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Original Research Article

The Fen that vanished: The untold story of drainage and peat extraction in Bagno Chlebowo peatland with implications for nature conservation

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A B S T R A C T

Peatlands have been among the world's fastest-disappearing ecosystems, facing human pressure, especially over the last two centuries. The drainage of peatlands has long been pursued to expand agricultural and forestry areas as well as for peat extraction. One of the most degraded peatlands in western Poland is the Bagno Chlebowo, of which a small part is legally protected, having a raised bog status. The peatland has been undergoing drainage and peat mining since the 19th century, and regardless of its partial protection since 1959, it continues to be subjected to drainage, further compromising the function of the nature reserve. Our research focuses on reconstructing the impact of anthropogenic pressure on the state of the peatland over the last 600 years. We applied palaeoecological methods to reconstruct changes in water table levels, acidity (pH) and local plant cover over time. Additionally, we utilized historical maps to gather data on the area's land use and land cover changes. Our findings reveal that drainage and peat harvesting significantly increased the pH level of the peatland, consequently promoting *Sphagnum* expansion. These recent changes in vegetation cover and increased acidity have led to inaccuracies in correctly identifying peatland type. Therefore, the palaeoecological record makes us question its current protection status as a true raised bog, suggesting that the site was a fen for most of the time of its functioning. We demonstrate that long-term reconstructions are, therefore, substantial for nature conservation to (1) properly assess the status of wetlands, (2) identify baseline conditions, and (3) plan suitable restoration and protection methods.

1. Introduction

Peatlands cover approximately 3 % of the Earth's surface globally, providing numerous ecosystem services (Bonn et al., 2014; Rydin and Jeglum, 2013). One of the most important is the accumulation of atmospheric carbon, which has a significant impact on climate (Charman et al., 2013; Lamentowicz et al., 2024; Parish et al., 2008; Yu, 2012). Peatlands also play a crucial role in water retention and reduction of the risk of flooding (Delle Grazie and Gill, 2022) and possess exceptional biodiversity (Minayeva et al., 2017; Parish et al., 2008).

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Because of the human impact, the majority of peatlands in Europe no longer fulfill their ecosystem functions (Temmink et al., 2023). Many have lost their wetland characteristics, such as optimal wetness that supports peat and carbon accumulation, leading to their transition from carbon sinks to carbon sources (Buttler et al., 2023; Swindles et al., 2019; Turetsky et al., 2011; Turunen et al., 2002; Zhang et al., 2022). In Poland alone, it is estimated that out of 1.6 million hectares of peatlands, 1.3 million hectares are degraded (Kotowski and Jabłońska, 2024). This degradation, occurring over centuries, is primarily linked to drainage. In pursuit of expanding agricultural and forestry areas, humans introduced land drainage systems, the consequences of which are noticeable today (Holden et al., 2006; Landry and Rochefort, 2012; Paavilainen and Päivänen, 1995). By lowering the water table, drainage accelerates peat decomposition, releasing significant amounts of carbon dioxide into the atmosphere, further accelerating climate change (Abdalla et al., 2016; Limpens et al., 2008). Biodiversity also suffers, as drainage degrades habitats for specialized species, allowing generalist or invasive species to dominate (Blann et al., 2009; Dudgeon et al., 2006). Additionally, dried peatlands become more susceptible to fires, further amplifying carbon emissions and ecosystem degradation (Frolking et al., 2011; Turetsky et al., 2015). This extensive drainage not only accelerates the decline of peatlands but also paves the way for their exploitation. Peat finds primary use in horticulture, with leading suppliers including countries abundant in peatlands such as Estonia or Latvia (Nurgul et al., 2018). Over the years, different disturbance types have pushed peatlands toward progressive degradation (Lamentowicz et al., 2020; Milecka et al., 2017; Mroczkowska et al., 2021), leaving mainly those already under protection or small sites located far away from agricultural fields in relatively good hydrological and ecological states (Marcisz et al., 2020).

In 2019, the IPCC released a report that included extensive information about peatlands, emphasizing their crucial global role (IPCC, 2019). Today, an increasing number of countries are recognizing the significance of peatlands within their territories. Consequently, many nations implement national adaptation plans to protect and restore peatlands (Nordbeck and Hogl, 2023). However, these efforts often encounter difficulties, especially when restoration demands wetland conditions while agricultural activities require drainage. Additionally, the conservation of peatlands is frequently deprioritized, with the pursuit of faster and greater financial benefits taking precedence over conservation tasks (Barbier and Burgess, 2021). Despite international frameworks like the Paris Agreement recognizing the importance of peatlands for carbon storage and climate regulation, practical challenges include limited awareness, inadequate funding, and conflicting land-use policies. Even when peatlands are legally protected, they can still face significant human pressure, while other factors, such as ongoing forest management practices, can also impact their functioning (Lamentowicz and Konczal, 2024).

Fens are a unique type of peatland, distinguished by their minerotrophic conditions and a hydrological regime where the water table remains slightly below, at, or just above the surface (Grootjans et al., 2006; Wolf and Cooper, 2015; Zhang et al., 2021); distinctive water chemistry arises from inputs of ground or surface water, which contribute higher mineral concentrations, and a more alkaline pH compared to bogs (Cusell et al., 2013; Väliranta et al., 2016). Predominantly located in the mid to high latitudes of the Northern Hemisphere, fens are dominated by sedges and mosses (Hájek et al., 2021; van Diggelen et al., 2006). However, the human impact on fens often leads to their acidification (Lamers et al., 2002), this process can occur naturally as part of autogenic peatland dynamics (fen-to-bog transition) (Gorham et al., 1987; Rydin and Jeglum, 2013). Still, it can be accelerated by human activity (drought-induced acidification resulting from drainage) and high phosphorus influxes (Karpińska-Kołaczek et al., 2022; Lamentowicz et al., 2007; Lamers et al., 2015). Acidification progresses when the top peat layer exists higher above the water table, severing the peatland's connection to mineral-rich groundwater and triggering a shift from rich fen to poor fen (Lamers et al., 2015; Rydin and Jeglum, 2013). Centuries of ongoing drainage have contributed to the progressive loss of fens, reducing biodiversity and affecting their ecosystem functions (van Diggelen et al., 2006). This highlights the urgent need for re-evaluating conservation strategies for such ecosystems in the face of anthropogenic pressures like acidification that create novel bog-like ecosystems with lower plant diversity resulting from the land-use/climate-generated dry shifts.

One of western Poland's most severely degraded peatland areas is the Bagno Chlebowo. Historically, this area has been a vital source of peat for residents of nearby villages (Celka and Szkudlarz, 2000), especially significant during difficult times such as the II World War when the peat was the only source of fuel for heating available in the area (Personal communication with frequent visitor at the time, Czesław Grabicki). However, since the 19th century, extensive land drainage and peat extraction activities have occurred (Wełnicka et al., 2015). Until recently, a peat mine operated in the area, while drainage ditches continue to drain the land today. Despite these challenges, a nature reserve was established to protect the remaining fragments of the peatland that were identified as a raised bog (Regulation No. 62/320, 1959).

To reconstruct how the ongoing centuries of human activity changed the Bagno Chlebowo development we used palaeoecological analysis of the peat profile. In this context, palaeoecology offers valuable insights by reconstructing the environmental history of ecosystems, particularly peatlands (Booth et al., 2004; Czerwiński et al., 2021; Marcisz et al., 2024). Through the analysis of proxies such as plant macrofossils, palaeoecology allows for the reconstruction of past vegetation dynamics, while testate amoebae can be used to infer hydrological changes (Charman, 2001; Kołaczek et al., 2021; Mitchell and Payne, 2018). By integrating these various lines of evidence, paleoecology offers a comprehensive view of ecosystem development, identifying key historical shifts and establishing ecological baselines (Coffey et al., 2012; Finlayson et al., 2015; Froyd and Willis, 2008). Furthermore, palaeoecology facilitates the assessment of human impact by distinguishing between natural and anthropogenic factors that have driven vegetation composition (Coffey et al., 2011; van der Knaap et al., 2012). In addition to palaeoecological data, we utilised historical sources, such as archival documents and maps, to examine how land cover has changed. These records contain valuable information about the past state and development of ecosystems (Barabach, 2012; Słowiński et al., 2019). Combined with palaeoecological proxies they provide essential tools for understanding the complex history and natural conditions of ecosystems, supporting more informed restoration and conservation efforts (Crushell et al., 2008; Łuców et al., 2021; Marcisz et al., 2022).

In this study we investigate record from partly protected Bagno Chlebowo peatland to reconstruct past environmental changes in the context of the current conservation status of the site. We used a multi-proxy approach combining palaeoecological data (plant macrofossils, testate amoebae, peat accumulation rates and radiocarbon dating) with historical and cartographic materials. Specifically, we aim to: 1) assess the extent and impact of historical human activities, particularly drainage interventions, on the ecological characteristics of the Bagno Chlebowo peatland, with a focus on understanding changes in acidity levels over time, and 2) evaluate the effectiveness of current protective strategies for the Bagno Chlebowo in restoring and preserving its ecological conditions, with a particular emphasis on comparing present conditions to the pre-disturbance state.

2. Study area

The Bagno Chlebowo peatland (wetland complex composed of a nature reserve, fish ponds, and the remaining part of the peatland) covers an area of ca. 460 ha and lies in the young glacial landscape of northern Poland, within the Toruń-Eberswalde Proglacial Valley (Kondracki, 1998) in the eastern region of the Noteć Forest (*Polish*: Puszcza Notecka) (Fig. 1). The area surrounding the peatland was shaped by the eolian activity and the melting ice sheet during the post-glacial period, and its characteristic feature is the presence of the largest inland dunes in Poland (Galon, 1961; Kondracki, 1998). The Noteć Forest spans over 1 350 km^2, making it one of the largest forest complexes in Poland. It has been under legal protection since 2004 when it was designated part of the Natura 2000 network under the European Union's Habitat Directive (General Director of the State Forests, 2004). It is characterized by its predominantly sandy soils, which support vast monocultures of Scots pine (*Pinus sylvestris* L.) planted as part of forestry activities in the 19th and 20th centuries (Kusiak and Dymek-Kusiak, 2002). The studied peatland is densely covered by birch and pine trees, interspersed with deadwood. The dominant vegetation includes species of *Sphagnum fallax, Eriophorum angustifolium, Eriophorum vaginatum, Vaccinium myrtillus* and *Vaccinium oxycoccos* (Celka and Szkudlarz, 2000). The peatland is surrounded by managed grasslands. According to data from the Institute of Meteorology and Water Management, the region has a mild climate due to the significant influence of air masses of oceanic origin, resulting in an average annual temperature of 10.3°C and average annual precipitation of 550 mm (IMGW, 2022).

