Drewno 2020, Vol. 63, No. 206
DOI: 10.12841/wood.1644-3985.256.01

Krzysztof MICHALEC, Radosław WĄSIK, Anna BARSZCZ, Janusz M. SOWA

THE EFFECT OF STAND ORIGIN ON THE WOOD STRUCTURE OF NORWAY SPRUCE

A study was carried out to compare the annual ring width, latewood share and density of spruce wood from the north-eastern and south-western ranges of Norway spruce. Twelve trial plots were located in the north-eastern range, while within the south-western range eight trial plots were established in the Sudeten Mountains and twelve trial plots in the Carpathian Mountains. On every trial plot fifteen spruce trees were chosen, from which increment cores were sampled using a Pressler borer. Next, the increment cores had their surfaces smoothed, and measurements were made of the width of annual rings, latewood zones and the share of latewood. Then the cores were divided into 2 cm sections, for which the relative wood density was determined.

The analyses indicate that annual rings were wider in trees growing within the north-eastern range than in those from the south-western range, and the Kruskal-Wallis test showed the differences to be statistically significant. The latewood share followed an opposite pattern: the wood from the Mazury region had a higher proportion of latewood than the wood from the mountainous areas, and the statistical test again indicated that the differences were significant. The analysis of wood density showed slight differences between the density of wood from the north-eastern and south-western ranges, but in this case the Kruskal-Wallis test showed the differences to be statistically insignificant.

Keywords: annual ring width, latewood share, north-eastern Norway spruce range, south-western range

Introduction

Norway spruce (*Picea abies* [L.] Karst.) accounts for 6.3% by volume of all dominant tree species in Polish forests, placing it in fourth position in the volume-based ranking, following Scots pine, oak and beech [GUS 2017]. Its major natural range covers mountainous regions, although it can also be encountered in Warmia and Mazury. The latter regions are contained within the

Krzysztof MICHALEC✉ (*krzysztof.michalec@urk.edu.pl*), Radosław WĄSIK (*radoslaw.wasik@urk.edu.pl*), Anna BARSZCZ (*anna.barszcz@urk.edu.pl*), Janusz M. SOWA (*janusz.sowa@urk.edu.pl*), Department of Forest Utilization, Engineering and Forest Technology, University of Agriculture in Krakow, Krakow, Poland

north-eastern range of Norway spruce in Poland, while the mountain regions constitute its south-western range [Jaworski 2011].

There is a general opinion [Michalec 2007] that the wood obtained from mountainous spruce stands is of higher quality than that of lowland stands. Certain researchers [Grabczyński 1998; Ochał 2000], having analysed the variability in annual ring widths with altitude, have reported that as the height of the terrain above sea level increases, the annual ring width decreases. The same tendency applies to wood density, since the wood density of coniferous species is greater within the narrower annual rings [Krzysik 1974; Petty et al. 1990; Wąsik 2007; Jyske et al. 2008; Tomczak et al. 2009].

However, other researchers [Barzdajn 1996; Matras 2002; Szaban et al. 2014] have reported quite the opposite dependency, visible particularly when comparing the wood density of Norway spruce growing in different locations.

Having in mind these discrepancies in results, in the present study the authors performed an analysis of selected features of macrostructure, namely the annual ring width, the share of latewood, and the wood density, in individual trees from the north-eastern and south-western ranges of Norway spruce.

