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Vegetation changes caused by agricultural societies in the Great Mazurian Lake District

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ABSTRACT: The results of pollen analysis and radiocarbon datings of bottom sediments of four lakes: Lakes Miłkowskie, Wojnowo, Łazduny, and former Lake Staświńskie, situated in the eastern part of the Great Mazurian Lake District, were the basis for the reconstruction of vegetation changes during the last 4 millennia. In addition to the local pollen assemblage zones, which represent transformations of forest vegetation at the local level, three regional pollen assemblage zones were described, as were also the changes of plant communities developing in water basins. In the case of Lake Miłkowskie the variations in the composition of fossil green algae showed its evolution from an oligotrophic to strongly eutrophic water body as early as the 11th century AD.

The present studies have confirmed that the vegetation transformations in the Miłki-Staświny microregion differed from those in Szczepanki vicinity. In the first case, human activity, besides climate, proved decisive agent in vegetation cover development, in the second one it was a natural process of lake terrestrialization. Pollen record showed that a characteristic short-lasting phase of the intensive *Picea* development about 2000–1600 BC was delayed for at least a century compared to the Suwałki region. It was confirmed that the first *Carpinus* spread in the forests occurred about 1350 BC. The data provided evidence for metachronous beginning of formation and long-term persistence of anthropogenic forest communities dominated by birch in different parts of the area (1200 BC – 1100 AD in Miłki and Staświny regions, 200 BC – 1500 AD in Lake Łazduny region).

The investigations documented the spread of local cereal cultivation (*Triticum* and *Hordeum* types) during the middle Bronze Age. The phases of more intensified human impact on microregional vegetation were identified with the middle Bronze Age settlement (Lusatian culture); with the activity period of the West Baltic Burrow culture population; with the societies of the Bogaczewo culture and Prussian Galindians. The last phase of the very strong agricultural exploitation of the area that lasts to the present time, was initiated in the Middle Ages, about 1100 AD in Lakes Wojnowo and Miłkowskie regions and in the 16th century near Lake Łazduny. The datings of sediments deposited in the Middle Ages confirmed the asynchronous beginnings of the large-scale deforestations. Of special interest was the dating of the deforestation time in the surroundings of Lakes Miłkowskie and Wojnowo (in the Staświny settlement centre) to the earlier time than it was deduced from written sources and the presentation of arguments for the foundation of permanent settlement units prior the arrival of the Teutonic Order Knights. The stages of anthropogenic disturbances of vegetation distinguished in individual pollen diagrams in the most cases well reflected the history and intensity of settlement confirmed by archaeological findings and historical data.

KEYWORDS: palynology, vegetation history, human impact, radiocarbon chronology, adoption of agriculture, fire, large-scale clearings, settlement history, late Holocene, NE Poland

INTRODUCTION

The significant natural potential of the Great Mazurian Lake District for palaeoecological studies, resulting from the abundance of lakes and peat bogs, was hitherto little exploited in the analysis of the late Holocene palaeoenvironmental changes. Among the sites that were palynologically investigated after the second World War, only a few included pollen sequences reaching to modern times. These were pollen profiles from the following lakes: Mikołajskie (Ralska-Jasiewiczowa 1966, Ralska-Jasiewiczowa & Latałowa 1996), Kruklin, Mamry, Tałty (Stasiak 1967, 1971), and Dgał Wielki (Filbrandt-Czaja 2000). The insufficient number of radiocarbon dates of the late Holocene sediments resulted in a very generalized chronology of vegetation changes presented in these papers. This fact restricts the possibility of the reconstruction of the rates of environmental changes and their correlation with archaeological-historical and climatic data. The investigations of the environmental history of the Great Mazurian Lake District and its connection with the appearance of agricultural societies during the last millennia require on one hand the selection of deposits suitable for palaeoecological analyses and on the other, the information about the changing in time forms of local economic and settlement activities. The good recognition of radiocarbon and archaeological chronologies is of key significance in these studies. The time frames for the present investigations, which focus on the impact of agricultural societies on vegetation, were established on the basis of the first appearance of Cerealia type pollen grains about 3800 BC in the sediments of Lake Miłkowskie (Wacnik 2009a) and approximately at the same time in Lake Dgał Wielki (Filbrandt-Czaja 2000) as well as in cultural layers from an archaeological site Szczepanki 8 (Wacnik & Ralska-Jasiewiczowa 2008, Madeja et al. 2009). These data indicate a likely beginning of the interference in vegetation of people who were engaged, though on a very limited scale, in cultivating plants and raising livestock. In order to recognize anthropogenic vegetation changes in the late Holocene several new localities, situated a few to a dozen or so kilometers apart, were investigated. Thanks to their different dimensions, pollen records showed differences reflecting the unequal sizes of source areas for pollen transported to the sedimentation basins, which made possible the differentiation of local and regional phenomena. The region Staświny-Miłki-Szczepanki was selected for palynological investigations because human settlement in this terrain was well known due to the intensive archaeological explorations carried out by two teams. One of them, under the leadership of M. Karczewski and M. Karczewska from the University of Bialystok, studied the region of Paprotki Kolonia and Staświny, another one, under the leadership of W. Gumiński from the Warsaw University, worked on the sites Szczepanki and Dudka.

The questions connected with the process of the neolithization of north-eastern Poland, including the very beginning of the transformation from foraging to (partly) producing economy type, are as yet not fully understood. A particular feature of this area, is contrary to the rest of Poland, was a prolonged existence of foraging and a very late acceptance of farming as the basis for food procurement. Hitherto existing palynological studies of bottom sediments of Lakes Miłkowskie and Staświńskie, which are to a high degree representative for this region, have demonstrated that the impact of local Mesolithic and Neolithic populations on vegetation was insignificant, while climate remained the main agent controlling the dynamics of plant community changes. The use of fire for clearing small surfaces for economic and settlement purposes, and since ca 3800 BC also sporadically for farming, caused only small and temporary disturbances of the structure and taxonomic composition of forest communities. It was only the increased significance of producers' economy based on plant cultivation and animal raising, recorded in the middle Bronze Age from about 1400 BC, that resulted in more pronounced environmental changes (Wacnik 2005, 2009a). The character of anthropogenic disturbances during the early and middle Holocene that can be observed in this area, resembles those known from the majority of the Baltic countries.

The basic aim of the present paper was to describe the main stages of palaeoenvironmental changes, which occurred in the Great Mazurian Lake District from the onset of agriculture to modern times and to confirm that the large-area deforestations and enlargement of surfaces taken under cultivation were not synchronous over the whole area.

THE STUDY REGION

The Great Mazurian Lake District (1730 km^2) lies in a depression between the Mrągowo Lake District to the west and Ełk Lake District to the east. To the north it borders upon the Węgorapa District and to the south upon the Mazurian Plain, where the border is marked by marginal forms (moraines and kames)

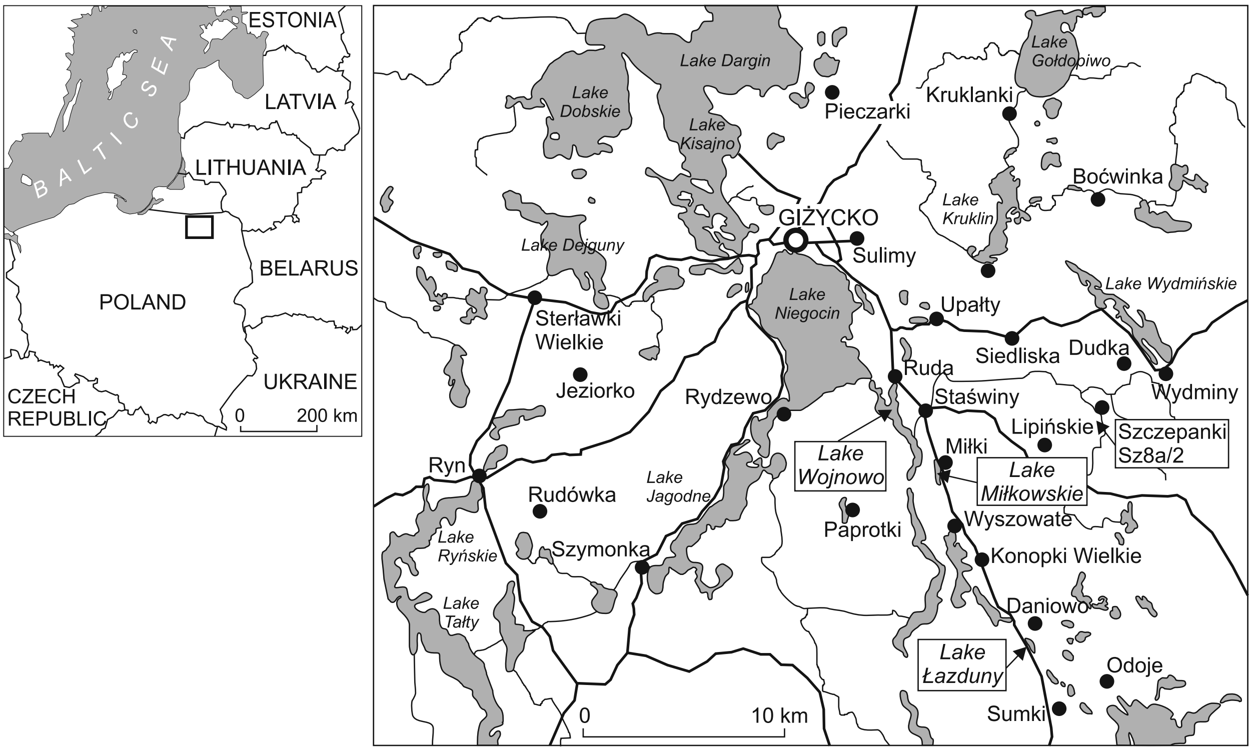

Fig. 1. Location of studied sites in the eastern part of the Great Mazurian Lake District. Main localities mentioned in the paper are marked on the map. Names of the studied palynological sites are framed

of the Pomeranian stage of the Vistula glaciation, running north of Ruciane, and south of Lakes Śniardwy, and Orzysz (Kondracki 1972). In respect of geomorphology the region is situated within the reach of the last glaciation formations and forms, between the I and VIII moraine ridges. The effect of glacier activity is the diversified hilly, mosaic relief with a great number of lakes. Some of the depressions are filled with mires that developed after the disappearance of lakes, for instance Bagna Nietlickie (Nietlickie Mires), Łąki Staświńskie (Staświńskie Meadows), and Łajty. The Great Lake District is divided into the southern part in Lake Śniardwy region, situated within the Vistula River catchment area, and the northern part, the region of Lake Mamry belonging to the Pregoła River catchment basin. The V and VI moraine ridges surround the Lake Niegocin reservoir from the south and to the east diverge in different directions. The moraines of the phase V run east through Konopki, while those of the phase VI near Miłki turn north towards Upałty forming thus the eastern border of Lake Niegocin. Northern part of the Great Mazurian Lake District has a more complicated pattern of marginal forms (Kondracki 1972). During the standstill of the Pomeranian phase glacier near Miłki the exaration basins were formed, which gave rise to the network of modern channel lakes including Lakes Miłkowskie, Wojnowo, and Łazduny (Fig. 1). Front moraines were formed at that time as well as local accumulations of kame sands and gravels. During the glacier recession, a fluvioglacial valley was formed west of Miłki, which drains the Lake Niegocin region to Lake Śniardwy (Szumiński & Liskowski 1993).

The climate of the Great Mazurian Lake District belongs to the coldest lowland climates in Poland with the mean annual temperature 6.5°C (mean temperature of January is –4.5°C, mean temperature of July 17.5°C). The length of the growing season is about 180–190 days, snow cover persists 90–110 days on average, and lakes are ice-covered for 34 months (Starkel 1999, Woś 1999). The climate of the study area is precisely characterized by climatic records of Puszcza Borecka Integrated Monitoring Station located near Giżycko. The number of days with ground frost is 130; mean annual precipitation is 570 mm with the predominance of summer rainfall (Siuta 1994).

The soil cover is strongly differentiated with the predominance of the zonal soils, namely brown soils and podzols. Hydrogenic and semi-hydrogenic soils cover the low lying terrains along rivers and near lakes (Fig. 2). The characteristic intrazonal soils of the Mazurian Lake District that occur also in the studied area, are gyttja soils formed from different types of lake sediments. They are often associated with peaty soils on fens (Uggla 1969, 1976, Bednarek & Prusinkiewicz 1999).

The abundance of water reservoirs is characteristic feature of the Great Mazurian Lake District. Some of them are joined by canals and form a network of lakes with an even water level at an elevation of 117 m a.s.l. Lakes Śniardwy (113.8 km²), Mamry (105 km²), Niegocin (27.8 km²), Orzysz, Jagodne, and Tałty belong to the greatest water bodies. Lake Tałty with 50.8 m water depth is also the deepest one. The first canals connecting Lakes Mamry, Śniardwy, and Niegocin were built in 1764–1765, the others in the 19th century. At present, the system of Mazurian lakes connected by rivers and canals is 106.2 km long. River network is here poorly developed (Kondracki 2000). The main watercourse in the investigated microregion is 23.6 km long Staświnka-Pamer River, which rises from Lake Pamer and falls to Lake Wojnowo at the village Staświny. Large areas are occupied by 65 peatlands (16% of the total area) and 43 gyttja lands covering ca 1780 ha (Gotkiewicz et al. 1995).

Due to the specific climatic conditions the vegetation has transitional character. The eastern borders of *Fagus sylvatica* and *Acer pseudoplatanus* natural ranges run through this area. *Abies alba* does not grow in the forests, which are dominated by *Pinus sylvestris*, and in the eastern areas *Picea abies* is common (Jutrzenka-Trzebiatowski 1999). According to the geobotanical division of Poland the Great Mazurian Lake District belongs to the Northern

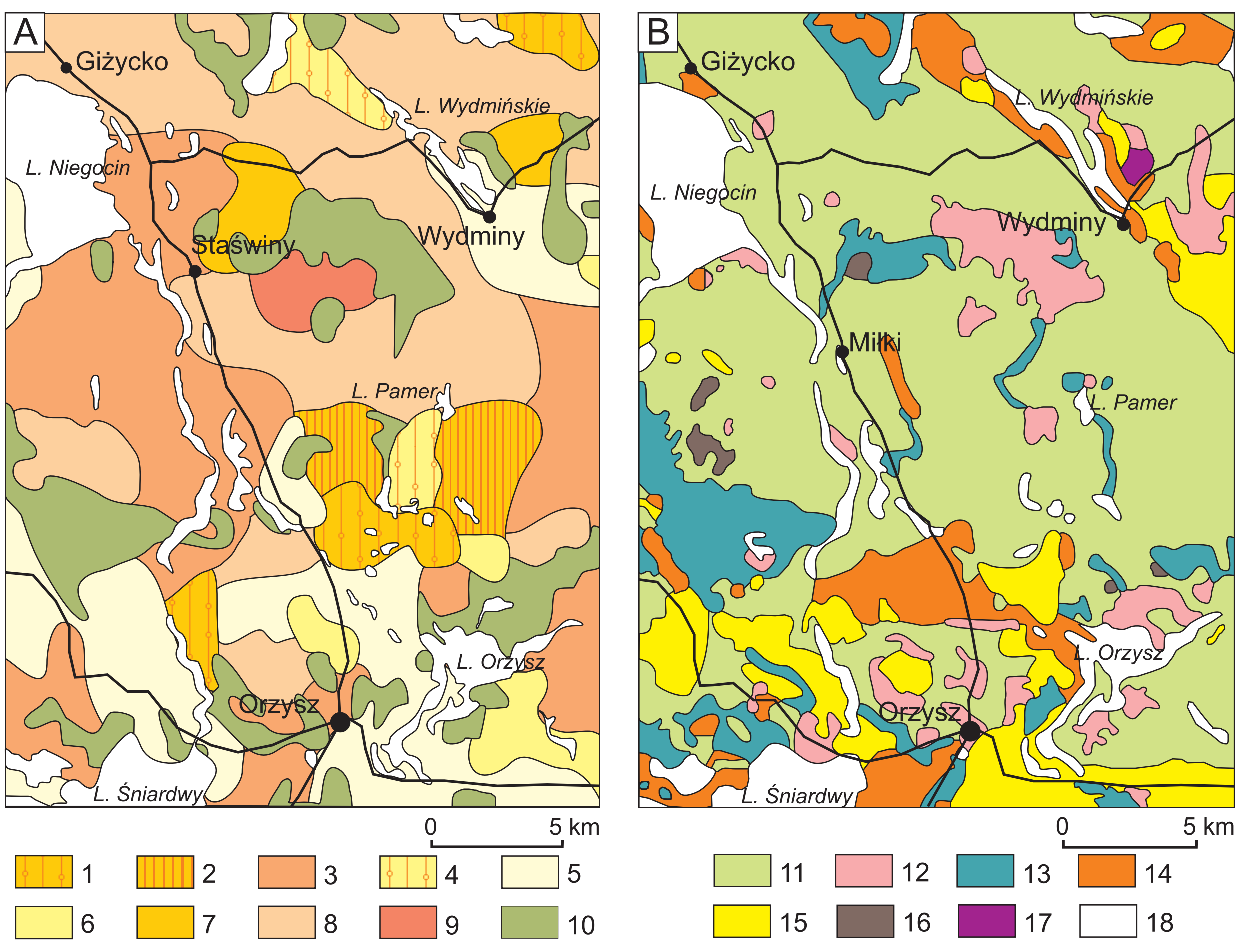

Fig. 2. Soils and potential natural vegetation in the studied microregion of the Great Mazurian Lake District (after Musierowicz A. 1961, Matuszkiewicz 1984, modified); **A**: **1** – brown soils formed from gravels and stones; **2** – brown soils formed from slightly loamy sands; **3** – brown soils formed from loam; **4** – podzols formed from gravels and stones, **5** – pozdols formed from loose sands; **6** – podzols formed from slightly loamy sands; **7 –** podzols formed from loamy sands; **8** – podzols formed from loam and sand, light; **9** – podzols formed from loam and sand, heavy; **10** – gyttja and peat soils; **B**: **11** – *Tilio-Carpinetum*; **12** – *Carici elongate-Alnetum*; **13** – *Fraxino-Alnetum*; **14** – *Querco-Pinetum*; **15** – *Peucedano-Pinetum*; **16** – *Potentillo albae-Quercetum typicum*; **17** – *Sphagno girg.-Piceetum*; **18** – lakes

Division, Mazuria-Kurpie Province, Mazurian Lake Region (Szafer & Zarzycki 1972). In the synchorological regional division of Poland it belongs to: IV. East-European Lowland, 1. Mazuria-Podlasie subboreal region (Starkel 1999). Nowadays, different types of pine and mixed pine forests from the alliances *Dicrano-Pinion* and *Piceion abietis* prevail on sandy soils, while oak-hornbeam forests from the alliance *Carpinion betuli* develop in morainic areas (Matuszkiewicz 2002).

The potential natural vegetation of the Great Mazurian Lake District would be formed mainly by the subboreal type of oak-hornbeam forest from the alliance *Carpinion betuli*. The southern parts of the Great Lake District lie within the range of pine and mixed pine forest associations from the alliance *Dicrano-Pinion*, that is to say *Querco-Pinetum*, *Serratulo-Pinetum*, and *Peucedano-Pinetum*. Locally there could also develop the azonal communities of the middle-European wet alderwoods (Matuszkiewicz 2002). There is a great discrepancy between the real and potential vegetation in this terrain. At present, woodland is dominated by pine and mixed pine forests, while the surface of oak-hornbeam forests is very limited due to the strong deforestation and the exploitation of terrains as plough-lands and meadows or pastures.

CHRONOLOGY OF LOCAL SETTLEMENT CHANGES. ARCHAEOLOGICAL-HISTORICAL SOURCES

In the middle Bronze Age a new settlement appeared on the territory of Mazuria, which was connected with the Mazuria-Warmia group of the Lusatian culture (Okulicz 1981). The population of this group inhabited large settlements localized mainly on morainic hills. Human activity in the microregion from which pollen profiles originate is confirmed by the settlement traces discovered in the environs of Wyszowate, Bagna Nietlickie, Konopki Wielkie, Rydzewo, and perhaps also in Czyprki (Karczewska et al. 2005). This settlement lasted until the beginning of the Iron Age. In the 6^{th} century BC the population identified with the ancestors of the West Baltic tribes arrived to the Great Lake District (Karczewska et al. 1996, 2005, Okulicz-Kozaryn 1997). They gave rise to the settlement-cultural complex of the West Baltic Barrow culture. The characteristic features of these people were cremation burials connected with building small tumuli over cinerary urns and the foundation, in close vicinity (on elevated ground), of fortified settlements as well as small lake dwellings (on artificial islands in lake bays). The settlement remnants of this culture are relatively numerous particularly in the environs of Orzysz and Giżycko (Okulicz 1981). The concentrations of relics of this culture nearest to the palynologically studied lakes were found around Lake Wojnowo and at the north-western shore of Lake Miłkowskie; in both cases they were connected probably with the settlement microregion having the centre at Staświny (fortified settlement on Święta Góra Mt.). Karczewska and Karczewski (2007) mention for the Staświny region one tumulus (at Ruda), seven settlements (one at water shore at Bogaczewo), and seven settlement traces of the West Baltic Barrow culture. The remnants of waterside settlements were also discovered, for instance in the surroundings of Szymonki, Konopki Małe, Paprotki Kolonia, and Pieczarki.

From the second half of 2^{nd} century AD (Roman Period) comes the relation of Claudius Ptolemeus, which states the existence of the Galindai tribe in this terrain. Archaeological culture that may constitute the material remnants of the Galindai people is called Bogaczewo culture (e.g. Nowakowski 1995, 2006, Engel et al. 2006). Rich cremation cemeteries of this culture are known from the surroundings of Ławki, Rudówka, Giżycko, Staświny, Paprotki Kolonia, and Czyprki (Karczewska & Karczewski 2007, Karczewski 2008). The relics of settlement microregions were found at Lakes Wojnowo, Ublik Wielki, and Boczne, at the edge of Bagna Nietlickie (Karczewska et al. 1996, 2005, Karczewska & Karczewski 2002, Karczewski 2006), and more to the west near Łajty (Karczewski 2008). Nineteen settlements and seven settlement traces dated to the Roman Period as well as two settlements from the late Roman Period were described from Lake Wojnowo region (Karczewska & Karczewski 2007). In the cemeteries, in addition to human cremation burials also offering pits with horse skeletons were discovered (Karczewski 2011). About the 6^{th} century AD the gradual collapse of the settlement and the depopulation of Galindia probably took place (Karczewski et al. 2005). According to G. Białuński (1996), however, the situation was somewhat different. He suggests that the old-Prussian settlement was scattered but still it persisted because "the studied terrain belonged to the Galindia-Sudowia borderland, was certainly less densely populated than other regions of the same tribes, but the settlement survived even here". Archaeological sources show that in the early Middle Ages (Prussian culture) one hill fort (Święta Góra Mt. at Staświny), 22 settlements, 48 settlement traces, and 5 places of bog iron ore smelting (near Staświny and Kleszczewo) existed in the Lake Wojnowo region (Karczewska & Karczewski 2007).

The excavations carried out by the same authors on the hill fort at Staświny have demonstrated the existence of three settlement phases dated to the early Iron Age (period III of the West Baltic Barrow culture), to the developed phase of the Migration Period (Olsztyn group), and to the Early Medieval time (Galindai settlement). In the 11th and 12th centuries population decreased due to the frequent wars with the neighbours, namely with Ruthenian prince Izasław (1057 AD), with Polish princes during the Bolesław Krzywousty times (the campaigns in 1107 and 1110/1111 AD), and with Jacwings. In the 11th century the Galindia castles extended, for instance in Jeziorko near Giżycko (Okulicz 1981). In 1253 (shortly before the occupation by the Teutonic Knights), by pope's donation the Great Lakes District became the property of Konrad, the prince of Łęczyca and Kujawy. The final fall of Prussian tribes occurred in 1286 after the conquest of Sudowia.

