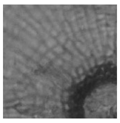
Could canopy forests survive agricultural colonization in the Polabí lowland (Czech Republic)?

EVA BŘÍZOVÁ & LUCIE JUŘIČKOVÁ



The Polabí lowland is one of the most important agricultural areas in Central Europe. Since the Neolithic Age, agriculture has prevented full expansion of the mixed deciduous forest. We studied the succession of molluscan assemblages and/or fossil pollen in this area to answer the question as to how long the canopy forest could survive ongoing human impact. Environments suitable for the fossilization of these two fossil types differ, and the joint occurrence of both is rare. However, the 0.75 m deep profile of alluvial loams and clays situated in the irregularly inundated floodplain area of the Dubanka stream yielded material rich in both mollusc shells and pollen. Very rich molluscan assemblages occur only in a 45 cm thick layer, which was dated using the AMS radiocarbon method to the Bronze Age (1796 BC–1258 BC). The molluscan assemblages consist of continuously occurring rare deciduous woodland species (such as *Discus perspectivus, Platyla polita, Cochlodina orthostoma, Ruthenica filograna*) and species of relict wetlands (*e.g. Perpolita petronella, Vertigo angustior, V. antivertigo, Vallonia enniensis*). Pollen analyses also suggest the presence of wetland assemblages, with a huge proportion of alder in the central part of the succession followed by willow. The deciduous forests consist of elm (*Ulmus*), oak (*Quercus*), lime tree (*Tilia*), maple (*Acer*) and hazel (*Corylus*). Pollen grains of spruce (*Picea*), white fir (*Abies*) and beech (*Fagus*) confirm the late Holocene age of the profile. These results provide evidence of a woodland and wetland mosaic which still covered this landscape during the Bronze Age, in contrast with the present-day monotonous open lowland. • Key words: canopy forest, Bronze Age, agriculture landscape, mollusc succession, pollen analyses, Holocene.

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A river floodplain is a very specific ecosystem of great importance in the landscape. The majority of authors accept the floodplain (alluvium) as consisting of soils or river sediments lining an area impacted by floods and built up by river erosion, relocation and accumulation over time. Broad rivers produce an alluvial terrace system affecting the whole character of the landscape, while deposits accumulated by small rivers affect only the local habitats. However, both cause an increase in the diversity of the abiotic environment and associated organisms (Kalicki 2006; Břízová 2007, 2008a; Jankovská 2008). The development of floodplains during the last few centuries can be described based on written sources or pictures of a particular landscape. The geology and geomorphology of river sediments provide information on millenniums of landscape history (*e.g.* Boothroyd & Nummendal 1978; Břízová & Havlíček 2000; Břízová *et al.* 2000, 2001, 2007; Tyráček 2001; Bridge 2003; Bridgland & Westaway 2007; Adamová *et al.* 2008; Hradecká *et al.* 2008; Brown *et al*. 2009). In suitable sedimentation environments (Břízová 1999a, Ložek 2003, Pišút *et al*. 2010), plant remains and pollen can supplement information on floodplain succession and enable dating in the order of centuries. It is only rarely that information on fossil mollusc shells can be added to this complex of knowledge because the fossilization conditions for pollen and molluscs are quite different (Ložek 2000, 2007). Previously, there had been only three known sites with a parallel occurrence of molluscan shells and pollen in Holocene sediments – Kobeřice (Kovanda 1987, Břízová 1994), Rynholec (Kovanda 1993, Břízová 1999b) and Dudváh (Pišút *et al.* 2010). The process of sediment accumulation by a river is repeatedly interrupted by river erosion (Dreslerová *et al.* 1994, Břízová 2001). Fluvial processes during the Late Glacial and Holocene depended largely on climatic conditions. Human activity, especially deforestation and agriculture, have further affected these processes since

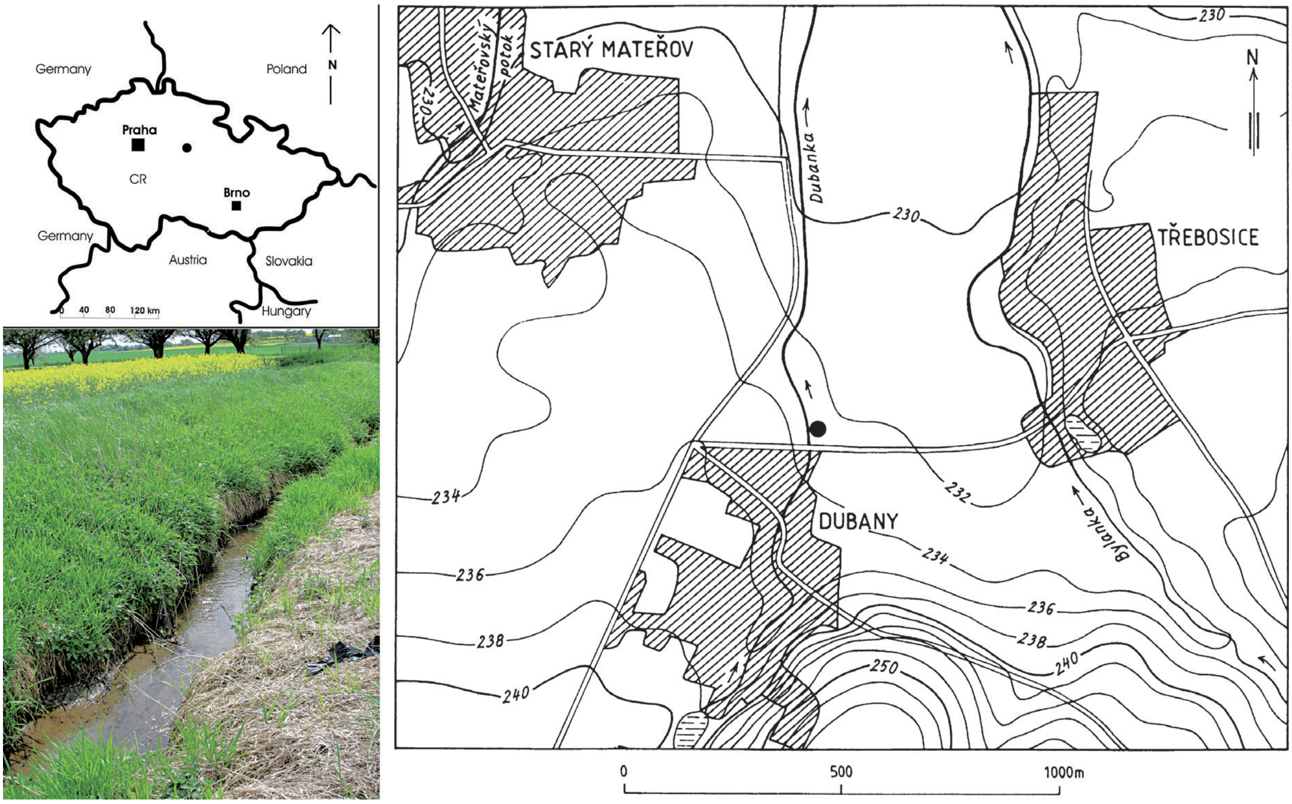


Figure 1. Location of the Dubany site and the present state.

Table 1. AMS radiocarbon age dating of the molluscan successions in Dubany.

