Drewno 2016, Vol. 59, No. 197
DOI: 10.12841/wood.1644-3985.C21.17

RESEARCH REPORTS

Magdalena Czajka, Ewa Fabisiak

RADIAL VARIATION OF MACROSTRUCTURAL PARAMETERS AND DENSITY OF WOOD IN DOMINANT TREES OF CONIFEROUS SPECIES

This paper presents the results of measurements of wood macrostructure parameters and wood density in dominant trees of Scots pine, Norway spruce, and European larch, originating from an even-aged stand, therefore growing on identical sites and in identical climatic conditions. The influence of the cambial age of annual rings and the cross-section area on the measured features was determined in this study. The measurements of macrostructural parameters were taken using an image analyser. Basic density was determined on samples containing three annual rings. In the analysed species the widths of annual rings demonstrated significant differences in the first 50 years of tree growth. The smallest widths of annual rings throughout the whole period of tree growth were observed in the case of spruce wood. The latewood share, analysed within 25-year increment zones, demonstrated statistically significant differentiation between tested species in all selected zones of the cross-section. For each of the tested species the lowest shares were observed for juvenile wood. The lowest density values were observed, therefore, in this zone. In the mature wood of larch and pine an approximate 20% increase in the density was observed and furthermore, all the way to the circumference, density showed slight fluctuations. In the case of spruce wood, the values of density within the analysed zone increased towards the circumference. Accordingly, larch wood and pine wood were characterised by greater uniformity of properties, compared to spruce wood. This observation has important practical implications, because density is a determinant of many properties that influence the technical quality of wood.

Keywords: macrostructural parameters, wood density, pine, spruce, larch

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Magdalena Czajka (*m_czajka@itd.poznan.pl*), Wood Technology Institute Poznań, Poland, Ewa Fabisiak✉ (*efabis@up.poznan.pl*), Poznań University of Life Sciences, Department of Wood Science, Poznań, Poland

Introduction

The radial variability of wood properties is determined by the dynamics in the formation of annual rings, thus by their width and the share of latewood. These parameters are significant elements of the technical quality assessment of coniferous wood. They depend on many factors, inter alia, genetic predispositions, tree age, the biosocial class of trees in a stand, the type of habitat, climatic conditions, and the geographic region [Zobel and Buijtenen 1989; Antonova and Stasova 1993; Wiemann and Williamson 2002; Mäkinen and Isomäki 2004; Riesco Muñoz et al. 2008; Pärn 2012]. The wood of the same species in one region of the country, obtained from a defined habitat, may have different properties than the wood growing on a different area or habitat [Burczyk and Giertych 1991; Witkowska and Lachowicz 2013; Szaban et al. 2014]. Some reports suggest that the environmental factors have a greater impact on the growth of an annual ring than the genetic factors [Zobel and Jett 1995].

A property directly connected with the macrostructure of wood is its density. Many literature reports promote wood density as the property, determining possible applications of wood. This is connected with a strong correlation between density and mechanical parameters of wood [Bamber and Burley 1983; Dinwoodie 2000; Roszyk et al. 2013] and with the fact, that density is a property which can be relatively easily measured.

Radial variation of many properties within a tree is also significantly influenced by the location of wood tissues at the cross-section (juvenile and mature wood) [Larson 1994; Helińska-Raczkowska and Fabisiak 1991, 1999].

Bearing this in mind, the authors decided to conduct comparative tests of the variability of macrostructural parameters and density of wood of various coniferous species, originating from the same biosocial class and growing in the same habitat and climate conditions. This research will allow determination of interspecies differences in the analysed parameters and together with other properties may provide a more complete description of the technical quality of raw wood material originating from a given geographic region.