In the 14th century a new administrative division was applied to monastic lands. According to the written sources an intensive exploitation of local forests took place at that time (Toeppen 1870, Białuński 1996a, b). When the peace treaty between Lithuania, Poland, and Teutonic Order was signed in 1422 the colonization of the terrain increased, mainly by the Masovian and German settlers. The first donations in the Lec (Giżycko) region (in 1387) were lands situated in Sterławki Wielkie. The 13-years war (1454–1466) caused the settlement set-back and considerable devastations. After the war the re-colonization began. In 1475 the villages Wyszowate, Konopki Wielkie, Miłki, and Staświny received the legal status (location see on Fig. 1). The granting of the foundation charter only confirmed the existence of these villages, but their beginnings must have been older. The existence of villages/habitation places e.g.: Kruklin, Lipińskie, and Szczepanki (near Szczepanki 8 palynological site), as well as Daniowo (1495 AD), Bielskie (ca 1476 AD), Sumki, Odoje, and Pianki (near Lake Łazduny palynological site) is confirmed between 1466–1525 AD (Karczewska et al. 1996, Biskup et al. 2008). Białuński (1996a) indicates that an iron work existed in Ruda (Eisenwerk) before 1508. He does not exclude the connection of the beginning of local metallurgy with Galindians and the hillfort at Staświny, as it is suggested by Karczewska and Karczewski (2007). In 1525 the secularization of Teutonic Order estates took place and the investigated terrain became part of the Ducal Prussia (as a fee of Poland). In the 16th century a new colonization campaign occurred, which resulted in population increase. This was also the time of numerous epidemics having negative influence on population density but, excluding the biggest one in 1559, their consequences were usually not very severe. After the prince Albrecht death (1568) the colonization campaign was almost completely stopped. The area of the former Galindia was strongly devastated by military operations during the "Swedish deluge". For 10 years following the Tartarian-Lithuanian invasions in 1656 and 1657 half of the land lay fallow. In 1657 Polish-Lithuanian detachments burnt the church in Miłki and the villages Staświny and Ruda (Karczewska et al. 2005). A very severe winter and the disaster of a bad year occurred in 1709, and in the next year a plague epidemic strongly affected Miłki killing 2740 people. The area suffered serious losses during the 7-years war (1756–1763) and the Napoleon campains in 1806 and 1807. In the 18th century canals were built, which joined some of the lakes into a system with an even water level at 117 m a.s.l. creating thus the so called Mazurian waterways (Toeppen 1870, Karczewski 2007). Epidemics occurred in the first half of the 17th and in the 18th century. In the 19th century (1831) a cholera epidemic was recorded, which killed 15000 people in East Prussia. In the next years epidemics happened again but with smaller intensity. The year 1867 was extremely bad due to the prolonged rains, which caused the emigration of part of the population. Considerable prosperity started in the second half of the 19th century. After the end of the war with France in 1870, the funds from the French contribution were allocated to the development of the industry, infrastructure, and agriculture in East Prussia. In the first half of the 19th century different activities connected with the drainage of the terrain were initiated. In 1825–1836 Lake Staświńskie was drained, which caused the lowering of water level by 2.2 m. This resulted in the formation of the large area of Łąki Staświńskie (Staświńskie Meadows) and the lowering of water level in the nearby Lake Kruklin by 6.3 m. In 1865 the drainage of Bagna Nietlickie was completed, which caused the decrease of water level in Lakes Wąż and Buwełno by 2 m (Toeppen 1870).

The intensive fights during the World War I caused enormous material losses and the escape of the population. Several villages were almost completely destroyed, for instance Marcinowa Wola, Staświny, and Wyszowate. Erection of fortifications modified the terrain. Evacuations, fights, and deportations of people from Mazuria during the winter 1944/1945 caused the depopulation of these areas. After the World War II people from the eastern borderlands of Poland (Wilno and Grodno regions) were displaced here as well as people from Masovia and Łemkowszczyzna in the frame of the so called "Wisła action" in 1947.

DESCRIPTION OF SITES

The sediments of four sites located in the eastern part of the Great Mazurian Lake District were studied (Fig. 1), namely Lake Miłkowskie, Lake Wojnowo, Lake Łazduny, and former Lake Staświńskie (Szczepanki 8). According to the subject matter of the present paper the investigations were limited to the upper sections of deposits filling the basins.

L a k e M i ł k o w s k i e, called also Lake Wobel, Łobel, or Niełeckie, former names: Wobel See, Milkener See (Karczewska et al. 2005), 53°51′N, 21°50′E, 124.8 m a.s.l.

Lake Miłkowskie, with water surface area of 23.7 ha, is situated in the village Miłki (Fig. 3). The lake is of glacial origin, it has the shape of an elongated ellipse running north-south (the length is ca 1280 m, diagonal line ca 200 m). It attains the maximum water depth

Fig. 3. Lake Miłkowskie. View over the lake (Phot. A. Wacnik) and coring of the bottom sediments (Phot. K. Więckowski)

of 15 m in the northern part, its average depth is 4.2 m (Choiński 1991). The reservoir is fed by two streams, and in addition to the surface run-off probably also by the inflow of shallow underground waters from the morainic upland (Tatur 1993). The lake is situated in a depression surrounded by morainic hills. Steep escarpments, over 10 m high, slope down to the water surface on both eastern and western lake sides, northern and southern slopes are gentler. On eastern side the lake adjoins farm buildings and Giżycko-Orzysz road, from the west and south it is surrounded by arable fields and meadows. This type of localizations caused strong water eutrophication. At the northern lake end there is an outflow to Lake Wojnowo. Lake Miłkowskie belongs to the catchment area of Lake Niegocin. The vegetation surrounding Lake Miłkowskie is devoid of forest and shows strong anthropogenic changes (Fig. 3). Forests cover only 10% of the area. A considerable area in Miłki rural district is taken by grasslands: meadows cover 15–20%, pastures 10–37%, fallows and waste lands 20–30% of agriculturally used grounds. Cereals dominate among cultivations, occupying 75–80% of arable land. To the distance of 500 m from lake shore the terrain is overgrown by herbaceous vegetation, with scattered trees occurring only near buildings, along roads, streams, and at the lake shores. A small planted pine forest, a dozen or so years old, grows south of the lake. The quality of lake water is improving since the closure of a dairy, which was the main source of contaminants until the eighties of the 20^{th} century.

Lake Wojnowo, former names: Wey Lang See, Hessen See (Karczewska et al. 2005), 53°57.901′N, 21°49.854′E, 115 m a.s.l.

Lake Wojnowo, 176.3 ha of water surface, is situated within the villages Miłki, Staświny, Ruda, and Kleszczewo (Fig. 1). It fills a glacial gully about 4.6 km long. Average water depth is 6.3 m. There are two depressions in the lake bottom, in the southern part the maximum depth is 14.2 m, in the northern part 11.7 m. Mean lake width equals 380 m. Lake's water belongs to the purity class III. A stream Głaźna Struga runs from the south end of Lake Wojnowo to Lake Buwełno, at the north one watercourse joins Kleszczewska Bay with Lake Niegocin through Lakes Niałk Mały and Niałk Duży, the other one connects Rudzka Bay with Lake Rudzkie Małe. River Staświnka falls to the lake from the east, as does the stream from Lake Miłkowskie. The

Fig. 4. Lake Wojnowo. View over the lake and coring site on frozen lake (Phot. A. Wacnik)

surroundings of the lake are strongly deforested and exploited agriculturally (Fig. 4).

L a k e Ł a z d u n y (former name: Lasdun See), 53°51.4′N, 21°57.3′E, 128.8 m a.s.l.

The lake, 0.8 km long, fills the sub-glacial channel running NNW-SSE, situated about 10 km south-east from Miłki (Fig. 1). It has strongly elongated shape, water body surface is 10.6 ha. The maximum water depth is 22.4 m, with the mean value of 9.1 m. From the southern side the lake is drained by a brook flowing to Lake Rzęśniki and next to Lake Orzysz. The catchment area of Lake Łazduny is small and equals about 20 ha. It is built of fluvioglacial sands and gravels covered with podzols. Contrary to all other sites its surroundings are almost completely wooded.

S t a ś w i ń s k i e M e a d o w s (former: Staświn, Stasswinner Wiesen, Eisermühl Wiesen), former Lake Staświńskie (Gumiński 2003).

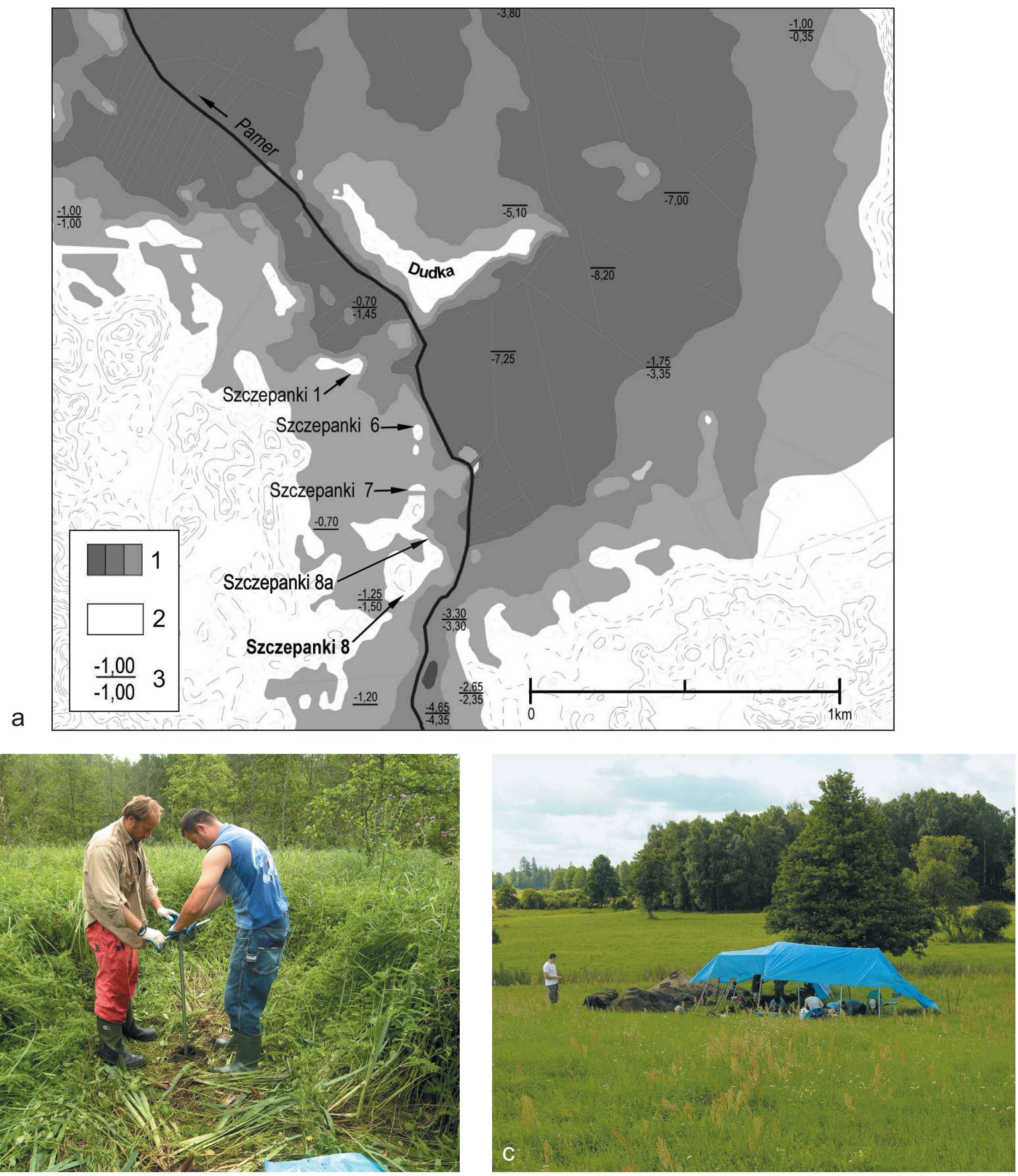

Fig. 5. Location of the site Szczepanki 8a in the southern part of former Lake Staświńskie (after Gumiński 2008); **a**: **1** – limnic sediments and peat, **2** – terrestrial sediments, **3** – thickness of peat/thickness of gyttja; **b**: coring of the sediments with the Instorf sampler (Phot. A. Wacnik); **c**: view over Szczepanki 8 archaeological site (Phot. A. Wacnik)

The site Szczepanki 8a (53°57.428′N, 21°59.280′E, 132 m a.s.l.; Fig. 5) is situated in the southern part of the area named Bagno Moczyska (Röster Wiesen). This large area, covering the surface of about 25 km^2, came into existence when the former lake, after becoming shallower and partly overgrown, was finally drained in 1836 (Toeppen 1870).

The Pamer/Staświnka River (canal) runs through Staświńskie Meadows and flows into Lake Wojnowo at Staświny. A local road Lipińskie-Wydminy (Fig. 1) divides the terrain of Staświńskie Meadows, wet and peaty in places, into the northern part and the southern part called Bagno Moczyska (Röster Wiesen). During the existence of the lake, several sandy islands were present within the reservoir (Fig. 5). Some of them, for instance Dudka and Szczepanki, were intensively inhabited by people during the Stone Age (e.g. Gumiński 1995, 2003). The edges of the Stawińskie Meadows gyttja land are used as grasslands, and its central part is occupied by reed rushes surrounded by sedges (Łachacz et al. 2009). This area is mostly woodless. In the studied microregion arable land prevails (62% of the surface). Raising cattle plays great role in the structure of agriculture. Small patches of woodland and open grazed thickets occur particularly in the southern part of the area. Forest border more or less follows shore line of the former lake. Geological investigations at Dudka showed that up to 1.2 m thick peat deposits reach as far as a dozen or so metres from the island, farther off only lake sediments occur (Żurek 2003). Forests cover about 22% of the area in the Szczepanki-Wydminy region (Plan of the local development of the Wydminy District 2004).

MATERIAL AND METHODS

FIELD WORKS

Lake Miłkowskie

In 1998 two twin sediment cores were acquired from a floating platform with the use of the Więckowski piston corer. Coring was performed in the deepest part of the lake, beneath 15 m of water, where the deposits had the greatest thickness equal 24.59 m. The whole sediment core was analysed palynologically and the results obtained for the bottom section were presented in earlier publications (Wacnik 2005, 2009a, b). The present paper deals only with the upper 16 m long section of the profile M3-M4/98 that accumulated from about 2300 BC to the present.

Lake Wojnowo

The material was collected in 2005 from the ice with the Więckowski piston corer (Fig. 4). Coring place was localized within the northern lake deep near Rudzka Bay, where water depth was 11.70 m. Coring was done from the two holes, from which 2 m long core sections were taken alternately with 20 cm overlap. The core 18.70 m long was recovered, but the base of the sediment was not reached. In the present work only the results obtained for the top 11 m of sediments are discussed, the accumulation of which lasted from about 1800 BC to the present.

Lake Łazduny

Cores for analysis were collected from the deepest part of the lake using the UWITEC USINGER and UWITEC equipment, in the frame of the NORPOLAR project, by the team from University of Gdańsk, directed by W. Tylmann (Tylmann et al. 2011, final report from project accomplishment, unpubl.). The profile chosen for palynological studies was 8.15 m thick. Only the results concerning the upper sediment section covering the time from about 2300 BC to the present are presented in this paper.

Former Lake Staświńskie, the site Szczepanki 8a

The material was collected with the Russian sampler Instorf at the edge of the former island, near archaeological sites Szczepanki 8 and 8a (Gumiński 2003). Several cores were selected for detailed analyses, including SzI/2005 (Wacnik & Ralska-Jasiewiczowa 2008), Sz30E1N (Madeja et al. 2009) and Sz8a/2. The bore-hole Sz8a/2 was situated at a few metres distance from an archaeological excavation, in which the relics of the Mesolithic and the para-Neolithic Zedmar culture settlements were discovered (Fig. 5). The total thickness of the recovered sediment was 3 m, but in this publication only the top section accumulated from about 2300 BC to 1500 AD will be described.

LABORATORY PREPARATION

Sediment description

L a k e M i ł k o w s k i e, the profile M3-M4/98

The lithology was elaborated by A. Tatur, A. Wasiłowska, and P. Gromadka from the Centre for Ecological Research, Polish Academy of Sciences (Wacnik et al., final report from project accomplishment, unpubl.)

0–3.7 m – gyttja rich in organic matter, relatively poor in iron compounds and silica. Lamination occurs from the bottom, laminae with more carbonates alternate with those containing clay rich in organic matter. The thickness of laminae couplets <2 mm at the bottom upwards increases up to 2 cm. Lamination irregular between 2.20 and 0.25 m, regular below and above that depth.

3.7–7.8 m – gyttja with downwards increasing amount of carbonates. At the top organic sediment, humic (30%), rich in clay and silt (30%), with silica (20%), and iron compounds (20%), contains only traces of carbonates, lamination irregular.

7.8–12.0 m – gyttja strongly organic (25%) in the central section, less so at the bottom and the top. Relatively low amount of iron compounds (< 10%) and silica (5%), regularly laminated.

12.0–13.7 m – gyttja, organic (30%) – ferruginous (25%)-marlaceous (20–40%) sediment with variable amount of carbonates and clay, rich in silica (12%), densely laminated.

13.7–17.5 m – gyttja, marlaceous sediments (40%), strongly organic (25%), and siliceous (15%), densely laminated.

17.5–18.17 m – gyttja, marlaceous sediments (50%), strongly organic (25%), and siliceous (15%), with relatively small amount of iron compounds (10%), densely laminated. Light carbonate sub-laminae appear.

18.17–19.89 m – gyttja, marlaceous sediments, strongly ferruginous, with considerable admixture of organic matter (15%) and small amount of silica (5%), towards the top they change to ferruginous (30%) – siliceous (25%) – organic (25%), clayey (20%), weakly carbonate (5%), densely laminated.

In total, 241 samples of bottom deposits were analyzed palynologically. Only 83 pollen samples came from the profile section discussed in the present work from which also 16 samples of pollen extracts were dated by the AMS ^{14}C method.

Lake Wojnowo

The 18.7 m long sediment core W/2005 was built of the fine detritus gyttja, dark olive at the top and brown at the bottom. Most of the sediment was homogenous. Sections at 12.1–13.4 m and 15.3–17.7 m were irregularly laminated.

84 samples were analysed palynologically and 3 samples of pollen extracts were AMS ^{14}C dated.

Lake Łazduny

The lithology was described by W. Tylmann from the Gdańsk Uniwersity (Tylmann et al., report from project accomplishment, unpubl.)

0–6.06 m – laminated clay, brown to grey-black in colour, with intercalations of fine-grained sand at the depth 0.59–0.605 m

6.06–6.065 m – fine-grained grey sand

6.065–6.18 m – laminated silt, grey-black

6.18–6.55 m – sandy silt, laminated, grey-black

6.55–6.56 m – homogenous silt, black

6.56–6.97 m – sandy silt, indistinctly laminated, grey-black

6.97–7.96 m – fine-grained sand, grey, indistinctly laminated at 6.97–7.22 m, homogenous below that depth

7.96–8.03 m – fine grained sand with gravel, homogenous, light grey

8.03–8.13 m – sandy silt, indistinctly laminated, grey-black

8.13–8.16 m – fine grained sand, homogenous, light brown

From the whole core, 103 samples taken every 8 cm were subjected to pollen analysis. From the section discussed in this publication, 44 samples were analyzed for pollen and 6 samples were dated by ^{14}C AMS method.

Former Lake Staświńskie, the profile Szczepanki Sz 8a/2

Core Sz 8a/2 was 3 m thick.

0–0.23 m – herbaceous peat, mackous, lumpy, penetrated by roots of modern plants.

0.23–0.91 m – herbaceous peat, strongly decomposed, below 0.45 more saturated with water, contains twig fragments.

0.91–0.95 m – herbaceous peat with humic substances and plant detritus, twigs visible.

0.95–1.28 m – fine detritus gyttja.

1.28–1.49 m – sandy detritus gyttja.

1.48–2.18 m – gyttja with a large number of *Equisetum fluviatile* remains.

2.18–2.28 m – clayey and sandy gyttja with a small number of *Eqiusetum fluviatile* remains.

2.28–2.5 m – mud with a few remains of *Equisetum fluviatile*.

2.5–3.0 m – mud with intercalations of fine-grained sand, with a small number of *Equisetum fluviatile* remains.

Pollen analysis was performed for 67 samples from the lacustrine-peaty profile but in this publication only 18 samples are included. For the radiocarbon dating 4 samples of plant macrofossils were used.

SAMPLE PREPARATION AND THE DETERMINATION OF MICROFOSSILS

Samples for pollen analysis were prepared with the standard Erdtman's acetolysis method (Berglund & Ralska-Jasiewiczowa 1986, Faegri & Iversen 1989). In each case 1 cm^3 of sediment was used. According to the degree of contamination by the mineral fraction the samples were treated with cold HF for 24 hours or boiled in HF for 15 minutes. Counting of all pollen grains and spores was continued until the number of 700 grains of trees and shrubs was achieved in each sample. For identification pollen keys were used (Beug 2004, Reille 1995, 1998) and the reference collection of modern sporomorphs at the Department of Palaeobotany of the W. Szafer Institute of Botany, Polish Academy of Sciences in Kraków. *Lycopodium* tablets were added in order to calculate the concentration of sporomorphs and non-pollen palynomorphs (Stockmarr 1971). Selected taxa of green algae were counted, including the genera *Pediastrum*, *Scenedesmus*, *Coelastrum*, *Tetraedron*, and *Botryococcus*. Their identification was based on publications by Jankovská and Komárek (2000), Komárek and Fott (1983), Komárek and Jankovská (2001), and Komárek and Marvan (1992). In the profiles from Lake Miłkowskie, Lake Wojnowo, and site Szczepanki 8a, wood charcoal microfragments were counted parallel to pollen grains on the same surface of slides as all the other microfossils. Two size groups were recorded, 10–100 µm and > 100 µm.

The results were presented in percentage pollen diagrams drawn in the program POLPAL for Windows

(Nalepka & Walanus 2003). Percentages were calculated from the total sum, which included trees and shrubs (AP), and herbaceous plants (NAP), except for local plants: aquatic and bog taxa, fern and sphagnum spores. The frequency of each taxon excluded from the total sum was calculated from the same total increased by the addition of the number of sporomorphs representing this particular taxon.

The diagrams were divided into local pollen assemblage zones (L PAZ) and subzones (L PASZ) on the basis of taxonomic composition of pollen spectra and percentage values of the most abundant or most characteristic taxa. Numerical analyses were also applied (ConSLink; Nalepka & Walanus 2003). In a similar way the developmental phases (I–III) of aquatic and reed swamp vegetation were distinguished. The results were presented on the BC/AD time scale.

CHRONOLOGY

Chronology of the profiles was based on AMS radiocarbon dating performed mostly in the Poznań Radiocarbon Laboratory. The sediments from Lakes Miłkowskie and Wojnowo contained no macroremains of terrestrial plants therefore it was necessary to use plant pollen as the only organic matter less contaminated than gyttja. The isolation of pollen concentrates from the sediment for AMS dating was performed by flotation in heavy liquid, with the use of $ZnCl_2$ solution of the adequate specific gravity (Nakagawa et al. 1998). In every case 5–8 cm^3 of sediment was used for this purpose. In none of the samples the complete removal of contaminants was possible. Samples with the lowest percentage number of plant detritus were selected for dating. Plant macrofossils from the site Szczepanki 8a and Lake Łazduny were extracted by maceration of the sediment in distilled water and picking diaspores and other plant particles. The results are presented in Table 1.

