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Continuity and change in the vegetation of a Central European oakwood

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Abstract

The issue of continuity in deciduous oakwood vegetation has been in the forefront of woodland ecological studies for many decades. The two basic questions that emerge from existing research are whether or not oakwoods can be characterized by long-term stability and what may be the driving forces of the observed stability or change. To answer these questions in a well-defined case study, we examined the history of a large subcontinental oakwood (Dúbrava) in the southeastern Czech Republic with interdisciplinary methods using palaeoecological and archival sources. Palaeoecology allowed us to reconstruct the vegetation composition and fire disturbances in Dúbrava in the past 2000 years, while written sources provided information about tree composition and management from the 14th century onwards. The pollen profiles show that the present oakwood was established in the mid-14th century with an abrupt change from shrubby, hazel-dominated vegetation to oak forest. This change was most probably caused by a ban on oak felling in AD 1350. From the 14th to the late 18th centuries Dúbrava had multiple uses, of which wood-pasture and hay-cutting kept the forest considerably open. The second remarkable change was dated to the late 18th century, when multiple-use management was abandoned and Dúbrava was divided into pasture-only and coppice-only parts. The last major shift occurred in the mid-19th century, when modern forestry and Scotch pine plantation became dominant. We conclude that Dúbrava Wood did not show stability in the long run and that its species composition has dramatically changed during the last two millennia. The most important driving force in the shaping and maintenance of the unique vegetation of Dúbrava was human management.

Keywords

ecosystem stability, historical ecology, management history, palynology, *Quercus*, temperate oakwood, written sources

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Introduction

Deciduous oakwoods have been on the decline for a century all over Europe, because oaks fail to regenerate. This phenomenon is often referred to as ‘Oak Change’ or ‘Oak Decline’ (Rackham, 2008; Watt, 1919). Available studies attribute it to various plant diseases (e.g. *Microsphaera alphitoides, Phytophthora* species), decline in human management or a combination of various factors (Jung et al., 2000; Luisi et al., 1993). Nonetheless, the term ‘oakwood’ denotes more than the dominance of oak species in the tree layer – deciduous oakwoods are specific biotic assemblages with many species more or less confined to this type of biotope (Ellenberg, 1996; Konvička et al., 2004).

The issue of continuity in deciduous oakwood vegetation has been in the forefront of woodland ecological studies for many decades. The two basic questions that emerge from existing research are whether or not oakwoods can be characterized by long-term stability and what may be the driving forces of the observed stability or change. Some scientists argued that deciduous oakwoods are the natural vegetation of the relatively warm and dry areas of Europe (Bohn and Neuhäusl, 2000; Ellenberg, 1996; Zólyomi, 1957), and are therefore stable communities occupying a restricted range of ecological conditions for several millennia. Others claimed that human management (burning, pasturing, litter raking and coppicing) rather than natural conditions played a decisive role in the maintenance of European deciduous oakwoods. This view is supported by the recent notable decline of oakwood species assemblages and the ‘invasion’ of hornbeam, maples, ash and lime following the abandonment of traditional management (Hédl et al., 2010; Kwiatkowska et al., 1997; Roleček, 2007). This opinion connects the stability of oakwoods to continuity of management on a millennial case, which implies fluctuations in vegetation with changes in human population densities around particular oak forests.

While the question of stability versus change can be approached using a single disciplinary perspective (such as palynology, Huntley and Webb, 1988; Segerström, 1997; Ritchie, 1995), the study of driving forces requires a multiproxy approach (Bürgi et al., 2004; Ireland et al., 2011; Pechony and Shindell, 2010). The comparison of natural scientific data with historical written sources is particularly useful in this respect, since historical sources can provide a framework of interpretation for palaeoecological data (Lindbladh et al., 2007; Veski et al., 2005). Archival data have been successfully used to detect driving forces of vegetation stability and change (Bürgi, 1999; Szabó, 2010b).

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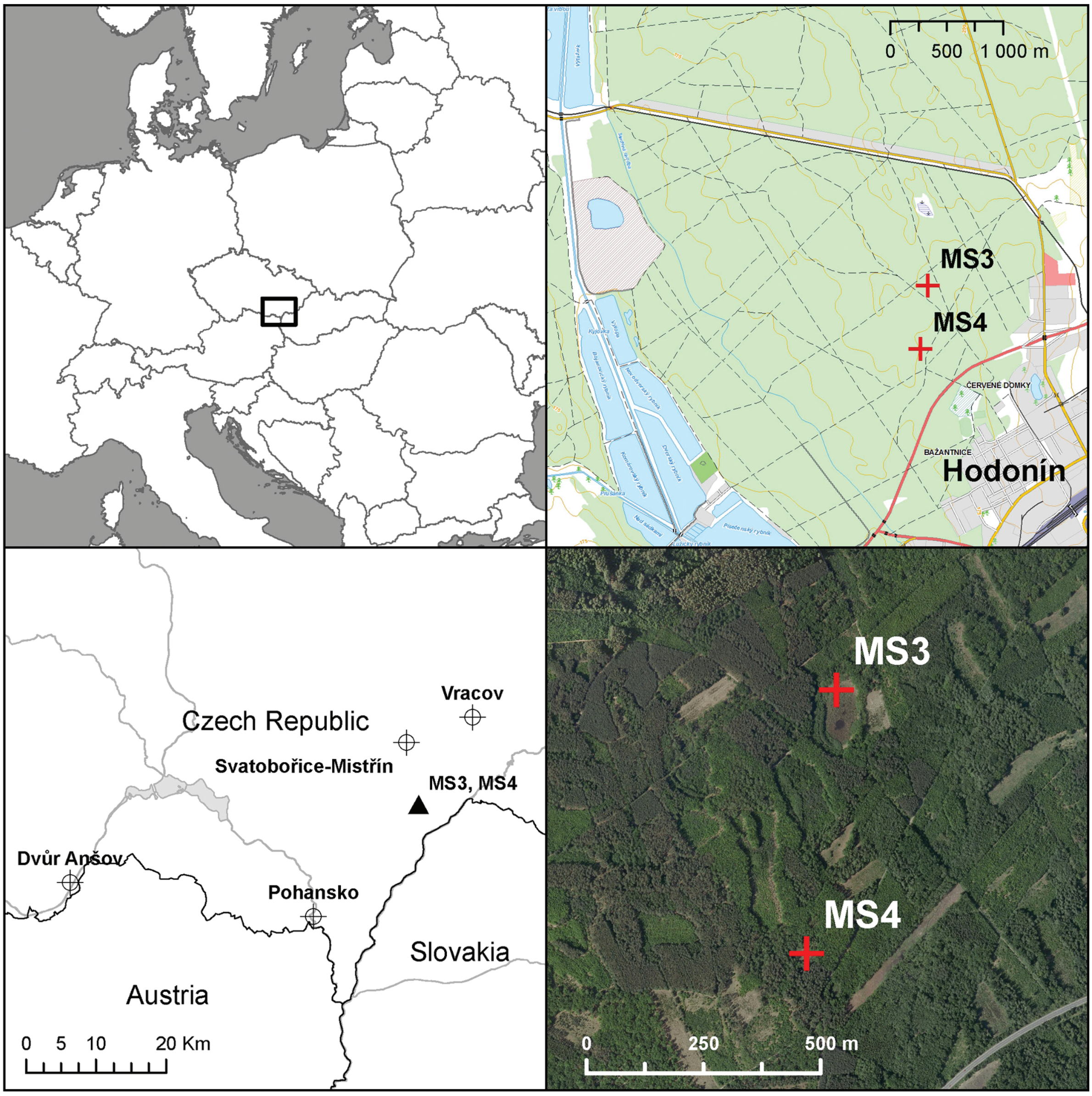