Materials and methods

The material used for testing was wood from the Norway spruce (*Picea abies* L.), Scots pine (*Pinus sylvestris* L.) and European larch (*Larix decidua* Mill.). The tests were carried out on wood from the class of dominant trees at an age of 104-106 years, from a stand growing in a habitat of mixed fresh forest. The stand was located in the forest division of Łopuchówko, a commune of Murowana Goślina (52°26'N; 16°43'E). Three trees from each species of the class of dominant trees had been chosen for investigations. Next, approximately 5 cm thick test discs were cut out at the diameter at breast height, and then approximately 4 cm wide slats were cut out from the discs along the north-south radius. With regards to macrostructural parameters, the width of the annual rings and the share of latewood was determined. The measurements of the width of the zones of earlywood and latewood were taken using an image analyser including a stereoscopic microscope fitted with a CD camera which was connected to a computer. The measurements were conducted using the Micro Scan Plus programme. The share of latewood was calculated as a quotient of the width of the latewood zones and the width of the entire annual ring. Wood density was determined on samples split along the borders of annual rings and including three annual rings each, in the direction from the core to the circumference. The authors determined basic density, i.e. the density, which is a quotient of the mass of oven-dry wood and the volume of maximally swollen wood. The results were analysed using the programme STATISTICA 10.0 PL, descriptive statistics and the single-factor variance analysis ANOVA. All tests were carried out for a significance level of $p < 0.05$.

Results and discussion

Table 1 presents basic descriptive statistics of the studied parameter. All the values of the properties determined in this study are averages of the measurements taken along the north and the south radius of the three test trees of each species. The average width of the annual rings was 1.12 mm for spruce wood, and for pine and larch it was very similar and equalled 1.52 mm and 1.53 mm, respectively. Table 1 also presents descriptive statistics of the share of latewood.

Table 1. Descriptive statistics of annual rings width, percentage of late wood of spruce, larch and pine wood and variance analysis

Species	Mean	Min	Max	Standard deviation	Standard error
Annual rings width (mm)					
Spruce	1.12	0.40	3.30	0.4111	0.0387
Larch	1.53	0.35	8.65	1.1209	0.1054
Pine	1.52	0.40	4.90	0.7764	0.0761
Percentage of late wood (%)					
Spruce	38.39	14.04	66.66	11.1155	1.0456
Larch	33.30	5.83	57.14	10.0873	0.9489
Pine	36.73	7.05	61.36	11.2128	1.0995

Results of variance analysis			
Source of variation	Value of test function $F_{(103;208)}$		Empirical level of significance α
	estimated	tabular α=0.05	
Cambial age of annual rings	Annual rings width		
	3.6316	1.3147	0.0000*
	Percentage of late wood		
	1.8291	1.3147	0.0001*

*Significant differences.

The highest share of late wood was observed for spruce wood (38%), and the lowest for larch (33%). Although the arithmetic averages of the measured features were very similar, the parameters of the rings produced in the same years of tree growth were compared. The analysis of ANOVA variance proved that the interspecies differences in the width of annual rings produced in the same vegetative periods and in the share of latewood were statistically significant (tab. 1).

Analysis of the radial variability of the studied parameters should take into account values and the course of these parameters in the juvenile and mature wood zones [Fabisiak 2005; Karlman et al. 2005; Gryc et al. 2011].

Previous research conducted using the same test material resulted in the determination of the boundary between juvenile and mature wood. Based on the variability of the tracheid length, the width of juvenile wood was determined to have been the first 25 annual rings [Czajka et al. 2015]. A detailed analysis of the properties determined in this study was therefore carried out in 25-year increment zones, counting from the pith to the circumference (further they were marked as zones I, II, III, and IV). Figure 1 presents the widths of annual rings and the shares of latewood in the 25-year increment zones of the cross-section. The differences in the widths of annual rings in the analysed areas of the cross-section of spruce, larch and pine wood were statistically significant in the first two increment zones (tab. 2). In the case of spruce wood, the widths of annual rings within the juvenile wood zone were two times smaller compared to larch and pine wood, and they equalled 1.29 mm, 2.44 mm, and 2.59 mm, respectively. The width of the annual rings for individual species was most even, in the last 50 years of tree growth, i.e. in zones III and IV, where the differences in this feature were statistically insignificant at a level of $p < 0.05$ (the significance level was $p = 0.1592$ and $p = 0.1205$, respectively).

