Geographical Origin and Log Quality Influence on the Mechanical Properties of Scots Pine Sawnwood

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This paper presents research conducted on pine timber sawn from logs obtained from three different forestry regions in western Poland. Forestry regions were characterized in terms of *i.e.* annual mean temperature and rainfall distribution, soil, growing stock, and technical quality and type of forest. The timber logs were classified in three different quality classes, A, B, and C as per PN-D 95017 (1992). The coefficients of correlation were calculated for pairs of the studied properties (density, modulus of elasticity (MOE), and static bending strength (MOR)) considering the forestry region of origin of the different quality logs. The statistical analysis revealed that there is a strict correlation between quality class of logs, geographical origin in terms of technical quality of forest, and physical and mechanical parameters of sawn timber.

Keywords: Pine timber; Regional diversity; MOE; MOR; Technical quality

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INTRODUCTION

Wood is a natural material with anisotropic structure. Wood density is considered to be the most important indicator of its quality. Within the same species, wood density varies in different trees (inter-tree variation), and also within the same tree (intra-tree variation) (Louzada 2000; Koga and Zhang 2004; Knapic *et al*. 2007). This notable variance in density has advantages and disadvantages. It can affect wood processing and its further usage. The final applications are chosen respect the specific property of sawn timber, therefore it is important to determine wood parameters and its diversity (Koga and Zhang 2004). The differences in the density of wood—particularly when used as a construction material—can also result from the differences in density values of different structural components (Louzada and Fonseca 2002; Gaspar *et al.* 2008).

The differences in wood properties within the same species depend, to a great extent, on habitat conditions (soil) and climate (Kobyliński 1967; Zobel and van Buijtenen 1989; Zobel and Jett 1995). Researching wood from different forest sites (Na, normal humidity very poor site; Nb, normal humidity poor site; and Nc, normal humidity fertile site) in Lithuania has revealed that wood from the Nb site had the highest values of static bending strength and compressive strength parallel to the grain (92.7 MPa and 82.5 MPa, respectively), which was different than in wood from other sites. An interesting finding was the lack of statistically significant differences between the average density values of wood from different sites (Aleinikovas and Grigaliûnas 2006). At the same time, the researchers confirmed the impact of climate differences on the relationship between the width of annual growth rings and wood density (Van der Maaten-Theunissen *et al.* 2013).

The territory of Poland, due to climate and soil conditions, has been divided into eight areas known as forestry regions (Grzywacz 1995). Dziewanowski conducted research on the quality of Polish-grown sawn pine timber in relation to its place of origin (Dziewanowski 1967). He discovered that regions with the highest pine wood quality are located in northern Poland, while regions with poor quality pine wood are located in the middle and southern parts of the country. The technical quality of Scots pine depending on geographic location was also studied by Paschalis. His studies of wood from Eastern Poland led him to conclude that the technical quality of pine wood (determined on the basis of modulus of elasticity values, among others) decreases from north to south and from east to west of Poland (Paschalis 1980). A similar phenomenon was also observed for spruce wood (Noskowiak 2017).

Knowing how place of origin impacts the mechanical properties of pine timber is particularly important when considering its application for example in construction. Jelonek *et al.* (2005) concluded that the density of pine wood from agricultural lands is greater than the density of pine growing on typical forest soils. Research revealed that there is a clear correlation between the compressive strength parallel to the grain and the density of pine wood grown on former agricultural lands and grown in typical forest areas. A stronger correlation was observed for wood from typical forest lands. Two kinds of forest habitat were analysed: fresh coniferous forest and fresh mixed coniferous forest. The study confirmed that the wood density of pines (*Pinus sylvestris* L.) that grew on post-agricultural lands was greater than the wood density of pines growing on typical forest lands. Research confirmed a clear correlation between compressive strength parallel to the grain and density, when analysed in both pine wood from post-agricultural lands and typical forest lands. At the same time, it was shown that the average wood density of Scots pine becomes lower at higher latitudes. This information is important given that in the future with a warmer climate, higher temperatures, and less precipitation during the vegetation period (Maracchi *et al.* 2005), the average wood density will likely increase, while its technical value will decrease.

Studies investigating the influence of place of origin and place of growth on the structural properties of wood, including its density, tree height, diameter, and volume, were conducted in various European countries for different wood species. Peltola *et al.* (2009) tested pine wood from Central and Southern Finland. The authors of the study concluded that it is difficult to precisely pinpoint the impact of the place of tree origin and growth on the tested parameters. They pointed out the need to broaden the scope of study and examine a larger group of trees and research sites.

