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Basic density of Scots pine wood – relationships between values calculated at different heights of the trunk

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Abstract: *Basic density of Scots pine wood – relationships between values calculated at different heights of the trunk.* The aim of this study was to analyse relationships between basic density of wood determined at different heights on the trunks of Scots pines, particularly between breast height and other parts of the stem. Analyses were conducted on material from 63 sample trees from Central Pomerania (northern Poland). Five samples were collected from the trunk of each mean sample tree. Each sample was located at a different height (level). The first came from the breast height level, while the second and the successive ones were denoted with relative values, i.e. 20 (SII), 40 (SIII), 60 (SIII) and 80% (SV) tree height. It was found among other things that basic density decreased with a reduction of distance from the tree top. The dynamic of these changes was particularly evident in the butt end of the trunk. Linear dependencies, confirmed by high linear correlation coefficients, were found between wood density at breast height and in other parts of the stem. Values of linear correlation coefficients and coefficients of determination decreased with an increase in the distance between breast height and the section. Breast height provides a representative cross-section of the stem. Basic wood density determined at this level may be used to model density in other parts of the stem.

Keywords: heterogeneity of wood, axial variation, breast height diameter

INTRODUCTION

Wood tissue varies greatly in terms of its characteristics and properties. At different structural levels (macrostructure, submicroscopic and chemical levels) primary differences are observed between early and late wood and between juvenile and mature wood [Moliński, Krauss 2008]. Apart from radial differentiation axial (longitudinal) variability may also be specific [Jyske et al. 2008; Tomczak 2008]. In order to determine the value of a selected trait or property which would be average for the entire stem a series of laboratory analyses may be conducted or modeling may be performed based on selected traits (variables).

Modeling of wood tissue properties is frequently performed on the basis of morphological traits of trees [Wilhelmsson et al. 2002] or macrostructural characteristics of wood [Bouriaud et al. 2004; Gardiner et al. 2011]. Sometimes prediction is based on the assumption that an interdependence exists within one trait or property. Such a situation is observed particularly when the breast height level is adopted as the reference level for the entire stem or its section. Among others Pazdrowski [1992] showed that there are dependencies between density at breast height and density in different parts of a 5-meter bole and that these effects are very significant. Similar conclusions in relation to Norway spruce were presented by Pavlovičs et al. [2010].

Breast height diameter, i.e. a diameter measured at a height of 130 cm from the tree base, is considered to be a representative part of the trunk. Most wood properties are tested at this level. At the assumption of its representative character we may thus assume that there is a relationship between wood density at breast height and wood density in other parts of the stem.

MATERIAL AND METHODS

Analyses were conducted on the material from 63 sample trees coming from seven sites located in northern Poland (the Regional Directorate of the State Forests in Szczecinek; Forests Disticts of Czaplinek, Czarnobór, Łupawa, Miastko (2 sites), Świdwin, Warcino).

Stand age ranged from 82 to 89 years, average breast height diameter ranged between 24 and 27 cm, while height - between 31 and 37 m. The other characteristics of stands were as follows: quality class I, broken crown closure, forest site type – fresh mixed coniferous forest.

Five samples were collected from the trunk of each sample tree. Each sample was collected from a different height (level). The first came from the breast height level, while the second and the successive ones were denoted with relative values, i.e. 20 (SII), 40 (SIII), 60 (SIII) and 80% (SV) tree height.

Samples for basic wood density testing were collected at each level. The analyses were conducted on two opposite radiuses – eastern and western. Samples covered the part of the trunk located between the pith and the circumference. Basic density is a ratio of over-dry wood mass green volume. Sample weight after drying was determined accurate to 0.001 g. Threshold moisture content of membranes was obtained by immersion of samples in water until they reached dimensional stability, i.e. till the moment when the increment in individual dimensions of the sample measured at a 72-hour interval is max. 0.2 mm (PN-D-04101:1979).

Statistical calculations were performed using the Statistica application. Tested traits did not have a normal distribution and for this reason non-parametric tests were used in the analyses.

RESULTS

At breast height (section I) basic wood density was 485 kg/m^3. Density decreased with an increase in the distance from breast height. At the level of section II density was lower than at breast height by 45 kg/m^3, at the level of section III it was by 82 kg/m^3, at level IV by 102 kg/m^3 and at level V it was by 92 kg/m^3. Recorded differences were statistically significant ($p<0,01$) (tab. 1). Basic wood density at all measurement levels correlated with that from breast height, while the correlation coefficient decreased with an increase in the distance between sections (tab. 2).