Figure 1. Location of Dúbrava Wood in the Czech Republic with the positions of previously published pollen profiles in the study area.

In this paper we present the results of interdisciplinary research on the long-term dynamics of a large lowland oakwood. This wood is among the best preserved subcontinental deciduous oakwoods in Central Europe (Roleček, 2007). Our study covers the past two millennia, and we integrate (1) pollen and macrocharcoal data from two small forest hollows, and (2) archival written documents on species composition and management at the site. We aim to answer the following two questions:

(1) Is the oakwood at the study site characterized by long-term stability in species composition or were there significant changes during the past two millennia?
(2) What were the driving forces of stability or change? Was the role of natural factors or human management apparently more important?

Materials and methods

Study site

Hodonínská Dúbrava is a large (*c*. 3300 ha) and relatively well-preserved ancient woodland (Figure 1). It is the core site of a specific type of subcontinental oakwoods, *Carici fritschii-Quercetum roboris* (Chytrý, 1997; Roleček, 2007) – a community endemic to this and a few adjacent sites. Because of low groundwater levels, other vegetation types, such as alluvial forests (*Alnion incanae*) and alder carrs (*Alnion glutinosae*) also occur. At higher and drier elevations mesic oak-hornbeam woods (*Carpinion*) prevail. Approximately half of the forest was turned into Scotch pine plantations in the 19th and 20th centuries.

Dúbrava is located at the NW edge of the Pannonian Basin (17°05′00′′E, 48°52′40′′N; Figure 1). Climate is 'humid continental' (cf. Peel et al., 2007). It is relatively warm and dry with *c*. 9°C of average annual temperature and 500–550 mm of precipitation (Tolasz et al., 2007). The site is gently sloping towards the SW, with elevations from 164 to 242 m. Dúbrava lies on the fringe of the wide alluvium of the Morava river, on 150–200 cm deep Quaternary blown sand deposits (Novák and Pelíšek, 1943). Soils are extremely nutrient-poor arenic dystric cambisols (AOPK CR 2002–2010), slightly acidic and prone to desiccation (Novák and Pelíšek, 1943). The water-table fluctuates during the year. The settlement history of the area is typical of Central European lowlands. People have been living in the region since the Palaeolithic with population peaks in the early Copper (4000–3400 BC), late Bronze (1200–750 BC) and late Iron Ages (400–1 BC)

Table 1. Calibration of radiocarbon dates of the MS3 and MS4 profiles.

Depth (cm)	Lab. code	Sample ID	Dated material	^{14}C age (BP)	Calibrated ^{14}C age	
					Mean	Range
40–38	UG-7745	MS3,1	Charcoal	2000 ± 25	AD 6	47 BC– AD 60
34–32	UG-7744	MS3,2	Carex seeds	610 ± 25	AD 1349	AD 1297–1401
14–12	UG-7743	MS3,3	Carex seeds	170 ± 20	AD 1808	AD 1665–1950
44–42	UG-8518	MS4	Charcoal	6420 ± 25	5413 BC	5472–5341 BC
35–33	UG-747	MS4,2	Seeds, charcoal	560 ± 25	AD 1368	AD 1313–1424
17–15	UG-7746	MS4,3	Carex seeds	120 ± 25	AD 1809	AD 1681 –1937

AD: Anno Domini; BC: Before Christ; BP: Before Present (1950).

(Měřínský and Šmerda, 2008a). Dúbrava Wood historically belonged to the estate of Hodonín.

Palaeoecological analyses

The SW part of Dúbrava with numerous spring-submerged depressions was surveyed in 2008. Guidance by R. Řepka helped us locate 15 sites. We chose the six best-preserved sites for coring using a Russian corer in 2008. All profiles were re-sampled for pollen analysis in July 2009, mostly taken from a trench using 10 cm × 10 cm × 50 cm metal boxes. All profiles were analysed for pollen at 5 cm resolution. Following the results of this preliminary analysis and radiocarbon dating (Table 1), we chose two pollen profiles denoted MS3 and MS4. The two sites represent treeless wetlands of *c*. 50–100 m in diameter. Vegetation is dominated by reed (*Phragmites communis*) at MS3 and by sedges (*Carex* spp.) at MS4. The nearest vicinity of both wetlands is forest of *Quercus petraea, Quercus robur* and *Pinus sylvestris*.

Organic sediments from MS3 and MS4 stored in metal boxes were subsampled by 1 cm. The preparation of samples for pollen analysis followed standard techniques (Faegri and Iversen, 1989). Samples containing mineral material were pre-treated with cold concentrated HF for 24 h and then processed by KOH and acetolysis. At least 500 pollen grains were identified using standard key and photo collections (Beug, 2004; Reille, 1992, 1995, 1998); for the determination of non-pollen palynomorphs we used van Geel et al. (1980/1981). The nomenclature of pollen types follows Beug (2004).

