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Vegetation changes and human activity around Lake Łańskie (Olsztyn Lake District, NE Poland) from the mid Holocene, based on palynological study

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ABSTRACT. Bottom sediments of Lake Łańskie in NE Poland (Olsztyn Lake District) were studied by pollen analysis, and vegetation changes from ca 4800 BC to modern times were reconstructed based on the results. Due to rapid sedimentation the changes in plant cover are recorded with high resolution. The variation of pollen spectra composition reflects changing shares of deciduous trees and the continuous dominance of pine forest. Nowadays the surroundings of Lake Łańskie are also heavily forested but as early as 1100 AD the deciduous trees began to be eliminated. On the basis of pollen data, five phases of increased human activity were distinguished. Based on the available archaeological chronology of local settlements, the first stage is connected with para-Neolithic groups of Ząbie-Szestno type and the Lusatian culture. They are followed by the West Baltic Barrow culture, Wielbark culture and Early Medieval Prussian tribes. The pollen record shows low intensity of exploitation of the terrain around Lake Łańskie, probably attributable to the brevity of episodes of human occupation in the near vicinity of the lake. The last phase, covering part of the Middle Ages (since ca 1000 AD) and modern times, is reflected in the most distinct vegetation changes on the pollen diagram, caused by increased intensity of settlement. In spite of the distinct diminution of forest cover around the lake the scale of deforestation was much lower than at other sites in NE Poland.

The main aims of this paper were to describe the changes in the palaeoenvironment which took place around Lake Łańskie (Olsztyn Lake District) and to find those changes in the plant cover which were the effect of human activity, and to confirm whether the changes of palaeoenvironment around Lake Łańskie were noted at the same time in adjacent areas.

KEYWORDS: palynology, human impact, vegetation history, settlement history, late Holocene, NE Poland

INTRODUCTION

The Mazurian Lake District, with its specific natural environment, is also distinguished by the record of the particular population groups that lived there at the Neolithic/Bronze Age transition, described as forest zone or para-Neolithic societies (Manasterski 2009). To reconstruct the vegetation cover changes there, including those caused by human activity, bottom sediments from Lake Łańskie in NE Poland (Fig. 1) were studied by pollen analysis. This material was selected for study because it comes from a site of archaeological investigations on a former island of Lake Łańskie where remnants of human groups connected with assemblages of Ząbie-Szestno type were identified, as well as traces of tribes representing younger cultures. This paper describes the phases of vegetation development in the surroundings of Lake Łańskie and assesses the extent of human impacts on the natural environment from the end of the Atlantic period.

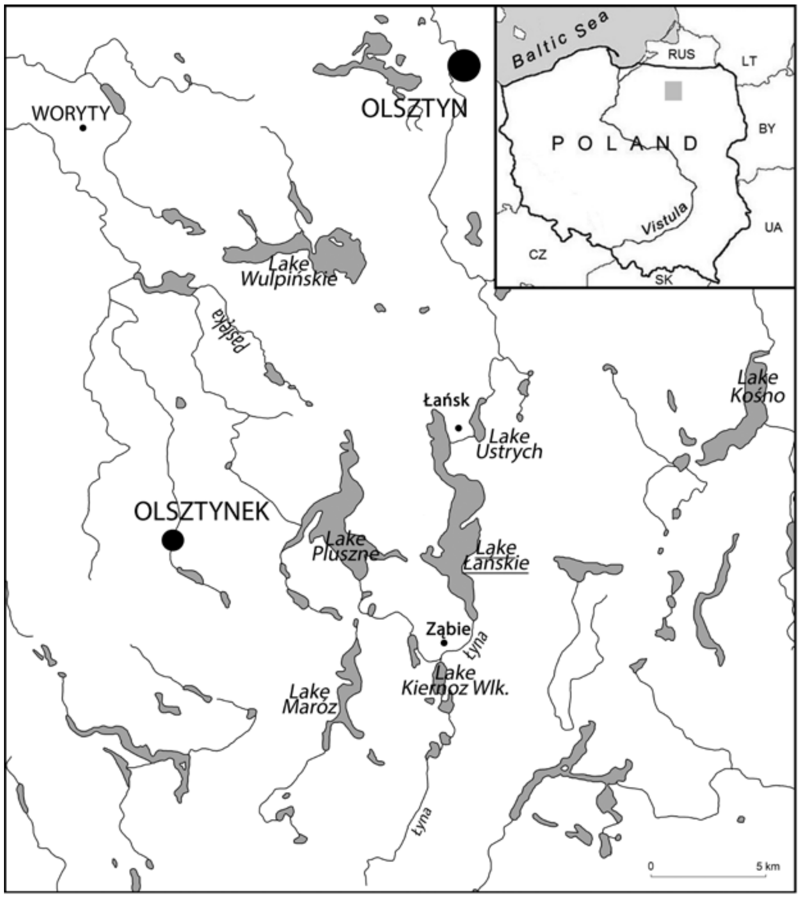

Fig. 1. Map of Poland and location of Olsztyn Lake District

PREVIOUS PALYNOLOGICAL STUDIES IN THE REGION

The history of palynological studies carried out in north-eastern Poland was reviewed by Kupryjanowicz (2008) and then Kołaczek et al. (2013). It appears that palynological sites are not evenly distributed in the palaeogeographical regions distinguished by Ralska-Jasiewiczowa (1989). Their density is greatest in the Great Mazurian Lake District (region P-x) and Suwałki-Augustów Lake District (region P-y). The number of sites is much lower in the much larger area of region P-w (Dobrzyń-Olsztyn Lake District), which includes the Olsztyn Lake District. The first palynological studies in north-eastern Poland were begun by Gross (e.g. 1935, 1936) before World War II. Unfortunately the lack of radiocarbon datings and pollen counts, often limited to tree pollen, limit their usefulness for palaeoecological investigations. That is why some regions are still poorly investigated in spite of the relatively large number of palynological sites (e.g. region P-y).

If we include only the palynological sites that have been studied following recently adopted standards and which relate to postglacial plant cover changes, it is evident that the majority of pollen sites in the Dobrzyń-Olsztyn Lake District (region P-w) are located in its western part. However, only a few of them give information about regional vegetation changes and can be used to draw isopollen maps for Poland (Ralska-Jasiewiczowa et al. 2004). These are Lake Oleczno (Filbrandt-Czaja 1999), Lake Klasztorne (Noryśkiewicz 1997), Mielno (Kępczyński 1960), Steklin (Noryśkiewicz 1982, Noryśkiewicz & Ralska-Jasiewiczowa 1989), Starżym (Noryśkiewicz 1987), Rudnickie Małe peat-bog (Drozdowski 1974, Drozdowski & Berglund 1976), Napole, Czystochleb (Filbrandt-Czaja & Noryśkiewicz 2003, Filbrandt-Czaja et al. 2003), and Czarne Błota (Niewiarowski & Noryśkiewicz 1983). The Woryty site, the reference site for the Olsztyn Lake District, located in the central part of region P-w (Dąbrowski 1981a, Pawlikowski et al. 1982, Noryśkiewicz & Ralska Jasiewiczowa 1989) is the site suitable for palaeoecological comparisons nearest to the Lake Łańskie palynological site.

THE STUDY REGION

According to the physicogeographic division of Poland (Kondracki 2002) the Olsztyn Lake District (area 3820 km^2) is situated at the western border of the Mazurian Lake District where it adjoins the Iława Lake District. To the east it borders the Mragowo Lake District. The northern border is formed by the Old Prussian Lowland (Nizina Staropruska), and the southern one by the Mazurian Plain (Równina Mazurska) and Lubawa Hummock (Garb Lubawski). The Olsztyn Lake District covers the range of the glacial Łyna lobe, which was separated during the last glaciation (mainly the Poznań and Pomerania phases). The traces of the glacier standstill are visible in the form of 7 concentric curves of front moraines running latitudinally. These hills, reaching 300 m a.s.l., are intersected by rivers flowing south-north, among which the Łyna river is the largest in the region. Glacier activity left lakes distributed mostly in the southern part of the region. The biggest lakes in the Łyna river catchment are Lake Łańskie and, a few kilometres away from it, Lake Pluszne (surface area 9 km^2, depth 52 m). The deepest lake of the Mazurian Lake District, Lake Wuksniki (surface area 1.2 km^2, depth 68 m), is in the catchment of the second-largest river, the Pasłęka, which drains the western part of the Olsztyn Lake District.

In respect of climate the Olsztyn Lake District belongs to the West Mazurian Region, which includes the western part of the Mazurian Lake District and is characterized as cold lowland climate (Woś 1999). Mean January temperature varies from –2.4 to –4.0°C, mean July temperature reaches 18.0°C, and mean annual temperature is 6.0–7.0°C. Winter lasts ca 100 days, snow cover 70–80 days, and the vegetation period 190–210 days. Mean annual precipitation is ca 600 mm, most of it falling in summer. South-west winds prevail (Woś 1999, Starkel 1999, Kożuchowski 2011).

The thickness of Quaternary sediments overlying the Cretaceous and Tertiary deposits varies between 60 and 200 m. Soil cover of the Olsztyn Lake District is formed by a complex of zonal soils, mainly brown soils and podzols, which developed chiefly from fluvioglacial sands and boulder clays. Higher areas often are covered by very poor rusty soils. Intrazonal hydrogenic and semi-hydrogenic soils, primarily peaty and gleyey soils, occur in depressions along rivers and around lakes. A special kind of intrazonal soil is gyttja soil formed from lake sediments (Bednarek & Prusinkiewicz 1999).

According to the geobotanical division of Poland the Olsztyn Lake District belongs to the Baltic Division, the Pomeranian Lake Districts Province and the Olsztyn Region (Szafer & Zarzycki 1972). The diversified topography and uneven distribution of lakes and rivers contribute to the formation of different habitat types and their diversified locations. The most significant associations among the forest communities are *Pino-Quercetum* on slightly acidic sandy soils and *Tilio-Carpinetum* on fertile soils. *Melico-Fagetum* and *Luzulopilosae-Fagetum* are frequent associations, particularly in the western part of the region.

The potential natural vegetation of the Olsztyn Lake District would be formed mainly by the sub-Atlantic oak-hornbeam forest community *Stellario-Carpinetum* in the northern and western parts, by the sub-continental lime-oak-hornbeam forest *Tilio-Carpinetum* in the central and eastern parts, and by forest communities representing the sub-continental oak-pine *Querco-Pinetum* and fresh pine *Peucedano-Pinetum* forests in the southern section (Fig. 2). Locally, elm carr *Fraxino-Alnetum* would cover wet habitats along slowly flowing waters, and wet alder woods *Carici elongatae-Alnetum* may have grown in depressions around overgrown lakes and on peat-bog margins (Matuszkiewicz 2008, Matuszkiewicz et al. 2012). The disparity between the potential and actual vegetation is due mainly to the present dominance of pine and the sharp reduction of forests with *Quercus*, *Carpinus*, *Tilia*, and *Alnus*, caused by deforestation of their habitats for economic purposes.

CHRONOLOGY OF LOCAL SETTLEMENT CHANGES

The settlement history of the surroundings of Lake Łańskie is known thanks to archaeological work undertaken in the first half of the 20th century. Surface surveys carried out on an island in Lake Pluszne (site VII at Pluski) in 1938 by L. Fromm and in 1989 by M. Hoffman revealed numerous flint pieces with use-wear patterns and fragments of hand-made

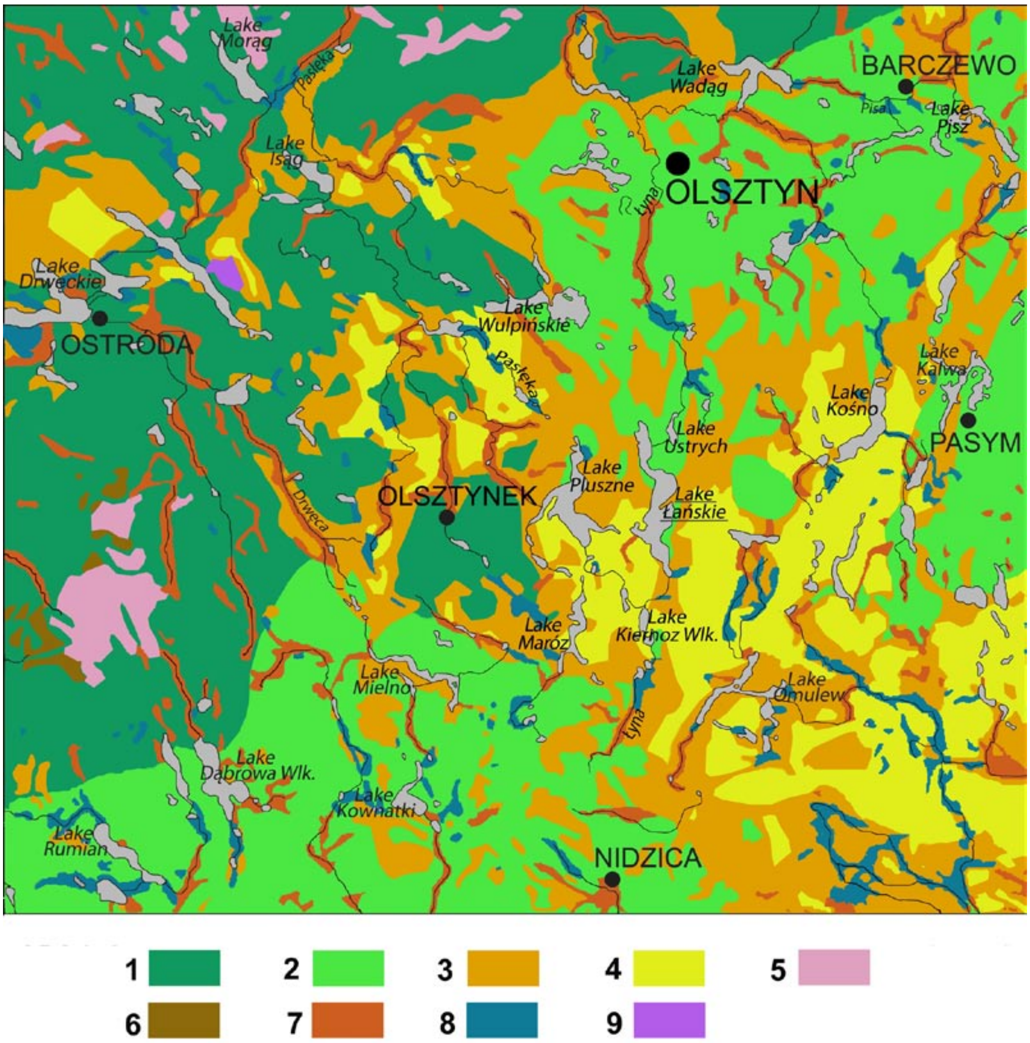

Fig. 2. Potential natural vegetation in the vicinity of Lake Łańskie (after Matuszkiewicz 2008, modified). **1** – *Stellario-Carpinetum*, **2** – *Tilio-Carpinetum*, **3** – *Querco-Pinetum*, **4** – *Peucedano-Pinetum*, **5** – *Melico-Fagetum*, **6** – *Luzulo pilosae-Fagetum*, **7** – *Fraxino-Alnetum*, **8** – *Carici elongatae-Alnetum*, **9** – *Fago-Quercetum*