Research investigating the influence of wood’s place of origin on timber properties in view of its application in construction has been conducted in other European countries. The Combigrade project that was conducted in Finland consisted of studying the influence of the place of origin of pine and spruce wood on the mechanical properties of timber used in construction applications. The tested wood was obtained from Finland (three regions) and Russia (two regions). The relationship between the parameters of round logs and the properties of timber produced from them was studied. Both non-destructive and destructive tests were carried out (Hanhijärvi *et al.* 2005). The examinations clearly indicated that pine timber from Russia had lower density, modulus of elasticity in bending, and static bending strength than timber from Finland.

One of the biggest research projects concerning the regional variance of wood properties was the International Gradewood Project. It included tests of pine and spruce timber from Poland, Slovakia, Slovenia, Romania, Ukraine, France, Sweden, Switzerland, Finland, and Russia (Ranta-Maunus *et al.* 2011). The results indicated that pine timber from Finland had the highest static bending strength (44.9 MPa) of all the regions under research. Concerning the modulus of elasticity, Polish timber had the highest value (12500 MPa), in comparison to Finnish timber (11900 MPa) and Swedish timber (11300 MPa). The density values of the timber batches under research spanned from 481 kg/m^3 (Swedish timber), through 493 kg/m^3 (Finnish timber), to 516 kg/m^3 (Polish timber).

In Austria, a project called Gebirgsholz – Wald ohne Grenzen (Kraler and Maderebner 2012) tested the influence of elevation above sea level at the place of growth of spruce trees, examining elevation's effects on the properties of the spruce timber. Timber from two regions was included in the research, Northern Tyrol and Southern Tyrol, and samples were taken from 22 elevations between 810 m and 2060 m above sea level. Apart from height above sea level, the research also considered whether the trees grew on a south- or north-facing slope. The obtained timber was strength-graded with visual and machine methods. It was observed that trees growing on northern slopes produced more high-grade timber than trees growing on southern slopes.

Studies have been conducted on Scots pine from different regions of Portugal that indicate mean wood density (588 kg/m^3) is only slightly higher compared to that from other European regions, confirming that wood density becomes slightly lower at higher latitudes (Fernandes *et al.* 2017). Concerning the radial section, the differences in density were caused by age, and not by geographic location or wood species.

The aim of the present study was to determine and compare selected physical and mechanical properties of pine wood from different habitats in Poland. In this context, a primary goal consisted of specifying whether pine wood characteristics depended on the forestry region and logs quality from which timber was obtained.

EXPERIMENTAL

Materials

The material for study consisted of pine timber (*Pinus sylvestris* L.) from logs obtained from three different forestry regions in Poland (Fig. 1): Silesia (Site 1), Greater Poland-Pomerania (Site 2), and the Baltic Forestry Region (Site 3). The timber from each Region was acquired from raw wood that was approximately 120 years old, from logs classified as A, B, and C quality classes (Table 1).

For each of the regions, timber was sawn from logs obtained from natural mixed forests. Specific locations of the sample collection sites were as follows: the Silesian Forestry Region, an area under the Regional Directorate of State Forests in Katowice (Forest Inspectorate Olesno, Forest District Sternalice, Division 14d, coordinates: 50°53'55.1"N, 18°25'26.1"E); the Greater Poland-Pomerania Forestry Region, an area under the Regional Directorate of State Forests in Zielona Góra (Forest Inspectorate Wymiarki, Forest District Lutynka, divisions 23c and 23d, geographic coordinates: 51°55'35.7"N, 15°06'04.9"E); and the Baltic Forestry Region, an area under the Regional Directorate of State Forests in Piła (Forest Inspectorate Kalisz Pomorski, Forest District Cybowo, division 526k, geographic coordinates: 53°29'72.8"N, 15°84'11.9"E). Habitat and geographical origin characteristics are shown in Table 2.