Tab. 1 Statistical characteristic of basic wood density of pine in sections

section	**average [kg/m^3]**	**n**	**standard deviation**	**min**	**max**	**Q25**	**mediana**	**Q75**
SI ($d_{1,3}$)	485	548	58	281	748	450	482	521
SII	440	473	59	299	792	404	437	475
SIII	403	406	47	298	625	374	401	432
SIV	383	303	39	268	564	357	379	405
SV	393	172	57	300	648	357	384	410

Tab. 2 Linear correlation coefficients (r) between values of basic wood density determined at different heights of the trunk in Scots pine

section	**SI**	**SII**	**SIII**	**SIV**	**SV**
SI ($d_{1,3}$)	---				
SII	**0,703437**	---			
SIII	**0,580069**	**0,697341**	---		
SIV	**0,530386**	**0,462750**	**0,763489**	---	
SV	**0,387774**	**0,360989**	**0,471575**	**0,408502**	---

Marked effects are significant with $p<0,01$

An analogous trend of changes was found for the coefficient of determination R^2. Its value decreased with an increase in the distance between sections, from the value of 0,359 (the coefficient between $d_{1.3}$ and section II) to 0,067 (the coefficient between $d_{1.3}$ and section V). Trend lines illustrating relationships between density at breast height and the other levels are almost parallel to one another (Fig. 1). Linear correlation coefficients are positive, thus a greater wood density at breast height will indicate a greater wood density in the other parts of the trunk.

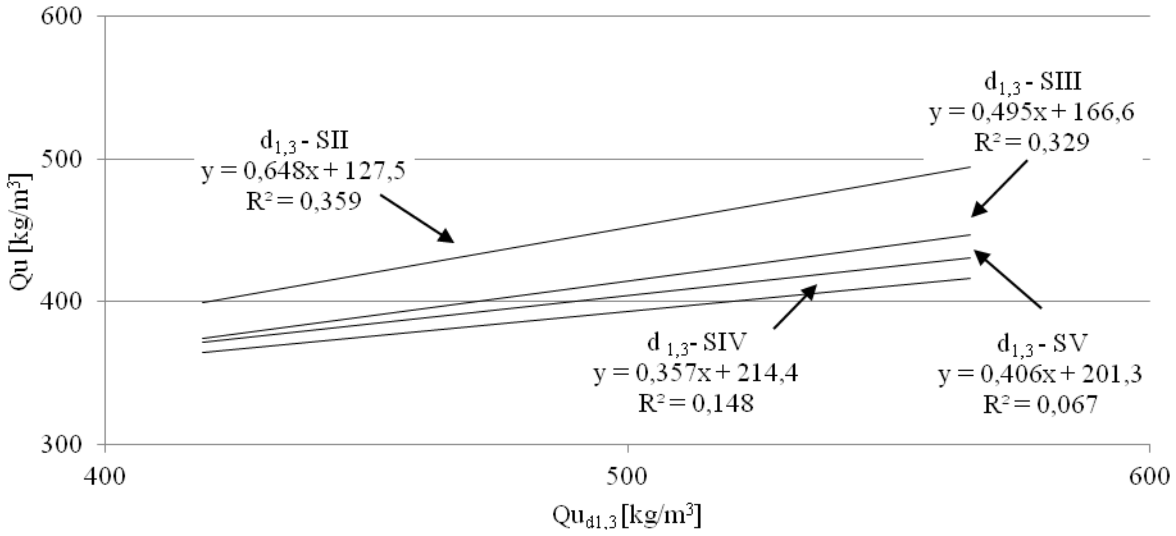

Fig. 1 Relationships between basic density of wood at breast height and basic density recorded at different heights of the trunk

DISCUSSION

Basic wood density in Scots pine decreased with a reduction of the distance from the tree top. The dynamic of these changes was particularly evident in the butt end of the stem. Between sections I (breast height) and III (40% tree height) basic density decreased by approx. 80 kg/m^3. In the tree top section the difference between sections III and V (80% tree height) was 10 kg/m^3. The lower part of the stem, in contrast to the tree top section, was characterised by statistically significant differences. Changes observed at the stem profile are typical of Scots pine [Helińska-Raczkowska, Fabisiak 1992; Repola 2006; Witkowska, Lachowicz 2013]. However, in the model proposed by Repol [2006] we may observe that wood density shows a constant decrease in values depending on the distance from the stem base, in contrast to the situation between sections IV and V, where basic wood density increased by 10 kg/m^3.