pottery including a Corded Ware culture pot. New surface prospecting was carried out in the ensuing years, and in 2002–2004 excavations were undertaken by staff of the Institute of Archaeology of Warsaw University. In 1994, during surface surveying carried out under the Archaeological Picture of Poland project, A. Mackiewicz discovered site X at Ząbie, situated on a promontory overlooking Lake Łańskie. Since 1997, archaeological excavations have been carried out there under the direction of Dr. A. Waluś. During field studies over 650 features of sepulchral or settlement character have been discovered, some of which were dated to the Neolithic (para-Neolithic)/ Bronze Age transition (Waluś & Manasterski 2002, Waluś 2004, Manasterski 2009, Waluś 2011). A number of discoveries in addition to the ones at Lake Łańskie and Lake Pluszne are relevant to our understanding of how para-Neolithic groups in the Mazurian Lake District functioned. These include Kownatki (Nidzica County), Barkweda (Olsztyn County), and to the north-east Dudka and Szczepanki (Giżycko County), and Ptasia Wyspa island in Lake Salęt, (Mrągowo County). Previously available archaeological data indicate that the Lake Łańskie area was settled in several stages. The oldest phase, known from the Ząbie X site, is represented by skeletal burials dated to the Corded Ware culture and connected with temporary seasonal stays of human groups. Under the influence of Globular Amphora culture groups on Niemen culture societies, a new syncretic group called Ząbie-Szestno assemblages (after the most important sites) began to form sometime between 2600/2500 BC. Then the early Bronze Age is marked by a strong influence of the Iwno culture and the transformation from hunting-gathering to foraging-farming societies intensifies. In effect, different groups emerge, Neolithic and para-Neolithic in character and with some early Bronze features, which later come under the influence of the Trzciniec culture. This settlement phase on the island in Lake Łańskie dates from 1950/1900 to 1650/1600 BC (i.e. I EB in north-east Poland; Dąbrowski 1997). At the turn of Bronze Age III and IV (1100–1000 BC) the Mazurian-Warmian group of the Lusatian culture appears in the Olsztyn Lake District (Okulicz 1981) and at the turn of Bronze Age IV and VI (1000–550 BC) a network of settlement was present (Fig. 3). Under its influence the culture phenomenon defined as Ząbie-Szestno assemblages comes to an end. A settlement of Ząbie-Szestno assemblages was also discovered at the Swaderki I site, on an island of Lake Święte (Jaremek & Nowakowska 2011). Although few remains of the Lusatian culture were discovered in the immediate vicinity of Lake Łańskie (site Ząbie), the occurrence of this culture in the Olsztyn Lake District was confirmed at, for example, the Woryty site (Dąbrowski & Mogielnicka-Urban 1976, Dąbrowski 1981a). At the beginning of the Iron Age the West Baltic Barrow culture (West Mazurian group) appears in the area (Fig. 4). Features connected with this culture predominate at the Ząbie site, constituting 90% of all findings there (Manasterski 2009). A fairly large amount of pottery as well as animal bones, mainly of domestic animals, fish bones and crustaceans were found in the examined household features. The pottery dates these findings to the 3rd century BC. The majority of findings at the Pluski VII site also belong to the West Baltic Barrow culture. A characteristic feature of this culture was the foundation of small defensive settlements, at times in the lakes on artificial islands made of sunken trunks. Trunks were arranged in layers and fixed with piles driven into the lake bottom (Kaczanowski & Kozłowski 1998). In the late pre-Roman period the number of settlements was significantly reduced due to the threats from the Wielbark and Przeworsk cultures (Hoffman 2000, Cieśliński 2009). The unsettled land thus created around Lake Łańskie and Lake Pluszne (Fig. 5) was repopulated only when early medieval people arrived. The following centuries witnessed the tribal

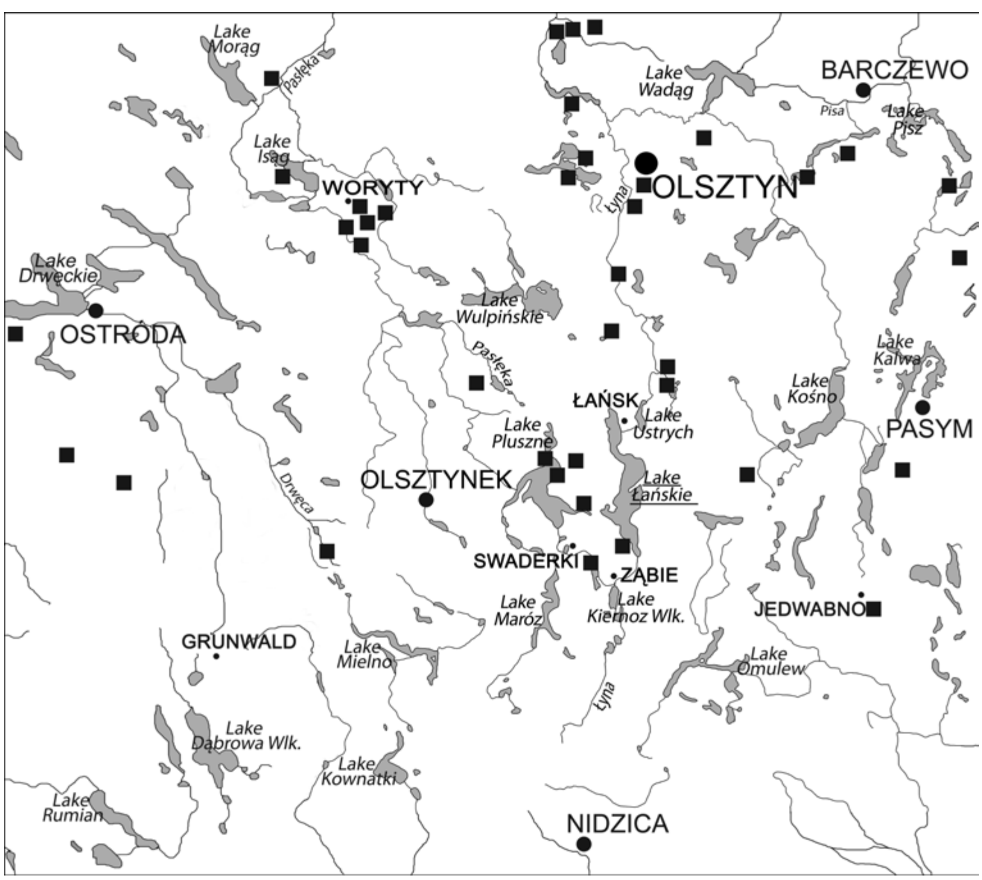

Fig. 3. Settlement remains in the Lake Łańskie area dated to the turn of Bronze Age the IV and VI (after Hoffmann 2000, modified)

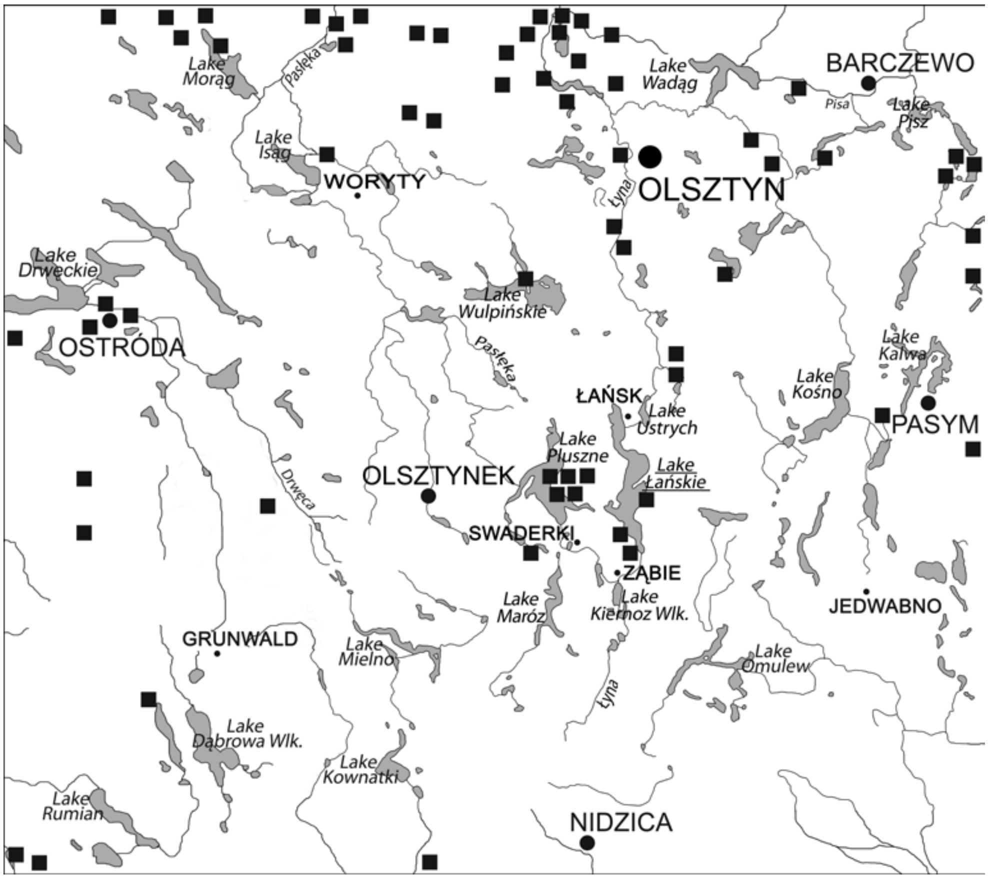

Fig. 4. Settlement remains in the Lake Łańskie area dated to the turn of the Hallstatt and La Tène (Hallstatt D and La Tène B) (after Hoffmann 2000, modified)

division of the Mazurian Lake District and the emergence of a new Prussian settlement culture (Achremczyk 2010).

When the repeated attempts of Polish rulers to Christianise the lands inhabited by the pagan Prussian tribes brought no success, Prince Konrad I Mazowiecki (Conrad I, Duke of Mazovia), called in the Order of Brothers of the German House of Saint Mary in Jerusalem (Teutonic Knights) in 1226 AD. Their aim was to conquer and Christianise the Prussian lands. After the defeat of the Prussians the Teutonic Knights founded a state and divided it into four dioceses, including the Warmian diocese.

At the end of the 13th century at the site of an Old Prussian stronghold the Teutonic Knights built a watchtower, around which a settlement developed. Decades later this settlement was granted a charter and from 1329 functioned as the town of Ostróda. The foundation of Ostróda and nearby Dąbrówno (1316), where a castle had existed before (Piotr z Dusburga 1326), indicates that colonisation encroached on forested areas of Sasinia and Galindia. There is information from 1351 that the castle in Olsztynek was already under construction. Wooden buildings were protected by a high palisade of tree trunks. Nidzica (1381) was the last town located in this area. The little villages of Bartążek (1335) and Stawiguda (1357) came into being at that time. In 1328 the administrator of Olsztynek together with the inhabitants were granted 50 feuds to use and the administrator also received permission to use nets for fishing in Lake Pluszne and a share of the income of bread and meat merchants (Toeppen 1859, Achremczyk 2010). According to an inventory from 1397, in the Olsztynek castle the reserves accumulated in case of war included, in addition to weapons, 504 barrels of rye, 744 barrels of wheat, 12 barrels of barley and almost 3 barrels of hops (Toeppen 1859). Town walls were built in Olsztynek as late as the 15th century. At the beginning of the 15th century the village of Ząbie was founded.

