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THE DECREASE IN BASIC DENSITY OF SPRUCE (*PICEA ABIES* (L.) KARST.) IN THE PAST THIRTY YEARS

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ABSTRACT

One of the most significant properties of wood is its density, which fundamentally affects its physical and mechanical properties. The most appropriate quantity for practical calculations in the forestry and wood processing industry is basic density, which allows a stock of wet wood to be converted to dry mass and vice versa. For the purposes of this research, thirteen spruce stands at the felling age were chosen in Orlicke hory Mts. and Slezske Beskydy Mts. (Silesian Beskids). In each stand, heartwood cores were extracted from 20 trees by means of the Pressler increment borer and their basic density was established. The cores were also used for the dendrochronological analysis of tree-ring width series. The resulting values of the basic density and tree-ring width were statistically processed and compared with the results of spruce basic density obtained in the research conducted in the 1970s. The comparison shows that the basic density of spruce, measured in the same altitudinal vegetation zones and edaphic categories, is considerably lower today than thirty years ago. While the basic density of spruce growing in the fifth altitudinal vegetation zone now ranges between 330 and 360 kg.m^{-3}, the density measured thirty years ago in the same altitudinal vegetation zone was 390–425 kg.m^{-3}. The significant decrease in the basic density of spruce wood fundamentally affects its strength and thus its possible further use.

KEYWORDS: Basic density, spruce, tree ring, Orlicke hory Mts., Slezské Beskydy Mts. (Silesian Beskids).

INTRODUCTION

Properties of wood are a result of its chemical composition and structure at all levels, i.e. submicroscopic, microscopic, and macroscopic. The most significant property of wood is the density, which fundamentally affects the other physical and mechanical properties. The most frequently mentioned factor of wood density is the width of tree rings. Majority of studies on spruce describe a decrease in density with an increasing tree-ring width (Bernhart 1964, Mozina

1960, Petty et al. 1990, Trendelenburg 1939, Gryc and Horáček 2007). Wider tree rings have a lower proportion of latewood, which consists of thick-walled anatomical elements – tracheids. Therefore, the resulting average density of wood is related to the ratio between the density of early (315 $kg.m^{-3}$) and late (712 $kg.m^{-3}$) wood (Reck 2002). This fact also explains the variability of wood density along the stem radius. The cambium of older trees forms narrower tree rings, which means the proportion of latewood is higher in comparison with tree rings in juvenile wood (Reck 2002, Palovič and Kamenický 1961, Trendelenburg 1939, Gryc et al. 2011). Spruce has the lowest wood density close to the pith, from where the density increases in the radial direction in proportion with the decrease in the tree-ring width; the highest value is reached near the edge in sapwood with narrow tree rings (Kollmann 1951). Moreover, there is an interesting similarity in the trends of latewood density and tracheid of latewood length (Jane 1956) as both of these increase along the stem radius, while earlywood density decreases in the direction from the pith to mature wood and then it is constant (Panshin and De Zeeuw 1980). A decrease in density of the first created tree rings was observed and described for wood of Sitka spruce (*Picea sitchensis* (Bong.) Carr)). The density decreased between the second and the sixth tree ring from 450 $kg.m^{-3}$ to 330 $kg.m^{-3}$. The decrease is caused by the increasing tree-ring width and a larger radial dimension of tracheids (Mitchell and Denne 1997).

The variability in wood density can also be observed along the stem height. With the same tree-ring width, the proportion of latewood and thus the density will be lower in higher positions in the stem than in lower positions (Kollmann 1951, Palovič and Kamenický 1961). However, some studies did not confirm this trend or observed the same density of wood along the spruce stem height (Bosshard 1985, Reck 2002). When establishing the basic density for entire stems, no statistically significant difference was found between the average of the basic density for the entire stem and the average of the basic density measured 1.3 m high from the stem basis (Přemyslovská et al. 2008).

Wood density

Specific gravity G_M (Forest Products Laboratory) is defined by the quotient of wood weight in an absolutely dry condition m_0 and its volume at a particular moisture content V_w (Koehler 1924):

$$G_M = m_0 / V_W \tag{1}$$

This density shows how much dry mass is in wet wood. The reduced density at w = 0 % is identical to the density of absolutely dry wood ρ_0. With an increasing moisture content, its value drops to the fibre saturation point and then remains constant. The value of density above the saturation point is minimal and does not depend on the wood moisture content because wood has stopped swelling. This quantity is then referred to as basic density ρ_k or reduced density in fresh state ρ_{rf}:

$$\rho_k = \rho_{rf} = m_0 / V_{max} \tag{2}$$

Basic density is a highly suitable quantity for technological calculations in forestry and wood processing industry as it allows a stock of wet wood (with moisture content above the saturation point) to be converted to dry mass in volumetric units and vice versa (Koehler 1924, Trendelenburg 1939, Kollmann 1951, Krzysik 1957, Perelygin 1965, Požgaj et al. 1993).