Materials and methods

A preliminary selection of stands for investigation was made based on descriptions contained in the forest management plans of particular forest districts. This selection included only stands where the spruce trees had reached a mature age, or at least where all tending treatments (late thinning) had been completed. These criteria were met by stands aged 70 years or more, covering areas of at least 3 hectares. The choice of stands for investigation was also dependent on the possibility of establishing 1 ha trial plots. At the preliminary stage of selection the following features were taken into account: tree species composition (monocultures or stands where the share of spruce prevailed amongst other tree species), growing stock index, site class, habitat type, and – in the case of the south-western range – the altitude and exposure of stands. For every forest district a few stands were identified, among which one or two were ultimately chosen as best meeting the required criteria. Finally, within the north-eastern Norway spruce range (Warmia and Mazury) 12 trial plots were established (located in 12 forest districts), while for the south-western range (mountainous regions) eight trial plots in the Sudeten Mountains (six forest districts) and 12 plots in the Carpathians (seven forest districts) were set up. These trial plots were located within the areas being the most representative for the conditions encountered in particular stands in terms of growing stock index, crown closure and quality of spruce wood. In the case of stands other than spruce monocultures, each trial plot was established in such a manner as to enclose the highest possible share of Norway spruce. Trial plots were quadrangular (100 × 100 m), covering an area of 1 ha. In each trial plot every tree with diameter equal to or exceeding 7 cm was measured for diameter at breast height, and then a group of 15 individuals was chosen for sampling of an increment core with the use of a Pressler borer. The selection of trial trees from which increment cores were sampled was performed according to Draudt's method [Grochowski 1973], based on adjusting the number of tested individuals proportionally to the number of trees within particular ranges, determined by the values of diameter at breast height. In mountainous regions (sloping terrain), for silvicultural reasons, increment cores were sampled from the slope foot upward. The increment core was always taken to a depth reaching the trunk pith, at a height of ca. 30 cm above ground level, but not exceeding a maximum depth of 40 cm.

The surfaces of the increment cores were then smoothed, and the samples were used for determining the width of annual rings, latewood zones, and the share of latewood. Next, the increment cores were scanned to obtain digital images. These images were used to perform measurements, made with an accuracy of 0.01 mm, using specialised software named Przyrost WP. Afterwards, the cores were divided into 2 cm sections, for which the relative wood density was determined, according to the following formula:

$$\gamma_w = \frac{m_0}{V_{\max}} \tag{1}$$

where: γ_w – relative wood density [g·cm^{-3}];
m_0 – weight of absolutely dry wood [g];
$V_{\max}$ – volume of wood in maximally swollen state [cm^3].

Wood volume was measured using the hydrostatic method (water displacement) [Olesen 1971]. Following measurement of the wood volume the samples were dried, and their weight in absolutely dry state was determined. Then the values of wood density within particular sections were recalculated proportionally for the entire increment core, according to the following formula:

$$\gamma_w = \frac{\sum_{i=1}^{n} \gamma_{si} p_i}{100} \tag{2}$$

where: γ_w – relative wood density [g·cm^{-3}];
γ_{si} – relative density of wood within a particular section of the increment core [g·cm^{-3}];
p_i – percentage of the particular section within the total area of the trunk cross-section [%];
n – number of sections [Niedzielska 1995].

Because the results obtained did not follow a normal distribution, for testing for significance of differences the Kruskal-Wallis test was employed, while for investigating possible correlations Pearson's test was used [Kot et al. 2007].

Results and discussion

The analyses led the authors to conclude that the widths of annual rings of trees growing in the north-eastern range of Norway spruce (Mazury) were greater than those from the south-western range (mountainous regions) (Fig. 1), with coefficients of variation equal to 43.0% and 45.3% respectively (Table 1). The minimum values of annual ring widths were also higher in the north-eastern range, and the Kruskal-Wallis test showed these differences to be statistically significant ($p < 0.001$). Moreover, the investigators proposed a further division of the south-western range of Norway spruce into two regions of its occurrence, namely the Sudeten and the Carpathian Mountains. On analysis of the annual ring widths within these two regions, it was established that their mean values were smaller in trees growing in the Sudeten Mountains than in those from the Carpathians (Fig. 1), despite the fact that both the minimum and maximum widths were greater in trees from the former region (Table 1). However, the statistical analyses did not prove these differences to be significant.