Sample name	Laboratory code	Material	Depth (m)	Conv. Age ± Err. yr BP ^{14}C	Calib. Age y.BC ^{14}C (95.4% probability)
Dubany MF 3	Poz-33200	shell	0.15–0.25	3,030 ± 40	1,408–1,132
Dubany MF 5	UGAMS 6450	shell	0.40–0.45	3,430 ± 30	1,877–1,639

the Neolithic Age (Kalicki 2006, Brown 2009). One of the most important areas of Neolithic settlement in Central Europe is the Polabí lowland. Many data indicate that the Polabí lowland has had an open landscape without canopy forest since the Neolithic Age (Dreslerová *et al.* 2004, Ložek 2007). However, there are important differences between the drier western part and more humid eastern part of this area where only Bronze Age settlements have been recorded (Pleiner *et al.* 1978, Ložek 2007). While fully developed forest molluscan fauna are recorded as not occurring in the western part, we have only scattered information on the eastern Polabí lowland which is very important biogeographically. The presence of canopy forests in the eastern Polabí is important in the light of connectivity of Central Bohemian woodland communities with the hilly surroundings which were much later impacted by agriculture. Moreover, the eastern Polabí adjoins an area from which Carpathian forest species may have potentially spread to the west.

Some very old data are available from this area (Babor 1901; Frankenberger 1913; Petrbok 1916, 1951; Hlaváč 1937), all of which either commented on or revised the fossil material of previously woodland molluscs (including *Discus perspectivus* and *Macrogastra tumida*) collected by J. Košťál in Jesničánky near Pardubice. Unfortunately, this material lacked a stratigraphic context and has been lost. However, it indicated the occurrence of woodland, wetland and freshwater snail species in Holocene sediments of an uncertain age. Kovanda (1971) characterized this site as a flat deposit of palustric limestones (alms, marls and calcareous fens). Another nearby site at Staré Jesenčany is built up of deposits of calcareous fens, fine grained tufas and alms (Kovanda 1971). Some wetland and woodland snail species of uncertain age (*Discus perspectivus*, *Cochlodina orthostoma*, *Vertigo moulinsiana*) have also been detected at this site (Hlaváč 1937, 1956; Volšan 1969). Unfortunately, both of these sites have been destroyed. These scattered historical data, though, give some indications of the presence of canopy forest snail species in some sites of the eastern Polabí lowland during the Holocene past. Thus, the discovery of

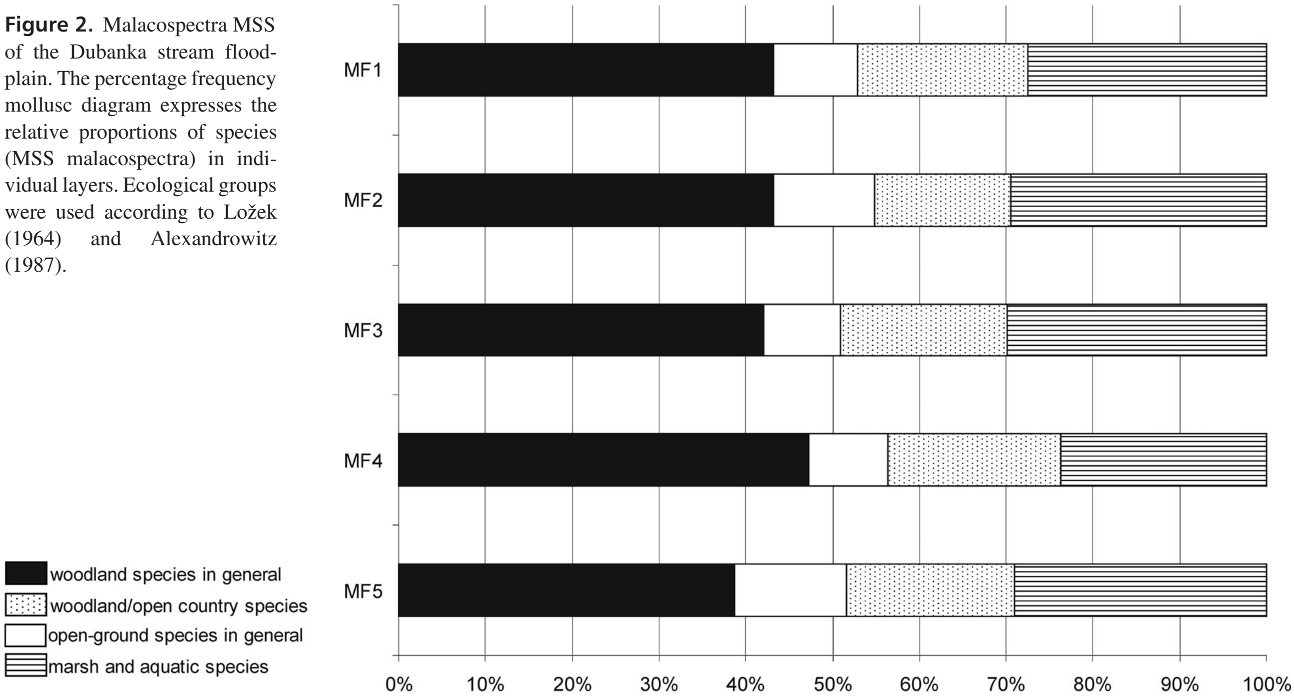


Figure 2. Malacospectra MSS of the Dubanka stream floodplain. The percentage frequency mollusc diagram expresses the relative proportions of species (MSS malacospectra) in individual layers. Ecological groups were used according to Ložek (1964) and Alexandrowitz (1987).

a site suitable for paleoecological research in this area was of great interest. Here we focus on the following questions: How old are the woodland snail species from the river floodplain of this prehistoric area? How long could the canopy forest survive human impacts? What was the appearence of this landscape in the past?

Material and methods

Description of the site

The Dubany site was discovered by J. Straka during Quaternary mapping in 1985. The profile was uncovered as tens-of-meters long outcrops on the right bank of the Dubanka stream (N49°59´ 46˝; E15°43´ 32˝; 233 m a.s.l.) southwest of the town of Pardubice (see Fig. 1). The various types of fluvial sediments had built up a complex of river accumulations on the younger terrace of the nearby Chrudimka river. Part of the flood loams is calcium rich with numerous floated tufa incrustations which offer suitable conditions for the fossilization of mollusc shells, and these layers (0.45 m) contain huge numbers of these shells. Calcareous sediments in a floodplain always indicate low river activity (Kovanda 1983). The complex of sediments with an abundance malacofauna thus documents relatively quiet river overbank sedimentation, probably in an irregularly inundated floodplain.

The profile under the sterile 0.5–1 m thick layer of floodplain loams was sampled to produce 5 malacological and 16 palynological samples, as described below.

Lithology

Lithology of the profile and location of the samples for mollusc fauna (MF) analyses:

0–0.10 m	dark grey clay loam with poorly scattered tufa incrustations, rusty spotted in the middle – MF 1
0.10–0.15 m	the same but darker and more humic – MF 2
0.15–0.25 m	the same but with numerous tufa incrustations (floated tufa) – MF 3
0.25–0.40 m	very dark grey humic loams with numerous small, rough tufa incrustations (floated tufa) – MF 4
0.40–0.45 m	grey-black highly humic clay loams with scattered tufa incrustations – MF 5
0.45–0.55 m	dark grey and rusty spotted clays – layer malacologically sterile
0.55–0.75 m	grey poorly spotted clay loams – layer malacologically sterile.

Molluscan samples

The molluscan successions were sampled using the standard methods (Ložek 1964) – 5 dm^3 samples of sediment were taken from all macroscopically distinguishable layers (see lithology) throughout the profile. Molluscan shells were extracted from the sediments by a combination of floating and sieving. After careful drying, each sample was disaggregated in water. Floating snails were repeatedly decanted into a 0.5 mm sieve and dried under laboratory

Table 2. Assemblages of molluscs in individual layers of the Dubanka stream floodplain sediments. For layer number, see above. Ecological characteristics: General ecological groups: A – woodland (in general); B – open country; C – woodland/open country; D – water, wetland. Ecological groups: 1 – woodland (*sensu stricto*); 2 – woodland, partly semi-opened habitats; 3 – damp woodland; 4 – xeric open habitat; 5 – open habitats in general (moist meadows to steppes). Woodland/open country: 6 – predominantly dry; 7 – mesic or various; 8 – predominantly damp; 9 – wetlands, banks; 10 – aquatic habitats. Biostratigraphic characteristics: + – loess species, (+) – local or ocasional loess species, ! – species characteristic of warm phases, (!) – eurythermic species of warm phases, !! – index species of warm phases, G – species surviving the Glacial out of loess zone, (G) – ditto as relics, M – modern immigrants (late Holocene index species). Presence in layers: R – rare (1–3 individuals); O – occasional (4–10 individuals); C – common (10–25 individuals); D – dominant (more than 75 individuals).