In order to establish the basic density of wood several types of samples can be used. The first type is a cross section of a tree stem (a disc). The advantage of this type of sampling is that the obtained results of basic density are of high quality and they characterize the section of the stem very well. The disadvantages are the high expenses of sample extraction as the sampled tree has to be felled and the timber is devaluated; another disadvantage is that the obtained samples are large, difficult to transport, store and also measure.

Another type of samples for wood basic density establishment is samples worked in compliance with stipulated criteria, e.g. country standards. However, this type retains all the disadvantages mentioned for cross sections, and there is one more – the difficult preparation and processing of the samples. Moreover, it is difficult to establish the proportion of the sample within the entire area of a cross section of the stem. The measurement of the basic density using these samples is mainly appropriate if the measuring is connected with the establishment of physical and mechanical properties of wood.

The last type of samples (cores) which can be used for the establishment of wood basic density is cores which are taken by means of the Pressler increment borer. Extracting the cores is the most suitable method for sampling in large field research studies. Cores are of small dimensions, easily handled, the tested trees need not be felled, this method is not demanding as far as the equipment is concerned and the proportion of the parts in the cross section of the stem can be easily ascertained (Přemyslovská et al. 2008).

MATERIAL AND METHODS

Spruce stands in two mountain ranges were selected for the research: Orlické hory Mts. and Slezské Beskydy Mts.

The three selected spruce stands in Orlické hory Mts. were aged over 90 years and were located at altitudes above 800 m a.s.l. The details of the sites are presented in the following table.

Tab. 1: The overview of the selected sites – Orlické hory Mts.

Site	Age	Altitude	Location
A	90	830 m a.s.l.	N 50°13.410 E 016°28.300
B	120	870 m a.s.l.	N 50°13.490 E 16°29.470
C	100	910 m a.s.l.	N 50°14.070 E 16°29.110

The sites chosen in the Slezské Beskydy Mts. were located in spruce stands in three different forest districts. The first four sites (P1–P4) were located in the district of Nýdek, sites P5–P8 were located in the Písek district, and the last two sites were in the district of Horní Lomná (Tab. 2).

In each site, cores from 20 randomly chosen sample trees were extracted. From each tree one core at 1.3 m above the stem basis was taken so that the core contained the entire segment from the pith to the cambium.

With respect to the changes in wood density along the stem radius, the cores were cut into 7 sections so that they represented 5 %, 5 %, 10 %, 20 %, 20 %, 20 %, 20 % out of the stem cross section area, starting from the pith. The basic density of the core was then established as a weighted arithmetic mean of individual sections in dependence on the percentage. To ascertain the volume of samples above the saturation point, we chose the water displacement method (Olesen 1971).

Tab. 2: The overview of the selected sites – Slezské Beskydy Mts.

Site	Age	Altitude	Location
P1	80	778 m a.s.l.	N 49°40.879 E 18°46.984
P2	90	673 m a.s.l.	N 49°40.177 E 18°47.036
P3	110	601 m a.s.l.	N 49°39.709 E 18°48.030
P4	50	560 m a.s.l.	N 49°39.351 E 18°42.251
P5	100	650 m a.s.l.	N 49°34.709 E 18°48.951
P6	120	753 m a.s.l.	N 49°39.709 E 18°48.032
P7	90	549 m a.s.l.	N 49°34.304 E 18°49.964
P8	120	759 m a.s.l.	N 49°35.551 E 18°48.973
P9	110	765 m a.s.l.	N 49°30.422 E 18°38.367
P10	120	794 m a.s.l.	N 49°35.551 E 18°48.975

The method consists in immersing a core in a beaker with distilled water which is placed on a laboratory scale (Scaltec SBC 41, 0.001 g accuracy). The volume of the displaced water equals the volume of the immersed core and it is ascertained by weighing. For accurate measuring the core was fixed on a needle, which was placed on a stand adapted to the purpose.

To establish the weight of individual core sections at a moisture content of 0 %, the cores were dried in a laboratory oven (SANYO MOV 112) at a temperature of 103°C in compliance with the sample preparation principles for testing physical and mechanical properties of wood stipulated in Czech standard ČSN 49 0103.