Table 1. Statistical characteristics for annual ring width and share of latewood

	North-eastern range (Mazury)	South-western range (mountains)	Sudeten			Carpathian		
	annual ring width	share of latewood	annual ring width	share of late-wood	annual ring width	share of late-wood	annual ring width	share of late-wood
Number of measure-ments	1223	1223	1610	1610	722	722	888	888
Min	0.7	9.4	0.4	8.7	0.7	10.7	0.4	8.7
Max	6.2	70.8	6.2	45.9	6.2	45.9	5.9	38.6
Median	2.7	23.6	2.0	24.9	2.0	27.0	2.0	24.1
Standard deviation	1.2	7.8	1.0	6.3	0.9	6.8	1.1	5.5
Coefficient of variation	43.0	32.4	45.3	24.3	42.9	24.9	46.7	22.5

On the other hand, the share of latewood followed an opposite pattern. Spruce wood obtained from Mazury had a lower share of latewood than that from the mountainous regions (Fig. 2), although the minimum and maximum values of this parameter were higher in the north-eastern range (Mazury)

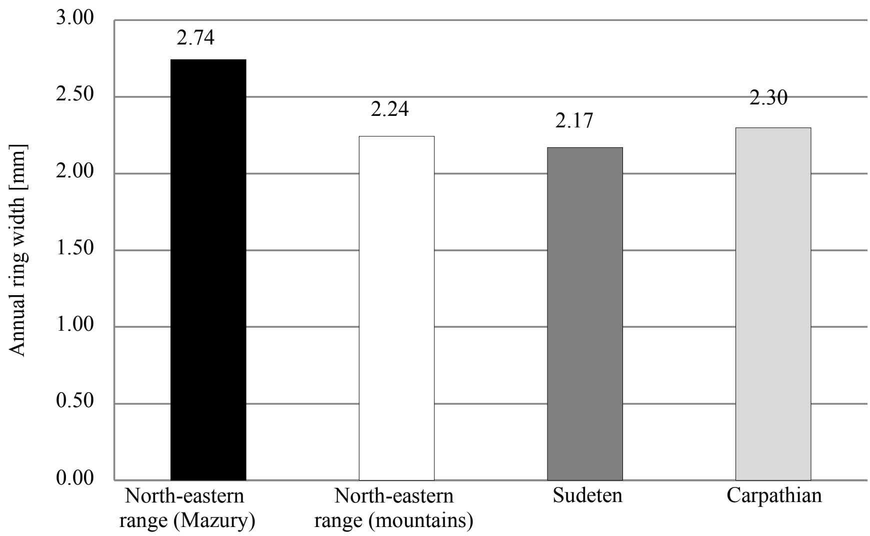

Fig. 1. Annual ring width depending on the provenance of wood under study

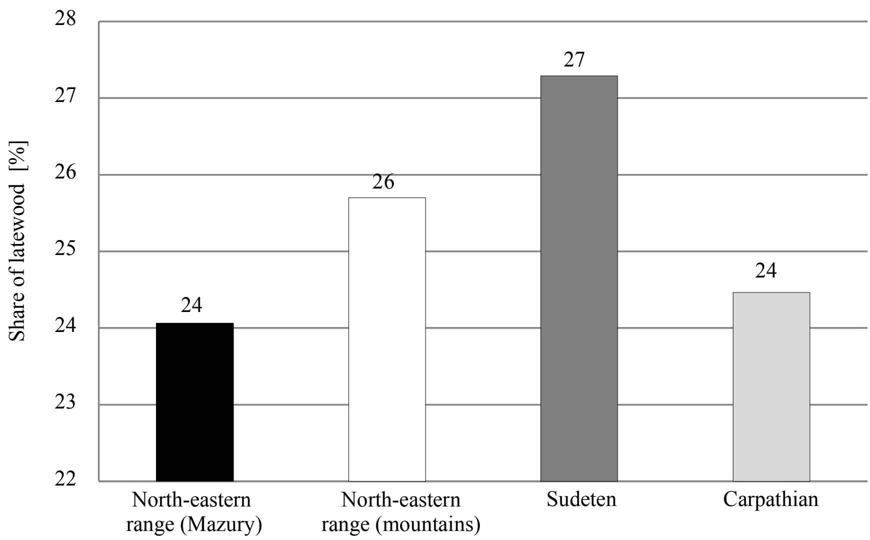

Fig. 2. Share of latewood depending on the provenance of wood under study

(Table 1). The Kruskal-Wallis test proved that the differences between the two groups of samples were significant ($p = 0.023$). Moreover, when the samples from the south-western range were divided into the Sudeten and Carpathian regions, it was established that the mean share of latewood (Fig. 2), the minimum and maximum values, and the variability in this feature (Table 1) were all higher for trees from the Sudeten Mountains. These differences were also confirmed as statistically significant by the Kruskal-Wallis test ($p = 0.014$).

