



DENDROCHRONOLOGICAL AND RADIOCARBON DATING OF SUBFOSSIL WOOD FROM THE MORAVA RIVER BASIN

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Abstract: The paper deals with dendrochronological and radiocarbon dating of subfossil trunks found in the basin of the Morava River. The research into subfossil trunks had been conducted in the Czech Republic in the past but the research stopped in 2001. 160 records of measurements of subfossil, predominantly oak trunk samples, are preserved from that time. Three years ago the research was reopened and again the most trunks were found in the basin of the Morava River. 92 samples of oak trunks and 7 samples of other tree species (poplar, elm, maple, beech) were taken from selected sites. The samples were processed in compliance with the standard dendrochronological methodology. To date the samples, Czech, Austrian, Polish and German standard chronologies were used. In cases when the dendrochronological dating was unsuccessful, the samples were sent for radiocarbon dating. In total, 35 samples were dated, mainly by the radiocarbon method. Subfossil trunks from gravel pit Tovačov were dated and classified into 4 different periods, the oldest being from 2780–2190 BC. In Osek nad Bečvou, the samples were taken from two sites. Whereas from the 4 trunks taken in the river channel each was from a different period, the trunks from the gravel pit come from 981–1015 AD. The trunks found in the Morava River basin near Strážnice were dated to the 10th–15th century. In the future, we expect to extend the amount of the acquired samples with the aim to create a link to the existing standard chronology or to create a long floating average tree-ring curve.

Keywords: dendrochronology, subfossil wood, oak, radiocarbon dating, the Morava River.

1. INTRODUCTION

Oak forests in Central Europe started to appear on river banks about 10,000 years ago, i.e. at the end of the Ice Age and the beginning of the Holocene (Becker, 1982; Leuschner *et al.*, 1986). Trunks of dead trees were deposited and preserved in various sediments. There are several theories concerning the mechanism of trunk deposition and preservation. The most frequently cited theory talks about bank erosion in meanders or river erosion during large floods (Kalicki and Krąpiec, 1995; Máčka and Krejčí, 2009). The fallen trees then soaked up water

and settled in deposited layers of channel alluvium under the water surface (Kalicki and Krąpiec, 1995; Florek, 1978; Kalicki and Krąpiec, 1991). The trunks were gradually hidden beneath the accretion on the slip-off slope during the channel migration (Kalicki and Krąpiec, 1995). The slip-off slope is the relatively gentle slope at the inner edge of a meander. In this position they were well protected against disintegration by microorganisms, especially fungi and bacteria (Krąpiec, 1996). These conditions allowed for their deposition for over 10,000 years (Becker, 1982). Today, these trunks are referred to as subfossil (Krąpiec, 1996; Kalicki and Krąpiec, 1995). Subfossil wood is unfossilized wood which has been deposited in rivers, swamps or moraine sediments for

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hundreds or thousands of years (Kaennel and Schweingruber; 1995). In former literature, subfossil oak trunks are referred to as “black oak” because of their colour (Kalicki and Krąpiec, 1995). The change of the wood shade into black is caused by ferric components dissolved in water reacting with tannins present in oak. The intensity of the shade is primarily determined by the time for which the wood has been deposited and the nature of the sediment. Besides the changes of the shade, there are also changes in physical and mechanical properties (Govorčín and Sinković, 1995). Oak is the most frequent species existing in the subfossil form, but to a smaller extent there are also pine, elm, maple, poplar, beech, ash and alder (Dvorská and Vít, 2002).

Currently, subfossil trunks are often found in Holocene alluvia, in gravel pits during alluvial sand and gravel extraction (Krąpiec, 1996; Kalicki and Krąpiec, 1995). In the area of the Czech Republic these trunks are most often found in unregulated reaches of big rivers, especially the Morava, the Vltava and the Labe Rivers, and in gravel pits that are located in the basins of these three rivers.

The longevity of oaks growing at river banks during the Holocene was relatively short – 95% of the trees only contain 150–400 tree rings. This fact is put in relation with the frequency of the above mentioned floods (Becker, 1993).