The obtained ^{14}C dates were used for construction of age-depth models of the analysed profiles. The models were built by means of the "free-shape" algorithm, developed by Goslar et al. (2009). For three of four profiles, calendar date at the top (0.0 m) was set at 2000±10 AD. One exception was the profile Szczepanki 8, where the topmost sediments were not preserved due to the erosion caused by agricultural exploitation of the site in modern times. Constructing age-depth model of the profile from Lake Miłkowskie, the set of ^{14}C dates from that lake was supplemented

Table 1. The results of AMS radiocarbon dating, and additional dates used in construction of age-depth models

Site name / profile	Depth [m] from a top of sediments	No. Lab.	Type of material	Age ^{14}C BP	Calendar age BC/AD (95% probability)	Lab. remarks
Lake Miłkowskie / M4/98	2.60–2.62	Poz-15438	pollen extract	640±60	1272–1413 AD	0.09 mgC
Lake Miłkowskie / M4/98	3.82[1]			905±50[1]		
Lake Miłkowskie / M4/98	4.31–4.33	Poz-15439	pollen extract	1355±30	632–710 AD	
Lake Miłkowskie / M4/98	4.71–4.73	Poz-15440	pollen extract	1465±30	550–645 AD	
Lake Miłkowskie / M4/98	5.71–5.73	Poz-15519	pollen extract	1950±30	2 BC – 125 AD	
Lake Miłkowskie / M4/98	6.20–6.22	Poz-15442	pollen extract	2070±30	173–19 BC	
Lake Miłkowskie / M4/98	6.60–6.62	Poz-15520	pollen extract	2330±30	420–360 BC	
Lake Miłkowskie / M4/98	7.03–7.05	Poz-15443	pollen extract	2365±30	523–386 BC	
Lake Miłkowskie / M4/98	7.43–7.45	Poz-15444	pollen extract	2410±30	549–399 BC	
Lake Miłkowskie / M4/98	7.83–7.85	Poz-15445	pollen extract	2480±30	769–503 BC	
Lake Miłkowskie / M4/98	8.60–8.62	Poz-15446	pollen extract	2465±30	670–481 BC	
Lake Miłkowskie / M4/98	8.02–8.04	Poz-15448	pollen extract	2595±35	830–750 BC	
Lake Miłkowskie / M4/98	8.41–8.43	Poz-15449	pollen extract	2790±30	1011–889 BC	
Lake Miłkowskie / M4/98	10.60–10.62	Poz-15523	pollen extract	2745±35	946–814 BC	
Lake Miłkowskie / M4/98	11.04–11.06	Poz-15524	pollen extract	2895±30	1210–996 BC	

Lake Miłkowskie / M4/98	11.82–11.84	Poz-15525	pollen extract	2960±35	1300–1052 BC	
Lake Miłkowskie / M4/98	12.42–12.50	Poz-2122	pollen extract	3020±70	1424–1054 BC	0.4 mgC
Lake Miłkowskie / M4/98	16.136–16.143	Poz-843	fragment of leaf nervure	5060±45	3964–3761 BC	
Lake Łazduny	0.635	GdA-2465	pollen extract	62±24	1695–1955 AD	
Lake Łazduny	0.925	GdA-2466	pollen extract	423±35	1419–1620 AD	
Lake Łazduny	1.18	GdA-2468	epiderm of *Pinus sylvestris*	533±36	1314–1442 AD	
Lake Łazduny	2.31	GdA-1910	epiderm of *Pinus sylvestris*	2000±20	45 BC – 54 AD	
Lake Łazduny	2.57	GdA-2469	epiderm of *Pinus sylvestris*	2422±29	747–402 BC	
Lake Łazduny	3.35	GdA-2470	epiderm of *Pinus sylvestris*	3767±39	2297–2113 BC	
Lake Łazduny	4.56	GdA-1911	stalk fragments	5785±25	4707–4554 BC	
Lake Wojnowo /W/2005	1.10–1.20	Poz-22051	pollen extract	905±30	1039–1208 AD	
Lake Wojnowo /W/2005	2.60–2.65	Poz-22052	pollen extract	1520±30	504–609 AD	
Lake Wojnowo /W/2005	3.70–3.75	Poz-22053	pollen extract	1860±30	80–231 AD	
Lake Wojnowo /W/2005	591[2]				700±65 BC[2]	
Lake Wojnowo /W/2005	854[2]				1350±70 BC[2]	
Lake Wojnowo /W/2005	994[2]				1630±150 BC[2]	
Lake Wojnowo /W/2005	1074[2]				1710±200 BC[2]	
Former Lake Staświńskie / Szczepanki Sz 8a/2	0.05[3]				<1450–1550 AD[3]	
Former Lake Staświńskie / Szczepanki Sz 8a/2	0.4–0.45	Poz-42981	*Betula* sec. *Albae* fruits, fruit scales;	2220±60	399–157 BC	0.2 mgC
Former Lake Staświńskie / Szczepanki Sz 8a/2	0.6–0.65	Poz-42980	*Betula* sec. *Albae* fruits, fruit scales; *Alnus glutinosa* fruit	3010±35	1386–1153 BC	0.8 mgC
Former Lake Staświńskie / Szczepanki Sz 8a/2	0.8–0.85	Poz-42979	*Betula* sec. *Albae* fruits, fruit scales; *Alnus glutinosa* fruits, *Urtica dioica* fruit	3920±35	2490–2293 BC	
Former Lake Staświńskie / Szczepanki Sz 8a/2	0.95–1.0	Poz-42978	*Betula* sec. *Albae* fruits, fruit scales; *Urtica dioica* fruits	4160±60[4]	2889–2580 BC	0.4 mgC
Former Lake Staświńskie / Szczepanki Sz 8a/2	0.97[5]			5060±45[5]		
Former Lake Staświńskie / Szczepanki 8 EZ 30E1N A62	1.05[6]			5580±40[6]		

[1] – ^{14}C date of level 1.1–1.2 m depth in palynological profile of the nearby Lake Wojnowo, attributed to the profile M3-M4/98 basing on correlation of changes of the pollen composition.
[2] – calendar dates of four levels in palynological profile from Lake Miłkowskie, attributed to the profile from Lake Wojnowo basing on correlation of changes of the pollen composition. Quoted uncertainties 1 σ of calendar dates take into account uncertainties of calendar dates of correlative levels in the profile M3-M4/98 (i.e. uncertainty of age-depth models illustrated in Fig. 6) and precision of correlation of the pollen spectra from both profiles.
[3] – calendar date being assumed the youngest possible date of the level 0.05 m in Sz 8a/2, the pollen spectrum of which still does not show any trace of stronger deforestation. It suggests the deposition of the upper part of sediment before historically confirmed existence of habitation places/villages in the vicinity of Szczepanki
[4] – ^{14}C date measured at the level of the main elm decline in the pollen profile Sz 8a/2 appears much younger than the date of *Ulmus* fall documented in many sites of the region.
[5] – ^{14}C date of *Ulmus* fall in the profile M3-M4-98 from Lake Miłkowskie, palynologically well correlated with the profile Sz 8a/2.
[6] – ^{14}C date from another profile Sz 30E1N from the same site Szczepanki 8, synchronised with the profile Sz 8a/2 basing on correlation of pollen records

with the date (905±50 BP, Tab. 1) measured in sediments of Lake Wojnowo, situated only 5 km apart. This was justified by the correlation of analogous changes of vegetation marked in palynological profiles of both lakes, which have been directly dated by ^{14}C in the Lake Wojnowo profile only.

The age-depth model of the profile M3-M4/98 from Lake Miłkowskie is shown in Figure 6. In the profile, several sections of different sedimentation rate are clearly distinguished, with the highest rate between ca 6.20 and 12.50 m. Worth pointing out is an especially high uncertainty of the model in the lower section (below 12.50 m), caused by a large depth span between the ^{14}C dated samples. Similar effect of large time span is visible in age-depth model of Lake Łazduny, in the sections between 1.18–2.31 m, 2.57–3.35 m, and 3.35–4.56 m (Fig. 7).

The age-depth model of the profile from Lake Wojnowo (Fig. 8) is based on directly obtained ^{14}C dates in the upper part only, while below the depth of 5.91 m, the model relies on calendar dates of four levels of the profiles M3-M4/98, palynologically correlated with the appropriate levels of the profile from Lake Wojnowo (Tab. 1).

The age-depth model from Szczepanki 8 (Fig. 9) relies on ^{14}C dates measured in the profile itself, one date measured in another profile from the same site (Tab. 1), ^{14}C date of the *Ulmus* fall, measured in the profile from Lake Miłkowskie, and an estimate of the latest possible calendar date of the top of the analysed core.

FORMER PALYNOLOGICAL STUDIES OF THE SITES INCLUDED IN THIS PAPER AND IN THEIR SURROUNDINGS

Late Glacial and early Holocene vegetation history in Lake Miłkowskie area was the subject of a few publications (Wacnik 2005, 2009a, b, Czernik 2009). The master thesis of R. Tatur (1993, unpubl.) concerned the youngest section of the Holocene. The preliminary

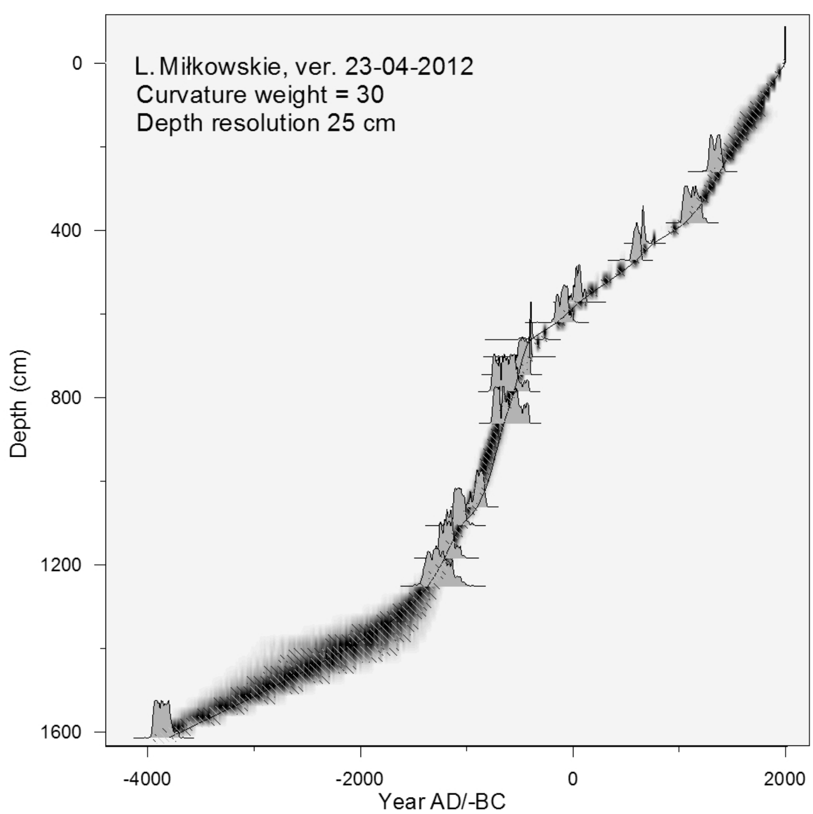

Fig. 6. Age-depth model of the profile M3-M4/98 of sediments from Lake Miłkowskie. Grey silhouettes represent probability distributions of calibrated ^{14}C dates of individual samples. The most probable course of the age-depth relationship (the best-fit model, Goslar et al. 2009) is shown by solid line. The dashed patterns represent 68% and 95% confidence intervals of calendar dates (AD/-BC) at given depths along the profile, while modelled probability distributions of these dates are presented by grey band displayed around the best-fit line

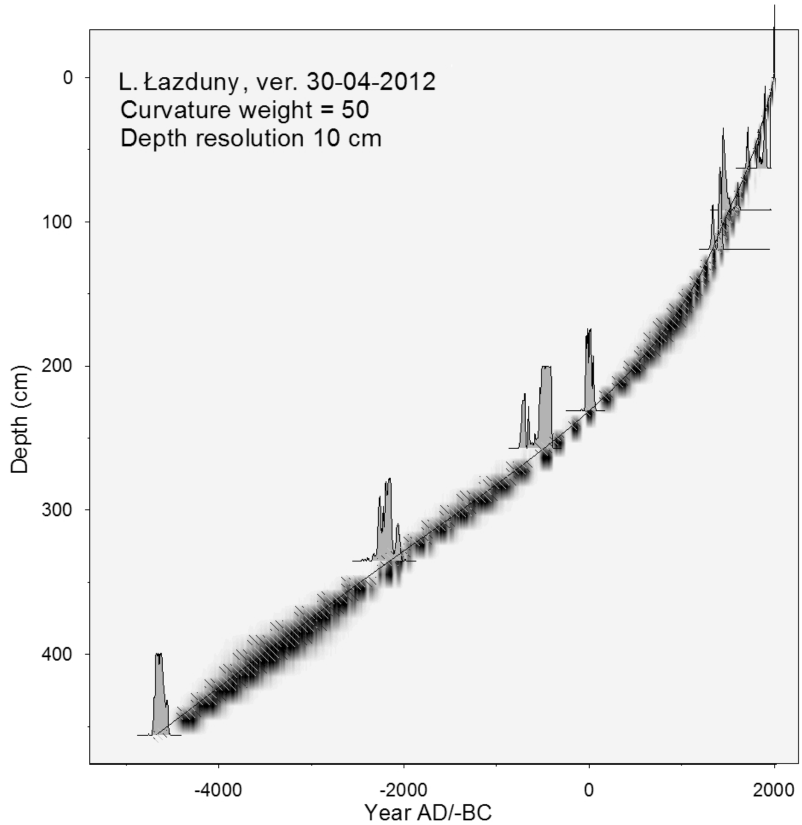

Fig. 7. Age-depth model of the profile of sediments from Lake Łazduny. For explanations see Fig. 6

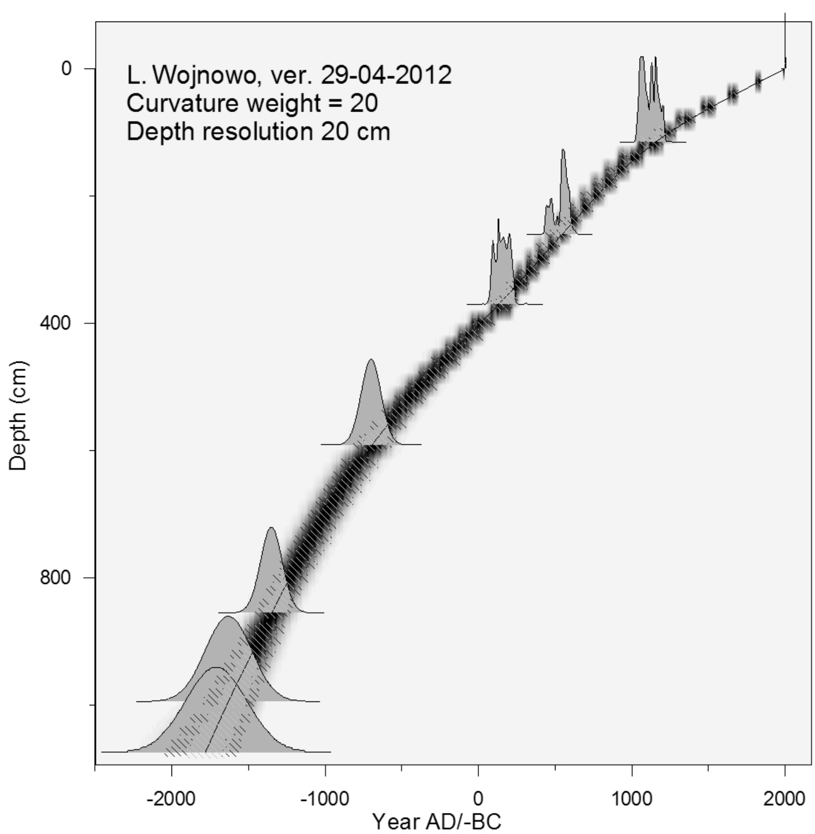

Fig. 8. Age-depth model of the profile W/2005 of sediments from Lake Wojnowo. For explanations see Fig. 6

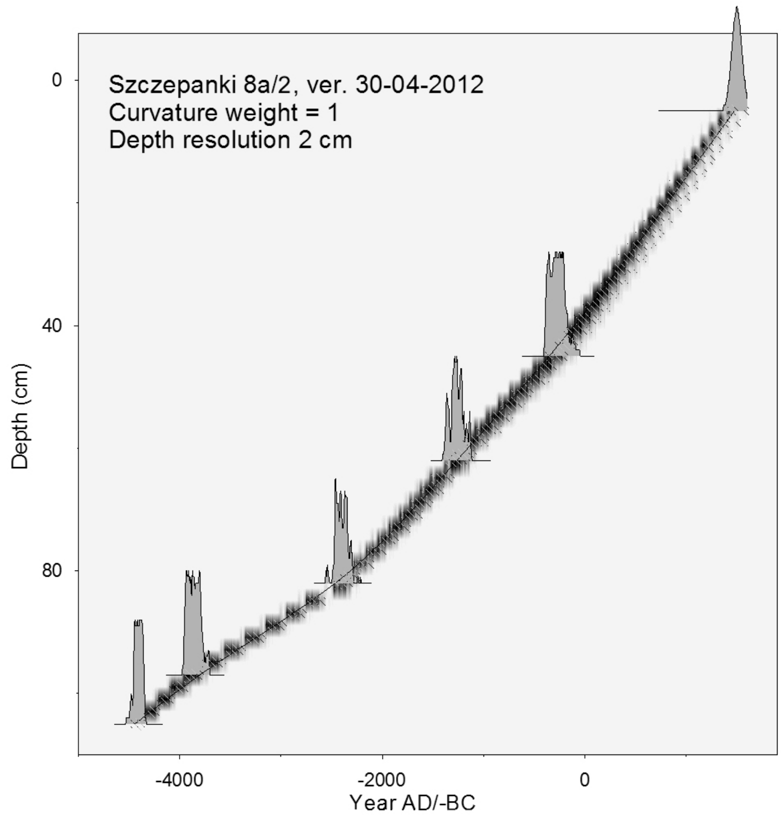

Fig. 9. Age-depth model of the profile of sediments from Szczepanki 8a/2. For explanations see Fig. 6

results of pollen analysis of new materials from Lake Miłkowskie were presented by Wacnik (2009c) and Madeja et al. (2010). In the case of Lake Wojnowo only the preliminary information about vegetation changes during the last 2 millennia were published (Wacnik 2009c). In the vicinity of these two sites palynological studies were carried out on the Bagna Nietlickie area, namely in Lake Jędzelek and at lake-peat bog sites Nietlice I and II (Kupryjanowicz 2002, Karczewski et al. 2007). No palaeobotanical investigations were hitherto carried out on Lake Łazduny. Palynological examination of deposits from the former Lake Staświńskie was started before the World War II by H. Gross (1935, 1940), and was continued by D. Nalepka (1995) at the locality Dudka. Palynological investigations on a newly discovered site at Szczepanki 8 were initiated by A. Wacnik. They concerned lake sediments of the shore zone of the former island, which contained the relics of prehistoric settlement, and the materials coming directly from culture layers (Wacnik & Ralska-Jasiewiczowa 2008, Madeja et al. 2009). The present studies deal with the nearby archaeological site Szczepanki 8a.

RESULTS AND DISCUSSION

VEGETATION DEVELOPMENT IN THE MIŁKI-STAŚWINY-WYDMINY MICROREGION IN THE LIGHT OF PALYNOLOGICAL DATA

The results of pollen analysis from Lake Miłkowskie are presented in Table 2 and Figures 10a, b, from Lake Wojnowo in Table 3 and Figures 11a, b, from Lake Łazduny in Table 4 and Figures 12a, b, and from the former Lake Staświńskie in Table 5 and Figures 13a, b.

Local pollen assemblage zones and zones of local vegetation transformations, which are delimited in pollen diagrams, allow to describe the stages of vegetation change in the microregion and in water basins themselves. The comparative analysis of local vegetation changes was the basis for the characterization of the regional changes (Fig. 14). It allowed to draw conclusions concerning vegetation transformations in the eastern part of the Great Mazurian Lake District. The present publication is devoted to vegetation alterations connected with the activity of farming societies. Three zones of regional changes of forest communities were distinguished between 2300 BC and 2000 AD.

Table 2. Lake Miłkowskie. Changes of local vegetation

L PAZ and L PASZ; depth; approximate age	Description of zones: Terrestrial vegetation	Description of zones: Aquatic and shore-line vegetation	Phase of basin development
M 1; *Alnus-Corylus-Quercus*; 14.20–13.20 m; 2246 BC – 1635 BC	High but decreasing *Corylus* (up to 25.2%), low and stable *Ulmus* (ca 1.5%), *Betula* (up to 25.7%), *Tilia* (up to 5.7%). High frequency of *Quercus* (16.6%) and *Alnus* (33%). Stable *Fraxinus* (ca 3%) and *Pinus* (ca 15%). Rise of *Carpinus* (up to 4%) and *Picea* (up to 2.1%). NAP represented mostly by pollen of Poaceae up to 2.7%. In several spectra *Plantago lanceolata*, *Plantago major*, *Rumex acetosella*-t., and Cerealia. Upper zone boundary: increase of *Fraxinus*, fall of *Alnus* and *Quercus*.	Regular occurrence of *Sparganium*-t. and *Phragmites* pollen. *Equisetum*, *Thelypteris palustris*, and *Sphagnum* spores. Abundant *Tetraedron* (up to 46%) and *Botryococcus*. Systematically *Scenedesmus*, *Coelastrum reticulatum*, and *Pediastrum* mainly *P. boryanum* var. *longicorne*, *P. boryanum* var. *perforatum/cornutum*, *P. boryanum* var. *boryanum*, and *Pediastrum duplex* var. *duplex/gracillimum*.	I; 14.20–12.1 m; 2246–1256 BC
M 2; *Alnus-Fraxinus-Picea*; 13.20–2.25 m; 1635 BC – 1300 BC	Decrease of *Corylus* (from 14 to ca 6%). *Quercus* up to 13%. Rise of *Fraxinus* up to 8.6% at the bottom, and then fall to ca 3%. *Carpinus* with maximum up to 9% at the top. *Picea* up to 7.6%. *Ulmus* up to 2.1%. *Populus* below 1%. *Alnus* up to 32%. Stable values of *Pinus* (up to 22%), *Tilia* (up to 5.9%), and *Betula* (up to 30%). Continuous *Fagus* below 1%. More frequent Poaceae (5.5%), *Artemisia* (1.9%), and regularly *Rumex acetosella*-t., and Cerealia. Upper zone boundary: drop of *Corylus*, *Quercus*, and rise of *Betula*.		
M 3; *Betula-Carpinus*; 12.25–3.7 m; 1300 BC – 1100 AD	Fast increase and high values of *Betula* (up to 51.7%). Consistently decreasing frequency of *Alnus* (from 20.5% to ca 10%), *Corylus* (from 6.4% to 2%) and *Tilia* (from 3% to 1%). High but oscillating frequency of *Quercus* (up to 14.4%) and *Pinus* (do 29%). Continuous but low curves of *Ulmus* and *Fraxinus.* Rising *Carpinus* frequency (up to 7.9%). Stable and low *Picea* frequency (up to 2.2%). Almost continuous curves of *Fagus*, *Salix*, and *Populus*. Several times *Juniperus*, *Taxus*, *Sorbus*, and *Rhamnus*. Fluctuating NAP. Relatively abundant Poaceae (up to 5%) and Cyperaceae (up to 2%). Regularly occurring human indicators: *Artemisia*, *Plantago lanceolata*, *Rumex acetosella*-t., Cerealia, and *Secale cereale*. Upper zone boundary: sudden reduction of AP. Strong decrease of *Betula*, *Quercus*, short-lasting rise of *Carpinus*, *Picea*, and NAP.	Regularly *Phragmites* (up to 1.5%), *Sparganium*-t. and Filicales monolete. A few times *Nuphar*, *Nymphaea alba*, and *Typha latifolia* pollen. At the bottom and at the top numerous *Coelastrum reticulatum* (up to 9.5%) and the presence of *C. polychordum*. At the bottom fast disappearance of *Tetraedron*. *Botryococcus* (up to 7.5%) predominates among green algae. Regularly recorded few coenobia of *Pediastrum*, mainly *P. boryanum* var. *longicorne*, *P. duplex* var. *rugulosum*, and *P. boryanum* var. *boryanum*.	II; 12.1–3.7 m; 1256 BC – 1100 AD
M 3a; *Quercus-Betula*; 12.25–12.07 m; 1300–1256 BC	Rise of *Betula* up to 25%. At the top 12% of *Quercus* pollen. High *Alnus* frequency. *Corylus* up to ca 6%.		
M 3b; *Betula*; 12.07–10.2 m; 1256–828 BC	Continued rise of *Betula* up to 42%. High *Pinus* pollen frequency up to 21%. After a culmination (14%) systematic *Quercus* fall. Some decrease of *Alnus*. Stable *Carpinus* (up to 4%) and *Tilia* (up to 3%). Continuous curves of Poaceae, Cyperaceae, *Artemisia*, *Secale cereale*, and *Plantago lanceolata*.		
M 3c; *Carpinus-Pinus*; 10.2–9.4 m; 828–734 BC	Fall of *Betula* (to 26%) contemporaneous with short-lasting increases of *Pinus* (up to 29%), *Corylus* (up to 6%), *Carpinus* (up to 6%), and *Alnus* (up to 19%). Slightly limited NAP frequency.		
M 3d; *Betula*; 9.4–6.6 m; 734–395 BC	Repeated rise of *Betula* (up to 45%), *Pinus* reduction (to 25%). Stable and high *Alnus* frequency (up to 18%). *Carpinus* up to 4%, *Corylus* 4%, *Quercus* 12%, and *Picea* to 1%. Continuous curves of e.g. Poaceae (up to 4%), *Artemisia*, and *Secale cereale*.		
M 3e; *Betula-Carpinus-Quercus*; 6.6–6.1 m; 395–86 BC	Stable and high frequency of *Betula* up to 43%. *Quercus* up to 11%. Rise of *Carpinus* up to 8%. Low *Corylus* (to 3%) and *Picea* (to 1.5%). Decreased percentages of *Alnus* (to 14%) and NAP.		
M 3f; *Alnus-Pinus*; 6.1–5.4 m; 86 BC – 252 AD	A few percent fall of *Betula* (down to 34%) and *Carpinus* (to 7%). Short rises of *Pinus* (up to 27%) and *Alnus* (up to 15%). *Quercus* frequency up to 11%. 1–2% curves of *Corylus*, *Picea*, and *Ulmus*.		