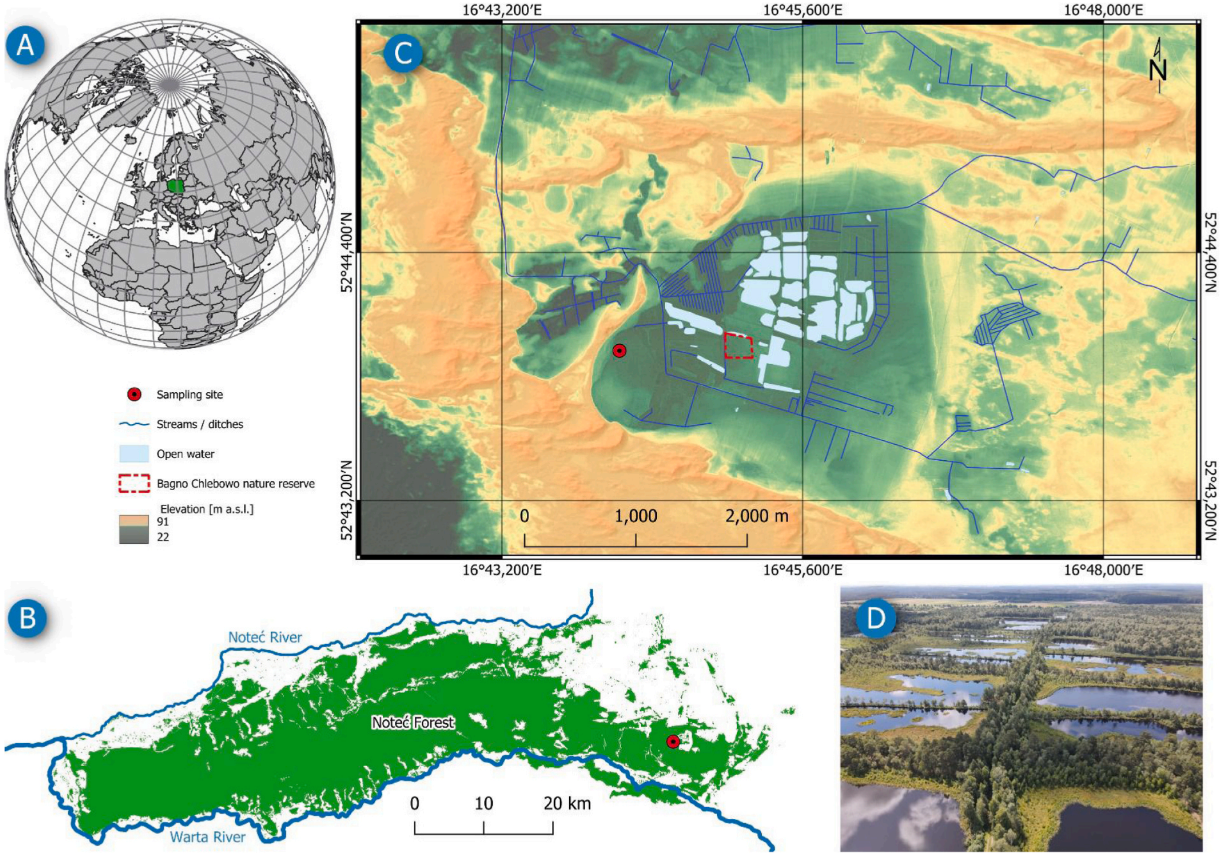

Fig. 1. Location of the study site. A – location of Poland on the globe; B – the extent of the Noteć Forest; C – detailed map of the Bagno Chlebowo peatland; D – aerial photograph of the Bagno Chlebowo.

3. Methods

3.1. Peat coring and samplings

In November 2021, a peat core was extracted from the western section of the peatland (52°43'54''N, 16°44'7''E – coordinates according to standard WGS 84). A Wardenaar corer was used for the extraction, with chamber dimensions measuring 10 cm × 10 cm × 100 cm (Wardenaar, 1987). The 1 m of the peat monolith was collected, but only the top 50 cm was analysed. This section was sliced into 2 cm-thick sub-samples, resulting in 25 contiguous samples designated for each palaeoecological analysis.

3.2. Radiocarbon dating and chronology

Five samples containing *Sphagnum* stems and other plant remains were used for radiocarbon dating at the Poznan Radiocarbon Laboratory using the AMS method (Table 1.). A Bayesian age-depth model was created in OxCal to estimate absolute chronology. IntCal20 (Reimer et al., 2013) and BombNH1 (Hua et al., 2013) ^{14}C atmospheric curves were used as the calibration sets. The *P*_Sequence command with a parameter k of 0.1 cm^{-1} was used to calculate the model, assuming $log_{10}(k/k0) = 1$, and interpolation = 1 cm. Due to the transition manifested in the plant macrofossil diagram, a boundary command at the depth of 35 cm was introduced.

3.3. Cartography

Information about the past changes in land-use and land-cover (LULC) was obtained from two historical maps from various periods and compared with a recent vector database – Topographic Objects Database (BDOT10k, from 2020). The most accurate, large-scale historical maps available for this region were used in the analysis: the oldest one – Ur-Messtischblatt (sheet 1713, 1:25,000) comes from 1832, and the second one – Messtischblatt from 1892 (sheet Polajewo, 1:25,000). The maps were georeferenced using ground control points derived from BDOT10k and contemporary orthoimages to give the raster images spatial rectification. The land use types were classified into four classes in each mapping: forests, open areas, open water, and wetlands, while streams and ditches were represented as linear features. The LULC analysis was conducted within the peatland and the surrounding areas, covering a total area of 41.53 km^2.

3.4. Plant macrofossil analysis

The analysis of plant macrofossils was carried out according to a modified protocol developed by Mauquoy et al. (2010). Each sample of about 5 cm^3 was washed on a sieve with a mesh diameter of 200 μm. The composition of main peat components (e.g. roots and mosses) was estimated using a binocular microscope as a percentage. Fruits, seeds, caryopses, achenes, scales (bud scales, catkin scales), anthers, opercula, sporangia, fungal sclerotia were counted in total numbers in each sample. Tissues of monocotyledonous plants and leaves of mosses (brown and *Sphagnum* mosses) were identified on slides at × 200 and × 400 magnifications. The material was identified with the support of the relevant guides to identification (Anderberg, 1994; Berggren, 1981; Mauquoy et al., 2010). The diagram was created using the C2 software (Juggins, 2003).

Table 1
Radiocarbon dates. Abbreviations: Poz – Poznan Radiocarbon Laboratory, Poland.

Depth (depth used in the model) [cm]	Laboratory code – number	^{14}C date ± uncertainty [^{14}C yr BP]	Calibrated date [cal. CE] (uncertainty 2σ – 95.4 %)	Modelled date [cal. CE] (uncertainty 2σ – 95.4 %)	Material dated; remarks
14.5	Poz−157096	108.75 ± 0.35 pMC	1952 — 1960 (7.5 %) 1995 — 2005 (88.0 %)	1950 — 1964 (83.4 %) 1997 — 2002 (12.1 %)	*Sphagnum* stems
29.5	Poz−157097	165 ± 30	1661 — 1706 (17.2 %) 1720 — 1818 (44.0 %) 1832 — 1892 (14.9 %) 1906 — … (19.5 %)	1800 — 1809 (2.1 %) 1834 — 1948 (93.3 %)	*Sphagnum* stems
34.5	Poz−156956	160 ± 30	1663 — 1708 (16.8 %) 1719 — 1786 (31.5 %) 1792 — 1820 (10.0 %) 1832 — 1892 (17.7 %) 1906 — … (19.5 %)	1752 — 1782 (5.2 %) 1793 — 1940 (90.2 %)	Epiderms, charcoal
40.5	Poz−157099	250 ± 30	1522 — 1576 (15.9 %) 1624 — 1680 (54.8 %) 1740 —1753 (1.8 %) 1762 — 1800 (22.1 %) 1940 — … (0.9 %).	1544 — 1553 (0.6 %) 1622 — 1684 (83.3 %) 1736 — 1754 (2.0 %) 1762 — 1800 (9.6 %)	Epiderms
49.5	Poz−156818	470 ± 30	1407 —1460 (95.4 %)	1408 — 1460 (95.4 %)	Epiderms

3.5. Testate amoeba analysis

To analyze testate amoebae, samples of approximately 5 cm^3 of peat were sampled according to the standard procedure following Booth et al. (2010). Each sample was sieved through a 300 μm-large mesh size, and the filtrate was then subjected to microscopic analysis. The testate amoebae were analyzed under a light microscope at × 200 and × 400 magnification. Taxonomic monographs (Clarke, 2003; Mazei and Tsyganov, 2006) and online resources (Siemensma, 2024) were used to identify testate amoebae taxa. To obtain meaningful reconstruction values, a sum of 100 shells per sample was counted (Payne and Mitchell, 2008), but this was not possible in the bottom section of the core (between 30 and 50 cm). Quantitative reconstructions of changes of the depth to the water table (DWT) and acidity (pH) were performed in C2 software (Juggins, 2003) using the European training set (Amesbury et al., 2016). The same software was used to draw the diagram.

4. Results

4.1. Age-depth model

The age-depth model revealed a Model Agreement Index (A_{model}) of 56 % (Bronk Ramsey, 2008) (Fig. 2). The extracted peat core covers the period from 1435 CE. Peat accumulation rates are generally low throughout the core. However, until the phase of the transition, the average accumulation rate is 0.04 cm/year, and afterwards, it accelerates to an average of 0.22 cm/year.

4.2. Cartography

In 1832, a small network of drainage ditches, spanning 3.85 km, was visible in the northern part of the analyzed study area (Fig. 3). Forested areas dominated the landscape, covering 72.48 % (30.11 km^2) of the total area. Wetlands constituted 32.06 % (13.32 km^2), while open spaces accounted for 27.56 % (11.45 km^2). No lakes or ponds were determined at that time.

By 1892, the landscape had undergone significant changes. The total length of drainage ditches increased dramatically to 66.87 km, extending across nearly the entire wetland area. Forest cover declined to 59.24 % (24.61 km^2), while open spaces expanded

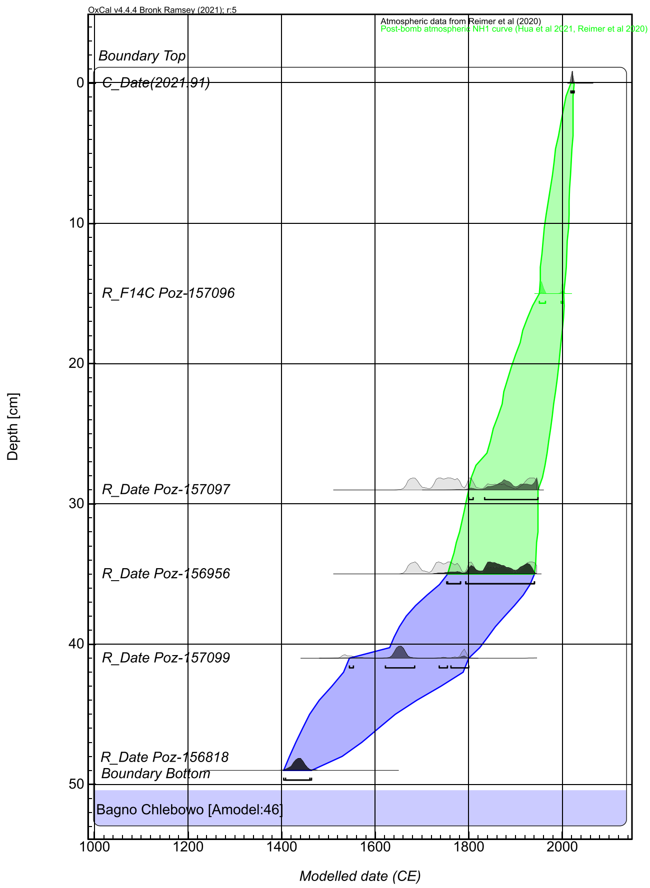

Fig. 2. Age-depth model of the Bagno Chlebowo peat core. The colours blue and green mark the transition in the peat core from fen to poor fen.