The measuring of tree ring width was conducted in compliance with the standard dendrochronological methodology (Cook and Kairiūkštis 1990). For the measuring, a specialized measuring table connected to a computer was used. The measuring table is equipped with a screw mechanism and an impulsemeter, which records the table top shift interval, i.e. the width of tree rings (Frouz et al. 2008). The last part of the measuring equipment is a stereo magnifying glass with a crosshair fixed to a stand. The measuring is processed in the PAST4 (©Sciem) application (Rybníček et al. 2010a). Annual increments are measured with 0.01 mm accuracy (Rybníček et al. 2010b). The methodological procedures for tree-ring width measuring performed by Matovič (1983) who led the research in the 1970s, have been presented in previous studies (Přemyslovská et al. 2008).

RESULTS

Orlické hory Mts

The above mentioned methodology was used to establish the basic density at the three selected sites of the Orlické hory Mts. (Tab. 3). The mean value of the basic density at site A was 339.81 kg.m^{-3}. The sample set was of low variability with a variation coefficient of 6.17 %. Similar results were found at site B with a mean of 330.94 kg.m^{-3} and variation coefficient 8.2 %. The mean basic density in site C was 348.31 kg.m^{-3} and again with low variability – 8.5 %.

Tab. 3: Basic density in kg.m^{-3} for individual sites.

Site	n	Average	Median	Variance	Standard deviation	Min.	Max.
A	20	339.81	336	450.51	20.99	312.89	392.54
B	20	330.94	340.65	737.09	27.15	279.78	387.69
C	20	348.31	343.67	850.77	29.17	305.92	418.22

To compare the similarity of means and variance of basic density at the individual sites, the homogeneity of variance test (F-test) and the two sample t-test (Tab. 4, Tab. 5) were carried out. Based on F-test results, we can conclude that all sets come from a set with the same variance. Based on t-test results, we can conclude that there is no statistically significant difference among the basic density values at the individual sites.

Tab. 4: Results of F-test for the values of wood basic density at selected sites in Orlické hory Mts.

Sites	F	DF	p	Upper confidence interval	Lower confidence interval	Variance quotient
A – B	0.598	20	0.258	0.242	1.473	0.598
A – C	0.518	20	0.153	0.206	1.285	0.518
B – C	0.866	20	0.752	0.345	2.150	0.866

Tab. 5: Results of t-test for the values of wood basic density at selected sites in Orlické hory Mts.

Sites	Mean estimate		DF	t	p	Confidence interval	
A – B	339.81	330.94	40	1.185	0.243	-6.261	24.008
A – C	339.81	348.31	39	-1.074	0.289	-24.486	7.499
B – C	330.94	348.31	39	-1.974	0.055	-35.157	0.424

Slezské Beskydy Mts.

The above mentioned methodology was used to establish the basic density at the ten selected sites of the Slezské Beskydy Mts. (Tab. 6).

To compare the similarity of means and variance of basic density at the individual sites, the homogeneity of variance test (F-test) and the two sample t-test (parametric t-test when the sets had the same distribution, Welsch t-test when they did not come from a set with the same variance (Welch 1947)) were carried out.

Based on the results of the t-test, we can state that there are some statistically significant differences in the basic density values among individual sites.

For better clarity we are presenting a simplified table of the values of probability p instead of full results of the statistical survey. The italics highlight the values where zero hypothesis (H0) was rejected and therefore we can conclude that the sets do not have the same variance based on the F-test and that there is a statistically significant difference in means among the tested sets based on the t-test (Tab. 7).

Tab. 6: Basic density in kg.m^{-3} for individual sites.

Site	n	Average	Median	Variance	Standard deviation	Variation coefficient (%)	Min.	Max.
P1	20	364.35	361.8	1931.43	43.95	12.06	280.95	462.09
P2	20	344.02	341.95	1292.26	35.95	10.45	280.82	413.68
P3	20	358.76	359.25	802.31	28.33	7.9	298.56	412.9
P4	20	337.68	330.85	1210	34.79	10.3	287.16	413.08
P5	20	375.62	371.7	1867.36	43.21	11.5	314.64	460.7
P6	20	342.84	332.71	618.12	24.86	7.25	310.37	383.04
P7	20	355.88	353.91	1016.78	31.89	8.96	313.69	419.01
P8	20	348.78	352.69	542.56	23.29	6.68	309.94	386.93
P9	20	330.66	322.1	1031.82	32.12	9.71	284.44	423.1
P10	20	358.75	365.5	2390.62	48.89	13.63	239.54	427.4

Tab. 7: Values of probability p (F-test / t-test) for selected sites in the Slezské Beskydy Mts; the italics highlighted values show that the basic density in the compared sites is significantly different.

