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Age and origin of the central-European mires: value of natural peat archives for science and nature conservation

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Abstract: Understanding the timing and environmental context of mire formation in central Europe is important for reconstructing landscape history and informing conservation efforts. We analysed 220 still-active mires in the Czech and Slovak Republics to determine their age, origin, and protection status. This overall dataset was supplemented by plant macrofossil analyses of basal peat samples from 36 sites in a mire-rich model region (Třeboň Basin, Jihlavské vrchy, and Žďárské vrchy hills), where information on mire age has been scarce. Fens dominate the overall dataset, while bogs are less frequent and particularly rare in the Western Carpathians. The oldest extant mires began accumulating peat during the full-glacial, even though mire formation was very scarce at that time (seven sites). Apparent fen-inception frequency increased markedly during the late Holocene, coinciding with intensified human land use and landscape opening, while bog formation was mostly driven by climatic conditions in earlier periods. Mire development from aquatic environments was less common than in northern Europe. Mire inception intensity further coincided with major climatic changes during the late glacial and Holocene. Frequency of dated basal peat ages increased after late-glacial warming (~14.2 kyr cal BP), declined sharply during the cold and dry Younger Dryas and the warm and dry early Holocene (~10.5–8.5 kyr cal BP), and resumed as moisture availability increased after ~8.5 kyr cal BP. A further decline occurred during the early late Holocene (~3.5–2.8 kyr cal BP). Initial habitats were reconstructed for 145 sites using plant macrofossils, pollen, and peat characteristics. Of these, 43.5% originated as open mires, 34.5% as waterlogged forests or forest springs, ~10% as semi-open habitats, and ~12% as aquatic environments later often surrounded by fens. In the model region, open-habitat origins were more frequent, while aquatic origins were rare. Macrofossil data revealed clear differences between young and old basal samples. Young mires, often initiating near fishponds, dominated the Třeboň Basin, whereas late-glacial and early Holocene mires in the Žďárské and Jihlavské vrchy hills contained boreal, cold-adapted taxa now considered glacial relicts. A similar proportion of bogs (15%) and fens (18.3%) remain unprotected, including older ones, highlighting the need to protect mires not only because of their unique recent biota but also because of their valuable peat archives and seed banks.

Keywords: Czech Republic, natural archives, past vegetation, peat, plant macrofossils, radiocarbon date, Slovak Republic

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Introduction

Mires are peat-accumulating wetlands in which a persistently high water table determines anaerobic, nutrient-limited conditions that slow decomposition and enable long-term peat formation. Although they cover only a small fraction of Earth's land surface, peatlands store enormous carbon stocks, holding roughly twice as much carbon as all global forest biomass (Gorham 1991, Yu et al. 2010). They can be divided into two principal types, differing primarily in water sources. Bogs are ombrogenous mires that receive water solely from precipitation and therefore exhibit acidic, nutrient-poor conditions dominated by *Sphagnum* species and species adapted to low nutrient levels (Hájek et al. 2006, Rydin & Jeglum 2013). In contrast, fens are fed by groundwater of varying mineral richness and reaction, supporting more nutrient- and mineral-demanding sedges, more herbs and non-*Sphagnum* bryophytes. The specific chemical and hydrological conditions structure distinct plant communities and maintain habitat specialists with narrow ecological tolerances (e.g. Bedford & Godwin 2003, Peterka et al. 2017). Despite their ecological importance, mires rank among the most threatened ecosystems globally. Drainage for agriculture, forestry, and peat extraction has lowered groundwater levels, accelerated peat oxidation, and increased carbon emissions (Gorham 1991, Tanneberger et al. 2020). Changes in hydrological regimes disrupt peat accumulation processes and drive vegetation shifts, often leading to the loss of open-habitat specialists, particularly in unmanaged fens (Hájková et al. 2022). As a consequence, many mire species are now highly endangered.

The peat accumulated in mires serves not only as a major long-term carbon store but also as a unique palaeoecological archive. The slow, anoxic deposition of organic matter in the catotelm enables the preservation of plant macrofossils, pollen, and other biological proxies, providing an unparalleled record for reconstructing past vegetation and environmental change at millennial timescales (van Geel 1978, Barber et al. 2004, Mäkilä & Saarnisto 2008). Because peat layers accumulate incrementally, their stratigraphy enables a precise chronological reconstruction of local habitat development and landscape history through radiocarbon dating of specific layers (Goslar et al. 2005). Because plant macrofossils can often be identified to the species level, analysis of peat layers not only enables the direct reconstruction of past habitats (Hájková et al. 2026) but also provides insights into shifts in the distributional ranges of individual species and their potential relict status (Jankovská & Rybníček 1988, Hájková et al. 2018). Knowledge of the historical occurrence of species can be used to communicate nature conservation goals to the wider public (Hockings 1998, Roleček et al. 2020). In addition, peat deposits often contain long-term seed banks that reflect species present during earlier successional stages, offering insight into past plant community dynamics and resilience (Bauer et al. 2003, Tuittila et al. 2013, Gałka et al. 2017). Moreover, the long-term seed bank also provides an essential source of propagules that can facilitate the spontaneous recovery of mire vegetation once hydrological conditions are restored, supporting the re-establishment of characteristic fen and bog species (Grootjans et al. 2012, Kelly et al. 2016). This natural regenerative capacity is particularly valuable on sites where the species composition of the vegetation has been impoverished.

Mires are among the few terrestrial habitats that can be directly dated**,** as their peat deposits contain well-preserved plant macrofossils suitable for radiocarbon analysis.

Radiocarbon dating works by measuring the remaining activity of ^{14}C, a radioactive isotope formed naturally in the atmosphere and incorporated into plant tissues before burial; as ^{14}C decays at a known rate, its residual concentration allows the age of peat layers up to ~50,000 years to be estimated (Libby 1946, Godwin 1962). Over recent decades, advancements such as accelerator mass spectrometry (AMS), improved chemical pretreatment, and refined calibration models have greatly increased dating precision and enabled detailed peat chronologies and age–depth models (Piotrowska et al. 2011). These developments provide the high temporal precision needed to track ecological succession and compare mire trajectories across the Holocene (Cubizolle et al. 2012, Hájková et al. 2012).

In this paper, we summarize all available ^{14}C dates from the basal layers of current mires in the Czech and Slovak Republics, including 20 newly dated samples, to answer the main question: Which climatic and anthropogenic processes controlled the formation of extant central-European mires, and what are the implications for nature conservation?

Specifically, we (i) identify periods of higher and lower frequency of mire inception, (ii) examine the age-dependent spatial distribution of mires, (iii) reconstruct habitats and species associated with old and young basal sediments in both the entire and the model area with special attention to the occurrence of species that are currently rare and (iv) demonstrate and discuss the importance of this knowledge for nature conservation.

Methods

Data compilation at the level of the Czech and Slovak Republics

We gathered all known radiocarbon ages for 220 of the currently active mires, including minerotrophic mires supplied by groundwater (vegetation class *Scheuchzerio-Caricetea* except for *Sphagnion cuspidati*, hereafter assigned to fens) and ombrotrophic mires supplied by rainwater (vegetation class *Oxycocco-Sphagnetea* and *Sphagnion cuspidati*, hereafter assigned to bogs). The sites were classified into these two types based on information about their water sources (rainwater versus groundwater), topography, and current species composition. Fens originating from the activity of landslides represent a specific type of fen and are more common in the Western Carpathians (e.g. Šímová et al. 2019). In some cases, not only fens and bogs, but also fen meadows and tall-sedge stands with some surviving fen species were included, as they have potential for restoration for conservation purposes. When multiple basal radiocarbon dates were available for the locality, the oldest age was selected. Only mires with a dated basal layer were included. The geographical coordinates, radiocarbon ages, and the periods to which they belong were entered into a database. We also compiled information on vegetation composition at the onset of peat formation, based on plant macrofossils (in most cases), pollen, or sediment descriptions (in the case of lake sediment gyttja), yielding rough vegetation or habitat units. In this study, we classified samples only into broadly characterized vegetation formations, differing especially in the presence of trees and fen specialists, as defined by Peterka et al. (2022b). When plant macrofossil composition data were available, the following rules were applied: (i) the samples containing > 50% wood were assigned to "forest" (coniferous, deciduous and mixed according to prevailing trees); (ii) the samples containing 30–50% wood and the presence of at least two open-fen specialists were

assigned to the "transitional" category (between forest and open fen habitats) – these samples mostly represented the transitional stage between forest and open fen after human-induced deforestation; (iii) the samples containing < 30% wood and the presence of at least two open-fen specialists were assigned to "open fen". Moreover, samples containing open-spring species, such as *Montia fontana* or *Dichodontium palustre*, were assigned to (iv) "springs", and, because of their scarcity, were plotted together with open fens in a single "fen or spring" category in the diagram. The samples containing the forest-spring species (i.e. *Carex remota*; Hinterlang 1992, Peterka et al. 2023) were assigned to (v) "forest spring", and the samples with the presence of aquatic plants were assigned to (vi) "lake" or "lake+fen" when both groups of plant species were represented among the macrofossils. Literature data for which these characteristics were unavailable were omitted from this analysis, except for the "lake" habitat, which was also identified based on aquatic plant pollen and sediment description (assigned as gyttja). All sites were mapped in ArcGIS (Esri 2025) to show the geographical distribution of current mires with known age, with the onset of peat formation indicated by different symbols.

