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Joanna Święta-Musznicka[1], Kamil Niedziółka[2]

COMPARISON OF PALAEOECOLOGICAL AND ARCHAEOLOGICAL EVIDENCE OF HUMAN ACTIVITY FROM THE LATE BRONZE AGE TO THE EARLY IRON AGE IN CENTRAL POMERANIA (NORTHERN POLAND)

ABSTRACT

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This article presents a synthesis of palaeoenvironmental and archaeological data from the Bronze/Iron Age transition (1200-500 BC) in Central Pomerania. Based on pollen, non-pollen palynomorphs (NPPs), charcoal, and geochemical analysis of the sediments from Wierzchowo Lake, five stages of local environmental transformation have been distinguished. Anthropogenic influence on vegetation was relatively limited from the Middle Bronze Age to the Period V of the Bronze Age, according to Montelius (hereinafter referred to as PBA V). A substantial increase in settlement populations and significant environmental changes (deforestation, spread of ruderal habitats, and increased lake eutrophication) correspond to the transition between the PBA V and Hallstatt C phases. During the Hallstatt C/Władysławowo II A2 phase, a brief period of diminished settlement activity preceded the subsequent increase in human impact observed during the spread of societies linked to the Pomeranian culture. The final phase spans approximately 200 years of weakened settlements preceding the expansion of groups associated with the younger pre-Roman Period.

Keywords: Lusatian culture, Pomeranian culture, settlement development, pollen and NPPs data, environmental changes

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1 Faculty of Biology, University of Gdańsk, Wita Stwosza 59, 80-308 Gdańsk, Poland; j.musznicka@ug.edu.pl; ORCID: 0000-0002-0720-1628

2 Faculty of History, University of Gdańsk, Bielańska 5, 80-851 Gdańsk, Poland; kamil.niedziolka@ug.edu.pl; ORCID: 0000-0001-7368-1167

INTRODUCTION

Palaeoecological data from numerous Pomeranian sites (*i.e.*, the Pomerania region of Poland) indicate an abrupt vegetation change associated with the final decline of diverse deciduous woodlands dominated by broad-leaved trees during the Bronze/Iron Age transition (approximately 1200-500 BC; see Latałowa 2003; Ralska-Jasiewiczowa 2004). The causes of changes in vegetation composition and landscape transformation are attributed to both climate shifts and human activity. The process of transition from a relatively dry, warm, and continental climate to cooler and wetter conditions has been recorded over a similar period in both hemispheres (van Geel *et al.* 2000; Chen *et al.* 2025) and has been linked to a decline in solar activity (Bond *et al.* 2001; Beer and van Geel 2008, 152-154). This climate shift led to a new phase in forest history in Pomerania, characterised by the expansion of *Carpinus betulus* and *Fagus sylvatica* within forest communities. At the same time, the dynamics of the vegetation changes were also shaped by human influence. This was related to the activities of societies, which, in the classical view, were associated with the Lusatian and Pomeranian cultures (both strongly linked to the Urnfield tradition), as well as the Jastorf culture (Bukowski 1998; Dzięgielewski 2016; 2017; 2018; 2023; Ślu-sarska 2022; 2023).

Palynological data indicate that, depending on the site's location, natural conditions, particularly the soil cover and land use in its immediate vicinity, the settlement phases exhibit different dynamics and characteristics (*e.g.*, the predominance of crop cultivation or animal husbandry indicators). The exceptions here are sites (*e.g.*, Święta-Musznicka 2005) where, due to the low sedimentation rate, it was not possible to separate the levels corresponding to the Lusatian and Pomeranian cultures, and they are therefore considered together as one cultural horizon (Lusatian/Pomeranian phase). In the eastern Baltic coastal zone (Latałowa 1982a), in the Gdańsk Upland (Pędziszewska and Latałowa 2016), at some sites in the Kashubian Lakeland (Pędziszewska *et al.* 2015), in the eastern part of the Tuchola Forest (Miotk 1986; Filbrandt-Czaja 2009), and in Central Pomerania (Madeja 2012), a short but distinct settlement hiatus between the Lusatian and Pomeranian culture phases is marked. However, for other sites in the Kashubian Lakeland, palynological data suggest continuity of settlement between the two cultures (Pędziszewska 2008). This variation is also visible, to some extent, from the perspective of archaeological data, in relation to both the western (Ślusarska 2022; 2023) and eastern parts of Pomerania (Dzięgielewski 2017). Due to the current state of research, the situation in the central part of Pomerania, which is the focus of this study, remains unclear in this respect.

In recent years, new data have been published on the history of the development of plant communities in Central Pomerania (Fig. 1). In this article, we have utilised published palynological data from Wierzchowo Lake (Niedziółka and Święta-Musznicka 2023), which indicate that the first significant development of settlement in Central Pomerania did not occur

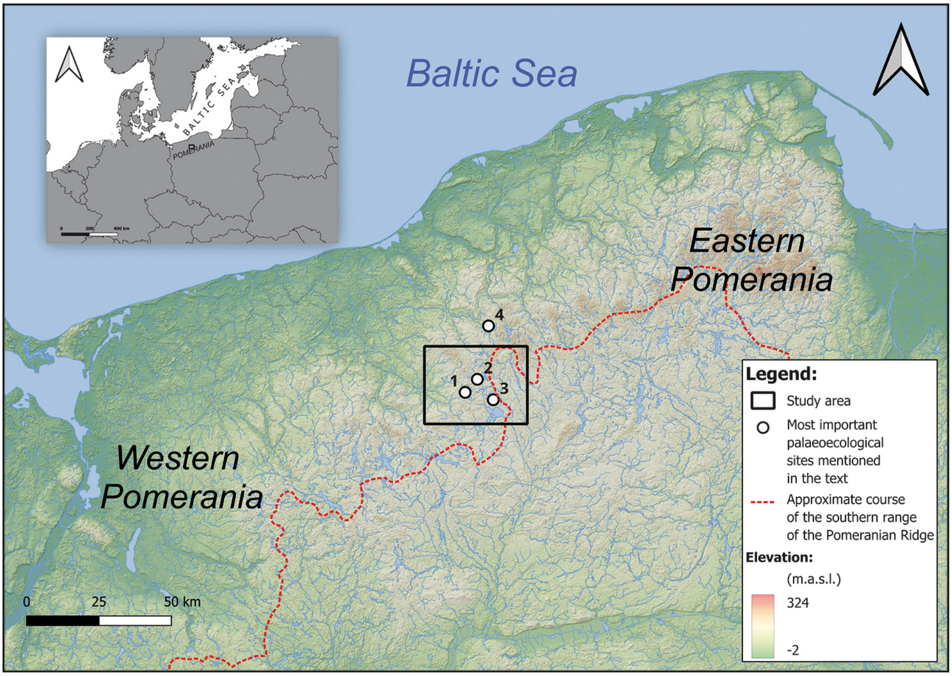

Fig. 1. Location of the study area and the four most important palaeoecological sites mentioned in the text: 1 – Kusowskie Bagno (after Lamentowicz *et al.* 2015); 2 – Wierzchowo Lake (after Niedziółka and Święta-Musznicka 2023); 3 – Spore Lake (after Pleskot *et al.* 2022a, 2022b); 4 – Kwiecko Lake (after Madeja 2012)

until the end of the Late Bronze Age. However, our aim was not only to demonstrate significant changes in the vegetation during this period (*e.g.*, deforestation, spread of ruderal habitats), but also to track the response of the local aquatic ecosystem to the dynamics of human settlement. To evaluate changes in the trophic status and water level of the lake, we utilised new, unpublished data on the representation of wetland and aquatic plants, as well as selected NPP (non-pollen palynomorph) taxa. The bioindicator properties of plants and green and blue-green algae were used to illustrate the response of the local ecosystem to climate change and to support conclusions regarding the scale of grazing. The reconstruction of the settlement in the studied area at the transition from the Bronze to the Iron Age is based on all available archaeological data within the study area. From a geographical point of view, it concerns not only the vicinity of Wierzchowo Lake, but also the areas around the nearest palaeoecological sites: Kusowskie Bagno (Lamentowicz *et al.* 2015) and Spore Lake (Pleskot *et al.* 2020; Pleskot *et al.* 2022a; 2022b). In this article, we also refer to the available archaeobotanical data to fully evaluate the role of plant cultivation in the economy of the societies inhabiting Pomerania at the turn of the Bronze and Iron Ages (*e.g.*, Klichowska 1967; 1979; Urban 2019).

Bearing in mind the above facts, as well as recently published archaeological data, we aim to synthesise the palaeoenvironmental and archaeological data from the turn of the Bronze and Iron Ages in Central Pomerania, and to answer the following questions:

1. What was the composition of vegetation before settlement development that appeared during the late phases of the Bronze Age (appearance of societies of the so-called Lusatian culture)?

2. Can we observe significant changes in the local environment during the late phases of the Bronze Age as a result of human settlement?

3. Can we observe significant changes in the local environment during the Early Iron Age as a result of human settlement?

4. Was there continuity of settlement between the Lusatian and Pomeranian cultures, or was there a hiatus in human occupation?

5. Are the changes in settlement intensity revealed by the pollen records consistent with the archaeological evidence related to this chronological frame?

The answers to these questions will significantly broaden our understanding of the relationship between humans and the environment in this area, which has been neglected in terms of research, from both palaeoenvironmental and archaeological perspectives.