Ecological group		Biostratigraphy	List of species	Layer				
				1	2	3	4	5
A	1	!	*Acanthinula aculeata*		R	R	O	
		!	*Aegopinella pura*	R	(R)	R	R	
		!	*Cochlodina laminata*	C	R	O	C	R
		!	*Cochlodina orthostoma*			R		
		!!	*Discus perspectivus*	R	R	R	(R)	
		(G)	*Discus ruderatus*	R	R	R	R	
		!	*Ena montana*			(R)	R	(R)
		!	*Isognomostoma isognomostomos*	C	R	C	R	R
		!	*Macrogastra plicatula*	C	R	O	R	
		(MS)	*Monachoides incarnatus*	O	A	O	C	R
		!	*Petasina unidentata*	O	R	R	O	
		!	*Platyla polita*	C	C	C	C	R
		!	*Ruthenica filograna*		R	R	R	
		!	*Semilimax semilimax*	O	O	R	O	
		(!)	*Vertigo pusilla*	R	R		O	
	2	!	*Aegopinella* cf. *minor*	O	O	(R)	C	R
		!	*Alinda biplicata*	C	O	C	O	(R)
		(+)	*Arianta arbustorum*	O	O	R	C	R
		!	*Cepaea hortensis*	C	C	R	R	R
		!	cf. *Helix pomatia*				R	
		!	*Discus rotundatus*	A	A	C	C	O
		(G)	*Eucobresia diaphana*	R		R	R	
		(!)	*Fruticicola fruticum*	O	O	(R)	R	
		(+)	*Vitrea crystallina*	A	O	C	O	R
	3	(G)	*Clausilia pumila*	(R)			R	R
		!	*Macrogastra ventricosa*	O	R	R	R	
		G	*Perforatella bidentata*	C	R	(R)	R	
B	4	M	*Cecilioides acicula*	A	C	A	C	O
	5	+	*Pupilla muscorum*	O	O	C	R	R
		(!)	*Truncatellina cylindrica*		R			
		(+)	*Vallonia costata*	A	A	A	C	R
		G	*Vallonia pulchella*	A	D	A	C	R
		(G)	*Vertigo pygmaea*	R	R	O	O	
C	7	(+)	*Clausilia parvula*				R	
		(+)	*Cochlicopa lubrica*	C	A	A	R	O
		(G)	*Euconulus* cf. *praticola*	R				
		(+)	*Euconulus fulvus*		R		R	
			Limacidae/Agriolimacidae	O	O	R		
		(+)	*Perpolita hammonis*	A	C	C	O	

Table 2. continued

Ecological group		Biostratigraphy	List of species	Layer				
				1	2	3	4	5
C	7	(+)	*Punctum pygmaeum*	O	R	R	R	
		+	*Trochulus* cf. *sericeus*			(C)	C	(R)
		+	*Trochulus hispidus*	C		C	(C)	(R)
		G	*Vertigo cf. alpestris*			R		
			Vitrea contracta	R			R	
	8	!	*Carychium tridentatum*	D	O	O	O	R
		(G)	*Perpolita petronella*	O	O	O	R	(R)
		+	*Succinella oblonga*	A	A	A	C	O
		(G)	*Vertigo substriata*			R		
D	9	G	*Carychium minimum*	D	D	D	D	O
			Oxyloma elegans	O	R	R		
		(+)	*Succinea putris*	A	A	A	R	
		(!)	*Vallonia enniensis*			R		
		(G)	*Vertigo angustior*	A	D	C	O	R
		(G)	*Vertigo antivertigo*	C	A	O	R	
		(+)	*Zonitoides nitidus*	D	D	D	D	O
	10	(+)	*Anisus leucostoma*	D	D	D	D	C
		(+)	*Aplexa hypnorum*	C	R	O	C	
		(+)	*Galba truncatula*	D	D	D	D	O
			Pisidium casertanum	D	D	D	D	C
			Pisidium milium		R	R		
			Pisidium nitidum	R	R	R		
			Pisidium obtusale	C	C	R	R	
			Pisidium personatum	D	C	C	D	C
			Pisidium subtruncatum		R	R	R	R
		(+)	*Radix ovata*	R		R	R	R
Number of species				51	51	57	55	31

conditions. The sediment was then sorted by sieving, shells were systematically removed from the sediment fractions, followed by drying and examination under a binocular microscope.

A percentage frequency mollusc diagram was created expressing the relative proportions of species (MSS malacospectra) in the separate layers. Ecological groups were defined according to Ložek (1964) and Alexandrowitz (1987).

Pollen samples

Pollen was sampled at regular intervals – 16 samples at 5 cm distances over the entire 0.75 m deep profile. After one day of maceration in hydrofluoric acid (Overbeck 1958), Erdman's (1943, 1954) modified method was used. Maceration in HF serves to decompose of inorganic particles (Overbeck 1958, Faegri & Iversen 1964), the acetolysis method was used to decompose cellulose and surplus organic remains which prevent clear observation and calculation of palynological objects. Glycerin with ethyl alcohol and distilled water were used as the mounting medium. Mounts were observed and counted under the microscope. For the pollen diagram, the sum of wood (AP) and herb (NAP) pollen grains was set as 100%. Based on this sum, absolute values of wood and herb pollen grains were recalculated (Table 5). There were approximately 500 pollen grains in a single sample. A pollen diagram was constructed based on these relative values using the software POLPAL (Walanus & Nalepka 1999). Spores and the remains of other organisms were not counted, but noted. Relative dating of the pollen spectrum was estimated, and a reconstruction of the vegetation succession was produced using Firbas' (1949, 1952) division, modified by Mangerud (Walanus & Nalepka 2010). The taxonomical classification of pollen follows Hejný & Slavík (1988–1992), Slavík (1995–2000), Kubát *et al.* (2004), Slavík & Štěpánková (2004) and Štěpánková *et al.* (2010).

Dating

Radiocarbon data analyses were performed in the Poznań Radiocarbon Laboratory, Poland, and the Centre for Applied Isotope Studies at the University of Georgia, USA. Mollusc shells were measured by the AMS (Accelerator Mass Spectrometry) method and calibrated for variable initial ^{14}C concentration using the OxCal v4.1 calibration program (Bronk Ramsey 2009, see Table 1).

Results

Molluscan analyses

Table 2 shows the molluscan assemblages in the separate layers. Altogether, 65 species were recorded in five layers (MF1–MF5). Species of all ecological groups (*sensu* Ložek 1964, Alexandrowitz 1987) were found except for woodland/open country species of predominantly dry habitats (group 6). Twenty-seven woodland species represent 42% of the total molluscan species diversity. The more important rare woodland species are *Discus perspectivus, Platyla polita, Acanthinula aculeata, Cochlodina orthostoma, Macrogastra plicatula, Ruthenica filograna, Ena montana, Aegopinella pura, Petasina unidentata* and *Isognomostoma isognomostomos*. All these species indicate a fully developed canopy forest. In the youngest layer (MF1) there is a mosaic of woodland, woodland/open country and open country species with species of wetland and stagnant water. A similar mosaic occurs throughout the whole succession. However, the main habitat type in this site was forest, and other non-woodland species characterize the habitat diversity of nearby surroundings. Both the maximum number of woodland species, including the most rare (*Cochlodina orthostoma, Ruthenica filograna*), and the maximum species diversity (57 species) occur in MF 3, dated to the early Bronze Age. The minimum species diversity in MF 5 could have been affected by poorer fossilization conditions (Fig. 2).