Table 1. Selected Quality and Dimensional Requirements of Round Softwood According to PN-92/D-95017

<table>
<tr><th rowspan="2">Defect or feature of wood</th><th colspan="4">Permitted size of the defect or feature of wood in the class</th></tr>
<tr><th>A</th><th>B</th><th>C</th><th>D</th></tr>
<tr><td>Minimum diameter at the thinner end [cm]</td><td>22</td><td colspan="3">14</td></tr>
<tr><td>Dead knots</td><td colspan="2">Permitted with a diameter of up to 2 cm; in pine and larch wood unpermitted</td><td colspan="2">Unlimited</td></tr>
<tr><td rowspan="2">Burls</td><td colspan="2">Up to 1 cm is not taken into account; otherwise:</td><td colspan="2" rowspan="2">Unlimited</td></tr>
<tr><td>Unpermitted</td><td>Permitted on ½ of circumference</td></tr>
<tr><td rowspan="2">End split</td><td colspan="2">Permitted to</td><td colspan="2" rowspan="2">Unlimited</td></tr>
<tr><td>1/5 of logs diameter</td><td>1/3 of logs diameter</td></tr>
<tr><td>Seasoning split</td><td>Permitted widths up to 3mm</td><td colspan="3">Unlimited</td></tr>
<tr><td>End and edge split, through shake</td><td colspan="3">Unpermitted</td><td>Unlimited</td></tr>
<tr><td rowspan="2">Curvature</td><td colspan="4">Permitted if allowing for the manipulation of logs 2.7 m with one-sided curvature</td></tr>
<tr><td>2 cm / 1 m</td><td colspan="2">3 cm / 1 m</td><td>8 cm / 1 m</td></tr>
<tr><td rowspan="2">Heart rot</td><td colspan="4">Permitted on one of the faces up to:</td></tr>
<tr><td>1/5 of logs diameter</td><td colspan="2">1/3 of logs diameter</td><td>1/2 of logs diameter</td></tr>
</table>

The timber was dried under industrial conditions in a chamber drier, up to approximately 12% MC (moisture content), and planed. The nominal cross-section dimensions of the tested timber batch after drying and planing were 40 mm × 138 mm the length was 3500 mm. Each batch of timber contained 150 pieces. The exact number of pieces obtained from logs of different quality classes is presented in Table 3.

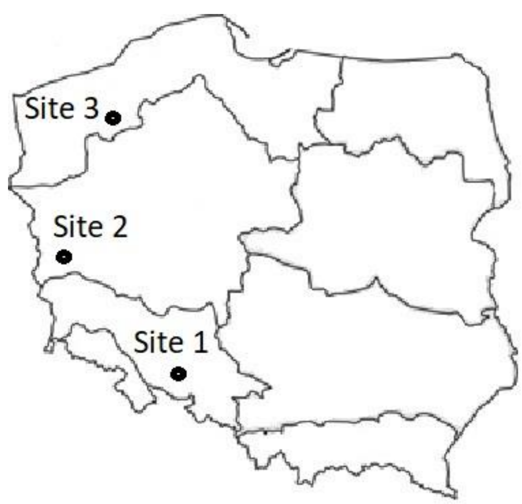

Fig. 1. Location of sample collection sites, where: Site 1 – Silesia, Site 2 - Greater Poland-Pomerania, and Site 3 - the Baltic Forestry Region

Table 2. Habitat and Geographical Origin Characteristics

Forestry Region (Inspectorate)	Climate	Type of forest	Soil	Share of pine [%]	Growing stock [m^3/ha]	Other species	Technical quality
Silesian (Olesno)	Submontane lowlands and structural basins	Moist mixed forest	Sands, peat soils, clays and silts, rendzina and loess soils	94	156	Spruce Beech	2*
Greater Poland Pomerania (Wymiarki)	Large valleys, quite moderate and warm	Moist mixed forest	Post-glacial, mostly sands and clays	87	136	Oak Alder	2*
Baltic (Kalisz Pomorski)	Pomeranian Lakeland	Fresh mixed forest	Haplic Podzols originating from weak loamy sands and loamy sands	69	159	Beech Spruce	3**

*** Technical quality 2 -** corresponds to stands that are usually well adjusted to the habitat, with good development dynamics, healthy, straight, well cleaned tree-length trunks expected to provide good quality sawn timber;
**** Technical quality 3 -** corresponds to generally healthy stands adjusted to the habitat, with poor development dynamics, tree-length trunks and tree crowns that are partially defective, not fully straight, slightly tapered and containing knots, usually not well cleaned, expected to provide sawn timber of worse quality;

