



Late Holocene Environmental Changes and Human Subsistence in an Alluvial Landscape: A Case Study from the Pohansko Site on the Dyje (Thaya) River in Czechia

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Abstract

We examined the data from the floodplain settlement at Pohansko to uncover environmental changes, vegetation development, and floodplain dynamics that influenced the settlement's history and subsistence strategies. Most of the landscape was deforested during the Middle Holocene, while woodlands primarily limited to the alluvium were not significantly affected by human occupation. Human impact gradually increased from the Late Iron Age, peaking in the Early Middle Ages. The questions examined focused on the subsistence strategy and food sources. The archaeobotanical and palynological results suggest that supplies were brought from the hinterland, where chernozem soils were better suited for agricultural production. Woodland vegetation returned after the settlement's decline in the early tenth century CE. Archaeological evidence indicates that human settlement impacted the area from prehistoric times through the Early Middle Ages but not afterward. This finding starkly contrasts with the documented High Medieval regional expansion of settlements and population growth linked to the region's deforestation of uplands and alluvial aggradation.

Keywords Late holocene · Alluvium · Human impact · Subsistence · Settlement history · Pohansko · Czechia

Introduction

Gradually increasing human influence, soil aggradation in floodplains, and extensive deforestation of floodplains (Zolitschka et al., 2003) characterize Central Europe's late Holocene period (4200 years cal BP onward). The extent of human impact varied at the regional scale and depended on the ecological setting and the depth of cultural changes due to population dynamics. Several palynological sequences have inferred the history of vegetation changes in southern Moravia and the neighboring northeastern Pannonia (Jamrichová et al., 2017). The late Holocene landscape of Pannonia was covered by open-canopy oak woodlands and steppe vegetation that persisted throughout the Holocene (Havinga, 1972; Kuneš et al., 2015; Petr et al., 2013). Charcoal from archaeological locations has been the subject of reconstructions of woodland vegetation in the hinterland of these locations (Doláková et al., 2010, 2020; Novák et al., 2017, 2021; Opravil, 1983). Because the fuelwood gathering was non-selective, charcoals reflect the surrounding woodland vegetation of the time (Kočár et al., 2014a, 2014b).

Fluctuations in settlement and population density were associated with broader social and cultural change. The

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Migration Period (ca. 300–600 CE) witnessed a decline in human impact in some palaeoecological records, although many records indicate no change (Helama et al., 2017). Beginning with the mid-sixth CE, early Slavs superseded Germanic tribes. They frequently settled near rivers or directly within alluvial floodplains (e.g., Kuna et al., 2013). This activity culminated during the eighth–ninth century CE with the development of settlement clusters near the Morava and Dyje Rivers. After the seizure of Moravia by the Duchy of Bohemia in the tenth century, the settlement structure changed utterly. Local sedimentary evidence from several sites allows for identifying flooding events superposed on Great Moravian structures (Nehyba et al., 2020), dated to the late ninth century (Nehyba et al., 2021). This led to the idea that the change in the local settlement structure was associated with floods (c.f. Macháček, 2007). However, such a temporal relationship is yet to be proved. Significant changes in floodplains, such as the acceleration of aggradation, occurred as early as the thirteenth century and during the fifteenth and sixteenth centuries (Petřík et al., 2019; Kadlec et al., 2009; Grygar et al., 2016; Vejrostková et al., 2019) in connection with deforestation and changes in agricultural practices (Klápště, 2005; Le Goff, 1964).

The transformation is also clearly visible in subsistence change and archaeobotanical evidence. The beginning of the Common Era saw a marked shift from the prehistoric variety of crops, namely an abrupt predominance of hexaploid wheat (Kočár & Dreslerová, 2010a, 2010b), which lasted until the Early Middle Ages. By contrast, the High Medieval range of crops mainly consisted of rye and oats, wheat being marginal. It is, however, necessary to distinguish between general radical shifts and presumed differences associated with local ecological and social conditions. Our current knowledge is based on archaeobotanical and anthracological analyses from large-scale excavations at sites such as Mikulčice, where a waterlogged context has been interpreted by E. Opravil (1983) based on the vegetation and floodplain development. Nonetheless, there are still gaps in our knowledge of the Early Medieval economy and agricultural practices (Látková, 2017).

We focused on reconstructing vegetation and environmental changes at the Pohansko site during the first millennium CE by examining sediments deposited in oxbow lakes and former channels of the Dyje River. Our research aimed at reconstructing environmental and vegetation changes in the context of past settlements and deriving information about the subsistence strategy and the use of natural resources. We created three datasets: (a) off-site palaeobotanical and physical proxy data for the natural profile of the former river oxbow, (b) one characterizing the alluvial sediment record of the Dyje River floodplain, (c) archaeobotanical evidence of Early Medieval human activity. Analyzing these datasets allowed us to address the role of human

presence in the development of the landscape and to answer the following questions: 1. How did the floodplain of the Dyje River develop in the late Holocene, and how did local vegetation change with it? 2. What bearing did it have on how human activity affected the palaeoecological record? We also focused on changes in settlement and subsistence strategy associated with the dynamics of alluvium deposition, especially during the Early Medieval Period.

Geographical Setting and Site Description

The Pohansko site is situated on flat alluvium at the confluence of the Dyje and Morava Rivers, on the borders of Czechia, Austria, and Slovakia near the well-known Early Medieval sites Pohansko and Lány (Fig. 1). The present-day climate is warm and dry; the annual mean temperature is 9.5 °C, and the mean annual precipitation total is 550 mm.

The bedrock is built of Tertiary maritime sediments of the Vienna basin (relevant geological maps for the present-day Austrian and Czech part of the area can be found at www.geologie.ac.at/en/services/web-services and www.mapy.geology.cz/geocr_50, respectively). Loamy overbank sediments cover the alluvium of the Dyje River (Havlíček, 2001) of 4 to 6 m thick, superimposed over five meters of gravel dated to the Last Glacial period (Havlíček et al., 2016). Numerous sandy elevations, called *Hrúdy*, are interpreted as remnants of the youngest terraces (Petřík et al., 2019) dated to the Late Glacial period (Nehyba et al., 2020). Gravel terraces and loess deposits cover the area outside the alluvium. The alluvium is vegetated by woodlands dominated by *Quercus*, *Tilia*, *Ulmus*, coniferous pine plantations, and meadows. Wetland vegetation with tall sedges and *Alnus* grows around oxbows. Beyond the alluvial floodplain are oak and pine woods, mainly on sandy bedrock, but the landscape primarily consists of cornfields on loess bedrock.

We have looked for suitable sedimental archives of late Holocene floodplain deposits in vanished oxbows, where paleoenvironmental records were present. The borehole site of Erlwiesen (Alder meadow) is situated approximately 1.7 km southwest of the Pohansko (48° 42' 52,66" N; 16° 52' 38,55" E) in Austria (Fig. 1). The northern part of this meander was subjected to peat extraction, whereas the southern part, located in Austria, has a preserved infill.