The lack of significant diversity of the radial increment of trees growing in the same vegetative periods is a result of similar dynamics of division of the initial cells of cambium in the tested tree species [Larson 1994].

On the other hand, the share of latewood demonstrated statistically significant differences between the tested species in each of the separated zones of the trunk cross-section (tab. 2). Within the zone of the first 25 annual rings the share was the greatest in spruce wood and equalled 35%, and in pine and larch wood it was 10 percentage points lower (fig. 1). In the next zone of the cross-section the latewood share increased to approximately 35% for larch wood and approximately 40% for pine wood, and in further cross-section zones it demonstrated insignificant fluctuations. Only in the case of spruce wood, was the latewood share very even along the tree radius, with the exception of the last zone of the cross-section, where it increased to approximately 45%, although the widths of annual rings in this zone were very similar to the widths of annual rings in zones II and III. It should be mentioned here, that the variability of the proportion of earlywood and latewood in trees growing in the same habitat conditions are influenced by the interaction of genetic and environmental factors [Creber and Chaloner 1984].

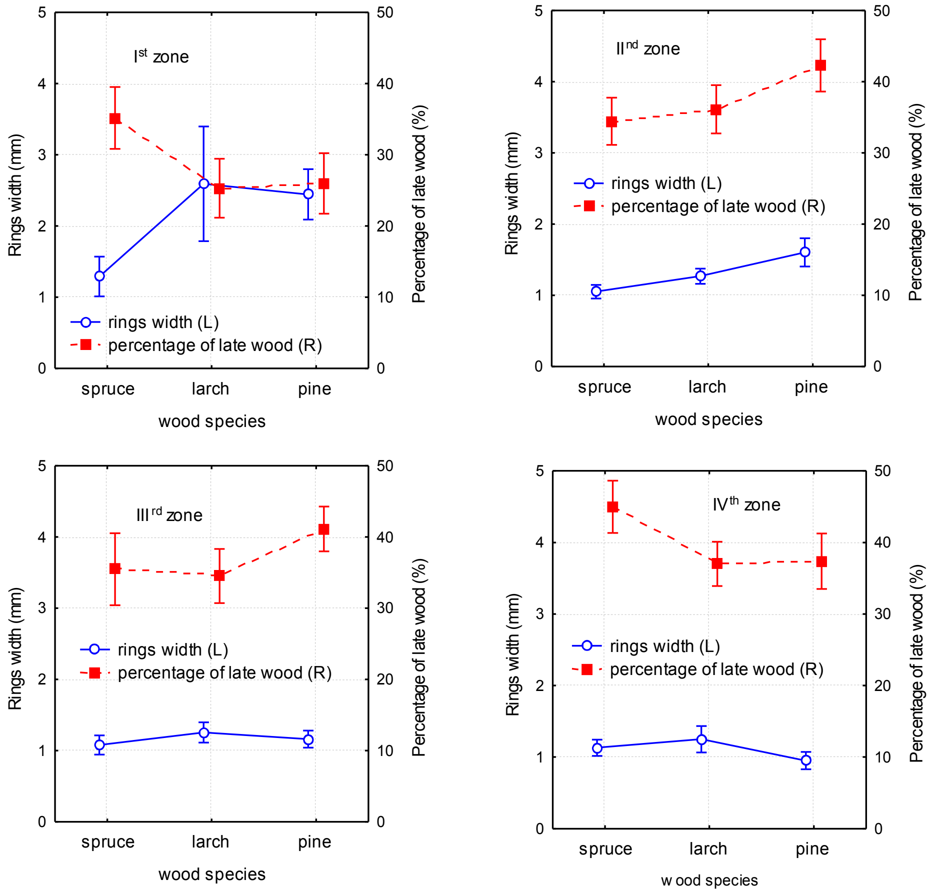

Fig. 1. The mean of the rings' width and the percentage of late wood in the test zone of spruce, larch and pine wood; vertical bars denote a confidence interval of 95%