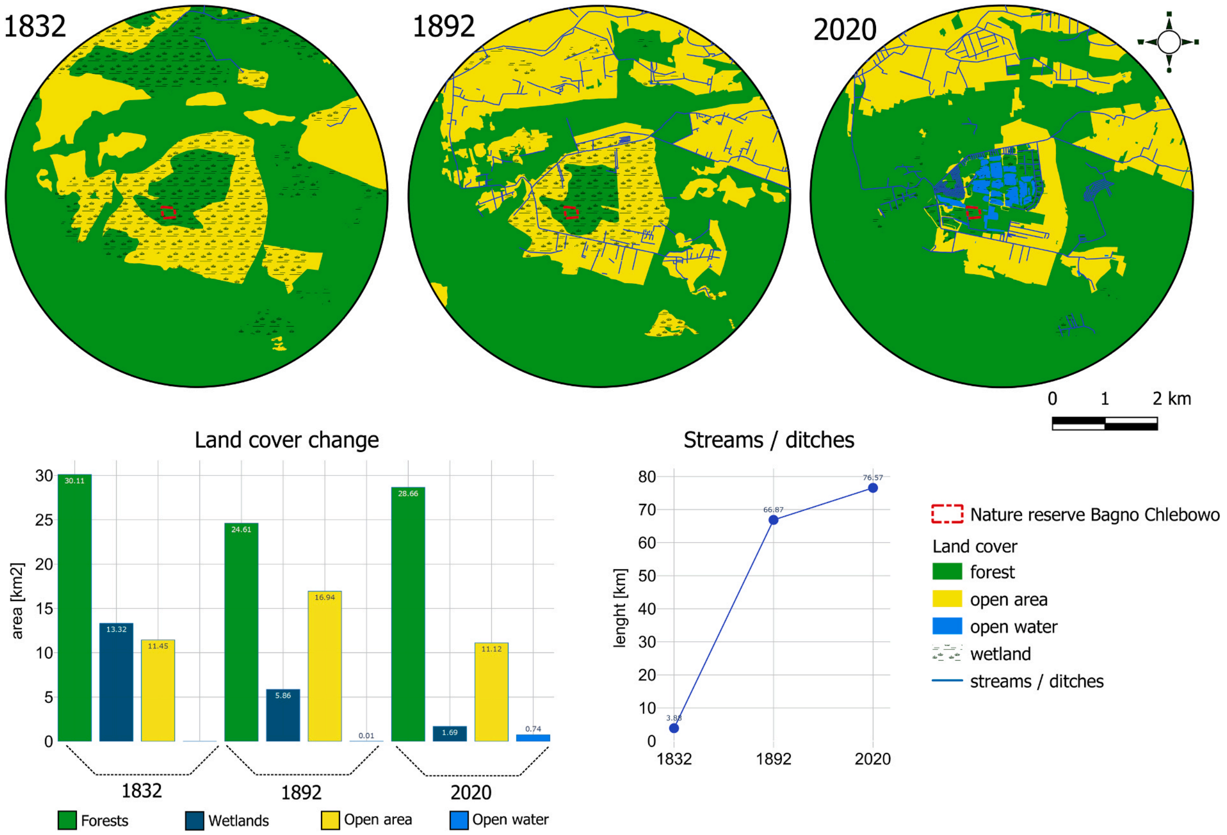

Fig. 3. Land cover changes at the Bagno Chlebowo peatland between 1832 and 2020.

to 40.78 % (16.94 km^2). The wetland area was reduced by half, shrinking to 14.11 % (5.86 km^2). Additionally, open water bodies began to appear within the study area, however they covered just 0.02 % of the total investigated area.

By 2020, the drainage ditch network had further expanded, reaching a total length of 76.57 km. A dense network of ditches now covers the central portion of the wetland. The area of open water increased to 1.78 % (0.74 km^2), now represented by fish ponds. Compared to the previous period, open spaces decreased to 26.77 % (11.12 km^2), while forest cover rebounded to 68.98 %

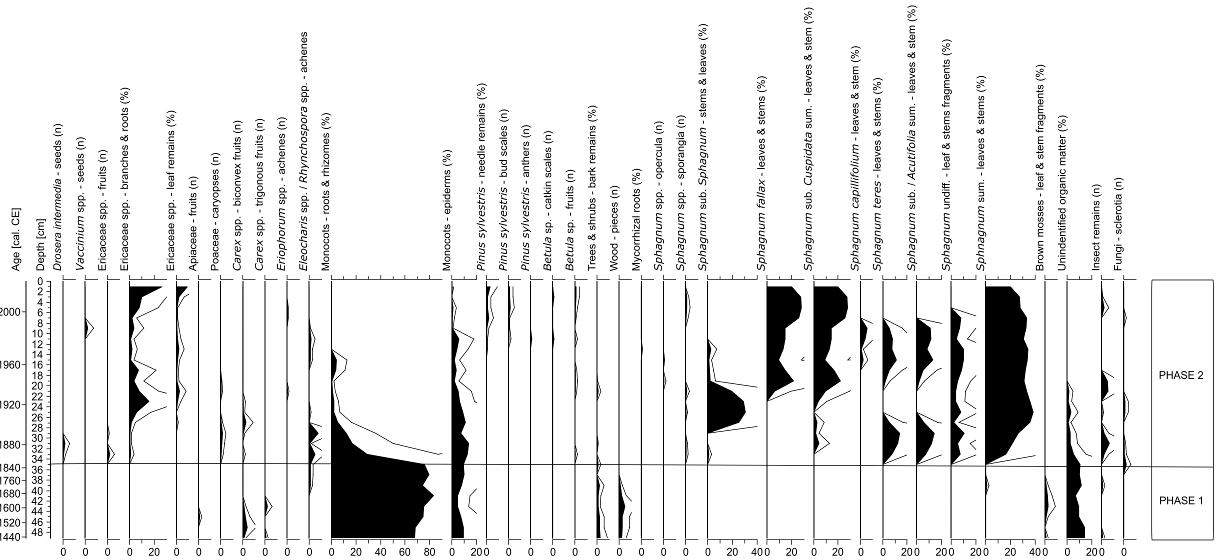

Fig. 4. Diagram showing macrofossil percentages with 3 times exaggeration.

(28.66 km^2). The area of wetlands decreased by more than threefold compared to 1892 and almost fivefold compared to 1832, now accounting for about 4.07 % of the total analyzed area.

4.3. *Palaeoecological analyses*

Based on the analyses of plant macrofossils, testate amoebae and peat accumulation rates, we identified two distinct phases of peatland development over time.

4.3.1. *Phase 1 (50–35 cm; 1435–1860 CE) – minerotrophic fen*

In phase 1, the peat is composed mainly of monocots, their remains (roots, rhizomes and epidermis) account for 81–90 % of the sample content (Fig. 4). Other plant remains include unidentified organic matter (7–15 %), brown mosses (up to 3 %) and bark fragments of trees and shrubs (up to 2 %). In addition, in this phase, we observed pieces of tree wood (up to 5 pieces), and biconvex and trigonous fruits of *Carex*. The *Sphagnum* mosses are entirely absent in this phase.

The counts of testate amoebae individuals were conducted until 50 shells per sample were reached, due to their low abundance (Fig. 5). At the beginning of this phase, the dominant species were *Cryptodifflugia oviformis* (34 %), *Heleopera petricola* (20 %), and *Physochila griseola* (17 %). Later in this phase, at depth of 41 cm and above (1660–1860 CE), the community composition shifted, with species such as *Centropyxis aculeata* (33 %), *Cyclopyxis eurystoma* (21 %), and *Cyclopyxis kahli* (15 %) becoming dominant. This phase was marked by a gradual decline in groundwater levels, starting at 6 cm at the beginning and dropping to approximately 14 cm by its end. Concurrently, the pH level exhibited an increasing trend, stabilizing between 4.0 and 4.5.

4.3.2. *Phase 2 (35–0 cm; 1860–2021 CE) – transition to acidic poor fen*

At the boundary between phase 1 and phase 2, there are remains of species *Drosera intermedia* and *Eleocharis* spp./*Rhynchospora* spp. From the beginning of phase 2, *Sphagnum* mosses start to dominate while the percentage of monocots declines. Brown mosses disappear completely. Ericaceae remains (branch fragments, roots, leaf remains, seeds), including *Vaccinium* appear. *Sphagnum teres* (belonging to the subgenus *Acutifolia*, up to 29 %) appears at the beginning of the phase and then recedes in favour of the subgenus *Sphagnum* (up to 53 %).

In 1945 CE, *Sphagnum* sub. *Sphagnum* disappears, while *Sphagnum* sub. *Cuspidata*, predominantly represented by *Sphagnum fallax* (up to 73 %), emerges. At the end of the phase *S. fallax* is the dominant species.

Due to a higher abundance of testate amoebae, it was possible to reach 100 tests count per sample during the microscopic analyses. At the beginning of this phase, similar species dominate as in the first phase, with *C. aculeata* (30 %), *C. eurystoma* (18 %), and *C. kahli* (12 %) being the most prevalent. During this period, the water table is low, at approximately 12.8 cm.

Around 1891 CE, *Galeripora discoides* sharply increases in abundance, reaching 55 % and becoming the dominant species of this phase. Concurrently, the water level rises and stabilizes at around 5 cm, accompanied by a noticeable decline in pH from 4.5 to 3.8, indicating increasing acidity.

By approximately 1933 CE (at a depth of 21 cm), *Archerella flavum* becomes the dominant species (29 %), while *G. discoides* declines significantly. In contrast, other species such as *Hyalosphenia elegans* (44 %), *P. griseola* (19 %), and *Hyalosphenia papilio* (8 %) increase in abundance. In the upper part of this layer, the community composition shifts again, with *Assulina muscorum* (18 %), *Euglypha* spp. (17 %), *Nebela tincta* (17 %), and *Alabasta militaris* (10 %) dominating. During this stage, the groundwater level drops to approximately 18.2 cm.

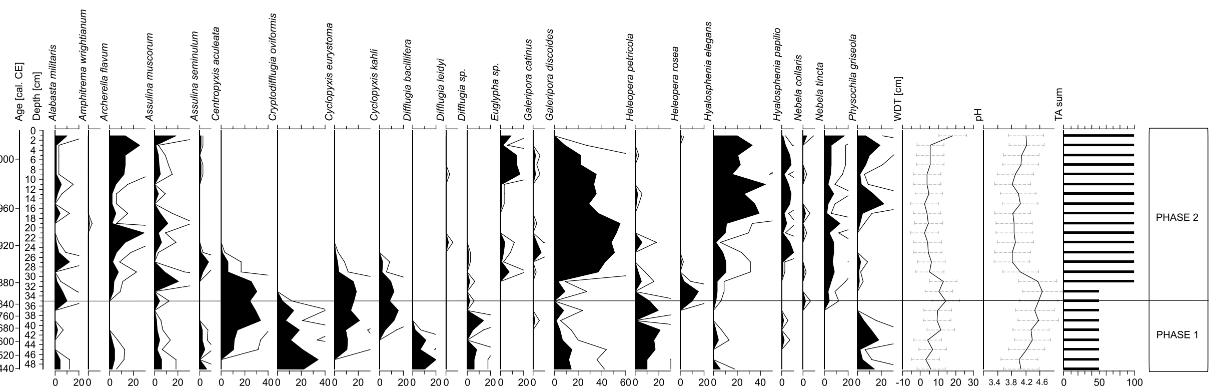

Fig. 5. Testate amoebae percentage diagram with 3 times exaggeration.