Macrocharcoal analysis was carried out on the same sections as the pollen analyses. Sediments were sampled continuously at 1 cm increments using a calibrated sampler of 2 ml volume. The macrocharcoal analysis of MS3 took place after the removal of parts of the sediment for radiocarbon dating, therefore charcoal data from some parts are missing. Extracted material was deflocculated with 10% KOH and subsequently non-charred organic particles were bleached by 3% hydrogen peroxide (Schlachter and Horn, 2010). Particles larger than 125 μm were separated from the samples by wet sieving. Quantification of charred particles was performed using optical analysis of microphotographs processed by ImageJ software (Rasband, 1997). Charcoal fragments were identified according to their black colour and characteristic shape (Enache and Cumming, 2006).

Pollen data are presented as percentages based on terrestrial pollen sum, from which aquatics and local mire plants, pteridophyta, algae, fungi and other non-pollen palynomorphs were excluded. Charcoal concentration is expressed as the number of pieces per 2 ml. Percentage pollen diagrams with macrocharcoal histograms were created in Tilia v. 1.7.16 (Grimm, 2011). The pollen profiles were divided into three (MS3) or four (MS4) pollen zones based on the results of ConsLink and visual analyses. For a comparison of archival and pollen data, it is necessary to understand the relevant source area of pollen (RSAP) (Sugita, 1994). In the case of small basins situated within forests Sugita (1994) estimated the RSAP to be 50–100 m and about 40–50% of pollen coming from trees growing within this radius, while the rest (background pollen) originating from outside the RSAP. Calcote (1995) confirmed this estimation by empirical research of fossil pollen in forest hollows.

Selected plant macrofossils or charcoal taken from three depths in each profile were used for AMS radiocarbon dating in the Center for Applied Isotopes Studies, University of Georgia, Athens GA, USA. An age–depth relationship model was constructed for both profiles using Clam v.1.0 R code (Blaauw, 2010; R development Core Team, 2008). IntCal04 calibration curve (Reimer et al., 2004) was used to calibrate radiocarbon dates. To estimate the age of every pollen sample, linear interpolation between the midpoints of calibrated dated levels was applied (Table 1). The age–depth model was forced to go through 0 cm = 2009 BC/AD (BC ages are negative) (Figure 2). In this paper we use calibrated years. The radiocarbon date of the organic sediment from the base of the MS4 profile (5413 BC obtained from charcoal) gave a result apparently too old when compared with the MS3 profile, and was not used. This date may have resulted from the sandy base allowing the vertical migration of plant macroremains and charcoal. However, the date could possibly be correct, which would refer to slow accumulation of organic material. Nonetheless, the continuous presence of *Juglans*, which is known to be a Roman import in the region (Hajnalová, 2001), in both profiles appears to indicate that the base of MS4 is unlikely to be older than the Roman Period.

Archival research

To find out about the history of management and vegetation in Dúbrava, we studied the written records produced by the Hodonín estate administration from the 14th to the 20th centuries. All sources are presently kept at the Moravian Archives (MZA) in Brno. Written sources are precisely dated, which allowed us to establish a firm chronology of management changes. When compared with data on management, for most of the study period information on vegetation was patchy and rather vague. However, for the last two centuries precise data are available on tree species composition. The following kinds of sources were used:

(1) *Charters* are records of legal transactions. The first charters dealing directly with Dúbrava are from the mid-14th century, while the last ones are from the 18th century.
(2) *Urbaria* are conscriptions of all incomes from an estate. Four *urbaria* survive that provide relevant information about the Hodonín estate. They date from 1600 (MZA F5 kniha 1a, analyzed in Chocholáč, 1994), *c*. 1654 (incomplete: MZA F5 kniha 1), 1691 (MZA F5 kniha 3) and 1805 (MZA F5 kniha 4).

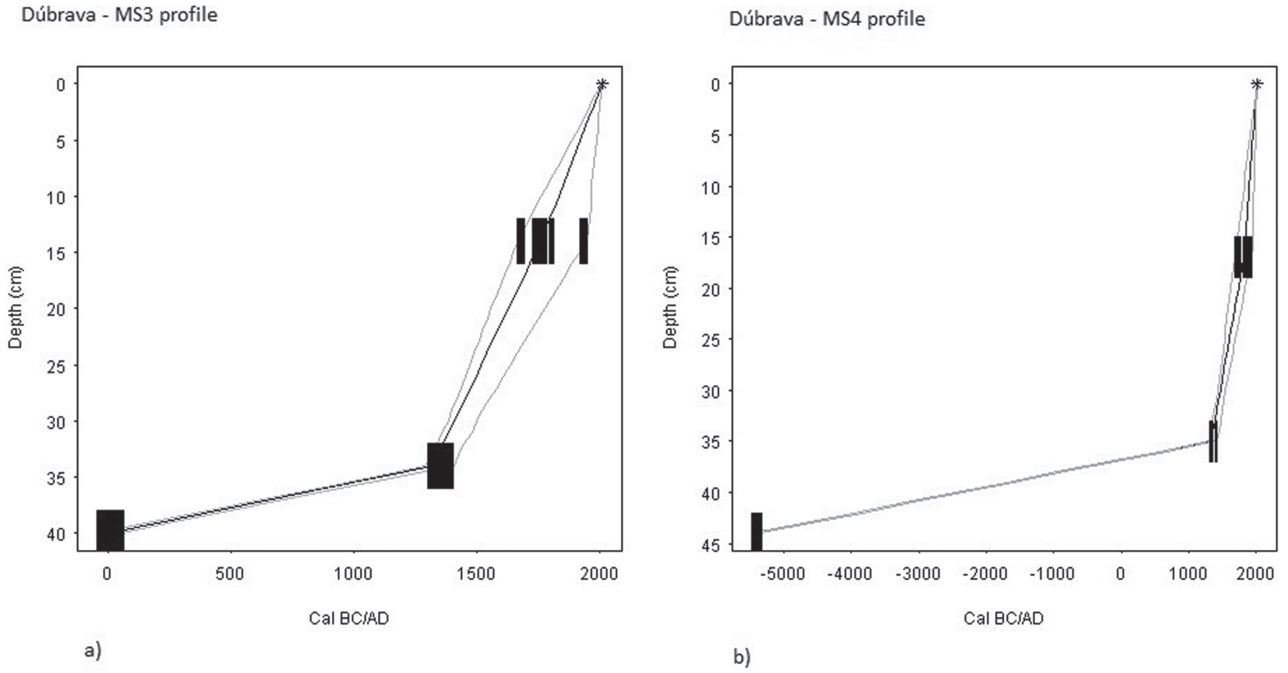

Figure 2. Age–depth relationship of (a) MS 3 and (b) MS4 profiles based on three radiocarbon dates for each profile. Cal.: calibrated ages; AD: Anno Domini (after Christ); BC: Before Christ.

