Veget Hist Archaeobot (2014) 23:419–437
DOI 10.1007/s00334-014-0465-z

ORIGINAL ARTICLE

The Iron Age in the Mrągowo Lake District, Masuria, NE Poland: the Salęt settlement microregion as an example of long-lasting human impact on vegetation

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Received: 27 January 2014 / Accepted: 28 April 2014 / Published online: 6 June 2014

Abstract Pollen, non-pollen palynomorphs, charcoal and geochemical analyses of sediments from Lake Salęt (NE Poland) were used to reconstruct vegetation changes related to the activity of the West Balt tribes during the Iron Age, in the period between the second half of the 7th century BC and the beginning of the 10th century AD. We distinguished five phases of human impact on environment. Woodland clearing around the studied lake started at the end of the 7th century BC. The most characteristic feature of this area during the whole Iron Age was a very high representation of semi-natural *Betula* woodlands, which was probably linked to a shifting agriculture. This type of land use lasted for over 1,500 years, until the second half of the 9th century AD. The greatest reduction in *Betula* woodlands took place between cal. years 650 and 450 BC. Its regeneration took place after ca. AD 830 when human activity decreased.

Keywords Pollen · Microcharcoal · NPPs · Geochemistry · NE Poland · Human impact · Shifting agriculture · Iron Age · West Balts

Communicated by M. Latałowa.

Electronic supplementary material The online version of this article (doi:10.1007/s00334-014-0465-z) contains supplementary material, which is available to authorized users.

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Introduction

In Europe, one of the most significant changes in the human-environment relationship took place during the Iron Age. However, it must be noted that this period is defined here in several ways (e.g. Thurston 2009). The chronological system of the Iron Age in north-eastern Poland is slightly different to that adopted for the cultural situation in both Central and Northern Europe and is based on the Tischler system of relative chronology (Tischler 1885; Tischler and Kemke 1902). In the modern system of chronology, the division of the Iron Age in this part of Poland into the early Iron Age (mid 6th century BC to ca. AD 20; Hoffmann 2000), the Roman Period (ca. AD 20 to mid 4th century AD; Okulicz 1973) and the Migration Period (second half of the 4th to end of the 7th century AD; Godłowski 1974; Nowakowski 1996; Bitner-Wróblewska 2010) was proposed.

Technological advances, particularly the development of ferrous metallurgy and the wide dissemination of tools made from this metal, as well as the emergence of new types of these, meant that man effectively increased his capacity to master and transform the environment. This was primarily vegetation, which in many places underwent a remarkable transformation through the destruction or thinning of some woodlands and the formation of large deforested areas, which were used as fields, pastures and meadows, or were left as wasteland (e.g. Kreuz and Schäfer 2008; Giesecke et al. 2014). A broad range of changes resulted from extensive forms of economic activity, particularly related to domestic animal husbandry and slash-and-burn type agriculture (e.g. Alenius et al. 2008; Grabowski 2011). Intensive construction works utilizing large quantities of wood commonly used in all areas of construction were not without significance. Wood was also one of the most important fuel materials, and was used in a number of specialized branches of non-agricultural production, such as iron smelting, the distillation of wood tar and coal tar etc. (e.g. Collis 1984).

A special feature of the Iron Age in the north-eastern part of Central Europe was the spread of Balts cultures in the south-eastern coastal zone of the Baltic Sea. They were diversified into a number of local groups with ranges coincident with the borders of geographical sub-regions (Okulicz 1976). Starting from 7th century BC, the west-southern part of the Balt zone was occupied by the West Balt Barrow culture (e.g. Okulicz 1970, 1989; Hoffmann 2000). The population of this culture maintained long distance links with the peoples of the woodland zone of Eastern Europe, the Baltic seacoast and areas in south-eastern Europe (Hoffmann 2000). They were also engaged in trading amber, which they supplied to the Celts, who at this time were spread over much of western, central and southern Europe (Nowakowski 2004).

The subsequent West Balt culture (Bogaczewo Culture) developed during the period of the 1st to 4th century AD. The state of knowledge of the settlement pattern of this culture in the Masurian Lakeland is insufficient, and is based on advanced studies of settlement microregions carried out in only two areas. These were in the Mrągowo Lake District (a settlement microregion around Lake Salęt) and in the Great Masurian Lake District (a settlement microregion on the north shore of the palaeolake Wons and settlement microregion Staświny) (Karczewski 2012). In the period from around the second until the 4th century AD, long-distance links were maintained with other regions of the Baltic Sea, and also with the territory lying in the west and south occupied by the Germanic tribes of Vandals and Goths (identified with the Przeworsk culture and the Wielbark culture, respectively). An important element of these contacts was involvement in trade connected with the Amber Road, which ran from the Roman Empire to the Baltic seacoast (Nowakowski 1995; Nowakowski 2004; Nowakiewicz and Nowakiewicz-Rzeszotarska 2012). At the end of the fourth and at the beginning of the 5th century (early Migration Period), a demographic crisis in the territory of the Bogaczewo culture was registered (e.g. Szymański 2005; Bitner-Wróblewska 2010). However, the settlement in the Mrągowo Lake District, despite its partial decline, survived, and from ca. AD 450 revived to flourish anew. A new cultural unit with a mixed Balt-Germanic character, the Olsztyn Group, is described (Kowalski 2000; Bitner-Wróblewska 2010). This is because during the Late Migration Period in Masuria we see an accumulation, not encountered elsewhere in this part of Europe, of elements of interregional Germanic culture. The decline of the Olsztyn Group, dated to the 7th or even 8th century (Bitner-Wróblewska 2008; Kowalski 2000), is one of the greatest riddles of Masuria's archaeological past. An unprecedented rate of change (starting at the end of the 7th century, during the lifetime of one, or at most, two generations) in conjunction with a lack of traces of destruction, points to the existence of quite special and not fully understood causes which led to an abrupt break in a Balts settlement tradition of nearly 13 centuries duration (Okulicz 1973).