We have attempted to reconstruct river stream channels of the Early Medieval Period and linked off-site evidence from the Erlwiesen core to the known Pohansko settlement through LIDAR maps. On this basis, we have picked the site *Za bunkrem* (behind the concrete fortification from 1938), situated on the floodplain approximately 100 m west of the outer perimeter wall of Pohansko. It is a former river channel overlain by overbank deposits. We dug an open pit cutting through a point bar and a channel infill and sampled pottery sherds, charcoal, and sediments for pollen analysis. A

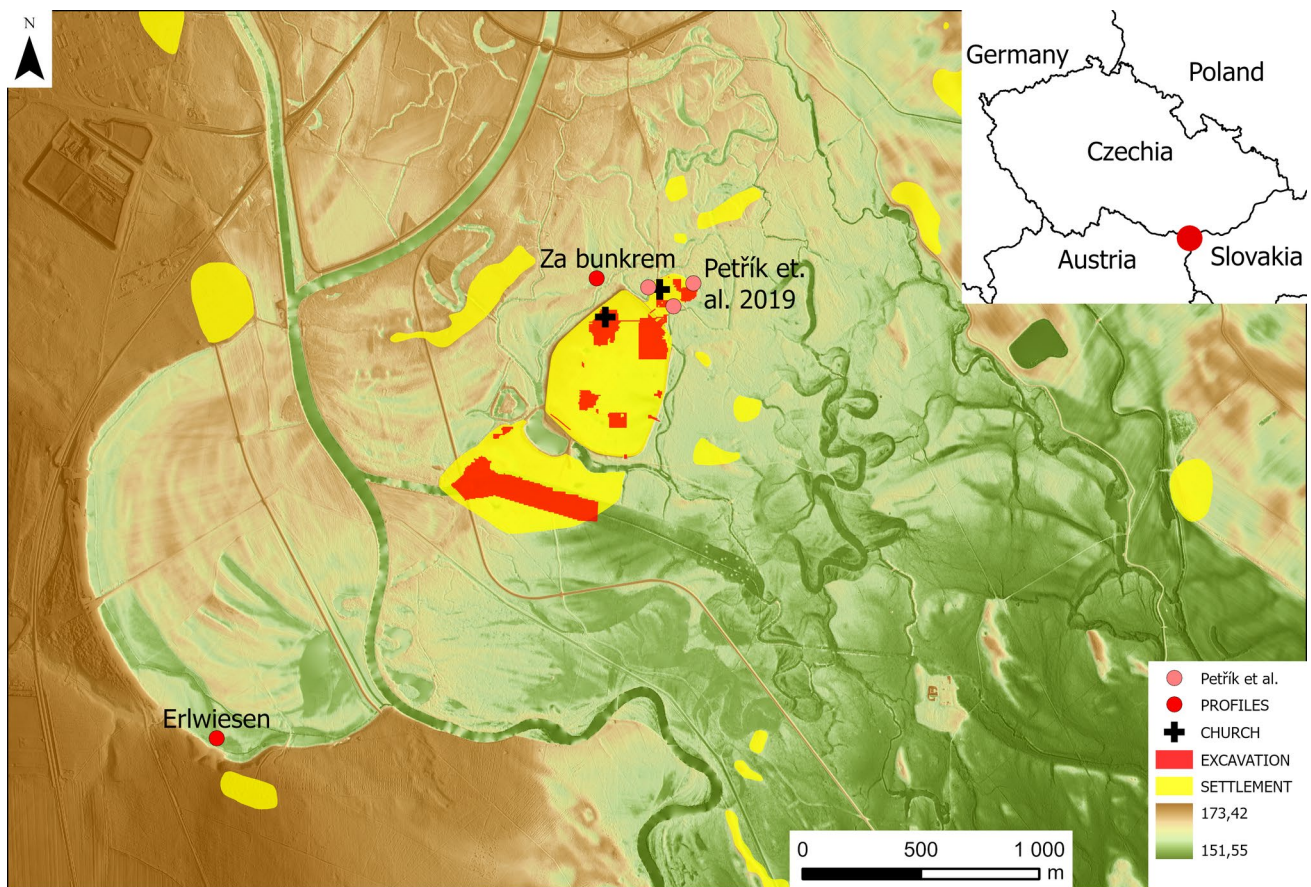


Fig. 1 Map of investigated site, location of boreholes, excavated archaeological features, and extend of prehistory settlement

cross-section of overbank deposits and sandy elevation is situated on the west side of the Early Medieval acropolis (Petřík et al., 2019).

Archaeological Evidence

Prehistoric evidence is associated with several features belonging to the Neolithic (5500–3700 BCE) and the Late Neolithic (3700–2200 BCE) periods (Dostál, 1968). There is also limited archaeological evidence from the Early Iron Age settlement (800–480 BCE) and Late Iron Age (400 BCE to the turn of the millennium), such as pottery and fragments of glass bracelets (Lauermann et al., 2014). Germanic and provincial Roman pottery was common from the turn of the millennium to circa 400 CE (Adler, 1977, 1979; Dostál, 1970). Early Slavs settled the alluvial plain area in the sixth century CE (Pittioni, 1935). One of the occupation climaxes in the alluvial area was the period associated with the existence of Great Moravia (833–905 / 905 CE), when large settlement clusters were built over older archaeological structures (Macháček et al., 2021). The area's population also partook in long-distance trade aided by the closeness of

major watercourses, which were demonstrably used to transport raw materials from the Bíle in the Carpathian Mountains 26 km away (Macháček, 2007). After the tenth century CE, the Pohansko site was abandoned and was settled again only at the beginning of the nineteenth century (Macháček, 2010; Miklín and Hradecký 2016).

The Early Medieval settlement has been particularly well-researched in the context of environmental change (Opravič, 1983; Macháček, 2007; Doláková et al., 2010; Doláková et al., 2020). Analysis of palaeobotanical samples and remains of wood from fortifications, graves, and charcoals, combined with information from geological research, enabled E. Opravič to reconstruct the landscape of the alluvial plain, which was starkly different from its present state (Opravič, 1978, 1983, 2000). His results, supplemented by palynological studies (Svobodová, 1990), indicate intense deforestation of the surroundings of the mid-ninth-century fortified centers. This, apart from the extensive use of timber for the frames of dwellings, increased demand for firewood for a growing population, which also needed a sufficient supply of staple foods.

Methods

The Erlwiesen profile was sampled using a 100 cm-long open tube with a 5 cm diameter. Two parallel overlapping cores were sampled to obtain precise stratigraphy (Fig. 2). The cores were subsampled in the laboratory at intervals of 2 cm for palynological, macrofossil, and physical proxy analysis.