Subfossil wood is a suitable material for the creation or extension of standard oak chronologies (Pilcher *et al.*, 1984; Becker, 1993). In Poland the created standard

chronology reaches from the current days till 474 BC and 1795–612 BC (Krąpiec, 1996, 2001), in Ireland till 5289 BC (Baillie, 1995) and in central Germany till 6255 BC (Leuschner, 1992). The longest standard chronology in the world was created in German Hohenheim and it reaches the year of 8480 BC (Becker, 1993, Spurk *et al.*, 1998). To create the standard chronology, it is necessary to collect and date a large amount of trunks. The research into subfossil trunks in the Czech Republic was conducted until the end of 2001. The main objective besides the oak standard chronology was to use tree-ring analyses to obtain other paleoecological data. The first and a very important step within the project was the creation of a databank of possible deposits of subfossil trunks and the selection of sites suitable for further research. These sites were then consistently explored and the found trunks were sampled. When the trunks were found in the original location, the geological examination of the profile was carried out. The obtained samples were processed by means of dendrochronology and floating standard chronologies for each site were created. These were then compared with south German standard chronology, or with the standard chronology for southern Poland. The samples which could not be dated by dendrochronology were dated by radiocarbon method. The results are presented in **Table 1** (Poláček *et al.*, 2005).

Table 1. Summary of results of subfossil trunks research before 2001 (Poláček *et al.*, 2005).

Site	Number of samples	Tree species	Number of dated samples	¹⁴ C age (yr BP)	Cal. age range 95.4% conf. intervals (yr AD/BC)	Final year	Dendrochronological dating
Mohelnice	6	oak	1	1580±45	390–600 AD	550	after 550
			2	1380±45	560–780 AD	564	after 564
			2	6170±50	5310–4950 BC	–	–
	3	ash	–	–	–	–	–
	1	alder	–	–	–	–	–
Horka nad Moravou	1	oak	1	2145±111	–	–	–
Troubky	1	oak	–	–	–	–	–
Kroměříž	15	oak	–	lost	–	–	–
Hulín	27	oak	12	3856±147	2900–1850BC	1668 BC	after 1668 BC
			22	–	–	1658	after 1658
Strážnice	70	oak	1	1000±40	970–1160 AD	–	–
			1	674±123	1030–1460 AD	–	–
			1	430±30	1420–1620 AD	–	–
			1	210±40	1630–1960 AD	–	–
Hodonín	18	oak	–	–	–	–	–
			1	beech	–	–	–
Mikulčice	5	oak	–	–	–	–	–
Břeclav - Pohansko	1	oak	–	–	–	–	–
Hustopeče nad Bečvou	11	oak	–	–	–	–	–

Note: Radiocarbon dating conducted in Gliwice Radiocarbon Laboratory

2. MATERIAL AND METHODS

For the purposes of research, samples from subfossil trunks were taken from selected sites (Fig. 1). The first site is gravel pit in Tovačov, 12 km to the west of Přerov (GPS – 49°24.264' N, 17°17.469' E; 200 m asl). The other two sites – a reach of the Bečva River near Osek nad Bečvou (GPS – 49°29.837' N, 17°31.271' E; 218 m asl) and the gravel pit in Osek nad Bečvou (GPS – 49°29.459' N, 17°31.531' E; 218 m asl) – are also located in the Přerov district. The last site is a reach of the Morava River near Strážnice (GPS – 48°55.530' N, 17°17.120' E; 176 m asl) in the district of Hodonín.

Using a chain saw we took discs 5 cm thick. The discs better show possible defects in the tree growth (doubled or missing tree rings, wood knots, waving rings, etc.). Incorrect recognition of a growth defect may affect the accuracy of measurements (Rybníček, 2004). Before the measurement itself it was necessary to work the surface with a razor blade or rub it so that the boundaries of the tree rings were well visible.