Table 2. Continued

L PAZ and L PASZ; depth; approximate age	Description of zones		Phase of basin development
	Terrestrial vegetation	Aquatic and shoreline vegetation	
M 3g; *Betula-Quercus-Carpinus*; 5.4–3.7 m; 252–1100 AD	The highest frequency of *Betula* (up to 51.7%). Abundant *Pinus* (up to 28%), *Quercus* (up to 10%), and *Carpinus* (up to 6.4). Lower on average representation of *Alnus* (to 17%). 1–2% frequency of *Picea* and *Corylus*. Continuous *Fagus* curve <1%. NAP very low.		
M 4; NAP-*Pinus-Picea*; 3.70–0.12 m; 1100–1968 AD	Strong reduction of *Betula* (from 30.4% to ca 10%) and *Quercus* (from 7.8% to ca 2%). Decreasing *Alnus* forms two culminations (15.5% and 14.3%). Increased frequency of *Pinus* (up to 37.6%), *Picea* (6.4%), and *Salix* (up to 5.5%). End of continuous curves of *Ulmus*, *Tilia*, and *Fraxinus*. Characteristic very high participation of herbaceous plants, particularly Poaceae (up to 14.4%), *Artemisia* (up to 4%), Cyperaceae (up to 4.6%), Cerealia (up to 5.8%), *Secale* (up to 11.1%), Brassicaceae (up to 5.6%), *Rumex acetosella*-t. (up to 6.1%), and *Centaurea cyanus* (up to 5%).	Higher representation of aquatics. Continuous curve of *Phragmites* (up to 3.7%). More abundant *Potamogeton* (up to 2.3%, *Myriophyllum* (*M. spicatum* and *M. verticillatum*), Filicales, *Sphagnum*, and *Equisetum*. Rapid development of green algae mainly *Pediastrum* (*P. boryanum* var. *boryanum*, *P. boryanum* var. *longicorne*, *P. boryanum* var. *perforatum / cornutum*, *P. duplex* var. *gracillimum / duplex*), and *Coelastrum*. Diminished frequency of *Botryococcus*.	III; 3.7–0.12 m; 1100–1968 AD
M 4a; NAP- *Picea*; 3.70–3.12 m; 1100–1270 AD	Rise of *Picea* (up to 6.5%). At the bottom short-lasting *Carpinus* maximum (up to 13.3%). The lowest frequency of *Betula*. Characteristic high culmination of *Cannabis* (up to 15%).		
M 4b; *Pinus-Salix-Juniperus*; 3.12–0.12 m; 1270–1968 AD	Very high frequency of *Pinus* (up to 29%). Abundant *Salix* (up to 36%) and *Picea* (up to 4%). Low frequency of *Carpinus* (up to 1.3%). Characteristic continuous *Juniperus* curve (up to 1.9%). The highest in the profile frequency of Cerealia (up to 5.8%) and *Secale* (up to 11%), *Rumex acetosella*-t. (up to 6.1%), *Centaurea cyanus* (up to 5%), Chenopodiaceae (up to 1.7%), and *Artemisia* (up to 4%). Very high Poaceae and Brassicaceae. At the top culminations of *Trifolium*-t. (up to 7%) and *Plantago lanceolata* (up to 3.4%). *Fagopyrum* pollen recorded in almost every spectrum. Single records of *Solanum nigrum*-t. and *Linum*.		

Table 3. Lake Wojnowo. Changes of local vegetation

L PAZ and L PASZ; depth; approximate age	Description of zones		Phase of basin development
	Terrestrial vegetation	Aquatic and shoreline vegetation	
W 1; *Alnus-Quercus-Corylus* (*Picea*); 10.94–8.34 m; 1800–1300 BC	Highest *Alnus* values with culmination up to 27.9%. Oscillations of *Pinus* (up to 25%), *Betula* (up to 23.4%), and *Quercus* (up to 15.9%). Steady reduction of *Corylus* (from 21% to ca 10%). Continuous curves of *Ulmus* (up to 3.8%), *Tilia* (up to 4.1%), and *Fraxinus* (up to 4.4%). Considerable participation of *Carpinus* (up to 5.2%) and *Picea* (up to 6.1%). Regular occurrence of *Fagus* pollen. At the top increased frequency of Poaceae (up to 2.5%), Cyperaceae (up to 1.9%) and anthropogenic indicators, e.g. *Artemisia* (up to 1.1%). Upper zone boundary: sharp decrease of *Corylus* and *Picea*, sharp rise of *Betula*.	Reed swamp plants regularly present: *Phragmites*, *Typha latifolia*, *Sparganium*-t., Polypodiaceae, *Equisetum*. Rare *Schoenoplectus*-t. cf., *Polygonum amphibium*-t., *Thelypteris palustris*, *Sphagnum*. Aquatic plants represented by *Potamogeton*, rare *Nymphaea alba*, *N. candida*, and *Nuphar*.	I; 1800 BC – 1100 AD
W 2; *Betula-Carpinus*; 8.34–1.25 m; 1300 BC – 1104 AD	Sharp rise and high values of *Betula* (up to 49.9%). Increased *Pinus* frequency (up to 32.7%). Abundant *Quercus* (up to 18%), *Carpinus* (with three culminations up to 10.8%), and *Alnus* (up to 17.7%). Characteristic *Picea* rise (up to 6.2%). After the 5% decrease at the bottom, *Corylus* (up to 6.4%) and *Tilia* (up to 4.6%) frequency remain at low level. Continuous *Ulmus* curve (up to 1.9%). Regular occurrence of *Fagus* pollen. Increased frequency of herbs, mainly Poaceae (up to 4.5%) and *Artemisia* (up to 1.6%). Regular occurrence of Cerealia, *Plantago lanceolata*, *Rumex acetosella*, and *Filipendula*. Upper zone boundary: sudden decrease of *Betula*, *Quercus*, and *Carpinus*, rise of herb pollen frequency: Poaceae, Cyperaceae, and human indicators.		

Table 3. Continued

L PAZ and L PASZ; depth; approximate age		Description of zones: Terrestrial vegetation	Description of zones: Aquatic and shoreline vegetation	Phase of basin development
	W 2a; *Betula*; 8.34–6.43 m; 1300–850 BC	Characteristic high *Betula* frequency (up to 39%). Low but increasing amount of *Picea* (up to 3%). Gradual *Fraxinus* decrease. Strong *Alnus* decline at the top (from 24 to 16%).		
	W 2b; *Carpinus-Pinus*; 6.43–5.70 m; 850–614 BC	Increase of *Carpinus* (up to 8.2%) and *Pinus* (up to 30.6%). Fall of *Betula* (37.3–27%) and *Quercus* (9.9–5.5%). Stable *Alnus* values (up to 16%). Low values of *Picea* (up to 2%), *Tilia* (up to 1.5%), and *Ulmus* (up to 1.8%). Low frequency of herbaceous plants except for Poaceae (up to 4%).		
	W 2c; *Quercus-Betula*; 5.70–4.35 m; 614–127 BC	Slight decrease of *Pinus* (to 32.7%) and small increase of *Betula* and *Picea*. Stable frequency of *Alnus*, *Quercus*, and *Carpinus*. Small *Corylus* decrease. Regular occurrence of Cerealia, *Secale*, and *Plantago lanceolata*. Higher representation of *Artemisia*. The highest AP concentration.		
	W 2d; *Carpinus*; 4.35–3.5 m; 127 BC – 210 AD	Maximum frequency of *Carpinus* (up to 11.8%). Strong *Pinus* decline. Stable representation of *Betula*, *Quercus*, *Corylus*. Continuous *Salix* curve. Distinct fall of AP concentration.		
	W 2e; *Betula-Picea-Salix*; 3.5–2.7 m; 210–510 AD	Distinct rise of *Betula* (up to 42%). Sudden *Alnus* fall at the top (13.9–3%). *Carpinus* reduction (8.2–4.5%). Culminations of *Picea* (up to 4.5%) and *Salix* (up to 2.5%). Relatively stable frequency of *Pinus* (ca 35%) and *Corylus* (ca 3.5%). Almost continuous curve of Cerealia and *Secale*. Regular occurrence of *Cannabis*, *Filipendula*, and *Potentilla*-t.		
	W 2f; *Carpinus-Quercus-Alnus*; 2.7–1.25 m; 510–1104 AD	*Carpinus* curve rises again and culminates at the top (up to 10.8%). Systematic *Betula* decrease (from 49.9% to 35.7%). Increase of *Alnus* (up to 13.1%), *Quercus* (up to 18%), *Corylus* (up to 6.4%), and *Tilia* (up to 4.6%). Higher *Picea* representation with a maximum at the top (up to 10.8%).		
W 3; *Pinus*-NAP; 1.25–0.1 m; 1104–1919 AD		The highest frequency of *Pinus sylvestris* (up to 44.7%). After the initial fall of *Alnus* (to 16.2%) and *Betula* at the bottom, repeated rise at the top. High but decreasing representation of *Picea* (to 7.7%). After rapid decreases low frequencies of *Carpinus*, *Tilia* and *Quercus*. *Juniperus* appears regularly (up to 1.1%). Fast rise of herbaceous plants, mainly Poaceae (up to 15.9%), Brassicaceae (up to 1.9%), *Artemisia* (up to 2.6%), *Rumex acetosella*-t. (up to 3.9%), Cerealia (up to 5.5%), and *Secale* (up to 7.9%). Regular occurrence of *Centaurea cyanus* (up to 1.3%).	Increase of frequencies of *Phragmites* (up to 2.7%), Filicales monolete (up to 1.4%) and *Equisetum*. Presence of *Rumex aquat./hydrolap*. Systematic occurrence of *Sphagnum*. Among the aquatic plants a few *Myriophyllum* and *Potamogeton*, and rare *Stratiotes*.	II; 1100–1919 AD
	W 3a; *Pinus-Picea*; 1.25–1.05 m; 1104–1215 AD	Rapid falls of *Betula*, *Quercus*, *Carpinus*, and *Tilia*. Fast rises of *Pinus* (up to 40%) and NAP. Picea culmination (8%). Abundant *Alnus* (up to 12%).		
	W 3b; *Pinus*; 1.05–0.3 m; 1215–1758 AD	Characteristic domination of *Pinus* and herbaceous plants. Stable values of *Quercus* about 3%. Almost continuous *Juniperus* curve. Strong reduction of AP concentration.		
	W 3c; *Betula-Alnus*; 0.3–0.1 m; 1758–1919 AD	Rapid *Pinus* fall from 40% down to 14%. A few percentage rise of *Betula* and *Alnus*.		

Table 4. Lake Łazduny. Changes of local vegetation

L PAZ; depth; approximate age	Description of zones: Terrestrial vegetation	Description of zones: Aquatic and shoreline vegetation	Phase of basin development
Ł 1; *Alnus-Quercus-Corylus-*(*Picea*); 3.45–2.89 m; 2367–1146 BC	Decrease of *Ulmus* (from 6.3% to 4.1%), *Tilia* (from 3% to 2%), and *Fraxinus.* Small rise of *Betula* (up to 12.4%). At the top distinct decrease of *Corylus* (from 14 to 6.6%). High *Quercus* frequency (up to 15%). *Alnus* oscillations (up to 19.7%) and short-lasting *Picea* culmination (up to 4.7%). Low *Carpinus betulus* curve. Low frequency of herbs, among which anthropogenic indicators appear, e.g. Cerealia and *Plantago lanceolata*. Upper zone boundary: fall of *Corylus*, *Picea*, *Alnus*, rise of *Pinus*, and *Carpinus*.	Regular occurrence of *Phragmites*. Rare *Cladium mariscus*, *Sparganium*-t., and *Rumex aquaticus*/*hydrolapathum*. Rare spores of *Thelypteris palustris*, *Sphagnum*, and *Equisetum*. Seldom pollen of macrophytes: *Potamogeton*, *Nymphaea alba*. Numerous green algae *Tetraedron minimum* (up to 18.4%) and *Botryococcus* (up to 5%). Regular presence of *Pediastrum* (*P. boryanum* var. *boryanum*, *P. boryanum* var. *longicorne*, *P. integrum*), *Scenedesmus*, and *Coelastrum reticulatum*.	I; 2367 BC – 1646 AD
Ł 2; *Carpinus-Alnus-Betula*; 2.89–2.49 m; 1146–329 BC	Distinct rise of *Betula* curve (up to 19%) in the younger part of the subzone. Abundant *Pinus* pollen (up to 42.7%). Increased *Carpinus* frequency (up to 2.6%). Systematic *Corylus* fall (from 7% to 3%). Low frequency of *Fraxinus* (up to 2%), *Tilia* (2%), *Quercus* (6%). Regular occurrence of *Fagus* pollen. Upper zone boundary: rise of *Betula*, fall of *Pinus*, and *Alnus*.		
Ł 3; *Betula-Carpinus*; 2.49–0.89 m; 329 BC – 1532 AD	Characteristic long-lasting phase of high birch pollen values, on average ca 30% (up to 44%). Several culminations of *Carpinus* pollen curve (up to 8.6%). Strong *Pinus sylvestris* oscillations (up to 50.3%). *Quercus* fall (max. 13.3%). Continued falls of *Ulmus*, *Fraxinus*, and *Tilia* (<1% on average) and *Corylus* (2.5% on average). Successive *Picea* increase (up to 2.2%) at the top. Regular occurrence of *Populus*, *Salix*, *Fagus*, and *Juniperus* pollen. Rise of pollen frequency of herbaceous plants, mainly of Poaceae (up to 3.5%), *Artemisia* (up to 1.3%), *Rumex acetosella* (up to 0.8%), and Cerealia (up to 0.8%). Upper zone boundary: falls of *Carpinus*, *Alnus*, and *Betula*.		
Ł 3a; *Betula*; 2.49–2.31 m; 329 BC – 3 AD	Double *Betula* culmination. Rise of *Carpinus* up to 8% and a smaller one of *Picea* up to 1.6%.		
Ł 3b; *Pinus-Betula*; 2.31–2.01 m; 3–481 AD	Short-lasting rise of *Pinus* up to 46%. Falls of *Carpinus*, *Tilia*, and *Ulmus*.		
Ł 3c; *Carpinus-Quercus*; 2.01–1.77 m; 481–795 AD	Increased representation of *Carpinus* (up to 9%) and *Quercus* (up to 10%). Small reduction of *Betula*. Decreasing tendency of *Alnus*.		
Ł 3d; *Betula-Picea*; 1.77–0.89 m; 795–1532 AD	After the high *Pinus* maximum at the bottom (50%) its fast decline down to 26%. The highest frequency of *Betula* (up to 44%). The decreases at the bottom followed by the rises of *Quercus*, *Carpinus*, and *Alnus*. Stable frequency of *Corylus* and *Picea.*		
Ł 4; *Pinus*-NAP; 0.89–0.01 m; 1532–1996 AD	After the short-lasting decrease, a quick rise of *Pinus* (up to 56%), contemporaneous with the distinct reduction of pollen representation of *Betula* (14% on average), *Quercus* (4% on average), *Carpinus* (ca 1–2%), *Corylus* (3% on average), and to smaller degree of *Alnus* (8% on average). Higher *Betula* frequency at the top and bottom of the zone (up to 29.6%). Continuous curve of *Juniperus* (up to 3.9%). Very high frequency of herbaceous plant pollen: Poaceae (up to 9.6%), Cyperaceae (up to 4.4%), *Artemisia* (up to 3.8%), *Rumex acetosella* (up to 4.5%), Cerealia (up to 3%) and *Secale* (up to 4%).	*Phragmites* rises up to 3%. Rare *Sparganium*-t. and *Nymphaea alba*. Increased percentages of Filicales, rare spores of *Equisetum*, and *Sphagnum*. Decreased values of *Tetraedron* (to 11.5%) and *Botryococcus* (to 2.9%). Continuous curve of *Pediastrum boryanum* var. *boryanum*. At the depth of 0.01 m a characteristic culmination of *Coelastrum polychordum*.	II; 1646–1996 AD

Table 5. Former Lake Staświńskie, Szczepanki 8a. Changes of local vegetation

<table>
<tr><th rowspan="2">L PAZ ; depth; approximate age</th><th colspan="2">Description of zones</th><th rowspan="2">Phase of basin development</th></tr>
<tr><th>Terrestrial vegetation</th><th>Aquatic and shoreline vegetation</th></tr>
<tr><td>Sz 1;
Alnus-Corylus-Picea (Quercus);
0.87–0.55 m;
2890–880 BC</td><td>Characteristic high frequency and short-lasting culmination of Alnus (up to 60%) at the bottom and Corylus (up to 12%). Low curves of Carpinus (up to 3.4%), Ulmus (up to 2.2%), Tilia (up to 2.7%), and Fraxinus (up to 1.3%). Stable and high Pinus frequency (up to 31%). Rise of Betula (up to 19.8%), Quercus (up to 9.2%), and Picea with a high maximum at the bottom (up to 11%). Rare NAP.
Upper zone boundary: reduction of Corylus and Tilia, increase of Betula.</td><td rowspan="2">Among the infrequent vascular plants Typha latifolia, Phragmites, Sparganium-t., Menyanthes occur regularly. Aquatic plants represented by pollen of Potamogeton, Myriophyllum spicatum, Nymphaea alba, N. candida and spines of Ceratophyllum. Almost continuous curve of Thelypteris palustris. Green algae very rare. Ca. 880 BC maxima of Scenedesmus (up to 54.9%) and Pediastrum: P. boryanum v. pseudoglabrum (up to 11%), P. boryanum v. boryanum (up to 5.5%), P. boryanum v. longicorne (up to 1%), P. duplex v. rugulosum (up to 5.1%), and P. integrum (up to 2.4%). Regular occurrence of P. kawraiskyi coenobia. Tetraedron abundant up to 13.7%.</td><td rowspan="2">I;
2890 BC
– 600 AD</td></tr>
<tr><td>Sz 2;
Betula-Pinus-Carpinus;
0.55–0.25 m;
800 BC – 600 AD</td><td>Characteristic high frequency of Betula (up to 58%). Stable representation of Picea (up to 4.8%) and Carpinus (up to 3.9%). Rise of Pinus (up to 35.9%). At the bottom strong decrease of Corylus (from 10.9% to 4.4%). Continued tendency of Alnus decrease (from 21.6% to 13.7%). Small Salix increase. Constant presence of Fagus pollen. Rise of herbaceous plant frequency.
Upper zone boundary: decrease of Betula and Alnus, and rise of Pinus.</td></tr>
<tr><td>Sz 3;
Pinus-Picea;
0.25–0.05 m;
600–1480 AD</td><td>Rapid rise of Pinus frequency (up to 58%) contemporaneous with the falls of Betula (from 27.4% to 11%), Alnus (from 13.7% to 3.9%), Corylus (from 4.3% to 2.1%), Carpinus (from 4.1% to 0.9%) and Quercus (from 6.1% to 3.5%). Increased frequency of herbaceous plant pollen, particularly of Poaceae, Cyperaceae, Cerealia, and Cichorioideae.</td><td>Single pollen grains of Menyanthes, spores of Sphagnum, Equisetum and coenobia of Pediastrum. Stable frequency of Filicales.</td><td>II;
600–1480 AD</td></tr>
</table>

LATE HOLOCENE VEGETATION HISTORY OF THE EASTERN PART OF THE GREAT MAZURIAN LAKE DISTRICT

The development of forest communities

Zone I *Alnus-Quercus-Corylus* (*Picea*) R PAZ (ca 2300–1300 BC in Lakes Miłkowskie and Wojnowo area; ca 2300–350 BC in Lake Łazduny area; Figs 10a, 11a, 12a)

The character of vegetation of the studied microregion was distinctly connected with the diversified habitat conditions typical for its hilly, young-glacial topography. The dominant position was taken by forest communities hardly disturbed by people. Morainic hills and other dry sandy areas were covered by mixed pine-oak forests with birch and undergrowth of hazel and juniper. Mesophilous-deciduous forests of oak-hornbeam type, formed by various species, spread on more fertile and moist soils. The values of *Carpinus* pollen up to 9% (in the Miłki area) indicate a significant amount of hornbeam in the woodland communities about 1350 BC (see also Ralska-Jasiewiczowa et al. 2004). Slightly earlier, about 1850–1200 BC, the first spruce pollen maximum up to 8% was recorded which is a characteristic feature of this region. In case of Szczepanki area expansion of *Picea* riched high values earlier, at ca 2000–1600 BC. Spruce occurred as an important admixture in different community types. Rich undergrowth of oak-hornbeam forests was formed by shrubs of *Corylus avellana* and *Sorbus aucuparia*, less frequently also with *Frangula alnus*, *Rhamnus catharticus*, *Euonymus europaea*, *Cornus sanguinea*, and *Sambucus nigra*.