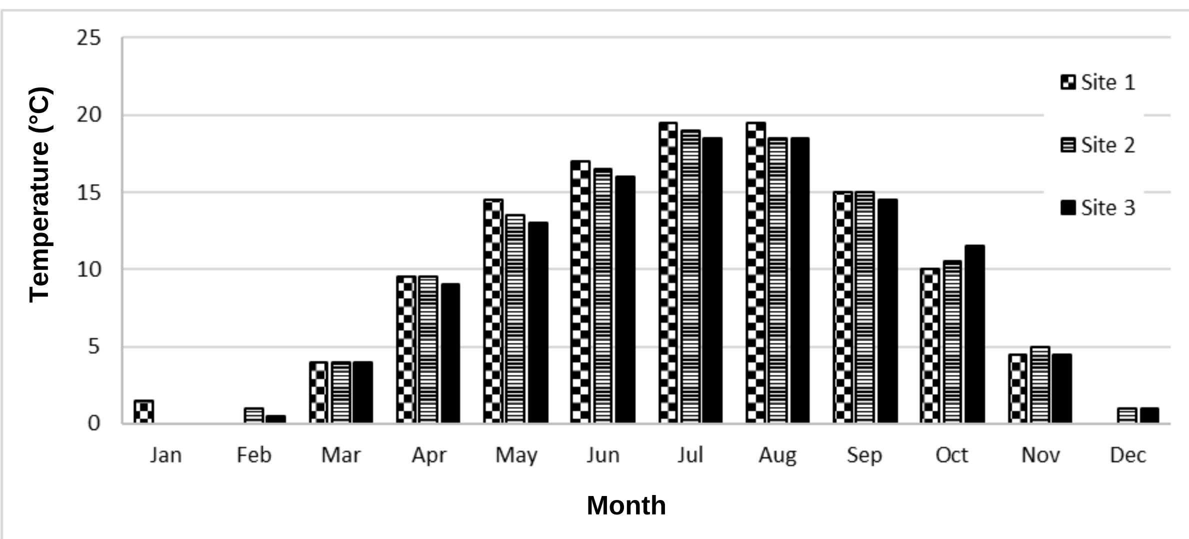

Fig. 2. Annual mean temperature distribution for sample collection sites [based on www.meteoblue.com]

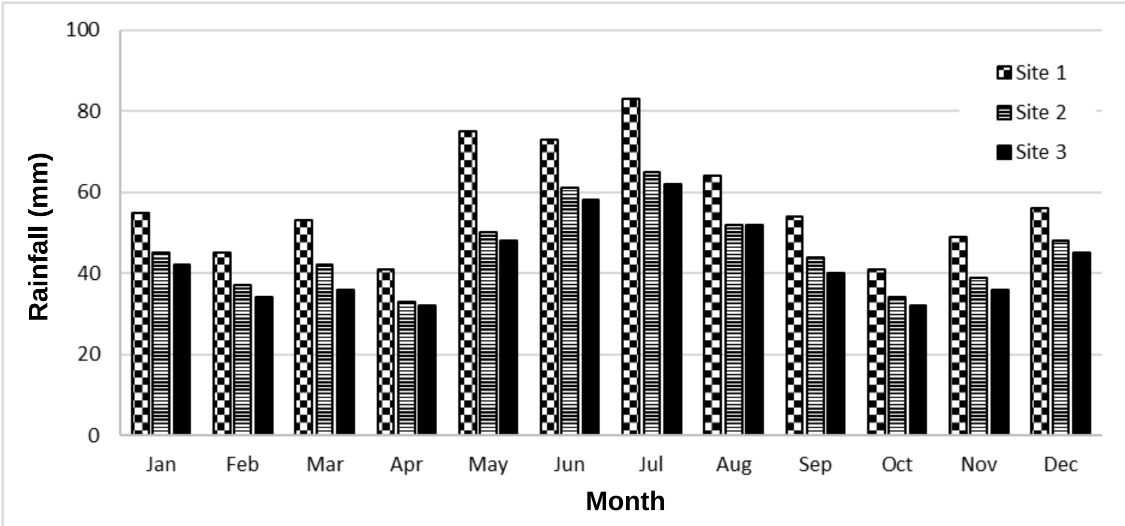

Fig. 3. Annual mean rainfall distribution for sample collection sites [based on www.meteoblue.com]

Table 3. Number of Pieces in Each Timber Batch

		Total	Site 1	Site 2	Site 3
Total		450	150	150	150
Log Quality Class	A	24	13	11	0
	B	90	59	15	16
	C	236	78	124	134

Methods

Destructive tests of timber

The destructive tests of the research material included the determination of the global modulus of elasticity in static bending (MOE) and static bending strength (MOR). Tests were performed in accordance with the EN 408 + A1 (2012) standard, using a 10 Tf load machine TIRA Test 2300 (TIRA GmbH, Schalkau, Germany). The static diagram of the test is presented in Fig. 4. The tests were performed with control of displacement. The speed of the crosshead was 3 mm/min. During the test, the value of the load and the bend were registered. Bending was determined with the help of additional equipment in the form of movement sensors by Novotechnik, type TRS 75 (Southborough, MA, USA), with a resolution of 0.01 mm.