Samples for the pollen analysis from the Erlwiesen cores (Fig. 3) and cores from the *Za Bunkrem* site were processed using a standard method of acetolysis with the use of hydrofluoric acid (Moore et al., 1991). Pollen atlases (Beug, 2004; Moore et al., 1991) were used for pollen grain identification. The program POLPAL (Nalepka & Walanus, 2003) was used to plot pollen diagrams and to delimit local pollen zones based on ConsLink and PCA analyses. *Alnus* and wetland species were excluded from the pollen sum.

Charcoal and charred macro-remains were extracted by flotation during excavation from 2008 to 2015. The total number of floated samples was 3,455 (Doláková et al., 2020). Standard flotation was used to extract plant macro-remains and charcoal

from the sediment (Pearsall, 1989). Macro-remains of plants were selected and classified under a stereoscopic microscope from fraction sizes of more than 0.25 mm. Palaeobotanical material was identified by using a comparative collection of plant diaspores. The basic literature for the determination of plant macro-remains was used (Anderberg, 1994; Bojňanský & Fargašová, 2007; Cappers et al., 2006; Jacomet, 2006). Macro-fossils from the Erlwiesen site (Fig. 4) were rinsed through a sieve with a mesh diameter of 200 µm by a spray of tap water. They were then dried and examined under a dissecting microscope at magnifications of 12× and greater. Plant remains were identified using keys, atlases, and other publications (Cappers et al., 2006; Velichkevich & Zastawniak., 2006, 2008). Macro-fossil diagrams were drawn using the program POLPAL (Nalepka & Walanus, 2003).

Charcoal analysis was performed only on fragments from the largest fraction (> 2 mm); flotation was carried out during the excavation at Pohansko (Jacomet & Kreuz, 1999). The extraction of charcoal at the *Za bunkrem* site followed the standard wet sieving procedure using staggered sieves with a mesh size of 1 mm. Charcoals were identified using

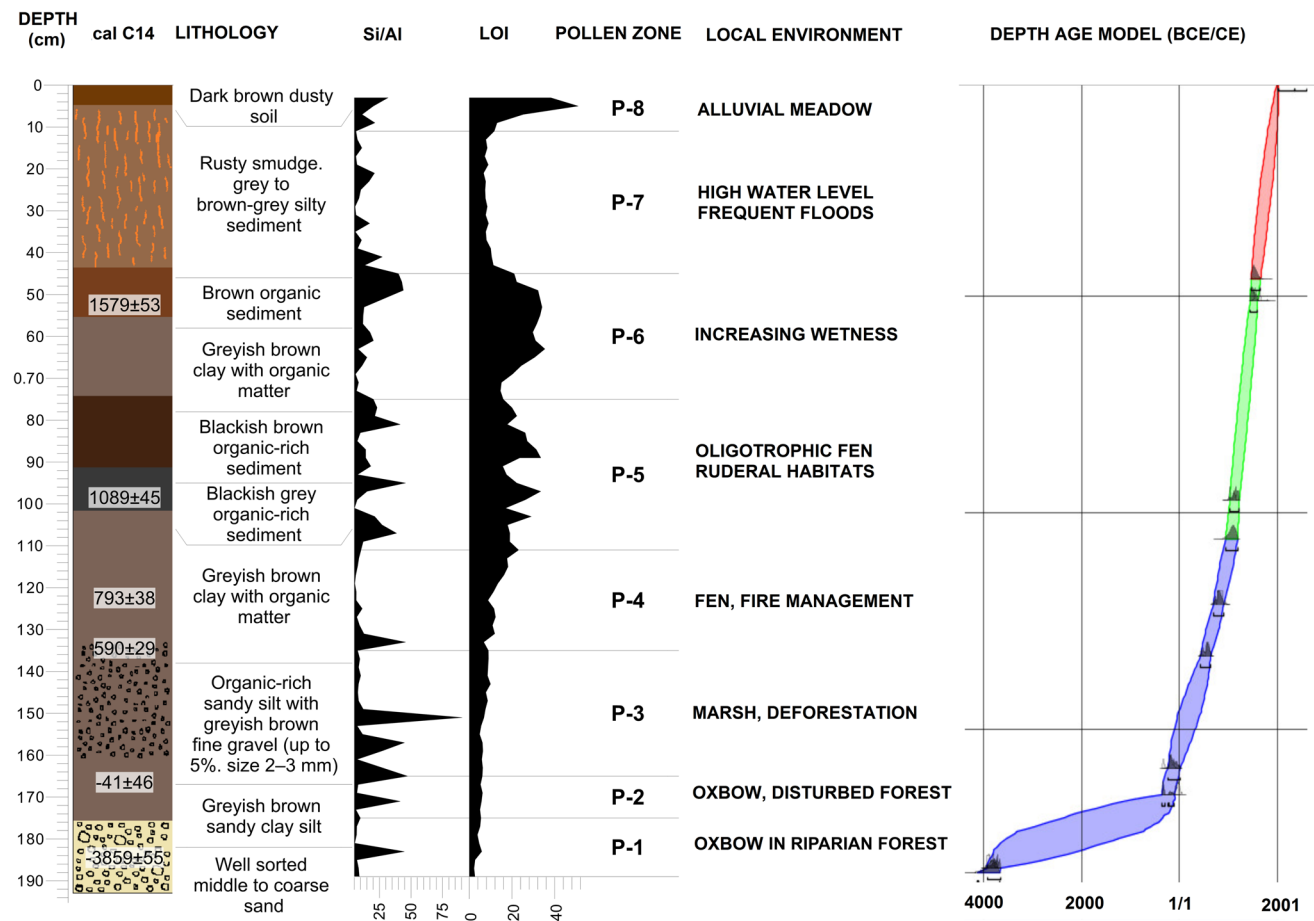


Fig. 2 Lithology, chronology, and local development of Erlwiesen profile. Al/Si ratio and LOI are in percentage. Depth Age scheme was created in OxCal 4.4 (Bronk Ramsey, 2009)

