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AXIAL AND RADIAL VARIATION OF SAPWOOD AND HEARTWOOD IN STEMS OF COMMON OAK (*QUERCUS ROBUR* L.) AND SELECTED BIOMETRIC TRAITS OF TREES AND SITE FERTILITY

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Abstract. The study is an attempt to determine variation in the proportions of sapwood and heartwood in the radial and axial sections in stems of common oak (*Quercus robur* L.), representing the main tree stand (according to Kraft biosocial classification), age classes V (81-100 years) and VI (101-120 years), growing in the fresh mixed forest and fresh forest sites. Sample trees were selected according to Urich I method from four plots (of 1 ha each). For each model tree its crown projection area was determined. After felling all necessary biometric traits of tree stem and live crown were measured. Stems were divided into 2-metre sections, from which centres discs were cut in order to determine selected wood macrostructure parameters and volumes of sapwood rings and heartwood cylinders. Additional discs were cut from breast height and kerf planes of trees. When analyzing results for individual discs and trees arithmetic means of widths (or volumes) of studied wood zones were used. During the study the irregularities were determined of sapwood and heartwood zones in stems. Strong and plus interrelations were found between crown volume and crown projection area (as area of cylinder external surface) and sapwood area at the cross stem section, although some of the correlation coefficients were not significant. Large variation was observed in the proportions of volumes of sapwood and heartwood in individual Kraft's biosocial classes. Differences were also found in sapwood and heartwood radial share between age classes, and rather small differences between forest site types.

Key words: site conditions, fresh mixed forest, fresh forest, Kraft's classification of tree position in the stand, timber, raw wood material

INTRODUCTION

Wood still ranks the fifth commodity in terms of its importance in global trade. It is also likely that in the future the dynamically developing pulp and chemical industry

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may replace many branches of petrochemical industry. For these reasons appropriate utilization of wood is of great importance for the entire contemporary civilisation [Plomion et al. 2001].

Specific characteristics of sapwood and heartwood zones, depending on the tree species and potential utilization of wood, may be considered either positive or negative. This is connected with the characteristic feature of sapwood, which is its higher permeability and lower stability than those of heartwood [Krzysik 1978]. For example, in Douglas-fir (*Pseudotsuga menziesi* (Mirb.) Franco), some extractives (primarily dihydroquercetin) give the heartwood moderate durability (in this species), but can cause problems in the pulping process [Dellus et al. 1997, from Taylor 2003]. Thus, knowledge on the proportions of individual types of wood in the stem is of considerable importance both for the producer and its customer [Pazdrowski 1992].

With regards to wood technological properties, the quantity of heartwood determines the quality of log [Berthier et al. 2001]. The relative amount of sapwood and heartwood in a tree is variable and is related to factors such as species, age, rate of growth and site [Hillis 1987, from Bergström et al. 2004].

Recent research carried out by Berthier et al. [2001] suggests that heartwood forms as a response to a hydraulic stimulus and that heartwood can even develop irregularly, both radially and longitudinally in the trunk, to maintain a constant and optimal proportion of sapwood in the tree stem.

According to the “pipe-model theory” [Shinozaki et al. 1964, after Bergström et al. 2004], a given unit of conducting tissue (sapwood) is necessary to supply water to a given unit of transpiring foliage. This relationship was established for many coniferous species [Whitehead 1978, Albrektson 1984, Kaufmann and Troendle 1981, Whitehead et al. 1984, from Bergström et al. 2004]. The relationship between sapwood and heartwood is relatively constant within the homogeneous stand of a species, but it has been found to vary with growing conditions and position in the stem [Whitehead 1978, Albrektson 1984, both from Bergström et al. 2004]. As it was stated by Taylor at al. [2002, 2003], the effect of environmental factors on extractive formation during the conversion of sapwood to heartwood are unknown.

Aim of the paper: The study is an attempt to determine variation in the proportions of sapwood and heartwood in the radial and axial sections in stems of common oak (*Quercus robur* L.), representing age classes V (81-100 years old) and VI (101-120 years old), growing in the fresh mixed forest and fresh forest sites covered usually in conditions of polish lowland by phytocenosis stated by Matuszkiewicz [2007] as: in conditions of fresh mixed forest site mainly *Galio silvatici-Carpinetum* and *Luzulo pilosae-Fagetum* and *Potentilio albae-Quercetum*, sometimes *Calamagrostio arundinaceae*. In the conditions of fresh forest site the same study stated that typically is covered by *Galio silvatici-Carpinetum* and *Galio odorati-Fagetum*, sometimes *Calamagrostio arundinaceae* too.