After the secularization of the Teutonic Order in 1525, a new state, Ducal Prussia, was created, and southern Prussia was colonised by settlers coming mainly from Mazovia. At that time Olsztynek and its vicinity witnessed considerable economic development due to lively contacts with Poland. Olsztynek

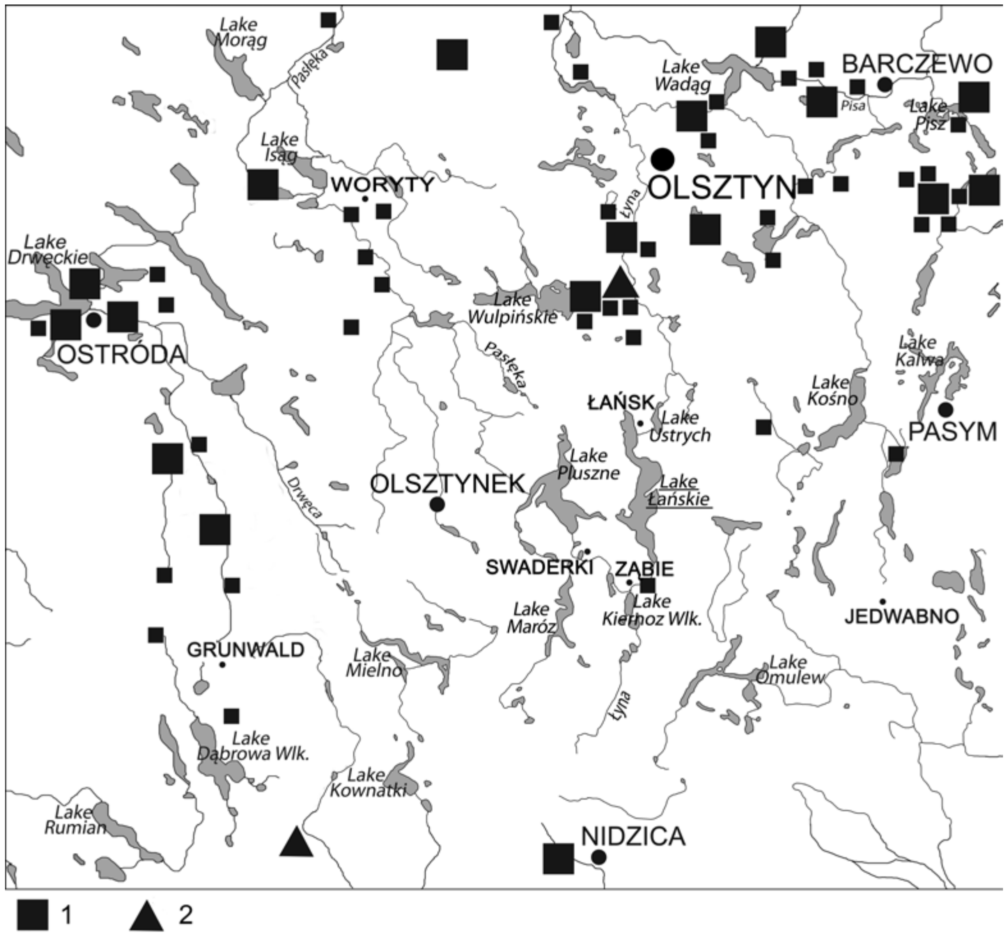

Fig. 5. Location of archaeological sites of Wielbark culture in the Lake Łańskie area; **1** – Wielbark culture, **2** – Przeworsk culture (after Cieśliński 2009, modified)

had several mills, and breweries that produced beer for local use and for sale. In Nidzica iron was smelted from bog iron ore which was abundant in Warmia and Mazuria; that required large quantities of charcoal produced from wood from the surrounding forests (Ratajczak & Rzepa 2011, Maruszewski 1976). In 1609, one farm situated near Olsztynek used the following quantities for one sowing: 108 barrels of winter rye, 60 barrels of barley, 180 barrels of oat, 385 litres of peas and the same amount of buckwheat, 330 litres of hemp, and 522 litres of flax (Toeppen 1859). Twelve shoemakers who lived in Olsztynek in 1610 paid fees to the Duke's treasury for permission to grind oak bark, used for tanning leather, at the mill in Swaderki, and land tax for 11 tanneries in Olsztynek (Toeppen 1859). The 17th century brought tragic events: Tartar invasions, famines and epidemics, but above all the Swedish wars, which began in 1626 and lasted, with breaks, until 1660, caused enormous devastation and population loss. In 1657, 300 of the 800 inhabitants of Olsztynek perished in a plague epidemic and the town itself was almost completely destroyed by fire in 1685. Restoration of East Prussia after the war devastation was interrupted by the great plague epidemic which in 1709–1711 depopulated whole regions (Kossert 2005). In Olsztynek 500 and in Nidzica about 200 people died, a quarter of the inhabitants. The town was surrounded by trenches and palisades and guards shot at people who tried to escape the town clandestinely. In addition, an exceptionally bitter winter in 1708/1709, followed by a very hot summer, worsened the crop failure and caused famine. The epidemic and the famine killed 200 000 of the 600 000 inhabitants of Prussia. A church book from Olsztynek records: "The year after the plague was a year of famine and extreme poverty. The consequences of the plague were equally great in the town and in the village. As in the other regions of Prussia, in the Olsztynek district vast fields lay fallow due to the lack of hands for their cultivation" (Toeppen 1859). This fatal course of events was interrupted by Frederic Wilhelm I, who after ascending to the throne in 1713 initiated a series of reforms, including agrarian reforms. New settlement in the depopulated areas began. Colonisation was stimulated by giving land free of charge to the new settlers. In 1738 Nidzica had 1142 inhabitants, and by 1751 their number increased to 1867. Potato was introduced in the 18th century and its cultivation quickly became popular, enriching the very modest diet of the inhabitants. The Napoleonic Wars at the beginning of the 19th century spawned a new wave of disasters which resulted in economic collapse and depopulation. In 1804 Olsztyn was destroyed by fire. In 1831 there was a cholera epidemic in this region; in Nidzica, 218 of 356 patients died. "To cleanse the air a pile of juniper shrubs was often burned on the market square" (Gregorovius 1883). In 1844 a catastrophically dry spring and rainy summer damaged the cereal and potato crops, causing famine and the spread of diseases. The economic boom that started in the second half of the 19th century led to a population rise. In 1852 Nidzica had 3229 inhabitants. In 1856 a road was built from Olsztynek to Ostróda and Nidzica and in 1887 the Olsztyn-Olsztynek-Działdowo railway was opened. In 1883 there were 29 horses, 85 head of cattle, 756 sheep, and 35 pigs (Maruszewski 1976). After drainage of 2500 ha of peatbogs, exploitation of neighbouring land increased. Economic development lasted until 1914, when the German forces won a battle with the Russian army between Działdowo and Olsztynek and military operations caused damage to several towns and villages. In 1945 the Soviet army defeated German troops and took over this area. After the war most of the localities were burned. The depopulated southern regions of East Prussia were annexed to Poland and the area was settled by people brought from Mazovia and from south-eastern Poland (forced removal of Lemko people) under Operation Vistula in 1947. In the 1950s a retreat for the Office of the Council of Ministers was built in Łańsk, which had an impact on its surroundings. Around this exclusive retreat the authorities did away with the nearby villages and took over the land for hunting (Białkowski 1990).

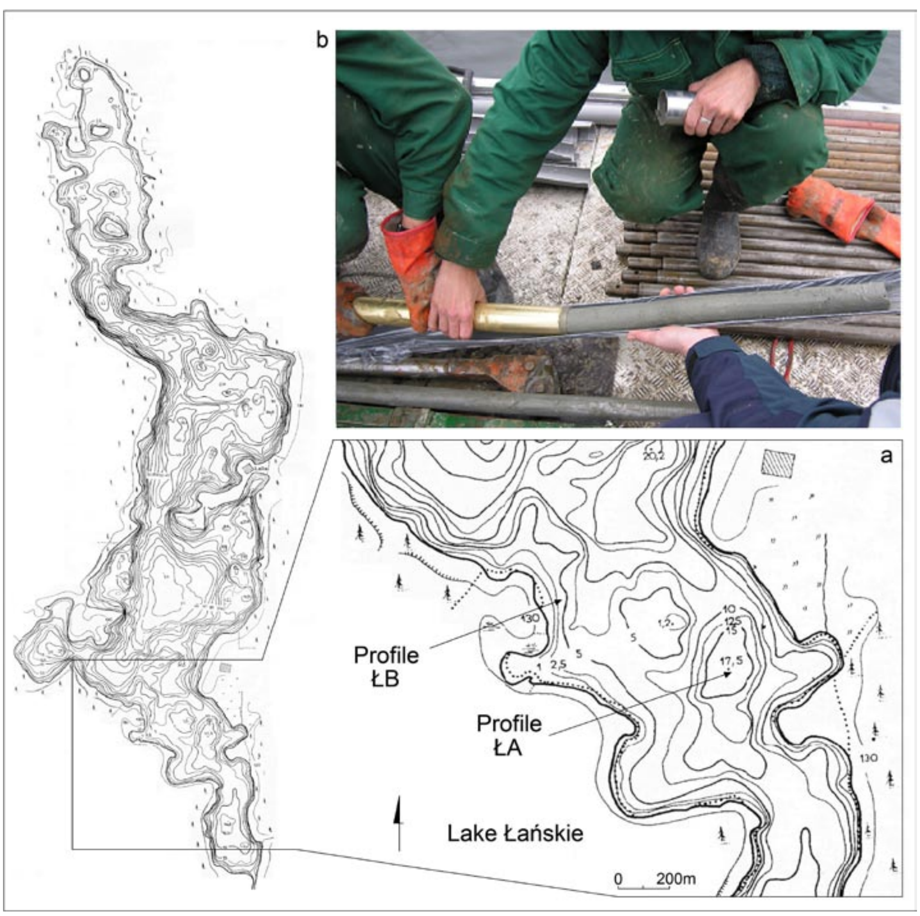

Fig. 6. **a** – Bathymetric map of Lake Łańskie, showing coring sites from which ŁA and ŁB profiles were taken; **b** – Example of sediment collected with Więckowski piston corer floating platform

STUDY SITE

Lake Łańskie (also called Lake Łańsk) is a large channel lake (surface area 1041.3 ha, elevation 135 m a.s.l.) in the Olsztyn Lake District. It extends ca 10.5 km meridionally and is 0.5–2.2 km wide (Fig. 6). The maximum depth is 53 m, 16 m on average (Choiński 1991). In the northern part of the lake are a few small islands totalling 7.3 ha in area. It is a flow-through lake. The river Łyna flows into the lake at the southern end and flows out in the north-east toward Lake Ustrych. The shoreline, ca 34 km long, is very diversified and forms several bays and peninsulas, an eastern one (Lalka) extending up to 1.3 km towards the centre of the lake. The lake shores are high, forming steep slopes in some places, and in some places are flat. The whole drainage basin of the lake covers the entire upper Łyna river catchment (437.4 km^2), while the immediate drainage basin covers slightly less than 860 ha and is 80% forested. There are no villages in the drainage basin, only buildings belonging to the retreat (Planter & Wróblewska 2004). The Lake Łańskie water is in water purity class II. Lake Łańskie is situated in the Napiwodzko-Ramucki Primeval Forest Protected Landscape Area, and at the north-east lake shore is a large nature reserve (1800 ha) called Las Warmiński (Warmia Forest).

MATERIAL AND METHODS

FIELDWORK

In 2008 two sediment cores were collected with a Więckowski piston corer from a floating platform on the southern part of the lake (Fig. 6). The Łańskie A (ŁA) core, 855 cm long, was taken at ca 300 m from the eastern shore of the lake, where water depth was 16 m. The base of the deposits was not reached. The Łańskie B (ŁB) core was collected near the western shore of the lake, where water depth was 2.5 m, several dozen metres from the promontory, formerly an island, where the Ząbie X archaeological site is. This core is short because the sediment base was reached at 105 cm depth.

LABORATORY PREPARATION

Sediment description

The sediments from both cores were composed of lacustrine gyttja. Sediment descriptions are given in Table 1.

Table 1. Sediment description of profiles ŁA and ŁB

Profile	Description of sediments
Łańskie A (ŁA)	1–255 cm calcareous gyttja, light grey
	255–357 cm calcareous gyttja, grey, with intercalations of fine-grained sand at 261 cm and 305 cm depth
	357–601 cm calcareous gyttja, light grey
	601–855 cm calcareous gyttja, dark grey
Łańskie B (ŁB)	5–95 cm calcareous gyttja
	95–105 cm sand

Sample preparation and determination of microfossils

Preparation of sediment for pollen analysis followed Erdtman's acetolysis method (Berglund & Ralska-Jasiewiczowa 1986, Faegri & Iversen 1989). Sediment samples (1 cm^3 volume) were treated with 10% HCl to dissolve carbonates and later heated in 10% KOH to remove humic compounds. The mineral fraction was removed using cold HF for 24 h. Indicator tablets of *Lycopodium* were added to each sample to enable calculation of microfossil concentration (Stockmarr 1971). In each sample the sporomorphs were counted until more than 1000 pollen grains of trees and shrubs were recorded. The pollen counts were lower in only a few samples. Identification of pollen grains relied on keys and atlases (Moore et al. 1991, Beug 2004) and the reference pollen slide collections of the W. Szafer Institute of Botany (Polish Academy of Sciences) and the Institute of Botany of the Jagiellonian University. A few green algae such as *Pediastrum* and *Tetraedron* were identified from literature data (Jankovská & Komárek 2000, Komárek & Jankovská 2001).

The results are presented as percentage diagrams drawn with POLPAL for Windows (Nalepka & Walanus 2003). Percentage values were calculated from the total sum, which included pollen of trees and shrubs (AP) and herbaceous plants (NAP) and excluding sporomorphs of local vegetation (aquatics, plants of wet places, spore plants). To calculate the percentage of a taxon excluded from the sum the number of its sporomorphs was added to the total (Figs 7, 8, 9).

The pollen diagram was divided into local pollen assemblage zones (L PAZ) and subzones (L PASZ) on the basis of the taxonomic composition of the pollen spectra and the percentage values of taxa showing the highest frequency, or on the basis of the most characteristic taxa. The division was supported by numerical analyses (ConSLink; Nalepka & Walanus 2003).

Because no macrofossils of terrestrial plants suitable for radiocarbon dating were found in the ŁA profile it was decided to isolate pollen grains with the use of heavy liquid: $ZnCl_2$ solution, of 1.88 g/cm^3 specific gravity (Nakagawa et al. 1998).