At about 2100–2050 BC spruce became more common in the woodlands of the Suwałki Lake District (Kupryjanowicz 2007, Lauterbach et al. 2010). Similar expansion was observed in Lithuania from ca 2050 BC (Kabailienė 2006), and earlier from ca 2600 BC in Estonia (Poska & Saarse 1999). Oak-hornbeam forests were the first to be changed anthropogenically due to the high quality of their habitats and the demand for timber. Pollen data indicate that oak was selectively cut, to a smaller degree also hazel, ash, lime, and alder. Hornbeam, spruce, and birch spread in their places. The presence of beech pollen in the sediment is interesting. In none of the studied sites its percentages reached the critical value of 2%, which is considered the evidence of the local presence of this tree (Huntley & Birks 1983, Lisitsyna et al. 2011). Also beech macrofossils were not found in the Great Lake District, except for a few wood/charcoal fragments reported from archaeological site at Dudka (Gumiński & Michniewicz 2003). However, the systematic investigations of charcoal and wood from the nearby site of the same age at Szczepanki did not confirm the occurrence of this tree (Cywa & Wacnik 2011, Cywa, pers. com.). *Fagus* pollen influx was calculated for several samples from the yearly laminated core sections from Lake Miłkowskie. Its maximum values were 64 pollen grains cm^{-2} $year^{-1}$. The results of the modern pollen monitoring in northern Poland indicate that the annual pollen-accumulation rates (PAR) for *Fagus* in an area with small *Fagus*-dominated patches in the forest (Tuchola Forests, Brodnica Lakeland) are ca 170–220 cm^{-2} $year^{-1}$. A *Fagus* PAR of ca 10–40 grains cm^{-2} $year^{-1}$ were recorded in situations where pollen traps were placed far away from the nearest beech tree (Pidek et al. 2010). It may thus be accepted that beech did not grow in the forests in the investigated microregion of the Mazurian Lake District.

In the whole microregion wet and periodically inundated habitats occupied large areas in depressions, around lakes, and along running waters. They were overgrown by forests resembling wet alderwoods and less frequently by carrs. Alderwoods were dominated by *Alnus glutinosa*, which occurred also in carrs together with *Betula*, *Fraxinus*, *Salix*, *Populus*, *Ulmus*, and *Picea*. *Frangula alnus* and *Cornus sanguinea* appeared in the undergrowth.

At the top of zone I the representation of herbaceous plants increased, including those directly connected with human activity, for instance Cerealia.

After Mayewski et al. (2004) a phase of global climate change occurred about 1550–550 BC (3500–2500 cal. BP). Studies conducted by Andersson et al. (2010) in Sweden revealed a low $\delta^{18}O$ and $\delta^{13}C$ values between 2050 and 1050 BC (4000–3000 cal. BP), especially around 1550 BC, what was interpreted as a result of precipitation increase and decrease of temperatures. Cooling and increased humidity of climate since ca 1550 BC was recorded also for instance in Finland and Estonia (Heikkilä & Seppä 2003). The increase of water level about 1900–1750 BC was reported in the Woryty region (Olsztyn Lake District; Ralska-Jasiewiczowa & Latałowa 1996) and about 1300–1200 BC in central Poland (Lake Gościąż; Ralska-Jasiewiczowa et al. 1998), while in southern Poland the phase of floods and landslides was dated to ca 1550–1250 BC (3500–3200 cal. BP) (e.g. Starkel et al. 2006). Dry phase recorded in mires of northern Poland ended about 1750–1650 BC (Żurek et al. 2002).

The picture of regional vegetation is complemented by local phenomena specific to individual sites. Pollen record from Lake Miłkowskie shows a short-lasting strong expansion of *Fraxinus* about 1650–1400 BC, preceded by a high maximum of *Alnus*. This might reflect a temporary but intensive development of the ash carr forest type. Contemporaneous, though less distinct changes can be seen in the profile from Lake Wojnowo. About 1400 BC short birch expansion was noted, correlated with the decrease of *Corylus* and *Picea* values, which may indicate that birch invaded areas previously cleared of woodland.

The changes of woodland composition may be connected with climatic oscillations and with deforestations carried out in order to provide space for cultivation and pasturage.

At the top of the zone plants that accompany settlement became relatively numerous. Plant cultivation near the lake was confirmed by the regularly encountered cereal pollen.

In Szczepanki region, a period of strong alder maxima correlated with the declines of oak, hazel, pine, and lime, caused by the exploitation of timber by the inhabitants of the camp-site on the island (Cywa & Wacnik 2011), was followed by forest regeneration phase, which reflected the settlement break. The disappearance of the settlement at the end of the Neolithic (Corded Ware culture, about 2000–1750 BC) is documented by the detailed archaeological excavations carried out on sites Szczepanki 8 and 8a (Gumiński 2003) and on twin site Dudka located in the same former lake (e.g. Gumiński 1999).

Zone II *Betula-Carpinus* R PAZ (ca 1300 BC – 1100 AD in Lakes Miłkowskie and Wojnowo area; ca 350 BC – 1450 AD in Lake Łazduny area; Figs 10a, 11a, 12a)

The region was still strongly wooded but forest communities distinctly changed. Mixed

Fig. 10. Late Holocene part of the percentage pollen diagram from Lake Miłkowskie sediments; **a:** Changes of frequency of arboreal, telmatophytes, and limnophytes taxa as well as concentration of arboreal (AP) and non-arboreal pollen (NAP); **1** – gyttja; M1-M4 – number of the L PAZ; abbreviations: **Al** – *Alnus*, **Co** – *Corylus avellana*, **Qu** – *Quercus*, **Fx** – *Fraxinus*, **Pc** – *Picea abies*, **Be** – *Betula*, **Cr** – *Carpinus betulus*, **Pi** – *Pinus sylvestris*, **Sx** – *Salix*, **Ju** – *Juniperus*, **NAP** – herbs; **b**: Changes of frequency of selected herb taxa, concentration of microcharcoal particles, and archaeological data about the local settlement

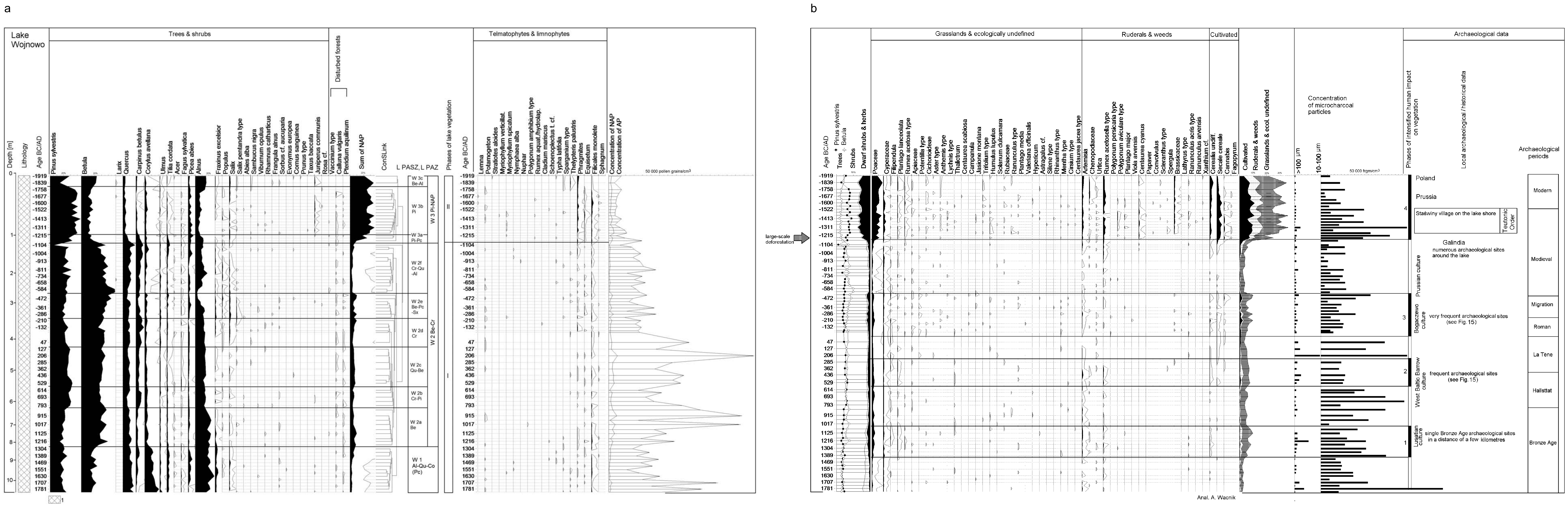

Fig. 11. Late Holocene part of the percentage pollen diagram from Lake Wojnowo sediments; **a:** Changes of frequency of arboreal, telmatophytes, and limnophytes taxa, as well as concentration of arboreal (AP) and non-arboreal pollen (NAP); **1** – gyttja; W1-W3 – number of the L PAZ; for explanations see Fig. 10; **b:** Changes of frequency of selected herb taxa and archaeological data about the local settlement

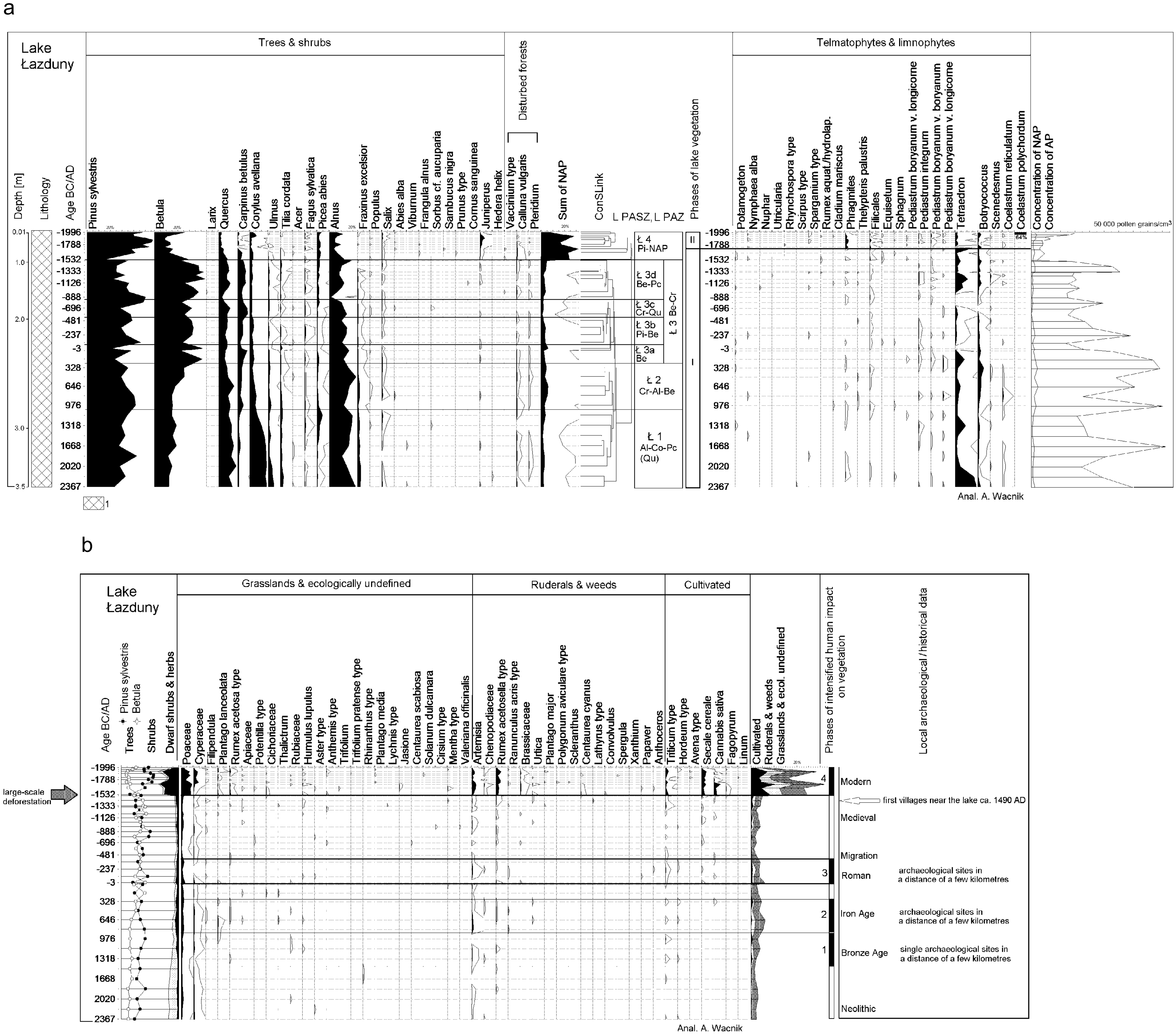

Fig. 12. Late Holocene part of the percentage pollen diagram from Lake Łazduny sediments; **a:** Changes of frequency of arboreal, telmatophytes, and limnophytes taxa as well as concentration of arboreal (AP) and non-arboreal pollen (NAP); **1** – gyttja; Ł1-Ł4 –number of the L PAZ; for explanations see Fig. 10; **b:** Changes of frequency of selected herb taxa, concentration of microcharcoal particles, and archaeological data about the local settlement

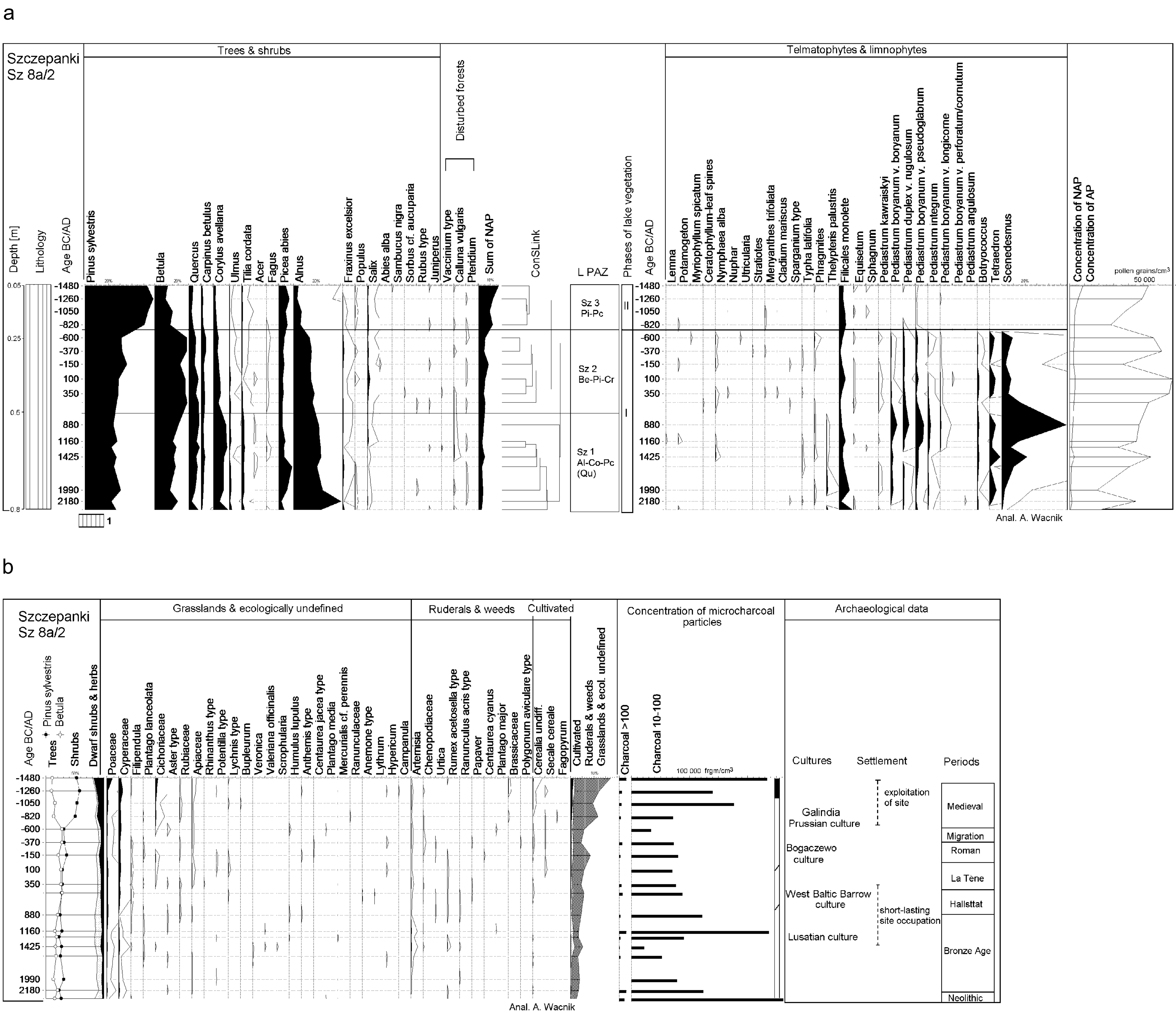

Fig. 13. Late Holocene part of the percentage pollen diagram from former Lake Staświny, profile Sz 8a/2 sediments; **a:** Changes of frequency of arboreal, telmatophytes, and limnophytes taxa as well as concentration of arboreal (AP) and non-arboreal pollen (NAP); **1** – herbaceous peat; Sz 1-Sz3 –number of the L PAZ; for explanations see Fig. 10; **b:** Changes of frequency of selected herb taxa, concentration of microchrcoal particles, and archaeological data about the local settlement

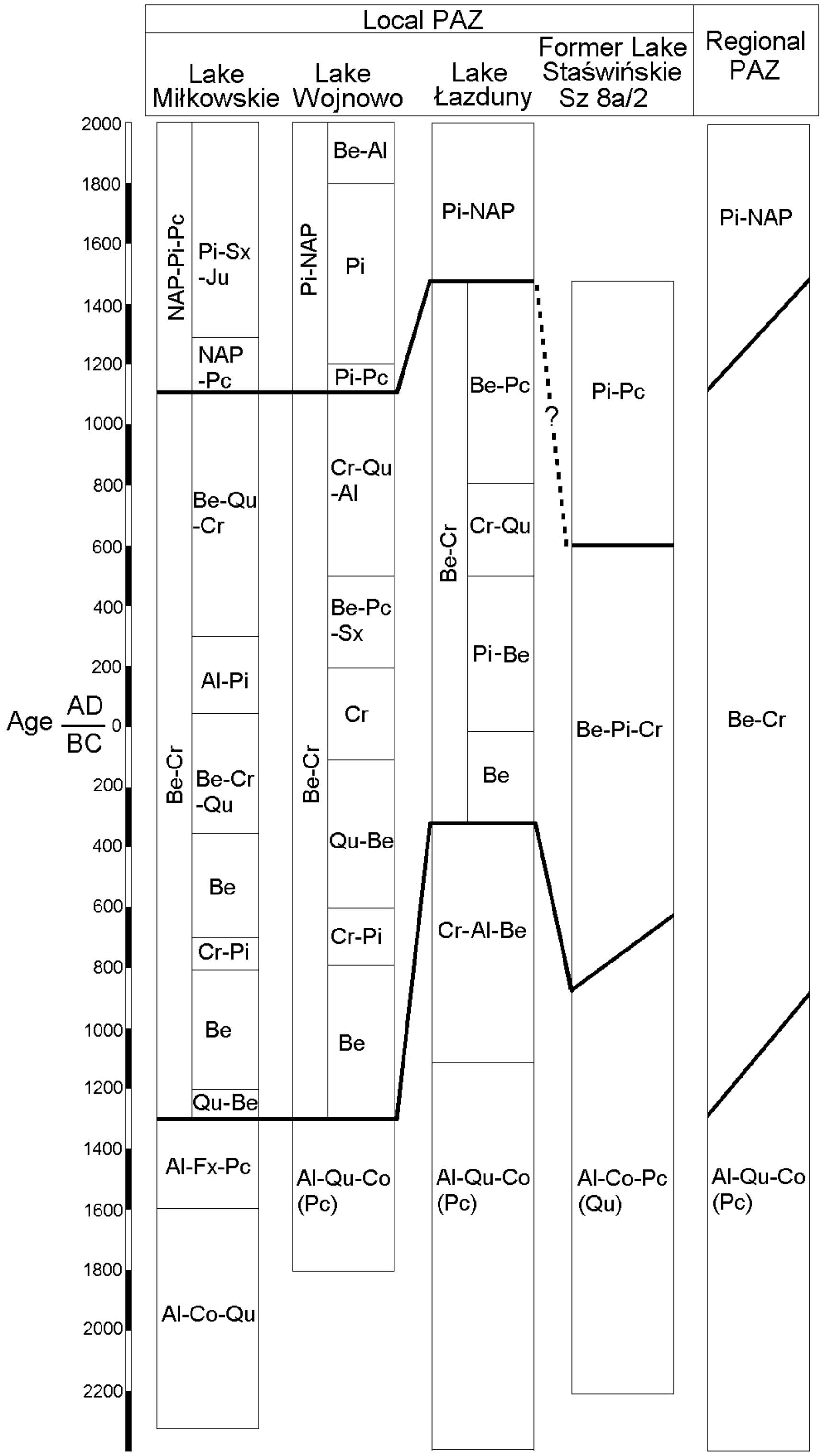

Fig. 14. Correlation of the Local Pollen Assemblage Zones (L PAZ) from the studied sites and the established Regional Pollen Assemblage Zones (R PAZ)

pine-oak forests built mainly of *Pinus sylvestris*, *Betula*, *Quercus robur*, and *Picea abies* developed on dry, sandy-gravelly soils. Pine was best represented near Lake Łazduny (33% of pollen on average) and distinctly less so around Lake Miłkowskie (20%). The top layer in oak-hornbeam forests was certainly composed of *Quercus* (*Q. robur*), *Tilia cordata*, *Acer platanoides*, and *Betula*, similarly as in Puszcza Borecka forest at present (Siuta 1994), while *Carpinus betulus* was common in the lower tree layer. *Fraxinus excelsior* and *Ulmus* appeared on moister habitats. Undergrowth was built mainly by *Corylus* and brushwood, sporadically with *Rhamnus catharticus*, *Viburnum*, *Frangula alnus*, *Cornus sanguinea*, and *Sorbus*. *Juniperus communis* was growing in cleared forests with *Calluna vulgaris* and *Pteridium aquilinum* in the herb layer.

Taxus baccata was present in mixed forests and carrs in the surroundings of Lake Miłkowskie. Wet alderwoods (of the modern *Carici elongatae-Alnetum* type), with fern *Thelypteris palustris* in the herb layer, spread on periodically flooded and low lying places without an outlet. In the whole region, moist and wet places created good conditions for the development of carrs with *Fraxinus*, *Alnus*, *Ulmus*, *Betula*, and *Salix*, having *Frangula alnus*, *Rhamnus catharticus*, *Viburnum*, *Cornus sanguinea*, and *Sorbus* cf. *aucuparia* in the undergrowth layer. *Humulus lupulus* was growing in such places. The decreasing pollen percentages of the components of many-species deciduous forests suggest that their area diminished. Birch, and to a lesser degree also willows and aspen, expanded in places of the selectively removed species and formed secondary communities, which were successively penetrated by more shadow-tolerant trees, such as for instance hornbeam. The analysis of wood exploited by the population of the West Baltic Barrow culture for the construction of lake dwellings at Pieczarki (near Giżycko) and Mołtajn (near Kętrzyn) in the Mazurian Lake District unmistakably indicate that deciduous trees were mainly used, namely birch, alder, oak, lime, willow, and ash (Gackowski 2010). This confirms the likely connection between the changes of the composition of forest communities and the activity of local societies.