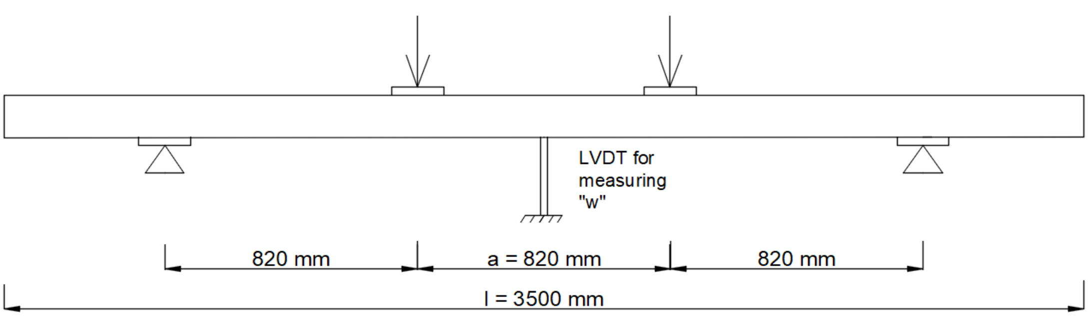

Fig. 4. Static diagram of a four-point bending test in accordance with EN 408 + A1 (2012); where LVDT – linear variable differential transformer

Statistical analysis

The statistical analysis of test results was performed in the Statistica v.13.3 software (StatSoft, Inc., Tulsa, OK, USA). The data was analysed and provided as the mean ± standard deviation. The analysis of variance (ANOVA) analysis for factor categories (multiple comparisons) included the qualitative factor of log geographical origin (Site 1, Site 2, and Site 3) and log quality class (A, B, and C), while the dependent variables were density, MOE, and MOR. The analysis was performed with a confidence level of 95% to determine the influence of individual factors (geographical origin and log quality class) independently, as well as the interaction between both factors at the same time.

RESULTS AND DISCUSSION

Table 4 presents the test results of wood density, modulus of elasticity, and bending strength together with the standard deviation, divided into geographic regions, and taking into account the quality class of logs from which timber was obtained.

Table 4. Average Values of Density, Modulus of Elasticity, and Bending Strength for the Pine Timber under Research

		Total	Site 1	Site 2	Site 3
Density (kg/m^3)	Total	524 (66)	537 (64)	533 (71)	503 (57)
	A	572 (58)	566 (67)	580 (47)	X
	B	564 (64)	563 (57)	618 (58)	514 (57)
	C	510 (61)	512 (59)	518 (65)	502 (56)
MOE (MPa)	Total	12100 (2700)	12800 (3200)	12500 (2300)	11000 (2000)
	A	13900 (3000)	14000 (3900)	13800 (1200)	X
	B	13800 (3000)	14200 (3100)	15000 (2100)	11400 (2100)
	C	11500 (2300)	11600 (2700)	12100 (2100)	10900 (2000)
MOR (MPa)	Total	44.7 (16.7)	47.7 (18.1)	47.3 (15.6)	39.4 (15.1)
	A	56.3 (18.4)	57.3 (22.7)	55.0 (12.6)	X
	B	55.3 (18.8)	54.9 (19.9)	67.8 (7.1)	45.8 (15.8)
	C	41.0 (14.3)	39.9 (11.9)	44.1 (14.5)	38.8 (14.9)

The values in parenthesis refer to the standard deviation.

The average density of the entire researched timber batch from the three selected forestry regions (450 pieces) amounted to 524 kg/m^3, the average MOE value was 12100 MPa, and the average MOR was 44.7 MPa. The coefficients of correlation for the entire timber batch were: 0.74 between density and MOE; 0.56 between density and MOR; and 0.74 between MOE and MOR. Previous studies of Polish-grown pine timber from five forestry regions (766 pieces) resulted in mean values of density of 486 kg/m^3, MOE of 9584 MPa, and MOR of 36.2 MPa (Krzosek 2009). The coefficients of correlation for the entire batch examined by Krzosek were as follows: density (DEN)/MOE of 0.79, DEN/MOR of 0.70, and MOR/MOE of 0.82. For the presented values, it was concluded that the timber batches in both studies had similar values of the tested properties and similar values of correlation coefficients. Another study of Polish pine timber (Noskowiak and Szumiński 2006) resulted in the following correlation coefficients: MOR/MOE of 0.70, DEN/MOE of 0.61, and DEN/MOR of 0.56. Research of Finnish pine timber (Hanhijarvi *et al.* 2005) resulted in a coefficient of determination MOR/MOE of 0.69, while for German pine timber the results of the correlation coefficient MOR/MOE were 0.71 (Glos and Schleifer 2002) and 0.81 (Glos *et al.* 2000). The coefficient of determination between DEN/MOR was 0.58 in Finnish timber, and the coefficient of correlation DEN/MOR in German pine timber was 0.47 (Glos and Schleifer 2002). The coefficient of determination for DEN/MOE in Finnish timber was 0.72. Values of coefficients were at a similar level for Polish pine timber and timber from other countries.