Variation in the proportions of volume of heartwood and sapwood zones was analysed, as well as variation in proportion of the share on the radius of the tree stem. When analysing the above mentioned problems it was attempted to find factors causing irregularity in the formation of sapwood and heartwood zones in stems of trees representing analysed populations. Moreover, it was also attempted in this study to determine interdependencies between selected biometric crown characteristics and the area of the sapwood zone at cross stem section.

Investigated relationships were analysed in reference to Kraft’s social classes of tree position in the stand, in relation to age classes and forest site types.

MATERIALS AND METHODS

Experimental material consisted of wood of common oak (*Quercus robur* L.) growing in fresh mixed forest and fresh forest sites in the Łopuchówko Forest Division, belonging to the Regional Directorate of the State Forests in Poznań.

In the course of works on the identification of phytocenosis of the Polish lowland (including Łopuchówko Forest District) was stated that in conditions of fresh mixed forest site appearing mainly *Galio silvatici-Carpinetum* and *Luzulo pilosae-Fagetum* and *Potentilio albae-Quercetum*, sometimes *Calamagrostio arundinaceae*. In the conditions of fresh forest site the same study stated that typically is covered by *Galio silvatici-Carpinetum* and *Galio odorati-Fagetum*, sometimes *Calamagrostio arundinaceae* too [Matuszkiewicz 2007].

Investigations were conducted in stands of age classes V (81-100 years) and VI (101-120 years) – according to the forest management plan, in which oak was found as the main tree species. The proportion of oak in the species composition ranged from 8 to 10, with an admixture of such tree species as common beech, hornbeam, silver birch, Norway maple, plane-tree maple, black alder, aspen, common ash, mazzard, Scots pine, European larch and Norway spruce.

In the four selected sample plots (of 1 ha each) breast height diameters were measured on all trees, while heights were measured in proportions to their percentage, and they were listed in terms of 2-cm diameter subclasses. Based on the obtained height and diameter characteristics a total of 12 model trees were selected (three per each sample plot), using the Urich I method [Grochowski 1973]. Sample trees representing wide population, as shows Table 1.

Table 1. Number of trees in sample plots
Tabela 1. Liczba drzew na powierzchniach próbnych

Forest site type Siedliskowy typ lasu	Age class Klasa wieku	Total number of oak trees Liczba drzew dębu	Number of sample trees Liczba drzew próbnych
Fresh forest Las świeży	V	527	3
Fresh forest Las świeży	VI	104	3
Fresh mixed forest Las mieszany świeży	V	274	3
Fresh mixed forest Las mieszany świeży	VI	321	3

The trees were next marked on site. When marking trees on site attention was paid whether they may definitely be classified to a specific Kraft's social class of tree position in the stand. Tree no. I according to Kraft's classification of tree position belonged to diameter class III (according to Urich I), tree no. II belonged to diameter class II, while tree no. III – to diameter class I. In the further part of the study only terminology connected with Kraft's social class of tree position was applied.

For each model tree identified on the sample plot the crown projection area was determined (from the four principal points of the compass and four intermediate ones), and next trees were felled. After felling their stem length was measured together with necessary measurements of the live crown. Stems were divided into 2-m sections, from which centres discs were cut in order to determine selected wood macrostructure characteristics and calculate the volume of sapwood rings and heartwood cylinders in each 2-m section of individual stems. Moreover, discs were cut from breast height and the kerf plane.

On collected discs radial widths of sapwood and heartwood zones were measured in the four principal points of the compass. When analysing results for individual discs and trees arithmetic means were used for widths of the analysed wood zones. Obtained in this way assessments of two analysed wood zones were used in calculation of relational share in the tree stem as well in volume as on radius. When calculating relational share of sapwood and heartwood on radius mean width of the zones was used. Formulae determining volume of sapwood and heartwood was used:

$$V_h = V_t - V_s,$$

where: V_h – volume of the heartwood,
V_t – total volume of the section 2 m long,
V_s – volume of the sapwood, and formula for calculating volume of the cylinder: $V = \pi \cdot r^2 \cdot 2$, where "r" is radius (of the single section of tree stem), measured in the middle of the section (it is so called Huber's formula) [Grochowski 1973].

Only sections of full length were used in calculations. Last section (including the top of tree), if do not gained size in length of 2 m was rejected from calculations.

