Silva Fennica vol. 53 no. 1 article id 9968
Category: research article
https://doi.org/10.14214/sf.9968

SILVA FENNICA

http://www.silvafennica.fi

ISSN-L 0037-5330 | ISSN 2242-4075 (Online)
The Finnish Society of Forest Science

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Variability in the basic density of silver birch wood in Poland

Lachowicz H., Bieniasz A., Wojtan R. (2019). Variability in the basic density of silver birch wood in Poland. Silva Fennica vol. 53 no. 1 article id 9968. 13 p. https://doi.org/10.14214/sf.9968

Highlights

- Location, tree age and forest habitat type, and the interactions between those factors, have a statistically significant impact on the basic density of silver birch wood.
- The average basic density of silver birch wood increases with the age of the tree.

Abstract

This work presents the findings of a study concerning variability in the basic density of silver birch (*Betula pendula* Roth) wood, depending on the geographical location of tree stands, the age and thickness of the trees, the forest habitat type, and interactions between some of these factors. The study was carried out on wood from trees aged approximately 30, 50 and 70 years in 12 forest districts located throughout Poland. In total 4777 wood samples, taken from 306 trees from 51 test plots, were measured. The location, the age of the trees, the thickness of the trees and the forest habitat type, as well as interactions between these factors, proved to have a significant influence on the basic density of silver birch wood. The highest mean values of the basic density of the birch wood were found in Sokołów forest district on the FBF habitat type (549 kg m^{-3}) and in Giżycko forest district on the FMBF habitat type (548 kg m^{-3}). For the entire set of examined material, the average values of the basic density of wood increase with tree age. For the examined material originating in FBF and FMBF habitats the average values of basic density showed no significant differences; however, in the cases of the forest districts of Giżycko, Łobez and Rudziniec, significant differences in the analysed property were observed.

Keywords *Betula pendula*; tree age; forest habitat type; thickness of trees; geographical location; physical properties of wood
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Received 16 February 2018 **Revised** 20 December 2018 **Accepted** 4 January 2019

1 Introduction

The density of wood is an important indicator of its quality in many areas of the forestry industry. It impacts productivity, the quality of pulp, and the possibility of making desired farm and genetic manipulations. The basic density is significant for the chemical processing of wood, because the amount of dry wood per unit volume determines the material yield (Krzysik 1978).

The basic density of the wood of silver birch (*Betula pendula* Roth), one of the prime forest-forming tree species in Poland and throughout the northern and eastern parts of Europe, has been examined in various aspects. The basic density of the wood of Finnish birch trees was extensively examined by Hakkila (1966) and Bhat (1980). The influence of the intensity of forest thinning on the quality of standing wood and other properties (including the basic density) has been investigated (Cameron et al. 1995). Basic density has also been considered in the context of anatomical structure (Helińska-Raczkowska and Fabisiak 1995) and the variability of the moisture content in freshly cut birch trunks (Helińska-Raczkowska 1996). Studies were conducted concerning variation in basic density in white and silver birch depending on the location along the trunk (Heräjärvi 2004), and comparing the basic density of the lumber wood of silver birch from tree farms and from natural forests (Möttönen and Luostarinen 2006). Attempts have been made to construct models for the vertical wood density of Scots pine, Norway spruce and birch stems (Repola 2006). This property was also studied in the stem wood of juvenile silver birch trees from plantations on former farmlands (Liepins and Rieksts-Riekstins 2013). Basic density was also studied in provenance trials of silver birch originating from the Baltic countries and Finland (Viherä-Aarnio and Velling 2017).

In the north-eastern part of Poland studies were carried out concerning the technical qualities of silver birch wood aged 50 and 70 years, in an FBF habitat, where the wood density at 12% moisture content was examined (Lachowicz 2010, 2012; Lachowicz et al. 2014).

The aforementioned studies provided an extensive introduction to the presently conducted investigations of birch wood, performed in accordance with the same methodology. As a result, a database has been created which is the most detailed to date, describing the variability of selected structural, physical and mechanical properties of silver birch wood in Poland (Lachowicz 2015).

No studies have thus far been conducted concerning the influence of geographical location, tree age, the thickness of the tree and the forest habitat type on the basic density of silver birch wood, covering the entire area of Poland.