To process the samples the PAST 4 application was used. We measured each sample in two mutually perpendicular directions. Measuring was conducted on a specialized measuring table with an accuracy of 0.01 mm. The first step after measuring was the comparison of individual ring curves (Rybníček *et al.*, 2007). As each sample was measured in two mutually perpendicular directions,

one curve was created for a sample out of these two. The well synchronizable curves were then used to create the average tree-ring curve, which highlighted the common minima and maxima and at the same time suppressed all the other oscillations caused by other influences (Cook and Kairiukstis, 1990). The average tree-ring curve was then compared with the standard chronologies for that particular species. The samples of subfossil oak trunks were compared with Czech, German, Austrian and Polish standard chronologies. The degree of resemblance among the curves was evaluated by means of the correlation coefficients and the parallelism coefficient (Gleichläufigkeit). These calculations facilitate the optical comparison of both curves, which is crucial for the final dating (Rybníček *et al.*, 2010).

The samples which could not be dated by the available standard chronologies were dated by a radiocarbon method. For radiocarbon dating it is necessary to use a sample with the minimum weight of 20–50 g (<http://www.carbon14.pl>).

3. RESULTS

During the past 2 years, 99 samples of subfossil trunks were taken from the selected sites in the basin of the Morava River and gravel pits which are located nearby. The proportions of particular tree species are shown in Fig. 2. There is over 90% of oak, where usually only

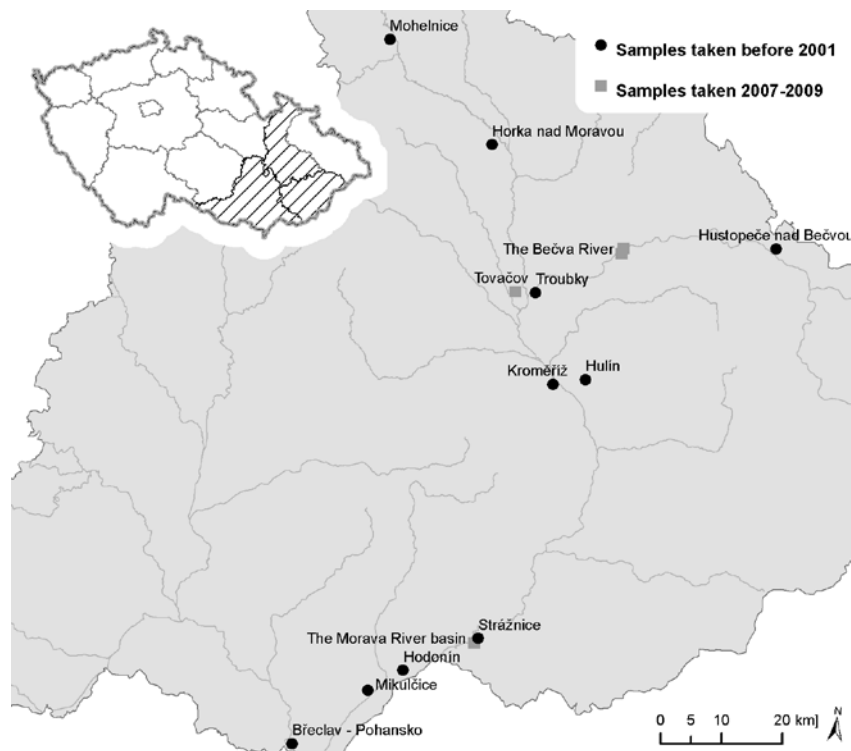


Fig. 1. Map showing site locations

the heartwood has been retained without sapwood or with only a few sapwood rings.

Tovačov

Table 2 shows the results of the dating of samples taken in gravel pit Tovačov. In total, 33 samples were acquired here. All of them were dated by the radiocarbon method. The samples could not be dated by dendrochronological methods as the living trees had been attacked by cockchafer (*Melolontha*, Linnaeus).

The Bečva River

In the Bečva River basin (the main tributary of the Morava River) samples were taken from two sites – river basin near Osek nad Bečvou and in 2009 in a newly opened gravel pit in the immediate vicinity of the stream. In total, 13 samples were taken from the river basin, out