The circular area of tree crown projection was calculated based on the mean radius of the tree crown and using formulae: $P = \pi \cdot r^2$, where "r" is the radius. Area of the tree crown as external area of cylinder was calculated with formulae: $A_C = 2\pi r(r + h)$. The volume of the tree crown was calculated with formulae [Królikowski and Steckiewicz 1964, Grochowski and Szymkiewicz 1957]:

$$V_{parab.} = L_k \cdot (D/2)^2 \cdot ½\pi,$$

where: L_k – length of the tree crown,
D – diameter of the tree crown,
r – radius of the tree crown.

Results of analyses are presented in the form of tables and figures.

RESULTS

Results show considerable variation in the proportions of sapwood and heartwood in the volume of trees in individual Kraft's social classes of tree position growing in fresh mixed forest and fresh forest sites, coming from stands of age classes V and VI.

Axial variation (along the stem) and radial variation are observed in the proportion of heartwood in the cross stem section, both in terms of individual forest site types and Kraft's classes of tree position. Trees included in the study were characterised by a larger proportion of heartwood volume in relation to the volume of sapwood. Among trees representing age class VI the predominance of heartwood in the volume was bigger than in trees from age class V. Trees from age class V growing in fresh forest sites contained on average 57.28% heartwood in stem volume, while trees from fresh mixed forest sites had a mean of 64.25% heartwood. In case of trees from age class VI the mean content of heartwood volume in the stem in trees from fresh forest was 62.03%, while in those from fresh mixed forest it was 66.48%. Large variation was observed in the proportions of individual volumes of sapwood and heartwood in individual Kraft's classes for trees representing analysed populations. The biggest content of heartwood in the individual tree volume was found in trees from Kraft's class II coming from age class VI, growing on fresh mixed forest sites (69.68%), while the smallest proportion of heartwood was recorded in trees from Kraft's class III growing in fresh forest sites and representing age class V (51.28%). The share of sapwood in the volume of trees from individual Kraft's classes showed an opposite trend to that found for the proportion of heartwood. The numerical characteristics of relative proportions of sapwood and heartwood in the volume of common oaks from the analyzed populations are presented in Table 2.

Table 2. Percentages of sapwood and heartwood volumes in stems of common oaks (total N = 12 sample trees representing four sample plots)
Tabela 2. Względny udział objętości bielu i twardzieli w pniach dębów szypułkowych (razem N = 12 drzew próbnych reprezentujących cztery powierzchnie)

Kraft's class Klasa Krafta	Age class V V klasa wieku				Age class VI VI klasa wieku			
	fresh forest las świeży N = 3		fresh mixed forest las mieszany świeży N = 3		fresh forest las świeży N = 3		fresh mixed forest las mieszany świeży N = 3	
	sapwood biel	heartwood twardziel	sapwood biel	heartwood twardziel	sapwood biel	heartwood twardziel	sapwood biel	heartwood twardziel
I	34.58	65.42	32.62	67.38	37.87	62.16	34.59	65.41
II	44.87	55.13	32.07	67.93	31.21	68.79	30.32	69.68
III	48.72	51.28	42.57	57.43	44.86	55.14	35.66	64.34
Arithmetic mean Średnia arytmetyczna	42.72	57.28	35.75	64.25	37.98	62.03	33.52	66.48
Standard deviation Odchylenie standardowe	5.97		4.83		5.57		2.31	
Coefficient of variation Współczynnik zmienności	13.97	10.42	13.50	7.51	14.67	8.98	6.88	3.47
Standard error Błąd standardowy	3.45		2.79		3.22		1.33	

When considering variation in the proportions of sapwood and heartwood in the radius of the cross stem section in relation to age classes in individual forest site types we may find variation in analysed stands. A higher proportion of heartwood than sapwood at the radius was observed in case of each of the age classes (Table 3).

Table 3. Percentage of sapwood and heartwood at the radius of cross stem section of common oaks (12 sample trees representing four sample plots)
Tabela 3. Udział względny bielu i twardzieli na promieniu przekroju pni dębów szypułkowych (razem N = 12 drzew próbnych reprezentujących cztery powierzchnie)