Palaeoecological investigations, particularly pollen analysis, have greatly contributed to our knowledge of prehistoric environments and the manner in which human activity affected them (e.g. Behre 1988; Latałowa 1999; Beug 2011). The interactions between human society and environmental change can be deduced preferably from pollen records in combination with the study of non-pollen palynomorphs (NPPs), especially fungal and algal spores, which have in recent decades substantially complemented palaeoecological research (e.g. van Geel et al. 1994, 2003; van Geel and Aptroot 2006; Święta-Musznicka et al. 2013).

In north-eastern Poland the state of multidisciplinary researches on man/environment relationships in the Iron Age is very limited (Karczewski 2012). In the Masurian Lakeland a direct comparison of archaeological and palaeoecological data is possible only in the case of two settlement microregions from the Great Masurian Lake District: the microregion at the paleolake Wons (e.g. Karczewska and Karczewski 2002; Karczewska et al. 2002; Kupryjanowicz et al. 2013) and the Staświny microregion (e.g. Wacnik 2009; Madeja et al. 2010; Karczewski 2011; Wacnik et al. 2012; Wacnik and Karczewski 2013). Recently, multidisciplinary palaeoenvironmental investigations have also been undertaken in the area of Lake Salęt in the Mrągowo Lake District, where detailed archaeological excavations have been ongoing for several decades, undertaken by the Institute of Archaeology, University of Warsaw, so there is now a significant accrual of archaeological data available (e.g. Okulicz 1973; Szymański 2003, 2005, 2007; Wróblewski 2006). However, prior to this study no palynological data that describe the past environment and agricultural history of the area have been collected at this site.

The aim of this paper is to present the first results of interdisciplinary palaeoecological research, the main objectives of which were to study the human impact on the environment, and changes in the economy of local groups of West Balts that inhabited the area around Lake Salęt during the Iron Age. Good recognition of these processes in the studied microregion will make it possible to formulate generalizations about the functioning of the West Balts settlement within the whole area under their influence.

Study area

The Mrągowo Lake District (ca. 2,000 km^2) lies in a large hump between the Great Masurian Lake District to the east, and the Olsztyn Lake District to the west. In terms of geomorphology the region is situated within the reach of the last glaciation formations and forms. The diversified hilly mosaic relief with a large number of lakes is the effect of glacier activity (Kondracki 2011).

The soil cover is strongly differentiated, with a predominance of zonal soils, namely eutric cambisols and podzols. Hydrogenic and semi-hydrogenic soils cover the low lying terrain along rivers and near lakes. The characteristic intrazonal soils of the Mrągowo Lake District that also occur in the region of the studied lake are gyttja soils formed from different types of lake sediments. They are often associated with peaty soils in fens (Uggla 1969; Bednarek and Prusinkiewicz 1999; Richling and Ostaszewska 2005).

The climate of the region is among the coldest lowland climates in Poland, with a mean annual temperature of 6.5 °C (the mean temperature in January is −4.0 °C; the mean temperature in July is 17.4 °C). Mean annual precipitation is 550 mm with a predominance of summer rainfall (Kożuchowski 2011). The length of the growing season is 206 days, snow cover persists for 98 days on average, and the lakes are ice-covered for 3–4 months (Woś 1999). All these features indicate the transitional character of the climate, resulting from the occurrence of different air masses, both oceanic and continental.

Due to the specific climatic conditions, the vegetation of the studied region also has a transitional character. It is exemplified by the co-occurrence of central European species (e.g. *Cladium mariscus*, *Juncus subnodulosus*; Gałka et al. 2014) and north-east European species like *Polemonium caeruleum*, *Nymphaea candida*, *Nuphar pumila*, as well as representing the range limit for numerous plant communities both of boreal (e.g. Sphagno-Piceetum, Querco-Piceetum) and oceanic type (e.g. Galio odorati-Fagetum, Luzulo pilosae-Fagetum, Stellario-Carpinetum, Fago-Quercetum) (Matuszkiewicz 2005). Also the eastern limits of *Fagus sylvatica* and *Acer pseudoplatanus* (Zając and Zając 2001), the western limit of *Quercus petraea* and the southern limit of *Salix lapponum* (Szafer and Zarzycki 1977) natural ranges run through this area.

The potential natural vegetation of the Mrągowo Lake District would be formed mainly by the subboreal type of

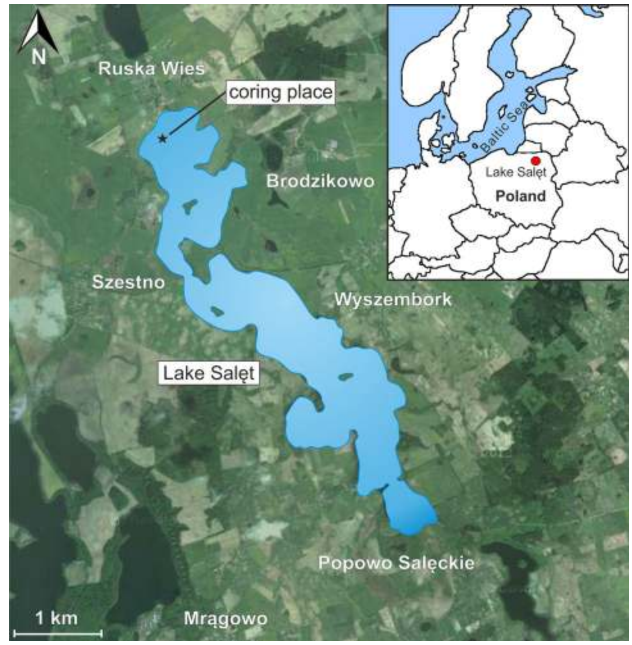

Fig. 1 Location of Lake Salęt and coring site (53°56′22.09″N, 21°19′20.19″E). Produced using Google Maps