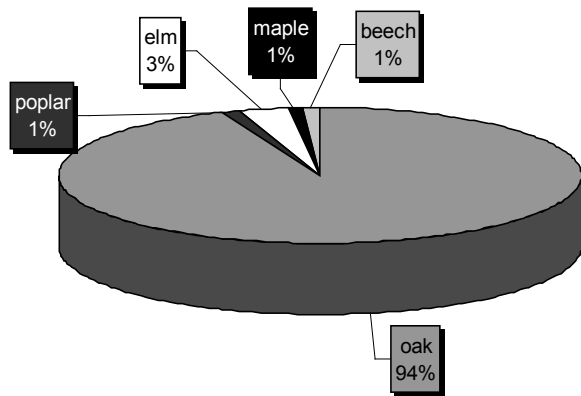


Fig. 2. The proportion of particular tree species in the existing samples

of which 9 samples were oak wood and then there was maple, poplar, elm and beech, one sample each. None of the samples could be dated by dendrochronological methods, due to a small number of tree rings. Therefore, the chosen samples were sent for radiocarbon dating (Table 3). 37 oak samples were taken from the gravel pit. Four of them were dated dendrochronologically using the south German oak standard chronology (Table 4).

The Morava River basin

16 samples in total were taken in the south of Moravia near Strážnice (the Hodonín district) during the past two years. Until now, 14 of them were dated; all of them were dated by the radiocarbon method (Table 5) and 10 by the dendrochronological method. It was possible to use three samples to create the average tree-ring curve which was dated by dendrochronology to year 1322 according to the Moravian standard chronology (morges2005).

When a dated curve overlaps the standard chronology by sixty rings, the critical value of Student's t-distribution with 0.1% level of significance is 3.46 (Šmelko and Wolf, 1977). The values of our t-tests are much higher

Table 3. The results of the dating of samples from the Bečva basin.

Sample no.	Tree species	Number of rings	Outermost ring	¹⁴ C age (yr BP)	Cal. age range 95.4% conf. intervals (yr AD/BC)
1	oak	68	+2ks	1030±60	885–1155 AD
2	oak	172	+2ak	1230±50	665–895 AD
3	oak	67	+4ak	2600±110	945–405 BC
4	oak	46	+3ak	730±50	1205–1320 AD

Note: Radiocarbon dating conducted in Gliwice Radiocarbon Laboratory

Table 2. The results of the dating of samples from gravel pit Tovačov.

Sample no.	Tree species	Number of rings	Outermost ring	¹⁴ C age (yr BP)	Cal. age range 95.4% conf. intervals (yr AD/BC)
1	oak	132	+2ak	3990±60	2675–2295 BC
2	oak	182	+2ak	3910±50	2500–2275 BC
3	oak	157	+11ks	4000±50	2670–2395 BC
4	oak	116	+10ks	3870±60	2490–2190 BC
5	oak	113	+1ak	2150±45	265–50 BC
6	oak	35	+4ak	2070±45	205 BC–25 AD
7	oak	54	+1ks	2060±40	195 BC–25 AD
8	oak	66	+1ks	4010±85	2780–2290 BC
9	oak	95	+3ak	2757±84	1129–789 BC
10	oak	105	+1ks	1815±82	48–404 AD
11	oak	57	+3ak	2053±83	233 BC–126 AD
12	oak	127	+2ks	3344±85	1783–1446 BC
13	oak	88	+4ks	1857±83	3 BC–352 AD

Used abbreviations: ak - For the samples which do not retain underbark rings (ak) only the year after which the trees stopped growing can be determined; ks - If heartwood and sapwood are retained (ks), the sample can be dated with the tolerance of several years (in the CR it is 5–21 rings).

Note: Radiocarbon dating conducted in Gliwice Radiocarbon Laboratory and laboratory in Prague

Table 4. The results of the dating of samples from gravel pit Osek nad Bečvou.

Sample no.	Tree species	Number of rings	Outermost ring	Initial year	Final year	Dendrochronological dating
1	oak	62	+2ak	919 AD	981 AD	after 983 AD
2	oak	115	+3ak	900 AD	1015 AD	after 1018 AD
3	oak	54	+2ak	931 AD	985 AD	after 987 AD
4	oak	52	+1ak	936 AD	988 AD	after 989 AD

than 3.46 (Table 5), which shows high reliability of the dating. The correctness of the synchronization is also proved by the agreement of the standard chronology with the average tree-ring curve in most of the extreme values (Fig. 3). The other samples were dated independently, by means of either the Moravian or the south German standard chronologies, to the period between the 10th and the 15th centuries (Table 6).

