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STAND FACTORS AFFECTING THE WOOD DENSITY OF NATURALLY REGENERATED YOUNG SILVER BIRCH GROWING AT THE LOWER ALTITUDE OF THE CZECH REPUBLIC REGION

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ABSTRACT

The objective of this study was to investigate the basic wood density (ρ_k) of the silver birch (*Betula pendula* Roth.) trees in relation to the stand structure. This research was conducted in three stands of different structure and ages, located in the region of the lower part of the Jeseníky Mountains in the Czech Republic. In total, 71 healthy dominant silver birch trees were randomly selected. Two samples (cores) were taken per tree for performing the tree-ring width analysis and ρ_k determination. We found that the average ρ_k of the three examined stands ranged from 471.8 to 494.6 kg·m^{-3}. The older trees showed a high variation of the ρ_k. The age of the tree and stem diameter positively influenced the ρ_k. Nevertheless, it was noted that the slenderness ratio had a negative influence on the ρ_k. Overall, the prediction of wood density using stand and tree characteristics, even when the management history records are available, remains a complex hypothesis.

KEYWORDS: *Betula pendula* Roth., stem diameter at breast height, tree-ring width, tree age, crown area.

INTRODUCTION

Silver birch (*Betula pendula* Roth.) is naturally distributed in the Eurasian continent, widely expanding from the Atlantic to eastern Siberia (Hultèn and Fries 1986). The species is considered to be an essential ecological element of the northern temperate and boreal forests (Hynynen et al. 2010) and one of the most commercially preferred birch species in Europe. In Finland and Russia, birch is commonly used for plywood, commanding high prices. Furthermore, birch timber is efficiently used for particleboard production providing satisfying qualities, classified between the pine and spruce particleboards. In Europe and North America, the species is preferred for producing hardwood pulp of good quality (Krames and Krenn 1986, Cameron 1996). The option of wider utilisation of the silver birch or other pioneer species in forestry as a counterpart to the widespread dieback of the allochthonous spruce stands or the limited forest regeneration after disturbances, has been discussed several times (Huth and Wagner 2006, Tesař et al. 2011, Kulla and Sitková 2012). Nevertheless, the industrial utilisation of the species has been overshadowed by the common preference of its competitors, i.e. the spruce and pine trees in the western and central Europe (Lokvenc and Chroust 1987, Spiecker et al. 2004).

Birches are successional pioneer species, rapidly occupying open deforested areas (clear-cuttings, forest fires) or abandoned agricultural lands. Hence, they are competitively weak, light-demanding, and stress-tolerant trees with fast juvenile growth (Fischer et al. 2002, Koski and Rousi 2005, Hynynen et al. 2010). Silver birch can adjust and grow in nutrient-poor, dry or wet habitats which are normally too stressful for other broadleaved species (Perala and Alm 1990, Chytrý 2012). The key trait for achieving a vigorous growth is the moisture and air content efficiency of the soil. Therefore, silver birch thrives in sandy forest sites whereas clayey and silty soils are too compact for the species (Sutinen et al. 2002, Koski and Rousi 2005).