Kraft's class Klasa Krafta	Age class V V klasa wieku				Age class VI VI klasa wieku			
	fresh forest las świeży		fresh mixed forest las mieszany świeży		fresh forest las świeży		fresh mixed forest las mieszany świeży	
	sapwood biel	heartwood twardziel	sapwood biel	heartwood twardziel	sapwood biel	heartwood twardziel	sapwood biel	heartwood twardziel
I	24.16	75.84	20.97	79.03	32.46	67.54	25.00	75.00
II	30.14	69.85	18.96	81.04	23.03	76.97	23.24	76.76
III	35.47	64.53	26.58	73.42	33.27	66.73	23.38	76.62
Arithmetic mean Średnia arytmetyczna	29.92	70.08	22.17	77.83	29.59	70.41	23.87	76.13
Standard deviation Odchylenie standardowe	4.62		3.22		4.65		0.80	
Coefficient of variation Współczynnik zmienności	15.44	6.59	14.54	4.14	15.71	6.60	3.34	1.05
Standard error Błąd standardowy	2.67		1.86		2.68		0.46	

Common oaks representing both age classes are characterised by a varying proportion of sapwood at the radius in individual forest site types. Among analysed trees from age class V, a lower share of sapwood at the radius was found for trees coming from fresh mixed forest (22.17%) than from fresh forest (29.92%). The content of heartwood at the radius in age class V was 70.08% for trees representing fresh forest and 77.83% for trees representing fresh mixed forest sites. In case of trees from age class VI differences in the proportions of sapwood and heartwood at the radius were also observed in individual forest site types analyzed in this study. A higher share of sapwood was recorded in trees from fresh forest (29.59%), while in stems of trees from fresh mixed forest sites sapwood constituted 23.87% at the radius. The share of heartwood was 76.13% at the radius in stems of trees from fresh mixed forest and 70.41% in stems of trees from fresh forest.

The mean content of sapwood at the radius was observed to vary in individual Kraft's classes (Fig. 1). The biggest sapwood content at the radius in age class V was found in Kraft's class III (31.02%), intermediate in Kraft's class II (24.55%), while the lowest in Kraft's class I (22.56%). The proportion of heartwood at the radius in trees from age class V showed an opposite trend to that of sapwood, in Kraft's class III amounting to 68.98% (the least among trees representing age class V), in Kraft's class II to 75.45% and in Kraft's class I to 77.44% (the most among trees from age class V).

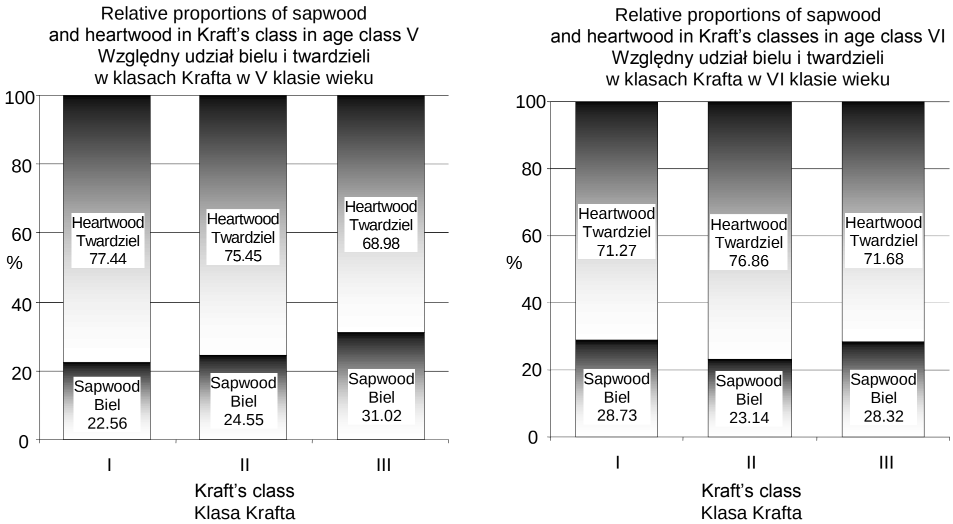

Fig. 1. Mean proportions of sapwood and heartwood at the radius of cross stem section in Kraft's classes in oaks from age classes V and VI (data from each section of the stems representing investigated population)

Rys. 1. Średni udział bielu i twardzieli na promieniu przekroju pnia w klasach Krafta u drzew z V i VI klasy wieku (dane z wszystkich sekcji pni reprezentujących analizowaną populację)

Different results were recorded in case of trees representing age class VI. The highest proportion of sapwood was found among trees from Kraft's class I (28.73%). The lowest percentage of sapwood was found in Kraft's class II (23.14%), while an intermediate value, although still high – in Kraft's class III (28.32%). The proportion of heartwood in Kraft's klass I was 71.27% (the least among trees from age class VI), in Kraft's class III it was 71.68% (an intermediate value), while in Kraft's class II it amounted to 76.86% (the highest value among trees of age class VI included in the study). The proportions of sapwood and heartwood at the radius in trees from individual Kraft's classes in terms of age classes are presented in Figure 1.