STUDY AREA AND HISTORY OF RESEARCH

Geographical delimitation and environmental description of the study area

The research area covers locations where materials for palaeoenvironmental analysis have been obtained in recent years. These are Wierzchowo Lake, Spore Lake, and Kusowskie Bagno (Fig. 1, no. 1-3). Furthermore, data obtained from Kwiecko Lake, located slightly north of the study area (Fig. 1, no. 4), will also be taken into account. From the point of view of physical and geographical divisions, this area covers the eastern part of the Drawsko Lakeland and a small fragment of the northern part of the Gwda River Valley (Solon *et al.* 2018; Niecikowski *et al.* 2021; Wiśniewski *et al.* 2021). The geomorphology, geological structure, and hydrographic network of the study area were formed by the last glaciation (Weichselian), resulting in a fairly diverse landscape with a relative elevation difference of 114 metres (64-233 m a.s.l.). The eastern part of this area is dominated by glacial sand and gravel, while the western part is mainly covered with glacial clay. There are also areas of sand, gravel and clay deposits associated with terminal moraines, kames consisting of silt and clay covering higher areas, as well as peat bogs located in depressions (Marszałek and Szymański 2005; Popielski 2006; Winnicki 2011; Zlonkiewicz 2012). Given this geological structure, the soil cover consists of poor soils, dominated by podzols and pseudo-podzols, with small pockets of more fertile brown soils (Kabała *et al.* 2019; WOD-GiG-Szczecin 2023). This type of soil composition, however, is characteristic of almost the entire Pomerania region.

There are numerous lakes in the study area, although most of them are small in size (Jańczak *et al.* 1996). The exceptions here are Wierzchowo Lake, with an area of 732 ha and a maximum depth of 26.5 metres, and Wielimie Lake, the largest water reservoir in this region (1,754.6 ha). The network of watercourses is relatively well-developed, with the Gwda River, which flows out of Wierzchowo Lake and flows directly south to the Warta River, likely serving as a convenient communication route in the past. It is worth noting that the research area is situated on the watershed running along the Pomeranian Ridge, which, during the Bronze Age, may have also served as a favourable communication route between the eastern and western parts of Pomerania (Horst 1990; Fogel 1993; Niedziółka 2017).

Based on the potential natural vegetation map and geobotanical regionalisation (Matuszkiewicz 1993; 2008; Matuszkiewicz *et al.* 2023), the study area would have predominantly been covered by pine forests (*Leucobryo-Pinetum*) and mesotrophic oak-pine forests (*Querco-Pinetum*), with smaller areas of subatlantic beech-oak-hornbeam (*Stellario-Carpinetum*), acidophilous beech-oak (*Fago-Quercetum*), and beech (*Luzulo pilosae-Fagetum*) woodlands. Wet environments would support azonal vegetation such as alder carrs (*Carici elongatae-Alnetum*) and bog pine forests (*Vaccinio uliginosi-Pinetum*). Due to the region's limited commercial development, forests continue to dominate the local landscape, particularly in the eastern part of the study area, where pine and mixed stands, including oak, beech, and birch, prevail. Acidophilous beech forests with oak are limited to only small, specific areas. Fertile woodland patches with oak and beech exist farther from the Wierzchowo site, and alder carrs survive near water bodies. The contemporary settlement network is sparse, with most of the area comprising wastelands, limited arable fields, meadows, and peatland ecosystems. The latter ones are most affected by human intervention. Certain bogs, like Kusowskie Bagno in the southwestern part of the study area, were drained for peat extraction in the 20th century CE but are now regenerating and supporting typical bog forest vegetation. Although drainage ditches were constructed, the northern part of this bog remains waterlogged and appears to have preserved some of its natural features (Lamentowicz *et al.* 2015, 262).

The above information suggests that during prehistoric and early historical periods, this area may have been relatively attractive for settlement from the perspective of societies that relied on extensive agriculture or animal husbandry. Some areas may also have been particularly attractive from a defensive point of view, such as the hillfort located in Grąbczyn (archaeological site no. 1; see: Olczak 1971; Olczak and Siuchniński 1970, 38-46; Niedziółka 2017).

Table 1. Catalogue of recognized archaeological sites located within the study area (AZP – the Polish Archaeological Record; nn – no number)

No.	Locality & site no.; AZP no.	Description	Chronology	Location accuracy	Source
1	Bobolice 57, 58, 59, 60; AZP 20-25/30-33	Loose finds from several PC cemeteries	HaD	unknown, marked with accuracy to the locality	La Baume 1963, 43, 51; Malinowski 1969, 178; AZP cards no. 20-25/30, 20-25/31, 20-25/32, 20-25/33
2	Chociwle 6; AZP 20-25/70	PC cemetery, numerous urns, four cist graves	Lt A-B	accurate, according to AZP	AZP card 20-25/70
3	Dalęcino, nn; AZP 23-25/nn	LC burial mound cemetery, approx. 20 burial mounds with pottery burnt bones, charcoal, and bronze items (knob, sickle, ring, pin)	PBA IV-V (?)	unknown, marked with accuracy to the locality	Kostrzewski 1958, 260; AZP card 23-25/nn
4	Dalęcino nn; AZP 24-25/nn	PC cemetery, cist graves with 1 and 2 urns; urn covered with a lid	HaC	unknown, marked with accuracy to the locality	Kostrzewski 1958, 361; Malinowski 1981a, 46 (assigned to Skotniki locality); AZP card 24-25/nn
5	Dalęcino, nn; AZP 24-25/nn	PC cemetery, cist graves with one or several urns, including a face urn	HaD (?)	unknown, marked with accuracy to the locality	Malinowski 1981b, 161 (assigned to Opoczyska locality); AZP card 24-25/nn
6	Gałowo, nn, AZP 24-26/nn	PC cemetery, cist graves	EIA (HaC-HaD?)	unknown, marked with accuracy to the locality	Malinowski 1979, 137; AZP card 24-26/nn
7	Grąbczyn (Grąbczyński Młyn) nn, AZP 21-25/64	Deposit of bronze items (9 items), found in a bog, in a 'stone hiding place' in the first half of the 19th century	PBA V	unknown, marked with accuracy to the locality	AZP card 24-25/64
8	Grąbczyn. 1 (+ 3, 4); AZP 21-25/1, 3, 4	A settlement with a large amount of archaeological material (mainly pottery) from the transition between the LBA and EIA, alleged hill-fort from the LBA	PBA V- HaC	accurate, according to AZP	Olczak 1971; Niedziółka 2017; Niedziółka, Święta-Musznicka 2023; AZP card 24-25/1, 3, 4
9	Grąbczyn, nn; AZP 21-25/nn	LC burial mound cemetery, five burial mounds	PBA IV-V (?)	accurate, verified in the field	Publication in preparation
10	Grzmiąca 5; AZP 22-23/16	PC cemetery, seven cist graves, some containing pottery vessels and bronze ornaments	HaC/D	accurate, according to AZP	Malinowski 1979, 182; AZP card 22-23/16

11	Kaliska 37; AZP 20-27/46	Two very large deposits of bronze items placed in the same location	PBA V HaC	accurate, according to the publication map	Kaczmarek et al.. 2021; Szczurek, Kaczmarek 2022
12	Kowalki 31; AZP 20-23/22	Alleged cemetery of the PC, probably a destroyed cremation grave	EIA	accurate, according to AZP	AZP card 20-23/22
13	Mieszałki 2; AZP 21-23/3	PC cemetery, one cup - burial accompanying vessel? loose find	HaD	accurate, according to AZP	Hamling 1963, 602-603
14	Mieszałki 1; AZP 21-23/22	Deposit of metal items, four necklaces made of gold	PBA V	unknown, marked with accuracy to the locality	AZP card 21-23/22
15	Parsęcki Młyn nn	Multi-phase urnfield cemetery, LC urn graves containing i.a. bronze pin from the 3rd period of the BA, a pin with a swan neck from the late BA; 34 cist graves associated with PC, richly decorated cinerary urns	PBA III - V BA, HaC - HaD - Lt A-B	approximate, marked with accuracy to the remains of an old mill in the village of Parsęcko	Skrzypek 2010, 30-39
16	Parsęcko 28; AZP 24-24/106, cemetery I	PC cemetery, cist graves, graves reinforced with stones, urns covered with bowls, lids and stones, charcoal found in graves. Traces of funeral feasts were spotted, *e.g.*, charred barley grains.	HaD	unknown, marked with accuracy to the locality	Malinowski 1981b, 179; AZP card 24-24/106
17	Parsęcko 29; AZP 24-24/107, cemetery II	PC cemetery, cist graves containing urns, including face urns. The spatial relationship to the cemetery I is unknown.	HaD (?)	unknown, marked with accuracy to the locality	Malinowski 1981b, 179-180; AZP card 24-24/107
18	Porost, stan. 10	PC cemetery, seven cist graves with stone reinforcement, inside which were cinerary urns, some of which had lids	late HaD - Lt A-B	accurate, based on a map from a published source	Skrzypek 1983, 3-22
19	Porost, 11; AZP 20-25/101	PC cemetery, two urn graves, two vessels, one knife	EIA	unknown, marked with accuracy to the locality	AZP card 20-25/101
20	Porost, 13; AZP 20-25/103	PC cemetery, four pottery vessels	Lt A-B	unknown, marked with accuracy to the locality	AZP card 20-25/103
21	Porost, 14; AZP 20-25/104	PC cemetery, three urns, two lids	Lt A-B	unknown, marked with accuracy to the locality	AZP card 20-25/104
22	Sępólno Wielkie 1, AZP 20-26/25	LC burial mound cemetery, approx. 20 burial mounds, containing fragments of pottery, a bronze fibula, a pin with a cylindrical head and one bronze ring	PBA III/IV (III BA according to T. Malinowski)	unknown, marked with accuracy to the locality	Kostrzewski 1958, 313

Table 1.