Carpinus woodland (Tilio-Carpinetum) and by mixed *Quercus-Pinus* woodland (Querco-Pinetum). The southern part of the mezoregion lies within the range of subboreal *Pinus* woodland (Peucedano-Pinetum). Locally, there would also develop azonal communities of middle-European wet *Alnus* woodlands (Carici elongatae-Alnetum), riparian woodlands (Fraxino-Alnetum) and bog pine woodlands (Vaccinio uliginosi-Pinetum) (Matuszkiewicz 2008). There is a great discrepancy between the real and potential vegetation in this terrain—woodlands occur mainly in the southern part of the region and are dominated by *Pinus* and mixed *Pinus* woodlands prevailing on sandy soils, while the area of *Quercus-Carpinus* woodlands is very limited due to heavy deforestation and the exploitation of terrain as plough-land and meadows or pastures.

Site description

Lake Salęt (53°56′22.09″N, 21°19′20.19″E) is a eutrophic, meromictic lake with a surface area of 327.7 ha. It is situated in the central part of the Mrągowo Lake District (Fig. 1).

The lake is of glacial origin (Kondracki 2011). It is situated in a depression surrounded by morainic hills. Steep escarpments, over 10 m high, slope down to the water surface on both the eastern and western lakesides; the northern and southern slopes are gentler. The lake is divided into two parts: the smaller, northern part is named Lake Salęt Mały, and the larger southern is Salęt Wielki (Fig. 1). The lake attains a maximum water depth of ca.

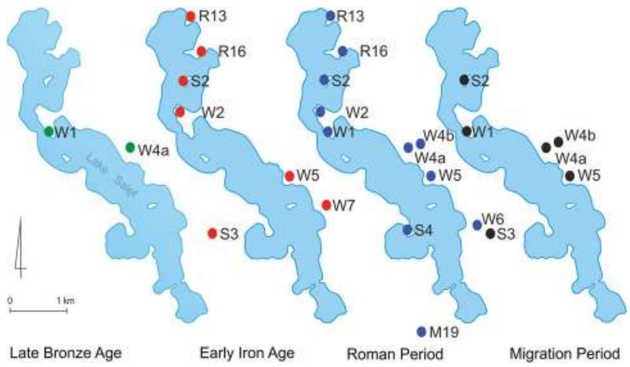

Fig. 2 Archaeological sites around Lake Salęt: M19—Muntowo, site XIX; R13—Ruska Wieś, site XIII; R16—Ruska Wieś, site XVI; S2—Szestno, site II; S3—Szestno, site III; S4—Szestno, site IV; W1—Wyszembork, site I; W2—Wyszembork, site II; W4a—Wyszembork, site IVa; W4b—Wyszembork, site IVb; W5—Wyszembork, site V; W6—Wyszembork, site VI; W7—Wyszembork, site VII

17.2 m in the northern part; its average depth is 4.9 m (Jańczak 1999). It is fed by one stream, and in addition to the surface run-off probably also by the inflow of shallow underground waters from the moraine upland.

The vegetation surrounding Lake Salęt is devoid of woodland and is strongly affected by human impact. Woodlands cover only ca. 10 % of the area. A considerable area is taken by grasslands: meadows and pastures cover ca. 30 %, and agriculturally used ground covers ca. 60 %. Up to a distance of 500 m from the lakeshore the terrain is overgrown by herbaceous vegetation, with scattered trees occurring only near buildings, along roads, streams, and at the lake shore.

Archaeological chronology of the Lake Salęt settlement microregion

In the late Bronze Age a settlement, which was connected with the Masuria-Warmia Group of the Lusatian culture, appeared on the territory around Lake Salęt (Okulicz 1981) and lasted until the beginning of the Iron Age. Its traces were discovered in Wyszembork, sites I and IVa (Nowakowska 2004; Szymański 2005) (Fig. 2).

Three settlement phases of the Iron Age were distinguished. The first (early Iron Age) corresponds to the West Balt Barrow culture. The settlement remnants of this culture are relatively numerous in the microregion: seven settlements have been identified: Wyszembork, sites II, V and VII; Szestno, sites II and III; Ruska Wieś, sites XIII and XVI (Gładki 2007; Szymański 2005). The second settlement phase is dated to the 1st to 4th century AD (Roman Period) and is correlated to the *Galindai* tribes, connected with the Bogaczewo culture (e.g. Nowakowski 1995, Nowakowski 2004). Nine settlements and a cemetery at Wyszembork site IVa dated to this period have been described (Szymański 2005). The third settlement phase corresponds to the Migration Period (Olsztyn Group), represented by five settlements and a cemetery at Wyszembork, site IVa (Szymański 2005). In about the 7th century AD the gradual collapse of the settlement and the depopulation of this area probably took place (Szymański 2005). However, Białuński (1999) suggests that in some regions of the Masurian Lakeland settlements were scattered but still persisted.

Materials and methods

Coring

In the winter of 2010 a sediment core was recovered from the frozen surface of Lake Salęt with the use of Więckowski's piston corer and a Kajak gravity corer. Coring was performed close to the deepest part of the lake (at a water depth of 15 m), where the deposits had the greatest thickness, equal to 15.7 m (Fig. 1). The present paper deals only with the section 7.0–3.8 m of the profile, which accumulated from ca. 750 BC to AD 920. Calcareous gyttja, rich in organic matter, and relatively poor in sand, clay and silt forms this part of the studied core.