Birch is placed among the most important broadleaved species in forestry, due to straight, slender and highly productive trees, although the total volume yield is lower than other fast-growing species (Hynynen et al. 2010). Under optimal site conditions the birch reaches around 24–25 m in height, within 30 years whereas, the poorest sites keep the height increment rather modest, i.e. 6 m in 30 years (Eriksson et al. 1997). Repola et al. (2007) found that the tree-ring width was about 3–4 mm when birch grew in favourable conditions. In average sites, it has been estimated that approximately 70% of the total biomass of a mature birch tree is apportioned to the stem, approximately 10% to the crown (branches and leaves) and hence, the remaining 20% to the stump and coarse roots (Repola et al. 2007). Hynynen et al. (2010) reported that the development of both crown and stem was directly related to the stand density; birch crowns tended to become shorter when they grew in dense stands. Furthermore, the higher the stand density was, the smaller the stem diameter got, forming slender trees. Silver birch is a typical pioneer tree species with rapid early growth which appears to be sensitive to many environmental conditions. External parameters such as heavy soils, high groundwater level, shade and suppressive competition of grass or shrubs, retard the tree growth and spoil the stem form (Koski and Rousi 2005). On the other hand, the root system is often deep and intensive forming highly adaptive trees in their grown environment (Ostonen et al. 2007). The decomposition of dead roots is fast, and hence, favourable for soil porosity. The silver birch trees must be dominant in the stand, with a wide spacing and low competition to maintain their vitality and achieve vigorous growth. To ensure this, Hynynen (1993) suggested ca. 600 stems ha^{-1} with a mean diameter of 25 cm, as the maximum number of silver birch trees in a stand, while the corresponding stem number in a Norway spruce stand is ca. 1400 ha^{-1}. Within this frame, Cameron (1996) reported that the thinning of a silver birch stand should begin at around 8–10 m mean height, corresponding to ca. 15–25 years old (depending on the growth rate). Thinning accelerates the radial growth rate and thus the timber yield. Nevertheless, in the case of silver birch stands, fast diameter increment not necessarily impairs high wood quality (Heräjärvi 2004). Furthermore, the emphasis should be given on selecting and retaining dominants and co-dominants of good stem form (Hynynen et al. 2010).

The environmental advantages of the pioneer species are indisputable (Podrázský 1992, Ulbrichová et al. 2005). The current heightened interest lies in the successful combination of the economical exploitation (Stark et al. 2015), with significant competitive quality of the biomass production (Buriánek 1993, Walle et al. 2007). Under this prism, density (the mass of wood contained in a unit volume) is known to be one of the most important physical properties and a reliable quality indicator of wood (Hakkila 1966, Heräjärvi 2004, Repola 2006).

The basic density (ρ_k) of silver birch wood ranges from 450 to 610 kg·m^{-3} (Ferm 1993, Brezeziecki and Kienast 1994, Heräjärvi 2004, Kula 2011, Liepiņš and Rieksts-Riekstiņš 2013, Köster et al. 2015) and decreases from the bottom to the top of the tree, although the vertical variation within the single stem is small (Hakkila 1966). Age is considered to be a key factor; birch produces denser wood as the tree ages (Bhat 1980, Ferm 1993, Heräjärvi 2004). Mature silver birch shows relatively large radial density variations (40–80 kg·m^{-3}), exhibiting higher wood density compared to other ruderal species in Europe (Brezeziecki and Kienast 1994, Heräjärvi 2004).

Based on literature, the average density of wood can be influenced by a vast number of factors interacting together; tree species, geographical location, site quality and position of the tree in the stand, tree age and size, growth rate, genetic and environmental parameters (Hakkila 1966, Uusvaara 1974, Briffa et al. 2002, Stener and Hedenberg 2003, Repola 2006, Baliuckienė and Baliukas 2006, Liepiņš and Rieksts-Riekstiņš 2013). The aim of this study was: (i) to analyse the basic wood density (ρ_k) of naturally regenerated young silver birch (*Betula pendula* Roth.) trees growing in three different stands in the Czech Republic and (ii) to detect relationships between ρ_k and various dendrometric traits (stem diameter, crown area, age, tree-ring width, slenderness ratio).

MATERIALS AND METHODS

Site characteristics

For this research, we selected three naturally regenerated silver birch stands (Krnov; I, Krnov; II, Bruntál; III) in the region of the lower part of Sudety Mountains, Czech Republic (PLO 28 - Předhůří Hrubého Jeseník; Tab. 1). Three circular sampling areas (0.01 ha) were centrally established (one area per stand), to reduce the edge effect. We estimated the variability of the stands by anatomising their structure (mixture, composition, number of trees per ha, average stem diameter). Additionally, we measured the crown projection of all trees.

The long-term average temperature in this region is about 7.5°C and the annual precipitation reaches up to 700 mm. The vegetation is classified as (Eu-fagenion) herb-rich beech woodland (Neuhäuslová et al. 1998).