In the study attention was focused on the effect of crown size on the incidence and quantitative variation in sapwood and heartwood content in the stem profile and cross stem section of common oaks representing age classes V and VI, coming from fresh mixed forest and fresh forest sites. High irregularity and variation was observed in crown size in individual mean sample trees in corresponding forest site types, as well as age classes and social classes of tree position (Table 4).

Table 4. Values of crown volume (as volume of paraboloid of revolution) and circular crown projection area in terms of social classes of tree position, age classes and forest site types

Tabela 4. Objętość korony (jako objętość paraboloidy obrotowej) i powierzchnia rzutu kołowego w zależności od klasy biosocjalnej Krafta, klasy wieku i siedliskowego typu lasu

Tree crown parameter Parametr korony	Mean Średnia	Standard deviation Odchylenie standardowe	Coefficient of variation Współczynnik zmienności	Standard error of the data mean Błąd standardowy średniej
Kraft's class I – I klasa Krafta				
Volume of paraboloid of revolution, m^3 Objętość paraboloidy obrotowej, m^3	422.25	382.52	90.59	191.26
Area circular, m^2 Powierzchnia rzutu kołowego, m^2	75.5	59.33	78.58	29.66
Kraft's class II – II klasa Krafta				
Volume of paraboloid of revolution, m^3 Objętość paraboloidy obrotowej, m^3	150.5	63.10	41.92	31.55
Area circular, m^2 Powierzchnia rzutu kołowego, m^2	31	15.12	48.76	7.56
Kraft's class III – III klasa Krafta				
Volume of paraboloid of revolution, m^3 Objętość paraboloidy obrotowej, m^3	89.25	17.28	19.36	8.64
Area circular, m^2 Powierzchnia rzutu kołowego, m^2	20.75	6.83	32.93	3.42
Age class V – V klasa wieku				
Volume of paraboloid of revolution, m^3 Objętość paraboloidy obrotowej, m^3	99	27.09	27.37	11,06
Area circular, m^2 Powierzchnia rzutu kołowego, m^2	19.17	4.98	25.98	2.03
Age class VI – VI klasa wieku				
Volume of paraboloid of revolution, m^3 Objętość paraboloidy obrotowej, m^3	342.33	334.58	97.74	136,59
Area circular, m^2 Powierzchnia rzutu kołowego, m^2	65.67	50.54	76.96	20.63
Fresh forest – Las świeży				
Volume of paraboloid of revolution, m^3 Objętość paraboloidy obrotowej, m^3	266.17	357.72	134.40	146,04
Area circular, m^2 Powierzchnia rzutu kołowego, m^2	47.5	55.37	116.56	22.60
Fresh mixed forest – Las mieszany świeży				
Volume of paraboloid of revolution, m^3 Objętość paraboloidy obrotowej, m^3	175.17	100.92	57.61	41,20
Area circular, m^2 Powierzchnia rzutu kołowego, m^2	37.33	23.29	62.39	9.51

A regularity was observed in this sense that trees representing Kraft's class I generally were characterized by a bigger crown volume than those from Kraft's classes II and III (means from all sample trees representing a given Kraft's social class of tree position). In case of trees from Kraft's class I crown volume calculated as the volume of a paraboloid of revolution was 422.25 m^3, whereas for trees from Kraft's class II the mean was 150.5 m^3 and those from Kraft's class III it was smallest, i.e. 89.25 m^3.