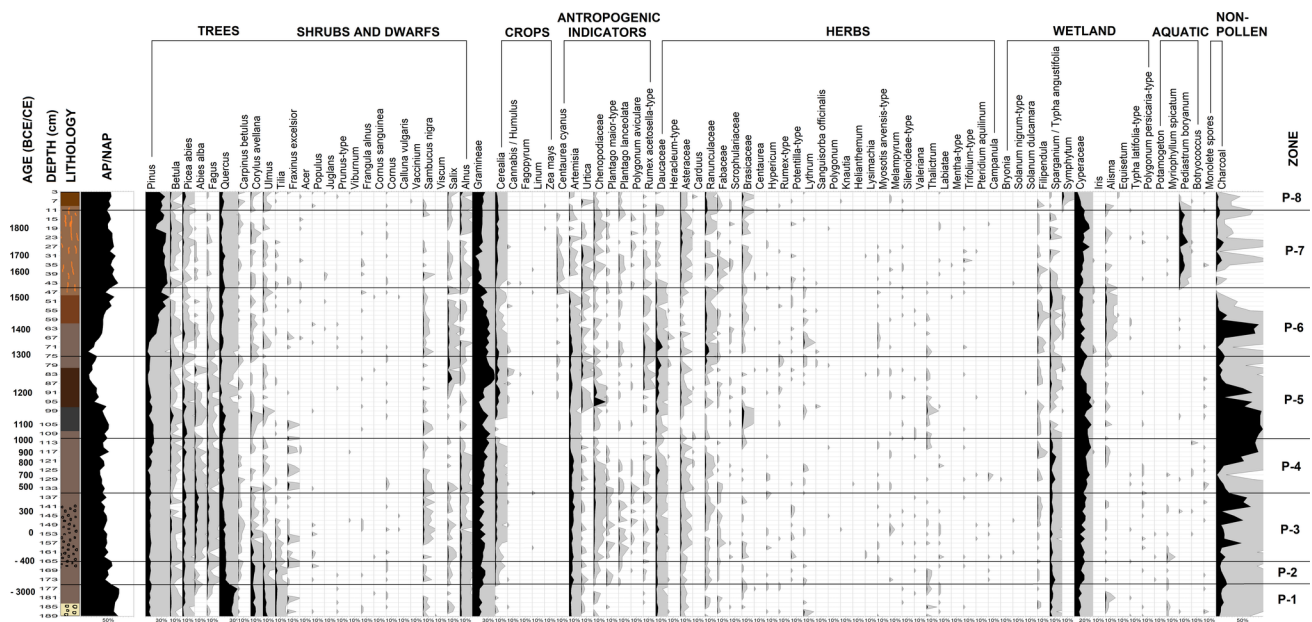


Fig. 3 Erlwiesen percentage pollen diagram of selected species, *Cyperaceae* and *Alnus* excluded from pollen sum, lithology sees Table 1

an episcopic microscope with 50–200 \times magnification and a reference collection (Schweingruber, 1990). They were quantified by counting the number of pieces and individually weighing the charcoals of individual tree taxa with an accuracy of ± 0.001 g.

The chemical composition of the Erlwiesen cores (Fig. 5) was determined using a Riga NexCG energy dispersive fluorescence (ED-XRF) spectrometer with a 50-W Pd tube and a silicon drift detector (SSD) with a resolution of up to 145 eV. Excitation of secondary targets was used to improve the signal-to-noise ratio. The measurement time was 120 s for every target. Samples were measured in powder form. XRF values of relevant elements and loss on ignition were normalized to give a sum of 100% to eliminate the effect of different organic content. Loss on ignition (LOI) was dried at 105 °C for 24 h, and the combustion length was 3 h at 550 °C. The LOI of sediments suggests the rate of allochthonous influx of inorganic material from the site's catchment area and the organic productivity of the peat within the site (Fig. 2).

Radiocarbon dating was applied to the material from Erlwiesen and the *Za bunkrem* site (Tab. 1). Plant macrofossils and charcoal were subjected to radiocarbon dating at the Radiocarbon Laboratory in Poznań, Poland (AMS). The calibration of ^{14}C dates was done in OxCal 4.4 (Bronk Ramsey, 2009). A depth–age model was created in the program OxCal 4.4 (Bronk Ramsey, 2009); the date obtained for depth 159 was excluded. The agreement of the model was 92%.

Results

Erlwiesen Profile – Local Floodplain

The Erlwiesen profile was divided according to the results of the pollen analysis (Fig. 3) into eight zones. Lithology and essential physical proxies (see LOI) show local environment changes (Fig. 2), including macro-remains analysis. ED-XRF and loss on ignition (LOI) data visualized the relations between organic matter content (expressed as LOI) and individual chemical elements (Fig. 4), the difference between elements indicating clastic material composed mainly of aluminosilicates, such as Si, K, Al or Zr, and those indicating sediments with a high content of organic matter, possibly contaminated by heavy metals such as lead, and/or with indicators of biological activity such as Ca and P. Distinction between an alkaline, carbonate-rich freshwater environment with biological activity are indicated by elements such as Na, Mg, Ca, P or S, and sediments containing Ti, Fe and Mn that indicate a floodplain with an oscillating groundwater level.

First Zone P-1 (189–175 cm, Circa 3953–3770 BCE to 2000 BCE)

A stream influenced the site's oxbow environment. The appearance of water macrophytes such as *Batrachium* sp. and *Potamogeton natans* indicates gradually decreasing fluvial activity. The chemical analysis shows an alkaline and carbonate-rich water environment reflected by a high Na, Mg,