Pollen analyses

The most important pollen grains and the pollen diagram are shown in Figs 3–6 and Table 5.
Comments on the pollen diagram follow:
LPAZ (local pollen assemblage zone):

D1-IV: *Pinus* – *Betula* – *Juniperus* – Poaceae – Apiaceae – *Artemisia* – (Dinoflagellata)

depth 0.55–0.75 m
The situation in this basal layer was complicated both stratigraphically and vegetationally. Preboreal flora and re-deposition of Dinoflagellata from the Cretaceous bedrock was observed. This re-deposition was caused by the parallel erosion of Cretaceous sediments and accumulation of Holocene grey clays. The dominance of Poaceae, Cyperaceae, *Alisma*, *Sparganium/Typha angustifolia* and Polypodiaceae is indicative of slowly overgrowing river banks and wetlands. Pioneer woods with Scots pine (*Pinus*) and birch (*Betula*) appear in this layer. Pollen grains of Apiaceae, *Artemisia* and a low content of wood pollen grains (AP < 50%) also indicate an open landscape.

D2-V: *Betula* – *Corylus* – Cyperaceae – Poaceae – *Rumex*

depth 0.50–0.55 m
A very thin layer of probably Boreal sediments. The loam clays were sediments from a wetland environment (Cyperaceae, Poaceae). The wood component markedly decreased – birch dominated, whereas pine disappeared. The first more extensive occurrence of alder was dated to this period.

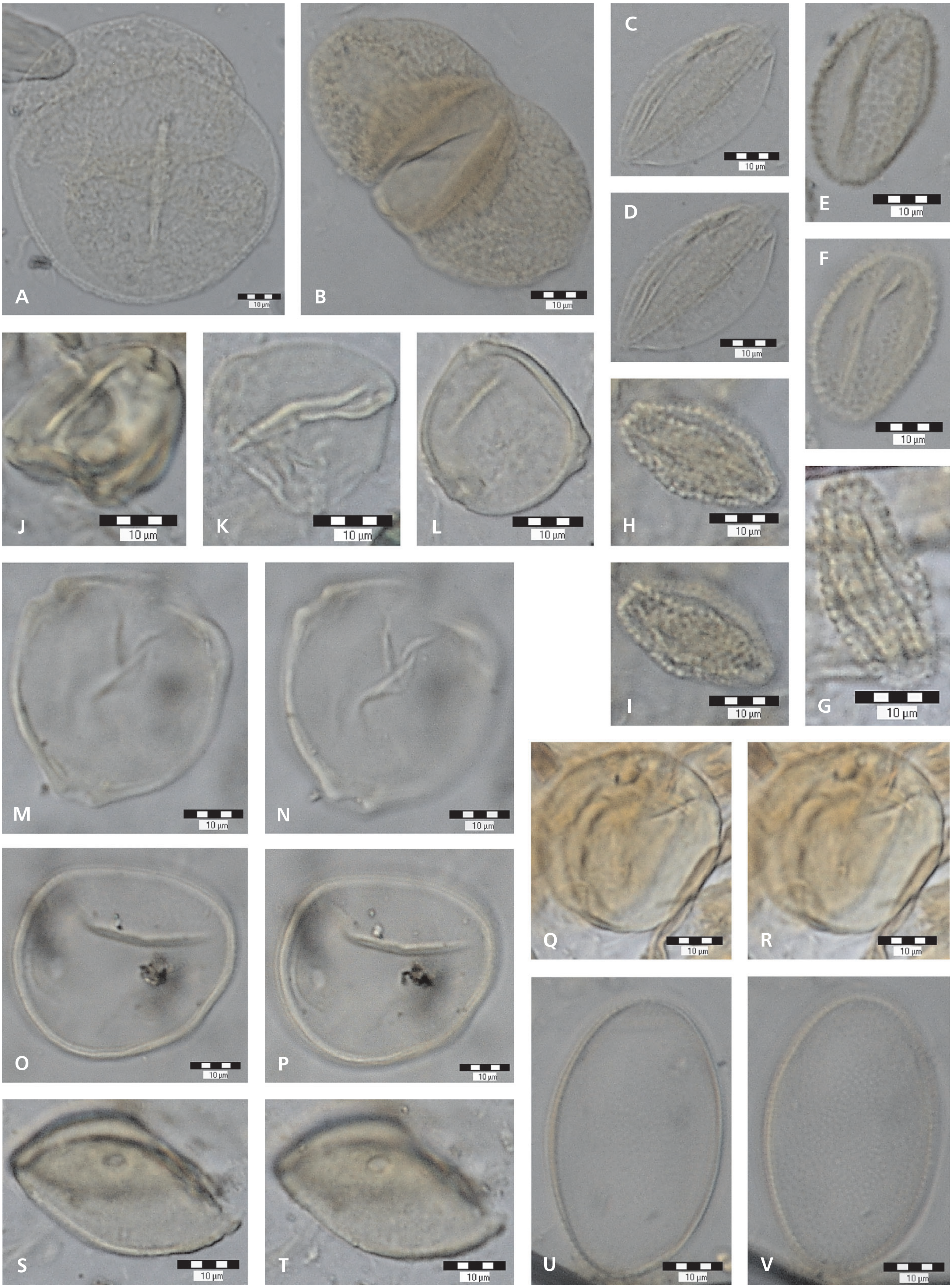
D3-VI–VIII: *Alnus* – *Salix* – Asteraceae Liguliflorae

depth 0.45–0.50 m
The vegetation implies sedimentation during some of the Atlantic climatic periods (VI–VII). Wetland vegetation with alder and willow probably occurred around the river. The first thermophilous trees appeared (*Ulmus, Quercus, Tilia, Acer*). The herb vegetation is relatively poor except for some Asteraceae (mainly Liguliflorae).

D4-VII–VIII: *Alnus* – Quercetum mixtum – (Polypodiaceae)

depth 0.40–0.45 m
An expansion of alder, with a humid climate supporting the occurrence of Polypodiaceae. The thermophilous trees

Figure 3. Palynomorphs from Dubany profile D – AP. • A, B – *Pinus*, depth 0.05, 0.10 m. • C, D – *Juniperus*, depth 0.10 m. • E–I – *Salix*, depth 0.10, 0.05 m. • J–L – Betula, depth 0.05, 0.10 m. • M, N – *Corylus*, depth 0.75 m. NAP. • O, P – Cerealia T. *Triticum*, depth 0.75 m. • Q–T – Poaceae, depth 0.05, 0.10 m. • U, V – *Iris*-type, depth 0.10 m. Scale 10 μm. Photo E. Břízová.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(*Ulmus, Quercus, Tilia*) continue to occur. Probably also an Atlantic (VII) period.

D5-VIII: ***Alnus – Corylus – Tilia***

depth 0.25–0.40 m
Alder continues to occur along with open water wetlands (maximal increase of *Potamogeton*). Other herbs were also noted, *e.g.* Brassicaceae, Asteraceae, Apiaceae and *Artemisia*. Compared to the previous layer, the Polypodiaceae decreased. These all indicate cooling in comparison with the D4 layer. The occurrence of fir (*Abies*), hornbeam (*Carpinus*) and beech (*Fagus*) make it possible to assume this layer was from the Subboreal period (VIII).

D6-IX: ***Pinus – Alnus – Juniperus – Salix***

depth 0.20–0.25 m
The decrease in alder, especially at the end of this period, and the increase in willow (*Salix*) and pine (*Pinus*) is typical for the high alluvial terraces of the Polabí lowland (Břízová 1999b, Dreslerová *et al.* 2004). The maximum increase was seen in *Juniperus*. The first occurrence of corn indicates the presence of humans in the surrounding landscape. The presence of spruce (*Picea*), fir (*Abies*), hornbeam (*Carpinus*) and beech (*Fagus*) probably indicate the Older Subatlantic period (IX) for this layer.