A linear dependence, confirmed by high linear correlation coefficients, was observed between wood density at breast height and the other parts of the trunk. The highest Pearson's linear correlation coefficient was found for the relationship between sections I (breast height) and II (20% tree height). The value of the coefficient decreased with an increase in the distance between breast height and a given section. The coefficient of determination (R^2) decreased analogously. This means that wood density may be influenced by a greater number of factors (variables), most frequently external, such as forest site type, social class of tree position in the stand or geographical location [Arnold, Mauseth 1999; Wiemann, Williamson 2002; Lachowicz 2011]. Variability in wood is also significantly influenced by cambial age [Grekin, Verkasalo 2010, Tomczak, Jelonek 2013]. The youngest, tree top part of the stem is composed of juvenile wood, having different properties than mature wood (mainly the lower part of the trunk) [Tomczak et al. 2010; Gryc et al. 2011; Tomczak, Jelonek 2012]. Juvenile wood comprises from several to around a dozen annual rings located at the pith, while mature wood in the form of a ring surrounds juvenile wood. At the stem profile mature wood is found to a certain tree height level. The range of its occurrence is markedly connected with the width of live crown and to a lesser degree with its length [Tomczak et al. 2007]. Morphological traits of trees may thus be the next variables, on the basis of which we may describe the structure and properties of wood. In contrast, Wąsik [2010] and Jelonek [2013] found no relationship between basic wood density and morphological traits of trees. However, we need to stress the fact that the study by Wąsik [2010] referred solely to the breast height level and the results reported by Jelonek [2013] were mean values for three measurement levels (breast height, at mid-length of pruned stem, from the base of live crown).

Wood functionality is based on the assumption of a balance between mechanical and physiological properties. In the model on the basis of which average density of the entire trunk may be estimated, density at breast height will constitute one of the variables. Precise estimation has to be based on other traits such as e.g. cambial age or morphological traits of trees. This pertains particularly to the parts located at the greatest distance from breast height.

CONCLUSIONS

1. Linear dependencies, confirmed by high linear correlation coefficients, are found between wood density at breast height and the other parts of the stem. Values of linear correlation coefficients and coefficients of determination decreased with an increase in the distance between breast height and a given section.
2. Breast height diameter is a representative cross section of the stem. Basic wood density determined at this level may be used to model density in other parts of the stem.

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Streszczenie: *Gęstość umowna drewna sosny zwyczajnej (Pinus sylvestris L.) – związki pomiędzy wartościami określonymi na różnych wysokościach pnia.* Celem pracy była analiza związków między gęstością umowną drewna określoną na różnych wysokościach pnia sosny zwyczajnej, a w szczególności między pierśnicą i innymi częściami strzały. Badania zostały przeprowadzone na materiale z 63 drzew modelowych, z regionu Środkowego Pomorza (północna Polska). Z pnia każdego drzewa modelowego pobrano pięć prób. Każda próba położona była na innej wysokości (poziomie). Pierwsza pochodziła z poziomu pierśnicy, drugą i kolejne wyznaczono wartością względną – 20 (SII), 40 (SIII), 60 (SIII), 80% (SV) wysokości drzewa. Stwierdzono między innymi, że gęstość umowna malała wraz ze spadkiem odległości od wierzchołka drzewa. Dynamika tych zmian była szczególnie widoczna w odziomkowej części pnia. Między gęstością drewna na poziomie pierśnicy i innymi częściami pnia stwierdzono zależności prostoliniowe potwierdzone wysokimi współczynnikami korelacji liniowej. W miarę wzrostu odległości między pierśnicą a sekcją wartości współczynników korelacji liniowej oraz determinacji malały. Pierśnica jest reprezentatywnym przekrojem poprzecznym pnia. Gęstość umowna drewna określona na tym poziomie może być wykorzystana do modelowania gęstości w innych częściach pnia.

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