F-test/ t-test	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
P1	-	0.12	0.64	0.03	0.42	0.06	0.49	0.17	0.01	0.71
P2	0.39	-	0.16	0.57	0.02	0.91	0.28	0.62	0.22	0.28
P3	0.06	0.31	-	0.04	0.15	0.07	0.76	0.23	0.01	0.99
P4	0.32	0.89	0.88	-	0	0.59	0.09	0.24	0.51	0.12
P5	0.94	0.43	0.07	0.35	-	0.01	0.11	0.02	0	0.26
P6	0.02	0.12	0.58	0.15	0.02	-	0.16	0.44	0.19	0.21
P7	0.17	0.61	0.61	0.71	0.19	0.29	-	0.43	0.02	0.83
P8	0.01	0.07	0.4	0.09	0.01	0.78	0.18	-	0.05	0.42
P9	0.18	0.63	0.59	0.73	0.21	0.27	0.98	0.17	-	0.04
P10	0.65	0.19	0.02	0.15	0.6	0.01	0.07	0	0.08	-

The comparison of individual sites shows that some sites have different means of wood basic density. It means that there were considerably different growth conditions at these sites.

The comparison of wood basic density at the selected sites in Orlické hory Mts. and Slezské Beskydy Mts.

The results of measuring at the selected sites in the Slezské Beskydy Mts. were compared with the results of measuring at the selected sites in Orlické hory Mts. (Tab. 8). The comparison shows that the means of basic density differ at some sites; one of appropriate hypotheses is that the growth conditions and thus the annual increments are significantly different at these sites.

Tab. 8: Values of probability p (F-test / t-test) for selected sites in Slezské Beskydy Mts. (lines) and Orlické hory Mts. (sites A, B, C). The italics highlight the values which show that the basic density at the compared sites differ significant.

	F-test			t-test		
	A	B	C	A	B	C
P1	0.00	0.04	0.08	0.03	0.01	0.18
P2	0.02	0.22	0.37	0.65	0.20	0.68
P3	0.19	0.85	0.90	0.02	0.00	0.26
P4	0.03	0.28	0.45	0.82	0.49	0.30
P5	0.00	0.045	0.10	0.00	0.00	0.02
P6	0.46	0.71	0.49	0.68	0.15	0.53
P7	0.07	0.48	0.70	0.06	0.01	0.44
P8	0.65	0.51	0.34	0.20	0.02	0.96
P9	0.07	0.46	0.68	0.29	0.98	0.08
P10	0.00	0.01	0.03	0.12	0.03	0.42

The comparison of wood basic density at the selected sites in the Orlické hory Mts. and the Slezské Beskydy Mts. with previous research

The results of wood basic density at the selected sites in the Orlické hory Mts. and Slezské Beskydy Mts. were compared with former results obtained at sites in the same altitudinal vegetation zones and edaphic categories (5S, 5N, 5F, 5A, 7K, 6S, 6K) in the research conducted by Matovič in the 1970s (Tab. 9) (Matovič 1983), extended by Přemyslovská et al. (2008). The comparison was made using F-tests and subsequently t-tests (parametric t-test when the sets had the same distribution, Welsch t-test when they did not come from a set with the same variance (Welch 1947)). The italics highlight the values where zero hypothesis (H0) was rejected and therefore we can conclude that the sets do not have the same variance based on the F-test and that there is statistically significant difference in means among the tested sets based on the t-test (Tabs. 10, 11, 12).

The comparison of tree-ring width at the selected sites in Orlické hory Mts. and Slezské Beskydy Mts. with previous research

The measurement of tree-ring width at the sites of the selected altitudinal vegetation zones and edaphic categories was conducted both within Matovič's research (1983) in the 1970s (6S, 5S, 5F, 5A) and within the current research (Přemyslovská et al. 2008) (Tab. 13). The sites of the Slezské Beskydy Mts. and the Orlické hory Mts. (A, B, C, P1…P10) were classified according to the edaphic typology and they created summarizing selection sets of tree-ring width in dependence on the altitudinal vegetation zone and edaphic category (E_6S, E_5S, E_5F, E_5A).