Taking into account the regional differences concerning location of sample collection sites (Fig. 1, Table 2) and its influence on the tested wood properties, it was concluded that the highest average density characterised timber from Site 1 (537 kg/m^3). A slightly lower value was found in timber from Site 2 (533 kg/m^3), and the lowest density was in case of timber from Site 3 (503 kg/m^3). An analysis of MOE values revealed that the highest mean MOE value (12800 MPa) of the timber was from Site 1. A slightly lower MOE (12500 MPa) was measured for timber from Site 2, and timber from Site 3 had the average MOE value of 11000 MPa.

Taking into account the results of the bending strength tests of pine timber, the highest average MOR value was calculated for timber from two of the Forestry Regions under research: Site 1 (47.7 MPa) and Site 2 (47.3 MPa). Timber from Site 3 had a mean MOR value of 39.4 MPa.

A regional variance of Polish-grown pine timber was also suggested in studies performed by Krzosek. He tested timber from five selected forestry regions in Poland. The average density of timber in his study, determined separately for the individual forestry regions, was between 443 kg/m^3 for timber from the Carpathian Forestry Region and 524 kg/m^3 for timber from the Baltic Forestry Region (which corresponds to Site 3 in the present study). The average values of the modulus of elasticity in timber from the individual forestry regions were between 7801 MPa (for the Carpathian Forestry Region) and 11126 MPa (for timber from the Greater Poland-Pomerania Forestry Region, which corresponds to Site 2). Regarding the bending strength, the average values for individual forestry regions spanned from 25.3 MPa (for the Carpathian Forestry Region) to 45.1 MPa (for timber from the Greater Poland-Pomerania Forestry Region, which corresponds to Site 2 in the present study) (Krzosek 2009).

The regional differences in the properties of Polish timber were also confirmed by research conducted within the framework of the Gradewood Project (Ranta-Maunus *et al.* 2011). It included Polish timber from two Forestry Regions, Silesia (Murów locality) and Masuria-Podlachia (Świętajno locality).

The average density of timber from Murów was 558 kg/m^3, and 515 kg/m^3 for timber from Świętajno. The average MOE value for timber from Murów was 12400 MPa, and 10900 MPa for timber from Świętajno. The average MOR value for timber from Murów was 42.0 MPa, and 36.5 MPa in that from Świętajno. A similar variance of properties was also observed for timber from other countries. Swedish timber from the Lapland region was found to have the following average values: density of 458 kg/m^3, MOE of 9100 MPa, and MOR of 37.8 MPa. Timber from the Västerbotten region had the following average values: density of 522 kg/m^3, MOE of 11800 MPa, and MOR of 56.4 MPa.

Regarding timber obtained from logs at Site 1, the average density of timber from class A logs was the highest (566 kg/m^3) for timber of that region. Timber from Class B had a slightly lower average density value (563 kg/m^3), and timber made of logs from Class

C had an average density value of 512 kg/m^3. The coefficients of correlation between the tested properties for the timber under research are presented in Table 5.

Table 5. Coefficients of Correlation between the Tested Properties of Timber from Three Forestry Regions

Site	Properties	Total	Class A logs	Class B logs	Class C logs
1	DEN/MOE	0.77	0.74	0.73	0.74
	DEN/MOR	0.53	0.25	0.56	0.34
	MOR/MOE	0.73	0.72	0.72	0.63
2	DEN/MOE	0.77	0.72	0.58	0.74
	DEN/MOR	0.65	0.37	0.34	0.61
	MOR/MOE	0.73	0.62	0.37	0.70
3	DEN/MOE	0.65	X	0.60	0.65
	DEN/MOR	0.40	X	0.30	0.40
	MOR/MOE	0.71	X	0.71	0.70
All	DEN/MOE	0.74	0.69	0.72	0.71
	DEN/MOR	0.74	0.26	0.53	0.49
	MOR/MOE	0.56	0.70	0.72	0.68