No.	Locality & site no.; AZP no.	Description	Chronology	Location accuracy	Source
23	Smilicz 1; AZP 24-23/49	PC cemetery, 23 cist graves, amateurishly excavated	HaC	accurate, according to AZP	AZP card 24-23/49
24	Stare Wierzchowo nn AZP 22-25/nn	PC cemetery, cist graves, Malinowski 1981, katalog cment. KP, t. 3, s. 68	EIA	unknown, marked with accuracy to the locality	Malinowski 1981a, 68; AZP card 22-25/nn
25	Stepień 8; AZP 22-26/6	LC urnfield cemetery, urn graves, partially reinforced with stones, some graves contained the remains of a pyre. A bronze sickle was found in one of the graves.	PBA IV - V (?)	unknown, marked with accuracy to the locality	Kostrzewski 1958, 320; AZP card 22-26/6
26	Sucha 2; AZP 22-23/4	PC cemetery, 1 cist grave containing, among other things, an iron arrowhead	EIA	unknown, marked with accuracy to the locality	Wołagiewicz, Wołągiewicz 1963, 13; AZP card 22-23/4
27	Sucha 3; AZP 22-23/5	LC urnfield burial mound cemetery – 1 burial mound with a chamber grave, bronze objects: knife, bronze fibula with a bow and spiral discs, tweezer, ring	PBA IV - V (?)	accurate, according to AZP	Kostrzewski 1958, 324; AZP card 22-23/5
28	Wierzchowo nn; AZP 22-25/nn	PC cemetery, cist graves	EIA	unknown, marked with accuracy to the locality	Malinowski 1981a, 149; AZP card 22-25/nn
29	Wierzchowo nn; AZP 21-25/62	Large deposit of bronze items (22 items)	V PBA V	unknown, marked with accuracy to the locality	Wilkens 1997 AZP card 21-25/62

Current state of research: palaeoenvironmental studies

In Central Pomerania, in the vicinity of Wierzchowo Lake (within a 20 km radius), palaeoecological studies have so far been carried out at three other sites. Wierzchowo Lake is the largest of them (723 ha). Each of the other reservoirs exceeds 80 ha in area, so the pollen source area of all sites is significant (Jacobson and Bradshaw 1981; Sugita 2007). We assume that for this reason, the available pollen data have a lower proportion of local components, and fluctuations in tree pollen composition largely reflect regional-scale changes in forest communities. Despite the overrepresentation of trees, it is reasonable to assume that a decline in their proportion, accompanied by an increase in the total sum of herbaceous pollen and anthropogenic taxa, indicates the development of local settlement (Behre 2007; Kreuz 2008). Given the low pollen productivity of most cereals (Broström *et al.* 2008; Abraham and Kozáková 2012) and many herbaceous plant taxa, such as those typical of pastures (Hjelle 1999), even their relatively low values may reflect local environmental changes caused by human activity in the catchment areas of larger lakes.

A profile from Kwiecko Lake (Madeja 2012), located to the north of the defined study area (Fig. 1, no. 4), provides valuable information on local vegetation changes from the beginning of the Preboreal to the late Middle Ages. In addition, the high-resolution pollen data from the site have been correlated with archaeological data, illustrating six settlement phases, including the human impact on the environment during the Lusatian and Pomeranian cultures. Unfortunately, the palaeoenvironmental reconstruction is based on palynological chronology rather than an age-depth model because the obtained radiocarbon dates were too old. Some dates were incorrect because the study used material from carbonate sediments, including moss tissues, which can absorb carbon from dissolved old carbon in the basin (Madeja and Latowski 2008). Nevertheless, we used data from the Kwiecko site to discuss the changes that occurred in the forest communities of Central Pomerania and the type of economy prevalent during the period of interest to us.

For the other two sites located within the study area (Kusowskie Bagno, Spore Lake, Fig. 1, nos 1 and 3), palaeoecological research has primarily focused on studying past hydroclimatic changes and their impact on local vegetation transformation. The reconstruction of the regional hydroclimatic signal from the Kusowskie Bagno was based on testate amoebae, stable carbon isotopes, and plant macrofossils from the local mire (Lamentowicz *et al.* 2015). In the case of Spore Lake, a chironomid-derived reconstruction of mean July air temperature is available (Pleskot *et al.* 2020; Pleskot *et al.* 2022a); unfortunately, the palynological data from both sites are published only in a simplified form. The summarised curves of anthropogenic indicators and cereals, combined with the lack of data on taxa associated with grazing or ruderal habitats, make it difficult to conclude the development of settlement in the vicinity of these sites. This is likely a result of the focus of these papers, as palynological data were used only as a proxy to describe the main changes in vegetation composition and human-induced deforestation in the catchment (Lamentowicz *et al.* 2015; Pleskot *et al.* 2022b), but unfortunately, without reference to archaeological sources. Therefore, the well-dated pollen profile from Wierzchowo Lake, which records environmental changes from the Neolithic to Medieval Times (Niedziółka and Święta-Musznicka 2023), can serve as a reference site in Central Pomerania for reconstructing settlement dynamics.

The results of analyses of plant macroremains from archaeological sites can serve as an additional source of information, providing important insights into the agricultural economies of prehistoric communities (Lityńska-Zając and Wasylikowa 2005). Unfortunately, for the period we are interested in, archaeobotanical data from Central Pomerania are available from only one Lusatian culture site, located to the southwest of our study area (Klichowska 1967). So far, archaeobotanical analyses at the investigated site of the Pomeranian culture in this area have not revealed any traces of cultivated plants (Abramów 2013). For this reason, we decided to use macroremains data on cultivated plants from a few sites located in neighbouring areas, *i.e.*, Eastern and Western Pomerania, the northern part of Greater Poland, Kuyavia and Chełmno Land, dating to the period of the Lusatian (Klichowska 1971; Urban 2019) and Pomeranian cultures' activity (Klichowska 1962; 1979; Podgórski 1979).

Current state of research: archaeology

Pomerania is very unevenly explored in terms of archaeological research on the Late Bronze Age and Early Iron Age. Its western (Ślusarska 2022; 2023) and especially its eastern parts (Dzięgielewski 2017; 2018; 2023; see also further references therein) are relatively well-explored, both in terms of synthetic and more detailed approaches. When it comes to scholarship covering the entire region, Józef Kostrzewski's classic work and Zbigniew Bukowski's later work remain important research resources (Kostrzewski 1958; Bukowski 1998). The work of Janusz Ostoja Zagórski (1982) should also be mentioned. It addresses issues related to the natural environment within the context of settlement network development during the Hallstatt period.

Broadly, research on the transition from the Bronze Age to the Iron Age in Central Pomerania is much more sparse. The few, more general studies of the region are incomparable with more recent data sets, due to the data collection methodologies of the time (Sikora 1975). The situation is similar regarding the research area presented here (Janocha and Lachowicz 1971; Skrzypek 2010). When it comes to specific archaeological sites (Table 1), the most notable finds in the area under study are deposits of bronze objects dating back to the Late Bronze Age. These include the famous hoard from Wierzchowo (Wilkens 1997, 223–225), as well as finds from Grąbczyn/Grąbczyński Młyn (Blajer 2001, 344); however, the exact findspots of these items remain unclear to this day. In recent years, a double hoard consisting of costume ornaments and horse harness elements was discovered in the immediate vicinity of the study area (Szczurek and Kaczmarek 2022;

Kaczmarek *et al.* 2021). Burial areas, frequently unrecognised, are also present in the region, although, much like research in the region more broadly, there is a dearth of publications. There is one known, possibly flat, burial ground associated with the Late Bronze Age located in Stepień (Kostrzewski 1958, 320), as well as two burial mound cemeteries from this period located in Dalęcino (unnumbered archaeological site, Table 1, no. 4) and Sępólno Wielkie 1 (Table 1, no. 22). It is also worth mentioning the multiphase cemetery (Middle/ Late Bronze and Early Iron Age) at Parsęcki Młyn. Cemeteries associated with the Early Iron Age are also known from several locations both within the study area and in its vicinity (Skrzypek 2010, 38, 39).

Recently, a study of the palynological profile taken from the Wierzchowo Lake was published. It is presented against the background of available archaeological data for the entire microregion (Niedziółka and Święta-Musznicka 2023), providing important insights into the relationship between humans and the environment in this area.

MATERIAL AND METHODS

Palaeoenvironmental study

The core for palaeoenvironmental study was taken from the southwestern part of the Wierzchowo Lake (53°51'26" N, 16°38'47" E) using a Więckowski piston corer. The profile was dominated by calcareous gyttja with variable proportions of fine-grained sand, silt, and traces of shell detritus (Table 2) and was analysed as a continuous sequence. In this paper, we focus on a 62 cm-long section of the core, spanning a depth range of 740 to 802 cm, where pollen analysis was conducted at a higher resolution.