D7-Xa: ***Pinus – Salix* – Cyperaceae – Chenopodiaceae – (*Sphagnum*)**

depth 0.10–0.20 m
A very thin layer. The low amount of palynomorpha coincides with the type of sediment (see lithology). The occurrence of wetlands is indicated by Cyperaceae and scattered willows, with *Sphagnum* at some sites. Pines again occur, with low but increasing amounts of birch. This layer can be dated to the older phase of the Younger Subatlantic (Xa).

D8-Xb: ***Salix – Pinus – Betula – Alnus – (Microthyrium microscopicum)***

depth 0–0.10 m
The last layer, probably from the younger phase of the Younger Subatlantic (Xb), is characterized by extensive willow forests, which are again replaced by alder at the end of this period. This situation is typical for other sites in the Polabí lowland (Břízová 1999b, Dreslerová *et al.* 2004). The occurrence of *Juniperus* and corn along with typical weeds (*e.g.* Apiaceae, *Artemisia*, Brassicaceae, Chenopodiaceae, Boraginaceae) and other plants is characteristic of sites on which humans have had a significant impact (*Plantago lanceolata*, Asteraceae).

Algae of the genera *Botryococcus, Pediastrum, Mougeotia* and some other undeterminable remains occurred throughout the whole profile, but especially along with wetland vegetation in the layers D1, D3, D4, D5, D6 and D8.

Re-deposition of palynomorphs probably from the Tertiary (*Sciadopytis, Tsuga, Carya, Engelhardtia*) was found in layers D1, D5, D6 and at the base of D8. Sporadic pollen grains of *Juglans* were found in the layers D3 and D4. Human impact was observable in the layer D5, probably of Neolithic Age.

Generally, the pollen of broadleaf trees predominate, especially alder, willow, birch, hazel and to some extent also oak, lime tree and hornbeam, rarely beech. Pine was the dominant coniferous tree; spruce and fir occur sparsely or probably at long distances from the river. *Juniperus* occurs especially in the younger part of the profile and could be indicative of poor soils or pastures in the surroundings.

Discussion

Conditions for the fossilization of pollen and molluscan shells are quite different. The acid oxygen-free environment important for the preservation of pollen is totally unsuitable for the preservation of shells which need calcareous sediments for fossilization. Thus, the common occurrence of pollen and snails in quaternary sediments is very rare (Kovanda 1987, 1993; Břízová 1994, 1999b; Pišút *et al.* 2010). When it happens, however, reconstruction of the environment based on more than one group of organisms makes an interesting comparison possible.

In this paper, pollen was used to determine the stratigraphy of the Dubany profile (D) with regard to the sediment characteristics. The pollen diagram (Fig. 6) was divided into 8 LPAZ, which were also (where possible) stratigraphically classified. Two layers of the profile were dated using molluscan shells (Table 1).

Wetlands had been formed around the Dubanka stream during the Late Glacial and Early Holocene. During favourable climatic conditions, this habitat was later overgrown by alder and willow (Table 3). Then, an invasion of floodplain forests during the Preboreal and Boreal was documented (Table 4, Fig. 4), as has been assumed to be a general phenomenon (Ložek 2003). Sediments from the base of the profile are probably of Preboreal Age (D1). The subsequent layers (D2–D8) however, did not contain the entire sediments of individual Holocene periods because

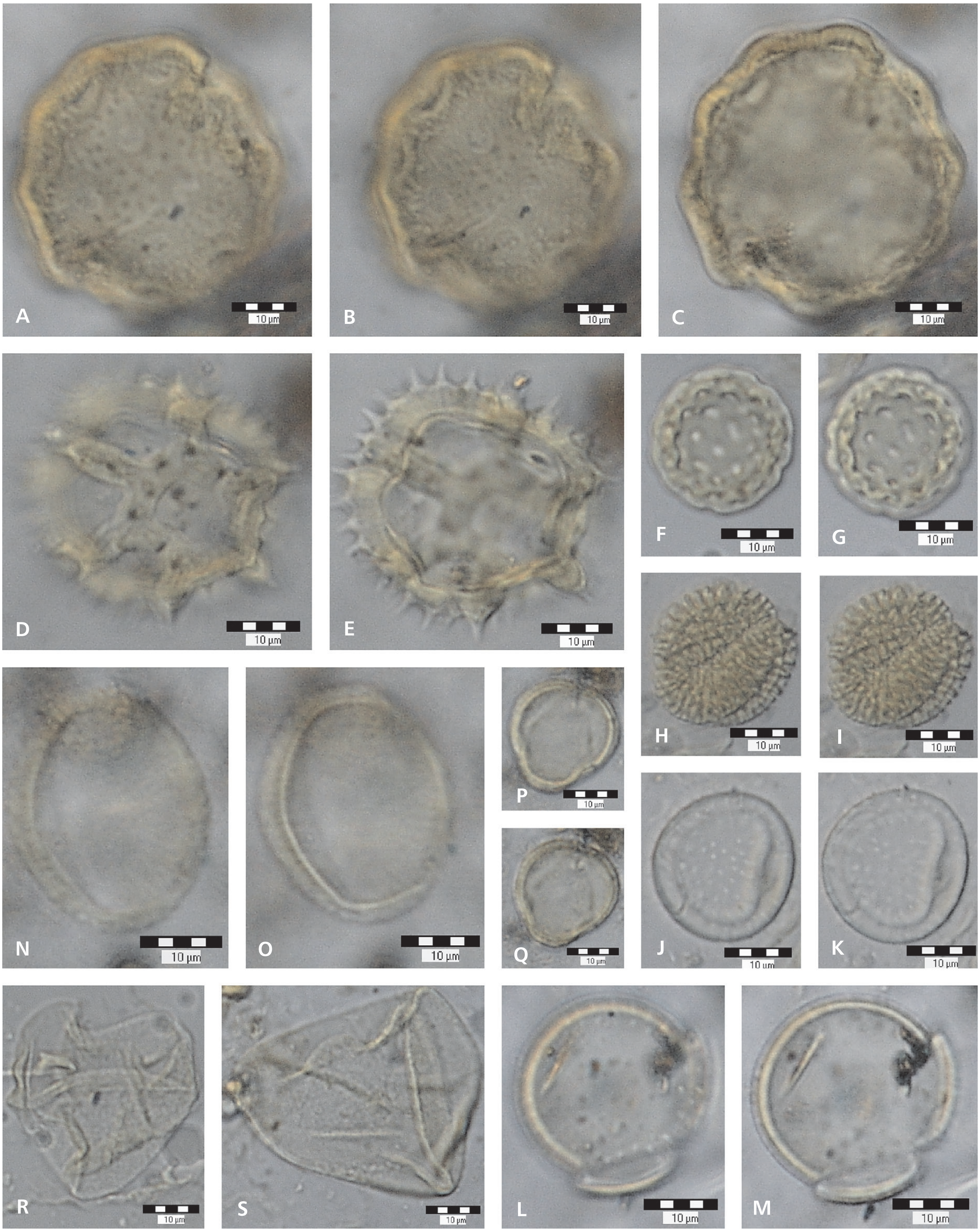


Figure 4. Palynomorphs from Dubany profile D – NAP. • A–C – Caryophyllaceae, depth 0.75 m. • D, E – Asteraceae Liguliflorae, depth 0.75 m. • F, G – Chenopodiaceae, depth 0.05 m. • H, I – Brassicaceae, depth 0.10 m. • J–M – *Lemna* cf. *minor*, depth 0.10, 0.75 m. • N–Q – *Artemisia*, depth 0.75 m. • R, S – Cyperaceae, depth 0.10 m. Scale 10 μm. Photo E. Břízová.