Chronology

The time scale of the ŁA profile is based on comparison of the characteristic shape of the *Carpinus* and *Pinus* curves in this profile with those in the reference site, Woryty P-24, whose time scale is based on radiocarbon dates (Noryśkiewicz & Ralska Jasiewiczowa 1989) presented in Figure 10. The

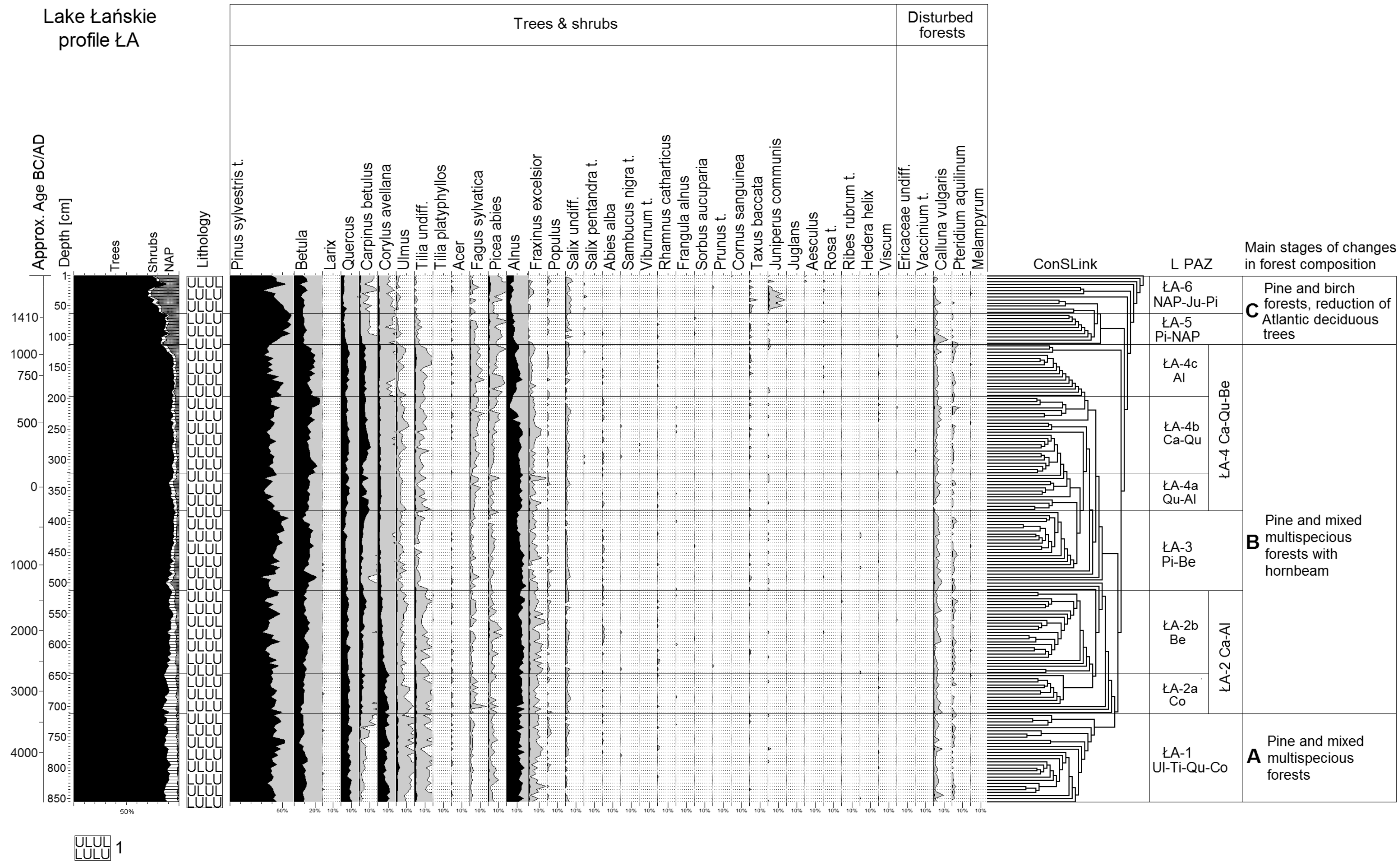

Fig. 7. Lake Łańskie, profile ŁA – percentage pollen diagram. Changes in frequency of arboreal plants and disturbed-forest plants. **1** – gyttja, **ŁA1** – **ŁA6** – numbers of L PAZ; abbreviations: **Ul** – *Ulmus*, **Ti** – *Tilia*, **Qu** – *Quercus*, **Co** – *Corylus avellana*, **Ca** – *Carpinus betulus*, **Al** – *Alnus*, **Be** – *Betula*, **Pi** – *Pinus sylvestris*, **NAP** – non-arboreal pollen (herbs), **Ju** – *Juniperus communis*

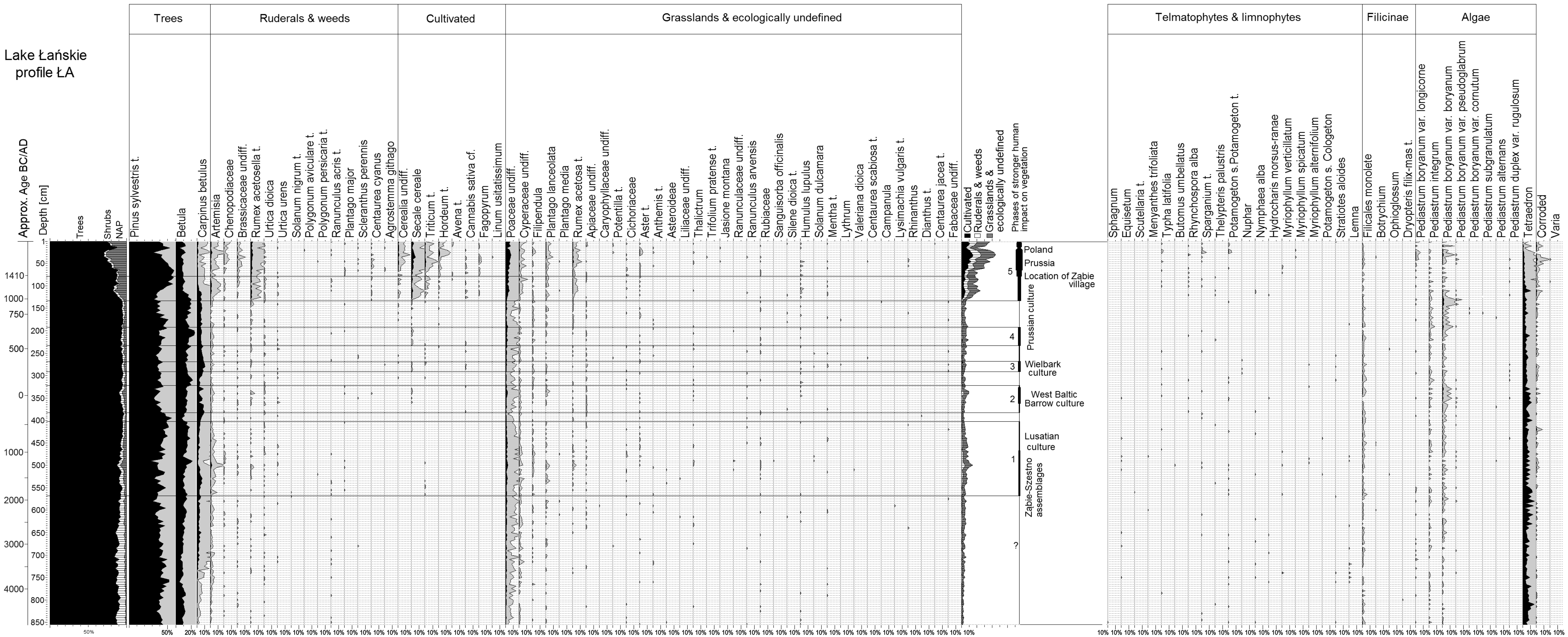

Fig. 8. Lake Łańskie, profile ŁA – percentage pollen diagram. Changes in frequency of herbs in total pollen, telmatophytes, limnophytes, Filicinae and algae, and phases of stronger human impact on vegetation

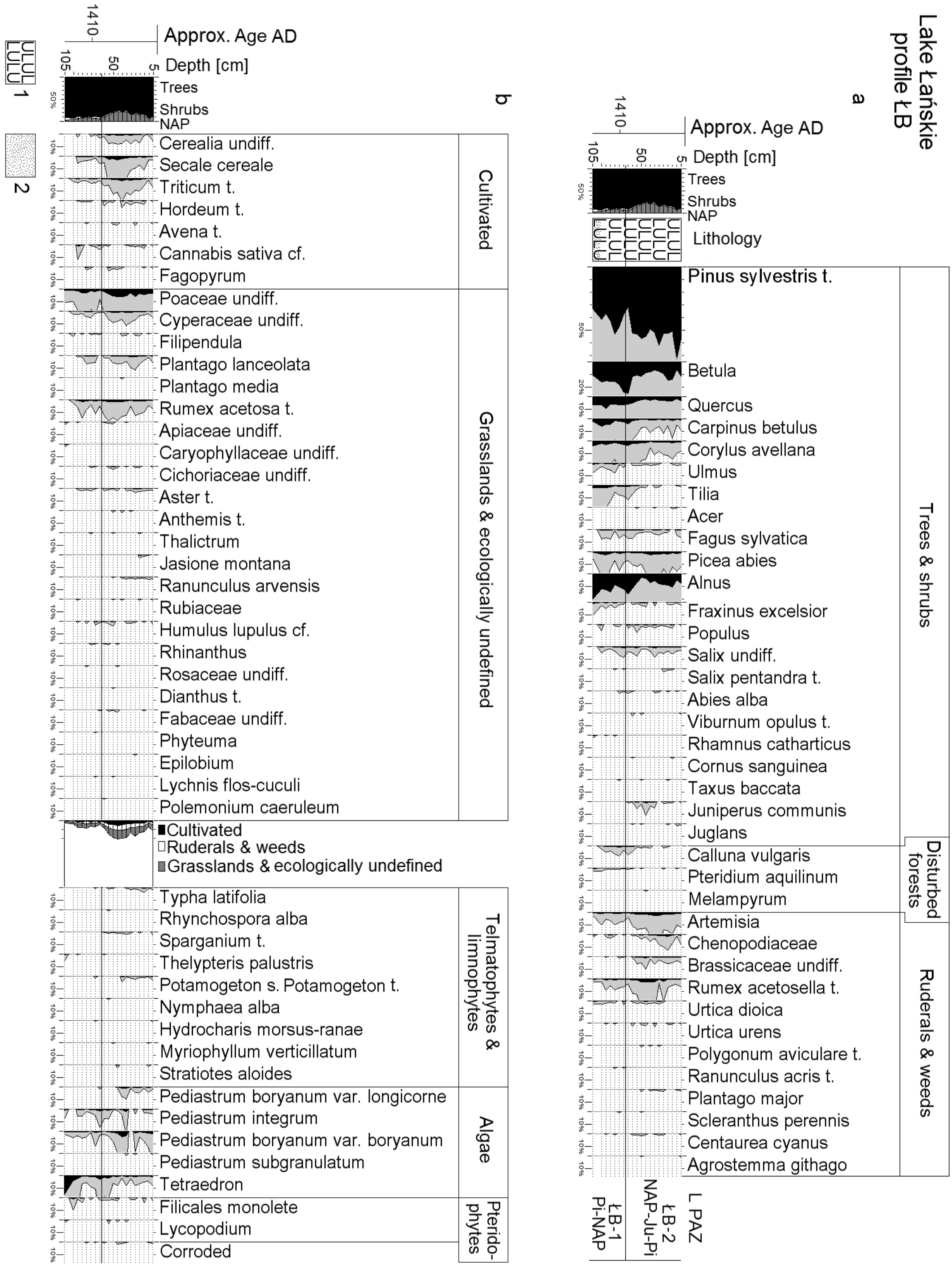

Fig. 9. Lake Łańskie, profile ŁB – percentage pollen diagram. Changes in frequency of arboreal plants, disturbed-forest plants, ruderals, weeds (a) and cultivated plants, grassland plants, ecologically undefined, telmatophytes, limnophytes, algae and pteridophytes (b). **1** – gyttja, **2** – sand. **ŁB1** – **ŁB2** – numbers of L PAZ; abbreviations: **Pi** – *Pinus sylvestris*, **NAP** – non-arboreal pollen (herbs), **Ju** – *Juniperus communis*

accuracy of the proposed time scale was confirmed by AMS dating of one sample of pollen extract from the ŁA profile isolated as described by Nakagawa et al. (1998). For the ŁB profile a single macrofossil was dated and the date obtained was interpolated to the ŁA profile (Table 2). The dates were calibrated with CALIB REV6.0.0 (Stuiver & Reimer 1993, Reimer et al. 2009).