Sediment sampling, dating and macrofossil analyses in the model area

We newly dated basal layers from 20 sites in mire-rich regions with few previously dated mires (the Třeboň Basin and the Bohemian-Moravian Highlands consisting of Jihlavské and Žďárské vrchy hills), yielding 20 new basal ^{14}C dates. The ages of four recently established localities, formed after a decline in fishpond water levels, were inferred from a time series of historical aerial photographs and old military maps (https://app.gisonline.cz/chytre-mapy). Sediment was drilled using a gouge auger (6 cm diameter, 100 cm length) in the deepest part of each site after a thorough prospection. Sediment samples were packed into zip-top plastic bags and stored in a refrigerator. All basal samples of ~50 ml were sieved through sieves with meshes of 1 mm, 0.5 mm, and 0.125 mm, and then all macrofossils were hand-picked and identified under a dissecting microscope using Cappers et al. (2006), Velichkevich & Zastawniak (2006, 2008), Hedenäs (2003) and other available identification sources and the reference seed collection of the Institute of Botany of the Czech Academy of Sciences. Wood fragments were identified using an online key (www.woodanatomy.ch). Plant macrofossils were quantified as absolute counts per sample for countable fossils (seeds, needles, etc.) or as volume percentages for bryophytes, tissues and wood fragments. Selected plant macrofossils from 20 localities lacking age information (mostly seeds of terrestrial plants, bryophyte stems, and leaves and conifer needles) were dated at the Isotoptech Zrt. Laboratory in Debrecen and the Center for applied isotope studies in Georgia (one sample) using AMS radiocarbon dating. Aquatic plant seeds were avoided because of the risk of hard-water error (Philippsen 2013).

Numerical analyses

A synthesis of radiocarbon-based ages in the Czech and Slovak Republics was conducted using summed probability density distributions generated with the Sum command in OxCal v.4 (Bronk Ramsey 2009) and the latest calibration curve, IntCal20 (Reimer et al. 2020). Because mires are habitats that require permanent and stable waterlogging and their modern distribution on Earth is concentrated in areas with high precipitation and low evaporation (Joosten et al. 2017), we selected five climate parameters (climatic moisture

index, annual PET, annual precipitation, mean annual temperature and mean temperature of warmest quarter) to illustrate changes in climatic conditions, especially humidity. For each locality, data were extracted from downscaled and debiased CCSM3 simulations at a 30 arc-second resolution (Divíšek 2021). The mean and standard deviation across all sites were calculated for time windows spanning 100 years each.

To analyse the level of nature protection at particular mire sites, we assigned them to small- and large-scale protected areas. In the Czech Republic, small-scale protected areas include PP/NPP (Natural/National Natural Monuments) and PR/NPR (Natural/National Natural Reserves); large-scale protected areas include Protected Landscape Areas (CHKO; with strict first zones) and National Parks (NP; with strict first or quiet zones). The small-scale protected areas and the first and quiet zones were considered strict nature protection areas in our categorization. In Slovakia, the small-scale category Protected area (CHA), which has no equivalent in the Czech Republic, was also considered strict protection. Moreover, there are five levels of protection in Slovakia, and areas of European importance (SKUEV). Protection levels 3–5, together with areas of European importance (SKUEV), were considered strict nature protection areas in our categorization.

To analyse the variability in species composition of basal samples from the model area with respect to sample age, we used a constrained multidimensional ordination method, specifically detrended canonical correspondence analysis (DCCA) with age as the constraining variable, implemented in Canoco software (Šmilauer & Lepš 2014). Plant macrofossil composition data from 36 localities were analysed; one locality (Klátov) was excluded during the analysis because it was an outlier. Of these, 20 samples came from newly radiocarbon-dated sites. Samples from the other 13 localities were analysed by the first author of this study during a previous dating campaign (Peterka et al. 2022a, b). We further used published data from three other localities in the same region (Rybníčková & Rybníček 1988: Kameničky, Roleček et al. 2020: Dářko, Hájková et al. 2023: Pihoviny).

Holocene periods used in the text follow Walker et al. (2012): early Holocene 11,700–8,200 cal yr BP, middle Holocene 8,200–4,200 cal yr BP and late Holocene 4,200 cal yr BP–recent. Late-glacial periods follow Rasmussen et al. (2014): Bølling period/GI-1e: ~14,640–14,030 cal yr BP; Younger Dryas/GS-1: ~12,850–11,650 cal yr BP and late glacial 14,640–11,650 cal yr BP. We assigned all glacial dates predating the onset of the late glacial to the full glacial period. Vascular plant names follow Kaplan et al. (2019), and bryophyte names follow Kučera et al. (2012).

Results

Structure of the datasets used in this study

In this study we used four different datasets for individual analyses: (1) the dataset of radiocarbon ages of basal peat layers for 220 mires in the Czech and Slovak Republics (hereafter referred to as dataset 1); (2) the dataset comprising 145 of these mires for which a rough reconstruction of the habitat was available (hereafter referred to as dataset 2); (3) the subset of 43 known-age mires in the model area (Třeboň Basin and the Bohemian-Moravian Highlands), 24 of which were newly dated for this study (hereafter referred to as dataset 3); (4) the dataset of detailed plant-macrofossil records from 36 mires from the model area (a subset of the previous 43 known-age mires; hereafter referred to as dataset 4).

Age and conservation status of the current mires

Across the entire study area (Czech and Slovak Republics; dataset 1), most of the analysed localities are currently fens or fen meadows (180), and only a minority are bogs (40; Table 1; Supplementary Table S1; Fig. 1), most of which occur in the Czech Republic, while being scarce in the Western Carpathians (only 2 bogs of known age). The highest number of minerotrophic fens originated in the late Holocene (85); lower and broadly similar numbers originated in the other Holocene periods and the late glacial (33, 28 and 27, respectively), whereas only a few originated in the full glacial (7). Contrary to fens, no current ombrotrophic bog began to accumulate peat during the full glacial. Those bogs originating in the late glacial (11) developed primarily as lakes (4) or minerotrophic fens (7). As in fens, bog inception was similarly frequent in the late glacial (11), early Holocene (13), and middle Holocene (11), but only five originated in the late Holocene. Geographically, dated bogs are situated mostly in the border mountains Šumava (maximum altitude 1,378 m a.s.l.), Krušné hory (1,244 m a.s.l.), Jizerské hory (1,127 m a.s.l.), Krkonoše (1,602 m a.s.l.), Orlické hory (1,115 m a.s.l.), Králický Sněžník (1,423 m a.s.l.) and Jeseníky Mts (1,491 m a.s.l.). Similarly, fens are also concentrated in mountainous areas, both along the borders and in lower mountain ranges elsewhere (e.g. Bohemian-Moravian Highlands, Slavkovský les Mts, etc.) or in basins (Doksy region, Třeboň Basin) and avoid the large lowlands (Podunajská nížina lowland, Dolnomoravský úval, etc.). This distribution of dated mires corresponds well with the total mire distribution in the study area.