Sample collection and preparation

In total, 71 healthy dominant silver birch trees were randomly selected. The stem diameter at breast height (DBH) and total tree heights were measured. Two wood cores were obtained per stem by using the Pressler increment borer, to be used for the tree-ring width analysis and ρ_k determination (Přemyslovská et al. 2008).

Tab. 1: Structure of the three studied stands.

Stand	Tree species	Number of trees (trees ha^{-1})	Species composition (%)	Mean DBH (cm)	Basal area at breast height (m^2 ha^{-1})	Species composition (%)
I	Birch	1976	53.15	10.02±3.52	17.41	84.74
	Sessile oak	233	6.32	4.26±1.02	0.35	1.71
	Mountain ash	333	9.01	4.01±1.03	0.45	2.19
	Large-leaved linden	900	24.32	4.02±2.35	1.53	7.45
	Willow	33	0.90	6.33	0.11	0.51
	Sycamore maple	33	0.90	2.55	0.02	0.08
	European beech	167	4.50	6.96±1.17	0.65	3.18
	Small-leaved linden	33	0.90	3.34	0.03	0.14
	Total	**3699**	**100.00**	**7.35±4.07**	**20.55**	**100.00**
II	Birch	1267	58.46	15.95±4.34	27.18	83.32
	Large-leaved linden	33	1.54	11.94	0.37	1.14
	Sessile oak	167	7.69	7.23±2.62	0.77	2.37
	Mountain ash	667	30.77	6.86±5.61	4.11	12.60
	Wild cherry	33	1.54	8.34	0.18	0.56
	Total	**2167**	**100.00**	**12.30±6.35**	**32.62**	**100.00**
III	Birch	1033	86.10	20.32±8.35	39.16	90.63
	Norway maple	33	2.78	3.63	0.03	0.08
	Sycamore maple	67	5.56	6.27±0.54	0.21	0.48
	European aspen	33	2.78	37.56	3.69	8.55
	Willow	33	2.78	6.62	0.11	0.27
	Total	**1199**	**100.00**	**19.17±9.53**	**43.21**	**100.00**

Measurements and data processing

The average age of the studied trees was calculated based on the number of tree-rings at breast height. The tree-ring width was measured by using the TimeTable measuring meaning device and the stereomicroscope Leica S6D (Leica Microsystems, Germany).

The stem slenderness ratio (SR) as a dimensionless value was calculated per tree as:

$$SR = \frac{H}{DBH} \qquad (1)$$

where: SR - slenderness ratio, H - tree height (m) and DBH - diameter at breast height (cm); (Liepiņš and Rieksts-Riekstiņš 2013, Oyebade et al. 2015).

Greater values of SR generally indicate taller and slender trees, probably facing issues of stability when the values exceed 100 (Adeyemi and Adesoye 2016). Optimal values indicating excellent stability for forest trees were found to be below 80 (Šmudla 2004, Adeyemi and Adesoye 2016).

The ρ_k was determined by using the Olesen method (1971). The stem cores were divided into smaller parts and soaked into distilled water to increase the moisture content over the fibre saturation point. Subsequently, the core parts were immersed into distilled water (beaker) which was placed on a laboratory scale (Scaltec SBC 41 (Scaltec, Germany) with an accuracy of 0.001 g. The displaced water volume equals the volume of the immersed core part, ascertained by weighing. To determine the weight of a core section at oven-dry moisture content, the cores were dried in a laboratory oven InuCell 22 (InuCell, Germany) at 105°C according to Dirnberger et al. (2017) and Černý et al. (2019).

The ρ_k is the value which denotes the oven-dried weight (0% moisture content) in relation with the maximum volume, i.e. at moisture content over the fibre saturation point, calculated as:

$$\rho_k = \frac{m_0}{V_{max}} \quad (\mathrm{kg \cdot m^{-3}}) \qquad (2)$$

where: ρ_k - basic wood density,
m_0 - mass of the wood at oven-dry moisture content,
V_{max} - volume of wood above the saturation point.