The gradual reduction of alder resulted from forest clearings carried out in the marginal zone of water reservoirs and the replacement of woodland by meadow communities. The most characteristic feature of this period was the expansion of birch. The isopollen maps for the time 600 BC – 600 AD show the distinct increase of *Betula* pollen values in the Great Mazurian Lake District (Ralska-Jasiewiczowa et al. 2004). This process is very evident in the profile from Lake Dgał Wielki (Filbrandt-Czaja 2000), slightly less clear in Lake Mikołajskie (Ralska-Jasiewiczowa 1966). *Betula* is a pioneer tree having high light demands during the whole life. Due to the production of a large number of small, light, winged-nutlets with good wind dispersal and the fast growth in the first years it is able to spread quickly over deforested areas. "Its growth is vigorous only when growing as dominant tree in a stand with relatively wide spacing and low degree of within-stand competition" (Hynynen et al. 2011). In this connection birch expansion can be treated as a sign of a strong destruction of the previous woodlands (Faliński 1997), in our case mainly of the deciduous forests of oak-hornbeam type, on a smaller scale of mixed pine forests and locally also of alderwoods. The birch pollen percentages remaining on a high level for a long period (for instance in the region of Miłki and Staświny from 1200 BC to 1100 AD and Lake Łazduny from 200 BC to 1450 AD) suggest that the same surfaces were cleared many times in order to prevent forest succession. Modern counterparts of birch coppices may be birch-aspen thickets that develop in the Mazurian Lake District in the succession from communities of clearings to mixed pine forest (Wójcik 1991). Systematic clearings were connected with the short-lasting agricultural use of grounds, which required temporary resting. The occurrence of charcoal microfragments >100 µm size indicates local intentional use of fire or accidental conflagrations. The similar development of communities with the dominance of birch was recorded, at more or less the same time, in the diagrams from the other parts of Poland, for instance in the neighbouring Olsztyn Lake District (Woryty; Pawlikowski et al. 1982), in the Biebrza River valley (Lake Maliszewskie; Balwierz & Żurek 1987), in the Suwalki Lake District (Lake Kluczysko; Wacnik unpubl.), in central Poland (Lake Błędowo; Bińka et al. 1991), in the Gostynin Lake District (Lake Białe; Wacnik et al. 2011), and in Wielkopolska (Lake Skrzetuszewskie; Tobolski & Okuniewska-Nowaczyk 1989).

In Puszcza Borecka forest the spread of *Betula pendula*, *Picea abies*, and *Populus tremula* can be observed nowadays in forest stands, from which lime was selectively removed (Siuta 1994). In the study area the most intensive birch expansion took place in the environs of Lakes Miłkowskie and Wojnowo, slightly less significant was in the region of Lake Łazduny, and negligible importance had near the site Szczepanki 8 (where it is seen in one pollen profile only). These differences correspond well to the local economic and settlement activities that are confirmed both by archaeological findings and different frequency of human indicators in pollen diagrams. The vegetation around Lakes Miłkowskie and Wojnowo was characterized also by the significant increase of *Carpinus* in the forest stands. Hornbeam expansion was favoured by the deforestation of larger areas where its regeneration by offshoots was made easier.

Four periods of the increased hornbeam percentages were recorded about 1350 BC, 800/750 BC, 200/100 BC – 150/200 AD, and 950/1150 AD. Four distinct hornbeam culminations were observed also in Lake Łazduny, but there they were dated to 1150 BC, 50 BC, 900 AD, and 1300–1500 AD. They are correlated with periods of the local decrease of the economic activity of people, which are confirmed by the contemporaneous falls of cereal pollen percentages. The *Alnus* minimum took place ca 600/500 BC contemporary with the high *Betula* participation and was noted only in Lakes Miłkowskie and Wojnowo. It was a local phenomenon, which clearly coincided with the beginning of agricultural activity of people representing the West Baltic Barrow culture. The connection of *Alnus* falls with human activity in the Iron Age was also observed in pollen diagrams from Finland (Saarse et al. 2010).

Zone II was the time of stronger and more persistent disturbances of the natural environment connected with human activity, which caused an increase of open areas. In spite of birch pollen overrepresentation, which concealed the presence of herbaceous plants in pollen rain, meadow plants were abundant and taxonomically differentiated. The representation of human indicators among herbs increased, including cultivated plants such as cereals (wheat, oat, and barley types, rye), buckwheat, and hemp. Great local differences reflected in pollen spectra emphasize the individual features of the vegetation in the surroundings of particular sites and are related to various intensity of settlement processes. Vegetation changes in the vicinity of Lake Miłkowskie resembled those in Lake Wojnowo region because both lakes were situated within the range of the influence of the same settlement centre (Staświny region). However, pollen record of human exploitation of the catchment area is clearer in Lake Miłkowskie due to the smaller surface of water body.

Similar but of smaller scale vegetation changes were observed in the vicinity of Lake Łazduny (the beginning of birch phase ca 200 BC, less ruderals and weeds). Obviously the weakest anthropogenic impact on vegetation was observed near the archaeological site at Szczepanki.

The existence of deforestations favouring the expansion of birch is indicated by the increased percentage number of herbaceous plants and higher concentration of wood microcharcoals in lake sediments. These phenomena are well illustrated in pollen record from Lake Miłkowskie. In the pollen diagram from Lake Wojnowo a higher representation of herbs and two periods of increased charcoal concentration were observed at the beginning of the birch phase about 1200 BC and in its central section about 350–150 BC. Later these values decreased and remained stable until about 1000 AD. In the case of Lake Łazduny the birch phase from the very beginning was associated with the increased frequency of herbs (no information about charcoal is available), while at Szczepanki these phenomena are poorly reflected.

In Szczepanki region the role of pine forests with birch, oak, and spruce increased from about 500 BC. Locally the birch thickets could grow. Oak-hornbeam type forest communities formed small wood patches. Wet alderwoods played significant role. The surroundings of the island were very swampy and the access to open water was difficult. Archaeological investigations showed the existence of a short settlement phase, approximately dated to the decline of the Bronze Age or to the beginning of the Iron Age connected with the presence of people representing the Lusatian or West Baltic Barrow cultures (Lisiecki 2003). A few pollen grains of agriculture indicators reflect the presence of this population in the area.

Zone III *Pinus*-NAP R PAZ (ca 1100–2000 AD in Lakes Miłkowskie and Wojnowo area; ca 1450–2000 AD in Lake Łazduny area; Figs 10a, 11a, 12a)

The youngest period of vegetation development was distinguished by rapid changes caused by the settlement stabilization and intensified human activities, which, for instance near Miłki and Lake Wojnowo, resulted in clearing of a large forest areas already in the early Middle Ages. Oak-hornbeam type forests were almost completely eliminated about 1100 AD. Mixed pine-oak forests were also cleared, probably by the selective cutting of oak. The marginal zone of water basins was as well affected to a significant degree by forest destruction. A little more forest stands survived on economically worthless areas. On the steep slopes, having no economic value and located far-away from villages, the patches of mixed pine forests survived. Alder, willows, and birch were growing on shores of water basins, in depressions devoid of outlets and along water courses. The deforestation was a quick process, which could have lasted some dozens of years. Pollen rain from that time was dominated by pine, the participation of birch, spruce, and oak was much smaller. *Juniperus communis* developed in thinned and grazed forests. Forest clearings made easy the long distance transport of pine pollen from sandy outwash plains south of the study area. The differences in species composition of wood communities can be seen on the map of C. Henneberg from the 16th century AD and also in present-day Mazurian forests. Deciduous forests cover 70% of the area in Puszcza Borecka forest (north of the study area) while in Puszcza Piska forest (south of the study area) only 67% (Jutrzenka-Trzebiatowski 1999). The neighbourhood of palynological sites was changed to farmland. Intensive farming, pasturage, soaking hemp in water, and settlement building near lake shores caused strong water eutrophication, distinctly recorded in geochemical changes of the sediments of Lake Miłkowskie. In the surroundings of Lake Łazduny similar strong deforestation was not recorded before about 1450 AD. There also the deciduous forest of oak-hornbeam type suffered mostly from clearings (the decrease of hornbeam, oak, and hazel), while the significance of pine forest communities increased. This indicates that the formation of extensive and permanently deforested areas have started at different times in different places. Evidently the greatest forest stands survived in the Szczepanki region, where the most important role belonged to pine forests with spruce, birch, and less common oak. The progressive overgrowing of Lake Staświńskie resulted in the gradual reduction of wet alderwood area. The exact age of the uppermost sediment section is not known because no radiocarbon dates are available.

Pollen record from Szczepanki unequivocally indicates that the alterations of local forest communities were caused by the natural changes of environmental conditions. Nevertheless with respect to the whole region human activities in the last millennium should be considered the main cause of drastic vegetation changes, modified by climatic oscillations on a limited scale (e.g. Büntgen et al. 2011, Büntgen & Tegel 2011).

Palynologically studied sediments from Lakes Wojnowo, Miłkowskie, and Łazduny were accumulated until the end of the 20th century. In the Wojnowo and Łazduny regions the regeneration of forest communities was observed in the last century, including the development of wet alderwoods and forest stands with birch, as an outcome of farming and settlement decrease particularly after the fall of Prussia. This process concerned the whole Mazurian Lake District and the neighbouring mesoregions, where the wooded area increased by a dozen or so percentages in the years 1900–1990 (Białuński 1996a, Jutrzenka-Trzebiatowski 1999).

The development of aquatic and reed swamp vegetation. Changes of water reservoirs

Lake Miłkowskie

In the period from 2250 to 1250 BC (phase I) the numerous green algae, including unicellular species from the genus *Tetraedron* and colonial species from the genus *Botryococcus* (particularly *B. pila* and *B. neglectus*), developed in water body. Coenobia of *Pediastrum* were frequently identified, mainly *P. boryanum* var. *boryanym*, *P. boryanum* var. *perforatum*/*cornutum*, and *P. boryanum* var. *longicorne* (Fig. 10a). In the studies of the Holocene sediments a lack of synchronism was noticed between the abundant occurrences of *Pediastrum* and *Botryococcus*, which was explained by their different ecological preferences. High frequency of *Tetraedron*, *Coelastrum*, and *Scenedesmus* is considered an indication of eutrophic water (Tyson 1995, Goslar et al. 1999). *Pediastrum* favours higher content of nutrients (Tyson 1995) and higher water alkality – pH values 5.0–6.25 (Zippi et al. 1992). The great concentration of *Pediastrum* coenobia is an indicator of high level of water trophy, while the abundance of *Botryococcus* suggests its lower level, and the numerous occurrence of *Tetraedron minimum* indicates slightly eutrophicated water. The appearance of *P. boryanum* var. *perforatum/cornutum* allows the supposition that the reservoir was fairly large and not overgrown by aquatic macrophytes (Komárek & Jankovská 2001). This conclusion is confirmed by the low representation of submerged plants, for instance *Potamogeton*, and plants having leaves floating on water surface like *Nuphar* and *Nymphaea alba*. Poorly developed near-shore vegetation belt was composed of *Thelypteris palustris*, *Equisetum*, *Sphagnum*, *Phragmites australis*, *Sparganium/Typha angustifolia*, and the representatives of Cyperaceae.

Between 1250 BC and 1055 AD (phase II) *Botryococcus* predominated among the green algae. *Tetraedron* and *Coelastrum reticulatum*, numerous initially, disappeared already at the bottom of the zone. *Pediastrum* was represented mainly by a few colonies of *P. boryanum* var. *longicorne* and *P. integrum*. The cosmopolitan variety *P. boryanum* var. *boryanum* and *P. boryanum* var. *longicorne* and *P. integrum*. *Pediastrum duplex* var. *gracillimum/duplex* (growing in oligotrophic waters), and also *P. duplex* var. *rugulosum* regularly occurred. Such a composition of green algae suggests the decrease of water trophy level. In the discussed period the lake was an oligotrophic reservoir.

The patches of vegetation with *Nuphar*, *Nymphaea alba*, *N. candida*, and *Potamogeton*, resembling the modern association *Nupharo-Nymphaeetum albae*, spread in the zone of shallow water. Among the aquatic macrophytes *Myriophyllum verticillatum* and *M. spicatum* appeared. The reed swamp belt was better developed.

The top sediment section (phase III) contained remnants of numerous green algae, particularly from the genera *Coelastrum* and *Pediastrum*, which indicated a rapid increase of water trophy and alkalinity. The most numerous were: *P. boryanum* var. *boryanym*, *P. boryanum* var. *longicorne*, *P. duplex* var. *gracillimum/duplex*, *P. boryanum* var. *perforatum/cornutum*, and *P. boryanum* var. *pseudoglabrum*. In palynological studies of the late Holocene sediments the relationship between the abundant occurrence of *Pediastrum* and the increased human activity was often emphasized. It was observed already in the Bronze Age (Lusatian culture) (Tobolski 1990, Milecka 1994, Latałowa 1992), but became stronger since the Middle Ages (Milecka 1991, Latałowa 1992, Makohonienko 2000).

The abundance of *Botryococcus* decreased. Among diatoms the indicator species of lower trophy became reduced, while the species from the genera *Cyclostephanos* and *Stephanodiscus* developed plentifully, indicating water hypertrophy and alkalinity (Sekulska-Nalewajko, report from project accomplishment, unpubl.). More intensive overgrowing of the reservoir by aquatic macrophytes is suggested by the increased frequency of *Potamogeton*, *Myriophyllum verticillatum*, *M. spicatum*, *Nuphar*, and *Nymphaea alba*. Close to lake shore a better developed reed swamp belt was formed by *Thelypteris palustris*, *Typha latifolia*, *Equisetum*, Cyperaceae (including *Cladium mariscus*), and abundant *Phragmites australis*. Peaty areas covered by *Sphagnum* were present in places.

Lake Wojnowo

From 1800 BC (phase I) a relatively low representation of aquatics, which included *Potamogeton* sect. *Coleogeton*, *P.* sect. *Eupotamogeton*, and *Myriophyllum spicatum* is registered (Fig. 11a). Later also *Nuphar*, *Nymphaea alba*, and *Lemna* appeared. In the shore zone there occurred some *Thelypteris palustris*, *Typha latifolia*, *Cladium mariscus*, *Equisetum*, *Sphagnum*, Cyperaceae, and *Phragmites australis*. During the younger phase II the reed swamp plants became more numerous, first of all *Phragmites* and *Equisetum*, suggesting the development of communities similar to the modern association *Thelypterido palustris-Phragmitetum australis*. Reed swamp vegetation included also *Rumex aquaticus/hydrolapathum*, *Equisetum*, *Typha latifolia*, *Schoenoplectus* cf., *Thelypteris palustris*, and *Sparganium/Typha angustifolia*.

Lake Łazduny

Vegetation changes in the lake shore belt and in open water allowed to distinguish two stages of development. Between 2300 BC and 1700 AD (phase I) the lake was surrounded by forest communities similar to the wet alderwoods and carrs, growing close to the poorly developed reed swamp belt (Fig. 12a). Among the reed swamp plants *Phragmites australis*, Cyperaceae, *Thelypteris palustris*, and *Sparganium/Typha angustifolia* were constantly recorded. *Cladium mariscus*, *Scirpus* cf., *Rumex aquaticus/hydrolapathum*, and *Equisetum* were scarce. The presence of *Sphagnum* indicates the existence of peaty areas. Aquatic macrophytes were uncommon; the occurrence of *Potamogeton*, *Nymphaea alba*, *Nuphar*, and *Utricularia* was recorded. In open water green algae from the genera *Tetraedron* and *Botryococcus* were fairly abundant. Frequently but not abundantly appeared the colonies of *Scenedesmus*, *Coelastrum reticulatum*, and *Pediastrum*; from the last mentioned genus *P. integrum*, *P. boryanum* var. *longicorne*, *P. boryanum* var. *boryanum*, and *Pediastrum duplex* var. *rugulosum* were identified.

From ca 1700 AD the near surroundings of the lake (phase II) became deforested and the reed swamp belt with *Phragmites australis*, Cyperaceae, and *Equisetum* developed profusely. The quantity of green algae was reduced. An interesting phenomenon was the strong development of *Coelastrum polychordum* recorded only in the uppermost sample. It is a rare species, the occurrence of which is usually related to eutrophicated waters. Modern data from alpine lakes indicate that this species develops in mesotrophic and eutrophic basins (http://www.laenderfinanzierungsprogramm.de/cms/) and in rather clear shallow waters of gravel pit lakes in southern Slovakia (Hindák & Hindáková 2002). According to Jankovská and Komárek (2000) *Coelastrum polychordum* occurs abundantly in eutrophicated waters, particularly due to the anthropogenic impact. In fossil materials from Poland *Coelastrum polychordum* was for the first time identified from Lake Świętokrzyskie sediments dated to the Boreal and Subboreal periods (Makohonienko 2000). In Lake Miłkowskie sediments this species appeared rarely in the Allerød, several times it was recorded in the Atlantic period and relatively frequently in the sediments deposited in the period 1200–600 BC and in the 11th century AD.

Former Lake Staświńskie, Szczepanki 8a

The quick overgrowing of the southern part of the lake resulted in the development of a fen. The course of this process was registered by changes in lithology and the transformation of plant communities documented by taxonomic composition of plant fossils. Pollen analysis of core Sz 8a/2, collected at the edge of the island directly at a place where Mesolithic and Neolithic people stayed, shows the existence of a fen already about 3100 BC (lithological border between the coarse detritus gyttja and peat at 0.95 m). Palaeobotanical analysis of peat layer dated to about 1800 BC (Fig. 13a) showed the regular presence of pollen of *Potamogeton*, *Nymphaea alba*, *Myriophyllum spicatum*, and *Ceratophyllum*, rarely of *Nuphar* pollen, and the occurrence of macrofossils of *Najas* (*N. marina*, *N. minor*, *N. flexilis*), *Nymphaea alba*, and *Nuphar* sp. (elaborated by Stachowicz-Rybka, Wacnik et al., final report from project accomplishment, unpubl.). These results indicate that this place either remained submerged in very shallow water for some time or was periodically flooded due to water-level fluctuations. The slope of the island was overgrown by wet alderwoods with *Alnus glutinosa*, *Betula*, *Urtica dioica* (fruits), *Solanum dulcamara* (fruits), and *Rubus idaeus* (seeds). Reed swamps developing in the shore zone were formed by *Phragmites australis*, *Typha latifolia*, *Equisetum*, *Thelypteris palustris*, and *Lycopus europaeus* (fruits). The presence of *Potamogeton praelongus*, *P. obtusifolius*, *P. pusillus*, *Stratiotes aloides* fruits as well as seeds of *Nymphaea alba* evidence the eutrophication of habitats (macroremains analyses elaborated by R. Stachowicz-Rybka, Wacnik et al., final report from project accomplishment, unpubl.).

About 500 BC *Thelypteris palustris* disappeared, while the representation of Cyperaceae pollen increased, the occurrence of *Carex pseudocyperus*, *C. elata*, *Eleocharis palustris*, and *Menyanthes trifoliata* was confirmed, and *Cladium mariscus* appeared (Fig. 13a). Progressive drying up of the site was indicated by the distinctly diminished number of water plants.

In the uppermost section of the sediment, that accumulated probably during the Middle Ages (10th–13th century AD), aquatic plants were not recorded, while plants of wet places were represented by pollen of the members of Cyperaceae family and *Menyanthes trifoliata*. Numerous pollen grains of Poaceae and Cichorioideae indicated the development of meadow communities.

The examination of another core from Szczepanki, namely core Sz 1/2005 collected about 60 m off the island edge toward the former lake centre, has demonstrated that about 1900–1500 BC this area was covered by reed swamp vegetation (Wacnik

& Ralska-Jasiewiczowa 2008). At that time the sediment has changed from the coarse detritus gyttja to the sedge-moss peat. A very distinct expansions of *Thelypteris palustris* (with a maximum about 1200–1000 BC), *Typha latifolia*, and *Menyanthes trifoliata*, which were recorded by pollen analysis, indicate that at the time of settlement collapse there existed a broad belt of reed swamp vegetation and the access to open water was possible only at some distance from the slope of the island (Gumiński 2003, Wacnik et al. 2007, Wacnik & Ralska-Jasiewiczowa 2008).

THE IMPACT OF ECONOMIC-SETTLEMENT CHANGES ON THE VEGETATION OF THE MICROREGION

The investigations, which were carried out in the last years on the territory of the Great Mazurian Lake District focused on the transformation of the subsistence strategy based on foraging (hunting, fishing, gathering) to that characterized by the increased role of the producers (farming, animal rising). They have demonstrated that about 2400 years elapsed between the first appearance of agriculture indicators and the increase of farming significance. As late as the middle Bronze Age, when local settlement became more stabilized, agriculture may be considered an important source of food supply. The latest analyses have shown that human impact on vegetation increased during the Bronze Age about 1400 BC, with the development of the Lusatian culture settlement (Wacnik 2005, 2009b).

Similar phenomena are known from the other countries situated north-east from Poland. The earliest evidences of local cereal cultivation in southeast Lithuania were dated to the middle Neolithic ca 3400–2800 BC but the increase of its importance in people's economy occurred much later, about 2600–2200 BC (e.g. Antanaitis-Jacobs & Stančikaitė 2006, Stančikaitė et al. 2006). Zernitskaya and Mikhailov (2009) showed that the introduction of farming in the central Belarus took place between 3800–2800 BC and even later in the northwestern part, while the development of farming and the use of ploughing started ca 1250–1 BC in the central and ca 200–1000 AD in the northern regions. In Estonia the beginning of cereal cultivation took place during the Neolithic, at about 4000 BC (at Rõuge in southern Estonia ca 3300 BC; Poska et al. 2004), but the transitional period between the introduction and adoption of crop farming lasted from about 1000 up to 3000 years (e.g. Poska & Saarse 2006, Poska et al. 2004). Also in Latvia the importance of crop cultivation started to increase from the late Neolithic about 2600–2200 BC. *Hordeum* is the oldest cereal in Latvia, and has been cultivated for at least the last 4000 years (Kalnina et al. 2004, Ozola et al. 2010).

Pollen record from the eastern part of the Great Mazurian Lake District showed distinct difference between the intensity of vegetation changes caused by man in the surroundings of Lakes Miłkowskie, Wojnowo, and Łazduny and in the environs of the site Szczepanki. The differences were so significant that the results obtained from these two areas had to be interpreted independently. In the area around the lakes four phases of the increased impact of local societies on vegetation could be distinguished. Anthropogenic transformations of the environment were chronologically correlated with the activities of the Lusatian culture (phase 1), the West Baltic Barrow culture (phase 2), and the Bogaczewo and Prussian cultures (phase 3). Phase 4 started during the existence of the Prussian culture in the before-Teutonic Order period (Lakes Miłkowskie and Wojnowo) or in the Teutonic Order period (Lake Łazduny) and lasted from the Middle Ages to modern times. In the vicinity of the archaeological site Szczepanki local plant communities were less effected by human economy and no such clear phases could be recognized.

THE SURROUNDINGS OF LAKES MIŁKOWSKIE, WOJNOWO, AND ŁAZDUNY (FIGS 10B, 11B, 12B)

Phase 1, ca 1400–1000 BC; the Bronze Age settlement the Lusatian culture (Fig. 15)

Pollen record has demonstrated strong transformations of forest communities, which were expressed in distinctly reduced significance of *Corylus* and *Tilia*, temporary decrease of *Carpinus* and *Picea*, fluctuations of *Quercus* percentages, and the beginning of *Betula* expansion. The increased concentrations of charcoal dust recorded in the sediments of Lakes Wojnowo and Miłkowskie (phase 1b) suggest that forests were cleared with the use of fire. Economic activity concentrated mainly

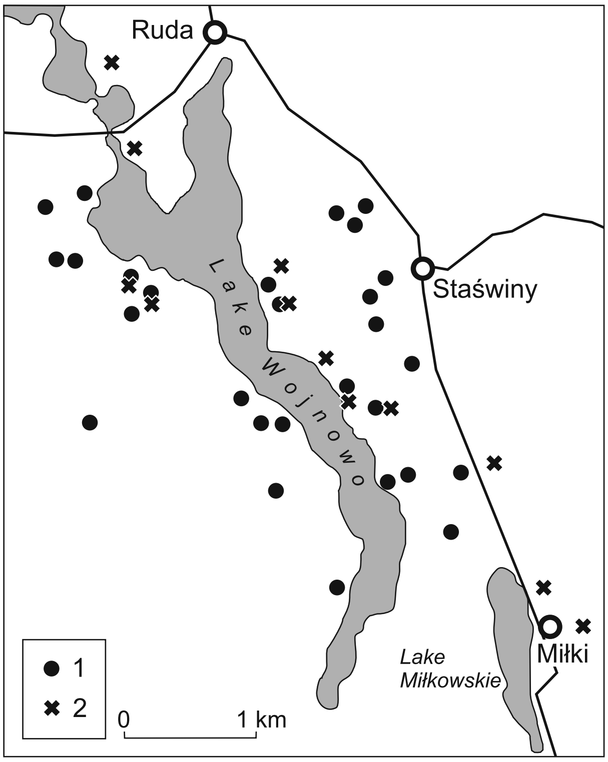

Fig. 15. Distribution of archaeological sites in the area of Lakes Wojnowo and Miłkowskie (based on Karczewski 2008); **1** – sites from the early Iron Age (the West Baltic Barrow culture), **2** – sites from the Roman Period (the Bogaczewo culture)

in areas overgrown by woods resembling the modern oak-hornbeam and mixed pine forests, which were cleared, but on a small scale only. The basis for the delimitation of the increased human activity phase was the regular occurrence of agriculture indicators (first of all of wheat type pollen) in all three pollen profiles and additionally of hemp in Miłki region, as well as higher percentage values of plants accompanying settlements, including *Artemisia*, *Rumex acetosella*, *Urtica*, *Plantago major*, Chenopodiaceae, and *Polygonum aviculare*. The taxonomic diversity of meadow plants also increased, among which Poaceae, *Plantago lanceolata*, *Rumex acetosa*, *Potentilla*, *Lychnis*, *Filipendula*, and Cichorioideae were quite frequent.