(3) *Estate conscriptions* describe the value of landed property in a given historical moment. A detailed conscription survives from 1692 (MZA F5 kniha 5).
(4) *Account books* were kept by woodland owners to register incomes generated by the cutting and selling of underwood and timber. For Dúbrava only a few remain, covering the years 1765–1772 (MZA F5 karton 538).
(5) *Forestry management plans* (FMP) are detailed surveys containing information on the name, size and position of each woodlot, as well as on tree composition and forest structure, supplemented by current and planned management. FMPs of Dúbrava are from 1851 (MZA F5 kniha 232), 1864 (MZA F5 kniha 233-236, 238, 240) 1906 (MZA F5 kniha 242, 244, 245), 1925 (MZA F263 kniha 1), 1936 (MZA F263 kniha 4, 5) and 1952 (MZA F302 kniha 4).
(6) *Forestry documents* were produced by the local forestry administration. Such documents include e.g. various surveys of woodland areas, discussion on types of management and detailed diaries of yearly activities.
(7) *Large-scale maps* (*c*. 1: 30,000 and larger) are generally available in the Czech Lands from the 18th century onwards. We used three nationwide surveys prepared by the Austrian Army in 1764–1783, 1836–1852 (both 1: 28,800) and 1876–1880 (1: 25,000), available online at http://oldmaps.geolab.cz. A much more detailed (1: 2880) set of maps were drawn in 1824–1843 as part of the so-called Stable Cadastre (Bičík et al., 2001). Finally, maps produced as parts of forestry management plans were used. Three sets of maps survive from Hodonín: 1851 (MZA F5 mapa 54–59), 1884 (MZA F5 mapa 60–64, note that the FMP itself is lost) and 1906 (MZA F5 mapa 65–70).

Results

Pollen stratigraphy and vegetation history

Based on changes in dominant taxa (Table 2), the pollen diagrams were divided into three (MS3) or four (MS4) phases. The first three phases are highly similar in both profiles, while the fourth one, covering the second half of the 20th century, is visible only in MS4 (Figures 3 and 4). Historical documents show corresponding results; major management changes happened approximately in the transition periods between the pollen zones. Because of the high similarity between the pollen spectra and historical sources, the results are presented jointly.

Roman period to the high Middle Ages (1st century AD–mid-14th century AD) – Phase 1. At the beginning of the sedimentation process dated to the 1st century AD, Dúbrava consisted mainly of light-demanding woody species, such as *Corylus* (19%) and *Betula* (17%). The relatively low proportion of tree pollen and of *Juniperus* (3%) also suggests open forest vegetation. A high amount of pollen of coniferous trees, such as *Picea* (18%) and *Abies* (6%) was also recorded. *Corylus* produces little pollen as an understorey species (Rackham, 1988). The observed high amount of *Corylus* in the profile suggests that it had a dominant position in the vegetation (Gardner, 2002), and that its pollen spread was hardly hindered by overstorey vegetation. This and the presence of *Juniperus* allow us to interpret the vegetation in the nearest vicinity of the study site as shrubby woodland. Such vegetation is implied in the original, high medieval name of Dúbrava, which was Klečka. This name was first recorded in a charter interpolation from AD 1350 (Boček, 1839: 204–205). In Old Czech, 'klečka' refers to a place with shrubs (Gebauer, 1970). The basal layers of both profiles contained low amounts of macroscopic charcoal particles. These provided no evidence for local fire events which could have been connected to the shrubby vegetation dominated by *Corylus* (cf. Tinner et al., 2005).

The composition of herbaceous pollen in Phase 1 indicates the presence of an intensively managed landscape. The high amount of *Artemisia*, Asteraceae, Silenaceae, Rubiaceae and *Valeriana officinalis*-type implies meadows. The constant occurrence of *Cerealia* indicates the presence of arable fields in the nearest vicinity of the site. Ruderal plants such as *Polygonum aviculare*-type and *Polygonum persicaria*-type indicate trampled habitats and cultivated land (Behre, 1981; Gaillard, 2007). At the end of Phase 1, the pollen of *Plantago lanceolata*-type, *Rumex acetosa*-type and *Melampyrum* appeared. These could be connected with grazed grasslands.

Table 2. Characteristics of main phases based on changes in pollen taxa and historical events.

	Cal. AD	MS3		MS4		Written sources	
		Max. %	Min. %	Max. %	Min. %		
Phase 4		n/a	n/a	*Betula, Populus* *Cerealia, Zea mays, Typha latifolia t.*	*Artemisia Chenopodiaceae Cyperaceae*	Dominance of high forests, afforestation of open areas, abandonment of drainage canals	
	1941	*Loranthus europaeus*	**Corylus** *Picea*	*Fraxinus*	**Corylus**		
Phase 3		*Poaceae, Equisetum*	*Artemisia, Asteraceae, Scrophulariaceae, Rubiaceae, Cyperaceae, Typha latifolia t.*	–	*Rubiaceae*	Strict coppicing regime in woodland later to be replaced by high-forests, grubbing out of one third of the Wood and turning it into pasture. Digging of of drainage canals. Beginning of *Pinus* plantations.	End of multiple management, separation of pasture and woodland
	1808/1809	**Quercus** *Betula, Pinus*	*Tilia, Alnus*	**Quercus** *Pinus*	*Picea, Ulmus, Alnus*		
Phase 2		*Chenopodiaceae, Asteraceae, Rubiaceae, Rumex acetosa t., Rhinanthus, Polygonum persicaria t., Cerealia, Secale, Podospora, Sporormiella*	–	*Chenopodiaceae, Asteraceae, Brassicaceae, Lotus t., Rubiaceae, Filipendula, Chaerophyllum hirs. Plantago lanceolata t., Polygonum aviculare t., Secale*	–	Multiple-use management: wood-pasture, hay meadows, coppicing, pannage, wild-fruit and oak gall collection, beehives and arable fields in the Wood. Gradual change in name from Klečka ('place with shrubs') to Dúbrava ('oakwood')	
	1349 /1348	**Corylus**, *Picea, Abies, Ulmus, Tilia, Juniperus, Alnus*	**Quercus**, *Pinus*	**Corylus**, *Picea, Tilia, Ulmus, Juniperus, Alnus*	**Quercus,** *Pinus*		Ban on cutting oaks
Phase 1		*Artemisia, Silenaceae, Senecio t., Scrophulariaceae, Valeriana off. t., Polygonum aviculare t., Polygonum persicaria t., Cyperaceae, Typha latifolia t., Sparganium t.*	*Cerealia, Secale*	*Silenaceae, Ranunculaceae, Senecio t., Apiaceae Geranium, Polygonum persicaria t.*	*Cerealia, Secale*	Original name Klečka refers to shrubby vegetation	
	6						