Finally, it was calculated as a weighted arithmetic mean value of the particular sections according to their proportion within the cross section (Ericson 1959).

Bartlett test, Kruskal-Wallis test, Student's t-test, Shapiro-Wilk test, and Spearman's correlations were used for the analysis of the data. The calculations and analyses were performed in the R® software, version 3.3.3 (R Core Team 2015) and LibreOffice Calc®, version 4.0.1 (The Document Foundation, WA, USA). The significance level was α = 0.05 throughout the study.

RESULTS AND DISCUSSION

The density of the first stand (I) was 3699 trees ha^{-1}, composed mainly of silver birch (around 53%) and large-leaved linden (around 24%) trees. The stand II was almost half dense (2167 trees ha^{-1}) in relation with the stand I and was mainly composed of silver birch (around 58%) and mountain ash (around 31%) trees. The sample stand III was the least dense (1199 trees·ha^{-1}) in comparison with the rest of the two examined stands (I and II) and almost exclusively composed of silver birch (86%).

Tree-rings

The average age at breast height of the silver birch trees was found to be different among the sample stands (Tab. 2). They were quite young in the first two stands (I: 17.8 and II: 22.1 years old), while the trees growing in the third stand were quite older (III: 35.1 years old). Nevertheless, the mean tree-ring width of the silver birch trees was wider in the second stand (II: 3.07 mm).

Tab. 2: Tree-ring widths (TRW) per sample stands.

Stand	Number of sample trees (trees·ha^{-1})	Average age of trees (years)	TRW (mm)			
			Mean	Median	Standard deviation	Coefficient of variation (%)
I	25	17.8	2.85	2.82	0.69	24.3
II	20	22.1	2.96	2.87	0.53	18.0
III	26	35.1	2.38	2.31	0.59	24.8

Stem Slenderness Ratio (SR)

The average tree height and DBH differed among the sampled stands (Tab. 3, Tab. 4, Fig. 1). The stand III presented the higher radial DBH variation in comparison with the other stands (I and II). The variances of DBH were found unequal among the stands (Bartlett test of homogeneity of variances). Hence, the Kruskal-Wallis test was used instead of parametric ANOVA. Pairwise comparisons (t-tests) confirmed the difference (Fig. 1). The silver birch trees growing in the stand I were found to be the slenderest, as depicted by the higher stem SR (Tab. 4).

Tab. 3: Tree height (H) and stem diameter at breast height (DBH) per sample stands.

Stand	Tree height (m)			DBH (cm)		
	Mean	Standard deviation	Coefficient of variation (%)	Mean	Standard deviation	Coefficient of variation (%)
I	13.67	2.34	17.1	12.31	3.20	26.7
II	17.82	3.48	19.5	16.86	4.22	25.0
III	20.52	4.15	20.2	21.96	7.09	32.3

Tab. 4: Stem slenderness ratio (SR) per sample stands.

Stand	Slenderness ratio			
	Mean	Median	Standard deviation	Coefficient of variation (%)
I	1.18	1.12	0.37	31.0
II	1.06	1.05	0.20	19.0
III	0.99	0.96	0.21	21.5

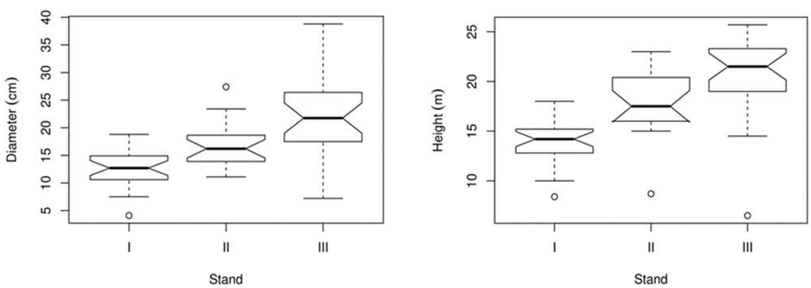

Fig. 1: Boxplots with notches of tree height (H) and diameter at breast height (DBH).