Dating

AMS radiocarbon dating of seven samples from the Salęt profile was performed in the Gliwice Absolute Dating Methods Centre (ESM Table 1). Only three dates deal directly with the part of the core that is discussed in this study. The sediments contained no macroremains of terrestrial plants, and 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 was performed by the removal of calcium carbonate using 38 % HCl, and humic acids using 10 % KOH. In every case 2–4 cm^3 of sediment was used for this purpose. The resulting conventional radiocarbon dates were calibrated against the IntCal09 calibration curve (Reimer et al. 2009) using the OxCal Version 4.1.7 program (Bronk Ramsey 2010).

Short-lived radionuclides ^{210}Pb were measured in the uppermost 30 cm. Measurements were carried out in the Institute of Geological Sciences of the Polish Academy of Sciences in Warsaw.

The ^{14}C and ^{210}Pb dates were used for construction of an age-depth model for the analysed profile (Fig. 3). This model was built by means of the polynomial second-degree

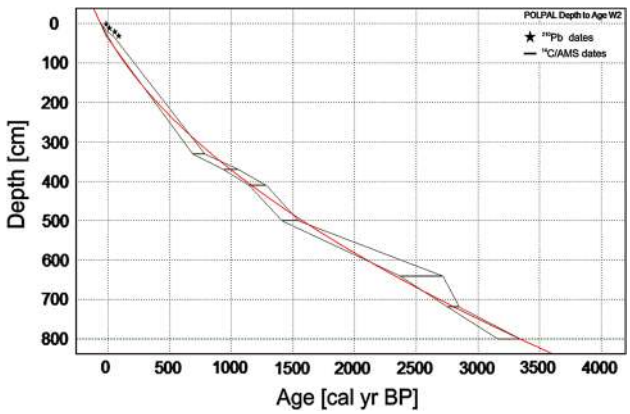

Fig. 3 Age-depth model of the Salęt profile based on AMS ^{14}C dates and ^{210}Pb dates

curve fitting in the POLPAL program (Nalepka and Walanus 2003; Walanus and Nalepka 2004).

Pollen, NPPs and charcoal particles

Samples of 1 cm^3 were prepared using the standard procedure of Erdtman's acetolysis (Berglund and Ralska-Jasiewiczowa 1986). Depending on the content of mineral matter the samples were treated with a heavy liquid (CdI_2 + KI). *Lycopodium* tablets were added to each sample to enable quantitative analysis of microfossil concentration (Stockmarr 1971). Palynological and microcharcoal analysis was performed on 43 samples from the studied part of the Salęt profile. The density of the investigated samples differs in the lower and upper part of the profile (every 10 cm at depth 470–700 cm and every 5 cm at depth 380–470 cm respectively) and hence the precision of the information obtained also differs—an average interval of 52 years in the lower and 23 years in the upper part of the profile.

Pollen analysis was carried out with an Olympus BX43 light microscope with a magnification of 600×; a larger magnification was used to identify problematic and small palynomorphs. For taxonomical identification pollen keys (e.g. Beug 2004) and the reference collection of modern pollen slides were used. More than 1,000 terrestrial pollen grains were counted and identified in each sample. NPPs were counted along with the pollen. NPPs were identified according to van Geel (1978, 2001), Bell (1983), Jankovská and Komárek (2000), van Geel et al. (2003), Turton and McAndrews (2006) and van Geel and Aptroot (2006). Names of NPP taxa include a three letter code “HdV” for the Hugo de Vries Laboratory of the University of Amsterdam, The Netherlands, where the relevant NPPs were identified for the first time.

The microcharcoal particles were counted in the pollen slides and grouped into four size classes: 10–30, 30–70, 70–100 and >100 µm. According to Rull (2009) the larger particles better reflect the incidence of local fires, whereas the smaller particles are more indicative of regional fires. Particles <10 µm were ignored, as they cannot be safely identified (Blackford 2000). Charcoal particles were identified with a light microscope at 400× magnification. Charcoal selection was restricted to fragments that were black, completely opaque and angular (Swain1973; Clark 1988).

Calculations and presentation of palynological and microcharcoal data were performed with POLPAL for Windows (Nalepka and Walanus 2003). The AP + NAP sum was used for percentage calculations, both in the pollen and the NPP diagram. The pollen diagram was stratigraphically ordered and zoned with constrained cluster analysis (CONISS) and divided into local pollen assemblage zones (LPAZ), which were named according to the specific composition of pollen spectra. The human impact groups follow Behre (1981), Berglund and Ralska-Jasiewiczowa (1986) and Gaillard and Berglund (1988).

Geochemical analyses

All sediment core sections were scanned to detect major and trace elements with an ITRAX XRF-core scanner (COX Analytical Systems) at the GEOPOLAR laboratory, University of Bremen. Sections were scanned with a Mo-tube with a step size of 5 mm and a count time of 10 s. Tube settings were kept constant for all sections using a voltage of 30 kV and a current of 20 mA. Element data produced by the scanner are semi-quantitative and are expressed as total counts, i.e. integrated peak area. Peak area counts of elements were normalized by coherent radiation (i.e. scatter of the primary X-ray radiation), which should reduce the sediment matrix effect (Croudace et al. 2006).

Results

Palynological data

According to the pollen data for the full profile (M. Szal unpubl. data), the pollen diagram presented in this paper includes only one pollen zone, S-6 *Carpinus-Betula-Quercus*. It was divided into six subzones, five of them are described here (Fig. 4; ESM Table 2). They reflect five human impact phases covering the period between ca. 750 BC and AD 920.