The aim of this study is to examine the basic density of silver birch wood depending on the geographical location of forest stands, the age and thickness of trees and the forest habitat type, as well as interactions between these factors.

The results obtained may be used to conduct further scientific and technological research, and may have a significant impact on the ways in which silver birch is used. This will contribute to a better-balanced approach to the utilisation of the wood of this species.

2 Material and methods

This study was conducted on forest stands under the administration of the State Forests National Forest Holding (PGL LP). Based on data from the Bureau for Forest Management and Geodesy, obtained in the form of tables of area and merchantable volume (dated 1 January 2012) and of the geographical location of forest districts in principal resource bases of birch, forest districts which fulfilled the methodological criteria for the establishment of test plots were chosen. Stands with birch trees of approximately 30, 50 and 70 years of age were chosen, in fresh broadleaved forest (FBF) and fresh mixed broadleaved forest (FMBF) habitat types. Forest habitat type is a basic unit in the system of classification of forest habitats; a single type includes forest areas with similar habitat conditions in terms of the fertility and humidity of the soil, climate and landform features, and geological structure. Areas belonging to the same forest habitat type are associated with similar production capacity and silviculture (Forest Data Bank 2017). FBF is a lowland forest habitat type and includes very fertile and fresh forest habitats. It is found on sites with brown soil, mainly leach, sometimes acidic or proper brown soil, proper lessive, with mull type humus or typical mull. FMBF is also a lowland forest habitat type, and includes fresh habitats of average fertility. It is associated with brown leach, podzol or acidic soils, proper fawn soils, spodic, sometimes on podzoluvisols, proper podzol or rusty soils, mostly with typical humus.

Field studies were conducted in 12 forest districts throughout Poland with trees in three age classes: 30, 50 and 70 years old. The districts (and the studied habitat types) were as follows: Płońsk (FBF), Sokołów (FBF), Biała Podlaska (FBF), Płaska (FBF), Górowo Iławeckie (FBF), Elbląg (FBF), Mircze (FBF), Giżycko (FBF and FMBF), Bobolice (FBF and FMBF), Łobez (FBF and FMBF), Lipinki (FBF and FMBF), Rudziniec (FBF and FMBF) (Fig. 1). The ages of the trees in the three classes lay in ranges around 30 years (26–33), 50 years (40–53) and 70 years (66–72). Before areas were chosen, the records held at the forest district offices were compared with the actual field conditions. The selection was also determined by the accessibility of stands and the ability to transport timber after felling. Of the accessible areas, those selected offered the best quality of raw wood on the trunk and enabled the taking of samples for further testing.

In total, samples were obtained from 51 test plots (including material from the 12 plots that were used in the pilot scheme studies conducted in northeast Poland).

On the test plots, the diameters at breast height (DBH) of all trees were measured; those with diameters of less than 7 cm were excluded. The sample trees on the test plots were chosen using Hartig's method based on the mean DBH, using three thickness classes: class 1 – the thinnest trees, class 2 – average thickness trees, and class 3 – the thickest trees (Grochowski 1973). From each thickness class, two trees with DBH close to the mean DBH for the class were chosen and felled, making six trees from each sample plot. In total, sample materials were collected from 306 trees. Two or three 50-centimetre-long trunk sections were cut out (below the 1.3-metre height point

Fig. 1. Geographical layout of the forest districts where the test plots were located (Lachowicz 2015).

and 50–100 cm above it – that is, on the trunk between heights of 0.8 and 1.8–2.3 m), and were then split open and marked appropriately. Samples were taken from this height because the wood from the lower part of the trunk is the most valuable, and this conforms to the methodology used in previous studies of other species carried out at the Department.

The wood was divided into split logs and debarked to increase the evenness of drying and avoid scalding. Wood was also removed from the inner part of the split logs, so that the samples would be cut from the outer part of the trunk. The material was also sorted to exclude split logs with defects such as knots, structural faults and discolouration. The remaining test material was arranged in special stacks and left to season naturally for several months. The split logs were rearranged in the stacks several times during this period to ensure even drying.