RESULTS AND DISCUSSION

The results of pollen analysis are presented in Tables 3 and 4, which show the L PAZ division, and in Figures 7, 8, and 9. In order to present the vegetation changes recorded in the profile from Lake Łańskie in the context

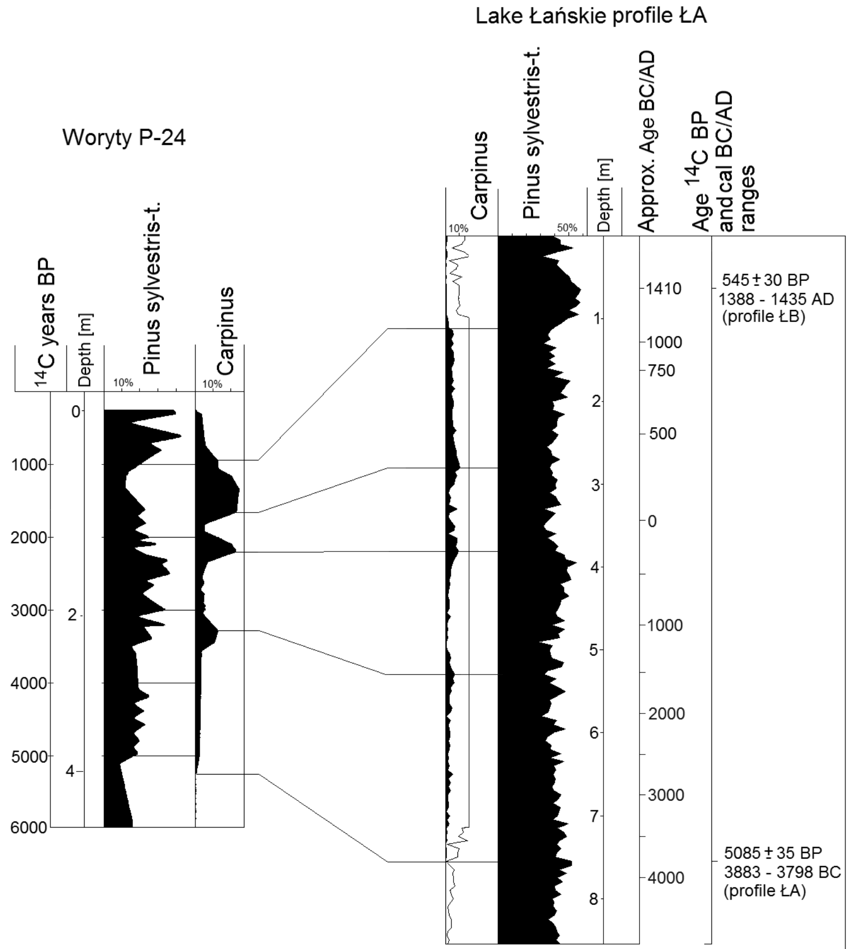

Fig. 10. Age estimation for ŁA profile based on the correlation of the *Carpinus* and *Pinus* percentage curves from the Woryty P-24 site (after Noryśkiewicz & Ralska Jasiewiczowa 1989) with those in profile ŁA

Table 2. Results of AMS radiocarbon dating of materials from profiles ŁA and ŁB. Asterisk (*) indicates too-old dates which were not used in the time scale for ŁA profile

Profile	Laboratory code	Type of dated material / depth	^{14}C age BP	Calendar age BC/AD (95% probability)
ŁA	Poz-54702	pollen extract / 140 cm	2520 ± 30	695–539 BC*
ŁA	Poz-54703	pollen extract / 275 cm	2920 ± 30	1214–1015 BC*
ŁA	Poz-54704	pollen extract / 365 cm	3375 ± 30	1747–1607 BC*
ŁA	Poz-54705	pollen extract / 530 cm	4235 ± 35	2909–2859 BC*
ŁA	Poz-54706	pollen extract / 755 cm	5085 ± 35	3883–3798 BC
ŁB	Poz-51173	wood fragment / 75 cm	545 ± 30	1388–1435 AD

of regional processes the following reference profiles were selected: Lake Miłkowskie situated east of Lake Łańskie in the Great Mazurian Lake District (Wacnik et al. 2012), Lake Gościąż located in central Poland (Ralska-Jasiewiczowa et al. 1998), and the Woryty site ca 22 km north of Lake Łańskie. Figure 11 summarises the comparison.

THE HISTORY OF LOCAL VEGETATION

The profile from Lake Łańskie does not cover the whole Holocene. The occurrence of *Carpinus*, *Fagus*, *Hedera*, and *Viscum* in the oldest zone's L PAZ (ŁA-1), the characteristic curves for the other taxa and the radiocarbon dating results indicate that the record of vegetation changes in profile ŁA-1 begins at the end of the Atlantic period (after Mangerud et al. 1974).

STAGE A

Pine and mixed multispecies forest

Zone ŁA-1 ***Ulmus-Tilia-Quercus-Corylus.*** The terrain near Lake Łańskie was overgrown mostly by pine, which was the main component of the various types of pine-dominated forest. Having low habitat requirements, pine

Table 3. Description of local pollen assemblage zones (L PAZ) and local pollen assemblage subzones (L PASZ) distinguished in profile ŁA

L PAZ and L PASZ Depth (cm) Approximate age	Description of zones
ŁA-1 *Ulmus-Tilia-Quercus-Corylus* 855–715 cm ca 4800 (?) BC–3400 BC	Very high frequency of *Pinus* (up to 56.5%) and high *Alnus* (up to 19%), *Betula* (up to 14%), *Corylus* (up to 12.7%), and *Quercus* (up to 11.5%). Continuous curves of *Ulmus* (up to 4.11%), *Tilia* (up to 3%), *Carpinus* (up to 1.7%), *Fagus* (up to 0.5%), *Fraxinus* (up to 1.8%), and *Picea* (up to 1.1%). Sporadic occurrence of *Abies*, *Rhamnus*, *Taxus*, *Juniperus*, and *Viscum*. NAP low, represented mostly by pollen of Poaceae (up to 1.6%) and *Artemisia* (up to 0.7%). In some spectra are human indicators: Chenopodiaceae, Brassicaceae, *Plantago lanceolata*, and *Rumex acetosella* t. Upper zone boundary: increase of *Carpinus*
ŁA-2 *Carpinus-Alnus* 715–515 cm ca 3400 BC–1350 BC	*Pinus* very high (up to 54.5%). *Betula* slowly increasing (from 6.3% to 17.5%). High values of *Alnus* (up to 19.5%). *Quercus* up to 10.2%. *Corylus* decreasing (from 12% to 3%). Slight decrease of *Ulmus* (up to 4.9%). Increase of *Carpinus* (from 1.5% to 8.2%). Low curves of *Tilia*, *Picea*, and *Fraxinus*. Almost continuous curves of *Fagus*, *Salix*, and *Populus*. Sporadic occurrence of *Abies*, *Acer*, *Rhamnus*, *Taxus*, and *Juniperus*. NAP low. Relatively abundant Poaceae (up to 2.9%). Human indicators occur regularly: *Artemisia* (almost continuous curve), Chenopodiaceae, Brassicaceae, *Plantago lanceolata*, *Plantago major*, *Rumex acetosella* t., and *Urtica urens*. Upper zone boundary: reduction of *Carpinus* and *Tilia*, increase of *Betula*
ŁA-2a *Corylus* 715–650 cm ca 3400 BC–2700 BC	Very high values of *Pinus* (up to 54.5%). *Betula* (up to 11.5%), *Alnus* (up to 18.5%), *Quercus* (up to 10%), *Corylus* (up to 12%). Slight decrease of *Ulmus* (down to 1.9%). *Carpinus* slowly increasing (from 1.5% to 6.3%). Low but continuous curves of *Fagus*, *Tilia*, *Picea*, *Fraxinus*, *Salix*. Low NAP. Increase of Poaceae (from 0.5% to 2.4%). Almost continuous curve of *Artemisia* (up to 0.7%). Single grains of Chenopodiaceae, *Plantago lanceolata*, Brassicaceae, *Rumex acetosella* t., *Urtica urens*, and *Scleranthus perennis*
ŁA-2b *Betula*; 650–515 cm ca 2700 BC–1350 BC	*Pinus* very high (up to 55%) and fluctuating. Increase of *Betula* (up to 17.5%) and slightly of *Alnus* (up to 19.5%). Gradual increase of *Carpinus* (from 2.1% to 8.15%) and decrease of *Corylus* (from 9.8% to 3%). First appearance of *Triticum* t.
ŁA-3 *Pinus-Betula* 515–385 cm ca 1350 BC–300 BC	Very high *Pinus* (up to 62%). *Betula* higher with one peak (25.5%). *Quercus* and *Corylus* slightly decrease. Decrease of *Alnus* at top of zone (from 19.5% to 10.7%). *Carpinus* low after fall at zone bottom but increasing in upper part. *Ulmus*, *Tilia*, *Fagus*, *Picea*, *Fraxinus*, *Salix*, and *Populus* low. Sporadic occurrence of *Acer*, *Abies*, *Rhamnus*, *Taxus*, *Juniperus*, and *Hedera*. NAP low, represented mostly by Poaceae (up to 3.2%). More frequent human indicators, mostly *Artemisia* and Chenopodiaceae, *Rumex acetosella* t., *Urtica urens*. Upper zone boundary: reduction of *Pinus*, rise of *Alnus*, *Betula*, and *Quercus*
ŁA-4 *Carpinus-Quercus-Betula* 385–115 cm ca 300 BC–150 AD	*Pinus* decreased but still dominating (up to 54%). *Betula* decreased with three maxima (up to 27.5%). More abundant *Quercus* (up to 9.5%), *Carpinus* (up to 11.5%x). *Alnus* up to 17.5% with depression in upper part of zone. Slightly increased but low *Corylus* (up to 4.1%), *Tilia* (up to 2%), *Fagus* (up to 1.5%), and *Picea* (up to 1.9%). Low *Fraxinus* and *Salix*. Sporadic occurrence of *Populus*, *Abies*, *Acer*, *Taxus*, and *Juniperus*. NAP low, represented mostly by Poaceae (up to 3.6%). Decrease of *Artemisia*, other human indicators present: Chenopodiaceae, Brassicaceae, *Rumexacetosella* t., *Urtica urens*, *Plantago major*, *Centaurea cyanus*, and *Agrostema githago*. *Secale cereale*, *Triticum* t., *Hordeum* t., Cerealia undiff., and *Cannabis sativa* cf. present. Upper zone boundary: increase of *Pinus* and NAP, decrease of *Betula*, *Quercus*, *Carpinus*, and *Alnus*
ŁA-4a *Quercus-Alnus* 385–325 cm ca 300 BC–100 AD	*Quercus* up to 9.4% and fluctuating, *Carpinus* up to 10.5%, decreasing and fluctuating. *Alnus* up to 18%
ŁA-4b *Carpinus-Quercus* 325–200 cm ca 100 AD–260 AD	After an initial rise (up to 11.5%) *Carpinus* gradually decreases. *Quercus* up to 9.2%. *Alnus* up to 17.5%, with fall at top of subzone
ŁA-4c *Alnus* 200–115 cm ca 260 AD–1100 AD	Rise of *Alnus* (up to 16.5%), slight rise of *Tilia* (up to 2%). *Pinus* (up to 56%), fluctuating and decreasing
ŁA-5 *Pinus*-NAP 115–65 cm ca 1100 AD –1500 AD	The highest *Pinus* in the whole profile (up to 66%). Decrease of *Betula* (to 13.5%), *Alnus* (to 11%), *Quercus* (to 6.3%), *Carpinus* (to 3.2%) and *Tilia* (to 0.7%). End of continuous curves of *Ulmus*, *Fagus*, and *Fraxinus*. Characteristic high percentages of herbaceous plants, particularly Poaceae (up to 6.2%), *Secale cereale* (2.25%), *Artemisia* (up to 1.7%), *Rumex acetosella* t. (up to 1.6%), Cyperaceae (up to 1.3%), *Rumex acetosa* t. (up to 0.8%), and *Triticum* t. (up to 0.8%). First appearance of *Fagopyrum* and *Avena* t. Upper zone boundary: fall of *Pinus*, rise of NAP and *Juniperus*

Table 3. Continued

L PAZ and L PASZ Depth (cm) Approximate age	Description of zones
ŁA-6 NAP-*Juniperus-Pinus* 65–1 cm ca 1500 AD–2000 AD	Fall of *Pinus* but with one high peak (68.5%). *Betula* up to 15%, *Alnus* up to 8%. Low percentage curves of *Picea* (up to 3.4%), *Carpinus* (up to 2.1%), *Corylus* (up to 1.9%), and *Salix* (up to 0.8%). Discontinuous curves of *Ulmus*, *Tilia*, *Fagus*, *Acer*, *Fraxinus*, *Populus*, and *Taxus*. Rise of *Juniperus* (up to 2%). Highest NAP in the whole profile. Rise of Poaceae (up to 8.5%), *Secale cereale* (up to 6.5%), *Rumex acetosella* t. (up to 3.9%), *Artemisia* (up to 3.2%), *Triticum* t. (up to 2%), *Hordeum* t. (up to 1.9%), Cerealia (up to 1.9%), Brassicaceae (up to 1,4%), *Plantago lanceolata* (up to 1.2%), *Rumex acetosa* t. (up to 1.2%), and Chenopodiaceae (up to 1.1%). Pollen of *Avena* t. present at top of zone. Single records of *Polygonum persicaria* t., *P. aviculare* t., and *Linum usitatissimum*

Table 4. Description of local pollen assemblage zones (L PAZ) and local pollen assemblage subzones (L PASZ) distinguished in profile ŁB

L PAZ and L PASZ depth	Description of zones
ŁB-1 *Pinus*-NAP 105–65 cm	Very high frequency of *Pinus* (up to 54%). *Betula* (up to 25%), *Alnus* (up to 24%), *Quercus* up to 10%), *Carpinus* (up to 6.5%), and *Tilia* (up to 2.2%). *Corylus* (up to 5%). Very low frequency of *Ulmus Fagus*, *Fraxinus*, *Tilia*, and *Populus*. Percentages of herbaceous plants up to 10%, particularly high Poaceae (up to 3%). *Secale cereale* (0.7%), *Artemisia* (up to 1%), *Rumex acetosella* t. (up to 1%), *Rumex acetosa* t. (up to 1.3%), and *Triticum* t. (up to 0.4%). Appearance of *Fagopyrum*, *Avena* t., and *Cannabis sativa* cf. Upper zone boundary: rise of NAP and beginning of *Juniperus*
ŁB-2 NAP-*Juniperus-Pinus* 65–5 cm	*Pinus* ca 52–57% but with one high peak (74.5%). Fall of *Betula* (up to 14.5%), *Alnus* (to 12%), *Quercus* (to 5.4%) and *Carpinus* (to 1.7%). Falls and low frequency of other trees (*Ulmus*, *Tilia*, *Acer*, *Fagus*, *Fraxinus*). Single pollen grains of *Juglans*. Appearance of *Juniperus* (up to 1.1%). High NAP but falling at top of zone, mostly Poaceae (up to 6.7%), *Secale cereale* (up to 3.3%), *Rumex acetosella* t. (up to 2.8%), *Artemisia* (up to 2.6%), *Triticum* t. (up to 2%), *Hordeum* t. (up to 0.6%), Cerealia (up to 0.8%), Brassicaceae (up to 1.%), *Plantago lanceolata* (up to 1.2%), *Rumex acetosa* t. (up to 1.2%), and Chenopodiaceae (up to 1.1%). Pollen of *Avena* t. present at top of zone. Single records of *Polygonum aviculare* t., and *Agrostemma ghitago*

could grow on poorer soils. In places it could form oak-pine mixed forest in which *Betula* and in smaller numbers also *Tilia* could occur as admixtures. The percentage values for deciduous trees such as *Fraxinus* and *Fagus* suggest that they were represented by single plants or did not grow in the area at all. The undergrowth included *Pteridium aquilinum*, and on drier sandier places also *Calluna vulgaris*. *Juniperus* was a rare element. Less competitive *Alnus* (Ellenberg 1996) occupied periodically inundated places where the pressure from other species was lower.