Descriptive statistics of the basic density of the studied wood species are presented in table 3. The radial variability of density was analysed in the 25-year increment zones, as were the previously discussed properties (fig. 2). Spruce wood, compared to pine and larch wood, was characterised by the lowest density throughout the whole period of tree growth . The density of spruce wood, had an average for the whole cross-section, of 423 kg/m^3, while in the case of larch it was 478 kg/m^3, and for pine it equalled 505 kg/m^3 (tab. 3). The obtained density values fell within the scope of previously published literature [Čunderlik et al. 2005; Gryc et al. 2011]. Irrespective of the species, the lowest values of density

Table 2. Analysis of the variance of annual rings width and percentage of latewood for cross-section zone in spruce, larch and pine wood

Source of variation	Cross-section zone	Value of test function $F_{(2;72)}$ estimated	Value of test function $F_{(2;72)}$ tabular $\alpha = 0.05$	Empirical level of significance α
Ring width in spruce, larch and pine wood	I	7.6024	3.1239	0.0010
	II	16.5401		0.0000
	III	1.8851		0.1592^{ns}
	IV	2.6590		0.1205^{ns}
Percentage of latewood in spruce, larch and pine wood	I	7.2042		0.0014
	II	6.0922		0.0035
	III	3.2568		0.0442
	IV	6.7379		0.0019

^{ns} – insignificant differences.

Table 3. Descriptive statistics of the basic density of spruce, larch and pine wood and variance analysis for the mature wood zone

Species	Mean	Min	Max	Standard deviation	Coefficient of variation
	kg/m^3				%
Spruce	423	366	509	39.3	9.2
Larch	478	298	550	54.0	11.3
Pine	505	270	633	79.9	15.8

Source of variation	Species	Value of test function $F_{(2;16)}$ estimated	Value of test function $F_{(2;16)}$ tabular $\alpha = 0.05$	Empirical level of significance α
Basic density of the cross-section zone in mature wood (zones II, III and IV)	Spruce	6.3361	3.6337	0.0094
	Larch	0.6704		0.5253^{ns}
	Pine	0.5399		0.5930^{ns}

^{ns} – insignificant differences.

were characteristic of the close-to-core annual rings. In the subsequent years of tree growth, as the sample grew away from the pith, the density increased and then stabilised at some level, with insignificant fluctuations. In the case of coniferous wood, juvenile wood is characterised by a lower density than mature wood, which is connected with the difference in the proportion of cell wall thickness to cell diameter in both types of wood. Within the juvenile wood zone, the share of latewood is lower than in further zones of the trunk cross-section [Kučera 1994; Sauter et al. 1999].

Analysing this property within one species, it may have been observed, that it increased the most between the zone encompassing the first 25 close-to-core annual rings (juvenile wood) and further zones of the cross-section. This difference was approximately 25% for pine wood, 16% for larch wood, and only

4% for spruce wood. Gryc et al. [2011] in their research on the density of wood from the close-to-core zone and close-to-circumference zone of 80-100 year old trees, observed similar differences, which equalled 18% for pine, 15% for spruce, and 8% for larch. In this study, it was observed that differences in the analysed feature were statistically insignificant between zones II, III and IV (hence in mature wood) in the case of pine wood and larch wood, which suggested high homogeneity of this feature in these zones (tab. 3). On the other hand, in the case of spruce wood, these differences were significant, furthermore, although the share of latewood in the last increment zone was the greatest, compared to the other species, the density values were the lowest among the tested species. This observation proves, that the variability of the latewood share may be a determinant of wood quality, expressed by its density, only within particular species and not between species.