After seasoning, when the wood moisture content had reached approximately 15%, samples were formed for the analysis of basic density. The basic density of wood was determined using block samples measuring 20×20×30 mm (where the third measurement is taken in a longitudinal direction). To calculate the volume of wood in its maximum swelling state the samples were moistened to approximately 30% moisture content (the saturation point of wood grain) and measured with electronic callipers in three directions (radial, tangential and longitudinal) with an accuracy of up to 0.01 mm. Afterwards the samples were dried to oven-dry state and weighed with technical weighing scales with an accuracy of 0.001 g. The moisture content of the samples was determined by an oven-drying method. The basic density of the silver birch wood was evaluated for the 4777 samples using the following formula:

$$\rho_u = m_0 / V_{max} \quad (1)$$

where:
ρ_u is the basic density of the wood [kg m^{-3}],
m_0 is the mass of oven-dry wood [kg],
V_{max} is the volume of the wood at its fibre saturation point [m^3].

Due to the wide range of analyses performed and the sheer number of samples collected, it was necessary to adopt an appropriate statistical method (Bruchwald 1989; Stanisz 2006; Kala 2009). The results obtained were subjected to statistical analysis, enabling determination of the influence of location, tree age, the thickness class of the trees and the habitat type on the mean values of the basic density of wood. For this purpose, two-way ANOVA was used. The analysis of means was carried out with the use of Tukey's studentized range test. The significance of the differences was evaluated by the HSD (Honestly Significant Difference) calculated for a confidence level of 95%.

3 Results

The basic density of birch wood was calculated with respect to the location, tree age and forest habitat type (Table 1).

The lowest mean basic density of birch wood with respect to tree age (477 kg m^{-3}) was recorded for 30-year-old birch trees in Łobez district on an FBF habitat, and the highest (564 kg m^{-3}) for 70-year-old birch trees growing in a forest of FMBF habitat type in Giżycko district, equivalent to an increase of 18.34%. The lowest mean basic density of birch wood with respect to geographical location (512 kg m^{-3}) was found in Płaska district on an FBF habitat, while the highest (549 kg m^{-3}) was found in Sokołów district on an FBF habitat type; this difference is equivalent to an increase of 7.21%.

Table 1. The basic density of birch wood [kg m^{-3}] with respect to location and tree age.

Location – Forest district	Tree age	Number of samples (N)	Average	Minimum	Maximum
1 Płońsk FBF	30	80	516	417	616
	50	89	544	438	637
	70	96	550	482	615
	Total	265	538	417	637
2 Sokołów FBF	30	93	545	450	647
	50	96	557	461	620
	70	96	544	445	616
	Total	285	549	445	647
3 Biała Podlaska FBF	30	87	511	433	577
	50	96	548	470	652
	70	90	547	489	607
	Total	273	536	433	652
4 Płaska FBF	30	93	517	447	585
	50	96	501	435	592
	70	96	518	450	577
	Total	285	512	435	592
5 Giżycko FBF	30	96	520	443	574
	50	55	514	443	639
	70	96	548	476	617
	Total	247	530	443	639
6 Giżycko FMBF	30	96	527	442	636
	50	96	555	456	630
	70	96	564	510	629
	Total	288	548	442	636
7 Górowo Iławeckie FBF	30	96	506	441	567
	50	96	523	414	609
	70	94	545	460	624
	Total	286	525	414	624
8 Elbląg FBF	30	96	518	413	616
	50	96	520	475	585
	70	96	527	439	625
	Total	288	522	413	625
9 Mircze FBF	30	96	527	457	585
	50	96	542	444	617
	70	96	532	487	625
	Total	288	534	444	625
10 Bobolice FBF	30	95	507	407	569
	50	96	518	456	590
	70	96	533	490	586
	Total	287	519	407	590
11 Bobolice FMBF	30	90	519	459	576
	50	95	495	400	574
	70	95	532	432	593
	Total	280	515	400	593
12 Łobez FBF	30	87	477	404	562
	50	96	547	462	608
	70	96	561	504	634
	Total	279	530	404	634
13 Łobez FMBF	30	91	487	425	552
	50	96	511	469	565
	70	96	540	499	592
	Total	283	513	425	592

Table 1 continued.

