only found in the case of compressive strength. The difference in wood density and impact bending strength was not significantly confirmed at any of the investigated localities. The slight differences found in the mechanical properties are almost negligible and insignificant in terms of practical application.
3. The dependence of strength characteristics on density was found in most cases to be higher in compressive strength, regardless of the type of stand regeneration. The highest value, R = 0.7, was found at the stand regenerated via the clear-cutting method at Locality 1. From these results it can be stated that density can be used to predict the strength properties of wood.
4. The density values are comparable to the density values found in the Czech Republic. Compressive strength achieves somewhat lower values than those specified in literature. As these are young stands, it can be assumed that with increasing age, strength characteristics will increase as well.

ACKNOWLEDGEMENT

The research was supported by the Ministry of Agriculture of the Czech Republic [project number QJ1520037 – „Increasing the adaptability of pine (*Pinus sylvestris* L.) silviculture in the conditions of the Czech Republic"] and by Internal Grant Agency of the Faculty of Forestry and Wood Sciences [A03/18].

REFERENCES

1. Agestam, E., Ekö, P.M., Johansson, U., 1998: Timber quality and volume growth in naturally regenerated and planted Scots pine stands in S.W. Sweden. Studia Forestalia Suecica 204: 1-17.
2. Auty, D., Achim, A., 2008: The relationship between standing tree acoustic assessment and timber quality in Scots pine and the practical implications for assessing timber quality from naturally regenerated stands. Forestry 81(4): 475–487.
3. Bílek, L., Zeidler, A., Pulkrab, K., Ulbrichová, I., Vacek, S., Borůvka, V., Vítámvás, J., Remeš, J., Vacek, Z., Sloup, R., 2018: Pěstební a ekonomické aspekty clonné obnovy borovice lesní. (Silvicultural and economical aspects of shelterwood regeneration of Scots pine). Lesnický průvodce. Strnady, 56 pp.
4. ČSN 49 0101, 1980: Drevo. Všeobecné požiadavky na fyzikálne a mechanické skúšky (Wood. General requirements for physical and mechanical testing).
5. ČSN 49 0108, 1993: Drevo. Zisťovanie hustoty (Wood. Determination of the density).

6. ČSN 49 0117, 1980: Drevo. Rázová húževnatosť v ohybe (Wood. Impact strength in flexure).
7. ČSN 49 0110, 1980: Drevo. Medza pevnosti v tlaku v smere vlákien (Wood. Compression strength limits parallel to the grain).
8. Ekö, P.M., Agestam, E., 1994: A comparison of naturally regenerated and planted Scots pine (*Pinus sylvestris* L.) on fertile sites in southern Sweden. Forest & Landscape Research 1(2): 111-126.
9. Eriksson, D., Lindberg, H., Bergsten, U. 2006: Influence of silvicultural regime on wood structure characteristics and mechanical properties of clear wood in *Pinus sylvestris*. Silva Fennica 40(4): 743-762.
10. Fernandes, C., Gaspar, M.J., Pires, J., Alves, A., Simőes, R., Rodrigues, J.C., Silva, M.E., Carvalho, A., Brito, J.E., Lousada, J.L., 2017: Physical, chemical and mechanical properties of *Pinus sylvestris* wood at five sites in Portugal. iForest 10(4): 669-679.
11. Fritts, H.C., Vaganov, E.A., Sviderskaya, I.V., Shashkin, A.V., 1991: Climatic variation and tree-ring structure in conifers: Empirical and mechanistic models of tree-ring width, number of cells, cell size, cell-wall, thickness and wood density. Climate Research 1: 97–116.
12. Hautamäki, S., Kilpeläinen, H., Verkasalo, E., 2014: Factors and models for the bending properties of sawn timber from Finland and north-western Russia. Part II: Scots pine. Baltic Forestry 20(1): 142–156.
13. Herman, F. R., 1962: Shelterwood cutting to see if young-growth hem-lock can be regenerated by series of successive cut-tings. Pulp and Paper 36(1): 61-63.
14. Horáček, P., Fajstavr, M., Stojanović, M., 2017: The variability of wood density and compression strength of Norway spruce (*Picea abies* /L./ Karst.) within the stem. Beskydy 10(1,2): 17–26.
15. Ivković, M., Gapare, W., Wu, H., Espinoza, S., Rozenberg, P., 2013: Influence of cambial age and climate on ring width and wood density in *Pinus radiata* families. Annals of For¬est Science 70(5): 525–534.
16. Jelonek, T., Pazdrowski, W., Tomczak, A., Szaban, J., 2008: The effect of social position of a tree in the stand and site on wood quality of Scots pine (*Pinus sylvestris* L.). Electronic Journal of Polish Agricultural Universities 11(2): 1-13
17. Jelonek, T., Tomczak, A., Jakubowski, M., Pazdrowski, W., 2005: Properties of Scots pine (*Pinus sylvestris* L.) timber growing on former arable and forest land. Acta Scientiarum Polonorum Silvarum Colendarum Ratio et Industria Lignaria 4(2): 35–47.
18. Kask. R,. 2015: The influence of growth conditions on physico-mechanical properties of Scots pine (Pinus sylvestris L.) wood in Estonia. Institute of Forestry and Rural Engineering. Tartu, 164 pp.
19. Kollmann, F., 1951: Technologie des Holzes und der Holz¬werkstoffe. Springer-Verlag. Berlin, 1050 pp.
20. Kretschmann, D. E., Moody, R. C., Pellerin, R. F., Bendtsen, B. A., Cahill, J. M., Mcalister, R. H., Sharp, D. W. 1998: Properties of juvenile wood. Techline - properties and use of wood, composites, and fiber products. USDA. Forest Products Laboratory 09/98: 6–7.
21. Macdonald, E., Hubert, J., 2002: A review of the effects of silviculture on timber quality of Sitka spruce. Forestry 75(2): 107–138.
22. Nicholls, J.W.P., Brown, A.G., 1974: The relationship between ring width and wood characteristics in double-stemmed trees of Radiata pine. New Zealand Journal of Forestry Science 4: 105–111.

