Determination of the number of sapwood annual rings in oak in the region of southern Moravia

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ABSTRACT: The paper deals with the determination of the number of sapwood annual rings in oak (*Quercus* sp.) in relation to altitude, locality and stand age. Several different groups of samples were used from two localities of southern Moravia. The results of the study demonstrate the effects of site water regime and age on the growth of sapwood annual rings. On the other hand, the effect of altitude was not proved. The information can be of crucial importance for the dendrochronological dating of an incomplete sample for particular regions where sapwood is partly or totally missing.

Keywords: sapwood; oak; annual ring analysis; Czech Republic

Wood (xylem) is created by the dividing activity of the cambium secondary meristem (Hoadley 1990). During every growing period, trees growing in the temperate region create a new diameter (radial) increment of wood – an annual ring (Wagenführ 1999). The activity of cambium is affected by a number of external and internal factors. Climatic conditions and biotic agents are ranked among outer factors. Internal factors are genetically conditioned factors and the health condition of a tree. The annual ring width is unique for a certain time and place where a given tree grows (Klein 1998). Trees growing in the same region and thus in the same climatic conditions show the same response expressed by the annual ring width. Thus, there is similarity in the change of the annual ring width within a stand particularly as for maximum and minimum values (Douglass 1937). On the basis of these findings, it is possible to assign the year of origin to particular annual rings and to carry out the dating of other samples of wood according to the similarity of the sequence of annual rings of variable width. These problems are dealt with by a scientific discipline called dendrochronology (Kaennel, Schweingruber 1995).

The condition of the sample preservation or termination is a limiting factor in wood dating. If wood is not preserved up to the last annual ring, we cannot estimate for a certainty how many annual rings are missing. In the case of heartwood, thus also in oak if the sample includes the sapwood boundary, it is possible to count missing annual rings with a certain tolerance. The knowledge of the tree origin is, however, a precondition because in Europe the extent of the number of sapwood annual rings in oak ranges between 7 and 50. Through the study of particular regions and effects on the amount of sapwood the extensive number is reduced and the final dating is improved. That is why the determination of sapwood annual rings was carried out and the result is reported in this paper.

In the majority of countries of Central Europe, oak is most often used for dendrochronological dating. It occurs above all in the region of Poland, Germany and France. In the Czech Republic, oak is the most widespread broadleaved species, nevertheless, its propor-

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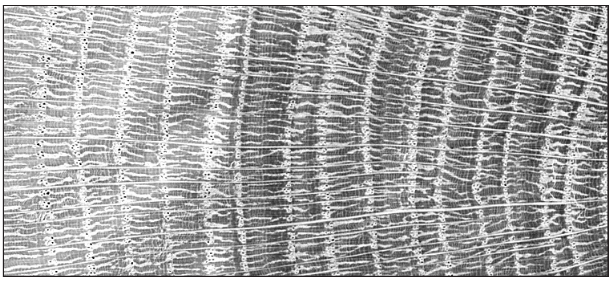

Fig. 1. The boundary of sapwood and heartwood in oak

tion in the present species composition of forests amounts to only 6.5%, which represents 166,603 ha (Report on the Condition of Forests and Forestry in the Czech Republic, 2002).

Oak belongs to the group of broadleaved species with ring-porous wood. On the cross-section of oak wood, it is possible to distinguish the central dark-coloured part, i.e. heartwood, and the lighter outer part, i.e. sapwood (Fig. 1). In addition to the lighter colouring sapwood of a growing tree is particularly characterized by the occurrence of living parenchymatous cells producing pith rays and axial wood parenchyma. These cells contain storage substances (e.g. starch). In addition to the presence of living cells with a storage function sapwood is characterized by free conductive elements enabling transpiration (Wagenführ 1999). On the other hand, heartwood is a physiologically dead plant tissue and conductive elements (vessels) are plugged due to parenchymatous cells growing into lumens of vessels (tylosis formation).

Selected autochthonous species of oak, i.e. pedunculate oak (*Quercus robur* L.) and sessile oak (*Quercus petraea* [Matt.] Liebl.), do not show any evident differences in the anatomical structure of wood important for dendrochronological purposes and thus they are not generally distinguished (Berger et al. 1971).

Within a tree, the sapwood width increases with the stem height (Panshin, Zeuuw 1980). 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 a transpiration stream and sapwood width. At an age of 100 years, the sapwood of trees with small crowns is only 4 to 7 cm wide. Trees the crowns 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).