Location – Forest district	Tree age	Number of samples (N)	Average	Minimum	Maximum
14 Lipinki FBF	30	89	501	427	565
	50	96	526	469	608
	70	96	536	490	611
	Total	281	521	427	611
15 Lipinki FMBF	30	95	501	405	558
	50	96	534	450	596
	70	96	551	489	603
	Total	287	528	405	603
16 Rudziniec FBF	30	96	500	447	601
	50	96	526	435	602
	70	96	537	504	589
	Total	288	521	435	602
17 Rudziniec FMBF	30	95	537	450	618
	50	96	526	423	606
	70	96	554	491	642
	Total	287	539	423	642
FBF		3352	528	404	652
FMBF		1425	529	400	642
Age 30		1571	513	404	647
Age 50		1583	529	400	652
Age 70		1623	542	432	642
Total		4777	528	400	652

FBF – fresh broadleaved forest
FMBF – fresh mixed broadleaved forest

The average values of basic density for the complete set of analysed data with respect to forest habitat types differed only slightly, amounting to 528 kg m^{-3} for the FBF habitat type and 529 kg m^{-3} for the FMBF habitat type. The basic density values were found to rise with increasing tree age: 513 kg m^{-3}, 529 kg m^{-3} and 542 kg m^{-3} for ages of 30, 50 and 70 years respectively.

The mean basic density of silver birch wood for the entire analysed material amounted to 528 kg m^{-3}. The lowest density of a single test sample determined in the analysed material was 400 kg m^{-3} (on FMBF) and the highest was 652 kg m^{-3} (on FBF). Both of these results concerned 50-year-old birch trees.

It was shown that the geographical location of the test plots and the age of the trees, as well as interactions between them, generated statistically significant differences in the studied material in terms of the average values of basic density of wood in the analysed groups (Table 2).

Table 2. Influence of location and tree age and the interaction of those properties on the basic density of wood (two-factor analysis of variance).

Source of variance	F empirical	p-value
Intercept	1148482	< 0.0001 *
Location	31	< 0.0001 *
Age	301	< 0.0001 *
Location-Age (interaction)	16	< 0.0001 *

* statistically significant at the 0.05 level

Table 3. Groups of homogeneous locations in terms of the mean values of basic density of wood.

Location	Mean	1	2	3	4	5	6
Płaska - FBF	512	****					
Łobez - FMBF	513	****					
Bobolice - FMBF	515	****	****				
Bobolice - FBF	519	****	****	****			
Rudziniec - FBF	521	****	****	****			
Lipinki - FBF	521	****	****	****			
Elbląg - FBF	522	****	****	****			
Górowo Iławeckie - FBF	525		****	****	****		
Lipinki - FMBF	528			****	****	****	
Giżycko - FBF	530			****	****	****	
Łobez - FBF	530			****	****	****	
Mircze - FBF	534				****	****	
Biała Podlaska - FBF	536					****	
Płońsk - FBF	538					****	****
Rudziniec - FMBF	539					****	****
Giżycko - FMBF	548						****
Sokołów - FBF	549						****

FBF – fresh broadleaved forest
FMBF – fresh mixed broadleaved forest

The columns of Table 3 show the groups of locations that did not display statistically significant differences in the values of basic density. Forest districts containing trees with the lowest mean basic density of wood, not differing significantly within the group, are Płaska (FBF), Łobez (FMBF), Bobolice (FMBF and FBF), Rudziniec (FBF), Lipinki (FBF) and Elbląg (FBF). The highest basic density values, shown in column 6, were found in the districts of Płońsk (FBF), Rudziniec (FMBF), Giżycko (FMBF) and Sokołów (FBF).

The comparison of basic density values between different tree ages showed statistically significant differences between all groups. The average values of basic density rise with increasing age.

Analysis of the dependence of the basic density of wood on the location of the test plots and tree age demonstrated the existence of homogeneous groups (Fig. 2).

In the forest districts of Płońsk, Płaska, Giżycko (FBF and FMBF habitats), Górowo Iławeckie, Elbląg, Bobolice, Łobez, Lipinki and Rudziniec (both studied forest habitat types) the highest mean basic density was recorded for the oldest trees (70 years). Among those listed, only in four cases – in the forest districts of Płaska, Giżycko (FBF), Bobolice (FMBF) and Rudziniec (FMBF) – was the mean basic density of wood from 30-year-old birch trees higher than that of wood from 50-year-old trees. In the remainder, the basic density rose with increasing tree age. The forest districts where the basic density of wood from 50-year-old trees was highest were Sokołów, Biała Podlaska and Mircze. Among these, in Sokołów district, the lowest mean basic density was recorded for the wood from 70-year-old trees, and in the districts of Biała Podlaska and Mircze for wood from 30-year-old trees. Birch wood from Sokołów and Elbląg districts had very similar mean values of basic density for all examined tree ages.