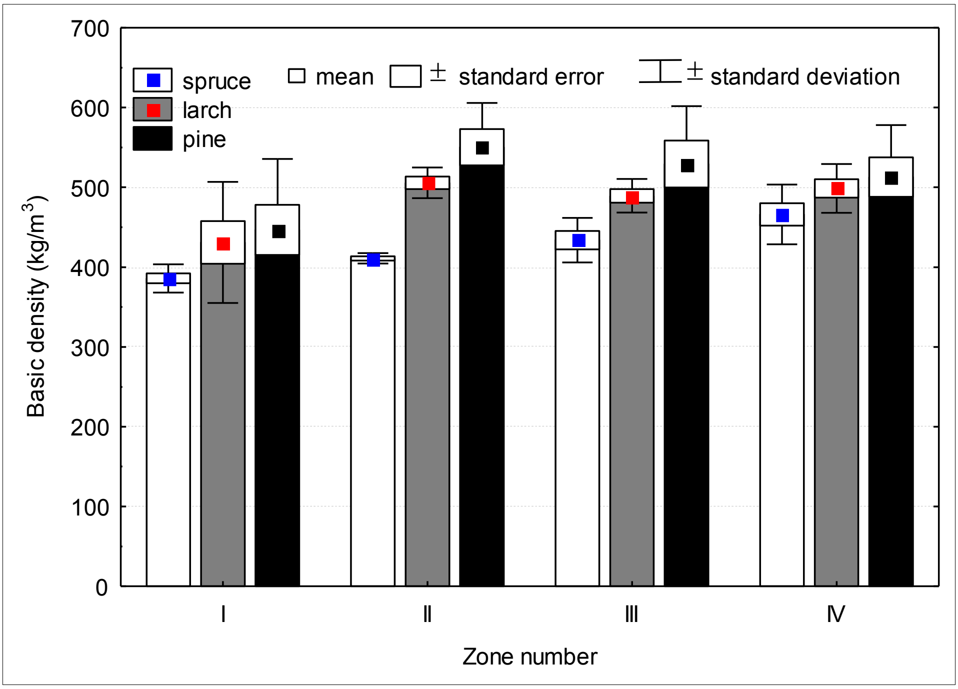

Fig. 2. Radial variation of basic density in 25-year increment zones of spruce, larch and pine wood

Conclusions

The research conducted indicates that the widths of annual rings in the analysed coniferous species demonstrated significant differences only in the first 50 years of tree growth. Amongst the studied species, spruce wood was characterised by the narrowest annual rings (throughout the whole period of tree growth). In the case of this species, the width of annual rings in the first selected zone of the cross-section, i.e. in the juvenile wood, was two times smaller than in the case of pine wood and larch wood. The share of latewood, analysed within 25-year increment zones, demonstrated statistically significant differentiation between the studied species in all selected zones of the cross-section. The lowest values of this parameter were observed in each of the studied species within the period of juvenile growth of the trees. Accordingly, these zones of the cross-section were characterised by the lowest density (390 kg/m^3 for spruce, 430 kg/m^3 for larch, and 450 kg/m^3 for pine). In the case of larch and pine, an approximate 20% increase in density was observed in the subsequent zone of the cross-section, i.e. in the mature wood, and in further zones density slightly fluctuated all the way to the circumference. In the case of spruce wood, a gradual increase in density was observed in the mature zone (approximately 11%). Although the share of latewood was the highest in spruce wood, compared to larch and pine, the density demonstrated the lowest values. This observation proves, that the variability of the latewood share may be a determinant of wood quality, expressed by its density, only within particular species and not between species.