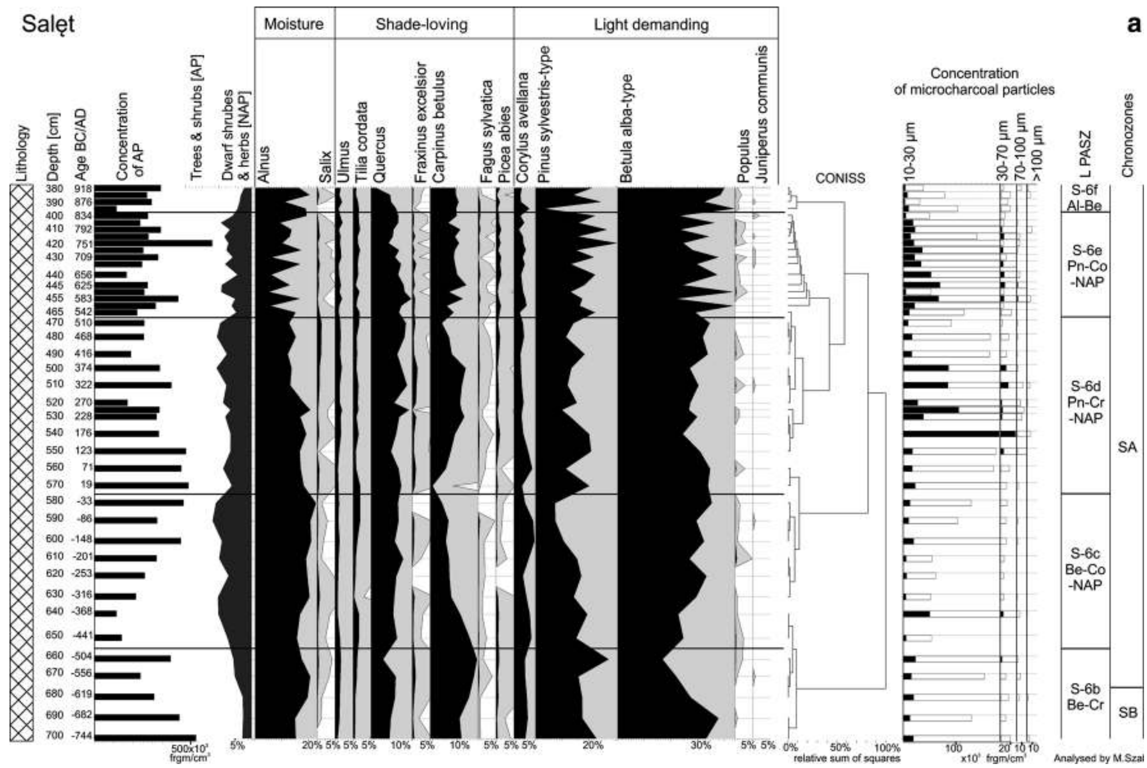

Fig. 4 **a** Pollen percentage diagram with selected important woody taxa, AP concentration and charcoal record from the Salęt core, lithology: *grey–brown* calcareous-detritus gyttja, **b** pollen (selected important herb taxa) and NPPs percentage diagram showing the human impact on local vegetation and its correlation with local settlement history; archaeological data: **a** local context, **b** regional context. (Color figure online)

Phase 1: ca. 750–450 BC, end of the Bronze to beginning of the early Iron Age (Betula-Carpinus LPASZ, 655–700 cm)

Vegetation in the vicinity of Lake Salęt at the transition from the Bronze to the Iron Age can be reconstructed on the basis of the pollen record contained in the *Betula-Carpinus* local subzone (Fig. 4). It shows that the *Betula* woodlands played a dominant role in the landscape of this period (Fig. 4a). They were probably secondary semi-natural communities which formed in habitats transformed by exploitation during earlier settlement stages. *Carpinus* woodlands developed intensively, which is documented by relatively high values of *Carpinus betulus* pollen. Large areas were occupied by *Quercus* stands. There were *Pinus* and different mixed woodlands *Pinus-Quercus* and *Pinus-Betula*. *Alnus* grew on wetland habitats in the surroundings of the lakes and on the outskirts of river valleys. A relatively small area was occupied by *Ulmus*, *Tilia*, *Fraxinus* and *Picea*. Other trees were rather sporadic.

The start of continuous pollen curves of a few human activity indicators (e.g. Cerealia-type, *Plantago lanceolata* and *Rumex acetosa*-type) and an increase in the frequency of several others (e.g. Poaceae, Cyperaceae and *Artemisia*), document the appearance of anthropogenic communities fields, meadows, pastures and ruderal associations—at the end of this phase, after ca. 550 BC (Fig. 4b). These changes probably reflected the first stage of a settlement of the West Balt Barrow culture. They might also be connected with the terminal phase of the Lusatian settlement, which was recorded in numerous pollen diagrams from the Masurian Lake District (e.g. Ralska-Jasiewiczowa and Latałowa 1996, Wacnik et al. 2012).

Phase 2: ca. 450–1 BC, early Iron Age (Betula–Corylus-NAP LPASZ, 575–655 cm)

Rather high pollen percentages of trees (ca. 90 %) and low ones of herbs indicate a forested landscape. However, a decrease in the pollen values of *Carpinus betulus, Tilia cordata, Ulmus* and *Picea abies*, coinciding with increasing frequencies of pioneers (*Betula* and *Corylus avellana*) and light-demanding (*Populus*) taxa, suggests a progressive opening of the vegetation. *Cannabis/Humulus*-type pollen most probably indicates that *Humulus lupulus* grew in this area as a native plant.