Analysing data from Table 5, it was concluded that the highest coefficient of correlation was found—independent of the quality class of the logs from which the timber was obtained—for the correlation between density and MOE (it was 0.74 for timber made of Class A logs, 0.73 for Class B logs, and 0.74 for Class C logs). The lowest coefficient of correlation, independent of the quality class of logs from which the study's timber was made, appeared in the relationship between density and MOR (it amounted to 0.25 for timber made of Class A logs, 0.56 for Class B logs, and 0.34 for Class C logs).

Regarding timber made of logs from Site 2, the highest average density value was determined for timber made of Class B logs (618 kg/m^3). Timber made of logs from Class A had the average density value that was lower by 6%, and timber made of logs from Class C had the average density value lower by approximately 16% compared to timber made of logs from Class B logs. The coefficients of correlation between the tested properties for timber from Site 2 are found in Table 5. An analysis of the data presented in Table 5 shows that the relationships were similar to those determined for timber from Site 1. Concerning timber made of logs from Site 3, there were no logs classified as the Class A quality. In that habitat, there were no logs that met the criteria of the Class A, and thus the tested timber was only from Classes B and C. The average density of timber made of Class B logs from that forestry region was 514 kg/m^3, and the average density of timber made of Class C logs was 502 kg/m^3.

Regarding timber made of logs from Site 1, the highest average MOE value (14,200 MPa) was determined for timber made of Class B logs. The average MOE value for timber from Class A logs from this region was slightly lower (by 1%). Timber made of Class C logs had the average MOE lower by 18% compared to timber made of Class B logs.

In timber made of logs from Site 2, the highest average MOE value (15,000 MPa) was found in timber made of Class B logs. Timber made of Class A logs from this region had an average MOE value lower by 8%, while timber from Class C logs had the lowest MOE value for that region, lower by 19% compared to timber made of Class B logs.

Regarding timber made of logs from Site 3, the average MOE value for timber from Class B logs was 11,400 MPa. For Class C logs, the average MOE value was lower by 4%.

Concerning timber made of logs from Site 1, the highest average MOR value (57.3 MPa) was determined for timber made of Class A logs. The average MOR value for timber from Class B logs from that region was slightly lower (by 4%). Timber made of Class C logs had the lowest average MOR (39.9 MPa).

Regarding timber made of logs from Site 2, the highest average MOR value (67.8 MPa) was in the timber made of Class B logs. Timber made of Class A logs from this region had an average MOR lower by 19%, while timber from Class C logs had the lowest MOR value for that region. In timber made of logs from Site 3, the average MOR value for timber from Class B logs was 45.8 MPa. For Class C logs, the average MOR value was lower by 15% compared to timber made of Class B logs.

For the conducted analysis, it was concluded that the highest average density (618 kg/m^3), the highest average MOE (15,000 MPa), and the highest average MOR (67.8 MPa) was the timber made from Class B logs obtained in Site 2.

Taking into account the quality class of the pine logs that were used to make the timber examined in this study, the highest density was found for logs in Class A (572 kg/m^3), the lowest (by 11%) was in timber made of Class C logs. Timber made of Class B logs had an average density slightly lower (by 1%) than timber made of Class A logs. The highest value of MOE was observed for timber made of Class A logs (13,900 MPa), and the lowest for timber made of Class C logs (11500 MPa). For timber made of Class B logs, the MOR was 13,800 MPa. Regarding bending strength, the highest value was observed for timber made of Class A logs (56.3 MPa), and the lowest for timber made of Class C logs (lower by 27% in comparison to timber made of Class A logs). For timber made of Class B logs, the bending strength was 55.3 MPa. For all the tested properties (density, MOE, and MOR), the highest values were observed for timber from Class A, and the lowest for timber made of logs from Class C. The difference between the average values of the tested properties obtained for timber made of logs from Classes A and B was minimal. The average values for timber made of Class C logs were clearly the lowest. Compared to the average values obtained for the entire batch under research, the average values for timber from Class A and Class B logs were higher than the average values for the entire batch. In Class C logs, the average values of density, MOE, and MOR were lower than the average values for the entire timber batch (450 pieces). Moreover, the analysis of results also included calculations of the correlation coefficients between the parameters under research for logs of the same quality class, independent of their geographic origin. The values of those coefficients are presented in Table 5.