Basic wood density (ρ_k)

The Shapiro-Wilk test proved that the ρ_k data obtained from all three sampled stands were normally distributed. The highest mean value of ρ_k (512.7 kg·m^{-3}) was detected in stand II (Tab. 5, Fig. 2) while the lowest ρ_k (482.9 kg·m^{-3}) was found to be at the stand I. The stand III showed the highest variation in ρ_k; i.e., almost twice as high in comparison with the rest of the stands.

The variances of ρ_k were unequal (Bartlett test of homogeneity of variances). Hence, we used the non-parametric Kruskal-Wallis test instead of ANOVA to compare means among the sample stands. The pairwise comparisons (t-tests with non-pooled standard deviation) revealed the difference in means between stand I and II as depicted in the boxplot.

Tab. 5: Basic wood density (kg·m⁻³).

Stands	Minimum	Median	Mean	Maximum	Coefficient of variation (%)
I	449.2	485.2	482.9	513.7	4.2
II	476.9	507.4	512.7	560.8	4.4
III	413.7	496.4	500.5	564.7	9.2

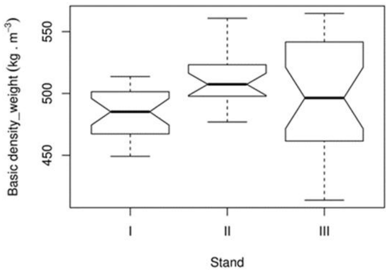

Fig. 2: Boxplot with notches of basic wood density.

Relationships of structural variables and basic wood density

Spearman's correlation analysis revealed significant relationships between ρ_k and several dendrometric traits (Tab. 6). Namely, we found significant positive correlations between the age and ρ_k, the DBH and ρ_k, the DBH and age, as well as the crown area and age. We also detected a negative correlation was found between SR and ρ_k. The SR was also negatively affected by the age, the tree-ring width and the crown area of the mature silver birch trees (Stand III). In all studied sample stands, the DBH was positively correlated with the crown area.

*Tab. 6: Spearman's correlation coefficients. Significant codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '•' 0.1.*

Stand	Parameters	Density	Age	TRW	DBH	Crown area	Height
I	**Age**	0.13					
	TRW	-0.19	-0.20				
	DBH	-0.26	-0.06	0.87 ***			
	Crown area	0.11	-0.06	0.58 ***	0.65 ***		
	Height	-0.54**	0.24	0.24	0.52**	0.01	
	Slenderness	0.07	0.15	-0.71***	-0.79***	-0.62***	-0.05
II	**Age**	-0.26					
	TRW	0.22	-0.01				
	DBH	-0.09	0.43•	0.71 ***			
	Crown area	-0.05	0.39	0.45•	0.59 **		
	Height	-0.39	0.60**	0.37	0.66***	0.05	
	Slenderness	-0.35	-0.03	-0.44•	-0.49*	-0.71***	0.31
III	**Age**	0.48 **					
	TRW	0.26	0.22				
	DBH	0.48 **	0.68 ***	0.80 ***			
	Crown area	0.17	0.54 **	0.53 **	0.55 ***		
	Height	0.26	0.57***	0.67***	0.80***	0.38•	
	Slenderness	-0.49**	-0.65***	-0.56***	-0.73***	-0.62***	-0.24

Silver birch trees dominated in all examined stands. The stand I consisted of silver birch mixed mostly with large-leaved linden trees, forming a very dense forest. The silver birch trees were young with small DBH. In the stand II, the species was in mixture with mountain ash trees. The forest was less dense and the silver birch trees were quite older with larger DBH. Finally, the stand III was dominated by mature silver birch trees in a less dense forest.

Bonham and Barnett (2001) reported that juvenile wood in silver birch stem is located from the pith to 10–15th tree-ring. Thus, it is clear that the stem volume of silver birch trees in our stands was formed by juvenile wood, except stand III where the juvenile wood proportion was approximately 30%.