5. Discussion

5.1. The history of the transformation of the Bagno Chlebowo peatland

Our research shows that over the last 200 years Bagno Chlebowo peatland has undergone significant changes, primarily due to increased density of established drainage ditches and intensive peat harvesting. To protect habitat loss, a nature reserve was established; however, this reserve only covers a tiny portion of the entire peatland area (ca. 4.42 ha what makes only 0.95 % of the peatland area), being an island surrounded by the "mining landscape".

As indicated by the plant macrofossil analysis, up to 1860 CE the peat was composed primarily of monocot plants, with dominant *Carex* communities. This taxonomic composition suggests the presence of a minerotrophic fen and likely partially wooded. Around 1891 CE, drainage works were implemented in the peatland, evidenced by the emergence and rapid increase in the abundance of the testate amoeba taxon - *Galeripora discoides*. Its high abundance indicates unstable hydrological conditions, as this species exhibits high tolerance to fluctuating water levels (Lamentowicz and Mitchell, 2005). The intense drainage disrupted the peatland's connection to groundwater; by lowering the water table, the surface layers of the peatland became disconnected from groundwater influence and are currently rain-fed, resulting in the peatland's acidification. Simultaneously, transformations in the surrounding forest landscape likely intensified the acidification process. In the 19th century, the Noteć Forest was transformed into a monoculture dominated by Scots pine (*Pinus sylvestris*) (Barabach, 2015; Broda, 2000). Such monocultures not only exacerbate acidification within the catchment area of peatlands, but also lead to soil nutrient depletion, reduced productivity, and diminished forest biodiversity (Bąk et al., 2024; Jactel et al., 2009). A significant drop in pH in Bagno Chlebowo created favourable conditions for the spread of peat mosses (*Sphagnum*) on the surface of the site, which thrive in acidic environments and actively reshape the peatland ecosystem. The proliferation of *Sphagnum* has helped stabilize the groundwater level and increase the abundance of testate amoebae species. In the uppermost layers, the testate amoeba assemblage is dominated by *Assulina muscorum*, *Euglypha* spp., *Nebela tincta*, and *Alabasta militaris* — taxa characteristic of very dry and acidic habitats (Amesbury et al., 2016; Lamentowicz and Mitchell, 2005). This shift in vegetation and soil dynamics highlights the complex interplay between human interventions and the natural processes governing peatland ecosystems.

As Dawson et al. (2003) demonstrated, many species adapted to water-saturated conditions are losing their habitats due to the lowering of the water table. In the Bagno Chlebowo peatland, brown mosses, particularly sensitive to changes, were gradually replaced by *Sphagnum* mosses approximately 180 years ago. In their publication, Celka and Szkudlarz (2000) highlighted the disappearance of several species from Bagno Chlebowo as a result of these transformations. The most sensitive species, such as *Saxifraga hirculus* and *Scheuchzeria palustris*, likely vanished soon after the onset of drainage. Later, other species that initially resisted the changing conditions, such as *Drosera intermedia*, *Carex limosa*, and *Rhynchospora alba*, disappeared. Drainage significantly reduces biodiversity, leading to the dominance of one or a few species within the ecological complex. Among trees, for instance, Scots pine (*Pinus sylvestris*) and downy birch (*Betula pubescens*) now dominate the landscape. This shift, driven by drainage and the drying of peatlands, is a common process. We are witnessing the widespread degradation of fens, a process with profound ecological implications (Grootjans et al., 2006; van Diggelen et al., 2006; Wassen et al., 1996). A similar transformation, as observed in Bagno Chlebowo, occurred in the Okoniny peatland in the Tuchola Forest, described thoroughly by Bąk et al. (2024). Changes in forest management and progressive climate warming significantly influenced the development of this peatland, which has undergone a complete transformation over the past 200 years. The authors note an increase in acidity during the analyzed period and a decline in the water table over recent decades. This acidification also led to the dominance of *Sphagnum* species in the peatland. A comparable transition is also highlighted by Lamentowicz et al. (2007), where a rapid shift to wetter conditions and lower pH levels caused a change in vegetation within the peatland. The site transformed into a *Sphagnum*-dominated poor fen with some bog plants, likely triggered by forest clearance.

The rapid loss of specialized plant species in fens due to the acidification or spread of *Sphagnum* reflects a broader global environmental issue. Tahvanainen (2011) reported that drainage of the catchment area beginning in 1968, along with ongoing climate change, led to a shift in the hydrology of the aapa mire system in Finland—from a highly minerotrophic to ombrotrophic state. Using a series of aerial photographs, Tahvanainen (2011) documented a crucial vegetation change: within just two decades of catchment disturbance, fen vegetation was almost entirely replaced by *Sphagnum* mosses, indicating a transformation toward bog-like conditions. Similarly, Paulissen et al. (2013) demonstrated that altered hydrology and changes in nutrient dynamics—specifically phosphorus enrichment and ammonium toxicity—were key drivers of rapid shifts in the bryophyte composition of Dutch fens. Their study observed the replacement of early-successional brown mosses and *Sphagnum* species by acidophylous, late-successional bryophytes. In a related study, Hájek et al. (2015) found that calcicolous brown mosses, which are adapted to high-calcium fen environments, have been retreating to microhabitats with the highest pH levels. These specialized species are increasingly being replaced by more nutrient-demanding taxa such as *Calliergonella cuspidata* and *Sphagnum palustre*, even in rich fens. Long-term studies have confirmed that the process of ombrotrophication can be very rapid (Gorhamand Janssens, 1992; Hughes and Barber, 2003), especially when anthropogenic impacts on the peatland catchment are significant (Lamentowicz et al., 2020, Bąk et al., 2024).

The peat mining in the Bagno Chlebowo peatland stopped in 1992; however, its impact remains visible to this day. The ongoing drainage ditches traversing the peatland continue to disrupt the ecological functionality of the entire wetland (including the nature reserve) by depleting groundwater levels. This persistent drainage accelerates the degradation of the peatland ecosystem, a process also noticed in many sites in various locations (Blann et al., 2009; Holden et al., 2006). In areas where peat was extracted, post-extraction depressions formed, which are now filled with open water and repurposed as fish ponds. The remaining sections of the peatland, including the reserve, are unmanaged, with no restoration plan. Unfortunately, restoring Bagno Chlebowo to a fen is not possible due to the extensive degradation of the area. The fens of Europe are suffering from acidification, as seen in the Chlebowo case. Over the last 300 years, most of European peatlands have not been natural (Swindles et al., 2019). Furthermore, we can predict that without mining and drainage, the fen would still exist. It is essential to note that this peatland is not solely dependent on precipitation and is hydrologically dependent on the catchment area. Restoration by blocking the drainage ditches might positively impact the peatland hydrology. However, the area is partly private, so the active protection remains challenging. Despite these obstacles, rewetting is essential to improving the condition of Bagno Chlebowo. As shown by a large body of research, blocking drainage ditches can significantly improve peatlands' health by restoring hydrology, promoting carbon sequestration, and supporting vegetation recovery (Beyer et al. (2021); Howie et al. (2009); Wilson et al. (2022).

5.2. High-quality palaeoecology and its importance for peatland type assessment and nature conservation

The transformation of Bagno Chlebowo has led to numerous erroneous conclusions regarding its environmental protection habitat classification. As previously mentioned, several official documents concerning the protection of this area, such as Regulation No. 62, item 320 (1959) and Regulation Item 626 (2022), incorrectly describe it as a raised bog. These documents likely relied on a preliminary pre-exploitation peat survey conducted in 1972, which aimed to define the boundaries of the Bagno Chlebowo peatland, assess its thickness and resources, and evaluate the essential characteristics of the peat for potential utility (Lisiak and Włodarczak, 1972). Through drilling conducted during fieldwork, they determined that *Sphagnum* was the main component of the peat. Additionally, the report highlighted that the plant cover was typical of raised bog environments, leading to misclassification. However, a technical study on the Bagno Chlebowo in 1989 presented an entirely different peatland classification (Ilnicki, 1989). Ilnicki (1989) noted that the 1972 documentation did not meet the standards of official peatland surveys conducted by certified experts. As a result, a new series of field studies, including drilling across the peatland, was carried out. The report states: "The data presented in the table clearly indicate that contrary to commonly held beliefs, we are not dealing in Chlebowo with a deposit of raised bog or transitional types, but with a mixed deposit structure, where the lower levels consist of fen peat, and the upper levels are composed of various types of raised bog peat" [translated from Polish: „*Z danych zawartych w tabeli wynika niedwuznacznie, iż wbrew powszechnie utartym przekonaniom nie mamy w Chlebowie do czynienia ze złożem typy wysokiego czy przejściowego, lecz z typem mieszanym budowy złoża, w którym poziomy dolne budują torfy niskie bagienne, poziomy górne różne gatunki torfów wysokich*"] Ilnicki (1989). Unfortunately, the findings of this documentation failed to reach a broader audience, and the early misclassification of the Bagno Chlebowo peatland as a raised bog continues to have significant consequences. The scans of the documentation provided by Lisiak and Włodarczak (1972) and Ilnicki (1989) are presented in Supplement 1.

Several articles continue to perpetuate the misclassification of the peatland type (Celka and Szkudlarz, 2000, 2006, 2010; Czyż et al., 2016; Szkudlarz and Celka, 2004; Wełnicka et al., 2015). The most problematic example comes from the monograph by Chmiel and Kasprowicz (2004), which serves as a guidebook for field courses on the flora and vegetation of the Greater Poland (Polish: *Wielkopolska*) region. It incorrectly asserts that Bagno Chlebowo is one of the largest raised bogs in Greater Poland. This guide is widely used in student field courses at various education levels (from Bachelor to PhD courses), where one of the key topics, as outlined in the book, is the formation conditions of a raised bog consisting of hollows and hummocks. As a result, even educational practices are affected, contributing to disseminating incorrect information in academic settings and field-based teaching. While the classification of Bagno Chlebowo as a raised bog is supported by the occurrence of species commonly found in such habitats, this alone is insufficient to confirm its ombrotrophic character. In this case, the observed vegetation likely emerged due to anthropogenic acidification rather than natural succession. The plant community primarily comprises poor fen species, including *Carex rostrata*, *Eriophorum vaginatum*, and *Sphagnum fallax*, which predominantly grow on the floating mats formed within former peat extraction ponds. Ultimately, the accurate classification of a peatland must be based on an analysis of its peat layers, not solely on surface vegetation. Geological studies, such as drilling, and detailed knowledge of peatland hydrology and the character of water supply into the peatland basin are essential to determine whether a peatland is genuinely a raised bog or if it has recently transformed from a fen to a poor fen. This presents a contemporary challenge to the accurate classification of peatlands and, in consequence, conducting appropriately directed protection and conservation.