References

Antonova G.F., Stasova V.V. [1993]: Effects of environmental factors on wood formation in Scots pine stems. Trees 7: 214-219

Bamber R.K., Burley J. [1983]: The wood properties of radiate pine. Oxford, CAB

Burczyk J., Giertych M. [1991]: Response of Norway spruce (*Picea abies* (L.) Karst.) annual increment to drought for various provenances and locations. Silvae Genetica 40 [3]: 146-152

Creber G.T., Chaloner W.G. [1984]: Influence of environmental factors on the wood structure of living and fossil trees. Botanical Review 50: 357-448

Čunderlik I., Barcík Š, Kotlínová M., Pivolusková E. [2005]: Selected physical and mechanical properties of juvenile Scott pine wood. Acta Facultatis Xylologiae XLVII: 5-11

Czajka M., **Fabisiak E., Krauss A.** [2015]: Duration of juvenile period in diameter growth of trees selected coniferous species. Annals of Warsaw University of Life Sciences – SGGW Forestry and Technology 92: 68-73

Dinwoodie J.M. [2000]: Timber: Its nature and behaviour. E&FN Spon: London, New York

Fabisiak E. [2005]: Variation of fundamental anatomical elements and wood density of selected tree species. Yearbooks of the Agricultural Academy in Poznan 369: 1-176

Gryc V., Vavrčik H., Horn K. [2011]: Density of juvenile and mature wood selected coniferous species. Journal of Forest Science 57 [3]: 123-130

Helińska-Raczkowska L., Fabisiak E. [1991]: Radial variation and growth rate in the length of axial elements of sessile oak wood. IAWA Bulletin 12 [3]: 257-262

Helińska-Raczkowska L., Fabisiak E. [1999]: Radial variation of earlywood vessel lumen diameter as an indicator of the juvenile growth period in ash (*Fraxinus excelsior* L.) Holz als Roh- und Werkstoff 57: 283-286

Karlman L., Mörling T., Martinsson O. [2005]: Wood density, annual ring width and latewood content in larch and Scots pine. Eurasian Journal of Forest Research 8: 91-96

Kučera B. [1994]: A hypothesis relating current annual height increment to juvenile wood formation in Norway spruce. Wood and Fiber Science 26 [1]: 152-167

Larson P.R. [1994]: The vascular cambium. Development and structure. Springer-Verlag, Berlin

Mäkinen H., Isomäki A. [2004]: Thinning intensity and growth of Scots pine stands in Finland. Forestry 77 [4]: 349-364

Pärn H. [2012]: Changes in the radial growth of two consecutive generations of Scots pine (*Pinus sylvestris* L.) stands. Baltic Forestry 18 [1]: 12-24

Riesco Muñoz G., Soilán Cañas M. A., Rodríguez Soalleiro R. [2008]: Physical properties of wood in thinned Scots pines (*Pinus sylvestris* L.) from plantations in northern Spain. Annals of Forest Science 65: 507p8 DOI: 10.1051/forest:2008026

Roszyk E., Moliński W., Fabisiak E. [2013]: Radial variation of mechanical properties of pine wood (*Pinus sylvestris* L.) determined upon tensile stress. Wood Research 58 [3]: 329-342

Sauter U.H., Mutz R., Munro B.D. [1999]: Determining juvenile-mature wood transition in scots pine using latewood density. Wood and Fiber Science 31 [4]: 416-425

Szaban J., Kowalkowski W., Karaszewski Z., Jakubowski M. [2014]: Effect of tree provenance on basic wood density of Norway spruce (*Picea abies* [L.] Karst.) grown on an experimental plot at Siemianice forest experimental station. Drewno 57 [191]: 135-143

Wiemann M. C., Williamson G. B. [2002]: Geographic variation in wood specific gravity: effects of latitude, temperature, and precipitation. Wood and Fiber Science 34 [1]: 96-107

Witkowska J., Lachowicz H. [2013]: Variability of conventional wood density of Scots pine (*Pinus sylvestris* L.) depending on the selected factors. Sylwan 157 [5]: 336-347

Zobel B.J., van Buijtenen J.P. [1989]: Wood variation: Its causes and control. Springer--Verlag, Berlin

Zobel B.J., Jett J.B. [1995]: Genetics of wood production. Springer-Verlag, Berlin, Heidelberg, New York

Submission date: 17.06.2015

Online publication date: 7.10.2016