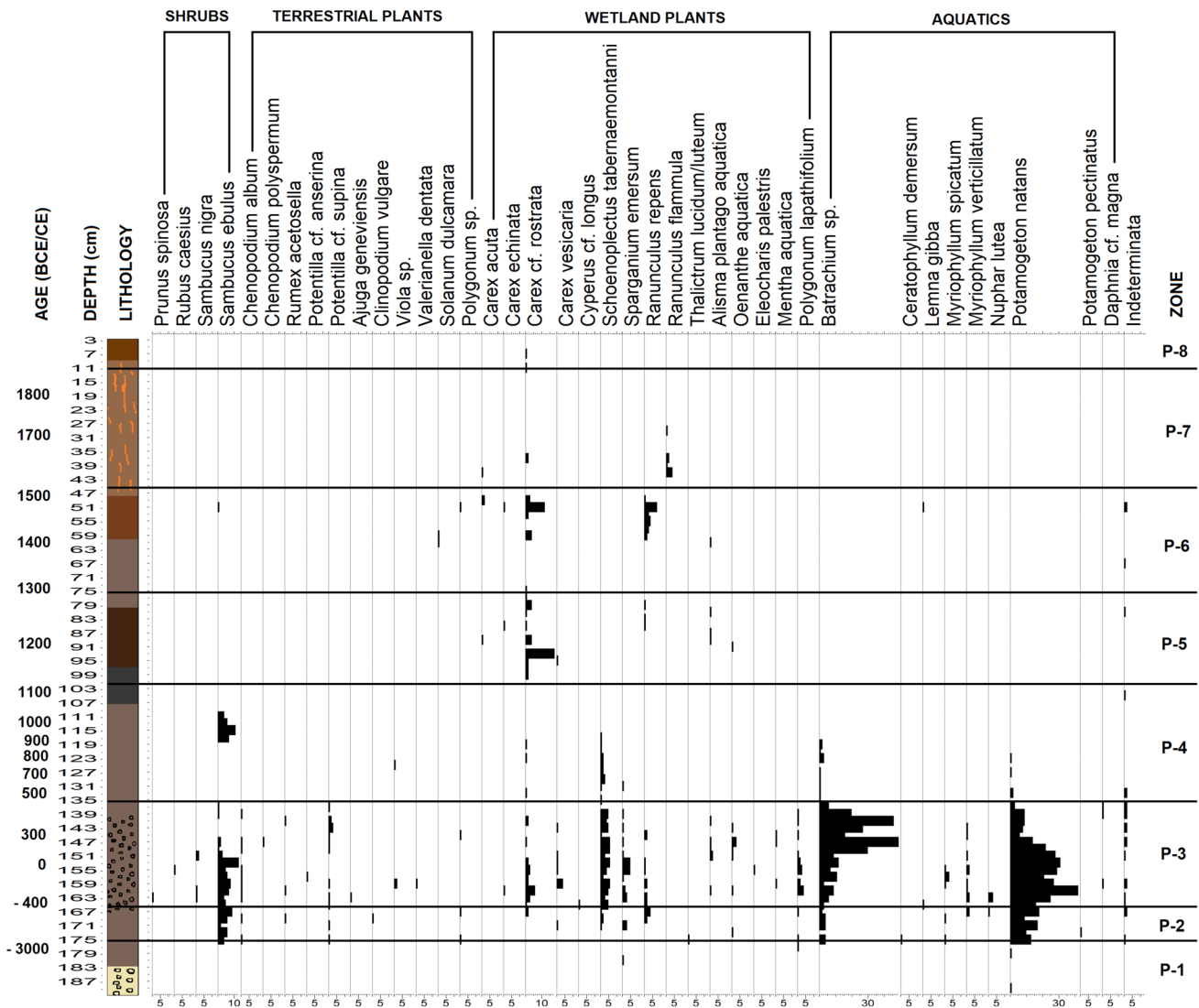


Fig. 4 Macro-remains of Erlwiesen profile, numbers of plant remain, lithology sees Table 1

and Ca content. Oscillating Si/Al ratios reflect the presence of an active stream. The surrounding vegetation is a riparian forest with a dominance of *Quercus*, *Tilia*, and *Ulmus*.

Zone P-2 (175–165 cm, 2000 BCE to 95 BCE)

The site was part of an oxbow, occasionally under the influence of a stream. The vegetation consisted of developed aquatic plant communities of *Batrachium* sp. and *Potamogeton natans*. The oscillating Si/Al ratio continues to reflect the presence of an active stream. Littoral vegetation is indicated by *Schoenoplectus tabernaemontanni* and *Sparganium emersum*. There is evidence of a declining alluvial forest, with dominating *Quercus*. Grasses, cereals, and ruderal species such as *Artemisia* and the *Chenopodiaceae* are abundant due to human activity, resulting

in deforestation. Macro-remains of *Sambucus ebulus*, a species of ecotones and non-wooded habitats, represent terrestrial vegetation.

Zone P-3 (135–165 cm, 95 BCE to 549 CE)

The site had the character of a marsh influenced by fluvial activity and sand influx. Chemical proxies indicate the same presence of flowing water as in the P-2 zone. Macro-fossil evidence shows rich aquatic plant communities and littoral vegetation as in zone P-2. The landscape was more open, and the vegetation was strongly influenced by human activity, as evidenced by an increasing abundance of cereal and ruderal taxa; micro-charcoal is abundant. *Abies* and *Carpinus* were increasingly present. *Sambucus ebulus* indicates open habitats.

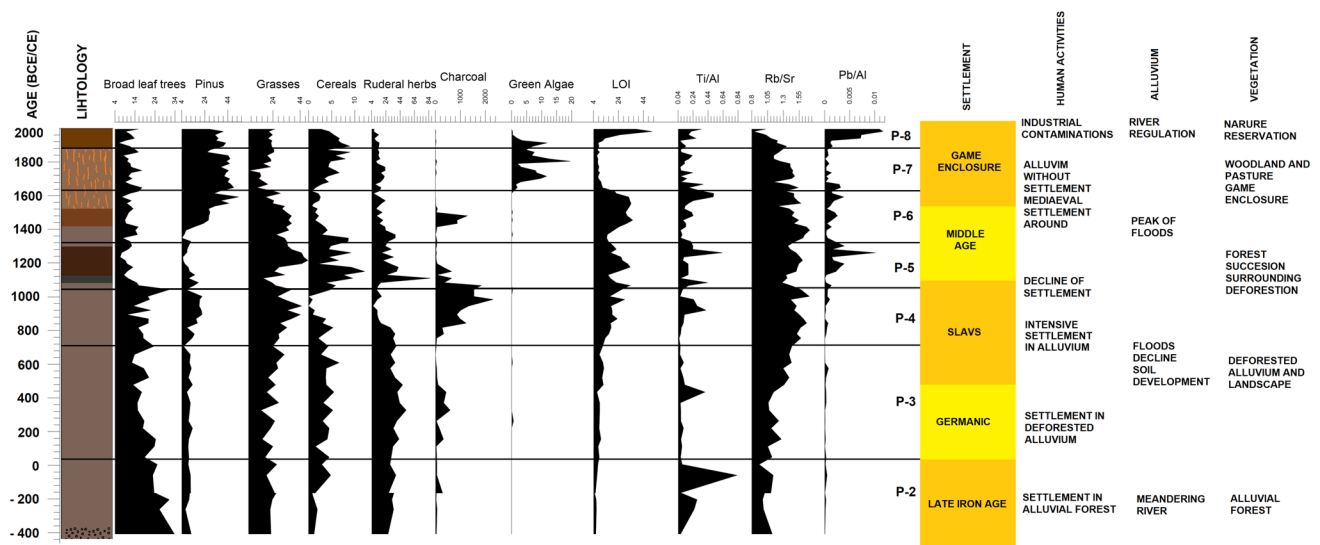


Fig. 5 Development of Soutok landscape, vegetation, alluvium, and settlement changes. Percentage pollen curve, selected element content in ppm, percentage of Loss on Ignition, and interpretation

Table 1 ^{14}C dates obtained from the Erlwiesen profile and the *Za bunkrem* site

Sample	Lab. Code	C14 age	Calibration (BCE/CE)	Material
Erlwiesen 51	Poz-87352	285 ± 30 BP	1493 – 1791 CE	Seeds
Erlwiesen 97	Poz-87347	985 ± 30 BP	990 – 1154 CE	Charcoal
Erlwiesen 121	Poz-87346	1195 ± 30 BP	720 – 941 CE	<i>Schoenoplectus lacustris</i> seeds
Erlwiesen 133	Poz-87348	1485 ± 30 BP	474 – 646 CE	<i>Schoenoplectus lacustris</i> seeds
Erlwiesen 159	Poz-87345	2150 ± 30 BP	356 – 61 BCE	Charcoal
Erlwiesen 165	Poz-87349	2035 ± 30 BP	160 – 50 BCE	Sambucus, Prunus seeds
Erlwiesen 183	Poz-87351	5045 ± 30 BP	3953 – 3770 BCE	Bark
Za bunkrem	Poz-96366	1005 ± 35 BP	972 – 1154 CE	Charcoal