Tab. 9: Basic density in kg.m^{-3} for sites of the same forest type measured within the research conducted (Matovič 1983).

Site	n	Average	Median	Variance	Standard deviation	Variation coefficient (%)	Min.	Max.
5S	81	389.69	391.87	1281.35	35.8	9.19	314.67	495.01
5N	19	424.27	427.22	1187.65	34.46	8.12	381.07	526.28
5F	20	408.95	408.95	1914.41	43.75	10.7	331.69	496.16
5A	20	403.44	403.44	495.37	22.26	5.52	370.00	477.80
7K	39	395.29	400.36	1110.59	33.33	8.43	328.38	450.76
6S	41	418.50	412.01	943.14	30.71	7.34	357.78	504.07
6K	61	446.49	444.85	1100.08	33.17	7.43	367.35	528.20

Tab. 10: Results of F-tests comparing the values of wood basic density at the selected sites in the Orlické hory Mts. and those obtained (Matovič 1983).

Sites	F	DF	p	Upper confidence interval	Lower confidence interval	Variance quotient
7K - A	1.162	19	0.740	0.468	2.917	1.162
7K - B	0.694	19	0.432	0.280	1.743	0.694
7K - C	0.602	19	0.277	0.238	1.521	0.602
6S - A	2.279	59	0.044	1.024	4.440	2.278
6S - B	1.362	59	0.449	0.612	2.654	1.362
6S - C	1.180	59	0.712	0.519	2.322	1.180
6K - A	2.293	62	0.042	1.033	4.441	2.293
6K - B	1.370	62	0.439	0.618	2.654	1.371
6K - C	1.187	62	0.699	0.524	2.322	1.187

Tab. 11: Results of t-tests comparing the values of wood basic density at the selected sites in the Orlické hory Mts. and those obtained (Matovič 1983).

Sites	Mean estimate		DF	t	p	Confidence interval	
7K - A	372.5	339.81	39	4.798	2.36E-005	18.907	46.465
7K - B	372.5	330.94	39	5.310	4.69E-006	25.729	57.390
7K - C	372.5	348.31	38	2.931	0.006	7.482	40.904
6S - A	371.65	339.81	53	5.185	3.43E-006	19.524	44.156
6S - B	371.65	330.94	79	5.247	1.26E-006	25.272	56.156
6S - C	371.65	348.31	78	2.909	0.005	7.367	39.328
6K - A	395.37	339.81	52	9.132	2.02E-012	43.354	67.765
6K - B	395.37	330.94	82	8.324	1.59E-012	49.035	79.831
6K - C	395.37	348.31	81	5.879	8.82E-008	31.138	62.994

Tab. 12: Values of probability p (F-test/t-test) for the selected sites in the Slezské Beskydy Mts. and the research by Matovič (1983) (the highlighted fields correspond to the forest type). The columns show the altitudinal vegetation zone and edaphic categories. The values in italics show that the basic density at the compared sites differs significantly.

	F-test				t-test			
	5S	5F	5N	5A	5S	5F	5N	5A
P1	0.21	0.99	0.31	0.01	0.01	0	0	0
P2	0.92	0.4	0.86	0.04	0	0	0	0
P3	0.25	0.07	0.4	0.3	0	0	0	0
P4	0.93	0.33	0.97	0.06	0	0	0	0
P5	0.25	0.96	0.34	0.01	0.14	0.02	0	0.01
P6	0.08	0.02	0.16	0.63	0	0	0	0
P7	0.58	0.18	0.73	0.13	0	0	0	0
P8	0.04	0.01	0.1	0.85	0	0	0	0
P9	0.61	0.19	0.76	0.12	0	0	0	0
P10	0.06	0.63	0.14	0	0	0	0	0

Tab. 13: Tree-ring width in mm for sites of the same forest type measured within Matovič's research (1983) (6S, 5S, 5F, 5A) and the current selection sets from the same sites but a different period (the current measuring from sites in the Slezské Beskydy Mts. and Orlické hory Mts. expressed according to the edaphic typology E_6S, E_5S, E_5F, E_5A).