Cal.: calibrated ages; AD: Anno Domini (after Christ); Max%: maximum (or increasing) of pollen percentage; Min%: minimum (or decreasing) of pollen percentage.

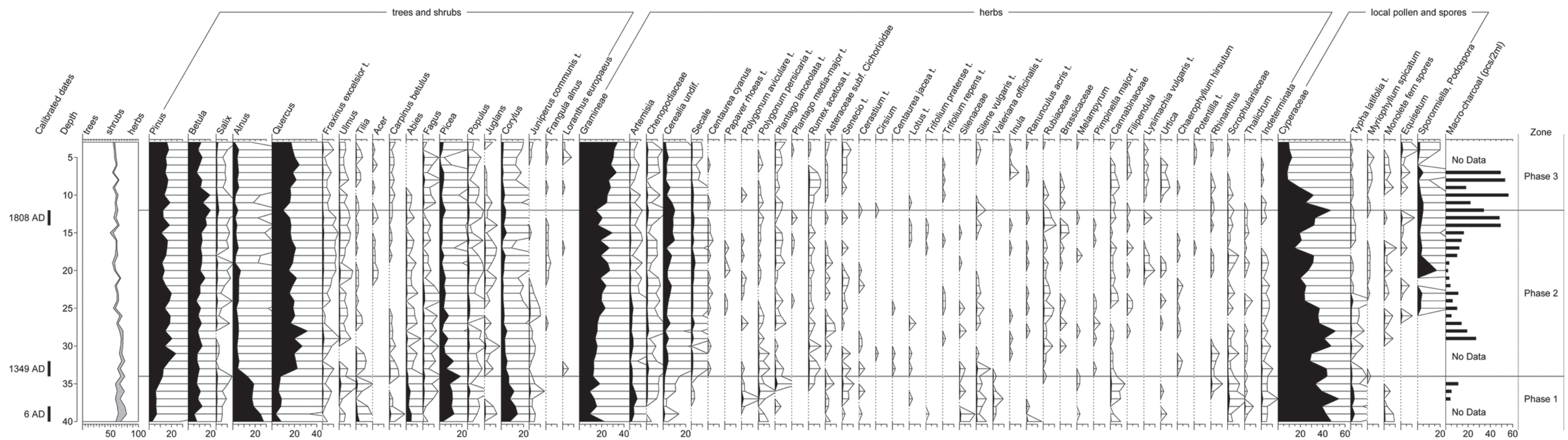

Figure 3. Percentage pollen diagram of selected pollen types with macro-charcoal concentrations from MS3 core. Parts of sediment without macrocharcoal analysis are marked as No Data.

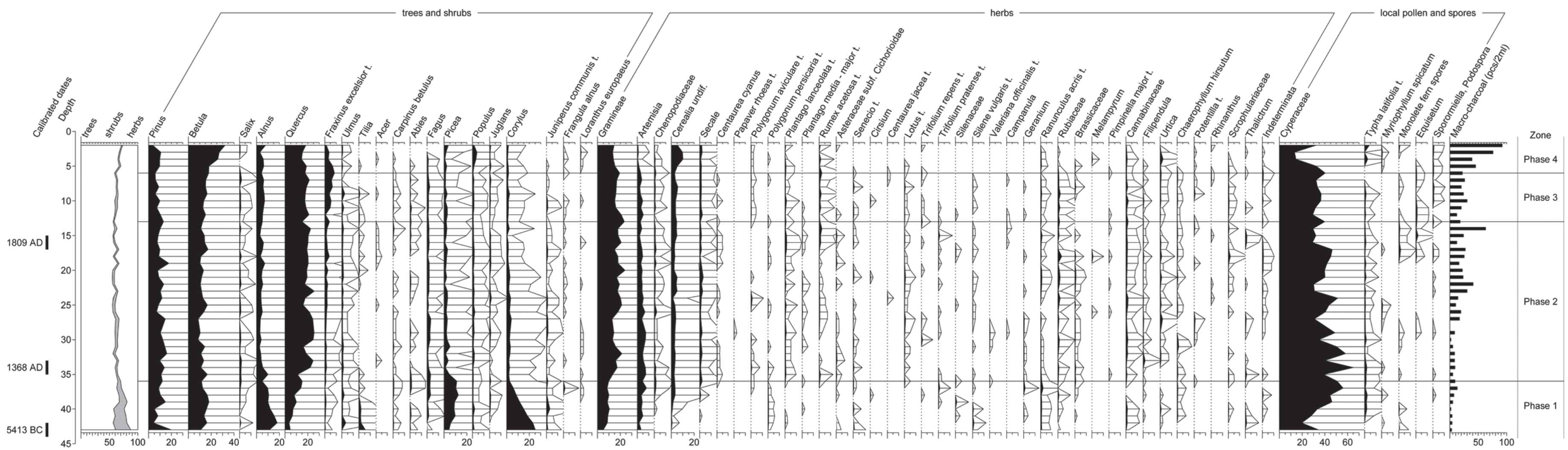

Figure 4. Percentage pollen diagram of selected pollen types with macrocharcoal concentrations from MS4 core.