Zone P-4 (101–135 cm, 549–1043 CE)

Local wetland vegetation consisted mainly of members of the *Cyperaceae* family and was strongly affected by anthropogenic activity. A decline of *Sparganium/Typha angustifolia* pollen indicates an infilling of the oxbow. Aquatic plant macro-fossils are declining, as are those of littoral species. *Sambucus ebulus* indicates treeless vegetation. The local vegetation was strongly affected by fire. Herb charcoal is recorded in the micro-fossil record but not in the macro-fossil record because of fragmentation during the wet sieving. Wood charcoal was not recorded, suggesting that the site was treeless. According to chemical proxy data, organic matter production has an apparent rise with a ‘lake event’ at a depth of 130 cm. An interesting trend is an increase in

indicators of chemical weathering, such as Rb/K and Rb/Sr. Around 900 CE, there is evidence of increasing fire management and a decline in cereal production, culminating in a hiatus in the pollen record at a depth of 103 cm (1020 CE).

Zone P-5 (75–101 cm, 1043–1328 CE)

The appearance of *Salix* after the *Chenopodiaceae* peak indicates a lessened human impact on the vegetation of the alluvium. The site had the character of an oligotrophic fen with an accumulation of peat, marked by a dominance of *Carex rostrata*. LOI increased to 45%. Chemical proxies indicate similar conditions as in the previous zone, with a high production of organic matter and a record

of intensive chemical weathering. However, some events are above the depths of 06 cm and 90 cm, and around 80 cm, possibly connected with an influx of clastic material. Evidence of heavy metal contamination at the turn of the thirteenth and fourteenth centuries is probably due to mining and ore processing in the Dyje River catchment (Hrubý et al., 2014). This zone exhibits the maximal extent of deforestation and an expansion of grasses and cereals. A peak of ruderal *Chenopodiaceae* is probably correlated with local fire activity. There is also a decline in *Quercus*, *Abies*, and *Picea*.

Zone P-6 (45–75 cm, 1328–1626 CE)

A significant upsurge in *Alisma* pollen, also recorded in the macro-fossil spectrum, possibly indicates increasing local wetness. The occurrence of *Lemna gibba* is evidence of a high water level. Otherwise, the trend in this zone is like that observed in zones P4 and P5, only without events of clastic material influx and with increased production of organic matter. There is a decline in anthropogenic indicators, cereals, and microcharcoals. *Pinus* expands to formerly deforested sites. Alluvial vegetation communities remain unchanged.

Zone P-7 (11–45 cm, 1626–1927 CE)

Pediastrum sp. green algae, particularly *Cyperaceae*, indicate a high water level, as do the macro-remains of *Ranunculus flammula*. A decline of *Carex rostrata* and *C. acuta* illustrates changes in sediment accumulation. Specifically, a decrease in the content of organic matter (LOI) and an influx of aluminosilicates indicate flooding and the formation of overbank deposits (Grygar et al., 2011). There were significant expanses of cornfields in the surroundings. A simultaneous expansion of *cyanus* is typical of medieval agriculture practices. Woodland vegetation with *Pinus* dominance is without changes.

Zone P-8 (3–11 cm, 1927 CE – Recent Topsoil)

Algae, such as *Pediastrum* sp., declined, as did members of the *Cypharecea*, indicating a lower water level and accumulation of organic matter. This was probably a result of building a flood dam, which decreased the frequency and severity of flooding. *Symphytum* cf. *officinale* indicates the existence of wet alluvial meadows like those occurring in the area at present. A continuing influx of clastic sediments correlates with contamination by heavy metals (mainly lead). An increase in *Picea* and the disappearance of *Abies* result from modern forestry management. A decline of *Centaurea cyanus* reflects modern agricultural practices.

Site Za Bunkrem

The cross-section through fluvial sediments at the site *Za Bunkrem* captures a sequence of point bar deposits and an infill of a former channel. This infill has probably been reworked, but the presence of Early Medieval pottery and 14C dating (972–1154 CE) place the channel activity in the Early Medieval Period, as the dating pertains to the channel's infilling, not the active stream. Based on a predominance of *Quercus* pollen over that of *Pinus* and other trees, the age of this site possibly corresponds to the P-5 or older zone of the Erlwiesen profile. The ratio of cereal pollen to that of secondary anthropogenic indicators is similar, too. *Calluna vulgaris* pollen documents the diversity of the former alluvial landscape. The charcoal evidence probably reflects a different taphonomy across a wider catchment area. Only fifteen pieces of charcoal were identified: ten of *Quercus*, five of *Ulmus*, and one of *Carpinus*.

On-site Archaeobotanical Evidence

Long-term archaeological research of Pohansko focused on the Slavic occupations provided many samples with charcoal ($N=626$) with a total number of 4217 identification determinations. Charcoal analysis indicates the presence of a mosaic landscape of wooded and open habitats with mesophilic oak and hardwood riparian woodlands dominated by *Quercus* (82.9%). Less common are *Carpinus* (4.1%), *Fraxinus* (1.2%), *Acer* (1.1%), *Ulmus* (4.8%), *Tilia* (0.1%) and *Alnus* (0.95%). Open vegetation is suggested by a relatively high abundance of shrubs on woodland edges and woodland openings, such as *Cornus* (0.3%), *Corylus* (0.2%), and *Pomoidea* (0.7%). Interesting are finds of charcoal of *Abies* (0.02%), *Picea/Abies* sp. (0.36%), *Picea* (0.02%), and *Fagus* (0.12%), which are species typical of present-day forests growing at higher elevations in this region.

177 samples date with certainty to the Early Medieval Period; ambiguous samples were excluded from the analyses. The total number of pieces of seeds identified was 31,460. Despite intensive sampling for charred seeds, number of positive samples was relatively low. The assemblage recovered was limited and predominantly consisted of seeds of cultivated crops. One object containing charred seeds of *Avena* sp. was excluded from the sum. Among the finds of cereals, *Triticum aestivum* (43.9%), *Secale cereale* (43.2%), *Hordeum vulgare* (7.8%), and *Panicum miliaceum* (3.7%) were the most numerous. Less common was *Avena* (1.4%). Non-cereal cultivated plants found include legumes (462 pieces), namely *Pisum sativum* (58.9%), *Lenz culinary* (23.4%), *Vicia faba* (9.3%), *Vicia Avila* (7.6%), and *Lathyrus sativus* (0.9%). Other cultivated plants are *Cannabis* (49 seeds), *Linum usitatissimum* (2 seeds), *Cerasus avium* (1

seed) and 14 pieces of *Cerasus* sp., *Persica vulgaris* (6 fragments of seeds) and one seed of *Vitis* sp. The spectrum of naturally occurring plants collected consists of *Corylus avellana* (100 pieces of nuts), two damaged seeds of *Malus/Prunus*, *Prunus mahaleb* (2 seeds), *Prunus spinosa* (20 seeds), *Rosa* sp. (2 seeds) and *Sambucus ebulus* (1 seed).