Table 3. Habitat succession in the Dubany site based on pollen and molluscan analyses.

Depth (m)	LPAZ (local pollen assemblage zone)	Molluscan fauna	Relative dating	Absolute dating uncal.	Prevailing habitat
0–0.10	D8-Xb	MF1	Younger Subatlantic (younger phase)		Open county (*Juniperus*), alder, scattered willows
0.10–0.20	D7-Xa	MF2	Younger Subatlantic (older phase)		Wetland, scattered woodland (willow, *Betula*)
0.20–0.25	D6-IX	MF3	Older Subatlantic	3030 ± 40BP	Woodland (willow, *Pinus*), open landscape (*Juniperus*), maximum number of open country snails
0.25–0.40	D5-VIII	MF4	Subboreal		Alder, woodland (*Abies, Carpinus, Fagus*), maximum number of woodland snails
0.40–0.45	D4-VII–VIII	MF5	Atlantic–Subboreal	3430 ± 30BP	Alder, floodplain forest (*Quercus, Tilia, Ulmus*), humid climate (Polypodiaceae)
0.45–0.50	D3-VI–VIII		Atlantic–Subboreal		Alder, willow and wetland
0.50–0.55	D2-V		Boreal		Open landscape with wetlands (Cyperaceae, Poaceae) and scattered pioneer woods (*Betula*)
0.55–0.75	D1-IV		Preboreal		Open landscape (Apiaceae, *Artemisia*) with wetlands (*Sparganium/Typha*) and pioneer woods (*Pinus, Betula*)

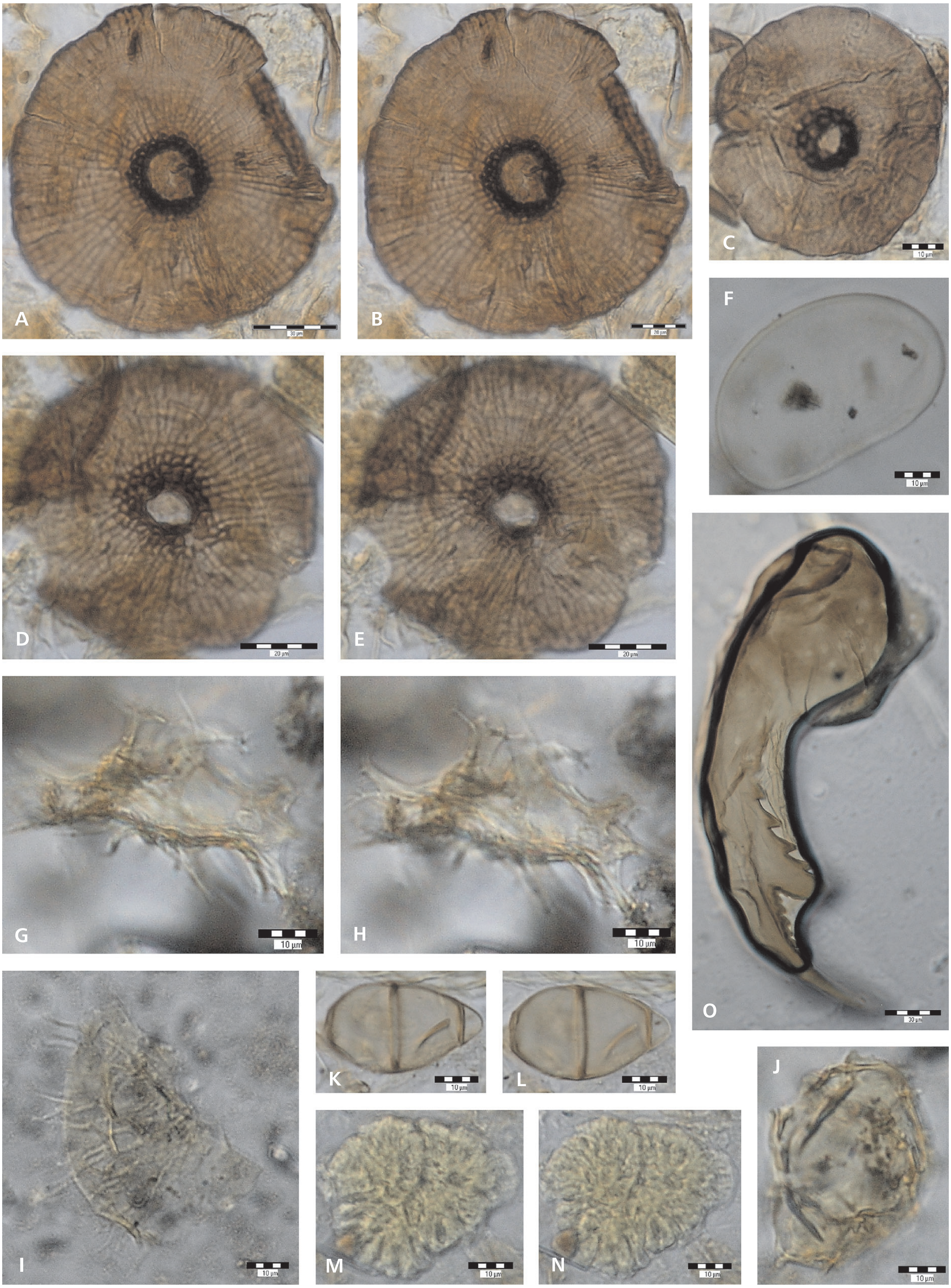
Table 4. Stratigraphic table of Holocene periods used in the text (Břízová *in* Dreslerová *et al*. 2004, Walanus & Nalepka 2010).

Holocene	Modified stratigraphy by Břízová (*in* Dreslerová *et al*. 2004), uncal. BP	Modified stratigraphy by Mangerud (Walanus & Nalepka 2010), conv. BP	Modified stratigraphy by Mangerud (Walanus & Nalepka 2010), cal. BC
SUBATLANTIC IX, X	2,800/2,300–recent	2,500–recent	600–recent
SUBBOREAL VIII	5,100/4,500–2,800/2,300	5,000–2,500	3,800–600
ATLANTIC VI, VII	7,700–5,100/4,500	8,000–5,000	7,000–3,800
BOREAL V	9,100–7,700	9,000–8,000	8,200–7,000
PREBOREAL IV	10,250–9,100	10,000–9,000	9,500–8,200

the river destroyed older sediments during periods of erosion and covered them with younger material (see also Břízová 2004, 2005, 2008b; Břízová *et al.* 2007). This denuding and immixture of material is typical for climatic optima with higher precipitation. For this reason, the biostratigraphic classification of layers D3, D4 and D5 is unreliable. Human impact is combined with natural influences in D5 layer. Elements of a climatic optimum (Atlantic) mix together with Subboreal species in these three layers (Fig. 6), though the D5 layer generally conforms to the Subboreal based on pollen data. Similar sedimentation with a great admixture of re-deposited material was observed during the same period in lake sediments from southern Moravia (Břízová 2009). The biostratigraphical comparison with radiocarbon dating is shown in Tables 3 and 4.