The rise in frequency of pollen indicators of ruderal communities (especially *Artemisia* and Chenopodiaceae), meadow and pasture (mainly Poaceae, Cyperaceae, *Plantago lanceolata*, *Rumex acetosa*-type and Apiaceae),

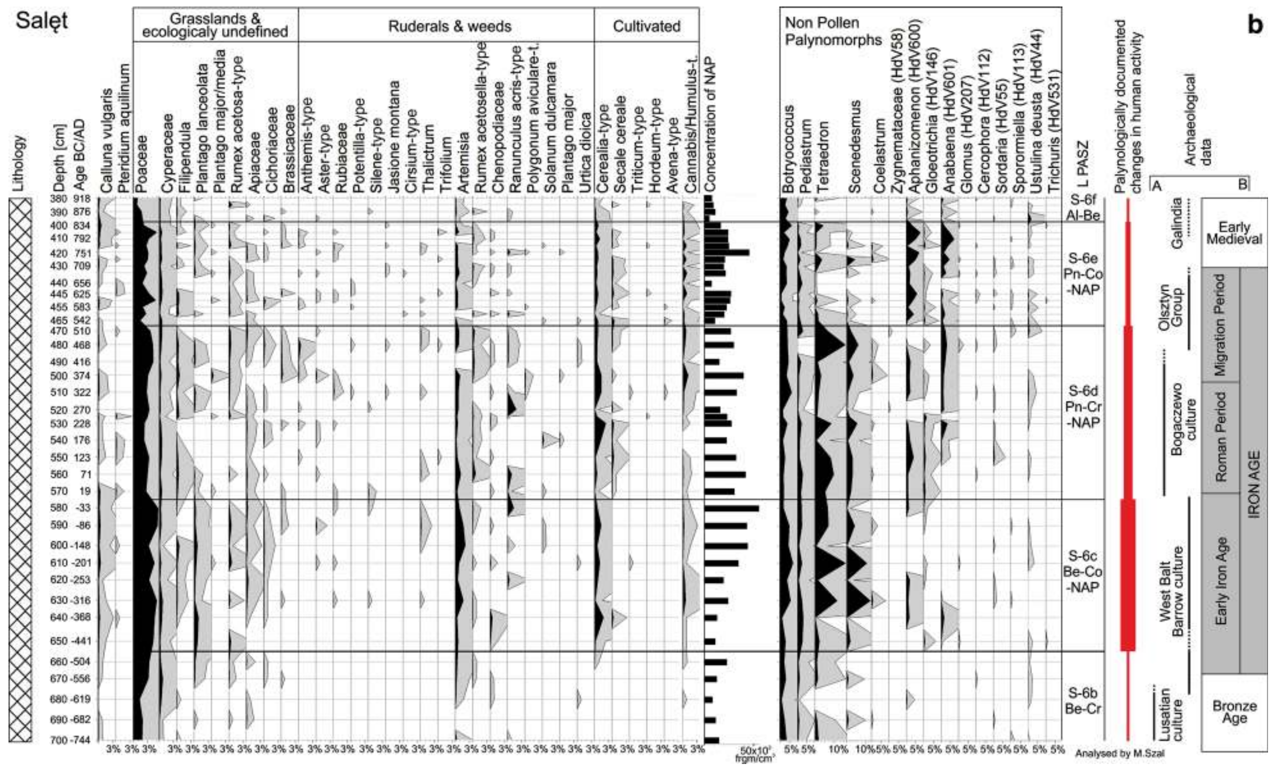

Fig. 4 continued

accompanied by the occurrence of *Pteridium aquilinum* spores, shows that the surroundings of Lake Sałęt have been to some extent influenced by man. One apparent sign of human impact is the appearance of cereal fields (clear peak in Cerealia-type and single pollen grains of *Triticum*-type and *Secale cereale*).

The drop in the *Picea abies* pollen curve, concurrent with the slight increase in *Artemisia*, *Plantago lanceolata*, Chenopodiaceae pollen and charcoal particles, obviously resulted from further human activities associated with the settlement of the West Balt Barrow culture.

The occurrence of *Glomus*, though in low frequencies, is here noteworthy as this is a mycorrhizal fungus commonly associated with the roots of trees and shrubs (van Geel et al. 1989), and when recorded in lake deposits points to soil erosion in the catchment area (Anderson et al. 1984).

The increasing human impact in the catchment area of Lake Sałęt, as can be interpreted from the pollen records of human impact indicators, apparently had its effect on the trophic conditions of the water in this lake. Therefore remains of green algae in lake sediments, for example the coenobia of *Pediastrum*, *Botryococcus*, *Scenedesmus* and *Tetraedron*, as well as cyanobacteria (*Aphanizomenon*, *Gloeotrichia* and *Anabaena*) can play an important role in inferring past lake conditions, and almost all are known to be dominant in more eutrophic systems (cf. Van Geel and Grenfell 1996; Jankovská and Komárek 2000; Medeanic et al. 2003; Zamaloa and Tell 2005; Medeanic 2006). Of these, the most abundant was *Tetraedron*, classified by Bakker and van Smeerdijk (1982), *Botryococcus* and *Scenedesmus*, all indicative of the eu- to mesotrophic conditions of open freshwater, but thriving best in eutrophic shallow pools (van Geel 2001; Montoya et al. 2010; Guiry and Guiry 2013).

Phase 3: ca. AD *1–550, Roman and beginning Migration Period (Pinus-Carpinus-NAP LPASZ, 467.5–575 cm)*

During the oldest part of this phase some dropping in human activity and woodland return into open areas occurred. This could have been the result of dispersion of earlier concentrated settlement. Later, an increase in the pollen of human indicators coincides with the rise of the charcoal curve, reflecting activity associated with numerous Roman settlements situated in the vicinity of Lake Sałęt (Fig. 4b). Open areas were used for cultivation, as denoted by the high percentages of Cerealia-type. The continuous *S. cereale* curve indicates that the onset of rye cultivation probably occurred at that time. The occurrences of *Cannabis/Humulus*-type together with *Urtica* are likely to be connected with human activity in the region.