4. DISCUSSION AND CONCLUSION

In the Czech Republic two kinds of oak are predominant – *Quercus robur* L. (Pedunculate Oak) and *Quercus petraea* (Matt.) Liebl. (Sessile Oak). Because the wood of these two kinds is not distinguishable by means of anatomical analysis, both kinds will be referred to by their species name – oak. Oak is a tree species which grows mainly in lowland floodplain forests. In the Czech Republic, it is to be found mainly in alluvial plains of large low-plain rivers (the Morava, the Vltava, the Labe). Subfossil trunks are remnants of floodplain forests. Because the river bed is in almost the same location, it is possible to find subfossil trunks in the river basins. Table 1 shows that within the research conducted in the Czech Republic before 2001 subfossil trunks were very often found near the Morava River and its main tributary, the Bečva River. For these reasons, these sites were selected and contacted

when the research was being established. These are mainly unregulated reaches of rivers and gravel pits or sand pits.

In the area of the Morava, 99 trunks in total were found during the past two years, out of which 29 trunks were from the river basin and 70 came from gravel pits. Over 90% of them are oak samples, and exceptionally beech, maple, poplar or elm were found (Fig. 1). This may mean that there were mainly mixed forests but especially oak was preserved, which is a logical consequence of its high resistance. The number of rings in the samples ranges between 35 and 185. Literature says that the number of rings is usually between 150 and 400 tree rings, which is related to the frequency of floods which make trees die (Becker, 1993). We can presume that most of

Table 5. The results of sample correlation with the standard chronology.

A	B	C	D	E	F
MORGES2005	4.88	5.25	61.60	112	1322

A	standard chronology
B	T.test 1 (according to Baillie & Pilcher)
C	T.test 2 (according to Hollstein)
D	curve parallelism in percents
E	sample overlap with standard chronology in years
F	dating

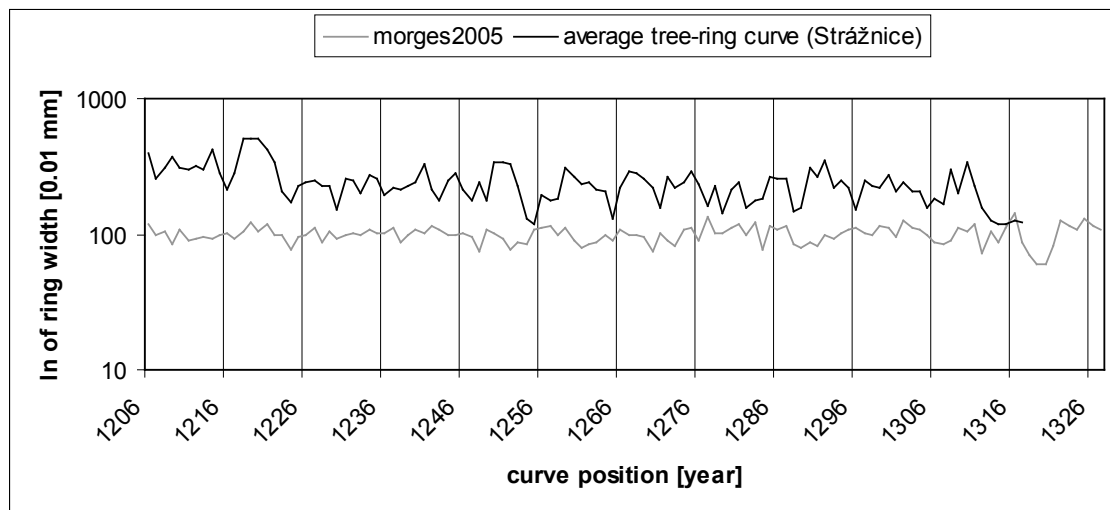
**Fig. 3.** Synchronization of the average tree-ring curve with the Moravian oak standard chronology MORGES2005.

Table 6. The results of the dating of samples from the Morava River near Strážnice.