The analyses of wood density revealed slight differences between the density of wood obtained from the north-eastern range of Norway spruce (Mazury) and that of trees from the south-western range (mountainous regions) (Fig. 3, Table 2). The wood of spruces from the Sudeten Mountains was denser than that from the Carpathians. However, the Kruskal-Wallis test did not indicate any significant differences between either the ranges or the specific mountain regions (p = 0.066).

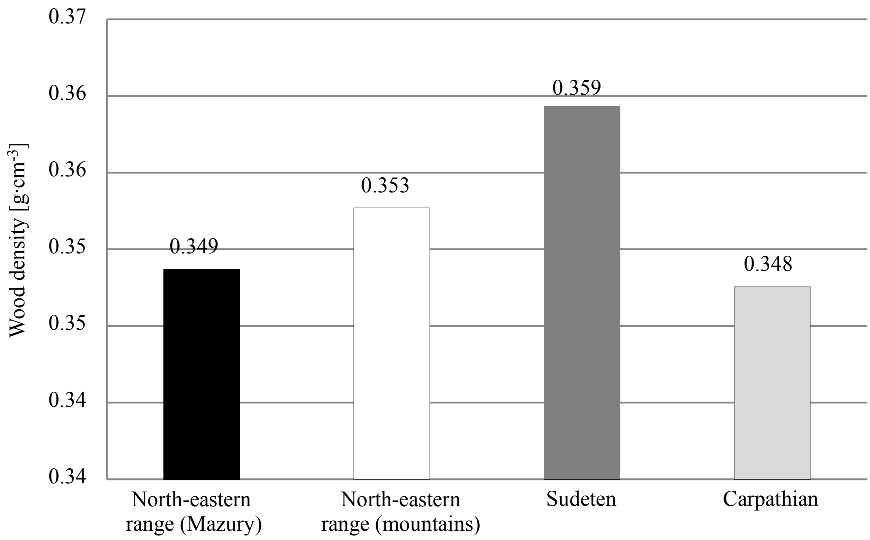

Fig. 3. Wood density depending on the provenance of wood under study

Table 2. Statistical characteristics for wood density

	North-eastern range (Mazury)	South-western range (mountains)	Sudeten	Carpathian
Number of measurements	1223	1610	722	888
Min	0.248	0.269	0.274	0.269
Max	0.523	0.545	0.490	0.545
Median	0.341	0.347	0.349	0.342
Standard deviation	0.05	0.04	0.04	0.04
Coefficient of variation	13.74	11.85	11.86	11.62

In addition, the relationship between the studied wood features was analysed using the Pearson correlation test (Table 3). It was found that in all studied data groups (ranges and regions) there is a high negative correlation between the width of annual growth and the share of latewood. Considering the share of latewood and wood density, it was found that in the south-western range (and in the two studied regions) the correlation between these features was highly positive, while in the north-eastern range it was weakly positive. The dependence of wood density on the width of annual growth varied differently: from weak negative correlation (in the north-eastern range), through moderate negative correlation (in the south-western range and the Carpathian region) to high negative correlation (in the Sudeten region).