Such classification challenges are particularly evident in Poland, where some peatland ecosystems require closer attention. For example, the Rzecin peatland, located within the Noteć Forest near Bagno Chlebowo, was granted protection under the Natura 2000 program (PLH300019) in 2008, classified as a fen. However, its classification and the nature of its vegetation remain debated in the literature. According to the Wetland Spatial Information System of Poland (Oświecimska-Piasko et al., 2006), the Rzecin peatland is classified as a fen. In contrast, more detailed studies by Wojterska et al. (2001) suggest it represents a poor fen. Similar findings are presented in studies by Barabach (2012), (2015), Lamentowicz et al. (2015) and Milecka et al. (2017), where the authors used aerial photographs and palaeoecological methods to reconstruct the environmental history of the peatland. Rzecin was believed to be a natural, undisturbed habitat with minimal human impact for many years. However, palaeoecological studies revealed that, as a result of anthropogenic activities and undertaken forest management practices, a substantial portion of the wetland only developed within the last few centuries as a floating mat that overgrew Lake Rzecińskie, making it much younger than previously assumed. These studies emphasize the crucial impact of human interventions, particularly hydrotechnical modifications, in shaping vegetation and ecosystem dynamics. They reveal that ecosystems often perceived as natural may have a far more complex history influenced by human activity.

Another example of the challenge in peatland classification is Czerwone Bagno, located in the Biebrza River Valley in eastern Poland. Known for its primeval landscapes, particularly the forested mires of the Middle Biebrza Basin, Czerwone Bagno has been designated as a Strictly Protected Area within Biebrza National Park. Many sources claim that Czerwone Bagno is one of the few large peatlands in Poland that has remained in a natural state. Interestingly, a report prepared by the Naturalists' Club (2007), which focused on protecting and restoring peatlands, classified Czerwone Bagno as a raised bog peatland, recommending it for conservation. However, from 2007 to 2010, a project titled "Conservation of the Biodiversity of Czerwone Bagno – a Relict of the Great Raised Bogs of

Central Europe – PL 0082" was conducted to assess the current condition of the area and develop conservation guidelines (Grygoruk, 2013). Initial findings indicated that the peatland was originally a mineral-rich fen with an open landscape but was locally transformed into an ombrotrophic peatland, dominated by bog-pine forest. Anthropogenic activities, such as constructing the Woźnawiejski and Augustowski canals, likely accelerated the ombrotrophication process by reducing groundwater inflow to the upper peat layers (Grygoruk et al., 2011). These findings led to a reassessment of earlier assumptions about the natural development of Czerwone Bagno and its classification as the raised bog, demonstrating that human interventions have played a much more significant role in shaping the area than previously assumed.

Ecosystem restoration and protection are vital to biodiversity conservation (Erwin, 2009; Young, 2000). However, identifying appropriate reference conditions for restoration poses a significant challenge, as ecosystems often undergo profound changes due to natural disturbances and human influence (Stoddard et al., 2006). This makes it difficult to determine their original ecological baseline. The long-term insights palaeoecology provides are invaluable because they track ecosystem state changes across millennia (Booth et al., 2004; Ellis, 2021; Lamentowicz et al., 2019). This allows researchers to differentiate between human-induced alterations and the natural fluctuations that ecosystems experience over time (Nogué et al., 2021). The Bagno Chlebowo example highlights the essential role that palaeoecological research plays in identifying and understanding peatland history. Examining the past often provides critical insights into the change and current state of such ecosystems (Gałka et al., 2013; Lavoie and Richard, 2000). One of the significant palaeoecology advantages is its ability to inform modern conservation strategies by providing evidence of how ecosystems have responded to past climate changes, disturbances, and environmental shifts (Lamentowicz and Obremska, 2010; Lamentowicz et al., 2016; Marcisz et al., 2022; Marcisz et al., 2019). For instance, palaeoecological studies have revealed that certain ecosystems possess resilient traits, such as the capacity to recover from disturbances or adapt to changing conditions (Brown et al., 2023). Understanding these traits can guide restoration efforts, helping identify species likely to thrive under future environmental scenarios (Antala et al., 2022). Thus, the insights from palaeoecological research are critical for developing more effective and ecologically informed conservation and restoration strategies (Lamentowicz et al., 2019; Marcisz et al., 2022).

Peatlands are among the most valuable ecosystems, offering key/critical ecosystem services (Costanza et al., 2014; Mitsch et al., 2015; Sanderson et al., 2023). However, anthropogenic impact is often underestimated due to a general lack of awareness and understanding resulting from the shortage of the data (Polajnar, 2008). Even established protected areas often suffer from inadequate management, with minimal efforts to enhance their ecological condition (Hermoso et al., 2016). The critical support might be provided by the solid palaeoecological knowledge collected in high resolution (Manzano et al., 2020). Nonetheless, we should raise awareness of our environmental assets and how they can contribute to better conditions around us. Increasing public awareness and securing adequate funding are essential steps toward improving peatland protection and restoration efforts (Barbier et al., 2021). By doing so, we can ensure that these valuable ecosystems continue to provide their vital services for future generations.

6. Summary

The case of Bagno Chlebowo highlights the critical role of scientific research and palaeoecology in understanding and protecting peatland ecosystems impacted by human activities. This research reveals the historical trajectory of Bagno Chlebowo and underscores the need for accurate classification to effectively guide conservation efforts. Our findings indicate that drainage and peat extraction have significantly transformed the peatland ecosystem. Furthermore, the lack of consideration for palaeoecological data in environmental protection efforts has led to incorrect classifications of this peatland. To address the challenges posed by outdated data in educational materials, scientific literature, and conservation plans, it is essential to revise these resources to align with the actual characteristics of the peatland. Misclassifications can jeopardize restoration projects, potentially harming the fragile ecosystem instead of supporting its recovery. Thus, an accurate identification of the peatland type and a comprehensive understanding of its stratigraphy are vital for developing effective conservation and restoration strategies that ensure the long-term health of the Bagno Chlebowo peatland.

CRediT authorship contribution statement

Daria Wochal: Fieldwork, Testate amoeba analysis, Selection of plant macrofossils for AMS radiocarbon dating, Age-depth modelling, Data interpretation, Visualization, Writing (original draft), Funding acquisition, **Katarzyna Marcisz**: Fieldwork, Support in testate amoeba analysis, Data interpretation, Writing (commenting and editing), Funding acquisition, **Jan Barabach:** Acquisition of cartographic materials, Analysis of land cover changes, Data interpretation, Writing (commenting and editing), Funding acquisition, **Mariusz Bąk**: Plant macrofossil analysis, Data interpretation, Writing (commenting and editing), **Mariusz Lamentowicz**: Conceptualization, Fieldwork, Support in testate amoeba analysis, Selection of plant macrofossils for AMS radiocarbon dating, Data interpretation, Writing (commenting and editing), Funding acquisition

Ethics

This manuscript does not include human or animal research.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.gecco.2025.e03647.

Data availability

Palaeoecological data are available in the Mendeley Data repository under https://doi.org/10.17632/gvk8m5vk2k.1. Geospatial data on land use changes are available in the RepOD respoditory under https://doi.org/10.18150/WDM4GQ.

References

Abdalla, M., Hastings, A., Truu, J., Espenberg, M., Mander, Ü., Smith, P., 2016. Emissions of methane from northern peatlands: a review of management impacts and implications for future management options. Ecol. Evol. 6 (19), 7080–7102. https://doi.org/10.1002/ece3.2469.

Amesbury, M.J., Swindles, G.T., Bobrov, A., Charman, D.J., Holden, J., Lamentowicz, M., Mallon, G., Mazei, Y., Mitchell, E.A.D., Payne, R.J., Roland, T.P., Turner, T. E., Warner, B.G., 2016. Development of a new pan-European testate amoeba transfer function for reconstructing peatland palaeohydrology. Quat. Sci. Rev. 152, 132–151. https://doi.org/10.1016/j.quascirev.2016.09.024.

Anderberg, A. 1994. Atlas of seeds and small fruits of Northwest- European plant species with morphological descriptions. Part 4: Resedaceae – Umbelliferae, Risbergs Tryckeri AB, Uddevalla,.

Antala, M., Juszczak, R., van der Tol, C., Rastogi, A., 2022. Impact of climate change-induced alterations in peatland vegetation phenology and composition on carbon balance. Sci. Total Environ., 154294 https://doi.org/10.1016/j.scitotenv.2022.154294.

Bąk, M., Lamentowicz, M., Kołaczek, P., Wochal, D., Matulewski, P., Kopeć, D., Wietecha, M., Jaster, D., Marcisz, K., 2024. Assessing the impact of forest management and climate on a peatland under Scots pine monoculture using a multidisciplinary approach. Biogeosciences 21 (22), 5143–5172. https://doi.org/10.5194/bg-21-5143-2024.

Barabach, J., 2012. The history of Lake Rzecin and its surroundings drawn on maps as a background to palaeoecological reconstruction. Limnol. Rev. 12 (3), 103–114. https://doi.org/10.2478/v10194-011-0050-0.

Barabach, J. 2015. Zapis zdarzeń katastrofalnych na obszarze Puszczy Noteckiej w osadach Torfowiska Rzecin. https://doi.org/10.13140/RG.2.2.20454.24645.

Barbier, E.B., Burgess, J.C., 2021. Economics of Peatlands Conservation, Restoration and Sustainable Management. SSRN Electron. J. https://doi.org/10.2139/ssrn.4695533.

Berggren, G. 1981. Atlas of Seeds and Small Fruits of North-west European Plant Species with Morphological Descriptions: Part 3 Salicaceae–Cruciferae. Berlings.

Beyer, F., Jansen, F., Jurasinski, G., Koch, M., Schröder, B., Koebsch, F., 2021. Drought years in peatland rewetting: rapid vegetation succession can maintain the net CO₂ sink function. Biogeosciences 18 (3), 917–935. ⟨https://doi.org/10.5194/bg-18-917-2021⟩.

Blann, K.L., Anderson, J.L., Sands, G.R., Vondracek, B., 2009. Effects of agricultural drainage on aquatic ecosystems: a review. Crit. Rev. Environ. Sci. Technol. 39 (11), 909–1001. https://doi.org/10.1080/10643380801977966.

Bonn, A., Reed, M.S., Evans, C.D., Joosten, H., Bain, C., Farmer, J., Emmer, I., Couwenberg, J., Moxey, A., Artz, R., Tanneberger, F., von Unger, M., Smyth, M.-A., Birnie, D., 2014. Investing in nature: developing ecosystem service markets for peatland restoration. Ecosyst. Serv. https://doi.org/10.1016/j.ecoser.2014.06.011.

Booth, R.K., Jackson, S.T., Gray, C.E.D., 2004. Paleoecology and high-resolution paleohydrology of a kettle peatland in upper Michigan. Quat. Res. 61, 1–13. ⟨https://www.ncbi.nlm.nih.gov/pubmed/853⟩.

Booth, R.K., Lamentowicz, M., Charman, D.J., 2010. Preparation and analysis of testate amoebae in peatland paleoenvironmental studies. Mires Peat 7 (2010/11), 1–7.

Broda, J. 2000. Historia leśnictwa w Polsce. Wydawnictwo Akademii Rolniczej im. Augusta Cieszkowskiego w Poznaniu, Poznań.

Bronk Ramsey, C., 2008. Deposition models for chronological records. Quat. Sci. Rev. 27 (1–2), 42–60 https://doi.org/10.1016/j.quascirev.2007.01.019.