Throughout this phase the smallest particles of microscopic charcoal were present at very high values, which is evidence of fires far away from the studied site. Fire could have served as a tool for clearing ground for cultivation and could have provided ash for fertilizing fields (by burning fields after harvesting, or by burning new wooded areas). Microcharcoals could also have come from daily hearth fires for cooking or settlement damaged by fire, which happened regularly, however by accident. The simultaneous occurrence of a wide range of NPP taxa, various algae (*Botryococcus*, *Tetraedron*, *Scenedesmus*, Zygnemataceae) and cyanobacteria (*Aphanizomenon*, *Anabaena*, *Gloeotrichia*) showed increasing eutrophication of the lake environment.

Phase 4: ca. AD *550–850, Migration Period and beginning of the early Medieval (Pinus-Corylus-NAP LPASZ, 397.5–467.5 cm)*

The spread of some trees, mainly *Pinus* and *Carpinus*, but also *Picea* and *Tilia*, documents the development of the tree-covered areas. Despite the continuous occurrence of human indicators, including cultivated plants and weeds typical of permanent fields (e.g. Chenopodiaceae), the degree of anthropogenic vegetation changes declined slightly at about AD 550–600. Further vegetation changes confirm the increasing human influence on the environment around Lake Salęt. A high representation of ruderal plants and cereals indicate the existence of settlements and cultivated land nearby.

The pollen data from this phase (except for its early beginning) may be considered as a representation of continuous cultivation and cattle breeding. The contemporary presence of microcharcoals and several dung indicators provide further evidence of the persistent presence of livestock, with grazing in already established grassland periodically managed with fire, around Lake Salęt.

Phase 5: ca. AD *850–920, Early Medieval (Alnus-Betula LPASZ, 380–397.5 cm)*

The period of intensive settlement, agriculture and animal husbandry was followed by a regression phase recorded in the pollen spectra at a depth of 380–395 cm and dated back to about AD 850–920 (Fig. 4). This time span is characterized by a decrease in the number and diversity of human pollen indicators, and it represents a period of a reduction in agricultural activities or relocation of open plots outside the investigated site. The AP/NAP ratio shows that the expanding woodland gained more ground at the expense of open grassland and agricultural fields. The setback in arable farming promoted regeneration of trees, especially of *Betula* (*Betula* sect. *Alba*-type), *Pinus* (*Pinus sylvestris*-type), *Alnus* and *Quercus*. The population decreased, many farms were abandoned, and fields remained uncultivated. In the pollen diagram this event coincides with the decrease in Cerealia-type and *Cannabis/Humulus*-type. NAP frequency and concentration of charcoal particles diminish. However, pollen of Cerealia-type, *S. cereale* and *Hordeum*-type is still present, which means that agriculture remained a form of activity for the local population. The presence of charred particles in the largest class (>100 µm) most probably points to activity within the settlement, rather than woodland clearing. In fact, agriculture and animal husbandry still existed.

Coprophilous fungi are more sporadic in comparison to the earlier period, although the presence of *Cercophora*-type (HdV112) and *Sporormiella*-type (HdV113) may well indicate dung and animal presence. Among the recorded fungal spores were spores of *Ustulina deusta* (*Kretzschmaria deusta*) (HdV44), known to be confined to wooded sites. Its occurrence around Lake Salęt agrees with the *Alnus*, *Quercus* and *Fagus sylvatica* trends, and these trees are all suitable hosts for this parasite (van Geel and Aptroot 2006). *Kretzschmaria deusta* has also been described as a very local tree cover indicator (van Geel and Andersen 1988), but it seems it can occur in sites at a 100 m distance from woodlands (Cugny et al. 2010).

Geochemistry

Values of K, Ti, Fe and Mn (Fig. 5) increase towards a maximum around 660 cm (human phase 1: 655–700 cm), indicating an enhanced influx of minerogenic material as a result of overland flow, runoff or wind-driven transport of clastic material, most likely related to deforestation and erosion of uncovered soils. Elemental ratios of Fe/Mn and Fe/Ca show a similar pattern, with maximum values at depth 655–665 cm and a subsequent strong decrease that coincide with the period of intense erosion at the transition between human phase 1 and 2. Higher values of Fe/Ca may also indicate a greater eutrophy of the lake during that time. This may be related to enhanced nutrient transport from intensively eroded catchment soils. After this initial stage a constant decrease in erosion is observed, and more stable conditions are established at the end of human phase 2 (575 cm).

A transition between human phase 2 and 3 is marked by a considerable change in Ca content, from decrease in the older part of phase 2 to rapid increase at the onset of phase 3. However, this significant drop in Ca content at the transition zone between the two phases is not accompanied by an increase in any of the lithogenic elements. During human phase 3 (467.5–575 cm) a slow increase in Ti and K, a relatively high content of Ca, and stable values of Fe and Mn are observed.

No dramatic changes were observed either in human phase 4 (397.5–467.5 cm). Very stable conditions occurred without any geochemical evidence of remarkable erosion