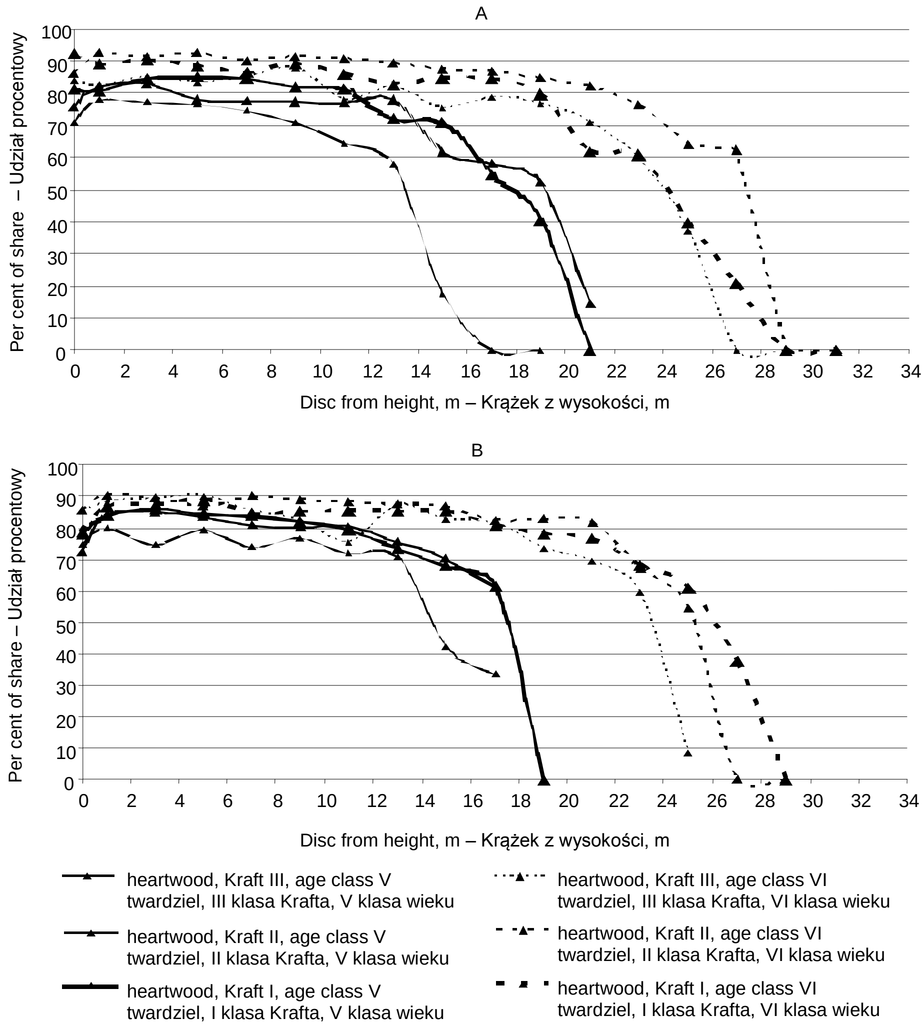

Fig. 2. Contents of sapwood and heartwood at the radius (in age classes V and VI) in tree stems growth in condition of fresh forest (A) and fresh mixed forest (B) representing different Kraft biosocial class

Rys. 2. Szerokość względna twardzieli na promieniu (w V i VI klasie wieku) u pni drzew wyrosłych w warunkach lasu świeżego (A) i lasu mieszanego świeżego (B) reprezentujących różne kasy biosocjalne wg Krafta

In terms of the area of circular crown projection the biggest values were recorded for trees representing Kraft's class I (75.5 m^2), intermediate values were found for crowns of trees from Kraft's class II (31 m^2), while the lowest values – for those from Kraft's class III (20.75 m^2). Numerical variation of crown volume and crown projection area in relation to age classes, social classes of tree position and forest site types is presented in Table 4.

Figure 2 presents radial proportions of sapwood and heartwood distributed along stems of common oaks, depending on age classes in relation to their social class of tree position in the stand. Strong variation was observed in both analysed age classes. The proportions of sapwood and heartwood at the radius in relation to diameter at the measurement point were very irregular. This is probably connected with the trend to form swellings on the stem connected with growing branches – in time overgrown by new layers of wood.

A varied effect of the tree crown, dependent on the age class and the type of analysed parameter, was observed on the mean percentage of sapwood in analyzed age classes (mean for all discs). These dependencies are presented in Table 5.

Table 5. Relation between tree crown parameters and sapwood area at breast height
Tabela 5. Zależności pomiędzy cechami korony a bielem na wysokości pierśnicy

Age class Klasa wieku	Treats Cechy	Sapwood area Powierzchnia bielu	Statistical significance Statystyczna istotność
V	volume of tree crown, as volume of paraboloid of revolution objętość korony jako objętość paraboloidy obrotowej	0.757	value not significant statystycznie nieistotna
	area of tree crown as area of cylinder external surface powierzchnia zewnętrzna płaszcza korony jako powierzchnia walca	0.718	value not significant statystycznie nieistotna
VI	volume of tree crown, as volume of paraboloid of revolution objętość korony jako paraboloidy obrotowej	**0.923**	**value significant** **statystycznie istotna**
	area of tree crown as area of cylinder external surface powierzchnia zewnętrzna płaszcza korony jako powierzchnia walca	**0.919**	**value significant** **statystycznie istotna**

DISCUSSION

The focus in wood industry is on internal wood structure. As it was stated by Jakubowski [2004], important elements of wood macrostructure, of importance in terms of wood utilization, include also sapwood and heartwood. This is true both for coniferous and broad-leaved tree species.