Samples for pollen analysis were acetolyzed (Fægri and Iversen 1989). Pollen and spore identification followed Beug (2004) and Punt *et al.* (1976-2003). The analysis was subsequently expanded to encompass the identification of microcharcoal particles >20 μm and

Table 2. Lake sediments description

Unit no.	Depth (cm)	Description/ Troels-Smith formula (1955)
1	740-742	detritus-calcareous gyttia with admixture of fine-grained sand, silt and traces of shell detritus/ Ld^{4}Lc2 Gmin1 AsAg1 test. (moll.) ++ nig. 3, strf. 0, elas. 2, sicc. 2, humo. 4, 5Y 2,5/1
2	742-784	calcareous gyttia with admixture of fine-grained sand and silt, traces of shell detritus at the depth of 775-776/ Lc3 Gmin1 AsAg+++ test. (moll.) +, nig. 2, strf. 0, elas. 3, sicc. 3, lim. sup. 0, 5Y 4/1
3	784-802	calcareous gyttia with admixture of silt and fine-grained sand, Lc4 AsAg+++ Gmin +++, nig. 1-2, strf. 0, elas. 3, sicc. 3, lim. sup. 0, 5Y 6/1- 5Y4/1

NPPs (van Geel 2001), including coprophilous fungi (van Geel *et al.* 2003; Henry 2020) and green and blue-green algae (Komárek and Jankovská 2001; Kuhry 1997). The identification of phases illustrating environmental changes in the vicinity of the site was based on the ratio of arboreal pollen to non-arboreal pollen, the proportion and diversity of anthropogenic indicators (Behre 1981; Brun 2011), and the changes in microcharcoal. To determine the human impact on the lake ecosystem, the bioindication properties of NPPs and selected geochemical indicators were also used. Loss on ignition (LOI) was applied to calculate the percentage contribution of organic matter in lake sediments (Heiri *et al.* 2001). Nitrogen and phosphorus contents were employed as markers of higher nutrient loading and eutrophication of the lake due to increased human impact on the environment (Smol 2008), and titanium served as an indicator of mineral matter delivery from the catchment affected by deforestation-induced erosion (Davies *et al.* 2015). The proportions of calcium and iron were examined to estimate lake level changes (Pleskot *et al.* 2018, 454; Tylmann *et al.* 2024, 9).

Table 3. AMS provenance and results (dates calibrated using the calibration curve with OxCal v4.4.4)

Sample no.	Lab. code (Poz-)	^{14}C yr BP	yr cal. AD/BC 95.4% ranges	Material dated
706-708	133500	850±30	1054 (0.9%) 1060 AD 1157 (94.6%) 1267 AD	*Betula* sect. *albae* (fruits, bud scales), *Alnus glutinosa* (fruits, fragments of cone), *Pinus sylvestris* (periderm), bud scales, leaf fragments
724-726	140135	1885±30	78 (7.1%) 101 AD 107 (88.3%) 234 AD	*Betula* sect. *albae* (fruits), *Pinus sylvestris* (periderm), bud scales, leaf fragments
776-778	117449	2615±30	825 (95.4%) 771 BC	*Betula* sect. *albae* (fruits), *Alnus glutinosa* (fruits), *Pinus sylvestris* (periderm), bud scales, leaf fragments
874-876	140835	5210±35	4221 (2.6%) 4201 BC 4164 (8.0%) 4132 BC 4061 (84.9%) 3955 BC	*Betula* sect. *albae* (fruit and bud scale), *Alnus glutinosa* (fruit, fragment of cone), *Pinus sylvestris* (periderm), bud scales, leaf fragments
958-960	157093	6930±40	5963 (1.0%) 5956 5896 (94.5%) 5725	*Betula* sect. *albae* (fruit and bud scale), *Alnus glutinosa* (fruit), *Pinus sylvestris* (periderm), *Schoenoplectus lacustris* (fruit), bud scales
984-986	160780	9080±50	8455 (0.7%) 8444 8435 (94.7%) 8225	*Betula* sect. *albae* (fruit and bud scale), *Pinus sylvestris* (periderm, seed, dwarf shoot), *Carex* sp. (fruits), bud scales
1006-1009	140209	9560±50	9191 (1.0%) 9177 BC 9163 (94.4%) 8753 BC	*Carex rostrata, C. pseudocyperus, Schoenoplectus lacustris* (fruits), *Betula* sect. *albae* (fruits), *Pinus sylvestris* (periderm, dwarf shoot), bud scales

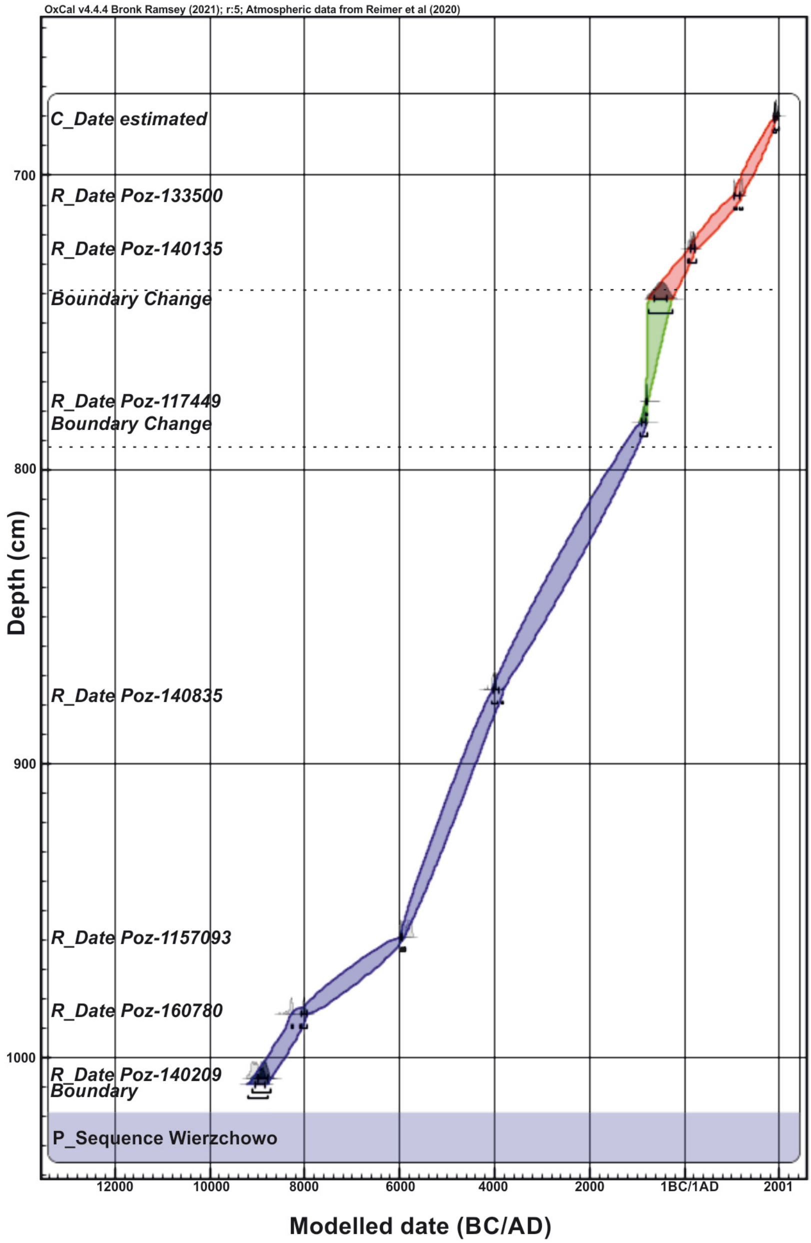

Fig. 2. The age-depth model (95.4% probability) for the analyzed profile and graphs showing the probability ranges (2σ) for individually calibrated ^{14}C dates (Poz- acc. to Table 3). The section of profile selected for further analysis is limited by horizontal dashed lines