Brown, K.A., Bunting, M.J., Carvalho, F., de Bello, F., Mander, L., Marcisz, K., Mottl, O., Reitalu, T., Svenning, J.C., 2023. Trait-based approaches as ecological time machines: developing tools for reconstructing long-term variation in ecosystems. Funct. Ecol. https://doi.org/10.1111/1365-2435.14415.

Buttler, A., Bragazza, L., Laggoun-Défarge, F., Gogo, S., Toussaint, M., Lamentowicz, M., Chojnicki, B., Słowiński, M., Słowińska, S., Zielińska, M., Reczuga, M., Barabach, J., Marcisz, K., Lamentowicz, Ł., Harenda, K., Lapshina, E., Gilbert, D., Schlaepfer, R., Jassey, V., 2023. Ericoid shrub encroachment shifts aboveground-belowground linkages in three peatlands across Europe and Western Siberia. Glob. Chang Biol. 29 (23), 6772–6793. https://doi.org/10.1111/gcb.16904.

Celka, Z., Szkudlarz, P., 2000. Anthropogenic transformations of the Bagno Chlebowo (Wielkopolska Province). In: Jackowiak, B., Żukowski, W. (Eds.), Mechanisms of Anthropogenic Changes of the Plant Cover. Publications of the Department of Plant Taxonomy.

Celka, Z., Szkudlarz, P., 2006. The condition and resources of the isolated population Vaccinium uliginosum(Ericaceae) on the example of the peat bog "Bagna" near Chlebowo (Wielkopolska). Dendrobiology 56, 13–18.

Celka, Z., Szkudlarz, P., 2010. Spontaneous occurrence and dispersion of Aronia ×prunifolia (Marshall) Rehder (Rosaceae) in Poland on the example of the "Bagna" bog complex near Chlebowo (western Poland). Acta Soc. Bot. Pol. 79, 37–42.
Charman, D.J., 2001. Biostratigraphic and palaeoenvironmental applications of testate amoebae. Quat. Sci. Rev. 20, 1753–1764.
Charman, D.J., Beilman, D.W., Blaauw, M., Booth, R.K., Brewer, S., Chambers, F.M., Christen, J.A., Gallego-Sala, A., Harrison, S.P., Hughes, P.D.M., Jackson, S.T., Korhola, A., Mauquoy, D., Mitchell, F.J.G., Prentice, I.C., van der Linden, M., De Vleeschouwer, F., Yu, Z.C., Alm, J., Zhao, Y., 2013. Climate-related changes in peatland carbon accumulation during the last millennium. Biogeosciences 10 (2), 929–944. https://doi.org/10.5194/bg-10-929-2013.
Chmiel, J., & Kasprowicz, M.2004. Flora i roślinność Środkowej Wielkopolski. Przewodnik do ćwiczeń terenowych. Biblioteka pomocy dydaktycznych Bogucki Wyd. Naukowe, Poznań.
Clarke, K.J., 2003. Guide to Identification of Soil Protozoa - Testate Amoebae. Freshwater Biological Association. 〈https://www.ncbi.nlm.nih.gov/pubmed/948〉.
Coffey, E.E.D., Froyd, C.A., Willis, K.J., 2011. When is an invasive not an invasive? Macrofossil evidence of doubtful native plant species in the Galápagos Islands. ECOLOGY 92 (4), 805–812. 〈http://www.scopus.com/inward/record.url?eid= 2-s2.0-79955671022&partnerID= 40&md5=c3268a67f7924abe31ffe9917d49c903〉.
Coffey, E.E.D., Froyd, C.A., Willis, K.J., 2012. Lake or bog? Reconstructing baseline ecological conditions for the protected Galápagos Sphagnum peatbogs. Quat. Sci. Rev. 52, 60–74. https://doi.org/10.1016/j.quascirev.2012.08.002.
Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S.J., Kubiszewski, I., Farber, S., Turner, R.K., 2014. Changes in the global value of ecosystem services. Glob. Environ. Change 26, 152–158. https://doi.org/10.1016/j.gloenvcha.2014.04.002.
Crushell, P., Connolly, A., Schouten, M., Mitchell, F.J.G., 2008. The changing landscape of Clara Bog: the history of an Irish raised bog. Ir. Geogr. 41 (1), 89–111. https://doi.org/10.1080/00750770801915596.
Cusell, C., Lamers, L.P.M., van Wirdum, G., Kooijman, A., Strecker, A., 2013. Impacts of water level fluctuation on mesotrophic rich fens: acidification vs. eutrophication. J. Appl. Ecol. 50 (4), 998–1009. https://doi.org/10.1111/1365-2664.12096.
Czerwiński, S., Guzowski, P., Lamentowicz, M., Gałka, M., Karpińska-Kołaczek, M., Poniat, R., Łokas, E., Diaconu, A.-C., Schwarzer, J., Miecznik, M., Kołaczek, P., 2021. Environmental implications of past socioeconomic events in Greater Poland during the last 1200 years. Synthesis of paleoecological and historical data. Quat. Sci. Rev. 259, 106902. https://doi.org/10.1016/j.quascirev.2021.106902.
Czyż, P., Kowalik, A., Rutkowski, P., 2016. Application of Landsat satellite images for research on changes of vegetation conditions in the "Bagno Chlebowo" Natura 2000 site. Acta Sci. Pol. Silvarum Colendarum Ratio Et. Ind. Lignaria 15, 145–160. https://doi.org/10.17306/J.AFW.2016.3.17.
Dawson, T.P., Berry, P.M., Kampa, E., 2003. Climate change impacts on freshwater wetland habitats. J. Nat. Conserv. 11 (1), 25–30. https://doi.org/10.1078/1617-1381-00031.
Delle Grazie, F.M., Gill, L.W., 2022. Review of the ecosystem services of temperate wetlands and their valuation tools. Water 14 (9). https://doi.org/10.3390/w14091345.
van der Knaap, W., van Leeuwen, J.F., Froyd, C.A., Willis, K.J., 2012. Detecting the provenance of Galapagos non-native pollen: the role of humans and air currents as transport mechanisms. Holocene 22 (12), 1373–1383. https://doi.org/10.1177/0959683612449763.
van Diggelen, R., Middleton, B., Bakker, J., Grootjans, A., Wassen, M., 2006. Fens and floodplains of the temperate zone: present status, threats, conservation and restoration. Appl. Veg. Sci. 9 (2), 157–162. https://doi.org/10.1111/j.1654-109x.2006.tb00664.x.
Dudgeon, D., Arthington, A.H., Gessner, M.O., Kawabata, Z., Knowler, D.J., Lévêque, C., Naiman, R.J., Prieur-Richard, A.H., Soto, D., Stiassny, M.L., Sullivan, C.A., 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biol. Rev. Camb. Philos. Soc. 81 (2), 163–182. https://doi.org/10.1017/s1464793105006950.
Ellis, E.C., 2021. Land use and ecological change: a 12,000-year history. Annu. Rev. Environ. Resour. 46 (1), 1–33. https://doi.org/10.1146/annurev-environ-012220-010822.
Erwin, K.L., 2009. Wetlands and global climate change: the role of wetland restoration in a changing world. Wetl. Ecol. Manag. 17 (1), 71–84. 〈http://www.scopus.com/scopus/inward/record.url?eid= 2-s2.0-58349083234&partnerID= 40〉.
Finlayson, C.M., Clarke, S.J., Davidson, N.C., Gell, P., 2015. Role of palaeoecology in describing the ecological character of wetlands. Mar. Freshw. Res. https://doi.org/10.1071/MF15293.
Frolking, S., Talbot, J., Jones, M.C., Treat, C.C., Kauffman, J.B., Tuittila, E.-S., Roulet, N., 2011. Peatlands in the Earth's 21st century climate system. Environ. Rev. 19 (NA), 371–396. https://doi.org/10.1139/a11-014.
Froyd, C., Willis, K.J., 2008. Emerging issues in biodiversity & conservation management: the need for a palaeoecological perspective. Quat. Sci. Rev. 27, 1723–1732.
Gałka, M., Miotk-Szpiganowicz, G., Goslar, T., Jęśko, M., van der Knaap, W.O., Lamentowicz, M., 2013. Palaeohydrology, fires and vegetation succession in the southern Baltic during the last 7500 years reconstructed from a raised bog based on multi-proxy data. Palaeogeogr., Palaeoclimatol., Palaeoecol. 370, 209–221. https://doi.org/10.1016/j.palaeo.2012.12.011.
Galon, R. 1961. Morphology of the Noteć-Warta-or Toruń-Eberswalde-ice Marginal Streamway. [With Summaries in Polish and Russian, and Maps.]. Wyd. geol. 〈https://books.google.pl/books?id=ZxvHtgAACAAJ〉.
General Director of State Forests, 2004. Ordinance No. 62 of the Director General of State Forests on the establishment of the Forest Promotional Complex "Puszcza Notecka". General Director of State Forests, Warsaw.
Gorham, E., Janssens, J.A., Wheeler, G.A., & Glaser, P.H. 1987. The Natural and Anthropogenic Acidification of Peatlands Effects of Atmospheric Pollutants on Forests, Wetlands and Agricultural Ecosystems. Berlin, Heidelberg.
Gorham, E., Janssens, J.A., 1992. Concepts of fen and bog re-examined inrelation to bryophyte cover and the acidity of surface waters. Acta Soc. Bot. Pol. 61, 7–20.
Grootjans, A.P., Adema, E.B., Bleuten, W., H., J, Madaras, M., Janáková, M., 2006. Hydrological landscape settings of base-rich fen mires and fen meadows: an overview. Appl. Veg. Sci. 9, 175–184.
Grygoruk, M. 2013. Variability of groundwater flow as a factor of mire ecohydrological evolution - example of Czerwone Bagno.
Grygoruk, M., Batelaan, O., Okruszko, T., Mirosław-Świątek, D., Chormański, J., Rycharski, M., 2011. Groundwater Modelling and Hydrological System Analysis of Wetlands in the Middle Biebrza Basin. In: Świątek, In.D., Okruszko, T. (Eds.), Modelling of Hydrological Processes in the Narew Catchment. Springer Berlin Heidelberg, pp. 89–109. https://doi.org/10.1007/978-3-642-19059-9_6.
Hájek, M., Hájková, P., Apostolova, I., Sopotlieva, D., Goia, I., Dítě, D., 2021. The vegetation of rich fens (Sphagno warnstorfii-Tomentypnion nitentis) at the southeastern margins of their European range. Veg. Classif. Surv. 2, 177–190. https://doi.org/10.3897/vcs/2021/69118.
Hájek, M., Jiroušek, M., Navrátilová, J., Horodyská, E., Peterka, T., Plesková, Z., Navrátil, J., Hájková, P., Hájek, T., 2015. Changes in the moss layer of Czech fens indicate early succession triggered by nutrient enrichment. Preslia 87, 279–301.
Hermoso, V., Abell, R., Linke, S., Boon, P., 2016. The role of protected areas for freshwater biodiversity conservation: challenges and opportunities in a rapidly changing world. Aquat. Conserv.: Mar. Freshw. Ecosyst. 26, 3–11. https://doi.org/10.1002/aqc.2681.
Holden, J., Evans, M.G., Burt, T.P., Horton, M., 2006. Impact of land drainage on peatland hydrology. J. Environ. Qual. 35 (5), 1764–1778. 〈http://www.scopus.com/scopus/inward/record.url?eid= 2-s2.0-33749354371&partner= 40&rel=R5.0.4〉.
Howie, S.A., Whitfield, P.H., Hebda, R.J., Munson, T.G., Dakin, R.A., Jeglum, J.K., 2009. Water table and vegetation response to ditch blocking: restoration of a raised bog in southwestern british columbia. Can. Water Resour. J. 34 (4), 381–392. 〈http://www.scopus.com/inward/record.url?eid= 2-s2.0-76349083327&partnerID= 40&md5= 8e95a32ffe49b419d3239f984b56a987〉.
Hua, Q., Barbetti, M., Rakowski, A.Z., 2013. Atmospheric radiocarbon for the period 1950-2010. Radiocarbon 55 (4), 2059–2072. 〈https://www.ncbi.nlm.nih.gov/pubmed/WOS:000326817600013〉.
Hughes, P.D.M., Barber, K.E., 2003. Mire development across the fen-bogtransition on the Teifi floodplain at Tregaron Bog, Ceredigion, Wales, and acomparison with 13 other raised bogs. J. Ecol. 91, 253–264.
Ilnicki, P. 1989. Dokumentacja techniczna złoża Chlebowo.
IMGW. 2022. Climate data for Poland. (〈https://www.imgw.pl/datasets〉).