Weeds of cornfields were represented by *Agrostema githago*, *Bromus secalinus* cf. *Convolvulus arvensis*, *Fallopia convolvulus*, *Galium aparine/spirium* sp. *Setaria* sp. *Echinochloa crus-galii* and *Vicia tetrasperma*. This species spectrum can be considered a general spectrum of weeds without any closer ecological information value. Ruderal vegetation is represented by *Chenopodium album*, *C. murale*, *C. hybridum*, *C. polyspermum*, *Xanthium strumarium*, *Malva neglecta*, and *Sambucus ebulus*. Trampled sites are indicated by *Polygonum arenastrum*, *Rumex acetosella*, and *Rumex sanguinalis*, which also indicate nutrient-rich and poor habitats.

Discussion

Development of the Dyje River Floodplain and Human Impact on the Vegetation

Pollen data show that human activity did not significantly affect the alluvial-edge (?) woodland during the Late Neolithic and Bronze Age periods (zone 2000 P1, 3953–2000 BCE). Before the turn of the millennium (P2, 2000–95 BCE), the alluvium was extensively inhabited but still wooded, with a dominance of *Quercus*, *Carpinus*, and *Ulmus* dominance and a surprisingly scarce presence of *Alnus* and *Salix*. A hardwood alluvial woodland corresponds with low flood activity and soil development in the alluvium (Petřík et al., 2019). This is in contrast with pollen evidence outside/beyond the alluvial floodplain, where there is visible human impact in pollen record since the Aeneolithic (4200 – 2000 BCE) and the continuity of open habitats since the onset of the Holocene (Kuneš et al., 2015), which was caused by early Holocene climate change and later human activities (Petr et al., 2013).

So far, our anthracological data synthesis indicates a noticeable abundance of *Salix* or *Alnus* in the pollen records of sites with prehistoric and early medieval settlements near the floodplain (Novák et al., 2017). This is, however, not the case at the Early Mediaeval settlements of Pohansko or Mikulčice (Opravil, 1983), where *Quercus* prevails, possibly because wood sources were exploited across a wider area. *Fagus* currently occurs near Hodonín but is scarce in the lowland pollen record (Jamrichová et al., 2013; Kuneš et al., 2015). Similar evidence has been provided by a previous pollen analysis of a water well dated to the ninth century, found in the Pohansko settlement (Doláková et al., 2010).

The occurrence of coniferous trees in the pollen record points to environmental gradients around the Erlwiesen site. *Pinus* stands can be reconstructed on sandy based on an analogy to the nearby Záhorská lowland, where *Pinus* is dominant in pollen records throughout the Holocene even though charcoal evidence indicates the presence of a *Quercus* and *Pinus* woodlands (Jamrichová et al., 2019). In contrast to this stands the scarce occurrence of *Pinus* charcoal at archaeological sites in the lowland (Novák et al., 2017). Scots pine (*Pinus sylvestris*) was the preferred tree species in lowland forests (Nožička, 1957) during the post-Medieval period; see the Erlwiesen LPZ from P-6 to P-8. Interpreting the occurrence of *Picea* in the lowlands is complicated. Some authors consider the possibility of long-distance transport (Rybníček, 1983) in the pollen record and macro-remains brought by driftwood down the river. In the prehistoric charcoal record, evidence of *Picea* is very scarce (Novák et al., 2017). Nevertheless, the historical occurrence of *Picea* in alluvial environments is documented by Opravil (1983). Spruce was planted extensively in modern times (see LPZ P-8), and pollen from its plantation overshadows that of naturally occurring spruce. *Abies* was frequent in the Czech lowland until modern times (Kozáková et al., 2011), but post-Medieval changes in woodland management (Nožička, 1957) pushed them out of low-lying areas.

The landscape around the Early Medieval settlement cluster of Pohansko was deforested to accommodate the expanding settlement and burial area. The local pollen record (Doláková et al., 2010) shows an abundance of open habitat species greater than that of arboreal pollen. Isotope evidence from a cow tooth supports the existence of meadows and ecotones in the area (Ivanov et al., 2018). The surroundings of large Early Medieval settlements, such as Stará Boleslav (Kozáková et al., 2014) or Mikulčice (Látková, 2017), were largely deforested. By contrast, small fortified Early Medieval settlements on the alluvium, such as Olomouc (Kočár et al., 2016), Hradištko or Libice (Kozáková et al., 2014), had only a tiny impact on the vegetation in their surroundings, and their existence is hardly discernible from the pollen record. On the other hand, the large settlement at Roztoky in the Vltava River Valley had deforested surroundings (Novák & Prach, 2024). Generally, the High-Medieval transition (Abraham et al., 2016; Kozáková et al., 2014) was associated with increasing human impact on the lowland environment; however, at Pohansko, the most intensive human impact occurred later during the Early Middle Ages.

Floodplain Dynamics and Settlement Changes

Alluvial deposits with buried soils and archaeological features at the Pohansko site indicate a relationship between flooding and human activity. Overbank deposits with buried soils in alluvium sequences have been recorded at

several sites along the Dyje River (Havlíček & Smolíková, 2004), including Pohansko (Havlíček, 2001, Havlíček & Smolíková, 2002). The older soil has been dated to around 1000 BCE (Havlíček & Smolíková, 2004), whereas the upper buried soil is superimposed by the Great Moravian fortification (Macháček, 2007). Soil development differed in elevated places inhabited by humans, where the soil may be interpreted as chernozem with a strong anthropic impact. What we know about the buried soil in the alluvium sedimented during the late Holocene of the Dyje River and its dating is insufficient, and the same applies to our knowledge about how it relates to the settlement of the area by humans (Petřík et al., 2019). A well-developed fossil soil containing evidence of intensive prehistoric settlement has been studied along the Dyje's tributary Svratka River (Vejrostová et al., 2019), dating from 4500 to 1000 BCE. The timing and extent of overbank sedimentation depend on the geomorphology of the catchment area. Fossil soil associated with the Early Medieval settlements, such as that at the site *Na Včelách* (Petřík et al., 2019), can be linked to the end of zone P-4, which shows an absence of frequent floods and no accumulation of overbank deposits. The low flood activity may be attributable to the aridity of the Late Antique Little Ice Age in the sixth century CE (Büntgen et al., 2016). Evidence of the Dark Age Cold Period (Helama et al., 2017) is not visible in the Erlwiesen sediment record; the hydrological regime seems stable and without high flooding activity. Reconstructions indicate that summers were wetter during the Great Moravian Empire (also known as the Early Medieval Pluvial – Büntgen et al., 2021). In the first millennium CE, there was no alluvial aggradation on the floodplain. Evidence of the Little Ice Age overlaps with deforestation (Dabkowski et al., 2019).