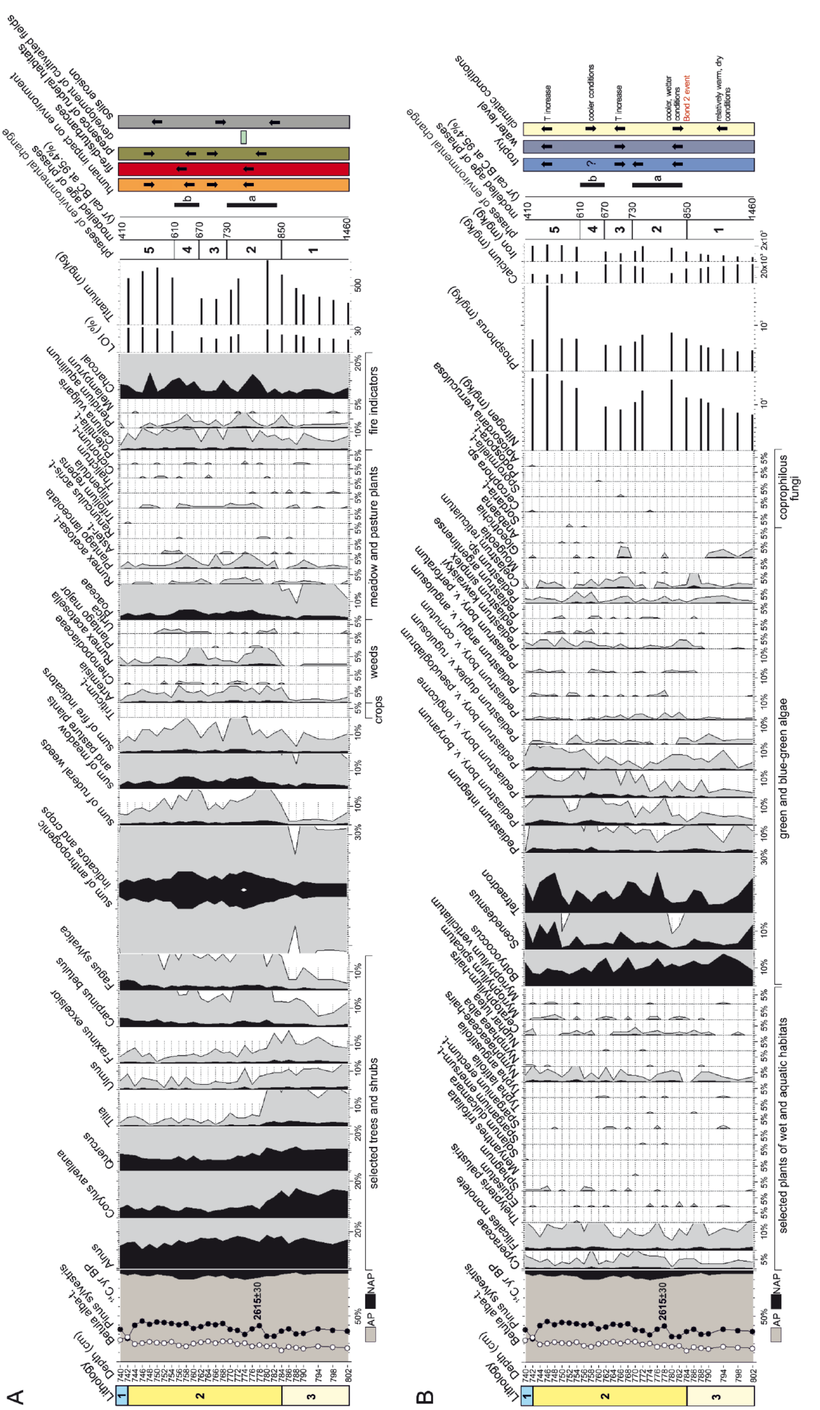

Fig. 3. The simplified diagram from Wierzchowo Lake (W/7 profile), A – illustrating environmental changes in the vicinity of the lake according to selected curves of trees, herbs, charcoal, and geochemical data; B – illustrating changes in the lake ecosystem according to selected curves of local plants, algae, coprophilous fungi, and geochemical data; lithological units acc. to Table 2; AP – arboreal pollen, NAP – non-arboreal pollen; black rectangle – the palaeoecological signal of human activity associated with Lusatian (a) and Pomeranian (b) cultures

The chronology of environmental change was established by AMS radiocarbon dating of 7 samples in the complete sequence of the profile (Table 3). Terrestrial plant remains from lake sediments were used for dating at the Poznań Radiocarbon Laboratory. Among the dated material, remains of trees (*Betula* sect. *albae*, *Pinus sylvestris*, bud scales) and plants of local origin, forming the wet communities around the lakes (*e.g.*, *Carex rostrata*, *C. pseudocyperus*, *Schoenoplectus lacustris*), predominated. To obtain calendar years, the BP dates were calibrated using OxCal version 4.4.4 (Bronk Ramsey 2021) based on the IntCal20 atmospheric curve (Reimer *et al.* 2020). The age-depth relationship of the sediments (Fig. 2) was determined using the set of consecutive ^{14}C dates supplemented by the estimated age of level 680, calculated based on the sedimentation rate in the upper part of the profile, which consisted of the same type of gyttja. An age/depth model was obtained using the OxCal P_Sequence algorithm with a 95.4% probability range and used to establish the chronology of individual stages of environmental change, expressed as a modelled median. Radiocarbon dating of the entire profile spans the time interval between approximately 8700 BC and 1880 CE, encompassing the entire Holocene sequence. The part of the profile presented in this article accumulated over a period of almost 1000 years, from 1460 to 410 BC (Fig. 3), and therefore covers a time span from the period preceding the expansion of the Lusatian culture in Central Pomerania during the Late Bronze Age to the Early Iron Age.

Archaeological study

The archaeological data discussed in this study were sourced through archival research conducted at the Provincial Conservation Service Office in Koszalin within the Polish Archaeological Record (AZP) archive. By integrating 1:10,000-scale topographic maps with AZP site cards in QGIS software, it was possible to prepare updated maps (Fig. 4) and analyse the entire study area. Data from a total of 9 AZP sheets were used: 21-24, 21-25, 21-26, 22-24, 22-25, 22-26, 23-24, 23-25, 23-26.

It is important to note, however, that the AZP was initially designed as a conservation and scientific programme, rather than a purely scientific one. Therefore, its data should be approached with caution and critical awareness. The chronological assessment of sites is especially uncertain when it relies predominantly on fragmented pottery collected from surface surveys, materials often disturbed by contemporary agricultural activities (Czerniak 1996; Matoga 1996; Niedziółka 2016). Uncritical dependence on AZP data for reconstructing prehistoric settlement patterns risks producing a distorted interpretation (Furmanek and Wroniecki 2020), potentially leading to the identification of non-existent sites or the omission of authentic ones.

A review of the available literature was conducted. A list of archaeological sites dating from the Late Bronze Age and Early Iron Age that have been investigated so far was compiled (accidental finds were also considered, see: Table 1). This made it possible to create

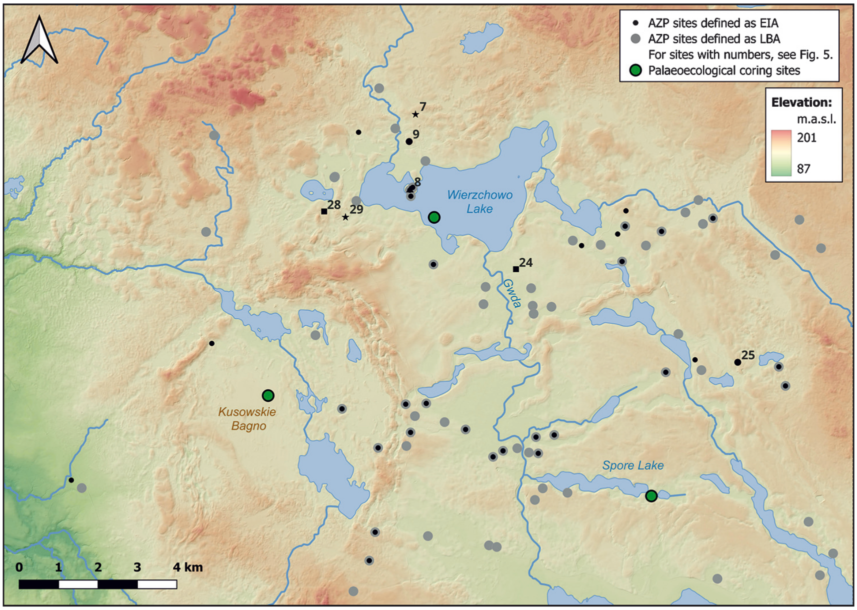

Fig. 4. Locations of palaeoecological sites presented on the background of the AZP data; better-known archaeological sites are marked with numbers (see: Table 1, Fig. 5)

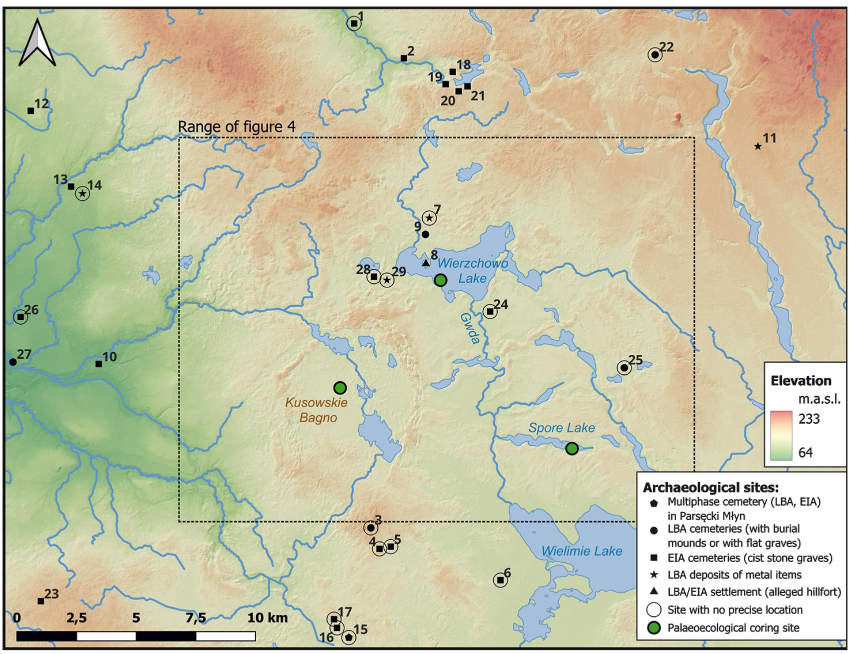

Fig. 5. Study area with marked locations of better-recognized archaeological sites from the LBA and EIA (see: Table 1)

a catalogue of known sites, the chronology of which, in most cases, was determined with greater precision than was the case with AZP sites discovered during surface surveys. This search had a wider range covering approximately the area of the neighbouring AZP sheets in relation to those mentioned above (*i.e.*, additionally sheets no. 20-23, 20-24, 20-25, 20-26, 20-27; 21-23, 21-27, 22-23, 22-27, 23-23, 23-27, 24-23, 24-24, 24-25, 24-26, 24-27; see: Fig. 5).

Comparison of palaeoenvironmental and archaeological data

In the final stage, the palaeoenvironmental data summarizing the history of the development of plant communities were divided into five phases according to the age-depth model (Fig. 2). These phases were then juxtaposed with the current periodisation of the Late Bronze Age and Early Iron Age for the area of Eastern and Central Pomerania by K. Dzięgielewski (2017, fig. 2; 2018, fig. 1), based on the earlier system developed by J. Podgórski (1992). The results, presented in Figures 3 and 6, enabled a comparison of the palaeoenvironmental analyses with the available archaeological data.

HUMAN IMPACT ON ENVIRONMENT IN CENTRAL POMERANIA AT THE TURN OF THE BRONZE AND IRON AGES

As mentioned above, within the time span of interest, we were able to distinguish five stages of environmental change that occurred near Wierzchowo Lake and in the local aquatic ecosystem under the influence of diverse human activity dynamics (Figs 3 and 6).