IPCC. 2019. IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.

Jactel, H., Nicoll, B.C., Branco, M., Gonzalez-Olabarria, J.R., Grodzki, W., Långström, B., Moreira, F., Netherer, S., Orazio, C., Piou, D., Santos, H., Schelhaas, M.J., Tojic, K., Vodde, F., 2009. The influences of forest stand management on biotic and abiotic risks of damage. Ann. For. Sci. 66 (7), 701. https://doi.org/10.1051/forest/2009054.

Juggins, S., 2003. C2 User guide. Software for ecological and palaeoecological data analysis and visualisation. University of Newcastle.

Karpińska-Kołaczek, M., Kołaczek, P., Czerwiński, S., Gałka, M., Guzowski, P., Lamentowicz, M., 2022. Anthropocene history of rich fen acidification in W Poland - Causes and indicators of change. Sci. Total Environ. 838 (Pt 1), 155785. https://doi.org/10.1016/j.scitotenv.2022.155785.

Kołaczek, P., Karpińska-Kołaczek, M., Czerwiński, S., Marcisz, K., & Lamentowicz, M. (2021). Palinologia. Mikroprzeszłość: Badania specjalistcyzne w archeologii, 13-30. https://doi.org/https://doi.org/10.14746/WA.2021.1.978-83-946591-8-9.

Kondracki, J., 1998. Geografia regionalna Polski. PWN.

Kotowski, W., Jabłońska, E., 2024. Ochr. mokradeł w Polsce 2 (315).

Kusiak, W., Dymek-Kusiak, A., 2002. Puszcza Notecka: Monografia przyrodniczo-gospodarcza. Wydaw, Przegląd Leśniczy.

Lamentowicz, M., Gałka, M., Lamentowicz, Ł., Obremska, M., Kühl, N., Lücke, A., Jassey, V.E.J., 2015. Reconstructing climate change and ombrotrophic bog development during the last 4000years in northern Poland using biotic proxies, stable isotopes and trait-based approach. Palaeogeogr., Palaeoclimatol., Palaeoecol. 418, 261–277. https://doi.org/10.1016/j.palaeo.2014.11.015.

Lamentowicz, M., Gałka, M., Marcisz, K., Słowiński, M., Kajukało-Drygalska, K., Dayras, M., Jassey, V., 2019. Unveiling tipping points in long-term ecological records from Sphagnum-dominated peatlands. Biol. Lett. 15 (4), 20190043. https://doi.org/10.1098/rsbl.2019.0043.

Lamentowicz, M., Konczal, S., 2024. Jak chronić torfowiska w lasach? ArcheaGraph.

Lamentowicz, M., Marcisz, K., Guzowski, P., Galka, M., Diaconu, A.C., Kolaczek, P., 2020. How Joannites' economy eradicated primeval forest and created anthroecosystems in medieval Central Europe. Sci. Rep. 10 (1), 18775. https://doi.org/10.1038/s41598-020-75692-4.

Lamentowicz, M., Mitchell, E., 2005. The ecology of testate amoebae (Protists) in sphagnum in North-western Poland in relation to peatland ecology. Micro Ecol. 50 (1), 48–63. https://doi.org/10.1007/s00248-004-0105-8.

Lamentowicz, M., Obremska, M., 2010. A rapid response of testate amoebae and vegetation to inundation of a kettle hole mire. J. Paleolimnology 43 (3), 499–511 https://doi.org/10.1007/s10933-009-9347-2.

Lamentowicz, M., Słowińska, S., Słowiński, M., Jassey, V.E.J., Chojnicki, B.H., Reczuga, M.K., Zielińska, M., Marcisz, K., Lamentowicz, Ł., Barabach, J., Samson, M., Kołaczek, P., Buttler, A., 2016. Combining short-term manipulative experiments with long-term palaeoecological investigations at high resolution to assess the response of Sphagnum peatlands to drought, fire and warming. MIRES PEAT 18 (20), 1–17. https://doi.org/10.19189/MaP.2016.OMB.244.

Lamentowicz, M., Tobolski, K., Mitchell, E.A.D., 2007. Palaeoecological evidence for anthropogenic acidification of a kettle-hole peatland in northern Poland. Holocene 17 (8), 1185–1196. https://doi.org/10.1177/0959683607085123.

Lamentowicz, L., Wochal, D., Czerwiński, S., Konczal, S., Landowska, J., Landowski, J., 2024. Torfowiskowe zasoby węgla w Borach Tucholskich. In: Lamentowicz, L., Konczal, S. (Eds.), Jak chronić torfowiska w lasach? ArcheaGraph, pp. 85–108.

Lamers, L.P.M., Smolders, A.J.P., Roelofs, J.G.M., 2002. The restoration of fens in the Netherlands. Hydrobiologia 478, 107–130. https://doi.org/10.1023/A:1021022529475.

Lamers, L.P., Vile, M.A., Grootjans, A.P., Acreman, M.C., van Diggelen, R., Evans, M.G., Richardson, C.J., Rochefort, L., Kooijman, A.M., Roelofs, J.G., Smolders, A.J., 2015. Ecological restoration of rich fens in Europe and North America: from trial and error to an evidence-based approach. Biol. Rev. Camb. Philos. Soc. 90 (1), 182–203. https://doi.org/10.1111/brv.12102.

Landry, J., Rochefort, L., 2012. The drainage of peatlands: impacts and rewetting techniques. Peatl. Ecol. Res. Group. ⟨http://www.gret-perg.ulaval.ca/uploads/tx_centrerecherche/Drainage_guide_Web_03.pdf⟩.

Lavoie, M., Richard, P.J.H., 2000. The paleoecology of a peatland in the Laurentian Highlands (Quebec): identifying the role of climate on peat accumulation. Geogr. Phys. Et. Quat. 54 (2), 169–185. ⟨https://www.ncbi.nlm.nih.gov/pubmed/893⟩ (Paper) ISI:000168028300004.

Limpens, J., Berendse, F., Blodau, C., Canadell, J.G., Freeman, C., Holden, J., Roulet, N., Rydin, H., Schaepman-Strub, G., 2008. Peatlands and the carbon cycle: from local processes to global implications - a synthesis. Biogeosciences Discuss. 5 (2), 1379–1419. ⟨http://www.scopus.com/inward/record.url?eid= 2-s2.0-41849128473&partnerID= 40&md5= 558e2fde41e45e5dc46d4075a72b9191⟩.

Lisiak, A., & Włodarczak, J. 1972. Dokumentacja torfowiska Chlebowo: badania wstępne.

Łuców, D., Lamentowicz, M., Kołaczek, P., Łokas, E., Marcisz, K., Obremska, M., Theuerkauf, M., Tyszkowski, S., Słowiński, M., 2021. Pine forest management and disturbance in Northern Poland: combining high-resolution 100-year-old paleoecological and remote sensing data. Front. Ecol. Evol. 9. https://doi.org/10.3389/fevo.2021.747976.

Manzano, S., Julier, A.C.M., Dirk, C.J., Razafimanantsoa, A.H.I., Samuels, I., Petersen, H., Gell, P., Hoffman, M.T., Gillson, L., 2020. Using the past to manage the future: the role of palaeoecological and long-term data in ecological restoration. Restor. Ecol. https://doi.org/10.1111/rec.13285.

Marcisz, K., Bąk, M., Kołaczek, P., Lamentowicz, L., Wochal, D., 2024. Historia lasu i mokradeł zapisana w torfowiskach. In: Lamentowicz, L., Konczal, S. (Eds.), Jak chronić torfowiska w lasach? ArcheaGraph, pp. 29–45.

Marcisz, K., Czerwiński, S., Lamentowicz, M., Łuców, D., Słowiński, M., 2022. How paleoecology can support peatland restoration. Glob. Chang. Mag. 30 (1), 12–13. https://doi.org/10.22498/pages.30.1.12.

Marcisz, K., Kołaczek, P., Gałka, M., Diaconu, A.-C., Lamentowicz, M., 2020. Exceptional hydrological stability of a Sphagnum-dominated peatland over the late Holocene. Quat. Sci. Rev. 231, 106180. https://doi.org/10.1016/j.quascirev.2020.106180.

Marcisz, K., Lamentowicz, M., Gałka, M., Colombaroli, D., Adolf, C., Tinner, W., 2019. Responses of vegetation and testate amoeba trait composition to fire disturbances in and around a bog in central European lowlands (northern Poland). Quat. Sci. Rev. 208, 129–139. https://doi.org/10.1016/j.quascirev.2019.02.003.

Mauquoy, D., Hughes, P.D.M., Geel, B. v, 2010. A protocol for plant macrofossil analysis of peat deposits. MIRES PEAT 7, 1–5.

Mazei, Y., Tsyganov, A.N., 2006. Freshwater testate amoebae. KMK.

Milecka, K., Kowalewski, G., Fiałkiewicz-Kozieł, B., Gałka, M., Lamentowicz, M., Chojnicki, B.H., Goslar, T., Barabach, J., 2017. Hydrological changes in the Rzecin peatland (Puszcza Notecka, Poland) induced by anthropogenic factors: implications for mire development and carbon sequestration. Holocene 27 (5), 651–664. https://doi.org/10.1177/0959683616670468.

Minayeva, T.Y., Bragg, O.M., Sirin, A.A., 2017. Towards ecosystem-based restoration of peatland biodiversity. MIRES PEAT 19. https://doi.org/10.19189/MaP.2013.OMB.150.

Minister of Climate and Environment, 2022. Regulation on the special area of habitat conservation Bagno Chlebowo (PLH300016). J. Laws Repub. Pol. 2022, Item 626.

Minister of Forestry and Wood Industry. (1959). Regulation on the designation of a nature reserve. Monitor Polski, 1959(No. 62, item 320).

Mitchell, E.A. D., & Payne, R. (2018). Testate Amoeba Analysis. 1-4. https://doi.org/10.1002/9781119188230.saseas0576.

Mitsch, W.J., Bernal, B., Hernandez, M.E., 2015. Ecosystem services of wetlands. Int. J. Biodivers. Sci., Ecosyst. Serv. Manag. 11 (1), 1–4. https://doi.org/10.1080/21513732.2015.1006250.