Regarding the conservation status of current mires with known age, most bogs (85%) are protected within small-scale protected areas (Nature Reserves or Nature Monuments), or within the highest zones of National Parks (first or quiet zones), and only 15% remain without formal protection nowadays. A slightly lower proportion of minerotrophic fens (70%) receive the highest level of protection; 12% are located only within large-scale protected areas in less strictly protected zones; and 18% are not protected at all (Table 1). A higher number of studied mires is located in the Czech Republic (137; of which 110 are under strict protection) and the Hercynicum (117), compared to Slovakia (80; of which 49 are under strict protection) and the Western Carpathians (103), respectively.

Focusing on the model study area (Třeboň Basin, Jihlavské and Žďárské vrchy hills), where detailed plant macrofossil analyses were performed for 36 mires (dataset 4; Table 2) and where altogether 43 mires of known age occur in total (dataset 3), fens (41) prevailed over bogs (2). Mire ages in the model area exhibit a distribution similar to that of the entire dataset, except for the absence of localities with a known origin in the full glacial period. Most mires receive the highest level of formal protection (36; 83.7%), whereas 2 localities (4.7%) have lower-level protection (Protected Landscape Area zones with a lower degree of protection) and 5 sites (11.6%) are not protected at all.

Age of mires in relation to Holocene periods and climate changes

The ages of the 220 mires analysed (dataset 1) are not distributed equally. Very few current Czech and Slovak mires began accumulating peat during the full glacial period before ~14.6 kyr cal BP. Specifically, only seven sites in our dataset originated between 17,000 and 14,870 cal BP. The frequency of dated basal peat ages increased shortly after

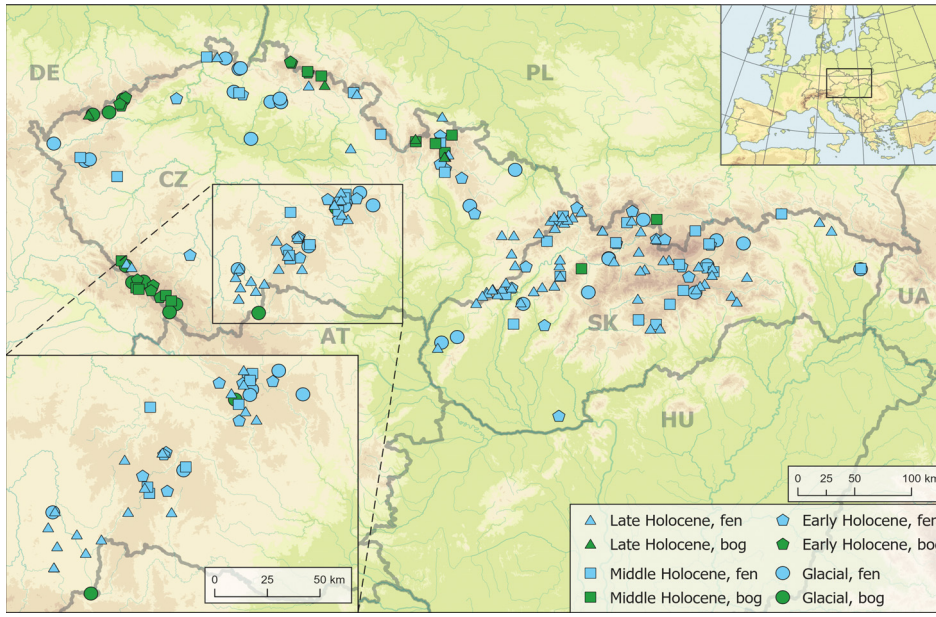

Fig. 1. Distribution map of the studied mires. Minerotrophic mires (fens) are shown in blue symbols; ombrotrophic mires (bogs) are shown in green symbols. Different symbols correspond to different periods of their formation.

Table 1. Number of modern fens and bogs of known age, dated to specific periods (from the full glacial to the late Holocene), their nature conservation status and geographic position.

	Entire area			Třeboň Basin+B-M Highlands		
	Fens	Bogs	Total	Fens	Bogs	Total
Periods:						
Late Holocene	85	5	90	18	0	18
Middle Holocene	33	11	44	7	0	7
Early Holocene	28	13	41	9	0	9
Late Glacial	27	11	38	7	2	9
Full Glacial	7	0	7	0	0	0
Altogether	180	40	220	41	2	43
Previously lake	10	7	17	1	0	1
Nature conservation status:						
Small-scale protected area (CZ+SK) and higher degree of protection (SK)	115	17	132	30	1	31
National Park (first/quiet zone)	3	17	20	0	0	0
National Park	4	0	4	0	0	0
Protected landscape area (first zone)	8	0	8	5	0	5
Protected landscape area	17	0	17	2	0	2
No protection	33	6	39	4	1	5
Geographical position:						
Czech Republic	100	37	137	41	2	43
Slovak Republic	79	1	80	–	–	–
Poland (near the border)	1	2	3	–	–	–
Western Carpathians	101	2	103	–	–	–
Hercynicum	79	38	117	41	2	43

Table 2. List of studied localities in the model area (Třeboň Basin, Bohemian-Moravian Highlands) used in the analyses and their radiocarbon ages. The new ^{14}C dates (20 localities) and old maps and aerial photos based datings (4 sites) are marked in bold. The number of localities corresponds with that used in the ordination diagram. The ages of young localities were assessed using aerial photographs and old military maps (marked with asterisks). Some localities were situated within fishponds (i.e. underwater) 60 or 90 cal BP (i.e. before 1950 AD).

Localities/depth (cm)	Material dated	Laboratory code	^{14}C age (uncal.)	Calib. age (median)	Reference
1. Babín/376.5	seeds, needles	LeA-2723	7,490±25	8,318	this study
2. Bahna/172	wood	LeA-2713	5,928±17	6,748	this study
3. Bažantka/154	–	DeA-24397	9,885±47	11,289	Peterka et al. 2022b
4. Borky/151.5	seeds, mosses	LeA-2717	7,861±21	8,627	this study
5. Damašek/155	–	DeA-24188	10,023±207	11,615	Peterka et al. 2022b
6. Dářko/650	–	Poz-96756	11,990±60	13,898	Roleček et al. 2020
7. Dvořiště/45*	–	–	–	60	this study
8. Hliníř/76.5	seeds	LeA-2726	11,601±27	13,469	this study
9. Hovízna/93.5	seeds, mosses	LeA-2724	1,005±13	925	this study
10. Hrádeček/115	seeds, needles	LeA-2721	1,381±14	1,297	this study
11. Hrachoviště/29.5*	–	–	–	90	this study
12. Chvojnov/135.5	seeds	DeA-24393	9,993±39	11,464	Peterka et al. 2022b
13. Kaliště/174.5	seeds, needles	LeA-2727	5,438±20	6,234	this study
14. Kameničky/122.5	not known	Hv-11536	11,070±245	12,998	Rybníčková & Rybníček 1988
15. Klátov/248.5	mosses, needles, seeds	DeA-24401	873±21	762	Peterka et al. 2022b
16. Kocanda/230	seeds, mosses	DeA-27971	11,556±47	13,419	Peterka et al. 2022a
17. Kukla/49.5*	–	–	–	60	this study
18. Louky u Černého lesa/135	wood	DeA-24398	3,421±24	3,662	Peterka et al. 2022b
19. Louky v Jeníkově/90.5	seeds	DeA-24395	9,837±51	11,243	Peterka et al. 2022b
20. Na Oklice/77.5	seeds, mosses, spindles	DeA-24189	2,221±39	2,227	Peterka et al. 2022b
21. Nad Svitákem/113.5	seeds, mosses	LeA-2715	10,049±49	11,563	this study
22. Návesník/115	seeds, mosses	LeA-2719	10,128±40	11,747	this study
23. Pihoviny/169.5	seeds, mosses	DeA-24399	12,046±49	13,896	Peterka et al. 2022b
24. Pod Kamenným vrchem/100.5	wood	LeA-2718	3,938±15	4,393	this study
25. Ratajské rybníky/88.5	seeds, needles	LeA-2722	1,931±13	1,855	this study
26. Rybník Pařez/151.5	wood, seeds	LeA-2734	4,807±17	5,507	this study
27. Staňkovský rybník/79*	–	–	–	90	this study
28. Starý vdovec/58.5	seeds	LeA-2720	225±11	185	this study
29. Šafranice/145	wood	LeA-2712	3,381±14	3,614	this study
30. Vílanecké rašeliniště/188.5	needles, seeds	DeA-24392	6,241±35	7,166	Peterka et al. 2022b
31. V Lisovech/134.5	seeds, mosses	LeA-2733	696±12	662	this study
32. V Rájích/120	needles	UG-74594	1,410±20	1,313	this study
33. Zhejral/85.5	plant tissues	LeA-2732	5,325±18	6,080	this study
34. Zlámanec/118	wood	LeA-2716	2,354±13	2,351	this study
35. Žemlička bazická/90	seeds, mosses, needles	LeA-2725	922±11	874	this study
36. Žemlička kyselá/33.5	seeds, needles	LeA-2731	110±12	109	this study