Areas with more fertile soils were covered by multispecies deciduous forests with *Quercus*, *Ulmus*, *Tilia*, and perhaps also *Fraxinus*. High forest density limited the development of undergrowth, in which *Corylus* predominated and *Rhamnus* occurred sporadically. The variation of *Corylus* frequency could be an effect of activity by para-Neolithic people making clearings in dense forests, which, however, did not affect the representation of herbaceous vegetation in the pollen record. Maple-lime forest resembling the lime-oak-hornbeam forest occurring nowadays in lake districts of north-eastern Poland (Jutrzenka-Trzebiatowski 1995) may have appeared on a very limited scale on steep slopes of the Łyna river and around the lake. The *Acer* and *Tilia* percentages are low but as insect-pollinated species they are poor pollen producers. *Acer* pollen percentages in modern deciduous forest with maple do not exceed 0.4% of the total (Noryśkiewicz et al. 2004). Towards the top of the zone the share of *Carpinus* increases, indicating its spread in fertile and periodically wet places (Faliński & Pawlaczyk 1993). The presence of *Viscum* indicates that the warmest-month temperature was not lower than 16°C (Granoszewski 2003).

The herbaceous vegetation percentages are very low. Small open areas, mainly in wet places near the lake, were overgrown by representatives of Poaceae and Cyperaceae, and *Filipendula* and *Thalictrum* also appeared there. The proportion of meadow plants (e.g. *Plantago lanceolata*) is small. The occurrence of Chenopodiaceae may suggest the presence of small patches of higher-nitrogen soil. *Artemisia* can grow on poor and fertile soils but is also more common in human-altered habitats

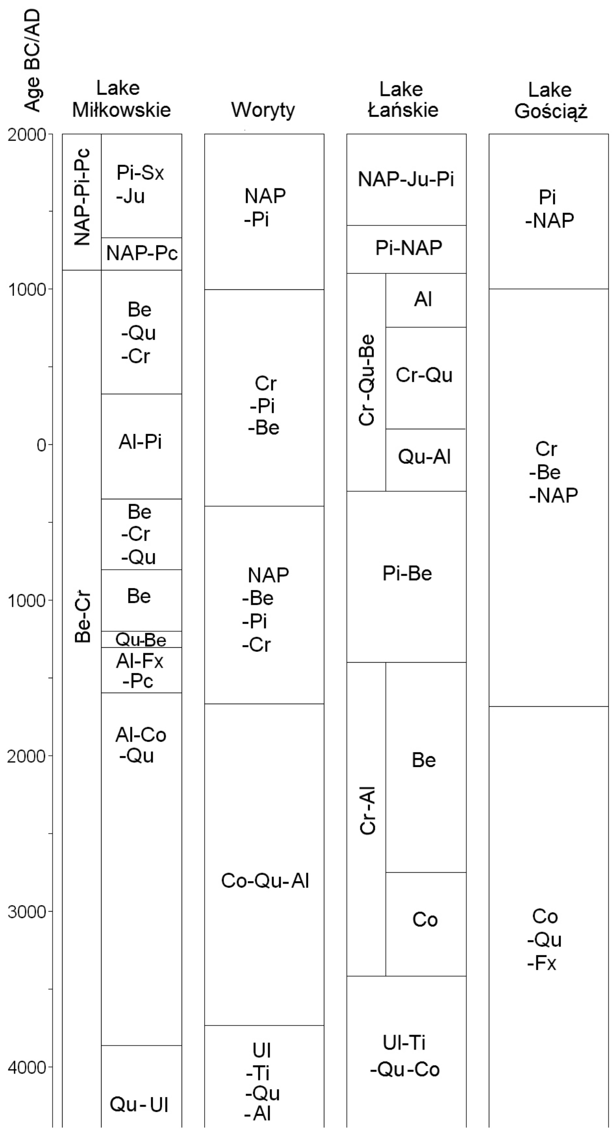

Fig. 11. Correlation of the local pollen assemblage zone (L PAZ) from the studied site (Lake Łańskie) with selected profiles in local (Woryty site) and regional (Lake Miłkowskie, Lake Gościąż) contexts

(Makohonienko et al. 2004). Alternatively, the occurrence of Chenopodiaceae and *Artemisia* might be related to their growth in natural communities developing in open areas. As the record of the older vegetation is not available we do not know whether the frequency of these plants really increased in the discussed L PAZ or had reached this level already in the previous period, during which their occurrence evidently was not related to human impacts on vegetation.

Among limnophytes and telmatophytes the most numerous are pollen grains of the subgenus *Potamogeton* t., which includes *Potamogeton natans* growing in stagnant waters and *Triglochin* occurring at lake shores. *Stratiotes aloides*, *Hydrocharis morsus-ranae*, *Nymphea alba*, and *Lemna* occurred in lake water; shores were overgrown by communities with *Sparganium* or *Typha angustifolia* and *T. latifolia*. Algae were rare, the most frequent being *Pediastrum boryanum* var. *boryanum*, *P. integrum* and *Tetraedron.*

STAGE B

Pine and mixed multispecies forest with *Carpinus*, beginning of anthropogenic disturbance of forests

Zone ŁA-2 *Carpinus-Alnus*. The nearest surroundings of the lake were still forested. The changes in plant cover composition that took place in the time corresponding to this pollen zone brought a gradual decrease of *Pine* and a simultaneous increase of *Betula*. The subsequent elimination of *Corylus* from the undergrowth of deciduous forests may have been caused by human economic activity (subzone ŁA-2b). However, the diminished occurrence of *Corylus* was not accompanied by a rise in herb pollen in the pollen rain composition; instead, the AP percentages increased, suggesting higher density of forest communities. The shrinking of areas covered by *Corylus* made possible to some extent the systematic spread of *Carpinus*. Climatic cooling, which started with the Holocene Thermal Maximum at ca 4500 cal. yr BP (ca 2550 BC) (Heikkilä & Seppä, 2003 Seppä & Poska 2004) also promoted the spread of *Carpinus*, which prefers more continental conditions (Gałka et al. 2013). The *Carpinus* percentages in the whole zone do not fall below 1%, considered an indicator value of its local presence (Huntley & Birks 1983). In effect, on more fertile soils small communities developed built of *Carpinus* and *Quercus* with a small admixture of *Tilia* and single trees of *Picea* on damp soils (Giesecke & Bennett 2004). A small rise of the *Picea* frequency (subzone ŁA-2b) may also reflect the trend of climate cooling and precipitation increase, which favoured the spread of *Picea* (Koprowski 2013). However, pine and pine-oak forests covering less fertile terrain had dominant shares the whole time.

Changes in forest composition were accompanied by a small increase of the herbaceous vegetation percentages. The area covered by Poaceae increased slightly. Some of the plant cover changes may have been caused by man, whose presence is confirmed by the occurrence of *Triticum* and other plants that may be interpreted as human activity indicators, such as *Plantago lanceolata*, *P. major*, *Artemisia*, Chenopodiaceae, Brassicaceae, *Rumex acetosella*, and *Urtica*.

The composition of telmatophytes and limnophytes underwent no significant changes and resembled that in the preceding zone. Among, algae, *Tetraedron* and *Pediastrum boryanum* var. *boryanum* are somewhat more abundant.

Zone ŁA-3 *Pinus-Betula*. The area around the lake was still heavily forested. The occurrence of *Carpinus* becomes distinctly limited and *Corylus* in the forest undergrowth is reduced. The proportions of *Tilia* and *Quercus* are also reduced. The decreased shares of these trees caused a brief increase of open areas recorded in the lower section of the zone, which was followed by the rapid expansion of areas covered by *Pinus* and *Betula*. *Betula*, a pioneer light-demanding tree able to grow quickly if there is no competition from other trees, quickly colonised areas opened up by forest clearing (Faliński 1997, Hynynen et al. 2010). At the top of the zone is another visible change of forest composition: regeneration of *Carpinus*. Undoubtedly these changes were initiated by people, as confirmed by the presence of human activity indicators. Of the taxa noted earlier, *Artemisia* is the most frequent. Changes in forest composition were accompanied by the rise of herbaceous vegetation, in which Poaceae taxa were the most abundant.

The taxonomic diversity of telmatophytes and limnophytes increased. Species such as *Butomus umbellatus* and *Myriophyllum alternifolium* appeared for the first time along lake shores or in the water. The proportions of algae remained at the same level as in the preceding zone.

Zone ŁA-4 *Carpinus-Quercus-Betula*. The high percentages of tree pollen indicate that the lake surroundings were dominated by forest communities. The changes in forest composition involved the expansion of mixed deciduous forests with *Carpinus*. Hornbeam regeneration recorded at the beginning of the zone was followed by several phases of different duration when it was felled and regenerated again, probably due to variation of the intensity of economic activity. Again the area overgrown by pioneer birch expanded. Pine continued to predominate although the total area covered by pine woods decreased. *Quercus* was the main forest tree. The proportions of *Tilia*, *Fagus*, and *Picea* increased slightly. Changes in water conditions caused by climate variation may be responsible for the sudden decline of the *Alnus* curve. The changes in forest composition are correlated with a small percentage rise for herbaceous plants. Representatives of Poaceae are the most numerous. The occurrence of pollen grains of cultivated plants indicates that they were grown near the lake.

Starting from the middle of the zone the proportions of telmatophytes and limnophytes gradually decrease, and they disappear almost completely at the top. Algae are represented most abundantly by *Pediastrum boryanum* var. *boryanum*, more frequent and the bottom and top of the zone, and *P. integrum*. *Tetaraedron*, more abundant at the bottom of the zone, gradually declines towards the top.

STAGE C

Pine and birch forests, reduction of Atlantic deciduous trees, cultural landscape

Zone ŁA-5 *Pinus-NAP*. During this phase, exploitation of land surrounding the lake reduced the size of areas occupied by forest. Atlantic deciduous trees such as *Carpinus*, *Tilia*, *Ulmus*, and *Fraxinus* were almost completely eliminated in the vicinity of the lake. Localities of *Alnus* growth also decreased in number. The lake surroundings were dominated by *Pinus*. Besides pine, only *Betula*, *Quercus*, and *Picea* were of some significance though they could occupy only very small areas. Open areas were covered by herbaceous vegetation, mainly Poaceae. *Calluna vulgaris* reaches the highest percentage values in the whole profile, confirming the existence of disturbed dry forest communities. The clear increase of human indicators among the wild plants and of cultivated plants, and the introduction of new species (*Avena* t., *Fagopyrum*), indicate more intensive economic exploitation of this area.

The vegetation of the lake shore developed again. Aquatics appeared but in low percentages. Green algae are less abundant than in the previous zone.

Zone ŁA-6 NAP-*Juniperus-Pinus*. Continued deforestation reduced the area occupied by *Pinus*. The presence of open areas is confirmed by the rapid spread of *Juniperus communis*. The more frequent occurrence of *Picea* may be connected with climate cooling during the Maunder Minimum (1645–1715 AD) when solar activity decreased (Eddy 1976). Herbaceous vegetation spread over the deforested areas, mainly ruderal, meadow, and cultivated plants. Although the percentage values for herbs are highest in this zone, the surroundings of the lake were still forested.

MICROREGIONAL VEGETATION CHANGES CAUSED BY HUMAN ACTIVITY

Pollen grains of plants that might be interpreted as human indicators (*sensu* Behre 1981) already appear before the phase 1 distinguished in the diagram. Due to the lack of older sediment, however, it is not clear whether their frequency increases in this section and thus whether it is connected with human activity. For this reason the first settlement phase was defined as occurring when the first cereal pollen grains appeared.

PHASE 1, CA 1900–450 BC, ZĄBIE-SZESTNO ASSEMBLAGES AND LUSATIAN CULTURE

The earliest phase of human impacts on vegetation in the Lake Łańskie area is dated to ca 1900–450 BC (Fig. 8). Its lower boundary is fixed chiefly at the first occurrence of *Triticum* t. pollen and the rise of the *Artemisia* curve continuing throughout that phase. Because ruderal plants including *Artemisia*, Chenopodiaceae, *Rumex acetosella*, and *Urtica* were present already below this level, the lower boundary of this phase might fall at ca 2600 BC or even earlier. The ruderal plant percentages are highest in the middle of the zone. Besides the plants recorded before, there appear *Plantago major* and in one sample *Polygonum persicaria* – a plant of ruderal and segetal habitats, known as a field weed since the Neolithic (Lityńska-Zając 2005). Among the meadow plants, Poaceae, *Rumex acetosa*, *Plantago lanceolata*, and *Filipendula* gain larger shares.

In woods the hazel undergrowth was reduced. In the middle of the phase, areas overgrown by *Tilia*, *Carpinus*, and *Quercus* were reduced in favour of *Pinus* and *Betula* but the total forest cover did not diminish. In spite of the increased occurrence of herbaceous plants the total of their pollen nears 5% in only one sample, suggesting that the landscape was dominated by forest. Possibly the human influence on vegetation was in fact stronger but the human-indicator pollen is masked on the diagram by the large quantities of pollen produced by wind-pollinated trees.

The plant cover changes noted in this phase may be connected with the activity of populations belonging to the group called the Ząbie-Szestno assemblages, and later the Lusatian culture. Traces of the presence of this group on the island in Lake Łańskie include features of economic character but with no traces of buildings. This indicates that lightweight, perhaps portable structures were raised and that the settlement on the island was not permanent. Bone remains indicate that the economy was based on shepherding (cattle, sheep/goats), with hunting and gathering playing a considerable role. The lack of pig remains confirms the pastoral-nomadic mode of life, which made pig husbandry impossible (Lasota-Moskalewska 2005). In forested areas grazing was possible on forest fringes and in forest glades or meadows along river banks (Górski et al. 2004). The nearby lakes were another important source of food (fishes, molluscs).