Table 3. Results of Pearson's correlation test

	North-eastern range (Mazury)	South-western range (mountains)	Sudeten		Carpathian			
	annual ring width	share of latewood	annual ring width	share of late-wood	annual ring width	share of late-wood	annual ring width	share of late-wood
Share of latewood	-0.513		-0.539		-0.542		-0.546	
Wood density	-0.224	0.277	-0.432	0.599	-0.509	0.586	-0.377	0.627

The present research shows that the wood of Norway spruce from its north--eastern and south-western ranges significantly differs in terms of annual ring widths and the share of latewood, while the differences in wood density proved to be statistically insignificant. This is in disagreement with the findings of Barzdajn [1996] and Matras [2002], who investigated the density of spruce wood from various regions of Poland. Those authors established that most spruce populations in the north-eastern range had a greater specific gravity, while the smallest specific gravity was recorded for individuals from the mountainous populations, particularly those growing at higher altitudes (negative correlation), despite the fact that the growth of the latter was considerably poorer. A similar pattern was reported by Szaban et al. [2014], who investigated the wood of spruce trees of various provenance. These authors stated that the wood of spruces growing in lowlands was denser than that from mountainous regions. Nabais et al. [2018], analysing the effect of climate on wood density in various tree species, found that in the case of spruce, climatic conditions do not affect the density of the wood. Studies conducted in south-western Germany by van der Maaten-Theunissen et al. [2013] also proved that spruce trees growing under warmer climatic conditions with lower rainfall produced higher-density wood than those developing in a cooler and wetter climate. In the present study, the climatic data of the compared ranges were not analysed in detail, as this was beyond the scope of the research. It is well-known, however, that the mountainous and north-eastern areas of Poland differ in terms of climate. Thus, indirectly, apart from traits associated with the race of spruce [Jaworski 2011] and a number of other factors affecting the studied characteristics of spruce wood [Krzysik 1974], climatic differences may affect the values of the studied parameters and their mutual relationships.

Conclusions

1. The annual ring width was significantly greater in trees from the north-eastern range of Norway spruce than in those from its south-western range. On comparison of this feature between individuals growing in the Sudeten and Carpathian Mountains, no statistically significant differences were revealed.

2. Statistically significant differences in the share of latewood were identified between spruces growing in the two studied ranges. Moreover, the share of latewood in trees from the Sudeten Mountains was significantly higher than in trees from the Carpathians.

3. In respect of wood density, no statistically significant differences were identified either between the ranges of the species or between the specific mountain regions (Sudeten, Carpathian).

4. Analysing the relationships between the studied features of wood by range and region, a high negative correlation was found between annual growth and the share of latewood, while in mountain stands the density of wood was positively correlated with the share of latewood. In the lowland stands these features exhibited only weak correlation. Analysis of the relationship between the annual growth rate and the density of wood in mountain areas indicated a high negative correlation of these features only in the Sudeten.

References

Barzdajn W. [1996]: Zmienność gęstości drewna świerka pospolitego [*Picea abies* (L.) Karsten] w Polsce (Variability of Norway spruce wood density in Poland). PTPN. Prace Komisji Nauk Rolniczych i Komisji Nauk Leśnych, 82: 7-14

Grabczyński S. [1998]: Przyrost pierśnicy drzew w sześćdziesięcioletnich drzewostanach świerkowych Beskidów Zachodnich (The growth in diameter at breast height in 60-year--old spruce stands in the Western Beskids). Sylwan 142 [9]: 13-17

Grochowski J. [1973]: Dendrometria (Forest mensuration). PWRiL. Warsaw

GUS [2017]: Leśnictwo 2017 (Forestry 2017). Warsaw

Jaworski A. [2011]: Hodowla lasu. Charakterystyka hodowlana drzew i krzewów leśnych. (Silviculture. Silvicultural characteristics of forest trees and shrubs). T. 3. PWRiL. Warsaw