Site	n	Mean	Median	Variance	Standard deviation	Variation coefficient (%)	Min.	Max.
6S	40	2.36	2.22	0.33	0.58	24.36	1.35	2.22
5S	161	2.02	2.01	0.17	0.41	20.10	1.13	2.01
5F	39	1.97	1.96	0.15	0.38	19.29	1.26	1.96
5A	25	2.00	1.89	0.19	0.43	21.70	1.14	1.89
E_6S	21	2.94	3.13	0.47	0.68	23.23	1.45	3.13
E_5S	104	2.25	2.26	0.38	0.61	27.20	0.49	2.26
E_5F	39	2.19	2.17	0.58	0.76	34.79	0.49	2.17
E_5A	20	2.63	2.58	0.24	0.49	18.56	1.99	2.58

The comparison (i.e. of the current research and Matovič's research (1983)) again consisted of F-tests and subsequent t-tests (parametric t-test when the sets had the same distribution, Welsch t-test when they did not come from a set with the same variance (Welch 1947)). The italics highlight the values where zero hypothesis (H0) was rejected and therefore we can conclude that the sets do not have the same variance based on the F-test and that there is statistically significant difference means among the tested sets based on the t-test (Tab. 14, Tab. 15).

Tab. 14: Results of F-tests comparing the values of variance of tree-ring width at the selected sites of Matovič's research (1983) (6S, 5S, 5F, 5A) and the current selection sets from the same sites but a different period (the current measuring from sites in the Slezské Beskydy Mts. and Orlické hory Mts. expressed according to the edaphic typology E_6S, E_5S, E_5F, E_5A).

Sites	F	DF	p	Upper confidence interval	Lower confidence interval	Variance quotient
6S-E_6S	0.71	39	0.35	1.47	0.31	0.71
5S-E_5S	0.44	160	0.00	0.62	0.31	0.44
5F-E_5F	0.25	38	0.00	0.48	0.13	0.25
5A-E_5A	0.79	24	0.58	1.86	0.32	0.79

Tab. 15: Results of t-tests comparing the mean values of tree-ring width at the selected sites of Matovič's research (1983) (6S, 5S, 5F, 5A) and the current selection sets from the same sites but a different period (the current measuring from sites in the Slezské Beskydy Mts. and Orlické hory Mts. expressed according to the edaphic typology E_6S, E_5S, E_5F, E_5A).

Sites	Mean estimate		DF	t	p	Confidence interval	
6S-E_6S	2.36	2.94	59	-3.52	0.00	-0.91	-0.25
5S-E_5S	2.02	2.25	161	-3.34	0.00	-0.36	-0.09
5F-E_5F	1.98	2.19	55	-1.57	0.12	-0.49	0.06
5A-E_5A	2.01	2.63	43	-4.58	0.00	-0.91	-0.35

DISCUSSION

Wood density is the most informative property for the assessment of wood strength (Panshin and De Zeeuw 1980). Its influence on wood strength is positive – with an increasing density wood strength increases as well (Požgaj et al. 1993). Basic density is one of the most important quantities for practical forestry and wood technology as it can be used to convert an amount of wet wood to dry mass and vice versa (Kollmann 1951). Due to the fact that the basic density changes along the stem radius, its establishment using a core as a whole would be inaccurate. The average value of wood basic density as established from the whole core differs from the real value by + 0.9 % calculated for spruce wood using a sample set of 20 trees. However, the deviation can reach up to + 9 % in individual trees (Ericson 1959). Therefore, the measurement of wood basic density was conducted in individual sections of the core. Then it was calculated as a weighted arithmetic mean of the particular sections according to their proportion within the cross section.

The basic density of spruce wood at the selected sites in the Orlické hory Mts. was established between 330.94 $kg.m^{-3}$ and 348.31 $kg.m^{-3}$. All the three sample sets had low variability with variation coefficients from 6.17 % to 8.5 %. Compared with the results of the research carried out in the 1970s, which took place at sites of the same altitudes and edaphic categories, the difference in spruce basic density is statistically significant.

The basic density of spruce wood at the ten selected sites in the Slezské Beskydy Mts. was established between 330.66 $kg.m^{-3}$ and 375.62 $kg.m^{-3}$. The difference in the values of basic density as measured in the current research and Matovič's research is again statistically significant.

The comparison shows that the basic density of wood, measured in the same altitudinal vegetation zones and edaphic categories, is markedly lower today than thirty years ago. While today the basic density of spruce growing in the fifth altitudinal vegetation zone ranges between about 330 and 360 $kg.m^{-3}$, thirty years ago it ranged between 390 and 425 $kg.m^{-3}$ in the same altitudinal vegetation zone (Přemyslovská et al. 2008).