The average ρ_k in the three examined stands ranged between 482.9 and 512.7 kg·m^{-3}, which was in line with the literature (Ferm 1993, Brezeziecki and Kienast 1994, Heräjärvi 2004, Kula 2011). Nevertheless, Liepiņš and Rieksts-Riekstiņš (2013) reported that the average ρ_k of young silver birch trees (11 to 15-year-old growing in former agriculture fields in Latvia), was 454.8 kg·m^{-3}. This was quite lower in comparison with the young trees in our study (stand I), probably due to juvenile wood or different altitude of the growing sites. The Latvian sites were situated in the lowlands (altitude bellow 150 m a.s.l) while our stands were located in the highlands of the Czech Republic (400 to 600 m a.s.l.). The ρ_k of silver birch growing in hemi boreal forests in Estonia (466.6 kg·m^{-3}) reported by Köster et al. (2015) was also lower than our findings.

Based on the literature, we acknowledged also the age as another key factor; birch produces denser wood as the tree ages. Our results did not resonate well with this; the average ρ_k of the 35-year-old silver birch was found to be lower. It should be underlined thought, that in the stand III (older silver birch trees), the variation of ρ_k was high, confirming a previous report (Heräjärvi 2004).

In our study, the highest value of mean tree-ring widths was 3.07 mm (the stand II), lower than the tree-ring width determined by Liepiņš and Rieksts-Riekstiņš (2013) in Latvia (5.79 mm). Bhat and Karkkainen (1980) reported that the ρ_k of mountain birch (*Betula tortuosa*) growing in mountainous areas, was on average 520.0 kg·m^{-3} (s = 27.2) with average tree-ring width 0.7 mm. Silver birch trees in our stands had lower ρ_k and bigger tree-ring widths (the lowest mean value 2.85 mm was detected in the stand I).

Detecting the relationships connecting the stem features with the ρ_k particularly in the mature silver birch (stand III) we significantly correlated tree age with ρ_k with a positive influence. Our results showed that ρ_k increased in older trees. This is consistent with results reported in previous research (Hakkila 1979, Bhat 1980, Liepiņš and Rieksts-Riekstiņš 2013). The relationship between ρ_k and tree age suggests that the stem wood of the silver birch in our study will continue to increase. Additionally, we strongly connected the age of the trees with DBH and crown area. A previous study on silver birch, reported that ρ_k was positively correlated with the age, SR, and height of the trees (Liepiņš and Rieksts-Riekstiņš 2013). Our findings were relatively in line with this, because we detected that the SR negatively affected the ρ_k in our mature, less dense stand. All examined stands in our study, resulted in high SR indicating that the stands were not in proper condition to withstand heavy winds (Adeyemi and Adesoye 2016). According to our correlation analysis, this affected the density and hence the quality of the wood. Therefore, we recognized that the number of trees in our stands was over the limit and the stands were highly dense. By this token, it is more likely that the structure of the examined stands negatively affected the stem growth of the silver trees. Aosaar et al. (2011) reported no dependency between DBH and wood density in Grey alder, while Heräjärvi (2004) stated no dependency on ρ_k and growth rate in silver birch. However, Liepiņš and Rieksts-Riekstiņš (2013) reported that trees with higher radial growth rate tended to have lower wood density, as demonstrated by the negative correlation between density and tree-ring width.

CONCLUSIONS

In this study, we found that that the age of the silver birches influenced positively the ρ_k. The silver birch trees growing in the examined stands had wider tree rings, low ρ_k, yet a high variation of values. Additionally, we found that all examined trees presented high SR, which had a significantly negative impact on the ρ_k, mostly of the mature ones growing in stand III. Since the high SR indicates taller and slender trees with stability issues, we concluded that the quality of our stands needs to be improved. Nevertheless, it remains difficult to predict wood density using stand and tree characteristics, even when the management history records are available.

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