Jyske T., Mäkinen H., Saranpää P. [2008]: Wood density within Norway spruce stems. Silva Fennica 42 [3]: 439-455

Kot S.M., Jakubowski J., Sokołowski A. [2007]: Statystyka (Statistics). Difin. Warsaw

Krzysik F. [1974]: Nauka o drewnie (Wood science). PWN. Warsaw

Matras J. [2002]: Zróżnicowanie gęstości drewna populacji świerka na powierzchni doświadczalnej w Knyszynie w relacji do zróżnicowania populacji matecznych (Variability of wood specific gravity among Norway spruce populations and the heritability of this feature for populations from the Knyszyn experimental plot). Prace IBL. Seria A. 2 [914]: 21-33
Michalec K. [2007]: Jakość surowca świerkowego (*Picea abies* [L.] Karst.) pochodzącego z głównych ośrodków i zasięgów jego występowania w Polsce (Quality of spruce raw material (*Picea abies* [L.] Karst.) from main centers and ranges of spruce distribution in Poland). Drewno – Wood. Prace Naukowe, Doniesienia, Komunikaty 50 [177]: 57-78
Nabais C., Hansen J.K., David-Schwartz R., Klisz M., López R., Rozenberg P. [2018]: The effect of climate on wood density: What provenance trials tell us? Forest Ecology and Management, 408: 148-156. https://doi.org/10.1016/j.foreco.2017.10.040
Niedzielska B. [1995]: Zmienność gęstości oraz podstawowych cech makroskopowej struktury drewna jodły (*Abies alba* Mill.) w granicach jej naturalnego występowania w Polsce (Variability of density and basic macrostructural features of wood of fir (*Abies alba* Mill.) in its natural boundary in Poland). Zesz. Nauk. AR w Krakowie. Rozprawy nr 198
Ochał W. [2000]: Struktura i dynamika przyrostu grubości drzew w drzewostanach świerkowych masywu Skrzyczne (Structure and dynamic of diameter increment in spruce forest of the Skrzyczne range). Sylwan 144 [1]: 75-85
Olesen P.O. [1971]: The water displacement method. The Royal Veterinary and Agricultural University of Copenhagen
Petty J.A., Macmillan D.C., Teward C.M. [1990]: Variation of density and growth ring width in stems of Sitka and Norway spruce. Forestry 63 [1]: 39-49
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 – Wood. Prace Naukowe, Doniesienia, Komunikaty 57 [191]: 135-143
Tomczak A., Pazdrowski W., Jelonek T., Grzywiński W. [2009]: Jakość drewna sosny zwyczajnej (*Pinus sylvestris* L.). Część I. Charakterystyka wybranych cech i właściwości drewna wpływających na jego jakość (Quality of Scots pine (*Pinus sylvestris* L.) wood Part I. Characteristics of selected wood traits and properties affecting its quality). Sylwan 153 [6]: 363-372
Van der Maaten-Theunissen M., Boden S., van der Maaten E. [2013]: Wood density variations of Norway spruce (*Picea abies* (L.) Karst.) under contrasting climate conditions in southwestern Germany. Ann. For. Res. 56 [1]: 91-103
Wąsik R. [2007]: Zmienność wybranych cech makrostruktury i gęstości drewna daglezji zielonej (*Pseudotsuga menziesii* var. *viridis* Franco) na terenie Polski (Variability of the features of macrostructure and wood density of Douglas fir (*Pseudotsuga menziesii* var. *viridis* Franco) in Poland). Drewno – Wood. Prace Naukowe, Doniesienia, Komunikaty 50 [178]: 57-85

Acknowledgements

This Research was financed by the Ministry of Science and Higher Education of the Republic of Poland.

Submission date: 5.01.2018

Online publication date: 5.10.2020