The number of sapwood annual rings is related to the geographical position of a site, tree age and tree growth rate. The number of annual rings in sapwood shows a certain variability from east to west. Trees growing in the east show fewer sapwood annual rings (Baillie 1995). Aged trees show more sapwood annual rings than younger trees and slowly-growing trees have more annual rings of sapwood than fast-growing trees (Wrobel, Eckstein 1993).

For example in N Wales and NW England, some 90% sapwood annual rings occur in the range of 20–45 annual rings (Hughes et al. 1981), in W Germany 9–33 (Hollstein 1980), in N Germany 10–30 (Wrobel et al. 1993), in southern Finland 9–18 (Baillie et al. 1985) and in Poland 9–23 (Wazny, Eckstein 1992).

MATERIAL AND METHODS

Two different localities were chosen for the collection of wood samples. The first locality was the vicinity of the Habrůvka village (co-ordinates 49°18´12´´N, 16°43´21´´E), the second one was the vicinity of the town of Velké Němčice (co-ordinates 48°59´35´´N, 16°40´27´´E).

Habrůvka is situated in the central part of the Moravian Karst at an altitude over 500 m belonging to the Drahany bioregion. Limestones occur west and south of the village. Right in the village and in

Table 1. Descriptive statistics of the number of sapwood annual rings for the Habrůvka locality

Number of annual rings	Habrůvka				
	waterlogged 75–100	waterlogged ≥ 100	dry 50–75	dry 75–100	dry ≥ 100
Mean value	11.70	10.9	15.00	12.67	15.22
Minimum	8.00	6.0	10.00	8.00	10.00
Maximum	14.00	15.0	19.00	15.00	21.00
Confidence interval limit*	1.43	1.3	2.02	2.00	2.48
Number of samples – *n*	10.00	20.0	10.00	9.00	9.00

*confidence interval limit on the confidence level α = 0.05

the direction of Křtiny, schists and sandstones occur, north of Habrůvka clays and sands referred to as Rudice layers.

The whole region shows a typical Central European climate. Summer is short to very short, temperate to moderately cold, the transitional period is long. Winter is normally long to long, moderately cold, slightly moist with the normal to long duration of snow cover. Mean annual temperature is about 7.7°C. In the coldest month of January, the temperature falls to –3°C. July is usually the warmest month when temperatures range about 17.8°C. In the major part of the region, the growing season begins at the end of March and ends at the beginning of November. Annual precipitation ranges about 650 mm and the majority of precipitation occurs in July (Hofmann 1999).

In this region near Habrůvka, in total 60 samples of pedunculate oak (*Quercus robur* L.) and sessile oak (*Quercus petraea* [Matt.] Liebl.) were taken. Due to the same anatomical structure, the two species were not distinguished. The samples were divided into groups: waterlogged soil, age 75–100 years; waterlogged soil, age ≥ 100 years; dry soil, age 50 to 75 years; dry soil, age 75–100 years; dry soil, age ≥ 100 years. The age group of 50–75 years did not occur in the stand on the waterlogged soil.

The second locality Velké Němčice is situated about 30 km south of Brno on the left bank of the Svratka river at an altitude of 184 m in a flat area. It occurs in the region of Ždanický les (Ždanice Forest) belonging to the Dyje-Morava bioregion. This bioregion is created by wide river floodplains.

Underlying beds are mainly sands and gravel sands of the lowest terrace, the soil surface being built of 2–5 m deep alluvial loams. Particularly in the southern part, partly buried dunes of drift sands have been formed (so-called "hrúdy"). The bioregion geomorphology is typically alluvial. The region altitude ranges from 155 to 185 m above sea level.

The whole area is situated in the warmest region of the CR – T 4. Its climate is markedly warm, one of the warmest in the country. The climate of floodplains is characterized by moderate ground-level temperature inversions.

In this locality, in total 60 samples of oak wood were taken (both *Quercus robur* L. and *Quercus petraea* [Matt.] Liebl.). The two species were not distinguished. The samples were divided into particular groups: waterlogged soil, age 50–75 years; waterlogged soil, age 75–100 years; dry soil, age 50 to 75 years; dry soil, age 75–100 years; dry soil, age ≥ 100 years. The age group of ≥ 100 years on waterlogged soil did not occur in the stand.

Collection and processing of the samples were carried out according to standard dendrochronological methods (Cook, Kairiukstis 1990). For sampling in particular localities, Pressler's increment borer 40 and 60 cm long was used. From each of the stems, one sample was taken roughly at a height of 1.3 m (Schweingruber 1983). Determination of the number of sapwood annual rings was carried out on a cross-section. Increment cores obtained from Pressler's increment borer were fixed into wooden lathes prepared in advance. The surface of samples was worked with a razor blade. Subsequently, the number of sapwood annual rings was counted. The border between sapwood and heartwood was distinguished by their visual difference in colour only. These data were classified into groups according to site water regime (dry, waterlogged), altitude (200 and 500 m) and age (50–75, 75–100, 100 and more).