Late Middle Ages to the early Modern Period (mid-14th century AD*–end of 18th century* AD*) – Phase 2.* The first great change in forest composition occurred in the mid-14th century. It was recorded in both profiles and is dated AD 1348 (MS3) and AD 1369 (MS4). This event is characterized by a rapid increase in *Quercus* (30%, i.e. by 20%), and in *Pinus* (to 10%). It was accompanied by a strong decline in *Corylus* (6%), *Abies* (1%) and *Picea* (4%). *Betula* did not change. The dominance of oak, birch and pine has been characteristic for Dúbrava ever since the beginning of Phase 2.

Two charters refer to the active protection of oaks in Dúbrava precisely in this period. The first one is the above-mentioned interpolated charter from 1350, which gave the citizens of Hodonín the right to take dry wood and grass in the Wood but forbade them to fell living oaks (Boček, 1839: 204–205, for a discussion on the dating of the charter, see Měřínský and Šmerda, 2008b). The other one is the foundation charter of the Augustinian monastery in Brno from AD 1370. It was included in this document that the tenants of the monastery had the right to cut timber and firewood in Dúbrava 'with the exception of oak trees, which they must not cut down at all' (translation from Latin original, MZA F5 karton 11 inv. č. 744, fol. 25–32). The ban on cutting oaks was included in a number of privileges in later centuries as well (e.g. 1531 – MZA F5 karton 3 inv. č. 29; 1600 *urbarium* – MZA F5 kniha 1a).

In Phase 2 the maxima of *Quercus* in both profiles (34% MS3; 28% MS4) and the highest percentage of AP (78%) were recorded. The subsequent decrease in *Quercus* pollen is synchronous with an increase in the pollen of the other main tree species: *Carpinus, Fagus, Abies* and *Picea.* From the middle of the 14th century onwards, the general increase in *Cerealia*, the start of a continuous pollen curve of *Secale* and the occurrence of weeds (*Centaurea cyanus* – a typical high-medieval weed, *Papaver rhoeas*-type) may be connected with the expansion of arable land as a consequence of population growth in the surrounding area. The unchanged curves of *Plantago lanceolata*-type, Rubiaceae, *Senecio*-type, *Rumex acetosa*-type, Chenopodiaceae and *Lotus*-type suggest the continuous presence of grasslands and pastures. This argument is also supported by findings of spores of coprophilous fungi (*Podospora, Sporormiella*) in the sediment. The pollen of *Juniperus* and the spores of *Sporormiella* are indicators of livestock farming (Davis, 1987).

We observed a gradual increase in macroscopic charcoal particles throughout Phase 2. This could be connected with higher fire susceptibility of the vegetation caused by the expansion of *Pinus* or with the intensification of human activities in the vicinity of the study sites. Higher concentrations of charcoal particles at the end of this phase in both profiles and a slight decrease in *Quercus* and increase in *Betula* and Cyperaceae may indicate a distinct fire event, however, the percentages of *Quercus, Betula* and Cyperaceae swiftly returned to their previous values.

In this period the name of the Wood changed. The original Klečka ('a place with shrubs') was gradually replaced by Dúbrava ('oakwood'). 'Dúbrava' was first used as a common noun that added information on the Wood (e.g. 1370: 'the oakwood [dúbrava] that is called Klečka' – MZA F5 karton 11 inv. č. 744, fol. 25–32), and only later became a geographical name. The last occurrence of the name Klečka is from 1531 (MZA F5 karton 3 inv. č. 29), after that only Dúbrava was used. Two *urbaria* (1600 – MZA F5 kniha 1a; 1691 – MZA F5 kniha 3) provide detailed information on the management of Dúbrava. The most characteristic feature was multiple use, which included wood-pasture, pannage (the fattening of domestic pigs on acorns), hay cutting in woodland meadows, firewood cutting and the collecting of strawberries and oak galls. There were managed ponds, beehives and even arable fields within the Wood. The system was complex but not random: every use was carefully regulated temporally and spatially. The *urbaria* also include a description of the boundaries of Dúbrava, from which it is clear that the boundaries of the Wood were similar to those of today and that a few hundred metres from the pollen sites we investigated there were arable fields. Relatively little direct information is available on tree species in this period: apart from frequent references to acorns and oak galls, the 1692 estate conscription (MZA F5 kniha 5) mentioned that Dúbrava comprised mostly of oaks and partly of aspen and birch. The lack of *Pinus* in this list is noteworthy.

Modern Period (19th century AD*–present) – Phases 3 and 4.* At the beginning of the 19th century the second major change in the composition of Dúbrava can be observed. In the pollen diagrams this was reflected by a change in tree composition. A moderate decline in *Quercus* and increase in *Betula, Pinus, Salix, Populus* and *Fraxinus* can be associated with several, possibly interacting factors. A significant decline in *Cerealia* and *Secale*, dated to the beginning of the 19th century, is visible in MS3 but not in MS4; the latter is characterized by an increase in *Polygonum aviculare*-type, *Trifolium repens*-type and large quantities of coprophilous fungal spores (*Podospora*). The apparent contradiction (increase in human activities in MS4, decrease in MS3) can be explained by the different location of the profiles within the Wood.

The last change was recognized only in MS4 and refers to Phase 4. It is dated to the mid-20th century and is characterized by a rapid increase in *Populus* and *Betula* and the disappearance of pasturing indicators, such as *Plantago lanceolata*-type, *Trifolium repens*-type and Rubiacae. It refers to the abandonment of pastures and fields inside or immediately outside the Wood and secondary succession with *Populus* and *Betula* as pioneer trees. The curve of *Quercus* rose again but it never reached the medieval maximum of the beginning of Phase 2. At the end of this phase we also recorded a decrease in the curves of other herbs, for example *Filipendula, Potentilla*-type*, Chaerophyllum hirsutum*, Silenaceae.

Macroscopic charcoal concentrations steeply increased towards the top of MS4. This indicates the presence of fire events in the fire-prone *Pinus* stands which were established by modern forestry. The increase in charcoal particles could also be associated with the construction of a railway line along Dúbrava Wood. The first steam engine on the Emperor Ferdinand Northern Railway passed through the town Hodonín in AD 1841 (Vykoupil, 2008).