The first phase represents the period from 1460 to 850 BC. The palynological data indicate the existence of a dense forest cover around the lake, with its edges overgrown by well-developed rush vegetation, including Cyperaceae, *Typha latifoli*a, *T. angustifolia*, and *Sparganium erectum*. It was composed of alder forest stands on wetland habitats and mixed deciduous woodlands, the most important components of which were *Corylus avellana* and *Quercus*, with admixtures of *Ulmus*, *Fraxinus excelsior*, *Tilia*, *Fagus sylvatica*, *Carpinus betulus,* and *Pinus sylvestris* communities on the less fertile mineral soils. During this period, the human impact on the local environment was somewhat limited, as indicated by a low proportion of anthropogenic indicators. However, given the high proportion of hazel and oak in the woodlands surrounding the lake, it cannot be ruled out that the activities of local societies led to the formation of coppice forests. This vegetation type was widespread in the microregion and throughout Pomerania (*e.g.*, Latałowa 1992; Milecka *et al.* 2004; Pędziszewska *et al.* 2015), and techniques to stimulate the development of hazel-oak thickets, including burning and trimming, were practised not only in the Neolithic but also in the Bronze Age (Madeja 2012; Kłusek and Kneisel 2021). The catchment of the Wierzchowo Lake may have been used for grazing, as indicated by the regular occurrence of *Plantago lanceolata* and *Rumex acetosa*-t., species typical of pastures (Latałowa 1992) or other anthropogenic habitats (Brun 2011). The grazing animals near the lake may have contributed to an influx of nutrients, leading to regular algal blooms in the local ecosystem. This is evidenced by the presence of *Gloeotrichia*, a blue-green algae indicative of eutrophic to mesotrophic waters (van Geel *et al.* 1994, 102; Kuhry 1997), and relatively warm

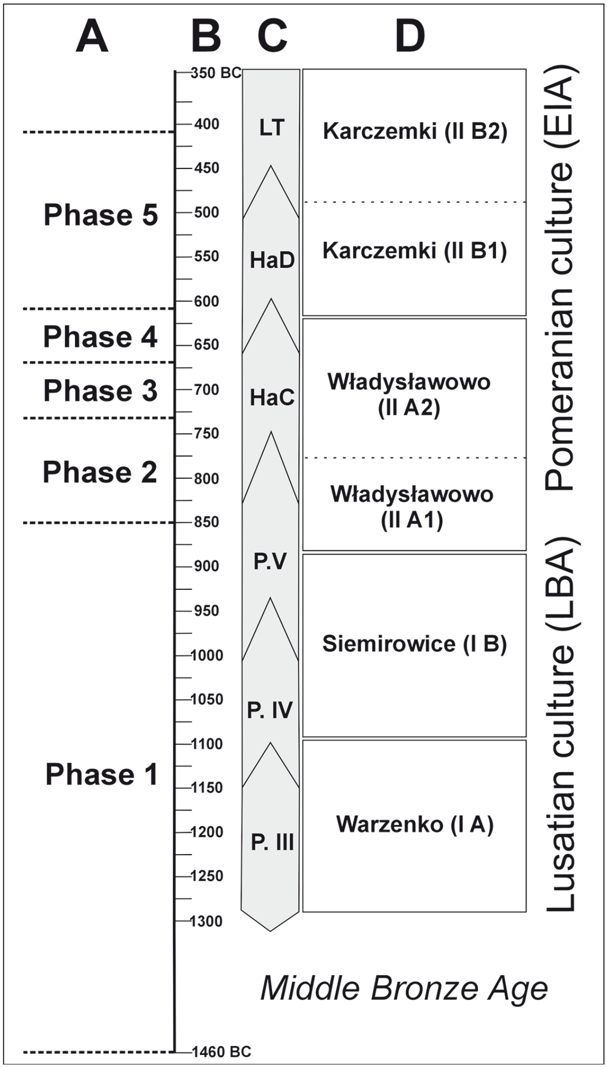

Fig. 6. Five stages of environmental change that occurred near Wierzchowo Lake juxtaposed with absolute and relative archaeological chronology and periodisation (A – phases of environmental change; B – calendar years, C – relative chronology, D – J. Podgórski periodisation [1992] updated by K. Dzięgielewski [2018]; figure based on: Dzięgielewski 2018, fig. 1)

climatic conditions (van Geel *et al.* 1989, 92-94). Important components of the green algae flora were *Pediastrum integrum*, *Pediastrum boryanum,* and *Coelastrum reticulatum*, which may have been favoured by a well-developed macrophyte zone (Apolinarska *et al.* 2018, 43) with *Nymphaea alba*, *Ceratophyllum*, *Myriophyllum spicatum* and *M. verticillatum*. The taxonomic composition of aquatic plants typical of eutrophic waters (Kłosowski and Kłosowski 2001) confirms the higher trophic status of the reservoir at this time. However, it should be emphasised that another factor supporting *Tetraedron* and *Coelastrum reticulatum* blooms may also have been higher temperatures in the local ecosystem (Jankovská and Komárek 2000, 69-71; Mirosław-Grabowska *et al.* 2015, 181) and drier conditions (Stivrins *et al.* 2015, 110).

From an archaeological point of view, the beginning of this phase is linked to the end of the PBA II and with the beginning of the PBA III ('Warzenko' phase according to the periodisation of J. Podgórski/K. Dzięgielewski: Fig. 6; see also: Podgórski 1992; Dzięgielewski 2017, fig. 2; 2018, fig. 1). The archaeological information for this period is consistent, to some extent, with the palynological data, as human activity during this time, particularly in Central Pomerania, was very limited (Gedl 1990, 27-36; Bukowski 1998, 117-26; Kaczmarek 2018, 11-16). Most of the sites consist mainly of burials, deposits of bronze items, and isolated finds. As such, archaeology does not provide much data on the economy of the inhabitants of Central Pomerania. The situation becomes clearer during the 'Siemirowice' phase, which can be compared with PBA IV and early PBA V (Fig. 6; see also: Dzięgielewski 2017, fig. 2). During these periods an increasing number of sites began to appear in both the eastern and central parts of Pomerania, with burial mounds still clearly dominating within the list of sites (Bukowski 1998). In the eastern and central parts of Pomerania, a local group associated with urnfields (in older literature referred to as the Kashubian [local] group of Lusatian culture; see: Dąbrowski 1979, 74) was already clearly distinguishable at that time. However, there are still no satisfactorily recognised settlements from this period, and it also seems that the economy was based more on animal husbandry than on cereal cultivation (Dzięgielewski 2017, 313).

A discussion of the role of cereal cultivation between PBA II and PBA V is difficult due to the lack of macroscopic remains from the archaeological sites in the studied area. Nevertheless, archaeobotanical data from Western Pomerania and Chełmno Land confirm that *Panicum miliaceum*, *Hordeum vulgare*, *Triticum dicoccum,* and *Triticum aestivum* were cultivated during this period (Urban 2019). However, the predominance of cereal remains in the form of imprints on pottery fragments and daub, as opposed to the accumulation of grains in storage pits, makes it difficult to determine the role of individual species in sowing practices and yields. An exception is the material found in storage pits and settlement layer in Bruszczewo (Greater Poland), dated to around 1370 BC. The dominance of *Triticum dicoccum* grains, with a small admixture of *Hordeum vulgare* and *Triticum monococcum* in the samples, suggests that it played a significant role in local agriculture (Klichowska 1971).

Regarding the presence of archaeological sites from the Early Iron Age in the study area, these are isolated discoveries (*e.g.*, early finds in a multiphase cemetery in Parsęcki Młyn, Tab. 1, no. 15, see also: Skrzypek 2010, 29, 30; or potentially from the cemetery in Sępólno Wielkie 1, tab. 1, no. 22), which is consistent with the palaeoenvironmental data indicating low human activity in the analysed area.

The second phase can be dated to the period between 850 and 730 BC (Fig. 3), which corresponds to the transition between the PBA V and Hallstatt C phases (*i.e.*, Władysławowo II A1 and partly Władysławowo II A2 (Fig. 6). It covers a time of significant environmental changes during the settlement and occupation of the microregion by groups of the Lusatian culture. The beginning of this phase is characterised by significant deforestation around the lake. The sharp decline in the proportion of *Corylus*, synchronised with the decline in *Quercus*, *Tilia*, *Ulmus,* and *Fraxinus,* suggests the destruction of forest stands growing on the more fertile soils. The more open landscape of Central Pomerania at that time – a result of human-induced deforestation – is also reflected in the pollen spectra from Spore Lake (Pleskot *et al.* 2022b) and Kusowskie Bagno (Lamentowicz *et al.* 2015). The simultaneous rise in microcharcoal content in the Wierzchowo Lake sediments and the increased representation of pollen from plants that colonise lands with sandy soil and after fires (*Pteridium aquilinum*, *Melampyrum*, *Calluna vulgaris*, *Rumex acetosella*) indicate the disturbance of woodland through fire. The considerable intensification of settlement processes during the Late Bronze Age is documented by the appearance of farming and settlement indicators, as well as an increase in LOI and titanium, which confirms the increase in erosion within the catchment.