Animal husbandry was based on forest grazing supplemented by pasturage in areas cleared from forest. Leaf fodder and acorns were probably the basic winter food of raised animals. Cereal cultivation played a significant role in the whole region. Anthropogenic changes connected with the Lusatian settlement were recorded also in the other pollen diagrams from the Mazurian Lake District (Ralska-Jasiewiczowa & Latałowa 1996, Kuprybjanowicz 2002), which confirms the broad territorial scale of human impact on vegetation. No archaeological traces of the Bronze Age settlement were found in the nearest vicinity of the studied lakes, but they are known from the localities situated at a few kilometre distance, for instance in Konopki Wielkie, Marcinowa Wola Kolonia, and Rydzewo (Karczewska et al. 2005).

A short period of wood regeneration occurred between 1000 and 700/600 BC. It found expression in the spread of hornbeam, birch, and pine in the surroundings of Lakes Wojonowo and Miłkowskie and the reduced participation of farming indicators.

Phase 2, ca 700/600–50 BC; the West Baltic Barrow culture settlement (Fig. 15)

A repeated increase of the number of human indicators can be seen in pollen diagrams. Cereal fields (*Secale cereale*, *Triticum*) and hemp cultivations (*Cannabis sativa*) existed in the neigbourhood of lakes. Ruderal and/or field weeds were regularly recorded, such as Chenopodiaceae, *Urtica*, *Plantago major*, *Polygonum aviculare*, *Scleranthus*, and *Artemisia*. *Rumex acetosella*, an indicator of acidic soils, was growing on dry pastures and fallow lands. The area of grasslands increased again favouring the growth of *Rumex acetosa*, *Plantago lanceolata*, and the representatives of Poaceae, Cichorioideae, Apiaceae, and *Ranunculus*. These rich herbaceous communities were the source of animal fodder. Until the Middle Ages agriculture functioned as shifting cultivation, combined with burning or, perhaps, with fallowing (Lityńska-Zając 2005). The highest concentration of microcharcoals (fraction > 100 μm), which confirmed the local character of fires and/or intentional use of burning, was discovered in the sediments of Lake Wojnowo, a slightly lower, but still considerable one in Lake Miłkowskie. Fire, in addition to felling trees, could serve as a tool for clearing ground for cultivation and, at the same time, could provide ashes for fertilizing fields. Experimental studies have shown that the long-lasting use of slash-and-burn technique is limited first of all by the difficulty in getting enough fire-wood (Rösch et al. 2004). Fuel could be provided by quickly growing birch thickets, which were common on fallows already from the decline of phase I. Perhaps the coppicing of birch was practised, as a regeneration method applied in short-rotation intensive management (Ferm 1993). The growth of coppice shoots is faster than that of planted seedlings (Hynynen et al. 2010). The shifting cultivation was used in many parts of Europe up to the 20th century. Jääts et al. (2010) on the basis of historical data describe two methods of swidden cultivation practised in Estonia. In one of them plots were prepared in an old-growth forest, where seeds were sown directly into the ash without ploughing. The other method was applied in a young secondary forest, where people re-used once cultivated plots after about 20–60 years of fallowing. In areas where small plots were regularly used for fire cultivation young trees and shrubs (bushland) predominated. Historical sources indicate that *Betula*, *Alnus incana*, and *Picea* prevailed among them. The authors indicate also that parts of the bushland neighbouring the permanent arable could be used as a land reserve, parts of which were cultivated only temporarily. Other more important uses of bushland were grazing and collection of timber for fuel (Jääts et al. 2010). The use of birch as fuel in the studied microregion was documented by the results of anthracological identifications from the cemetery in Paprotki Kolonia site 1, where birch absolutely dominated among charcoals from funeral pyres and fillings of grave pits. Charcoals of other trees, *Corylus avellana*, *Quercus*, *Alnus*, *Pinus*, and *Fraxinus* were much less frequent (Tomczyńska, unpubl., Cywa, unpubl. in: Karczewski 2011).

In thinned and grazed forests there occurred for instance *Juniperus*, *Calluna vulgaris*, and *Pteridium aquilinum*. The presence of *Plantago lanceolata* is usually connected with patches of herbaceous vegetation but in the forested areas it indicates a not intensive forest grazing (cf. Makohonienko et al. 1998). Woodland transformations associated with the settlement of the West Baltic Barrow culture were stronger and more permanent than in a previous phase. The information about the economy of these tribes comes from archaeobotanical and archaeozoological investigations of several sites, for instance at Jeziorko near Giżycko (Zabłocki 1950, Gręzak & Piątkowska-Małecka 2007), Pieczarki (Polcyn 2000), and Wyszembork in the Mrągowo Lake District (e.g. Lityńska-Zając 1997). At Wyszembork, sites 1 and 4, abundant material of charred cereal grains contained *Hordeum vulgare*, *Secale cereale*, and *Panicum miliaceum*. Seeds of *Cannabis sativa* (uncharred), *Pisum sativum*, and *Brassica* cf. *campestris*, possibly also cultivated, were found. Among field weeds there appeared for instance *Centaurea cyanus*, *Echinochloa crus-galli*, *Chenopodium album*, and *Scleranthus annuus* (Lityńska-Zając 1997). Archaeozoological examination of bones from the settlement at Jeziorko, dated to Hallstatt D and the beginning of the La Tène Period, showed that animal economy was based on cattle, sheep/goat and horse breeding. Wild animal hunting and fishing were less important. Consumption of small ruminants and horse was preferred. At the site Tarławki (20 km NW of Giżycko, the Great Mazurian Lake District) cattle was the basis of animal breeding, while sheep/goat, pigs, and horses were of lesser importance (Piątkowska-Małecka 2003). The abundant material of bones suggested that animal raising played an important role in the economy. Among plant remains from the lake dwelling site at Pieczarki the numerous grains of *Hordeum vulgare*, *Triticum spelta*, and *Panicum miliaceum*, as well as seeds of *Camelina sativa* were found. Cultivated plants were accompanied by weeds such as *Bromus secalinus*, *Chenopodium album*, *Avena fatua*, *Polygonum lapathifolium*, and *P. persicaria* (the two last mentioned species could have been collected for consumption). Edible plants gathered from the wild were also found, for instance *Corylus avellana*, *Fragaria vesca*, *F. viridis*, *Rubus caesius*, *R. idaeus*, *Pyrus communis*, and *Origanum vulgare* (Polcyn 2000). Macroremains of *Camelina sativa* are also known from the lake dwelling at the Lake Orzysz (Rossius 1933, after Gackowski 2000). The results of palynological investigations of culture layer connected with Lake Piłakno dwelling (the Mrągowo Lake District) have demonstrated a strong deforestation and an intensive cereal cultivation documented by over 11% of Cerealia pollen (Bukowski et al. 1965). The deforestations and changes of woodland structure are the consequence of agricultural activity. Anthropogenic disturbances corresponding to this phase were recorded also in pollen diagrams from Lakes Mikołajskie (Ralska-Jasiewiczowa 1966) and Dgał Wielki (Filbrandt-Czaja 2000).

Archaeological sources document the spread of settlement over the whole area. From the same period the relics of lake dwellings originate, which were preserved in the neighbourhood of Bogaczewo, Szymonka, and Konopki

Małe. Numerous archaeological traces were recognized in the region of the studied sites, for instance in the vicinity of Lakes Wojnowo and Miłkowskie (Karczewski 2008; fig. 3).

The decrease of the number and diversity of pollen indicators of local settlement in Lake Miłkowskie region between 300/200 BC and 50 AD suggests that from the decline of the West Baltic Barrow culture the exploitation of the area diminished. Near Lake Wojnowo this change was very weakly marked.

Phase 3, ca 50–600 AD; the settlement of the Bogaczewo and Prussian cultures (Fig. 15)

The increased diversity of settlement and farming indicators was observed again about 100–650 AD in the surroundings of Miłki and about 50–500 AD in the Staświny-Ruda and Lake Łazduny region. Anthropogenic changes during the Roman Period were recorded in the sediments of Lake Miłkowskie as a short-lasting episode, during which *Centaurea cyanus*, a weed of winter crops, appeared for the first time. This phase is better expressed in pollen sequence from Lake Wojnowo. Here, agricultural activity was carried out in a still wooded area. It is conceivable that, compared to the vicinity of Miłki, cereal cultivation had greater significance, mainly of *Secale cereale* and *Triticum*, while *Hordeum*, *Avena*, and *Cannabis sativa* were grown on a smaller scale. Charred plant macroremains from the settlement and cemetery at Paprotki Kolonia document the cultivation of *Triticum spelta*, *T.* cf. *monococcum*, *Hordeum vulgare*, *Secale cereale*, and *Avena* (Karczewski 2011, Mueller-Bieniek, unpubl.). The identification of *Panicum miliaceum* grains suggests that Poaceae pollen can partly come from local millet cultivations (Pirożnikow 2002, Karczewski 2011). Among the field weeds there were *Viola arvensis*, *Polygonum persicaria*, and the representatives of the family Chenopodiaceae. Weedy taxa found in culture layers from sites 1 and 41 at Paprotki Kolonia included for instance *Chenopodium* sp., *Ch. album* type, cf. *Bromus* sp., *Fallopia convolvulus*, *Polygonum lapathifolium*, *Scleranthus annuus*, and *Echinochloa crus-galli*. Ruderal plants were represented by *Artemisia*, Chenopodiaceae, *Urtica*, and *Plantago major*. Poaceae were the main component of meadow plants, less frequently *Potentilla*, *Plantago lanceolata*, Apiaceae, Cichorioideae, *Lychnis*, *Rumex acetosa*, and *Trifolium* were recorded. The appearance of *Jasione montana* and *Rumex acetosella* was connected with the existence of sandy patches (Karczewski et al. 2009, Karczewski 2011, Mueller-Bieniek, unpubl.). The results of palaeozoological studies from the settlement at Paprotki Kolonia allow for the suggestion that the economy was based on animal husbandry, while cereal cultivation was of minor importance. The inhabitants of the settlement raised mostly cattle, sheep, and goats, as well as some pigs and horses. More distant areas could be exploited as pastures mainly for the small ruminants. Considerable role in food supply belonged to fishing, while hunting was of marginal importance (e.g. Gręzak et al. 2002). In spite of the existence of convincing evidence for the spread of agriculture in the Miłki-Staświny region during the Roman Period, the activity of farmers did not lead to the creation of extensive woodless terrains. However, considering the possibility that the occurrence of cultivation indicators could be masked by wind pollinated trees, we may suppose that meadows and fields were the permanent, though not dominant element of the local landscape. Archaeological traces of the Galindai population (Bogaczewo culture) are common in the discussed area. They concentrate in the two settlement microregions, namely near Bagna Nietlickie and Staświny (Karczewska & Karczewski 2007, Karczewski 2008, 2011). It seems almost certain that particularly the inhabitants of Staświny settlement exploited the surroundings of both lakes.

The traces of economic-settlement activity registered in pollen diagrams indicate its decline in the vicinity of Lakes Miłkowskie, Wojnowo, and Łazduny about 600–1000 AD, which is in accordance with the suggested by archaeologists decrease of population density in Galindia about the 6th century AD (Okulicz 1981, Karczewska et al. 2005). Cultivation indicators almost completely disappeared from pollen rain, while signs of the secondary succession (high but decreasing *Betula* pollen percentages) increased, as did also those of the regeneration of forests with oak, hornbeam, lime, and alder in the lake shore zone. These changes are particularly well recorded in pollen diagram from Lake Wojnowo.

The settlements and cemeteries from Marcinowa Wola Kolonia, Paprotki Kolonia, and several others from the close vicinity of Staświn, archaeologically studied in detail, are dated to the Roman and Migration Periods (Karczewska & Karczewski 2007). In the early Middle Ages a Galindian castle was built at the shore of Lake Wojnowo. In pollen spectra dated to the 6th century AD (probably corresponding to the time of the castle construction) the distinct declines of alder, oak, hornbeam, and hazel percentages were recorded, as well as the maximum spread of birch. These changes correlate with the beginning of the strong reduction of cultivation indicators.

Phase 4, from the Middle Ages to the present (1100–2000 AD Lakes Miłkowskie and Wojnowo; 1450–2000 AD Lake Łazduny)

About 1000/1100 AD forests were almost totally eliminated in the nearest surroundings of Lakes Miłkowskie and Wojnowo and the area was transformed permanently in an agricultural landscape. The beginning of the extensive deforestations in the Lake Dgał Wielki region Filbrandt-Czaja (2000) also dates to the early medieval time. The expansion of agriculture was favoured by climate. The reconstruction of summer temperatures in Scandinavia indicates their increase in the period ca 980–1100 AD (Medieval Climate Anomaly). In addition, climate was generally drier between ca 1000 and 1200 AD (Büntgen & Tegel 2011). Goosse et al. (2012, and farther references there) also suggest the rise of summer temperature in Europe from 900 to 1050 AD.

The degree of the deforestation of Lakes Miłkowskie and Wojnowo environs suggests that the hitherto dispersed intra-forest settlement became consolidated already in the early Middle Ages and villages were formed near these lakes. According to these data the villages Miłki and Staświny should be significantly older than it appears from the historical information. The granting of the foundation charter, which confirmed their existence and defined their sizes, took place as late as in 1475. Toeppen (1870) writes that "From the information about the history of Galindia in pagan times it may be concluded, that its inhabitants occupied still the same, though earlier perhaps more extensive habitats". This suggestion may be correct with respect of the above mentioned localities in the context of the living of these people in the same area since the pre-Teutonic Order times. The change from the burn-and-fallow to fallow system of soil cultivation occurred in the early medieval time. In the 11th century AD the progress in agriculture was connected with the introduction of the iron coulter (Biskup et al. 2008). Agricultural activity connected with the foundation of fields, pastures, and probably also settlements directly on Lake Miłkowskie shores caused the radical increase of lake water trophy. Very high representation of human indicators among the herbaceous plants, including cultivated plants such as cereals (wheat, oat, barley types, and rye), buckwheat, and hemp, and the appearance of flax, give evidence that the tillage was carried out in close neighborhood of the investigated lakes and that plant cultivation played the main role in the structure of local economy. The results of modern pollen monitoring show that *Fagopyrum*, *Triticum* type, and *Hordeum* type appear in low percentages even when fields are located in a small distance from the sampling place (Pidek 2009). Therefore the values of a dozen or so percent of cereal pollen may be considered an indication of the existence of large scale cultivations in the vicinity of water basins since the 13th century AD.

The record in the Chronicle of Prussian Lands by Piotr from Dusburg (2005) confirms that flax cultivation was known to Prussians before the arrival of the Teutonic Order Knights. It results from the documents of the Order that hop was cultivated for beer production. It cannot be excluded that hop was cultivated also in Miłki region, because the *Humulus*-type pollen appeared there abundantly already in the older sediments, but hop was as well the component of the natural communities. Hop cultivation persisted for several centuries (Toeppen 1870). *Cannabis* pollen values up to 15% in the sediments of Lake Miłkowskie indicate that hemp must have been soaked in water at lake shores. Slightly later hemp cultivation appeared near Lake Łazduny, where its pollen reached the value of 5.8% about the 16th century AD. The cultivation of hemp was the most widespread in the Middle Ages and lost its significance after the fall of Teutonic State.

Since the Middle Ages *Centaurea cyanus* was growing abundantly in cereal fields. Its uncharred fruits occurred in archaeological sites in the Mazurian Lake District since the Iron Age (Lityńska-Zając 1997, 2005, Polcyn 2000). The appearance of this weed species was probably connected with the spread of the cultivation of winter crops. Other weeds that were regularly recorded included the representatives of Chenopodiaceae, *Papaver*, *Viola arvensis*, *Spergula*, *Convolvulus arvensis*, and *Polygonum aviculare*. In Lake Miłkowskie sediments spores of *Anthoceros punctatus* were frequently identified. This species is connected with the arable fields (Lechterbeck et al. 2009), but can also grow in damp stubble fields, fallow land, and ditchsides. The abundance of *Rumex acetosella* and the appearance of *Scleranthus*, which may grow in fallows, pastures, and fields, confirm the existence of dry habitats and the increased soil acidity. Ruderal plants including *Urtica*, *Plantago major*, *Artemisia*, Brassicaceae, and Chenopodiaceae spread around habitation places. Poaceae, Cichorioideae, *Lychnis*, *Filipendula*, *Rumex acetosa*, *Plantago lanceolata*, *P. media*, *Anthemis*-t., *Aster*-t., *Mentha*, *Centaurea jacea*, and *Trifolium* were components of meadow vegetation. In the profiles from Lakes Wojnowo and Miłkowskie a higher concentration of charcoal was recorded about the 13^{th}–14^{th} century AD, which may indicate conflagrations or more intensive use of fire. It is possible that local woods provided a timber used for iron production conducted at Ruda and Staświny.

The impact of various forms of economic activity of the Teutonic Order (e.g. extensive forest clearings recorded in historical sources, colonization campaigns, settlement foundations, building of roads and castles) on the vegetation of Galindia territory is recorded only in pollen diagram from Lake Łazduny, because this was the only site surrounded by woodland at the time of the arrival of this Order. In the other sites, where the deforestation took place at earlier times, the influence of the economic changes on the environment was poorly reflected in pollen record. The local hemp cultivation, which was very intensive in Miłki region still about the 12^{th} century AD, became limited during the Teutonic Order time. At the same time the expansion of *Rumex acetosella* and Poaceae and the beginning of the regular occurrence of *R. acetosa* and *Juniperus* is recorded, probably due to the increased area covered by meadows. According to the historical sources there was an obligation to provide the Order with hay, which undoubtedly stimulated the enlargement of the area of mown meadows (Toeppen 1870, Biskup et al. 2008). In the period 1466–1525 AD, after the intensive colonization campaign, several villages obtained legal status (Toeppen 1870, Karczewska et al. 2005, Biskup et al. 2008). At that time the surroundings of Lake Łazduny became deforested. The increased participation of spruce in the woods, which according to historical sources started in the 16^{th} and continued through the following centuries, is not reflected in the pollen record. Pollen diagrams date spruce expansion in the neighbourhood of Lakes Wojnowo and Miłkowskie to about the 9^{th} century AD. Strong deforestation of the studied area can be seen on the maps (Fig. 16) of C. Henneberg (1576 AD) and N. Naroński (ca 1663 AD; Szeliga 1997). The construction of the Mazurian water road (18^{th} century), followed by the drainage of extensive areas of wet meadows and peat-bogs (from the first half of the 19^{th} century), caused water level decrease in the whole region (Toeppen 1870, Karczewski 2008). These activities enlarged the meadow and pasture areas favouring thus the development of animal husbandry. In the vicinity of the studied lakes cereal cultivation, mainly of rye, gained in significance, though the Little Ice Age cold period dated to ca 1450–1850 AD (500–100 cal BP) in Northern Europe (Seppä et al. 2009) was not favourable to agriculture. Scandinavian summer temperatures were lowered ca 1570–1750 AD and 1780–1920 AD (Büntgen & Tegel 2011). During the Little Ice Age in the Alpine region, dated between 1420 and 1820 AD, summer temperature was 0.8°C lower than in the period 1901–2000 AD (Corona et al. 2010).

Written sources inform that potatoes, buckwheat, and vegetables were the basic Mazurian nourishment in the 19^{th} century. Toeppen (1870) writes that "In winter on the table there appear sauerkraut and pickled beets as a favourite dish (…). During the festivities of harvest and flax collecting they willingly eat noodles with poppy. They also use a lot of onion". Bread and farinaceous foods were considered dainties. Cucumbers, radish, and kale were cultivated as pig fodder. As a curious detail he mentions beer making from juniper berries. In Lake Miłkowskie sediments the *Solanum nigrum* morphological pollen type was identified, which includes also potato pollen (*Solanum tuberosum*). Hemp and buckwheat cultivations became limited. Palynological data indicate that fields were infested with weeds such as *Centaurea cyanus*, Chenopodiaceae, *Polygonum aviculare*,

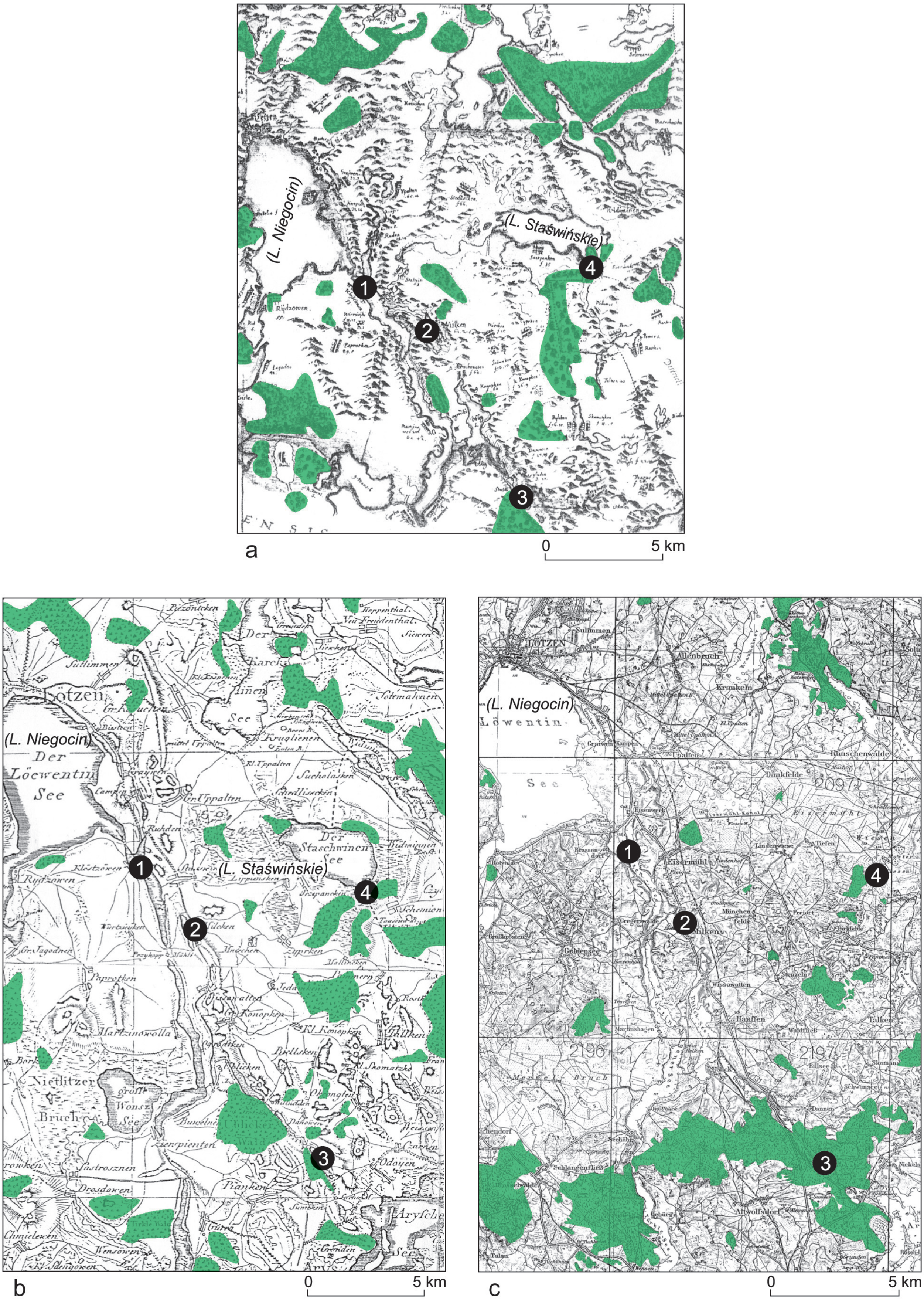

Fig. 16. Strong deforestation of the studied microregion presented on historical maps: **a** – 1663 AD (Szeliga 1997), **b** – 1804 AD, **c** – 1932 AD; forested area marked in green; **1** – Lake Wojnowo; **2** – Lake Miłkowskie; **3** – Lake Łazduny; **4** – former Lake Staświńskie, Szczepanki 8a

Papaver, *Convolvulus arvensis*, and *Scleranthus*. *Rumex acetosella* was common on fallow lands and pastures. High representation of Poaceae, Cichorioideae, *Trifolium*, *Plantago lanceolata*, *Rumex acetosa*, and the representatives of *Anthemis*-t. suggests that meadow communities must have covered vast areas. The Schroetter-Karte from 1804 illustrates differences in the degree of woodiness of the sourroundings of the investigated lakes. The area within 1 km radius from the coring places in Lake Miłkowskie and Wojnowo is almost woodless, whereas within the 5 km radius a small wooded area can be seen. The region of Lake Łazduny is much better forested (Fig. 16). These data are reflected in tree pollen percentages, which amount to 45% on average in Lake Miłkowskie sediments, to 65% in Lake Wojnowo (more regional record), and to 75% in Lake Łazduny.