Written sources show a major management change at the beginning of Phase 3. In the late 1780s Dúbrava was divided into two parts. The larger part (*c.* two-thirds of the whole) was enclosed by a woodbank (Szabó, 2010a) and turned into a coppice, while on the remaining one-third all trees were quickly removed and the area was turned into pasture. The former multiple management was abolished; pasturing, hay-cutting and pannage were banned. By the mid-19th century, however, the forestry administration changed its mind about management and started transforming the coppices into high-forests, partly with the help of *Pinus* plantations. Timber producing high-forests (including plantations) have formed the majority management type since the 1950s (as witnessed by consecutive forestry management plans: 1851 – MZA F5 kniha 232; 1864 – MZA F5 kniha 233-236, 238, 240; 1906 – MZA F5 kniha 242, 244, 245; 1925 – MZA F263 kniha 1; 1936: MZA F263 kniha 4, 5; 1952 – MZA F302 kniha 4). There were continuous efforts to afforest the open areas in the Dúbrava, however, these were unsuccessful until the 1920s. The pastures created in the late 18th century did not last long, and by 1906 (MZA F5 kniha 242, 244, 245) they reverted back to woodland (Figure 5).

The hydrological regime of the Wood was also changed. Some time in the 19th–20th centuries much of the territory of Dúbrava was drained by a network of channels. These channels connected

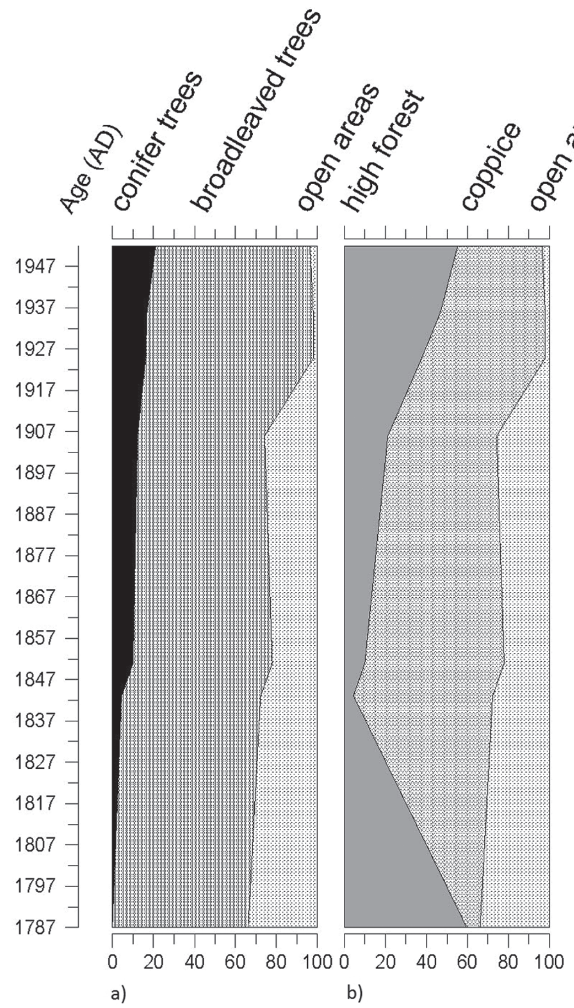

Figure 5. Changes in the amount of (a) broadleaved forest, conifer forest and open areas, (b) high forest, coppice and open areas and in Dúbrava since the end of the 18th century. Data prior to 1851 are approximate.

wetter areas and drained their water into larger canals that had been created in and around the Wood since the 15th century. These drainage channels are still visible in the field but are not maintained any more. Their dating is uncertain. The 1925 FMP (MZA F263 kniha 1) mentioned maintenance work on canals that were created before 1907, therefore we assume that the channels were dug already in the 19th century.

Discussion

The combination of pollen analysis, macrocharcoal analysis and the study of historical documents provides synergetic results about vegetation stability and historical human impact in Dúbrava Wood. Palaeoecological analyses enabled us to reconstruct vegetation composition and fire disturbances during the past 2000 years while written archival material revealed information on tree composition and management practices for the past seven centuries.

Stability/change in species composition in a regional context

Our results show that in the study period the species composition of Dúbrava went through significant changes. In the 14th century the vegetation of Dúbrava Wood changed from shrubby growth composed mainly of *Corylus* and *Betula* to subcontinental oakwood. In the past two centuries mesophilous species started to spread and *Pinus* plantations appeared – this process continues to the present.

To gain a more general picture of forest vegetation development in the study region, we used previously published palaeoecological data from four nearby sites: Vracov (Rybníčková and Rybníček, 1972; Svobodová, 1997), Svatobořice-Mistřín (Svobodová, 1989, 1997), Anšův Dvůr (Svobodová, 1990) and Pohansko (Doláková et al., 2010; Svobodová, 1990). They showed that *Quercus* started to spread in the study region in *c*. 6900 BC. After this date, grassy subxerophilous oakwoods or mixed oak-lime-hornbeam forests developed in mesic conditions, and floodplain forests prevailed in wet conditions. All four pollen profiles recorded the dominant presence of *Quercus* from *c*. 6900 BC to the early Middle Ages, *c*. 6th–9th centuries AD. Unlike at the other three sites, there were relatively high amounts of *Fagus* and *Abies* at Vracov from *c*. 3900 BC onwards. This may have resulted from long-distance transport as the site represents a larger lake basin. In contrast to the vegetation recorded in the four profiles, from the 1st to the 14th centuries AD Dúbrava consisted mainly of *Corylus* and *Betula. Quercus, Tilia, Ulmus* and *Carpinus* occurred only as admixture species. However, we cannot tell whether the vegetation observed at the beginning of the study period had been stable in previous centuries or whether it was the result of recent changes.

The most significant spread of oak in Dúbrava was recorded at the beginning of the 14th century. This process was accompanied by a decrease in other trees and shrubs, mainly *Corylus*. A comparison with other pollen diagrams from the region shows a similar decrease in *Corylus* and increase in *Quercus*, however, at a completely different date, in *c*. 1200 BC (Svobodová, 1997). The massive spread of oak recorded in Dúbrava has no analogues in southern Moravian pollen profiles in this period, all four of which show a decline in *Quercus* starting from the early Middle Ages.