An increasing incidence of floods is apparent from the record of the Erlwiesen site, where zone P-6 sees a rise in wetland vegetation (see the pollen curve of *Alisma*). Rivers change their fluvial character from meandering to anastomosing not because of climatic stability but because their channels get filled with sediment over time (Grygar et al., 2011). The moisture regime was imbalanced (Büntgen et al., 2021), and evidence of accelerated erosion is apparent in the foreground of the Bohemian massive (Petřík et al., 2015). Intensive deforestation of the Bohemian–Moravian Highlands (Hrubý et al., 2014) has been dated to the late thirteenth century CE, and it has been documented that it increased the incidence of floods and accelerated alluvial aggradation. The nearby Morava River was more sensitive to climatic extremes during the last millennium CE than Dyje, based on sedimentological data along the Strážnice River (Grygar et al., 2011). The character of overbank deposits changed from prevailing clay at the end of the first millennium CE to silty and sandy sediment in the Late Medieval period, also referred to as the Little Ice Age (Kadlec et al., 2009).

The early post-Medieval Period brought an acceleration of flooding dynamics associated with the accumulation of silty overbank deposits. Zone P-7 bears evidence of a high water level, embodied, for example, by green algae of the genus *Pediastrum*. The youngest deposits of the Pohansko section exhibit the same trend of increased silt deposition (Petřík et al., 2019). This stands contrary to reconstructions indicating decreased wetness during the pre-industrial period (Büntgen et al., 2021).

Subsistence Strategies Evidenced by Off-Site and On-Site Data from the Early Medieval Period

The local subsistence strategy is assessed based on archaeobotanical and archaeozoological evidence from Pohansko. The presence of charred *Triticum* grains in a La Tène paleochannel (Petřík et al., 2019) stands in contrast to the low abundance of cereal taxa in the pollen spectra, compared to non-alluvial sites (Kuneš et al., 2015). It is possible that cereals were brought to the site from fields outside the floodplain, where they were grown on chernozems soils, which were preferred for agriculture in the La Tène period over luvisolic soils (Kočár & Dreslerová, 2010b).

The early-medieval spectrum of cereal species observed at Pohansko is typical of the Early Medieval Period (Kočár & Dreslerová, 2010a, 2010b) floodplain sites such as Mikulčice (Látková, 2017), Olomouc (Kočár et al., 2016) or the Přerov hillfort (Procházka, 2017). However, there is a slight yet notable increase in the abundance of *Triticum* at the expense of *Secale cereale*. This can be explained by the geographical connection to Pannonia, where *Triticum* was the predominant cereal crop in the later Middle Ages and post-Medieval Period, unlike, for example, in northwestern Bohemia, with a dominance of *Secale cereale*. A similar increase in the proportion of wheat has been observed at the site Žatec, where hexaploid wheat prevailed during the transition between the early and the High Middle Ages (Čech et al., 2013; Kočár et al., 2010). At this site, however, this change reflected a shift in agricultural practices in the thirteenth century CE (Kočár & Dreslerová, 2010a), not a changing environment. The abundance of *Panicum* is paralleled at other Early Medieval sites, for example, Roztoky u Prahy (Kuna et al., 2013), Přerov (Procházka, 2017) or Mikulčice (Látková & Hajnalová, 2014). Wheat may be considered an emergency crop due to its short vegetation cycle, but its cultivation is laborious. It might have been used for cooking mash instead of baking bread (Kuna et al., 2013). Isotope evidence from Pohansko and the Mikulčice cemetery indicates that the population ate a terrestrial diet including red meat and only a little fish (Halffman & Velemínský, 2015; Kaupová et al., 2018). In addition, there is a strong isotope signal of millet consumption, corresponding with archaeobotanical evidence of abundant millet from Great Moravian sites (Ivanov et al.,

2018). The spectrum of cereal weeds recorded by archaeobotany demonstrates that crop fields were situated outside the alluvial floodplain zone on chernozem or loess soils, found approximately 3–4 km away from Pohansko.

Evidence of the legumes *Vicia ervilia* and *Lathyrus sativus* is extraordinary in the Czech archaeobotanical record (Kočár & Dreslerová, 2010a, 2010b) because they are typical for more southerly and warmer regions of Europe. Archaeobotanical evidence of weeds from the Pohansko site reflects a wide range of habitats, not a strictly alluvial environment. Regarding nutrient demands, the diversity of cereal weeds corresponds with the types of soil around the Soutok area, ranging from loess to sandy terraces.

Conclusion

It is impossible to explain changes in settlement dynamics and link them with floodplain dynamics without a broader political and economic context. The Pohansko area was intensively inhabited from the La Tène Period and through the Roman Period and became a significant settlement of the Great Moravian Empire. The cultural layer is associated with a fossil (buried) soil horizon developed in overbank deposits. The occurrence of this fossil-buried soil ended after the High Medieval Period due to the aggradation of the floodplain.

The proxy record of the former oxbow Erlwiesen allows us to reconstruct the environmental and settlement history of the Pohansko site over the last two millennia. The pollen record at the site indicates a deforested and densely inhabited landscape since the La Tène Period. The area was extensively inhabited during Roman times due to its proximity to the *Limes Romanum*, and the Dyje and Morava Rivers were essential communication routes. The Germanic settlement gradually transformed into a Slavonic one without any apparent hiatus. Slavs preferred floodplain sites and progressively transformed their society into tribal or state-like structures. This culminated in the Great Moravian period (850–906 CE), most remarkably evidenced by terrain relicts at the Pohansko site; however, this culmination lasted only a short time of probably about 40 years. This peak in settlement is indiscernible in the paleorecord because it correlated with the political and social importance of the site rather than with increased settlement density or landscape exploitation. The society was highly stratified and supported by economic activities in adjacent areas with chernozem soil outside the floodplain.

This increase in flooding in the eleventh century CE occurred later than the decline of the remaining floodplain settlement *Na Včelách* and the abandonment of the Pohansko area. The primary reason was that the settlement's center of gravity shifted to the nearby town of Břeclav, founded

around a royal castle in the High Medieval Period. The Pohansko site was then inhabited only on its periphery and was later transformed into a game enclosure.

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Data Availability <https://zenodo.org/records/14886564>.

Declarations

Ethical Approval Not applicable.

Competing Interests The authors declare no competing interests.

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