Human-induced vegetation changes are also recorded at the Woryty site. There the beginning of the second settlement phase is dated to ca 1900 BC, but no cereal pollen grains occur in this phase (Ralska-Jasiewiczowa 1981). The first cereal pollen grains in Lake Sałęt sediments occur later, during the first palynological settlement phase dated to 1400–900 cal. BC, connected with the activity of a population representing the Ząbie-Szestno assemblages (Szal et al. 2013). In the sediments of palynological sites in Chełmno Land the weak signs of human activity (e.g. presence of Cerealia-type pollen) are connected with the phase dated to 5500–3600 cal. BC (Noryśkiewicz 2013). In the sediments of Lake Wigry the first Cerealia-type pollen appears in the phase dated to 2175–2093 cal. BC (Kupryjanowicz 2007). Still earlier, ca 3800 BC, Cerealia-type pollen grains appear in the sediments of Lake Miłkowskie (Wacnik 2009) and at the Szczepanki 8 archaeological site (Madeja et al. 2009) in the Great Mazurian Lake District.

Much earlier, as early as ca 6000 ^{14}C BP, Cerealia-type pollen is recorded in Lithuania (Stančikaite et al. 2002).

The second part of this phase is connected with the Lusatian culture, which according to archaeological data appeared in this area at ca 1100/1000 BC and caused the disappearance of the population representing the Ząbie-Szestno assemblage. No cereals are recorded from that time. Ruderals such as *Artemisia* and Chenopodiaceae and meadow plants are still present but develop on a smaller scale than before. The decline of the percentages of herbaceous plants is associated with the beginning of the slow regeneration of *Carpinus* and *Pinus*. At the top of the zone the shares of herbaceous plants decline to ca 1%. The upper limit is based on the *Artemisia* minimum and the beginning of rapid *Carpinus* regeneration, which means that the period connected with the Lusatian culture lasted ca 550 years, until 450 BC. This picture agrees with the archaeological data, which provide no evidence for the continuous presence of a population of this culture near Lake Łańskie and Lake Pluszne, but as these lakes were at the periphery of the Woryty ecumene they probably were penetrated periodically by people (Dąbrowski 1981b). Perhaps the land previously exploited by tribes representing the Ząbie-Szestno assemblages were first used by the Lusatian culture population but later lost their significance. The record from the Woryty site portrays a different situation in which there was a large settlement complex of the Lusatian culture dated to 950–550 BC. Pollen analysis indicates very intensive economic exploitation of the area around the Woryty site, causing devastation of forest communities, replaced mainly by pasture and pig-raising areas, and on a smaller scale by cereal fields.

Then follows a short phase of diminished human impact on plant cover. The spread of woodland is visible in the pollen record (AP reaches ca 99%), connected among other things with regeneration of woodland communities with *Carpinus.*

PHASE 2; CA 300 BC–100 AD; WEST BALTIC BARROW CULTURE

The lower zone boundary was drawn at the beginning of the rise of the Poaceae and *Artemisia* curves and the fall of the tree pollen curve (Fig. 8). At this level pollen of *Cannabis sativa* t. was recorded for the first time. This boundary possibly should be placed slightly higher (365 cm, ca 120 BC), at the level where changes in the proportions of trees, Poaceae and *Artemisia* are more pronounced, *Rumex acetosella* and *Plantago lanceolata* appear, and the first signs of *Secale cereale* cultivation are noted. In an area forested to such a high degree, however, even such small changes as those accepted above as marking the beginning of phase 2 may be interpreted as indications of human activity. This zone is distinctly bipartite. The upper part shows clear evidence of intensified exploitation of areas surrounding the lake. Single *Secale cereale* pollen grains are recorded or the first time but the small percentages prevent speculation about the scale of cultivation or the distance of fields from the lake. Ruderal plants and field weeds are present, including *Artemisia*, *Urtica*, *Plantago major*, Chenopodiaceae, *Rumex acetosella*, *Scleranthus*, and *Centaurea cyanus*. Damaged querns and grinding-stones were found at the Ząbie X site but no macroremains of cereals that could have been used at that time were recovered from the features or from the culture layer. The fluctuations of the *Carpinus* and *Quercus* percentages may reflect periodic exploitation of the area. Small patches of meadow, probably grazed, were overgrown mainly by representatives of Poaceae, Apiaceae, *Aster*, *Filipendula*, *Rumex acetosa*, and *Plantago lanceolata*. The recovered bones showing evidence of meat consumption confirm the use of animals for food. Cattle bones were most numerous, followed by sheep and goat bones; pig and horse bones were rare (Piątkowska-Małecka 2003).

The archaeological and palynological evidence confirms the presence of people near the lake but their visits probably were temporary. The record in the diagram from Lake Miłkowskie presents a different picture: cereals appear through the whole phase connected with the West Baltic Barrow culture and reach up to several percent, suggesting local cultivation (Wacnik et al. 2012). The more intensive exploitation of the land near the Olsztyn Lake District is also confirmed by numerous findings of cultivated plant macrofossils at the Wyszembork site (Mrągowo Lake District) (Lityńska-Zając 1997). The activity of people of the West Baltic Barrow culture was also identified from sediments of Lake Salęt; together with signs of the activity of people representing other cultures it belongs to the second palynological settlement phase dated to 800 cal. BC–1000 AD (Szal et al. 2013).

Higher proportions of algae, mainly *Pediastrum*, are recorded in phase 2. Some authors connect the rise of *Pediastrum* percentages with higher water trophy (Tyson 1995), but in the case of Lake Łańskie we are dealing with *P. boryanum* var. *boryanum*, which is a common variety and cannot be considered an ecological indicator. In addition, single cenobia of *P. duplex* var. *rugulosum* and *P. boryanum* var. *longicorne* occur in this phase, both growing in pure, mostly dystrophic or only slightly eutrophic large water basins (Komárek & Jankovská 2001).

The upper limit of the phase is placed just above the level in which *Cannabis sativa* t. pollen occurs and *Secale cereale* disappears. This limit might also be set slightly higher in the diagram, where regeneration of *Carpinus* and less distinctly of *Quercus* begins.

PHASE 3, CA 250–360 AD, WIELBARK CULTURE; AND PHASE 4, CA 500–790 AD, PRUSSIAN CULTURE

The next phase of increased anthropopression on vegetation is represented by a short section of the diagram in which *Secale cereale* occurs and *Triticum* appears at the top (Fig. 8). *Cannabis sativa* is also present and *Artemisia* occurs slightly more frequently. *Agrostemma githago*, a mostly winter annual plant growing in segetal communities, appears for the first time. Some of the meadow plants, for example Poaceae and *Plantago lanceolata*, occur a little more frequently. The palynological evidence suggests economic exploitation of the lake vicinity on a relatively small scale. Archaeological data indicate that the Lake Łańskie surroundings were not inhabited at that time. Expansion of Wielbark culture settlement in the area began ca 110 AD and proceeded in several stages (Cieśliński 2009). Its widest territorial expansion took place ca 160/170–230 AD. This period apparently is not mirrored in the palynological record, which suggests that the Lake Łańskie area was not settled at that time. Phase 3 most probably can be connected with the period characterised in archaeological material by Roman imports and dated from ca 260 AD to the beginning of the 4th century. The next period corresponds to the Early Medieval settlement break which was an effect of the organised migration of people. It is difficult to decide whether Lake Łańskie region was completely abandoned or the terrain hitherto settled by Wielbark culture groups was now partly occupied by their former neighbours, as was the case in the Iława Lake District (Cieśliński 2009). The palynological indicators of economic exploitation of this area are very weak, albeit the percentages of *Artemisia* or Chenopodiaceae, for example, remain at the same level, and single pollen grains of *Triticum* t., Cerealia t. and *Cannabis sativa* regularly appear. Certainly the steady decrease of *Carpinus* occurring synchronously and the ensuing small changes in the *Quercus* share of forest were not connected with human activity but rather with the natural succession of plant communities expressed in the indistinct spread of taxa such as *Betula*, *Pinus*, and *Fraxinus* after abandonment of the land.

The beginning of phase 4 in the pollen diagram falls at the start of the 6th century. The occurrence of *Secale cereale* connects it with the Early Medieval presence of Prussian tribes. The percentages of most of the ruderal plants and tillage indicators remain steady or disappear. *Cannabis sativa* is present only at the bottom of the phase. *Artemisia* reaches slightly higher percentages and *Plantago major* is present. Meadow vegetation is represented by the more frequently appearing representatives of Poaceae and *Plantago lanceolata*. Among trees the proportions of *Carpinus* continue to decline gradually. This phase probably corresponds to the first Early Medieval phase of increased human activity described in profiles from Napole, Gronowo, Oleszek, and Czystochleb in the Chełmno Lake District, but there it is dated to the beginning of the 7th century (Filbrandt-Czaja et al. 2003, Noryśkiewicz 2008).

The proportions of AP pollen do not change because the very sharp decrease of mainly *Alnus* is soon compensated by the rise of *Betula*. At the same time a similar change occurs in the diagram from Lake Wojnowo, where the maximum spread of *Betula* is accompanied by the decline of trees, mainly *Alnus* (Wacnik et al. 2012). The fall of *Alnus* at Lake Łańskie was not caused by people. It may have been the effect of changing hydrological conditions in the lake vicinity, involving a drop in the water level (a little earlier, *Scleranthus* pollen occurs in two samples, the sum of telmatophytes and limnophytes decreases, and *Calluna vulgaris* increases) (Fig. 7). Because this phenomenon is observed also in diagrams from the other regions it may have a more regional character (e.g. Madeja 2012). It might be connected with the cooling and precipitation decrease noted in the first half of the 6th century, which lowered water levels in lakes in the northern hemisphere. The volcanic eruption in 536 AD near the equator (536 event) has been proposed as the cause of that (Charman et al. 2006, Larsen et al. 2008, Büntgen et al. 2011). A comparison of the isopollen maps for 1500 ± 100 BP and 1000 ± 100 BP shows the *Alnus* percentages decreasing all over Poland (Szczepanek et al. 2004), but the time resolution of successive maps does not allow a firm inference as to whether the alder decline occurred in the middle of the 6th century or was an effect of increased human activity around 1000 AD.

PHASE 5, MIDDLE AGES (FROM CA 1000 AD) TO THE PRESENT

The vegetation changes in the lake area seen at the beginning of this phase were caused by human activity. Information about settlement of the Lake Łańskie surroundings before they were occupied by the Teutonic Order is scarce. In this area, spreading between the Galindia Primeval Forest (Puszcza Galindzka) and Sasna (Ziemia Sasinów), there were scattered settlements of Prussian tribes, responsible for the observed changes of vegetation cover. The shrinking of areas previously covered by deciduous trees including *Betula*, *Quercus*, *Carpinus*, *Tilia*, *Ulmus*, and *Fraxinus* was connected with the expansion of land used for cultivation, pastures, and meadows. Timber was also required for building and firewood.

As early as about the 10th century the presence of *Secale cereale* pollen is constant, followed by the appearance of *Triticum* and *Hordeum* pollen types and single grains of *Avena* (Fig. 8). Their presence together with cereal weeds (*Centaurea cyanus*, Chenopodiaceae) suggests that cereal fields were not far from the lake. *Fagopyrum* was cultivated from the beginning of this phase. Because buckwheat produces little pollen and it is dispersed small distances, its fields must have been very near the lake (Behre 1981). At that time *Juglans* cultivation was started. Its pollen occurs from the 15th century but only in the ŁB profile. The inhabited areas created favourable conditions for the spread of ruderal communities, which are documented by the occurrence of *Artemisia*, Brassicaceae, Chenopodiaceeae, *Urtica*, and *Plantago major*. *Rumex acetosella* was common in fields, fallows and pastures. There were more meadows on the landscape, the main component of them being Poaceae together with other plants like *Rumex acetosa*, *Plantago lanceolata*, *Aster* t., *Mentha* t., *Filipendula*, *Anthemis* t., and *Plantago media*.

At the turn of the 14th/15th centuries the intensification of economic activity in the lake area is recorded in the pollen diagrams from both the ŁA and the ŁB profiles. The foundation of Ząbie village at the beginning of the 15th century must have influenced local vegetation cover. The abrupt rise of *Juniperus* indicates the presence of deforested areas and grazed woods. The importance of cereal cultivation increased. The set of cereal weeds (*Centaurea cyanus*, Chenopodiaceae, *Polygonum aviculare*, *Agrostemma githago*) suggests that winter crops were cultivated (Lityńska-Zając & Wasylikowa 2005); this is also confirmed by written sources ("The sowing in 1609 equaled 108 barrels of winter rye", Toeppen 1859). *Fagopyrum*, *Cannabis sativa*, and *Linum* were also cultivated. In local breweries, hop originating from natural habitats and/or from cultivation was used for beer production. Also more common were ruderal plants; among the meadow vegetation most dominant were representatives of Poaceae. The pollen record from the ŁB profile indicates that after the deforestation at the turn of the 14th/15th centuries there was a systematic increase of forest cover. Palynological indicators of land use rise earlier in Chełmno Land, where Teutonic colonisation took place at the beginning of the 13th century (Noryśkiewicz 2013).