The pollen profiles from Dúbrava ended with a visible decline in oak and an increase in ash, birch and pine in the 19th century. This increase in *Fraxinus* and *Pinus* was recorded in other pollen diagrams from the study region as well. The spreading of *Fraxinus* in predominantly oak forests is probably a natural reaction to the absence of organic matter removal and is part of a gradual change to a shady mesic forest (Hédl et al., 2010; Hofmeister et al., 2004). *Pinus* spread mainly as a result of plantation forestry.

Driving forces of stability/change in species composition

A possible explanation of the rapid spread of *Quercus* in Dúbrava in the 14th century ad could be provided by the onset of the 'Little Ice Age' (LIA), which began in *c*. ad 1300 (Matthews and Briffa, 2005). Climate change (cooler and moisture conditions) could have influenced vegetation composition and cause the spreading of *Quercus*, which is less sensitive to late frosts than *Fagus*. In Białowieża forest (Poland), Mitchell and Cole (1998) attribute the dominance of *Quercus* to a competitive edge in edaphic conditions. However, Faliński (1986) described the dominance of *Quercus* in this forest as a result of grazing (herbivores and cattle). After a reduction in grazing, *Quercus* was replaced by *Carpinus*. In our study region, no other pollen profile records an increase in *Quercus* in the LIA; climate change is therefore unlikely to have caused the dramatic change in the vegetation of Dúbrava. Another possible explanation of the massive spread of oak is fire. Recent studies form North America show that the widespread occurrence and dominance of oak is the result of frequent fires (Abrams, 1992). Today, oak is in decline because of fire suppression by humans, which leads to a gradual replacement of oak by shade-tolerant species (Dey, 2002; Little, 1974; Lorimer, 1993; Van Lear, 1991). However, the results of macrocharcoal analyses from Dúbrava showed no major fire event parallel with the sudden change in species composition at the beginning of Phase 2. There is some indication of a possible fire at the end of Phase 2, nevertheless even in this case higher concentrations of charcoal particles were not connected to any lasting influence on species composition. Fire is therefore unlikely to have been a driving force of species composition changes.

In a regional context, the changes in the species composition of Dúbrava Wood appear to be rather exceptional. In such cases, site history is often the best explanatory factor (Ejarque et al., 2009; Lindbladh et al., 2007; Veski et al., 2005). Two written documents mentioned the protection of oaks in the mid-14th century, which precisely coincides with the pollen data. However, the interpretation of these charters needs careful attention. Such bans were a commonplace in medieval charters and did not necessarily have to have any concrete consequences. In Sweden in the 18th and 19th centuries a similar ban is known to have caused a decline in oak numbers, although the socioeconomic conditions here were very different from late medieval Moravia (Eliasson and Nilsson, 2002). Nonetheless, in our case the existence of two charters and a simultaneous increase in oak pollen can hardly be a coincidence. These charters indicate that from the middle of the 14th century oaks were in fact actively protected in Dúbrava, which led to changes in the vegetation. According the Vera Hypothesis (Vera, 2000), an increase in wood-pasture (also recorded in the two charters) could also have promoted oaks. Similar conclusions were arrived at for an earlier period at Pohansko, where the spread of *Quercus* accompanied by a slight decrease in *Tilia, Fraxinus* and *Ulmus* in *c*. AD 600–700 was attributed mainly to grazing by pigs (Kratochvíl, 1981; Svobodová, 1990;).

From the 14th to the late 18th centuries, Dúbrava had multiple uses, some of which (pasturing and hay cutting) kept the Wood relatively open. In this phase the maxima of *Quercus* in both profiles (34% MS3; 28% MS4) and the highest percentage of AP (78%) were recorded. This is confirmed by the 1692 estate conscription, which claimed that the Wood comprised mostly of oaks. The change in species composition (slight decline in *Quercus* and spreading of *Fraxinus, Betula, Populus* and *Pinus*) at the end of this period could have multiple reasons. One is a change in hydrological conditions (the construction of drainage channels), another could be windbreak as suggested by an increase in pioneer trees (*Populus* and *Betula*). Written documents show that multiple-use management ended exactly at this time, and the part where the forest hollows are situated was turned into pure coppice and some 50 years later into high-forest. Therefore the change in species composition can also be associated with a reduction of grazed areas (disappearance of pasturing indicators) and the gradual conversion to high-forest. A similar situation was observed in Białowieża forest (Faliński, 1986; Mitchell and Cole, 1998), where species of open habitats gradually declined and mesophytic tree species (*Carpinus*) replaced oak. This has lead to the loss of species assemblages typical for subcontinental oakwoods (Kwiatkowska et al., 1997).

Protecting the unique vegetation of subcontinental oakwoods

Open canopy oakwoods currently host many endangered species (Spitzer et al., 2008). To sustain their populations, these species had to find suitable habitats throughout the Holocene. It is often argued that open oakwoods with wood-pasture continuity must have been present since prehistoric times (e.g. Vera, 2000; Vodka et al., 2009). While this is certainly possible, other management types and tree species compositions could have provided equally suitable conditions. For example Milovice Wood, a large subcontinental oakwood not far from Dúbrava, was managed as a coppice-with-standards for at least 600 years (Szabó, 2010b). Only when coppicing ceased did the subcontinental character of the vegetation begin to rapidly fade (Hédl et al., 2010). Our results indicate that open woodland could have consisted of various community types. In Dúbrava, open forest communities were apparently present from the first millennium AD, while the oakwood fully developed only in the 14th century. This suggests that even from the point of view of species sensitive to canopy openness, open oakwoods might not have been the only option for survival in the Holocene.

Conclusions

We conclude that Dúbrava Wood did not show stability in the long run and that its species composition has dramatically changed during the last two millennia. From AD 0 to 1350 Dúbrava was almost certainly not an oakwood. The origins of its present species composition date back to the 14th century, when intentional management caused a shift from shrubby, hazel-dominated vegetation towards an oakwood. The most important driving force in the shaping and maintenance of the unique vegetation of Dúbrava was human management. medieval management promoted oaks, and the open oakwoods were further maintained by multiple-use management in the early Modern Period. They were subsequently drastically reduced in extent by modern forestry plantations continuing to date. The species in the herb layer could have been present in the millennia preceding the past 2000 years; however, until the 14th century they had to survive in other types of vegetation than subcontinental oakwoods.

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