the onset of the late glacial, ~14.2 kyr cal BP, which corresponds to increased annual precipitation and mean temperatures of the warmest quarter (T WQ; Fig. 2) according to the CCSM3 model. A noticeable decrease in frequency of dated basal peat ages occurred in the early Holocene, specifically between ~10.5 and 8.5 kyr cal BP. This trend coincided with the peak of summer temperatures (T WQ), which, during this period, were the highest in the entire Holocene, and with the highest annual PET and a low climatic moisture

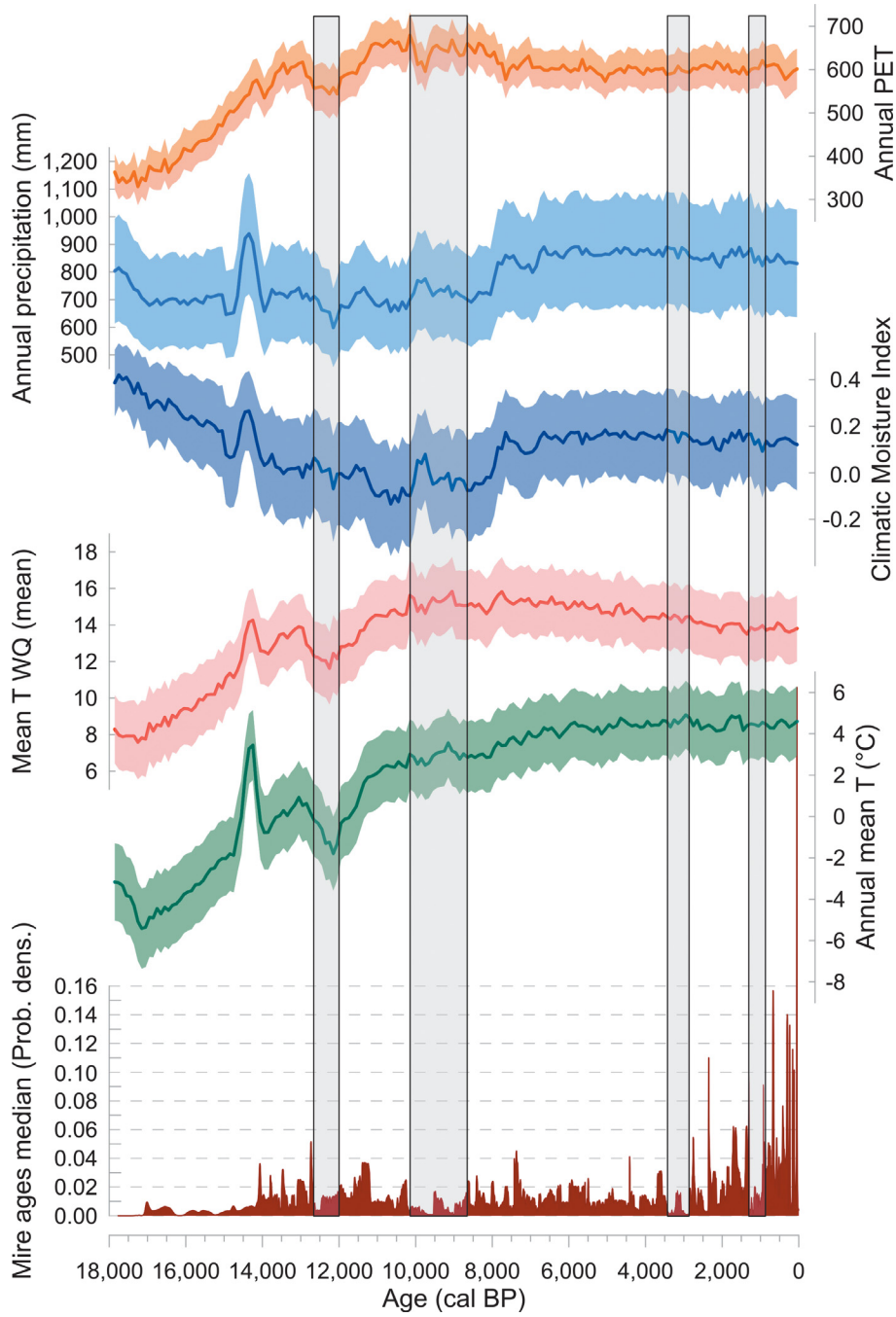

Fig. 2. Probability density histogram of calibrated BP ages of the basal peat layers from 220 mires in the Czech and Slovak Republics. For each site, only the oldest date was selected. The comparison of selected climate parameters derived from the CCSM3 climate model (mean T of WQ, climatic moisture index, annual PET, annual mean temperature, and annual precipitation) is also shown. The periods of distinctly lower frequency of dated basal peat ages are indicated by grey rectangles. Abbreviations: T – temperature, WQ – the warmest quarter of the year, PET – potential evapotranspiration.

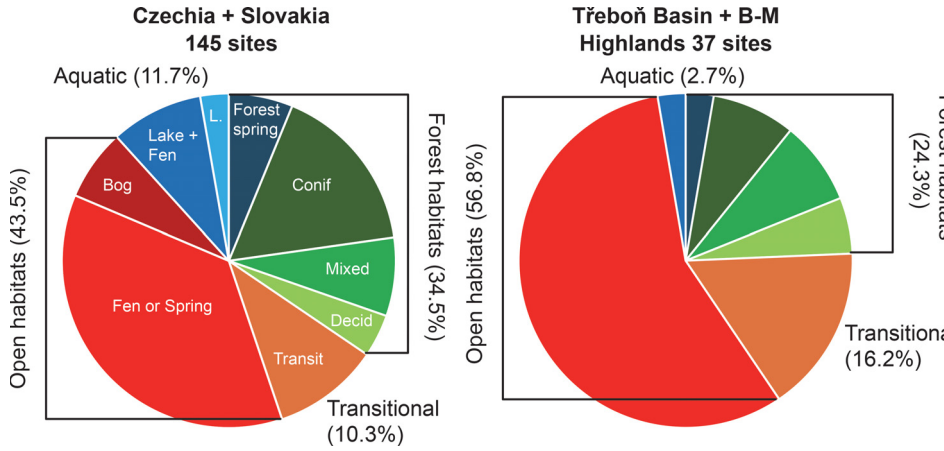

Fig. 3. Habitat proportions of the radiocarbon-dated basal samples from today's mires. On the left, the entire area of the Czech and Slovak Republics; on the right, the smaller area of the Třeboň Basin and the Bohemian-Moravian Highlands, studied in more detail. The same colours represent the same habitats in both diagrams. Abbreviations: L. – lake, Conif – coniferous forests, Mixed – mixed forests, Decid – deciduous forests, Transit – transitional between open and forest habitats.

index (Fig. 2). The apparent mire-inception frequency increased after ~8.5 kyr cal BP, coinciding with a higher annual precipitation and climatic moisture index. Another period of decreased frequency of dated basal peat ages occurred at the beginning of the late Holocene at ~3.5–2.8 kyr cal BP, when climatic moisture index and annual precipitation decreased. The highest frequency of dated basal peat ages was recorded in the last ~2,000 years.