Analysis of the dependence of the basic density on the age of the trees, thickness class and interactions between these factors demonstrated that statistically significant differences exist between the average values of the analysed property (Table 4). Only in the case of the youngest trees was no link identified between the thickness class and the basic density of wood. The values of wood density differed with age, and in the oldest analysed trees, there were statistically significant differences between the average basic density values for the samples representing each thickness class. The statistics characterising the basic density of wood classified by thickness class and age

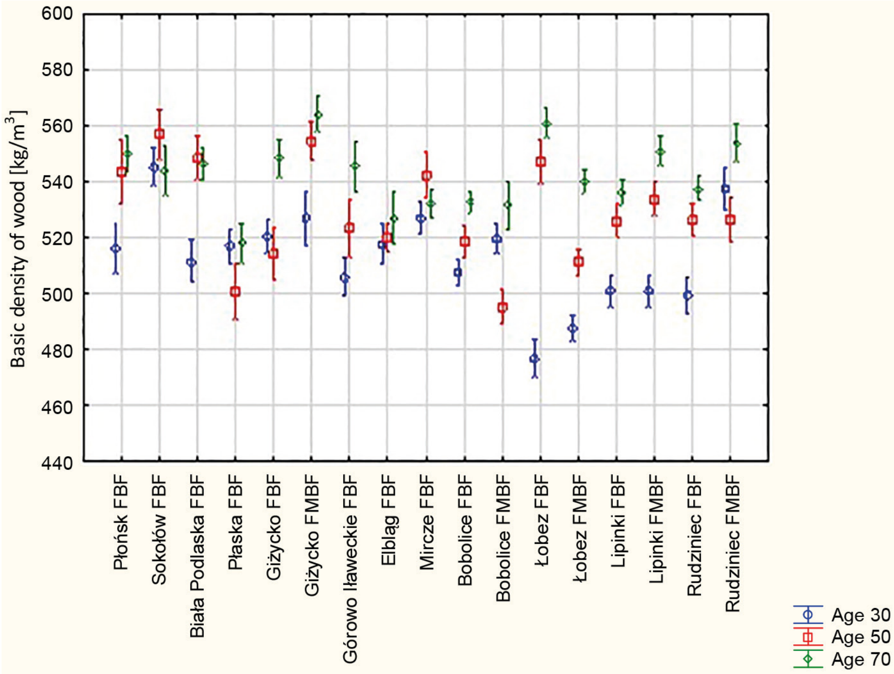

Fig. 2. Average values of basic density of wood and their standard errors, with respect to location and tree age.

Table 4. Influence of tree age and thickness class and the interaction of those properties on the basic density of wood (two-factor analysis of variance).

Source of variance	F empirical	p-value
Intercept	980706.861	< 0.0001 *
Age	252.457743	< 0.0001 *
Thickness class	12.4152923	< 0.0001 *
Age-Thickness class (interaction)	16.426154	< 0.0001 *

* statistically significant at the 0.05 level

Table 5. Properties of the basic density of wood for different tree age and thickness classes.

Age	Thickness class	Mean	Number of samples (N)
30	1	512	484
	2	513	544
	3	514	543
50	1	531	526
	2	521	523
	3	534	534
70	1	551	537
	2	541	544
	3	535	542
Total		528	4777

Table 6. Influence of location and the forest habitat type and the interaction of those properties on the basic density of wood (two-factor analysis of variance).

Source of variance	F empirical	p-value
Intercept	604983.0	< 0.0001 *
Location	30.0	< 0.0001 *
FHT	11.8	0.0006 *
Location-FHT (interaction)	24.6	< 0.0001 *

* statistically significant at the 0.05 level
FHT – forest habitat type

are shown in Table 5. The wood from trees aged 30 and 50 years had the highest mean basic density in the case of the thickest trees. In all three of the examined age classes the highest mean basic density of birch wood was found in the thinnest trees. Only for the 70-year-old trees did the value of the studied property diminish with an increase in tree thickness. In the case of 50-year-old birch trees, those of average thickness had lower mean basic density values.