Cartographic sources yield interesting information about changes in forest cover. The first maps showing the Warmia area come from 1464 (Grabowski 1997). In 1523 the first version of Gaspar Henneberg's map "Prussiae Regionis Sarmatiae Europeae Nobiliss" was drawn. The second version, supplemented by the settlement network and the actual extent of forests, shows the situation from 1600 AD

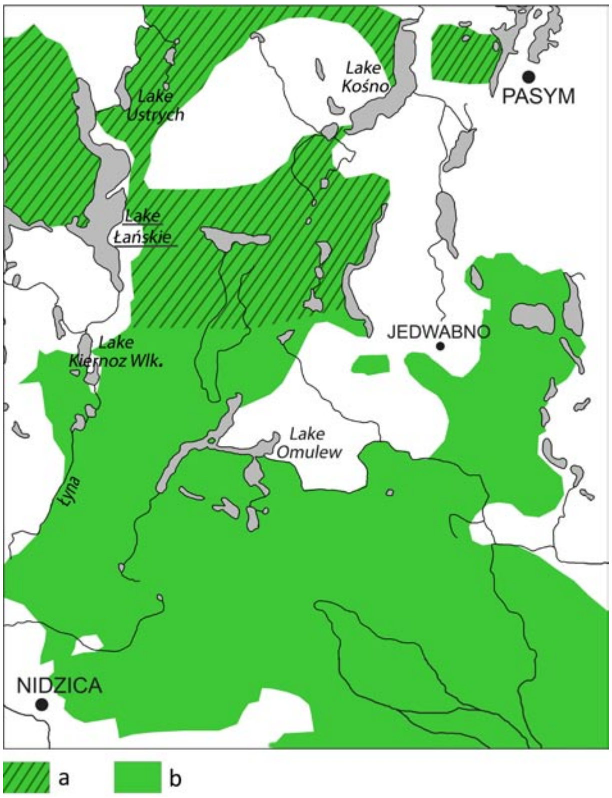

Fig. 12. Comparison of forest ranges in 1523 AD (a) and 1600 AD (b) on Henneberg's maps in the vicinity of Lake Łańskie (after Plit J. 2012, modified)

(Plit 2012). Lake Łańskie is at the edge of these maps but a comparison of them clearly shows the complete deforestation of the lake surroundings in 1600 AD (Fig. 12). Although there are distinct indications of forest clearance in the pollen diagram it is difficult to state whether the scale of deforestation was really so large or whether the lake vicinity remained at least partly wooded, because the tree pollen percentages (mostly *Pinus*) reach 70%. The map from 1755 prepared by Frederic Endersch indicates deforested areas, mainly south of Lake Łańskie (Fig. 13). Possibly the decline of *Juniperus* and the later-recorded (15–20 cm) reduction of some cereals and ruderal and meadow plants was due to the partial depopulation resulting from epidemics, but without radiocarbon dating these phenomena cannot be correlated. The map of the Lake Łańskie area from 1946 (Fig. 14) shows that it was forested to more or less the same degree as shown on the map from 1755. Similarly, the land at the north lake shore revealed no signs of deforestation. Nowadays the area around Lake Łańskie has even denser forest cover, probably thanks to the creation of a closed government centre in the 1950s (Fig. 15). The forest clearings seen today are mainly on land having more fertile soil, which would be sites of regeneration of forests with *Tilia* and *Carpinus* if anthropopression were absent (compare Figs 2 and 15).

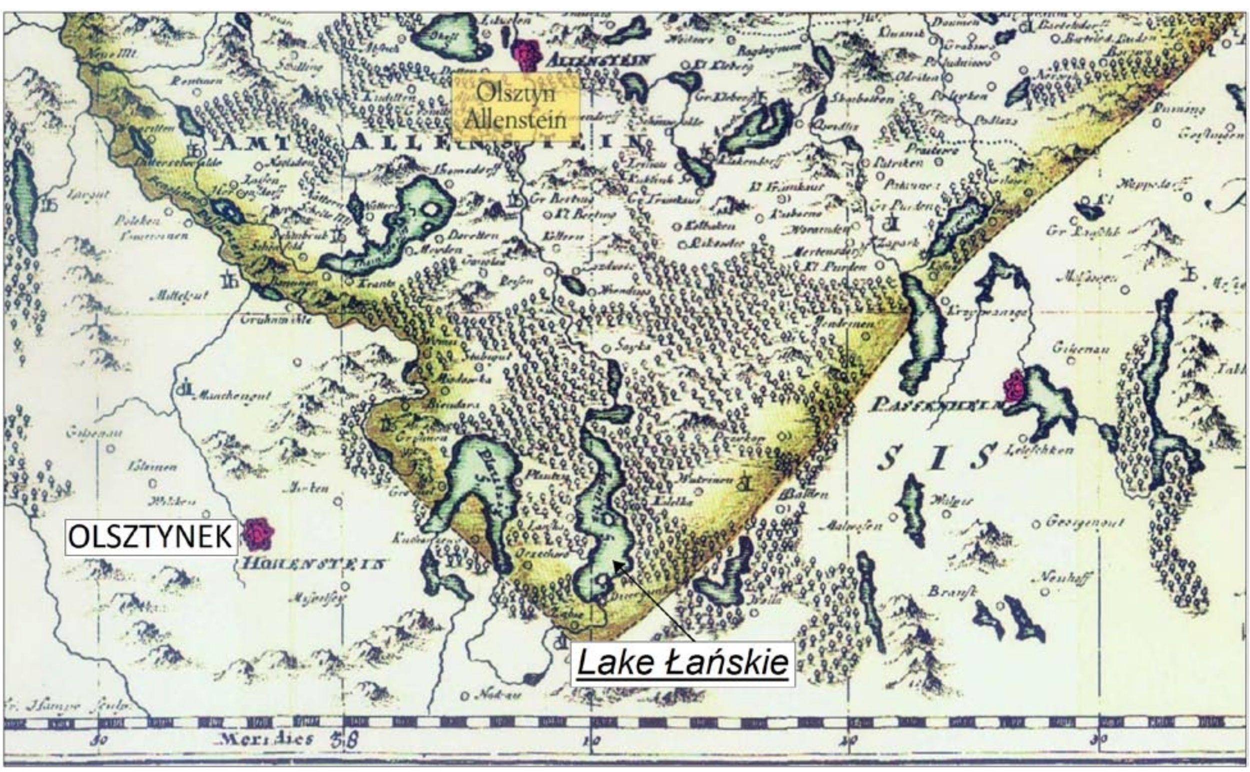

Fig. 13. *Tabula Geographica Episcopatum Warmiensen in Prussia Exhibens* – fragment of map of Warmia by Johann Friedrich Endersch published in 1755 (after www.domwarminski.pl, modified)

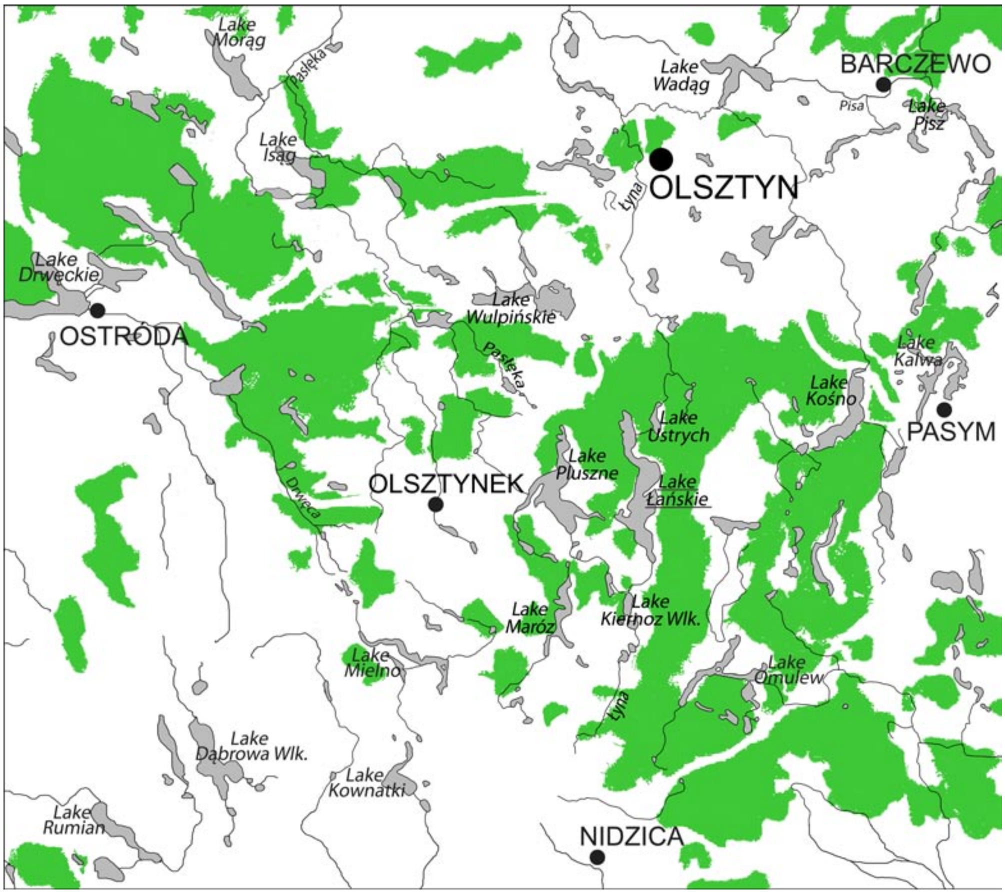

Fig. 14. Forest cover in the vicinity of Lake Łańskie in 1946 AD

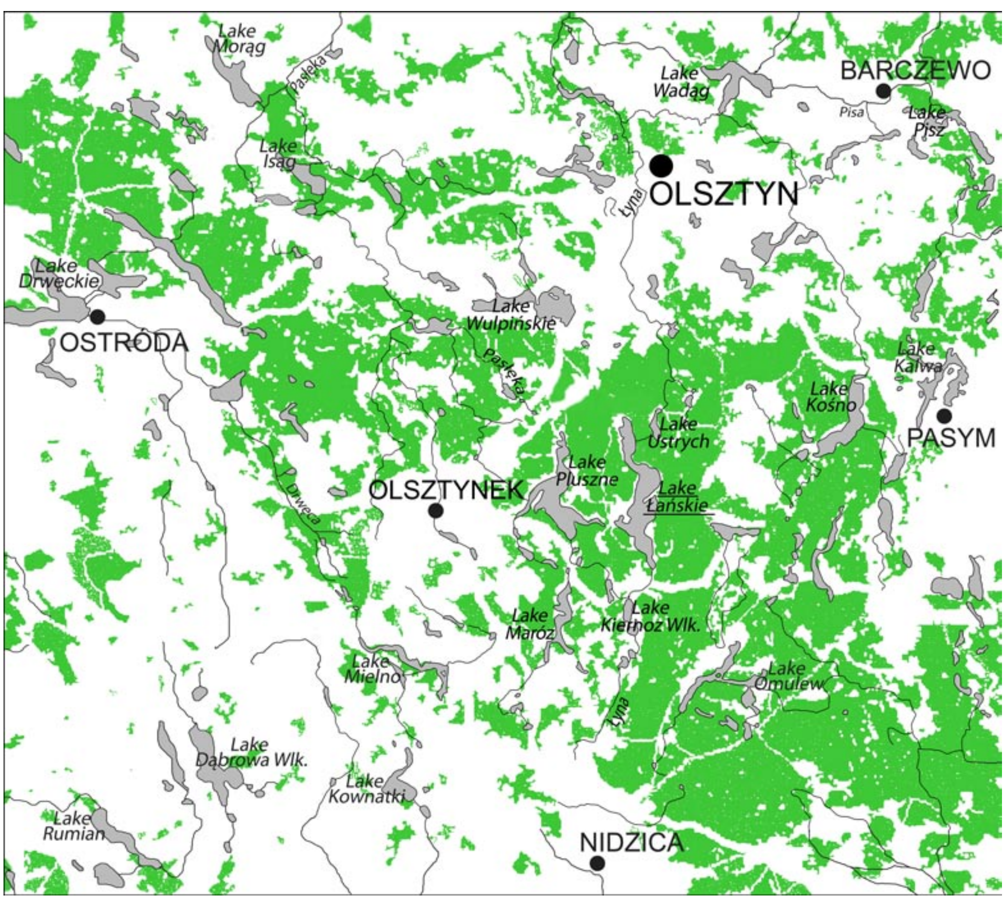

Fig. 15. Present forest cover in the vicinity of Lake Łańskie

SUMMARY

1. Bottom sediments of Lake Łańskie, which contain the record of vegetation changes since ca 4800 BC, were studied by pollen analysis.

2. Three main phases were distinguished in the history of the forests growing in the lake surroundings:

– A (ca 4800–3400 BC) From the very beginning the lake vicinity was almost completely forested. Pine forest or mixed pine forest with admixture of deciduous trees predominated. *Alnus* occurred in periodically inundated areas.

– B (ca 3400 BC–1100 AD) The lake surroundings were still forested. The share of *Carpinus* in the forest composition gradually increased. Seasonal declines of it were due in part to the activities of human groups. The spread of *Corylus* in the forest undergrowth became limited.

– C (ca 1100–2000 AD) Atlantic deciduous trees clearly declined. The shares of herbaceous vegetation increased but the bulk of the terrain around the lake was still forested. Pine and birch forests predominated, while trees growing on more fertile soils (*Tilia*, *Carpinus*) disappeared almost completely from the landscape.

3. Five phases of increased human activity were distinguished in the pollen diagram. The first (ca 1900–450 BC) is connected with the activities of groups of Ząbie-Szestno assemblages and the Lusatian culture population that lived around Lake Łańskie. In this phase the first cereal pollen grains appear (*Triticum* t.). The second phase (ca 300 BC–200 AD) corresponds to the activity of West Baltic Barrow culture people. The first *Secale cereale* pollen grains are recorded from this phase. Human indicators appear in the pollen diagram but this phase is much less pronounced than in other profiles from the Great Mazurian Lake District, perhaps suggesting that human groups stayed in the vicinity of Lake Łańskie only temporarily. The next short phases, 3 and 4, were distinguished mainly by the occurrence of *Secale cereale* pollen and correspond to the activity of human groups representing the Wielbark culture (250–360 AD) and the Early Medieval Prussian tribes (500–790 AD). The pollen record indicates that the economic exploitation of the area in the near vicinity of Lake Łańskie was not very intensive. The latest, most pronounced phase is bipartite. It begins at ca 1000 AD but the distinct intensification of land exploitation occurs at the turn of the 14th/15th centuries. Such strong land use was noted in the pollen diagrams from Chełmno Land at the beginning of the 13th century. The results from palynological study are in accordance with archaeological and historical data.

4. As the impact of human activity on vegetation was not significant until ca 1000 AD, it may be supposed that some of the observed vegetation changes were not caused by people but were the effects of changes in climate.

5. The sudden decline of *Alnus* recorded at ca 500 AD correlates with the so-called 536 AD event, which was responsible for climate cooling and reduced precipitation.

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