Past vegetation at the time of mire formation

Initial vegetation composition could be reconstructed for 145 of the 220 study sites (dataset 2; Fig. 3A) based on basal-sample analysis. These reconstructions relied primarily on plant macrofossils, supplemented in some cases by pollen data and sediment stratigraphy (see Methods for details). Most localities originated as open mires (bogs, fens or springs; 43.5%) or forested habitats (various types of waterlogged and mire forests and forest springs; 34.5%). In forest stages, the most frequent tree species was *Picea abies* (36 occurrences), followed by *Alnus* sp. (18) and *Abies alba* (17), while other trees were rather rare, such as *Betula* sp. (5), *Fagus sylvatica* (4), *Pinus* sp. (3) and *Taxus baccata* (1). Of the sites, 10.3% were transitional (semi-open), i.e. containing both open-mire and forest indicators, and 11.7% originated as aquatic habitats, mostly associated with mire habitats along the shores. When focusing on the age of waterlogged forests, they were generally more abundant in basal samples dating to the middle and late Holocene (Fig. 4).

Focusing on the model study area (37 mires in the Třeboň Basin, Jihlavské and Žďárské vrchy hills; dataset 4), there was a higher prevalence of sites originating as open habitats (56.8%) than as forested habitats (~24.3%). 16.2% of sites originated as transitional habitats, either semi-open habitats or mosaics of open and forested areas, a slightly higher proportion than in the entire study area (10.3%, dataset 2). In contrast, only one site originated as an aquatic habitat (Fig. 3B).

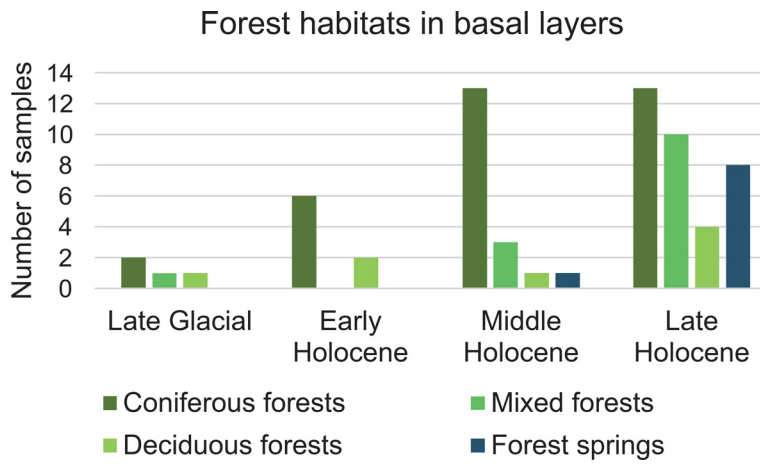

Fig. 4. Representation of reconstructed waterlogged forests and forest springs in the basal peat samples. Transitional samples were also included, because they contained tree macrofossils.

Reconstructed basal vegetation in the model area in relation to age

Dating of 37 samples from the model area (dataset 4) showed that relatively young mires currently predominate in the Třeboň Basin. Most of these young mires are located near fishponds, and in four cases, historical aerial photographs indicate that they were part of a fishpond until only decades ago (see Methods for details). Two other mires were not formerly part of fishponds but were also relatively young, with estimated ages of ~100–200 years. Even mires not apparently associated with fishponds were generally of relatively young origin, with basal ages of ~850–1,300 cal BP.

The macrofossil analysis further revealed a consistent signal of aquatic conditions in mires associated with fishponds: Bryozoa statoblasts were present in the sediments of all sampled fens near fishponds (see ordination diagram in Fig. 5A and B). These sediments also contained acidophilous species (*Eriophorum vaginatum*, *Rhynchospora alba*, *Sphagnum palustre*), reed-bed taxa presently frequent around fishponds (*Lycopus europaeus*, *Persicaria minor*), wetland taxa preferring mires in general (*Carex echinata*, *C. flava*, *Ranunculus flammula*), but also some mire specialists (*Carex lasiocarpa*, *Meesia triquetra*). The only old and still existing mire analysed from the Třeboň Basin was the Hliníř mire, where the younger peat overlay older glacial palaeolake sediment (~13.5 kyr cal BP at a depth of 75–78 cm) containing *Batrachium* sp., *Myriophyllum spicatum*, *Potamogeton praelongus*, *P. pusillus* agg., *Stuckenia filiformis* and other aquatic taxa (for full data see Supplementary Table S2). Among fen species, *Carex rostrata* was dominant, and *Menyanthes trifoliata* was present. The most significant record from the Hliníř mire is that of *Arctostaphylos uva-ursi* seeds. Other old sites of late glacial and early Holocene age are mostly from the Žďárské vrchy hills and partly from the Jihlavské vrchy hills, and contain boreal moss species such as *Helodium blandowii*, *Tomentypnum nitens*, *Drepanocladus trifarius*, and *Scorpidium scorpioides*. Macrofossils of trees such as *Alnus* sp. and sclerotia of the mycorrhizal fungus *Cenococcum geophilum* are positioned near the middle of the ordination axis representing time, i.e. in samples representing the middle and late Holocene. Under the coniferous forests, some mire plant species survived (e.g. *Carex appropinquata*,