In the forest districts where the properties of the wood of birch trees growing in FBF and FMBF habitats were studied, an analysis of the relation between the basic density of wood and the location of the test plots and forest habitat type was carried out. It was shown that both factors, as well as the interactions between them, generate statistically significant differences in the average values of density among the analysed groups (Table 6).

Relationships between the mean basic density of wood from different forest habitat types in individual forest districts are shown in Fig. 3. Statistically significant differences among the basic densities in the examined forest habitat types exist in the districts of Giżycko, Łobez and

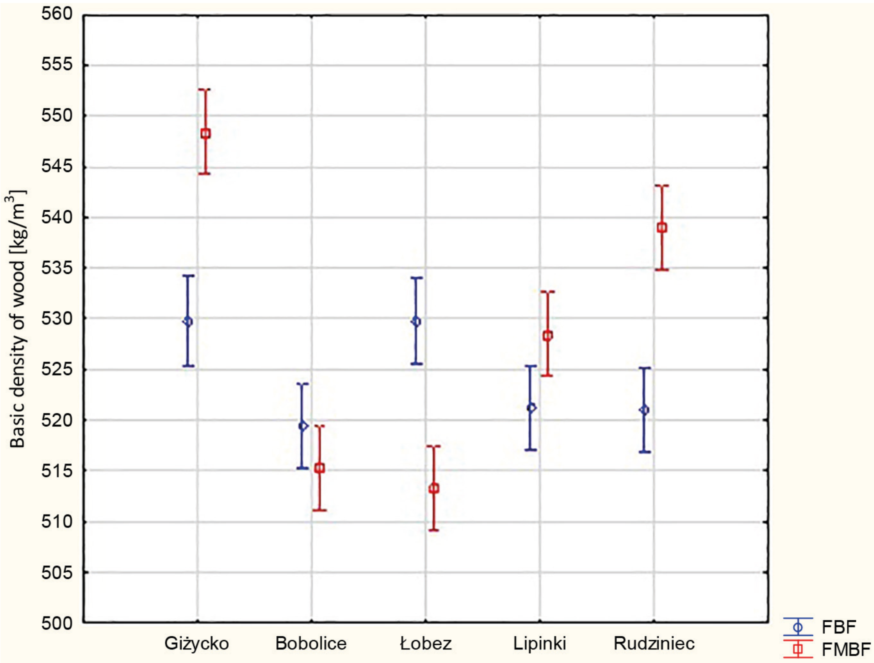

Fig. 3. Average values of basic density of wood from selected locations in different forest habitat types.

Rudziniec. A higher mean basic density of wood was determined in the samples originating from trees that grew in the FMBF habitat type in the districts of Giżycko, Lipinki and Rudziniec – here the density was lower in the more fertile FBF type habitats. In the Bobolice and Łobez districts, an opposite tendency was observed, with an increase in average values of wood density as the habitat's fertility improved from FMBF to FBF.

4 Discussion

According to Halińska-Raczkowska (1996) the basic density of birch wood ranges between 375 kg m^{-3} and 590 kg m^{-3}, with most values lying between 430 kg m^{-3} and 530 kg m^{-3}. The average value obtained in this study (528 kg m^{-3}) lies within this range. The minimum basic density for a single sample (400 kg m^{-3}) lies within the aforementioned wider range, whereas the maximum (652 kg m^{-3}) is much higher than the cited values. In another study by Halińska-Raczkowska and Fabisiak (1995) similar data are given, together with an average value of 480 kg m^{-3}.

Wood from locations throughout Poland, and from two forest habitat types, was studied. The wood selected for the study came from stands with similar taxonomic features. It is difficult to decide what factors cause the differences in the density of silver birch wood. Populations of birch with good technical quality can be found in various regions of Poland. This is confirmed by the results of experiments on population and stock variability in the growth features of that species, which indicate that birches are subject to a random distribution of population features, and stocks with the highest values of parameters for particular features can be found within any population, regardless of its origin. Groups of locations homogeneous in terms of average values of basic density are spread throughout the entire area of Poland and they do not follow any pattern in terms of geographical location. The location of forest stands has a considerable influence on the basic density of silver birch wood, as in the case of the density at 12% moisture content (Lachowicz 2010, 2015).