The highest coefficients of correlation between the tested timber properties were observed for timber made of Class B logs. The coefficients of correlation between DEN/MOE and MOR/MOE achieved similar values, independent of the quality class of the logs. The biggest differences were found in the correlation coefficient for DEN/MOR. The highest value of this coefficient (0.53) was observed for timber made of Class B logs. For timber made of Class C logs, the value of the correlation coefficient DEN/MOR was slightly lower at 0.49. The lowest correlation coefficient DEN/MOR value—clearly different from the remaining values—was observed for timber made of Class A logs. The only explanation of this atypical situation was the fact that the number of timber pieces made of Class A logs was small (24 timber pieces).

Table 6. Values of Probability Level for the Significance Test for Density, MOE, and MOR

Dependent Variable	Qualitative Variable		
	Class	Site	Class * site
Density	**0.002130**	**0.015746**	**0.002669**
MOE	**0.002280**	0.377304	**0.016709**
MOR	**0.005158**	0.06193	**0.01540**

Note: Bolded values are statistically significant

From the conducted statistical analysis (Table 6), it can be concluded that the quality class of logs from which the timber was made had a significant influence on differentiating the values of density, MOE, and MOR. Regarding the qualitative factor of log origin from a given forestry region, significant differentiation was observed only in density values. The influence of the interaction of both factors—log quality class and their origin—indicated important differences in density, MOE, and MOR values.

A detailed analysis of quality classes of the logs from which timber was made (Table 7) showed that there were no significant differences between the average values of density, MOE, and MOR for timber made of Class A and Class B logs. There were significant differences between the average values of density, MOE, and MOR when the properties of timber from Class A to Class C logs were compared, and analogically when timber made of Class B logs were compared to Class C logs. The analysis of results, deepened by statistical analysis, proved that it would be reasonable to adjust the principles that classify logs into quality classes.

Table 7. Probability of *Post hoc* Tests for Log Quality Classes as Differentiating Factors

Property	Quality Class	A	B	C
Density	A		0.488758	**0.000011**
	B	0.488758		**0.000014**
	C	**0.000011**	**0.000014**	
MOE	A		0.987094	**0.002405**
	B	0.987094		**0.000022**
	C	**0.002405**	**0.000022**	
MOR	A		0.974813	**0.001892**
	B	0.974813		**0.000022**
	C	**0.001892**	**0.000022**	

Note: Bolded values are statistically significant

A detailed analysis (limited, like Table 7, to density values) concerning the origin of logs from different forestry regions (Table 8) revealed that there were no significant differences between the average timber density values for timber from Sites 1 and 2. Significant differences between the average density values were observed when comparing the timber properties of logs from Site 1 and Site 3, and analogically when comparing logs from Site 2 and Site 3. This dependencies may be explained by the differences in the technical quality of the stand from which logs were obtained under Site 1, 2 and 3. In the case of Site 1 and 2, the technical quality of the stand was described as 2, while in the case of Site 3 - 3. This could have had an impact on statistically significant differences in mean values of density and MOE between sawn timber originating from Site 1 and 3 and Site 2 and 3.

Table 8. Probability of *Post hoc* Tests for Log Origin (Different Forestry Regions) as the Differentiating Factor

Property	Site	Site 1	Site 2	Site 3
Density	Site 1		0.597144	**0.000020**
	Site 2	0.597144		**0.000077**
	Site 3	**0.000020**	**0.000077**	

Note: Bolded values are statistically significant

CONCLUSIONS

1. The technical quality of forests has an influence on the density and MOE of tested sawn timber.
2. The quality class of logs has an influence on the tested wood properties (density, MOE, and MOR).
3. The highest value of the correlation coefficient for the entire batch of timber was observed in the DEN/MOE relationship (0.75). Taking into account the geographic origin, the highest value of the coefficient DEN/MOE was observed in timber from the Silesian Forestry Region (Site 1) (0.77).
4. Independent of the geographic origin, timber made of Class B logs had the highest average values of density, MOE, and MOR. The lowest average values of the tested properties were observed in timber of Class C logs.

ACKNOWLEDGMENTS

The authors are grateful for the support of the National Centre for Research and Development, Poland, under “Environment, Agriculture and Forestry” – BIOSTRATEG strategic R&D programme, agreement No. BIOSTRATEG3/344303/14/NCBR/2018.

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Article submitted: July 27, 2020; Peer review completed: October 25, 2020; Revised version received and accepted: November 15, 2020; Published: December 4, 2020.
DOI: 10.15376/biores.16.1.669-683