Sample no.	Tree species	Number of rings	Outermost ring	Initial year	Final year	Dendrochronological dating	¹⁴ C age (yr BP)	Cal. age range 95.4% conf. interval (yr AD/BC)
1	oak	119	+2ak	1455	1574	after 1576 AD	359±80	1416–1668 AD
2	oak	98	+2ak	–	–	–	758±81	1148–1397 AD
3	elm	–	–	–	–	–	310±80	1436–1684 AD
4	oak	57	+1ks	–	–	–	307±80	1436–1685 AD
5	–	–	–	–	–	–	4717±87	3664–3337 BC
6	oak	152	+2ak	1356	1508	after 1510 AD	576±80	1274–1451 AD
7	oak	90	+1ak	1232	1322	after 1323 AD	734±81	1153–1408 AD
8	oak	98	+2ak	1210	1308	after 1310 AD	701±81	1175–1413 AD
9	oak	57	+2ak	1226	1283	after 1285 AD	858±81	1026–1276 AD
10	oak	161	+2ak	897	1058	after 1060 AD	1053±81	798–1160 AD
11	oak	138	+7ak	1390	1528	after 1535 AD	321±80	1432–1682 AD
12	oak	107	+1ak	1479	1586	after 1587 AD	394±73	1416–1647 AD
13	oak	64	+3ak	1517	1581	after 1584 AD	418±73	1403–1645 AD
14	oak	185	+1ak	1462	1647	after 1648 AD	454±73	1390–1636 AD

Note: Radiocarbon dating conducted in laboratory in Prague

the trunks found in the Morava River basin died due to more frequent floods or other mechanism of tree dying. The most probable reason for tree dying is the shifting of river banks in the meander during the year, which can be up to several meters.

As most samples could not be dated by the dendrochronological method, the radiocarbon method was used. Most dated trunks (13 in total) came from Tovačov (Table 2) and they were all dated by the radiocarbon method. Using the results, we can divide the samples into four periods. The first group consists of five samples from years 2780–2190 BC. The second group has six samples from 265 BC–404 AD. The remaining two samples were number 12 (1129–789 BC) and number 22 (1783–1446 BC). We can conclude that the conditions of this site were favourable for the growth of oak forests for more than four thousand years. The samples could not be dated by dendrochronological methods because their tree rings show a regular four-year cycle in which each fourth ring was significantly narrower than the previous three. The cycle was probably caused by the fact that the living trees were attacked by cockchafer (*Melolontha*, Linnaeus) (Christensen, 1987). This beetle is a typical defoliator of mainly broad-leaved tree species in entire Europe, especially in low lands. Cockchafer can have three- to five-year life cycle dependent on climatic conditions. Its attack causes a considerable reduction in diameter increment as soon as in the year of attack. The deformed tree-ring curves cannot be dated by means of dendrochronology. Therefore, other samples could not be synchronized with samples dated by the radiocarbon method. The trend of the curves is so significantly affected by the attack that the results of other dated samples would be distorted. Moreover, these samples have to be excluded from the creation of the oak standard chronology of subfossil trunks.

A site with an abundant appearance of trunks is in Osek nad Bečvou. Besides the trunks found in the Bečva River, a lot of trunks were found during gravel extraction in the newly opened gravel pit. In total, 50 samples were taken here but it was not possible to use them to create the average tree-ring curve. Four samples from the gravel pit were dated by the German oak standard chronology to the period around 1000 AD. From the basin also four samples were dated – to the following periods: 945–405 BC, 665–895 AD, 885–1155 AD, 1205–1320 AD (Tables 3 and 4).

The most southern site with frequent findings of trunks is a 12 km long reach of the Morava River flowing past Strážnice. In total, 16 samples were taken here, out of which 14 were dated. Three samples were used to create the average tree-ring curve and this was dated by the Moravian oak standard chronology MORGES 2005 to the period after 1322 (Fig. 2, Table 5). The other samples were dated by dendrochronological or radiocarbon methods to the period between the 8th and the 17th centuries (Table 6). In total, 259 samples from the Morava River basin have been processed with the purpose of standard chronology creation. In the years to follow we expect that further sampling in the above mentioned sites will be carried out and other sites with possible appearance of subfossil trunks will be searched for.

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