We can hypothesize that during the last 30 years the growth conditions have changed and, in consequence, the basic density of spruce is considerably lower nowadays. The most frequently mentioned factor affecting wood density is the width of tree rings: with an increasing tree ring width spruce wood density decreases (Petty et al. 1990). This is caused by the fact that wider tree rings in conifers have a lower proportion of latewood. The results of the statistical analysis show an important fact: not all the monitored areas can be compared due to the variability of mean estimate and tree ring width. Therefore, considering the similar areas only (as regards the comparability of their mean values and variance) and excluding the tree ring width decrease as a possible cause, the density decrease can also be explained by a change in the proportion of early- and latewood, or a change in the thickness of cell walls, or the degree of their lignification. When there is a warm end of summer, latewood tracheids have a thicker cell wall than when the end of summer is cold (Schweingruber 1996). However, due to the fact we do not have the samples or the records about the proportion of early- and latewood from Matovič's previous studies, we cannot perform this comparison.

It is highly important to point out the marked decrease in the basic density of spruce wood at our sites in comparison with the values of spruce basic density measured in the same vegetation altitudinal zones and edaphic categories in the 1970s. As has been mentioned, wood density affects wood strength to a great degree. For example, we can see a linear dependence between wood density and wood strength in compression parallel to the grain (Bodig and Jayne 1982). When wood density decreases by 100 $kg.m^{-3}$, wood strength in compression parallel to the grain decreases by over 9 MPa (Požgaj et al. 1993); the bending strength decreases by over 30 % (Bodig and Jayne 1982). These decreases in values are so significant that for the selection of material it is necessary to consider the area from which the trees to be used for the production of wooden constructional elements come. At the same time, it is necessary that these material parameters are taken account of when wooden constructions are dimensioned.

CONCLUSIONS

The resulting values of the basic density and tree-ring width were statistically processed and compared with the results of spruce basic density obtained in the research conducted in the 1970s. The comparison shows that the basic density of spruce, measured in the same altitudinal vegetation zones and edaphic categories, is considerably lower today than thirty years ago. While the basic density of spruce growing in the fifth altitudinal vegetation zone now ranges between 330 and 360 $kg.m^{-3}$, the density measured thirty years ago in the same altitudinal vegetation zone was 390–425 $kg.m^{-3}$. The significant decrease in the basic density of spruce wood fundamentally affects its strength and thus its possible further use. The research has revealed a number of questions that cannot be answered satisfyingly at the level of tree rings. That is why research into the influence of climatic conditions on wood formation at the level of cells has been started.

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REFERENCES

1. Bernhart, A., 1964: Über die Rohdichte von Fichtenholz. Holz als Roh- und Werkstoff 22(6): 215-228.
2. Bodig, J., Jayne, B.A., 1982: Mechanics of wood and wood composites. Krieger Publishing Company, 736 pp.
3. Bosshard, H.H., 1985: Holzkunde. Band 2: Zur Biologie, Physik und Chemie des Holzes. Birkhäuser Verlag, Basel und Stuttgart, 312 pp.
4. Cook, E.R., Kairiūkštis, L.A., 1990: Methods of dendrochronology: Applications in the environmental sciences. Kluwer Academic Publisher and International Institute for Applied Systems Analysis, Dordrecht, Boston, London, 394 pp.
5. Ericson, B., 1959: A mercury immersion method for determining the wood density of increment core sections. Rapp. Avd. Skogsprod. Stockholm, No. 1: 1-31.
6. Frouz, J., Rybníček, M., Cudlín, P., Chmelíková, E., 2008: Influence of the wood ant, *Formica polyctena*, on soil nutrient and the spruce tree growth. Journal of Applied Entomology 132(4): 281-284.
7. Gryc, V., Horáček, P., 2007: The variability of Spruce (*Picea abies* (L.) Karst.)) wood density with present reaction wood. Journal of Forest Science 53(3): 129-137.
8. Gryc, V., Vavrčík, H., Horn, K., 2011: Density of juvenile and mature wood of selected coniferous species. Journal of Forest Science 57(3): 123-130.
9. Jane, F.W., 1956: The structure of wood. Adam & Charles Black, London, 428 pp.
10. Koehler, A.B.S., 1924: The properties and uses of wood. New-York and London: McGraw-Hill Book Company, Inc., 354 pp.
11. Kollmann, F., 1951: Technologie des Holzes und der Holzwerkstoffe. Springer-Verlag, Berlin, Band 1, 1050 pp.
12. Krzysik, F., 1957: Wood Science. (Nauka o drewnie). Warszawa: Państwowe Wydawnictwo Rolnicze i Leśne, 899 pp (in Polish).
13. Matovič, A., 1983: Variability in basic density of Norway spruce wood (*Picea abies* (L.) Karst.) in relation to tree height, age and site. (Variabilita konvenční hustoty dřeva smrku (*Picea abies* (L.) Karst.) se zřetelem na stanoviště, výšku a věk stromů). Vysoká škola zemědělská v Brně, Brno, 97 pp (in Czech).
14. Mitchell, M.D., Denne, M.P., 1997: Variation in density of *Picea sitchensis* in relation to within-tree trends in tracheid diameter and wall thickness. Forestry 70(1): 47-60.
15. Mozina, I., 1960: Über den Zusammenhang zwischen Jahrringbreite und Raumdichte bei Douglasienholz. Holz als Roh- und Werkstoff 18(11): 409-413.
16. Olesen, P.O., 1971: The water displacement method a fast and accurate method of determining the green volume of wood samples. Forest Tree Improvement, Arboretet Hørsholm 3, 23 pp. Akademisk Forlag, Copenhagen.