As it was stated by Björklund [1999] to focus on the heartwood may be most relevant from a wood utilization perspective, whereas from a physiological point of view it may be more relevant to focus on the sapwood. Correlations between sapwood width and some tree characteristics can therefore be expected to be stronger than corresponding correlations to heartwood diameter.

Sellin [1996, from Björklund 1999] found that tree age and growth rate together described 70% of the variation in sapwood content for *Picea abies* L. (Karst) in Estonia. Within a tree, the sapwood width increases with the stem height [Panshin and Zeuuw 1980, from Rybníček et al. 2006]. Similar observation was made during this study. These differences reflect the fact that a tree tries to maintain the constant volume of sapwood at various heights of the stem. The sapwood width is closely related to the crown width. There is a positive correlation between the size of assimilatory area, intensity of transpiration stream and sapwood width [Rybníček et al. 2006]. At an age of 100 years, the sapwood of trees with small crowns is only 4 to 7 cm wide. Trees the crown of which were systematically released at an age of 60 to 100 years reach the sapwood width over 15 cm. The sapwood width of oak is also related to site conditions. In sites with higher soil moisture, heartwood begins to create earlier and sapwood is narrower [Požgaj et al. 1997, from Rybníček et al. 2006].

Stokes and Berthier [2000, from Berthier et al. 2001] proposed that the increase in sapwood area at the base of the trunk (observed also during this case study) was due to decrease in hydraulic conductivity. Also it was fined by Gartner [1991, from Berthier et al. 2001] that cells in this zone are likely to have smaller lumens and thicker cell walls – connected with mechanical properties of the tree stem.

Medhurst and Beadle [2002] stated that leaf area: sapwood area ratio was dependent on tree size rather than silvicultural treatment. Analysis of the relationship between leaf area and sapwood area in *Eucaliptus nitens* (Deane and Maiden) Maiden across a wide range of sites under different silvicultural regimes has shown a consistent, non-linear relationship not influenced by site or treatment [Medhurst et al. 1999, from Medhurst and Beadle 2002]. Some authors illustrate proportions of sapwood and heartwood based on the volume proportions of these macrostructure elements in tree stems [Krzysik 1978, Pazdrowski 1992, Jakubowski 2004]. Another important element, which may prove suitable for the quality appraisal of timber is the radial proportion of sapwood and heartwood along the stem axis [Jelonek et al. 2006]. Jakubowski [2004] stated that the volume proportion of heartwood in the stem in coniferous species increases markedly with the age of the tree. A similar dependence was also observed in this study, as the proportion of heartwood volume in age class VI was higher than in age class V. Time is obviously an important factor in heartwood formation. This is shown by its bigger regularity at the radius along the stem in age classes V and VI than in age classes III and IV [Szymański et al. 2008], which is consistent with observations reported by Hejnowicz [2002]. However, other factors also play a role here, such as the size and efficiency of the assimilating organ, social class of tree position in the stand, tree genotype, latitude, forest site type and species-specific and individual traits, etc. This was reflected both in this and other studies. In analyzed age classes (V and VI) similar values were observed for correlations between crown parameters and width of sapwood. For comparison, in a study by Szymański et al. [2008] positive values were recorded for the linear correlation between crown volume (a strong correlation) and circular crown projection area (a strong correlation), and mean width of sapwood at the radius in stems of common oaks. On the basis of conducted observations and calculated linear correlation indexes between parameters of oak crowns and sapwood area at cross stem section at breast height it may be stated that the crown has a strong effect on sapwood transformation into heartwood in common oak. So it is possible to determine share of sapwood and heartwood in tree stems according to the crown size.

Values of correlation coefficients of crown size with sapwood area are bigger in age class VI than in age class V, thus with age the effect of the crown on heartwood formation increases. This finding is consistent with the results presented in the study concerning sapwood and heartwood in oaks from age classes III and IV [Szymański et al. 2008], where width of sapwood area was examined.