To determine statistical significance between particular variables in the number of sapwood annual rings Statistica 6.0 program was used and multifactorial analysis ANOVA was used for the evaluation of results.

RESULTS

Numbers of sapwood annual rings for the Habrůvka locality are given in Table 1. The smallest number of

Table 2. Descriptive statistics of the number of sapwood annual rings for the Velké Němčice locality

Number of annual rings	Velké Němčice				
	waterlogged 50–75	waterlogged 75–100	dry 50–75	dry 75–100	dry ≥ 100
Mean value	9.70	12.00	11.82	14.56	15.29
Minimum	5.00	8.00	8.00	10.00	10.00
Maximum	14.00	14.00	15.00	18.00	20.00
Confidence interval limit*	1.97	1.58	1.44	2.31	1.89
Number of samples – *n*	10.00	10.00	11.00	9.00	14.00

*confidence interval limit on the confidence level α = 0.05

Table 3. Results of hierarchic ANOVA between particular variables

	SS	Degree of freedom	MS	F	p
Intercept	17,251.10	1	17,251.10	2,266.750	0
"Var1"	11.63	1	11.63	1.528	0.219320
"Var2" (Var1)	199.71	2	99.86	13.121	0.000008
"Var3" (Var1 ×Var2)	162.86	6	27.14	3.566	0.003010

Var1 – variable for altitude, Var2 – variable for site water regime, Var3 – variable for age class, SS – sum of squares of deviations, MS – variance, F – test criterion, p – probability to obtain the same or more extreme test criterion than the calculated criterion under the condition of zero hypothesis

Table 4. Descriptive statistics of the number of sapwood annual rings for Habrůvka and Velké Němčice localities

Number of annual rings	Habrůvka + Velké Němčice					
	waterlogged 50–75	waterlogged 75–100	waterlogged ≥ 100	dry 50–75	dry 75–100	dry ≥ 100
Mean value	9.70	11.85	10.9	13.33	13.61	15.26
Minimum	5.00	8.00	60.0	8.00	8.00	10.00
Maximum	14.00	14.00	15.0	19.00	18.00	21.00
Confidence interval limit*	1.97	0.96	1.3	1.33	1.44	1.38
Number of samples – *n*	10.00	20.00	20.0	21.00	18.00	23.00

*confidence interval limit on the confidence level α = 0.05

sapwood annual rings in the given locality was 6, in the group "waterlogged, 100 and more". On the other hand, the maximum number of sapwood annual rings (21) was found in the group "dry, 100 and more". The highest value of the confidence interval limit (2. 48) was calculated for the group "dry, 100 and more".

Table 2 shows the number of sapwood annual rings in samples from the Velké Němčice locality.

Extreme values of the number of sapwood annual rings for this locality were demonstrated in the group "waterlogged, 50–75" (minimum value 5) and "dry, 100 and more" (maximum value 20). The group "dry, 75–100" showed the highest value of the confidence interval limit (2.31).

To determine statistical significance in the number of sapwood annual rings hierarchic ANOVA was used. Based on the hierarchic ANOVA results (Table 3), the variable altitude is not significant on the given confidence level 95% (p is higher than $\alpha = 0.05$). On the other hand, the variables site water regime and stand age are statistically significant ($p < \alpha$).

In relation to the hierarchic ANOVA results, particular groups of the same age and soil type were merged regardless of the altitude. In the groups created in this way, descriptive statistics was applied again (Table 4).

The lowest mean value (9.7) was calculated for "waterlogged group, 50–75" and the highest mean value (15.26) for "dry group, 100 and more". The lowest confidence interval limit (0.96) was found in "waterlogged group, 75–100". The highest confidence interval limit (1.97) was found in "waterlogged group, 50–75" (Fig. 2).