The economy of the Lusatian culture societies in Pomerania was based mainly on animal husbandry and, to a lesser extent, on plant cultivation, as suggested by archaeological (Dzięgielewski 2017; Urban 2024) and palaeobotanical (Latałowa 1997; Rembisz *et al.* 2009; Urban 2019) data. In the case of the Wierzchowo microregion, livestock farming was also more important than cereal cultivation. This is indicated by the low proportion of pollen from wheat (*Triticum*-t.; Wierzchowo Lake) or cereals (Kusowskie Bagno, Lamentowicz *et al.* 2015), its absence in the sediments of Spore Lake (Pleskot *et al.* 2022b) and the high proportion of pollen from plants typical of meadows and pastures (*e.g.*, Poaceae, *Plantago lanceolata*, *Ranunculus acris*-t., *Rumex acetosa*-t.) at all sites. However, this may have been specific to the area, where poor soils without much economic value predominate, as pollen data from the neighbouring Kwiecko site (Madeja 2012) and other parts of Pomerania, Wolin Island (Latałowa 1992), and the Kashubian Lakeland (Pędziszewska *et al.* 2015) indicate a larger scale of cereal cultivation. In addition, finds of macroremains confirm that during this period, cereals (*Panicum miliaceum*, *Hordeum vulgare*, *Triticum aestivum*, *T. dicoccum*) and legumes (*Pisum sativum*, *Vicia faba* var. *minor*) were cultivated in the areas neighbouring Pomerania, that is, Greater Poland, Kuyavia and Chełmno Land (Lityńska-Zając and Wasylikowa 2005; Urban 2019). Unfortunately, the only archaeobotanical material (indeterminate, charred grains) from the

Lusatian settlement at Central Pomerania (Klichowska 1967) is insufficient to determine whether the same species were cultivated in the region.

The previously mentioned data also correspond with the latest view of the economy of the groups inhabiting Eastern Pomerania after 900 BC. It appears that this was then when local groups began to place greater emphasis on agricultural development (Dzięgielewski 2023, 222). This was also associated with the expansion of local settlement to areas located directly on the seacoast (including the Gdańsk Bay). Human occupation near Wierzchowo Lake is also demonstrated by the regular presence of pollen from *Artemisia*, Chenopodiaceae, *Urtica,* and *Plantago major*, which are indicators of trodden places and ruderal habitats (Behre 1981). Significant local pressure from anthropogenic activity caused a rise in eutrophication of the lake, as illustrated by an increase in the proportion of nitrogen and phosphorus in the sediment. This provided favourable conditions for the development of green algae in the basin, including *Pediastrum boryanum* var. *cornutum*, *Pediastrum boryanum* var. *boryanum,* and *Tetraedron*, taxa typical of eutrophic bodies of water, although not very polluted lakes (Komárek and Jankovská 2001, 84-86; John *et al.* 2002).

The changes observed in the local environment coincided not only with an increase in human activity but also with a shift in climate from relatively dry and warm to cooler, wetter conditions (discussed in detail in Niedziółka and Święta-Musznicka, 2023). Such conditions may have limited the cultivation of cereals in poorer quality soils and favoured the spread of *Carpinus betulus* and *Fagus sylvatica* in local stands. The population expansion of both of these species in Pomerania has been linked to an increased opening of the landscape due to more intense human activity (Latałowa 1982b; Pędziszewska and Latałowa 2016). Additionally, in the case of the study area, the impact of climate change, as well as the removal of *Corylus* and *Quercus* from local forests, woodland disturbance due to fires, and increased livestock grazing, could have been potential drivers of beech and hornbeam population increases. Climate change also affected the transformation of the green algae assemblages in the basin. The decrease in the proportion of *Coelastrum reticulatum* in relation to the previous phase and the appearance of *Pediastrum kawraiskyi,* which prefers lower temperatures (Komárek and Jankovská 2001, 81), are indicative of a cooling of the lake water. Cooler climatic conditions and higher water levels in the basin are also indicated by geochemical data, indicating drops in calcium concurrent with peaks in iron. The changes visible in the Wierzchowo Lake ecosystem correlate with the climate conditions observed in the region (Pleskot *et al.* 2022a; Tylmann *et al.* 2024) and reflect global shifts that are linked to the Bond 2 event (Bond *et al.* 2001).

If we look at the turn of the PBA V and Hallstatt C around Wierzchowo Lake and the surrounding area, there is a certain number of archaeological sites that can be related to that period (Table 1). Unfortunately, their dating is not precise enough to assign them to this specific palaeoecological phase, rather than, for example, the later phase 3.

However, the two deposits from Kaliska 37 (Table 1: no. 11) are worth mentioning. They were deposited in precisely the same place, as two separate deposits, which proves their uniqueness, also emphasised by the size of this double discovery. The Kaliska I hoard consisted mainly of ornaments and jewellery (breastplates made from sickle–shaped rings, necklaces, plate fibulas, bracelets, and clothing buckles), as well as fewer items related to horses (including phaleras) and weapons (spearheads). These items were deposited in a large bronze vessel, which is a variant of the Gevelinghausen–Veio–Seddin type. In addition to the aforementioned items, the vessel also contained three other smaller bronze vessels (Kaczmarek *et al.* 2021). In the case of the deposit known as Kaliska II, these were mainly decorative elements of a horse harness (several dozen phaleras, bells), weapons (an antenna-type sword, a tanged sword, and spearheads), ornaments (fragments of clothing buckles) and two bronze vessels (Szczurek and Kaczmarek 2022). The chronology of these two hoards, based on detailed archaeological analysis supported by radiocarbon dating, indicates a time span of 800-730 BC for the Kaliska I deposit and 790-720 BC for the Kaliska II deposit. This corresponds very well with the chronological scope of the second phase. Moreover, two other interesting deposits from the transition between the Bronze and Iron Ages were discovered in the area around Wierzchowo Lake. These are the discoveries from Grąbczyn (Grąbczyński Młyn) containing ornaments (Tab. 1: no. 7; Blajer 2001, 344) and, in particular, the deposit from Wierzchowo (Tab. 1: no. 29; Wilkens 1997, 223–225) containing an impressive set of jewellery (*i.e.*, breastplates made from sickle–shaped rings), ornaments (*i.e.*, plate fibulas) and weapons (*i.e.*, Mörigen-type sword hilt) with distinctly Nordic connotations, as well as its local adaptations. These abundant deposits could therefore be potentially associated with the period of the first economic intensification within this area, which is also visible in the pollen diagrams.

During the third phase, dated between 730 and 670 BC (which can be correlated with the Hallstatt C/'Władysławowo' II A2 phase (Fig. 6), there was a brief period of diminishing settlement activity. This is indicated by the absence of cereals, the decrease in the proportion of ruderal weeds (*Artemisia*, Chenopodiaceae, *Urtica*), the lower proportion of meadow and pasture plants and the expansion of stands dominated by *Pinus* or, in places, also by *Fagus* and *Carpinus*. The inhibition of erosion processes in the catchment, as a result of vegetation cover regeneration, is also evident in the geochemical data, which shows a lower proportion of titanium and LOI. However, a variable representation of fire indicators (microcharcoal, *Pteridium aquilinum*, *Calluna vulgaris*), *Plantago lanceolata*, and the constant representation of *Quercus* and *Corylus* suggest further transformation of forest communities, possibly for grazing animals. It can be assumed that the scale of grazing was negligible, as indicated by a decrease in the trophic status of the lake (lower nitrogen and phosphorus content), due to less nutrient run-off from the catchment area. The periodic change in water quality is also confirmed by the lower representation of green algae, typically found in eutrophic waters (*Tetraedron*, *Pediastrum boryanum* var. *cornutum*), in the lake sediments. This phenomenon is consistent with a rise in *Pediastrum boryanum* var. *longicorne* and *Pediastrum integrum*, taxa responding positively to the supply of dystrophic waters from peat bogs (Komárek and Jankovská 2001, 87). Hence, it cannot be ruled out that Wierzchowo Lake was more loaded at this stage with water inflow from the neighbouring Wielkie Błoto peat-bog, located on its southern shore, in the vicinity of the coring site. A higher proportion of *Coelastrum reticulatum* than in Phase 2, and the occurrence of *Pediastrum simplex* may indicate improved climatic conditions, for example, increased summer temperature (Jankovská and Komárek 2000, 71). Moreover, data from the neighbouring Spore Lake (Pleskot *et al.* 2022a, 6) illustrate that there was an increase in temperature in the period *c.* 750-650 BC. This thermal change may have caused a periodic drop in water level at Wierzchowo Lake, as indicated by a rise in calcium with a decrease in iron. The question is, why was the area around the reservoir used less during this stage, despite the favourable climatic conditions? It can only be assumed that, as a result of previous agricultural activity, the soils became depleted and local groups had to move further away from the lake. From an archaeological perspective, this phase may seem particularly interesting, as it most likely encompasses the transitional period between the Lusatian culture and the post-Urnfield Pomeranian culture. While the distinction between the burial sites of these two cultural units is obvious (burial mounds with cremation burials vs. flat stone cist graves containing, among other things, face urns), the distinction between settlement sites is not so clear.

It is quite difficult to assign specific archaeological sites in the vicinity of Wierzchowo Lake to this phase. It cannot be ruled out that the cist graves in flat cemeteries from Dalęcino and Smilicz 1 (Tab. 1, nos 4 and 23; Kostrzewski 1958, 361; Malinowski 1981a, 46, in this case, Dalęcino was assigned to Skotniki locality), may be connected with this transitional phase. Unfortunately, dating these historically discovered contexts is impossible.

Following a decline in human activity, another increase in human settlement is observed during the fourth phase, which spans from 670 to 610 BC. In archaeological studies concerning Pomerania, this period is associated with Pomeranian cultural activity (Dzięgielewski 2017; 2018; 2023). In the pollen profile, the beginning of this phase is marked by a decline in the proportion of *Pinus sylvestris* and *Alnus*, pointing to woodland clearance around the lake and on its margins. The destruction of the plant communities growing on the lake shores is also evidenced by the lower representation of rush vegetation (decrease of Cyperaceae, lack of *Typha latifolia* and *Sparganium erectum*-t.). The simultaneous increase in the proportion of microcharcoal in lake sediments and higher representation of light-demanding taxa typical of vegetation spreading in disturbed forest habitats, especially on sandy soil (*Calluna vulgaris*, *Pteridium aquilinum*, *Rumex acetosella*), indicates woodland disturbance by fire. The important rise of *Plantago lanceolata* and Poaceae correlating with the presence of other meadow and pasture plant pollen (*Rumex acetosa*-t., *Aster*-t., *Cichorium*-t., *Ranunculus acris*-t.) and coprophilous fungi (*Sordaria*-t., *Podospora*-t.) could be indicative of grazing near the lake.