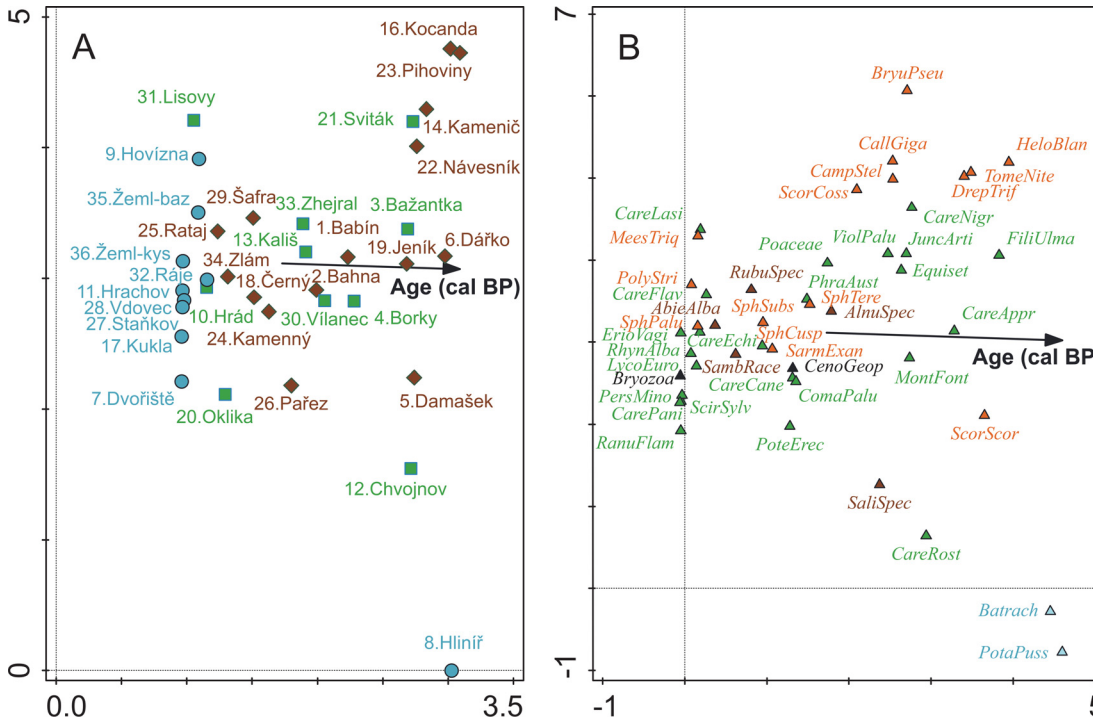

Fig. 5. DCCA ordination constrained by age (cal BP) based on the data from the model study area (P = 0.002, eigenvalues: 1st axis 0.411, 2nd axis 0.523). (A) Positions of localities in the ordination plot; the numbers correspond to those in Table 2. (B) Positions of species in the ordination plot. The blue colour indicates localities from the Třeboň Basin, the brown colour indicates Žďárské vrchy hills and the green colour indicates Jihlavské vrchy hills (Fig. 5A). In Fig. 5B, the green colour indicates vascular plants, the blue colour indicates aquatic plants, the orange colour indicates bryophytes, the brown colour indicates woody taxa, and the black colour indicates non-plant macrofossil remains (fungal sclerotia, Bryozoa statoblasts). Abbreviations of species: AbieAlba (*Abies alba*), AlnuSpec (*Alnus* sp.), BryuPseu (*Bryum pseudotriquetrum*), CallGiga (*Calliergon giganteum*), CampStel (*Campylium stellatum*), CareAppr (*Carex appropinquata*), CareCane (*C. canescens*), CareEchi (*C. echinata*), CareFlav (*C. flava* s.l.), CareLasi (*C. lasiocarpa*), CareNigr (*C. nigra*), CarePani (*C. panicea*), CareRost (*C. rostrata*), CenoGeop (*Cenococcum geophilum*), ComaPalu (*Comarum palustre*), DrepTrif (*Drepanocladus trifarius*), Equiset (*Equisetum* sp.), ErioVagi (*Eriophorum vaginatum*), FiliUlma (*Filipendula ulmaria*), HeloBlan (*Helodium blandowii*), JuncArti (*Juncus articulatus/alpinoarticulatus*), LycoEuro (*Lycopus europaeus*), MeesTriq (*Meesia triquetra*), MontFont (*Montia fontana*), PersMino (*Persicaria minor*), PhraAust (*Phragmites australis*), PolyStri (*Polytrichum strictum*), PoteErec (*Potentilla erecta*), RanuFlam (*Ranunculus flammula*), RhynAlba (*Rhynchospora alba*), RubuSpec (*Rubus* sp.), SaliSpec (*Salix* sp.), SambRace (*Sambucus racemosa*), SarmExan (*Sarmentypnum exannulatum*), ScirSylv (*Scirpus sylvaticus*), ScorCoss (*Scorpidium cossonii*), ScorScor (*S. scorpioides*), SphCusp (*Sphagnum* sect. *Cuspidata*), SphPalu (*S. palustre*), SphSubs (*S. subsecundum*), SphTeres (*S. teres*), TomeNite (*Tomentypnum nitens*), Batrach (*Batrachium species*), PotaPuss (*Potamogeton pusillus*), ViolPalu (*Viola palustris*).

C. canescens, *C. echinata*, etc.), but some samples contained no plant macrofossils, suggesting a more closed canopy and unsuitable conditions for mire vegetation (see Supplementary Table S2).

Discussion

Age of central-European mires and potential drivers of their origin

The uneven frequency of mire inception over time may have different causes. Climatic moisture is one of the most important drivers of mire inception and development. Climate may affect mires either directly through the balance between precipitation and evapotranspiration, or indirectly by the terrestrialization of water bodies when the climate is drier, or by landslide initiation when the climate is humid. Comparison of the mire-inception pattern with reconstructed climatic development by the Community Climate System Model version 3 (CCSM3; Collins et al. 2006) suggests that climate humidity may be one of the main drivers (Fig. 2). The scarcity of full-glacial mires in the entire study area of the Czech and Slovak Republics (7 sites; dataset 1) suggests that environmental conditions, especially low temperature and precipitation, were unsuitable for mire formation in that period. Climatic conditions ameliorated during the late glacial, ~14.2 kyr cal BP (Bølling period; GI-1e), when some of the current mires began accumulating peat due to higher temperatures, increased annual precipitation sums, and greater climatic moisture. The Bølling period represents one of the most distinct thermal pulses in the Northern Hemisphere during the late glacial, as recorded not only by the CCSM3 model but also by stable-isotope ($\delta^{18}O$) data from the Greenland ice core (Lowe et al. 2008). Kaiser et al. (2023) reported a similar pattern of mire development in the Krušné hory Mts based on 118 sites from both the Czech and German parts of the mountains, documenting the oldest calibrated radiocarbon age of ~14 kyr cal BP. Further, we recorded a decrease in the frequency of dated basal peat ages during the Younger Dryas, when a cold and dry oscillation is indicated by the CCSM3 model, stable isotope records in the NGRIP ice core, and numerous biotic reconstructions (Brauer et al. 1999, Schenk et al. 2018), as vegetation responded rapidly to this cold event. Then, apparent mire-inception frequency increased again at the beginning of the Holocene, but only until ~10.5 kyr cal BP, when peat formation frequency sharply declined during the warm and dry early Holocene between 10.5 and 8.5 kyr cal BP. The CCSM3 model suggests the highest summer temperatures (the so-called Holocene thermal maximum; Renssen et al. 2009) and intermediate precipitation at that time. This resulted in high potential evapotranspiration (annual PET) and relatively low climatic moisture (low climatic moisture index). A low frequency of dated basal peat ages during this period is also reported by Kaiser et al. (2023) in the Krušné hory Mts and by Cubizolle et al. (2012) in the Massif Central, France, suggesting that this pattern may be generally valid. The same hiatus in basal radiocarbon dates was also recorded by Hájková et al. (2012) in the Western Carpathians. Apparent mire-inception frequency increased as moisture availability rose at ~8.5 kyr cal BP (Starkel 1999, Hájková et al. 2016, Dabkowski et al. 2019), as also reported by all the above-mentioned studies. Another decrease in the frequency of basal peat ages occurred in the study area during the beginning of the late Holocene (3.5–2.8 kyr cal BP), but no distinct climate change is indicated by the CCSM3 model. Nevertheless, the hiatus falls within the 3,500–2,500 cal yr BP interval, one of the six major Holocene periods of significant rapid climate change (RCCs) identified by Mayewski et al. (2004). This period was characterized by North-Atlantic ice-rafting events (Bond et al. 1997; Bond 2 cold event) and alpine glacier advances (Denton & Karlén 1973) and coincided with both reduced mire inception, as also reported by Cubizolle et al. (2012) and Kaiser et al.

(2023), and lower water levels in central European lakes, yet within a slightly narrower interval (3.1–2.75 kyr cal BP; Magny 2004). The most recent decline in fen inception was shorter and less conspicuous, occurring before 1 kyr cal BP. This period corresponds to the Medieval Drought reconstructed by absolutely dated measurements of tree-ring stable carbon and oxygen isotopes (Büntgen et al. 2021).

However, factors other than climate may also have influenced the formation of mires across periods. Human activity, particularly in the late Holocene, may represent another important driver of mire formation, through deforestation followed by mowing, burning or grazing to keep the landscape sufficiently open to provide fodder for livestock (Rybníček & Rybníčková 2000, Hájková et al. 2023, 2026). Deforestation likely increased waterlogging due to reduced evapotranspiration (Farley et al. 2005) and possibly also increased water accumulation in the basins. This applies mainly to open fens, which showed a distinct increase in their inception over the last 2,000 years. In contrast, bog formation, which was primarily driven by climate, usually started earlier. Nevertheless, approximately half of the mires that initiated in the late Holocene originated in forest habitats, indicating that human-induced deforestation is only partly responsible for the observed increase in mire formation. Another reason might simply be a higher probability of peat and mire preservation in younger periods or relatively high humidity during the late Holocene.

It is also important to consider that, in certain periods, no new mires were initiated simply because suitable sites had already been occupied, and peat accumulation continued there. New mire formation after such phases would require an additional factor, such as anthropogenic deforestation (Hájková et al. 2012), or partly climate-driven processes such as terrestrialization of lakes (e.g. Hypkaňa in Vihorlat Mts, Hájková et al. 2016) or landslide inception (e.g. Kotelnice in Beskydy Mts, Šímová et al. 2019).

Potential biases and limitations of the radiocarbon-age database

Although we have collected radiocarbon dates for a large number of mires (n = 220), there may still be sources of inaccuracy in observed trends. Many mires, including ancient ones, have disappeared from the region due to alterations of the hydrological regime, peat extraction, and conversion to agricultural land (Chytrý et al. 2019). Many mires were probably destroyed not only by human activities in the modern period, but also in the more distant past by processes such as tectonic activity, erosion, desiccation or catchment-scale hydrological change. In the Třeboň Basin region, older mire sediments may have been removed during large-scale pond construction between the 14th and 16th centuries, leaving sedimentary hiatuses in the pond basins. Moreover, some supposedly old still-existing localities have not yet been radiocarbon-dated, such as Ruda mire in the Třeboň Basin, whose basal pollen spectra suggest a glacial or early Holocene age (P. Pokorný, pers. comm.). Another source of bias is that the deepest point identified during field sampling may not necessarily contain the oldest basal layer. Moreover, even the deepest profile may underestimate absolute mire age if the oldest deposits have been eroded or destroyed by anthropogenic activities such as fishpond construction, drainage, or peat mineralization. All these factors could introduce bias into the age distribution of the mires.