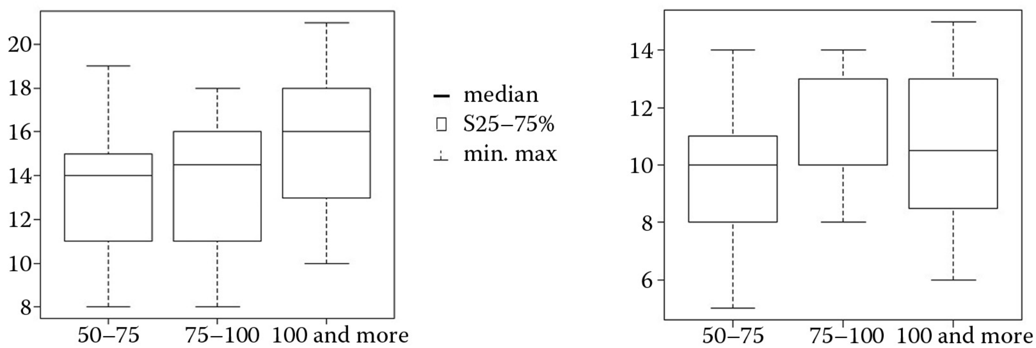

Fig. 2. Box diagrams of the number of sapwood annual rings for particular age groups. Left diagram – waterlogged group, right diagram – dry group

DISCUSSION AND CONCLUSIONS

The aim of the paper was to compare relationships between the number of sapwood annual rings and different growth conditions and age. No marked differences were found between the number of sapwood annual rings and the altitudes 200 and 500 m. In the Habrůvka locality with different water regimes of the sites, differences were observed: the dry type showed on average 3 annual rings more than the waterlogged type. The same result was obtained in the Velké Němčice locality, where, the difference was even 4 annual rings. Thus, the theory has been proved that trees characterized by a moisture deficit create a higher number of sapwood annual rings for their nutrition than fast-growing trees (Wrobel, Eckstein 1993). On the basis of groups created according to age we noticed large differences between particular groups. In Velké Němčice, the number of sapwood annual rings increased with increasing age whereas in Habrůvka, the number of sapwood annual rings decreased (with the exception of "dry group, 100 and more").

To determine the quality of these evaluations the analysis of particular groups was carried out in Statistica program by means of hierarchic ANOVA. The analysis demonstrated the insignificance of differences in mean values of the number of sapwood annual rings between samples from different altitudes. Other factors under investigation (age, water regime) were statistically significant. For that reason, localities of different altitudes were merged and subsequently divided according to site water regime and age. Thus, the primary set was enlarged and its informative potential was improved. Through the merger of localities the difference between the sites with different water regimes (dry, waterlogged) did not change markedly and it remained higher roughly 3 annual rings in a dry site.

It follows that the number of sapwood annual rings amounts to 5–21 rings in the region of southern Moravia.

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Stanovení počtu bělových letokruhů u dubu v oblasti jižní Moravy

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ABSTRAKT: Předmětem práce bylo stanovení počtu bělových letokruhů u dubu (*Quercus* sp.) v závislosti na nadmořské výšce, lokalitě a věku porostu. Bylo použito několik různých souborů vzorků ze dvou lokalit jižní Moravy. Z výsledků lze potvrdit vliv vodního režimu stanoviště a věku na růst bělových letokruhů. Naopak u nadmořské výšky tento vliv nebyl prokázán. Zjištěné informace mohou mít zásadní vliv při dendrochronologickém datování neúplného vzorku pro jednotlivé oblasti, kde bělové dřevo zčásti nebo úplně chybí.

Klíčová slova: běl; dub; letokruhová analýza; Česká republika

Cílem práce bylo porovnat závislost počtu bělových letokruhů na odlišných růstových podmínkách a věku. Bylo použito několik různých souborů vzorků ze dvou lokalit jižní Moravy. První lokalitou bylo okolí vesnice Habrůvka, druhou pak okolí města Velké Němčice. Lokality se navzájem lišily nadmořskou výškou (200 a 500 m n. m.). Na těchto lokalitách byly odebrány vzorky dřeva dubu letního (*Quercus robur* L.) i dubu zimního (*Quercus petraea* [Matt.] Liebl.). Jednotlivé druhy nebyly při dalším zpracování rozlišovány. Vzorky byly rozděleny do jednotlivých skupin na základě vodního režimu stanoviště a věku. Pro zajištění kvality těchto vyhodnocení byla v programu Statistica 6.0 provedena statistická analýza jednotlivých skupin pomocí hierarchické analýzy rozptylu (ANOVA). Byla potvrzena statistická nevýznamnost rozdílů ve středních hodnotách počtu bělových letokruhů u vzorků odlišných nadmořských výšek. Ostatní zkoumané faktory (věk, vodní režim stanoviště) byly statisticky významné.

Z celkových výsledků vyplývá, že počet bělových letokruhů u dubu v oblasti jižní Moravy činí 5 až 21 letokruhů. Zjištěné informace mohou mít zásadní vliv při dendrochronologickém datování neúplného vzorku pro jednotlivé oblasti, kde bělové dřevo zčásti nebo úplně chybí.

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