The Dubany site is situated in an area that has been settled since the Bronze Age. Although no detailed archeological research is available directly from this site to make integrated bioarcheological research at this site possible (Brown 2009), we have some archeological information from the surrounding area. The settlement density in the eastern Polabí lowland was relatively low in the Neolithic Age, but rapidly increased during the Bronze and Iron Ages (Pleiner *et al*. 1978, Jiráň & Venclová 2007–2008). The western part of this area including the České Středohoří Mts and Lower Ohře River floodplain, were probably never fully forested during the Holocene (Ložek 2007, Dreslerová *et al*. 2004). Thus, evidence of a canopy forest with nutrient-rich trees such as lime or elm, and the presence of woodland snails sensitive to human impact in particular (*Platyla polita, Cochlodina orthostoma, Ruthenica filograna, Petasina unidentata, Discus perspectivus etc.*) is important. Moreover, the majority of woodland snails have become extinct in this area only recently. Although the molluscan succession comprises only part of the whole paleobotanical succession, it provides valuable information. The radiocarbon dating places these layers at

Figure 5. Palynomorphs from Dubany profile D – Fungi. • A–E – *Microthyrium microscopicum*, depth 0.05 m. Pteridophyta. Polypodiaceae, depth 0.45 m. Flagellata. • G–J – Dinoflagellata, depth 0.75 m. Fungi. • K, L – Ascomycetes, depth 0.75 m. Algae. • M, N – *Botryococcus*, depth 0.05 m. • O – Cladocera, depth 0.10 m. Scale 10 μm (C, F, G–N), 20 μm (B, D, E), 30 μm (A, O). Photo E. Břízová.


A
B
C
D
E
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G
10 µm
H
10 µm
I
J
K
L
M
N
O

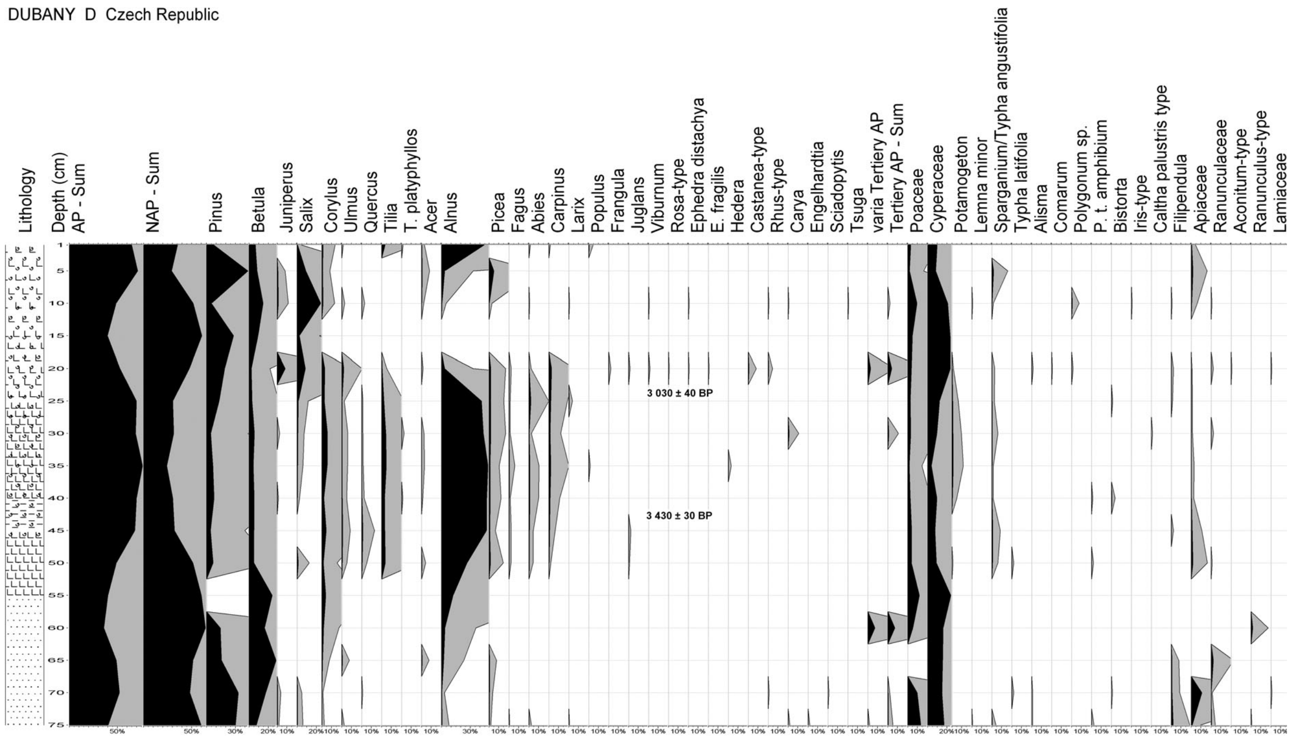

Figure 6. Pollen diagram of Dubany D (N49°59´ 46˝; E15°43´ 32˝; 233 m a.s.l.), Bohemia, the Czech Republic. Analysed by Eva Břízová. This figure continues on the opposite page.

the end of the Únětice culture (layer 5) and the Lužická culture (layer 3) of the Bronze Age (Jiráň & Venclová 2007–2008, Table 1).

The Dubanka is a small river, with a floodplain which is more related to the regional zone rather than to the actual distance downstream (Brown *et al*. 1997). Thus, evidence of the canopy forest can be of local importance. However, the species composition suggests the presence of an extensive deciduous virgin forest rather than a common Central European floodplain forest (*e.g*. Obrdlik *et al*. 1995, Čejka *et al*. 2007). Thus, this site was functioning as a forest refuge in an agricultural landscape from at least the Bronze Age to the Subatlantic Age. On the basis of indirect evidence (*e.g*. mention of deer in the Polabí forests in the popular books by Prof. Julius Komárek) we even believe that the forest could have survived there until the Middle Ages or almost modern times.

The Dubany and Hurychův dolec near Vysoké Mýto (Ložek 1982, 2009) are biogeographically important sites because of the documentation of Carpathian species spreading to the west. We can compare these successions with those in the so-called Moravian Gate – a narrow depression corresponding to the Carpathian foredeep. This very important geological structure forms the border between the Czech Massif and the Western Carpathians, and is part of the water-shed between the Baltic and Black seas. The presence of Carpathian deciduous forests has been documented in several molluscan successions situated in this area (Šibrava *et al*. 1959; Ložek 1961a, b; Ložek & Tyráček 1962). Carpathian species such as *Macrogastra latestriata, M. tumida, Vestia turgida, Plicuteria lubomirskii, Trochulus villosulus, Monachoides vicinus* or *Faustina faustina* together with rich mid-European woodland fauna occurred in the Moravian Gate since the Middle Holocene (Atlantic). The westward spread of these species via the so-called Třebovská Gate (a continuation of the water-shed on a Cretaceous rock substratum) during the Atlantic period has also been preliminarily documented in Hurychův dolec (Ložek 1982, 2009). However, none of the Carpathian species reach the eastern part of the Polabí lowland in Dubany. On the other hand, other woodland species could probably have seamlessly spread to this lowland.

In addition to woodland plant and snail species, the occurrence of some rare hygrophilous snail species (*Vertigo angustior, V. antivertigo, Vallonia enniensis, Perpolita petronella*) and plants (Polypodiaceae) indicate the presence of nutrient rich wetlands. Stagnant water and open country plants and snail species in Dubany complement a diverse landscape mosaic. Wild floodplain forests and wetlands surrounded by an agricultural landscape was probably the landscape near Pardubice during the Bronze Age. This picture sharply contrasts with the present-day monotonous open lowland.