The problem discussed in this study, apart from its importance from the point of view of pure science, is also significant for forestry and wood industry practice. More insight into factors affecting the formation of both types of wood in stems of forest-forming species, especially relatively little known broad-leaved species, may be used in the optimization of timber utilization, while the size of both zones inside the stem – for the individual selection and further propagation of economically valuable ecotypes. Due to the complexity of the problem such studies have to be continued.

CONCLUDING REMARKS

High irregularity was observed in the proportion of sapwood and heartwood zones in terms of radial and axial system. This is manifested in huge disproportions in the share of distinguished wood zones in tree stems.

1. The relative share of sapwood and heartwood zones in the volume was markedly varied. The highest volume was recorded for sapwood in age class V in fresh forest sites (approx. 43%), while the smallest in age class VI in fresh mixed forest sites (approx. 34%).

2. The mean proportion of sapwood at the radius was observed to vary in individual Kraft's classes. The highest mean proportion of sapwood at the radius in age class V is observed in Kraft's class III (approx. 31%), an intermediate value is found in Kraft's class II (approx. 25%), while the smallest in Kraft's class I (approx. 23%). In case of trees representing age class VI the highest percentage of sapwood was recorded for trees from Kraft's class I (approx. 29%), while the lowest share of sapwood was found in Kraft's class II (approx. 23%), with an intermediate value for Kraft's class III (approx. 28%).

3. Strong variation was found for radial proportions of sapwood and heartwood distribution along the stem in common oaks. This strong variation was observed in both analysed age classes in all Kraft's social classes of tree position in the stand.

4. The effect of the crown on sapwood area at breast height was found to be strong. The value of correlation coefficients for the relationship of sapwood area with the external crown projection area (as area of cylinder) in age class V was +0.718 (not significant), while in age class VI it was +0.923 (significant). For the dependence of sapwood ring area on crown volume these coefficients were +0.757 (not significant) at age class V, and +0.919 (significant) at age class VI.

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OSIOWE I PROMIENIOWE ZRÓŻNICOWANIE UDZIAŁU BIELU I TWARDZIELI W PNIACH DĘBÓW SZYPUŁKOWYCH (*QUERCUS ROBUR* L.) A WYBRANE CECHY BIOMETRYCZNE DRZEW I ŻYZNOŚĆ SIEDLISKA

Streszczenie. Praca jest próbą określenia zmienności udziału bielu i twardzieli w pniach dębów szypułkowych (*Quercus robur* L.) na przekroju poprzecznym oraz wzdłuż osi pnia. Drzewa poddane analizie wyrosły w warunkach lasu mieszanego świeżego oraz lasu świeżego i reprezentowały drzewostan główny według klasyfikacji biologicznej Krafta, w wieku 81-100 lat (V klasa wieku) oraz 101-120 lat (VI klasa wieku). Drzewa próbne wybrano zgodnie z założeniami dendrometrii – według metody Uricha (z równą liczbą drzew w stopniu grubości) na czterech powierzchniach badawczych (o areale 1 ha każda). Dla każdego drzewa modelowego oznaczonego na powierzchni pomierzono powierzchnię rzutu korony. Po ścięciu wykonano wszystkie niezbędne pomiary cech biometrycznych pni i żywej korony. Ze środków sekcji o długości 2 m wycięto krążki w celu pomiaru cech makrostruktury drewna oraz określenia objętości pierścienia bielu i walca twardzieli. Ponadto wycięto krążki z podstawy drzewa (miejsca ścięcia) oraz z pierśnicy (na wysokości 1,3 m). Opracowując wyniki, posługiwano się średnimi arytmetycznymi wartościami wyróżnionych stref określonymi dla pojedynczych krążków lub drzew. W toku prac stwierdzono nieregularność szerokości stref bielu i twardzieli w pniach dębów. Wykazano silną, dodatnią zależność pomiędzy objętością korony (jako objętość paraboloidy) i powierzchnią kołowego rzutu korony oraz powierzchnią bielu na przekroju poprzecznym. Niektóre współczynniki korelacji były nieistotne statystycznie. Rozpatrując indywidualnie klasy biosocjalne według Krafta, zaobserwowano dużą zmienność objętości bielu i twardzieli w pniach drzew. Ponadto wykazano zróżnicowanie w udziale bielu i twardzieli pomiędzy klasą wieku oraz stosunkowo niewielką zmienność pomiędzy siedliskowymi typami lasu.

Słowa kluczowe: warunki siedliskowe, las mieszany świeży, las świeży, klasyfikacja Krafta, drewno, surowiec drzewny

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