17. Palovič, J., Kamenický, J., 1961: Distribution of determining physical and mechanical properties in the stem of spruce and fir and their relationship to the development of new directions of technologies for processing of conifers. Part I: Variance and distribution of volumetric mass, tree ring width, latewood proportion. (Rozloženie rozhodujúcich fyzikálnych a mechanických vlastností v kmeni smreka a jedle a ich vzťah k rozvoju nových smerov technologií ihličnatých drevín. I. část: Rozptyl a rozloženie objemovej váhy, šírky ročných kruhov, podielu letného prírastku). Drevársky výskum 6(2): 85-102 (in Slovak).
18. Panshin, A.J., De Zeeuw, C., 1980: Textbook of wood technology: Structure, identification, properties, and uses of the commercial woods of the United States and Canada. New York, United States: McGraw-Hill Book Company, Inc., 722 pp.
19. Perelygin, L.M., 1965: Wood science. (Náuka o dreve). Bratislava: SNTL, 448 pp (in Slovak).
20. Petty, J.A., MacMillan, D.C., Steward, C.M., 1990: Variation of density and growth ring width in stems of Sitka and Norway Spruce. Forestry 63(1): 39-49.
21. Požgaj, A., Chovanec, D., Kurjatko, S., Babiak, M., 1993: Structure and properties of wood. (Štruktúra a vlastnosti dreva). Bratislava: Príroda, 722 pp (in Slovak).
22. Přemyslovská, E., Šlezingerová, J., Gandelová, L., 2008: Tree ring width and basic density of wood in different forest types. In: D. Elferts et al., eds. TRACE - Tree Rings in Archaeology, Climatology and Ecology. Volume 6: Proceedings of the DENDROSYMPOSIUM 2007 May 3rd - 6th 2007, Riga, Latvia. Scientific Technical Report STR 08/05, GeoForschungZentrum Potsdam. Pp 118-122.
23. Reck, P., 2002: Das Bauwachstum von kronenspannungfrei gewachsenen Fichten (*Picea abies* (L.) Karst.) unter besonderer Berücksichtigung der Holztechnologischen Eigenschaften. Dissertation, Freiburg, Albert-Ludwigs Universität, 260 pp.
24. Rybníček, M., Čermák, P., Žid, T., Kolář, T., 2010a: Radial growth and health condition of Norway Spruce (*Picea abies* (L.) Karst.) stands in relation to climate (Silesian Beskids, Czech Republic). Geochronometria 36(1): 9-16.
25. Rybníček, M., Koňas, P., Kolář, T., 2010b: The benefits of tree-ring curves detrending for dating archaeological wood. Geochronometria 35(1): 85-90.
26. Schweingruber, F.H., 1996: Tree rings and environment. Dendroecology. Birmensdorf, Swiss Federal Institute for Forest, Snow and Landscape Research. Berne, Stuttgart, Vienna, Haupt 609 pp.
27. Trendelenburg, R., 1939: Das Holz als Rohstoff - seine Entstehung, stoffliche Beschaffenheit und chemische Verwertung. München-Berlin, JF Lehmans Verlag, 435 pp.
28. Welch, B.L., 1947: The generalization of "Student's" problem when several different population variances are involved. Biometrika 34(1-2): 28-35.
29. Ústav pro hospodářskou úpravu lesů, 2003: UHUL typology. (Typologický systém ÚHÚL). Pp 1. Available at: http://www.uhul.cz/lestypol/typologicky_sys_uhul.php (in Czech).

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