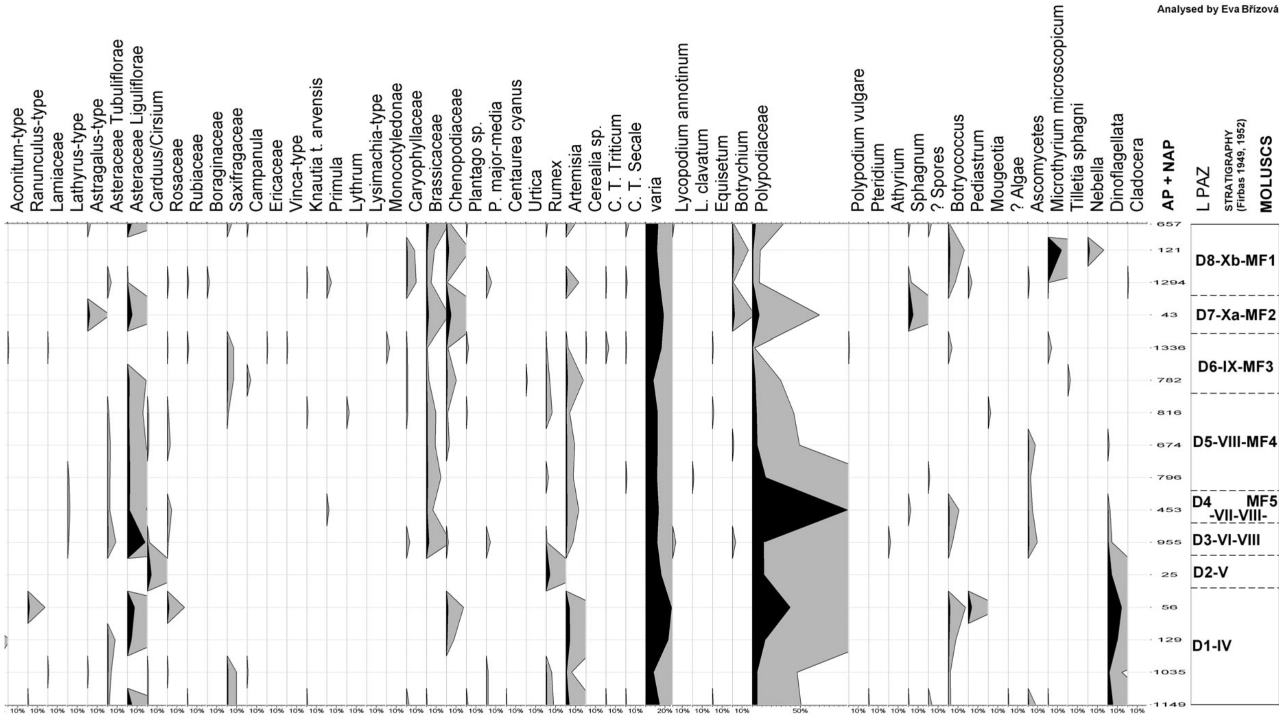

Table 5. Real amount of pollen grains and spores in individual samples from the locality of Dubany (D).

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Depth (cm)	1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
AP																
Pinus	50	52	66	12	252	101	35	44	61	18	65		8	20	342	344
Betula	42	10	188	4	29	24	45	28	42	23	47	6	9	36	178	87
Juniperus		1	15		110		2		1						4	2
Salix	3	11	317	1	114	9	6	4	2		12				5	7
Corylus	9	1	17		41	19	46	37	16	20	15	1	1	1	1	3
Ulmus	1		4		28	2	5	4	4	4	5			1		3
Quercus			4			1	1	1	2	6	5				1	
Tilia	23				7	18	35	32	24	15	36					
T. platyphyllos	1						2		1							
Acer	2	1	3		2		2	2	1		4			1		
Alnus	290	4	6		44	324	354	326	374	212	253	3	2	3	3	9
Picea		6	4		23	12	14	7	10	3	14			1	4	2
Fagus						1	1	4	1	1	2					1
Abies	1		1		3	16	2	7	8	2	4					3
Carpinus	1				36	15	10	14	9	3	2					
Larix			1			3										1
Populus	3							1								
Frangula					3											
Juglans					2					1	1					
Viburnum			1		2											
Rosa-type					1											

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Depth (cm)	1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
Ephedra distachya			1		1											
E. fragilis					1											
Hedera								2								
Castanea-type					11											
Rhus-type			1		6										1	
Carya			1				9									2
Engelhardtia																2
Sciadopytis															1	
Tsuga			1													
varia Tertiery AP					37								4			2
suma Tertiery AP			3		54		9						4		2	6
NAP																
Poaceae	20	2	122	2	50	19	24	10	19	18	35	3	3		101	154
Cyperaceae	64	10	268	10	313	96	77	25	75	34	87	6	9	20	153	195
Potamogeton					2	5	8	8	4		1					
Lemna minor			1													1
Sparganium/Typha angustifolia		2	2		4	2	5	1	1	4	6					5
Typha latifolia											2				2	
Alisma					2										1	1
Comarum					1											
Polygonum sp.			10		2											
P. t. *amphibium*									1		2					3
Bistorta						1			3						1	
Iris-type			1													
Caltha palustris type							1									
Filipendula			1		3	1				1				1	9	22
Apiaceae	3	2	8		1	1	1	2	2	5	16				114	11
Ranunculaceae			1		3		2				1			3	1	5
Aconitum-type					1											
Ranunculus-type													1			1
Lamiaceae					1										1	
Lathyrus-type									1	1	1					
Astragalus-type	2			1											1	
Asteraceae Tubuliflorae			5				1	2	2	1	8			1	4	2
Asteraceae Liguliflorae	26		1	2		15	13	13	20	9	174		4	5		53
Carduus/Cirsium							1	1			2	1			1	1
Rosaceae			2		1		1	2		2	1		1		1	
Rubiaceae			2		2											1
Boraginaceae			3													
Saxifragaceae	3				9	5	1								10	11
Campanula	1					3									1	
Ericaceae					1											
Vinca-type					1											
Knautia t. *arvensis*			1				1									1
Primula			6							1						
Lythrum							2									

Sample	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Depth (cm)	1	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
Lysimachia-type	1															
Monocotyledonae					4											
Caryophyllaceae		1	13		1	1	1				3					3
Brassicaceae	15	1	6	1	1	2	8	6	12	3	24					1
Chenopodiaceae	3	3	1	2	2	8	1	2			2		1	1		
Plantago sp.	1				3		1									2
P. major-media			7								4				2	2
Centaurea cyanus																1
Urtica						1										
Rumex	1				1	3	5		2		1	1			6	9
Artemisia	6		17		3	14	3	6	6	6	7		2	5	6	36
Cerealia sp.					1											
C. T. *Triticum*			1		4											1
C. T. *Secale*	2		2		1				1							1
varia	83	14	185	8	216	60	99	83	91	60	113	4	15	30	82	164
Sum AP	**426**	**86**	**628**	**17**	**702**	**545**	**560**	**513**	**556**	**308**	**465**	**10**	**20**	**63**	**538**	**462**
Sum NAP	**231**	**35**	**665**	**26**	**634**	**237**	**256**	**161**	**240**	**145**	**490**	**15**	**36**	**66**	**497**	**687**
AP + NAP = 100%	**657**	**121**	**1293**	**43**	**1336**	**782**	**816**	**674**	**796**	**453**	**955**	**25**	**56**	**129**	**1035**	**1149**
PTERIDOPHYTA																
Lycopodium annotinum	1										3					
L. clavatum									1							
Equisetum					1		1									1
Botrychium	1	2	1	1				1			3					
Polypodiaceae	21	1	9	3	3	23	35	33	109	448	111	3	22	17	48	58
Polypodium vulgare					1											
Pteridium																1
Athyrium											2					
BRYOPHYTA																
Sphagnum	1		4	2						1						1
?Spores	2								1							4
Sum of spores	**26**	**3**	**14**	**6**	**5**	**23**	**36**	**34**	**111**	**449**	**119**	**3**	**22**	**17**	**48**	**66**
ALGAE																
Botryococcus	1	2	9		5					5	4		1	1	2	3
Pediastrum			5										2			
Mougeotia							2									
?Algae																1
FUNGI																
Ascomycetes			2					5	2	2	9					9
Microthyrium microscopicum		17	1		5											1
Tilletia sphagni						2										
RHIZOPODA																
Nebella		2														
FLAGELLATA																
Dinoflagellata								1		1	4	1	8	13	15	59
CLADOCERA			1													

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