Based on the palynological data from our study site, it is difficult to determine the significance of crop cultivation in the agricultural economy of that time. The absence of cereal pollen may suggest that human influence was somewhat weaker than in the case of Lusatian cultural activity, and animal husbandry probably dominated the local economy. However, the possibility of under-representation of cereals in the Wierzchowo Lake sediments during this settlement phase must be taken into account, not only due to their low pollen productivity (Broström *et al.* 2008; Abraham and Kozáková 2012) but also their poor dispersal ability (Theuerkauf *et al.* 2016) within such a large reservoir. This conclusion is supported by data from sites near Wierzchowo, confirming that cereals (Lamentowicz *et al.* 2015), including wheat (Madeja 2012), were cultivated in Central Pomerania, although the importance of this activity was marginal compared to grazing.

Although the results from Wierzchowo Lake do not indicate cereal cultivation, data from other sites in Pomerania suggest otherwise. Evidence from smaller palynological sites in Eastern Pomerania, which reflect primarily local changes (Sugita 1993), indicates that *Triticum* and *Hordeum* cultivation may have played a key role in the economy of the Early Iron Age societies (Pędziszewska *et al.* 2015; Pędziszewska and Latałowa 2016; Lamentowicz *et al.* 2019). This is also supported by finds of macroremains on archaeological sites, including *Hordeum vulgare* and *Triticum dicoccum* grains, as well as imprints of *Triticum aestivum*, *Triticum spelta*, *Panicum miliaceum* and *Pisum sativum* (Klichowska 1962; 1979; Podgórski 1979). The primitive type of agriculture in small fields, cultivated in a garden system, covered only part of the food requirements, so the diet was still supplemented by gathering nuts, mushrooms, or forest fruit (Fudziński 2011).

Despite the lack of pollen from cultivated plants, the constant human presence in the vicinity of Wierzchowo Lake is evidenced by the high representation of ruderal weeds (*Artemisia*, Chenopodiaceae, and *Urtica*). Their proportions are comparable to those of the Lusatian phase. Hence, it can be assumed that human activity has caused a slight increase in dissolved nutrients in the water in the basin, resulting in algal blooms of *Tetraedron* and *Pediastrum boryanum* var. *boryanum*. An increase of *Pediastrum kawraiskyi* coinciding with a significant decline of *Coelastrum reticulatum* representation at the end of the phase may illustrate the algae's response to the impact of cooling on the aquatic ecosystem (Fiłoc *et al.* 2018, 111). Such climatic fluctuations could also have caused a drastic decrease in crop yields with the farming model of the Pomeranian culture population (small plots, cultivated in a garden system), where much depended on weather conditions (Fudziński 2011).

Harsh climatic conditions are also confirmed by the results of bioanthropological research. The high mortality rate of the population, certainly caused by difficult living conditions, is verified by bioanthropological studies of human remains from the cemeteries in the eastern part of Pomerania, in the Kashubian Lakeland (Fudziński 2011). As a result, this situation could have led to population shifts during the later, fifth phase, as the limited capacity of the local natural environment forced some local groups to seek more promising ecological niches. In this way, as if through a lens, one can observe a process that, on a larger scale, encompassed the entire eastern and central portions of Pomerania, leading to the gradual disappearance of post-urnfield cultures within this region and, at the same time, their appearance outside the borders of this region (Dzięgielewski 2016; 2017).

Unfortunately, this phase is too narrow to reliably assign it to specific archaeological sites from the study area. Most of these sites were recognised several decades ago, and in many cases, their documentation does not meet modern standards. Moreover, some of these materials have been lost.

The fifth phase covers about 200 years (610-410 BC) of diminished settlement activity in the Wierzchowo area. This is the period preceding the expansion of groups associated with the younger pre-Roman Period that has occurred over the last two centuries BC (Strobin 2016). Weakened human activity is indicated by an absence of cereals, a decline in the proportion of ruderal taxa (*Artemisia*, *Urtica*, Chenopodiaceae) and fewer meadow and pasture plants (Poaceae, *Plantago lanceolata*). A significant rise in the representation of *Fagus sylvatica* and *Carpinus betulus* and a higher proportion of *Quercus* and *Pinus sylvestris* illustrate the regeneration of forest cover around the lake. However, the higher titanium and LOI values suggest that there were areas with disturbed vegetation in the lake catchment, which promoted erosion. There may still have been small-scale grazing, as indicated by the continuous curve of the *Plantago lanceolata*, the first appearance of *Trifolium repens*, a plant typical of the more open grasslands, regarded as an important component of cattle's diet. Even the sporadic occurrence of *T. repens* is considered an indicator of the local presence of cattle dung (Dietre *et al.* 2012), which, in the case of the Wierzchowo site, is confirmed by the finds of coprophilous fungi spores (*Sordaria*-t., *Apiosordaria verruculosa*, *Cercophora* sp.). Washout of nutrients from animal dung into the reservoir may explain the high nitrogen and phosphorus content of the sediments during the period of low settlement. This resulted in an increase in water fertility, which favoured the expansion of macrophytes, including *Nymphaea alba*, *Myriophyllum spicatum*, *Myriophyllum verticillatum,* and green algae blooms, especially during the middle part of this phase. The significant increase in the proportion of *Tetraedron* and *Scenedesmus* demonstrates that, like other sites (Stivrins *et al.* 2015, 113, 114; Tylmann *et al.* 2024, 6), climate warming and a decrease in landscape openness were important environmental variables affecting phytoplankton community dynamics. The highest values for both taxa were recorded at a level dated to around 550 BC, that is, at a time which a marked increase in temperature was registered in the study area (Pleskot *et al.* 2022a, 6). The subsequent rise in the lake's water level, as indicated by the calcium-to-iron ratio, perfectly illustrates the variability in climatic conditions that prevailed during the early Iron Age.

Within the studied area, a relatively large number of cist grave cemeteries have been recorded so far (some of them contained face urns, see: Table 1 no. 5, 17), which can be associated with the classical phase of the Pomeranian culture linked with the Hallstatt D period or even with the subsequent early La Tène period (La Tène A-B, see: Table 1 no.: 2, 18, 20, 21). It seems that this area, despite its relative distance from Eastern Pomerania, was subject to the same influences and/or transformations as those that took place in the aforementioned part of Pomerania.

CONCLUSIONS

The palaeoecological data from Wierzchowo Lake precisely document the settlement dynamics in Central Pomerania during the turn of the Bronze and Iron Ages. By answering the questions outlined in the introduction, we demonstrate the potential of multiproxy studies and the use of high-resolution pollen analysis to capture even short-lived periods of local environmental transformation triggered by different types of human activity. This study also shows that palaeoenvironmental data correlate well with available archaeological data from the area of interest, despite the relative incompleteness of this historical dataset.

The comprehensive reconstruction of environmental changes illustrates that during the period from the Middle Bronze Age to the PBA V, the vicinity of Wierzchowo Lake was overgrown by mixed deciduous forests, and human influence on the vegetation was somewhat limited. A significant transformation of vegetation occurred around 850 BC, thus during the transition between the PBA V and Hallstatt C phases. The significant deforestation around the lake, the larger scale of livestock rearing, the intensification of erosion in the catchment, and a rise in the eutrophy of the lake illustrate the economic intensification during the period of the spread of Lusatian culture groups. Such a significant signal of environmental change is also confirmed by archaeological data indicating an increase in the number of Late Bronze Age archaeological sites, as well as their location near the lake, mainly in the western and northern parts of the catchment. Similar to other sites from Pomerania, a short but distinct settlement break between the Lusatian and Pomeranian culture phases is marked in the Wierzchowo area. However, our data indicate that during this period, further transformation of forest communities for grazing animals was possible, although the scale of this type of farming was negligible, as indicated by the decline in lake eutrophication. The absence of cereals during the Pomeranian culture phase may suggest that animal husbandry was the dominant economic activity in the local economy. At this time, settlement activity in the vicinity of Wierzchowo Lake is evidenced by woodland clearance, a similar proportion of ruderal weeds as in the Lusatian phase and a slight increase in the nutrients in the lake waters, resulting in algal blooms. This stage was terminated at ca. 610 BC, when diminished settlement activity caused a regeneration of forest cover around the lake. Nevertheless, pollen and geochemical data suggest small-scale grazing in more open grasslands and the presence of areas covered by disturbed vegetation, which promoted erosion. These weak, but ever-present, traces of economic activity since the Pomeranian culture phase are confirmed by numerous archaeological sites within the studied area, especially a relatively large number of cist grave cemeteries.

Our research demonstrates that the possibility of reconstructing settlement dynamics depends strongly on the size of the basin, as some anthropogenic indicators (mainly cereals) may be underrepresented in the sediments if the economy of local societies was mainly based on animal husbandry. The location and density of settlements in relation to the shoreline of the lake are also of great importance in this respect. Furthermore, the palaeoenvironmental study from the Wierzchowo area also provides new data on the transformation of the local terrestrial and aquatic environment as a result of climate change and shows correlations with cooler and wetter periods recognised both locally and at the supra-regional level, including the Bond 2 event.

In conclusion, it can be said that the multifaceted relationships between the natural environment and the people who inhabited it in the past are, in a sense, pushing archaeologists and palaeoecologists to collaborate more frequently in this area, while also offering great potential in this regard.

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