Mroczkowska, A., Kittel, P., Marcisz, K., Dolbunova, E., Gauthier, E., Lamentowicz, M., Mazurkevich, A., Obremska, M., Płóciennik, M., Kramkowski, M., Łuców, D., Kublitskiy, Y., Słowiński, M., 2021. Small peatland with a big story: 600-year paleoecological and historical data from a kettle-hole peatland in Western Russia. Holocene 31 (11-12), 1761–1776. https://doi.org/10.1177/09596836211033224.

Naturalists' Club, 2007. Wysokie torfowiska bałtyckie w Polsce. Program ochrony.

Nogué, S., Santos, A.M.C., Birks, H.J.B., Björck, S., Castilla-Beltrán, A., Connor, S., de Boer, E.J., de Nascimento, L., Felde, V.A., Fernández-Palacios, J.M., Froyd, C.A., Haberle, S.G., Hooghiemstra, H., Ljung, K., Norder, S.J., Peñuelas, J., Prebble, M., Stevenson, J., Whittaker, R.J., Steinbauer, M.J., 2021. The human dimension of biodiversity changes on islands. Science 372 (6541), 488–491. https://doi.org/10.1126/science.abd6706.

Nordbeck, R., Hogl, K., 2023. National peatland strategies in Europe: current status, key themes, and challenges. Reg. Environ. Change 24 (1). https://doi.org/10.1007/s10113-023-02166-4.

Nurgul, K., Ertan, Y., Üstün, Ş., Metin, T., Melek, E., Selda, O., Raziye, K., Hüsnü, Ü., Halime, Ü., 2018. Peat Use in Horticulture. In: Bülent, T., Metin, T. (Eds.), Peat. IntechOpen. https://doi.org/10.5772/intechopen.79171.

Oświecimska-Piasko, Z., Piórkowski, H., Dembek, W., Ostrzyżek, S., Jakubowski, W., Rycharski, M., Szewczyk, M., Siedlecki, T., & Grotek, A. 2006. System Informacji Przestrzennej o Mokradłach Polski. Online: ⟨http://www.gis-mokradla.info⟩.

Paavilainen, E., Päivänen, J., 1995. Peatland forestry: ecology and principles, 111. Springer Science & Business Media. ⟨https://books.google.com/books?hl=pl&lr= &id=RMLgyXtNOa0C&oi=fnd&pg=PA1&dq=Peatland+Forestry+Ecology+and+Principles&ots=uonmMY6hLp&sig= 2FTK37fmhFMlyCpRH9XiLmNfwmk⟩.

Parish, F., Sirin, A., Charman, D., Joosten, H., Minayeva, T., Silvius, M., & Stringer, L. (Eds.). (2008). Assessment on Peatlands, Biodiversity and Climate change. Global Environment Centre, Kuala Lumpur and Wetlands International, Wageningen.

Paulissen, M.P.C.P., Schaminée, J.H.J., During, H.J., Wieger Wamelink, G.W., Verhoeven, J.T.A., Ejrnæs, R., 2013. Expansion of acidophytic late-successional bryophytes in Dutch fens between 1940 and 2000. J. Veg. Sci. 25 (2), 525–533. https://doi.org/10.1111/jvs.12089.

Payne, R.J., Mitchell, E.A.D., 2008. How many is enough? Determining optimal count totals for ecological and palaeoecological studies of testate amoebae. J. Paleolimnology 42 (4), 483–495. https://doi.org/10.1007/s10933-008-9299-y.

Polajnar, K., 2008. Public awareness of wetlands and their conservation. Acta Geogr. Slov. 48 (1). https://doi.org/10.3986/ags48105.

Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Ramsey, C.B., Buck, C.E., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Haflidason, H., Hajdas, I., Hatte, C., Heaton, T.J., Hoffmann, D.L., Hogg, A.G., Hughen, K.A., van der Plicht, J., 2013. Intcal13 and marine13 radiocarbon age calibration curves 0-50,000 years Cal BP. Radiocarbon 55 (4), 1869–1887. ⟨https://www.ncbi.nlm.nih.gov/pubmed/WOS:000326817600002⟩.

Rydin, H., & Jeglum, J.K. (2013). The biology of peatlands (Vol. Second Edition). Oxford University Press.

Sanderson, N., Loisel, J., Gallego-Sala, A., Anshari, G., Novita, N., Marcisz, K., Lamentowicz, M., Bąk, M., Wochal, D., 2023. Setting a new research agenda for tropical peatlands, recent carbon accumulation and ecosystem services. Glob. Chang. Mag. 31 (2), 121. https://doi.org/10.22498/pages.31.2.121.

Siemensma, F. 2024. Microworld, world of amoeboid organisms. World-wide electronic publication (⟨www.arcella.nl⟩). Kortenhoef, the Netherlands. ⟨https://arcella.nl⟩.

Słowiński, M., Lamentowicz, M., Łuców, D., Barabach, J., Brykała, D., Tyszkowski, S., Pieńczewska, A., Śnieszko, Z., Dietze, E., Jażdżewski, K., Obremska, M., Ott, F., Brauer, A., Marcisz, K., 2019. Paleoecological and historical data as an important tool in ecosystem management. J. Environ. Manag. 236, 755–768. https://doi.org/10.1016/j.jenvman.2019.02.002.

Stoddard, J.L., Larsen, D.P., Hawkins, C.P., Johnson, R.K., Norris, R.H., 2006. Setting expectations for the ecological condition of streams: the concept of reference condition. Ecol. Appl. 16 (4), 1267–1276. https://doi.org/10.1890/1051-0761(2006)016[1267:seftec]2.0.co;2.

Swindles, G.T., Morris, P.J., Mullan, D.J., Payne, R.J., Roland, T.P., Amesbury, M.J., Lamentowicz, M., Turner, T.E., Gallego-Sala, A., Sim, T., Barr, I.D., Blaauw, M., Blundell, A., Chambers, F.M., Charman, D.J., Feurdean, A., Galloway, J.M., Gałka, M., Green, S.M., Warner, B., 2019. Widespread drying of European peatlands in recent centuries. Nat. Geosci. 12 (11), 922–928. https://doi.org/10.1038/s41561-019-0462-z.

Szkudlarz, P., Celka, Z., 2004. Refuges of peat-bog plants in complex near Chlebowo (Wielkopolska Province). Ecol. Quest. 4, 115–122.

Tahvanainen, T., 2011. Abrupt ombrotrophication of a boreal aapa mire triggered by hydrological disturbance in the catchment. J. Ecol. 404–415, 404–415. https://doi.org/10.1111/j.1365-2745.2010.01778.x.

Temmink, R., Robroek, B., van Dijk, G., Koks, A., Käärmelahti, S., Barthelmes, A., Wassen, M., Ziegler, R., Steele, M., Giesen, W., Joosten, H., Fritz, C., Lamers, L., Smolders, A., 2023. Wetscapes: restoring and maintaining peatland landscapes for sustainable futures. Ambio. https://doi.org/10.1007/s13280-023-01875-8.

Turetsky, M.R., Benscoter, B., Page, S., Rein, G., van der Werf, G.R., Watts, A., 2015. Global vulnerability of peatlands to fire and carbon loss. Nat. Geosci. 8 (1), 11–14. https://doi.org/10.1038/ngeo2325. ⟨http://www.nature.com/ngeo/journal/v8/n1/abs/ngeo2325.html#supplementary-information⟩.

Turetsky, M.R., Donahue, W.F., Benscoter, B.W., 2011. Experimental drying intensifies burning and carbon losses in a northern peatland. Nat. Commun. 2, 514. https://doi.org/10.1038/ncomms1523.

Turunen, J., Tomppo, E., Tolonen, K., Reinikainen, A., 2002. Estimating carbon accumulation rates of undrained mires in Finland - application to boreal and subarctic regions. Holocene 12 (1), 69–80. ⟨http://www.scopus.com/inward/record.url?eid= 2-s2.0-0036138253&partnerID= 40&md5=c1f189cd9bd476190519811575ef3bfd⟩.

Väliranta, M., Salojärvi, N., Vuorsalo, A., Juutinen, S., Korhola, A., Luoto, M., Tuittila, E.-S., 2016. Holocene fen–bog transitions, current status in Finland and future perspectives. Holocene 27 (5), 752–764. https://doi.org/10.1177/0959683616670471.

Wardenaar, E.C.P., 1987. A new hand tool for cutting peat profiles. Can. J. Bot. 65, 1772–1773.

Wassen, M.J., Van Diggelen, R., Wolejko, L., Verhoeven, J.T.A., 1996. A comparison of fens in natural and artificial landscapes. Vegetatio 126 (1), 5–26. ⟨http://www.scopus.com/inward/record.url?eid= 2-s2.0-0030304825&partnerID= 40⟩.

Wełnicka, A., Czyż, P., Rutkowski, P., 2015. Bagno Chlebowo na tle źródeł historycznych. Stud. Mater. OśR. Kult. Le. śN. 14.

Wilson, D., Mackin, F., Tuovinen, J., Moser, G., Farrell, C., Renou-Wilson, F., 2022. Carbon and climate implications of rewetting a raised bog in Ireland. Glob. Chang Biol. https://doi.org/10.1111/gcb.16359.

Wojterska, M., Stachnowicz, W., & Melosik, I. 2001. Flora i roślinność torfowiska nad jeziorem Rzecińskim koło Wronek. In A. Brzeg & M. Wojterska (Eds.), Brzeg, A. and Wojterska, M. 2001: Zespoły roślinne Wielkopolski, ich stan poznania i zagrożenie. In Wojterska, M., editor, Szata roślinna Wielkopolski i Pojezierza Południowopomorskiego. Przewodnik do sesji terenowych 52 zjazdu Polskiego Towarzystwa Botanicznego, (pp. 2011-2019). Bogucki Wydawnictwo Naukowe.

Wolf, E.C., Cooper, D.J., 2015. Fens of the Sierra Nevada, California, USA: patterns of distribution and vegetation. Mire Peat 15 (08).

Young, T.P., 2000. Restoration ecology and conservation biology. Biol. Conserv. 92, 73–83. https://doi.org/10.1016/S0006-3207(99)00057-9.

Yu, Z.C., 2012. Northern peatland carbon stocks and dynamics: a review. Biogeosciences 9 (10), 4071–4085. https://doi.org/10.5194/bg-9-4071-2012.

Zhang, H., Tuittila, E.S., Korrensalo, A., Laine, A.M., Uljas, S., Welti, N., Kerttula, J., Maljanen, M., Elliott, D., Vesala, T., Lohila, A., 2021. Methane production and oxidation potentials along a fen-bog gradient from southern boreal to subarctic peatlands in Finland. Glob. Chang Biol. 27 (18), 4449–4464. https://doi.org/10.1111/gcb.15740.

Zhang, H., Väliranta, M., Swindles, G., Aquino-López, M., Mullan, D., Tan, N., Amesbury, M., Babeshko, K., Bao, K., Bobrov, A., Chernyshov, V., Davies, M., Diaconu, A., Feurdean, A., Finkelstein, S., Garneau, M., Guo, Z., Jones, M., Kay, M., Zhao, Y., 2022. Recent climate change has driven divergent hydrological shifts in high-latitude peatlands. Nat. Commun. 13 (1), 4959. https://doi.org/10.1038/s41467-022-32711-4.