The uppermost sediment sections of these profiles were deposited in the 20th century. At that time the pollen records suggest the decrease of cereal cultivation intensity, spread of alderwoods at lake shores, and birch thickets on fallow lands. The historical map from 1932 shows widespread of woodland in Lake Łazduny area (Fig. 16). Pollen results accord well with the historical information about the depopulation and devastation of that area caused by the warfare during the World Wars I and II.

The site Szczepanki 8 near Wydminy (Fig. 13b)

Anthropogenic landscape changes were distinctly less pronounced in the region of the former Lake Staświńskie. Archaeological investigations have demonstrated that the island at Szczepanki was visited by people since the Palaeolithic, and later was inhabited seasonally in the Mesolithic. The permanent settlement was initiated by the population of the para-Neolithic Zedmar culture and lasted until the end of the Neolithic (Gumiński 2003). According to this author, the abandonment of the island was connected with the gradual worsening of living conditions as this part of the former lake underwent overgrowing. At the transition Bronze/Iron Age, after the several hundred years long break, the island at Szczepanki was shortly used by the population of the Lusatian or the West Baltic Barrow cultures (Lisiecki 2003). Younger artefacts were not found, except for the fragments of medieval pottery (Gumiński 2003, pers. com.) and one medieval pit at Dudka (Gumiński pers. com.).

Pollen record registered a possibility of weak exploitation of local woods with fire (higher concentration of microcharcoal particles in peat).

From the period about 1450–1150 BC only a few plant indicators of human activity were recorded in pollen profile Sz 8a/2. They included *Triticum*-t., plants growing in ruderal places, fallows (*Artemisia*, Chenopodiaceae, *Ranunculus acris*, *Plantago major*, *Rumex acetosella*), and grasslands (e.g. Poaceae, *Plantago lanceolata*, Cichorioideae, *Valeriana officinalis*, *Potentilla*, *Hypericum*). The scale of anthropogenic impact, to be sure, was in this case small, nevertheless pollen analysis confirmed the occasional exploitation of the island or its neighbourhood during the Bronze Age and clearing of forests with the use of fire (increased concentration of microcharcoals including the fraction >100 μm). About 1100–1000 BC a fire phase was recorded in the profile Sz I/2005 (Wacnik & Ralska-Jasiewiczowa 2008). Fire could be used not only for deforestation but also, for instance, as support in hunting. These events could have been connected with the stay of the Lusatian culture population.

After an episode characterized by a smaller taxonomic diversity of herbs, between 500 BC and 150 AD an increase of meadow plants was observed, represented by Poaceae, Cyperaceae, *Potentilla*, *Plantago lanceolata*, *Filipendula*, *Ranunculus*, *Lysimachia vulgaris*, Cichorioideae, and Rubiaceae, the spread of which was connected with the process of lake overgrowing. Regularly ruderal and field weeds appeared in pollen spectra, for instance *Artemisia*, Chenopodiaceae, *Plantago major*, *Urtica*, and *Papaver*, as well as cereals of *Triticum* type and *Secale*. On this basis it can be concluded that small fields used for cereal cultivation were located on dry areas near the lake. These phenomena can be correlated with the presence of the West Baltic Barrow culture and the Bogaczewo culture societies. Starting from 500 BC the composition and structure of forests gradually changed. The significance of *Betula* and *Carpinus* distinctly increased, but low sedimentation rate does not allow to draw more detailed conclusions. The development of pine forests, combined with the evidence of cereal cultivation suggest that agricultural use of land was continued, though with low intensity, during the successive centuries. Not before the Middle Ages the terrain of the site was used by humans again (medieval pottery at the top of the sediments). The wet terrain, however, doubtless remained beyond agricultural and settlement activity, as is indicated by the more regional pollen record from the profile Sz I/2005 (Wacnik & Ralska-Jasiewiczowa 2008). The 17th century map of N. Naroński (ca 1663) shows the Szczepanki region as wet and deforested area, with only small wood patches in the neighbourhood. More detailed Schroetter-Karte from 1804 suggests the existence of slightly more forested areas. On the historical map from 1932 forests cover near Szczepanki 8 the surface similar to that of the present time (Fig. 16).

THE BEGINNING OF THE LARGE-SCALE DEFORESTATIONS IN THE GREAT MAZURIAN LAKE DISTRICT

Historical sources indicate strong connection of the extensive forest clearings with the activity of the Teutonic Order Knights. In the 13th–16th century AD the Order has initiated forest management, building of castle and road networks, foundation of settlements, and the immigration of settlers on the territories of Prussian tribes in the frame of colonization campaigns (e.g. Toeppen 1870, Białuński 1996, Ważny 2005, Biskup et al. 2008). In palynological papers the beginning of the youngest phase of extensive deforestations and intensification of farming could not be precisely recognized

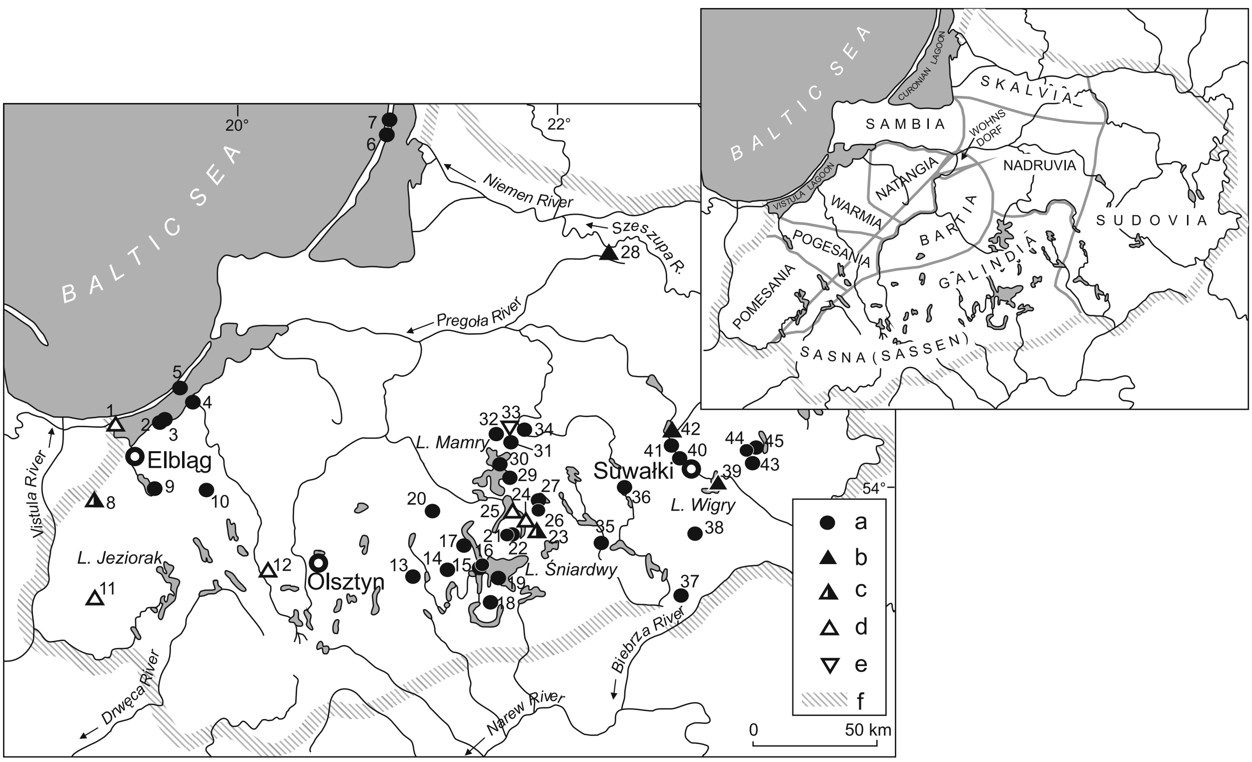

Fig. 17. Distribution of palynological sites (studied after 1965) from the former territory of Prussian tribes. Smaller map presents division of Prussia into tribal territories in the 13th century (based on Okulicz 1981).

a – pollen profiles without radiocarbon dates from the last 2 millennia; **b–e** – pollen profiles with radiocarbon dates from the last 2 millennia; **2** – sites strongly deforested after the second half of the 16th century (post-Teutonic Order times); **3** – sites strongly deforested in the time of the Teutonic State existence in Prussia (13th-beginning of 16th century); **4** – sites strongly deforested before the 13th century (pre-Teutonic Order times); **5** – no reliable information about the time of large-scale deforestation; **f** – the limit of the Prussian tribes territory in the 13th century. List of pollen sites: **1** – Stegna (Miotk-Szpiganowicz et al. 2010); **2** – Zalew Wiślany Piaski; **3** – Zalew Wiślany 2a; **4** – Zalew Wiślany III-a ZW; **5** – Krynica Morska, Mierzeja Wiślana (Savukynienė et al. 2003); **6** – Agilos Vingiakopė (Savukynienė et al. 2003; Moe et al. 2005); **7** – Juodkrantė (Savukynienė et al. 2003); **8** – Malbork (Brown & Pluskowski 2011); **9** – Lake Duzno; **10** – Stary Cieszyn; **11** – Lake Klasztorne; **12** – Woryty; **13** – Lake Piłakno (Bukowski et al. 1965); **14** – Lake Wągiel; **15** – Lake Mikołajskie; **16** – Lake Mikołajskie (II); **17** – Lake Tałty; **18** – Lake Jegocin; **19** – Lake Śniardwy; **20** – Poganowo (Szal & Kupryjanowicz 2011); **21** – Lake Jędzelek (Karczewski et al. 2007); **22** – Nietlice I & II (Kupryjanowicz 2002); **23** – Lake Łazduny; **24** – Lake Miłkowskie; **25** – Lake Wojnowo; **26** – Szczepanki; **27** – Dudka; **28** – Velikoye peat bog (Arslanov et al. 2011); **29** – Lake Dgał Wielki; **30** – Lake Mamry; **31** – Budzewo; **32** – Bałupiany; **33** – Lake Czarne (Karpińska-Kołaczek et al. 2011); **34** – Skalisko; **35** – Miłuki; **36** – Lake Gordejskie; **37** – Czerwone Bagno; **38** – Rospuda; **39** – Lake Wigry; **40** – Osowa; **41** – Lake Hańcza (Lauterbach et al. 2010); **42** – Lake Kluczysko (Wacnik, unpubl.); **43** – Malona; **44** – Sejny; **45** – Gajlik (for further references see Kupryjanowicz, 2008) because the uppermost profile sections have no reliable chronology.

From among almost 50 pollen profiles from the territories of the former Prussian land, which were elaborated after 1965 (see Kupryjanowicz 2008), only 12 have radiocarbon dates from the last two millennia. These are the following sites: Lake Klasztorne (Noryśkiewicz 1997), Malbork (Brown & Pluskowski 2011), Stegna (from the Gulf of Gdańsk coast; Miotk-Szpiganowicz et al. 2010), Woryty (Ralska-Jasiewiczowa & Latałowa 1996), Lake Wigry (Kupryjanowicz 2007), Szurpiły (Kupryjanowicz, unpubl.), Kluczysko (Wacnik, unpubl.), Lake Czarne (Karpińska-Kołaczek et al. 2011), Velikoye peat bog (Arslanov et al. 2011), and Lakes Miłkowskie, Wojnowo, and Łazduny (Fig. 17). In spite of the fact that the destructive influence of the Teutonic Order economy on forest communities is unquestionable, the latest investigations clearly indicate that different areas within the Prussian tribal territories were cleared from forests at different times. The investigations of the influence of Baltic Crusaders on environment, carried out in the framework of the project: *"The Environmental Impact of Conquest, Colonisation and Religious Conversion in the Medieval Baltic"* (leaded by A. Pluskowski) suggest that the period of the 13th–15th centuries AD is an important ecological horizon in the vegetation history of northern Poland (Brown & Pluskowski 2011).

The early Middle Ages deforestations were carried out in the surroundings of the sites situated in Gdańsk Bay (ca 900–1200 AD), Lake Klasztorne (8th–11th century AD), Woryty (ca 1100 AD), and Lakes Miłkowskie and Wojnowo (ca 1000/1100 AD). Forest clearings from the Teutonic Order time were described from the Malbork (13th century AD) and Lake Łazduny (beginning of 16th century AD) regions. As late as the 17th century AD the greater deforestations occurred in the Suwałki region, namely in the environs of Lakes Wigry, Szurpiły (Kupryjanowicz, pers com.), and Kluczysko, and near the Velikoye peat-bog in Kaliningrad area (Russia; Arslanov et al. 2011).

Pollen analysis from Lakes Miłkowskie and Wojnowo confirmed the possible deforestation of the surroundings of some settlements located in Galindia Forest (Puszcza Galindzka) in the pre-Teutonic Order time and the existence of open areas since the Prussian period to the present. Quick deforestation of the Staświny-Miłki region is connected with the existence of the settlement centre at Staświny and probably the centre of iron smelting in Ruda. On the other hand, the results obtained from Lake Łazduny, situated in a few kilometers distance, but surrounded by forests until the 16th century, show the limited range of the early medieval forest destructions. The results obtained from this profile are in accordance with the historical data concerning the foundation of habitation places/villages in the environs of Lake Łazduny at the turn of the 15th and 16th century AD (Biskup et al. 2008).

The analysis of the beginnings of permanent deforestations in north-eastern Poland indicates that they were directly connected with settlement intensity and stability, and palynological data precisely reflect local settlement processes.

SUMMARY

Palaeobotanical investigations carried out on four localities; Lakes Miłkowskie, Wojnowo, and Łazduny, and former Lake Staświńskie, situated in the microregion Miłki-Staświny-Wydminy, allowed to reconstruct the terrestrial vegetation changes and lake evolution in the late Holocene (the last 4 thousands years). The results were confronted with historical-archaeological and climatic data in order to reveal the cause-effect relationship in the observed vegetation disturbances. The detailed chronology was elaborated on the basis of AMS radiocarbon dates. The depth-age models were built by means of the "free-shape" algorithm. This procedure made possible the detailed analysis of the described events and their presentation on a secular scale. In addition to the pollen analysis the succession of the fossil green algae and the concentration changes of charcoal microfraction were examined. Lake Miłkowskie is the first basin in this part of Poland, for which the history of the selected green algae taxa during the 16 000 years of its existence was reconstructed (see also Wacnik 2009c). It has been confirmed that the environmental changes in the last 4 millennia were mainly caused by the economic – settlement activity of people, though climate fluctuations and natural lake evolution had some significance, too.

A distinct difference was observed in the character of vegetation changes between the

Miłki-Staświny region and the surroundings of the site Szczepanki, the main cause of which were the location of Szczepanki 8 site on an island and, connected with this, different history of the local settlement. The now existing Lakes Wojnowo, Miłkowskie, and Łazduny, four millennia ago were deep water reservoirs with scanty aquatic vegetation and narrow belts of reed swamps at the shores, situated in forested areas. At Szczepanki, the littoral zone of Lake Staświńskie, which surrounded the island, from 1900–1750 BC was becoming shallower and finally was overgrown by reed swamp vegetation.

In the late Holocene history of forests growing in the investigated terrain three phases of development were distinguished.

The first phase: 2300–1300 BC Lakes Miłkowskie and Wojnowo, 2300–350 BC Lake Łazduny

The region was almost completely wooded. Dry morainic hills surrounding the lakes were overgrown mainly by mixed pine forests. The patches of fertile, fresh soils were covered by oak-hornbeam type forests composed of deciduous trees with an admixture of spruce, which underwent insignificant anthropogenic disturbances. Considerable areas in lake shore zone and in other wet places were covered by alderwoods and carrs. Water basin in Szczepanki region gradually became shallower and overgrown by aquatic and reed swamp vegetation spreading in the near-shore belt. The terrain surrounding the island turned into a marshy area with small water-pools, making difficult the access to open water. It was probably possible only in very dry years or during winter, as a place attractive for hunters.

The second phase: 1300 BC – 1000 AD Lakes Miłkowskie and Wojnowo, 350 BC – 1450 AD Lake Łazduny

All the time the region was strongly forested. More pronounced and permanent vegetation changes concerned all forest types, particularly oak-hornbeam type forests, but also alderwoods in lake surroundings. Forest patches were cleared with the use of fire (certainly several times) and were used for farming for a short time. The characteristic episode of high birch percentages in pollen diagrams indicates the spread of the secondary communities on abandoned fields, which periodically lay fallow. This phase is dated to about 1200 BC – 1100 AD in Lakes Miłkowskie and Wojnowo, and to about 200 BC – 1400 AD in Lake Łazduny. In the profile from Szczepanki it is hardly marked between 500 BC and 600 AD. This was also the time of hornbeam expansion. The asynchronous *Carpinus* pollen culminations in different diagrams emphasize their connection with the decreased intensities of the local settlement activities. Four hornbeam curve culminations were recorded in pollen profiles, in Lakes Miłkowskie and Wojnowo dated to about 1350 BC, 800/750 BC, 200/100 BC – 150/200 AD, and 950/1150 AD, and in Lake Łazduny to about 1150 BC, 50 BC, 900 AD, and 1300–1500 AD. In the profile from Szczepanki percentage values of hornbeam are little differentiated.

The third phase: 1100 AD – 2000 AD Lakes Miłkowskie and Wojnowo; 1450 AD – 2000 AD Lake Łazduny

This phase corresponds to the time of the extensive woodland clearances and the appearance of vast areas exploited agriculturally. The settlement was stabilized and intensified. In Lake Miłkowskie sediments the intensification of erosive processes was recorded (increase of K, Mg) since the beginning of this phase. The primary lake production increased (Ca). At first the sedimentation rate was relatively low, lamination can be seen due to the periodical sediment enrichment in carbonates and clay rich in organic matter, but from the turn of the 12th and 13th century the accumulation rate significantly increased and marl was deposited, rich in organic matter and poor in iron compounds and biogenic silica (elaborated by A. Tatur, A. Wasiłowska and P. Gromadka, in: Wacnik et al., final report from project accomplishment, unpubl.).

The comparative analysis of phases of the increased anthropogenic impact on the environment allowed to delimit 4 stages of changes characteristic for the eastern part of the Great Mazurian Lake District.

The first stage dated to about 1400–1000 BC was connected with the agricultural activity of the Lusatian culture.

Small disturbances were recorded in communities of oak-hornbeam and mixed pine forests, which were cleared with the use of fire. The deforested areas were used for cereal cultivation and animal grazing. Animal husbandry was, however, based mainly on forest grazing and the use of leaf, branch, and acorn fodder in winter time. This brought about the selective cutting of deciduous forests and favoured the formation of birch thickets and the expansion of spruce and hornbeam. Hornbeam and birch formed thickets on abandoned fields.

The second stage of the regional anthropogenic vegetation transformations was dated to 700/600–50 BC and was connected with the activity of the West Baltic Barrow culture population.

Vegetation disturbances, stronger and applied to the greater areas, were recorded in all profiles. This agrees well with archaeological data, which indicate the existence of the intensive settlement of Baltic tribes in the region. New areas for tillage, pasturage, and settlement were still procured at the cost of oak-hornbeam type forests growing on the more fertile soils. To a lesser degree pine forests and alderwoods were cut, making thus the access to the water easier. The cultivation of rye and hemp increased. Fields were located nearer the lakes. The use of the burn-and-fallow method was recorded by the increased charcoal concentration in the sediment. This technique of soil cultivation favoured the spread of birch thickets.

The third stage of anthropogenic vegetation changes, dated to about 50–600 AD, is correlated with the activities of the Bogaczewo and Prussian culture tribes, which inhabited the study area in the Roman and Migration Periods and early Middle Ages.

An unusually distinct phase of anthropogenic vegetation transformations was recorded in Lake Wojnowo, situated in the centre of the settlement microregion, and in the nearby Lake Miłkowskie. The extensive enlargement of field area (cleared and fertilized with the use of fire) was recorded particularly in the latter site. The area of meadows also increased because of the great demand for pastures for domestic animals. The deforestation concerned all types of forest communities. The environmental disturbances had no effect on the type of sediments and the frequency of green algae (except for a short-lasting increase of *Coelastrum reticulatum* coenobia in Lake Miłkowskie). This stage was very weakly reflected in Szczepanki, which suggests that this terrain was agriculturally exploited only occasionally. Pollen records accord with archaeological data suggesting the recession of local settlement in the Galindia territory about the 6th century.

The fourth stage of the intensified anthropogenic changes, dated to 1100–2000 AD in Lakes Miłkowskie and Wojnowo, and to 1450–2000 AD in Lake Łazduny, was characterized by the foundation of denser and more stable settlement units at the shores of the studied lakes.

On the basis of written sources the management of the Puszcza Galindzka forest was hitherto attributed to the Teutonic Order (no radiocarbon dates of pollen profiles), but the present studies have shown that the large-scale deforestations were not synchronous over the whole area. In the eastern part of the Great Mazurian Lake District forests predominated in the landscape probably until the arrival of Teutonic Knights (at least to the colonization campaign at 1466–1525 AD, the neighbourhood of the Lake Łazduny), but the surroundings of the Prussian settlement centre near Staświny and Miłki were deforested already in the early Middle Ages by Prussian tribes. In the neighbourhood of Lakes Miłkowskie and Wojnowo forests were completely cleared in 10th/11th century and the area was used for farming. This was connected probably in part with the metallurgical activity carried out at Ruda and Staświny and with the demand for timber. Green algae from the genera *Pediastrum* and *Coelastrum* and diatom species indicative of water hypertrophy strongly developed in open water of Lake Miłkowskie (Sekulska-Nalewajko, pers. com.).

The sediments deposited in the 20th century showed the regeneration of forest communities caused by the decreased importance of agriculture connected with the population decline after the World War II.

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