Knowledge on the variation in basic density at different locations both provides the State Forests organisation with marketing information concerning the quality of raw birch timber, and enables firms purchasing timber to select appropriate types for specific applications.

The average density values for the entire set of examined material rise significantly with increasing tree age. The highest average value of basic density for all samples was found in 70-year-old trees. The wood of silver birch reaches its highest quality at an age of 50–70 years, after which depreciation of the raw material occurs (Krzysik 1939). This phenomenon was considered in designing the methodology for this study; no samples were taken from older trees, where very often hard rot can be found. Tree age has a statistically significant influence on the basic density of silver birch wood, as it does on the average value of wood density at 12% moisture content (Lachowicz 2015). The interaction of location and tree age considerably influences both properties.

Forest habitat type and location, as well as the interaction between these properties, have a statistically significant influence on the average value of the studied property among the analysed groups. In three out of five forest districts where samples originating in both forest habitat types were examined, statistically significant differences were recorded between the basic density of wood from FBF and FMBF habitats. In the districts of Giżycko and Rudziniec, the silver birch wood from the more fertile forest habitat (FBF) had a lower density than that from the poorer habitat (FMBF). In a total of three districts the basic density increased as the fertility of the habitat declined.

The downward trend in oven-dry density and room temperature density of silver birch wood from the south to the north of Europe, observed by Trendelenburg and Mayer-Wegelin (1955), is also reflected in the results of studies concerning the basic density. In the studies carried out in

Finland by Bhat (1980) and Heräjärvi (2004) the average values of basic density of silver birch wood amounted to 483.3 kg m^{-3} and 512 kg m^{-3} respectively. Both values are lower than those obtained during this study (528 kg m^{-3}). Möttönen and Luostarinen (2006), comparing the basic density of birch wood along the trunk from plantations and from natural growing forest, reported the average values for the whole trunk to be 454.5 kg m^{-3} in the case of plantations and 507 kg m^{-3} in the case of natural forest. These values are lower than the lowest average value recorded in this study, for the FBF habitat in the forest district of Płaska (512 kg m^{-3}). According to the latest provenance trials, which compared, among other things, the basic density of wood from 22-year-old silver birch trees from the Baltic countries and Finland, the origin of seed has no influence on the basic density of wood (Viherä-Aarnio and Velling 2017). The average values of basic density of birch wood at a height of 1.3 m, in two samples, were 473 and 481 kg m^{-3}. Comparing earlier results with those obtained in this study, it is found that the average value of the basic density of birch wood of a similar age (30 years) amounted to 513 kg m^{-3}, which confirms the downward trend in density from the south to the north of Europe.

5 Conclusions

The following conclusions can be drawn from the analysis of the basic density of silver birch wood depending on the geographical location of the stands, the age of the trees, the tree thickness and the forest habitat type and the interactions between those factors:

1. The basic density of silver birch wood in Poland was found to be considerably influenced by the location, the tree age, the tree thickness and forest habitat type and by the interactions between those factors.
2. From the point of view of the cellulose, paper and hardboard industries, higher productivity can be obtained from the wood grown in Sokołów forest district on the FBF habitat type and in Giżycko district on the FMBF habitat type, where the highest average basic densities of birch wood were recorded.
3. Identification of the value of the basic density of silver birch wood depending on location, tree age, forest habitat type and tree thickness enables production firms to select and purchase appropriate types of timber.
4. The results obtained here suggest the carrying out of breeding selection tests on trees in the stands from which birch wood with high basic density was obtained.
5. The results obtained in this study, compared with the results of studies from northern Europe, mainly from Finland, support the hypothesis of a downward trend in density from the south to the north of Europe. However, to obtain full confirmation of this, studies of birch wood basic density should be extended to different regions of Europe.
6. It would be advantageous to study variation in the basic density of silver birch wood in less fertile forest habitat types, where higher densities may be expected.

Acknowledgements

This work was supported by the General Directorate of the State Forests in Poland [grant number EO-2717-13/13].

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