The summed probability distribution of radiocarbon ages is well suited to showing broad chronological patterns, but by itself it does not demonstrate that more mires actually originated during a given period. The curve depends on research intensity, dating

density, the properties of the calibration curve, preservation probability, and the subset of mires that have survived to the present. Nevertheless, despite these potential biases, the principal age distribution is generally coherent, particularly with respect to climate. The decreased frequency of dated basal peat ages broadly corresponds to reduced precipitation and increased evapotranspiration, and vice versa, as indicated by the CCSM3 model. The apparent increase in mire-inception frequency over the last 2,000 years is less clearly related to climate and may be explained by a combination of wetter conditions, human influence through deforestation, and a higher probability of preservation of younger sediments compared with that of older sediments.

Mire age has repeatedly been reported as a significant predictor of current species richness and the occurrence of habitat specialists, as older sites may support the long-term persistence of relict and specialist species (Hájek et al. 2011, Horsák et al. 2012, Peterka et al. 2022b). Dating biases and errors, stratigraphic hiatuses or failure to sample the oldest parts of mires could also explain why the regional age (i.e. the oldest age within some radius around the locality) sometimes acts as a better predictor of the current richness of fen habitat specialists than the local age of a mire itself (Peterka et al. 2022b). Such a result, however, does not imply that local ages are too biased to be used as a predictor of current richness. Local mire age alone effectively explained the richness of specialists in calcareous fens of the Western Carpathians (Horsák et al. 2012), where several specialist taxa (e.g. *Carex hostiana*, *Primula farinosa*, *Trichophorum pumilum*) were significantly associated with old mires predating the middle Holocene (Hájek et al. 2011).

Vegetation of basal layers and presence of recently rare species

Analysis of 140 mires with known macrofossil-inferred vegetation composition at the onset of their formation has revealed an interesting pattern. Many mires originated as various types of mire and waterlogged forest with different dominant tree species. These forests were later thinned, likely due to human-induced deforestation. Coniferous and mixed waterlogged forests predominated over exclusively deciduous forests. This forested past, followed by deforestation linked to agropastoral activities, is typical of the mountainous regions of central Europe, such as the Alps (Gobet et al. 2005, Dwileski et al. 2025), the Hercynian Mountains (Novák et al. 2010, Hájková et al. 2023, Kaiser et al. 2023), and the Carpathians (Hájková et al. 2012, Geantă et al. 2014). The proportion of sites that originated as lake ecosystems is relatively small across the study area and even smaller within the model area. In other parts of Europe, such as the North European Plain, the opposite may be true, with lake sediments more frequently occurring at mire bases (Oksanen 2006, Kalnina et al. 2008, Gałka et al. 2016).

In the Třeboň Basin, the south-western part of our model study area, most of the existing radiocarbon-dated mires are young. They mostly occur near fishponds, where they are influenced by an irregular supply of pond water and its specific chemistry (Navrátilová et al. 2006, 2022). Some originated after water levels in the fishponds declined, as a consequence of changes in fishery management over the last century (e.g. Kukla, Dvořiště). Most fishponds are fertilized, and an extremely high water table is maintained, causing nutrient-rich water to overflow into nearby fens, thereby deteriorating habitat quality and species composition (Navrátilová et al. 2006). Looking further back in time, many glacial thermokarst lakes are documented in the Třeboň Basin (Hošek et al. 2019, Prach 2023)

and these lakes were accompanied by mire vegetation (Pokorný et al. 2010). The landscape transformation by extensive fishpond construction during the medieval period, which obscured the fen inception pattern, does not rule out the possibility that specialized mire species with boreal distributions (glacial relicts according to Dítě et al. 2018) persisted in the region since the glacial period. Some of them, such as *Carex lasiocarpa* and *Carex limosa*, still occur in the region's oldest fens, including Hliníř Natural Monument and Ruda National Natural Monument. In some cases, we have already recorded seeds or tissues of boreal vascular plant and bryophyte species in relatively young mire sediments in which they do not occur today (e.g. *C. lasiocarpa* in Hovízna – 925 cal yr BP; *Meesia triquetra* in PP Žemlička – 875 cal yr BP). *Carex lasiocarpa* likely disappeared from the Hovízna fen due to recent changes in the water regime, but it is still present in the surrounding area. *Meesia triquetra* is much rarer than *Carex lasiocarpa* in the Třeboň Basin region, with the nearest and only extant population occurring around the Svět fishpond, where it consists of a few nearby subpopulations (Kučera 2006).

The most conspicuous fossil finding is the presence of *Arctostaphylos uva-ursi* seeds in glacial lake sediment at the bottom of the Hliníř mire (Třeboň Basin). This species has its primary centre of distribution in the subarctic and boreal regions of the Northern Hemisphere (https://powo.science.kew.org). In the Czech Republic, it grows rarely on rocky or sandy substrates, in forested or open areas, in a few regions, such as the middle Vltava River valley, Džbán, České Středohoří Mts, and Dokesko. The nearest extant locality to our fossil finds is ~20 km away (the Židova strouha Natural Monument near the Lužnice River valley). Most of these sites have a relict character and low productivity due to extreme edaphic conditions; their vegetation belongs to the *Dicrano-Pinion* alliance (Křísa 1990). Fossil records of *A. uva-ursi* in the Czech Republic are very rare. According to the Plant macrofossil database of the Czech and Slovak Republics (https://www.sci.muni.cz/botany/mirecol/paleo/en; Hájková et al. 2018), they include two records dating to the end of the glacial period (Vlčí důl in Český ráj sandstones and Všetaty near the Labe River by Mělník, located ~160 and ~130 km from Hliníř, respectively) and one younger site located in Velká kotlina glacial cirque in the Hrubý Jeseník Mts (~1,450 cal yr BP). Our novel record, dated to ~13,500 cal yr BP, may indicate a formerly wider distribution of this species during cold periods, such as the late glacial. In the same sediment at Hliníř mire (13,470 cal yr BP), some rare aquatic plants have also been recorded. *Stuckenia filiformis* (syn. *Potamogeton filiformis*), a species with a boreal-montane distribution that thrives in cold, nutrient-poor to moderately nutrient-rich water bodies (Haynes & Hellquist 2000, Preston & Croft 2022), is now absent from the Czech Republic. Another species, *Potamogeton praelongus*, has similar ecological requirements and is very rare in the Czech Republic, where it is the subject of conservation programs (Prausová & Tomášová 2014, Prausová 2018). Both species are often found in glacial sediments in central Europe (Gałka & Sznel 2013, Gálová et al. 2016, Potůčková et al. 2018).

In addition to *Meesia triquetra* mentioned above, we documented other relict fen bryophyte species, including *Drepanocladus trifarius*, *Helodium blandowii*, and *Scorpidium scorpioides.* All these species require a high and stable water level. Substantial declines in their abundance have been observed over the last two centuries (Hájková et al. 2018). These species were found in the peat samples of both regions, the Třeboň Basin and the Bohemian-Moravian Highlands, in layers of varying age, ranging from 660 cal yr BP

(V Lisovech) and 2,230 cal yr BP (Na Oklice) to 8,320 cal yr BP (Babín) and 11,560–13,900 cal yr BP (Hliníř, Nad Svitákem, Návesník and Pihoviny). This pattern may suggest their continued occurrence in the region since the late glacial period, but more evidence is still needed, as direct evidence of local population continuity for these species (i.e. within a single profile) remains lacking.

Importance of peat archives for nature conservation

Peat layers are valuable palaeoecological archives, especially those of deep, old mires, which act as biodiversity refugia. Thus, protecting mires, especially old mires, is very important and should be a priority in nature conservation. Old, deep mires not only preserve a natural archive of high value to science, but also indicate more stable conditions for habitat specialists, because deep peat can develop only under consistently moist conditions and is better at maintaining wet conditions due to capillary action (Moskal et al. 2001, Rezanezhad et al. 2016). Such sites, which have evolved over thousands of years and provide unique conditions for specialist species, cannot be easily restored once destroyed (Kreyling et al. 2021).