23. Novák, V., 1970: Dřevařská technická příručka. (Wood handbook). SNTL. Praha, 748 pp.
24. Persson, A., 1975: Ved och pappersmassa fran gran och tall i olika forband. (Wood and pulp of Norway spruce and Scots pine at various spacings). SkogshOgsk Stockholm Inst Skogsprod Rapp Upps, 145 pp.
25. Požgaj, A., Chovanec, D., Kurjatko, S., Babiak, M., 1997: Štruktúra a vlastnosti dreva. (Structure and properties of wood). Príroda. Bratislava, 485 pp.
26. Raiskila, S., Saranpää, P., Fagerstedt, K., Laakso, T., Löija, M., Mahlberg, R., Paajanen, L., Ritschkoff, A.C., 2006: Growth rate and wood properties of Norway spruce cutting clones on different sites. Silva Fennica 40(2): 247-256.
27. Raiskila, S., Saranpää, P., Fagerstedt, K., Laakso, T., Löija, M., Mahlberg, R., Paajanen, L., Ritschkoff, A.C., 2006: Growth rate and wood properties of Norway spruce cutting clones on different sites. Silva Fennica 40(2): 247–256.
28. Repola, J., 2006: Models for vertical wood density of Scots pine, Norway spruce and birch stems, and their application to determine average wood density. Silva Fennica 40(4): 673-685.
29. Tomczak, A., Jelonek, T., 2013: Radial variation in the wood properties of Scots pine (*Pinus sylvestris* L.) grown on former agricultural soil. Forest Research Papers 74(2): 171-177.
30. Viewegh, J., Kusbach, A., Mikeska, M., 2003: Czech forest ekosystém classification. Journal of Forest Science 49(2): 85–93.
31. Wagenfuhr, R., 2002: Dřevo – obrazkovy lexikon. (Lexicon of Timbers). Grada Publishing, a.s. Prague, 348 pp.
32. Zeidler, A., Borůvka, V., Schönfelder, O., 2017: Comparison of wood quality of Douglas fir and spruce from afforested agricultural land and permanent forest land in the Czech Republic. Forests 9(1): 1-13.
33. Zeidler, A., Salem Mohamed, Z.,M., Borůvka, V., 2015: Mechanical properties of grand fir wood grown in the Czech Republic in vertical and horizontal positions. BioResources 10(1): 793-808.
34. Zeidler, A., Šedivka, P., 2015: Influence of selected factors on wood density variability in grand fir (*Abies grandis* /Douglas/ Lindl.). Wood research 60(1): 33-44.
35. Zobel, B.J., van Buijtenen, J.P., 1989: The Effect of Silvicultural Practices on Wood Properties. In Wood Variation. Pp 218–248, Springer, Berlin.

Ondřej Schönfelder, Aleš Zeidler, Vlastimil Borůvka*
Czech University of Life Sciences Prague
Faculty of Forestry and Wood Sciences
Department of Wood Processing And Biomaterials
Kamýcká 129
165 00 Praha 6 - Suchdol
Czech Republic
Phone: +420 224 383 636
*Corresponding author: boruvkav@fld.czu.cz

Lukáš Bílek
Czech University of Life Sciences Prague
Faculty of Forestry and Wood Sciences
Department of Silviculture
Kamýcká 129
165 00 Praha 6 - Suchdol
Czech Republic