Moreover, peat deposits in most mires might serve as seed banks for restoration and should therefore be preserved and, where appropriate, used in restoration. This potential has already been demonstrated by the restoration of a small pool in the Hrabanovská černava fen, where the long-extinct species *Potamogeton coloratus* subsequently appeared (Kaplan et al. 2014). Along with this species, other rare aquatic plants (e.g. *Utricularia vulgaris* and *Chara hispida*) were found in the newly created pool, and their propagules were detected in the sediment prior to restoration measures. Similarly, the finding of viable *Utricularia vulgaris* seeds in the upper peat layer during the palaeoecological research preceded the rediscovery of the species in a small pool in southern Moravia (Gálová & Hájková 2014). Although the longevity of the diaspores of mire plants is still not fully understood, viable bryophyte diaspore banks have been demonstrated in peat layers hundreds of years old (Callaghan et al. 2022), and studies on vascular plant seed banks consistently indicate long-term persistence on the scale of decades to centuries (Fernández-Pascual 2016, Solberg et al. 2020). Oospore viability exceeding 300 years has been demonstrated by Stobbe et al. (2014) for *Characeae*. Based on these findings, we emphasize that the upper sediment layers, which may contain viable seeds and spores, should not be removed, can be used for restoration, and that plant macrofossil analysis can provide information on the potential of these sediments as a source of seeds for rare species (Vellak et al. 2021). Therefore, only shallow pools should be created when restoring the semi-aquatic conditions at the sites, and the upper sediment layers should not be transported away – instead, if possible, the sediment may be used in the shallow littorals to restore the seed bank.

The value of mires as natural archives should not be viewed as competing with their current importance for biodiversity. Even ancient mires may now be depauperated, lacking species of high conservation value. Conversely, young mires (fen meadows) may also represent critical refugia (neorefugia sensu Nekola 1999) where endangered specialist species might have survived, while the ancient mires that acted as refugia over Holocene timescales have already disappeared regionally. In our view, the importance of mires as natural archives complements their role as habitats supporting unique biota. This

perspective may also provide an argument against the ill-considered construction of artificial pools and serve as an effective tool for communicating nature conservation goals to the public.

Practical conservation implications

Based on our results, we propose the following guidelines for conservation decisions based on palaeoecological knowledge:

(i) If terrain interventions or topsoil removal are planned, basic palaeoecological prospection, including measurements of sediment depth and radiocarbon dating of basal layers (when not yet available from existing research), should be carried out. If a peat deposit at least one metre deep is identified, it should be left undisturbed to conserve its irreplaceable natural archive, or rescue sampling of sediment profiles at such locations should be undertaken.

(ii) Formal protection of a mire site should be maintained even when the target rare or specialist species have recently gone extinct, if at least a one-metre-deep peat deposit with visibly undecomposed plant remains is present. Such sites are valuable not only for their sediments but also because they may be more suitable for successful future restoration than shallow, young sites, owing to the potential seed bank of rare species and the greater capacity of deep peat to maintain wet conditions through capillary action.

(iii) Finally, in any mire, palaeoecological research on upper peat layers (30–50 cm) may be a useful tool for revealing the history of the site and its vegetation, extending further back in time than historical floristic records. This opportunity is unusual among habitats and deserves wider use. Thus, basic analyses of plant macrofossils and pollen could be used more widely in nature conservation, and collaboration with palaeoecologists is strongly recommended.

Conclusions

We gathered numerous radiocarbon ages from basal layers of current mires. Advances in radiocarbon dating methods over the last few decades have provided sufficient dates for analysis, revealing periods of increased (late-glacial interstadials, middle Holocene) and decreased (Younger Dryas, early Holocene) mire formation in central Europe. Most of these changes are probably associated with changes in climate humidity, as suggested by the climatic reconstructions from the CCSM3 model. The increased frequency of mire inception over the last 2,000 years is probably linked to human activities such as deforestation. The biotic composition of basal samples from 140 mires shows that waterlogged and mire forests were relatively frequent initial habitats, particularly in the middle and late Holocene. As the old mires of glacial origin are much rarer than those of Holocene age, we stress the need to protect these old sites, including their sediments, which not only store carbon but also serve as irreplaceable archives. Combined with the fact that old mires typically host more specialist species, this demonstrates that they are not equivalent to younger ones in terms of conservation needs. As there is no way to compensate for the loss of old mires in terms of long-term persistence of relict populations, carbon storage, and, importantly, environmental archives, site-specific protection should always have the highest priority. This includes either passive or active conservation of environmental

conditions that guarantee the preservation not only of local biotic populations but also of the peat and its archive.

Supplementary materials

Table S1. Data for 220 mires with original radiocarbon ages, calibrated medians, conservation status, coordinates and references.

Table S2. Original plant macrofossil data from 36 mires analysed in the model area of the Třeboň Basin and the Bohemian-Moravian Highlands.

Supplementary materials are available at https://www.preslia.cz

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Stáří a původ rašelinišť ve střední Evropě: význam přírodních rašelinných archivů pro vědu a ochranu přírody

Porozumění časovému a environmentálnímu kontextu vzniku rašelinišť ve střední Evropě je zásadní pro rekonstrukci vývoje krajiny v minulosti i pro současnou ochranu přírody. Analyzovali jsme 220 lokalit rašelinišť v České republice a na Slovensku s cílem určit jejich stáří, původ a současnou úroveň ochrany; tyto údaje jsme doplnili podrobnou analýzou rostlinných makrozbytků z 36 lokalit ve studované oblasti, která je typická výskytem rašelinišť a kde byly znalosti o jejich stáří nedostatečné (Třeboňská pánev, Jihlavské a Žďárské vrchy). V datovém souboru převažují slatiniště sycená podzemní vodou, zatímco vrchoviště závislá na srážkové vodě jsou méně častá a v západních Karpatech vyloženě vzácná. Nejstarší dosud aktivní rašeliniště začala akumulovat rašelinu ve vrcholné době ledové, i když byla velmi vzácná. Častější vznik otevřených slatinišť v pozdním holocénu může souviset s intenzivnější přeměnou krajiny člověkem a odlesňováním, zatímco vznik vrchovišť, který je řízen především klimatem, byl datován spíše do středního a raného holocénu a jen vzácně do pozdního holocénu. Jak slatiniště, tak i vrchoviště někdy vznikala také jako jezera, která se později zazemnila. Časový průběh vzniku rašelinišť se obecně shodoval s významnými klimatickými změnami v holocénu a pozdní době ledové, přičemž jejich počet vzrostl bezprostředně po pozdně glaciálním oteplení (14,2 kyr kal. BP) a prudce poklesl během teplého a suchého raného holocénu (10,5–8,5 kyr kal. BP). Vznik rašelinišť se opět zintenzivnil s rostoucí klimatickou vlhkostí kolem 8,5 kyr kal. BP a byl znovu potlačen během raného pozdního holocénu (3,5–2,8 kyr kal. BP). Na základě makrozbytků rostlin, pylu a vlastností rašeliny bylo možné rekonstruovat vegetaci do širších vegetačních jednotek u 140 lokalit. 43,5 % těchto lokalit vzniklo jako otevřená rašeliniště (slatiniště, vrchoviště nebo prameniště), 34,5 % jako podmáčené a rašelinné lesy nebo lesní prameniště, 10 % jako polootevřená stanoviště nebo mozaika otevřených a lesních stanovišť a 12 % jako vodní prostředí, která mohla být obklopena slatiništi. V modelové oblasti byl podíl otevřených slatinišť ještě větší, zatímco jezerní původ byl vzácný. Analýza rostlinných makrozbytků ukázala rozdíly mezi mladými a starými bazálními vrstvami. V Třeboňské pánvi jsou dnes častá mladá rašeliniště vznikající blízko rybníků, zatímco ve Žďárských a Jihlavských vrších jsou častější stará rašeliniště, která už v době svého vzniku hostila boreální taxony dnes považované za glaciální relikty. Zhruba stejná část vrchovišť (15 %) a slatinišť (18,3 %) není v České republice a na Slovensku formálně chráněna. Naše zjištění poukazují na vliv klimatu a lidských aktivit na vznik rašelinišť a zdůrazňují význam ochrany starých rašelinišť, která obsahují cenné přírodní archívy a bohatou semennou banku využitelnou při ekologické obnově.

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