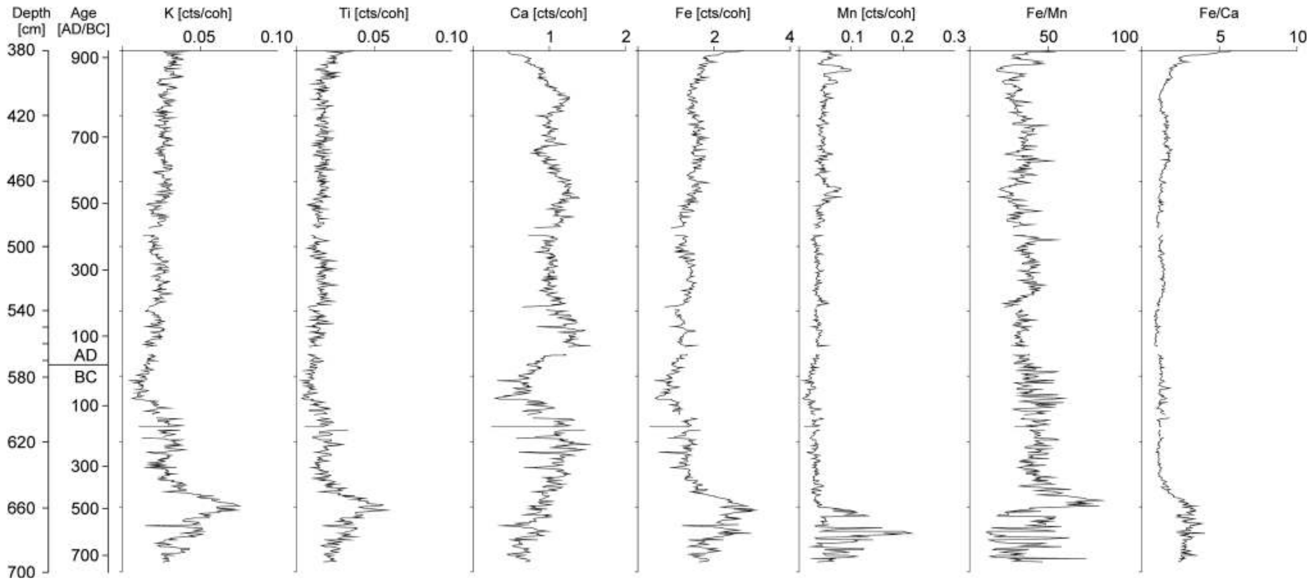

Fig. 5 Selected XRF-detected elements in the analyzed sediments of the Salęt core

or trophic status change. The only variable element was Ca, which started to decrease from the oldest part of phase 4. More variable conditions are recorded in phase 5 (380–397.5 cm) with an increase in Ti and Fe, and a continuous decrease in Ca content. However, it is difficult to interpret this variability as phase 5 covers a very short time period and no information is available on further trends.

Discussion

Palaeoecological evidence for local land-use changes in the Iron Age

Recorded archaeological data indicate that the beginning of relatively stable settlements in the vicinity of Lake Salęt was connected with the development of the West Balt Barrow culture (Fig. 2) the agricultural activities of which were confirmed by our pollen analysis (Fig. 4b). From about ca. 500 BC, an increase in the frequency of a few anthropogenic indicators (e.g. Cerealia-type, *Plantago lanceolata*, *Artemisia*, Poaceae, *Rumex acetosa*-type, *Ranunculus acris*-type, Chenopodiaceae) and an appearance of several others (e.g. *Secale cereale*, *Triticum*-type) is documented in the Salęt pollen profile (Fig. 4b). Moreover, the increasing anthropogenic settlement activity in the catchment area of Lake Salęt accelerated the eutrophication processes that stimulated growth of algae and cyanobacteria. In Estonia, which was also within the range of the West Balt Barrow culture, the persistent presence of crop taxa testifies to continuous agrarian activity from the Iron Age (since ca. 500 BC), when the percentage of cultivation indicators increases significantly (Poska et al. 2008).

The relatively high peaks of *P. lanceolata* and Poaceae as well as the increase in frequency of *Filipendula*, *R. acetosa*-type, Apiaceae and Cichorioideae pollen (Fig. 4b) document a large area of meadows and pastures, which suggest that free-grazing cattle played a major role in the agricultural economy of that time. The presence of coprophilous fungi ascospores of *Cercophora*-type may confirm this type of activity in the close vicinity of the studied lake (cf. Cugny et al. 2010). According to Iversen (1973), *P. lanceolata* is one of the most important plants in old-fashioned rough pastures, but it will not grow in grazed woodlands because of its high light requirements. Behre (1981) emphasized that this plant plays an important role in the recolonisation of fallow land, and hence is a diagnostic species of an earlier system of rotational farming. Being an indicator of fallow land, which was usually used as pasture, *P. lanceolata* indirectly indicates former cultivation, which can often be difficult to demonstrate (Behre 1981, 1986) due to the poor dispersal of Cerealia pollen (Vuorela 1973). Thus, a continuous *P. lanceolata* curve (from ca. 550 BC) (Fig. 4b) indicates cattle breeding and also possible cultivation in the investigated area.

The initial deforestation caused the most prominent increase in erosion intensity in the catchment during the analyzed period, which is well documented by significant elemental changes in the sediment, i.e. peaks in potassium, titanium, iron and manganese content around ca. 500 BC

(Fig. 5). Interestingly, subsequent deforestation did not produce such a clear signal in the chemical composition of the sediments.

A further increase in anthropogenic impact on the vegetation of the Lake Salęt surroundings was recorded at ca. AD 150 when new activities in crop cultivation and cattle rearing started (Fig. 4b). Recorded archaeological data indicate that the Roman Period was a time of general demographic and economic expansion on the whole southeastern coast of the Baltic Sea (Karczewski 2012). Settlement of that time was related here to the Bogaczewo culture, numerous sites of which were also discovered around Lake Salęt (Fig. 2).

Vegetation changes related to the Bogaczewo culture activity were characterized by an increased diversity of herbaceous plants treated as anthropogenic indicators, particulary cereals (besides pollen of *S. cereale* there appeared *Hordeum*-type, *Triticum*-type and *Avena*-type), and by the increase in the presence of charcoal, which suggests that slash-and-burn agriculture could have been the major cultivation method in Lake Salęt area.

During this period *Secale* cultivation spread in the vicinity of Lake Salęt. *S. cereale* was common in all of Europe as early as from the beginning of the Christian era, but it grew as a weed in *Hordeum* and *Triticum* fields. When grain cultivation moved north, the importance of *Secale* as the most frost-resistant cereal increased until the point where it began to be cultivated as a separate crop (Behre 1992). The results of palynological research show that almost throughout Estonia, *Secale* came to be cultivated in about the 6th century AD (Poska et al. 2004, 2008), but in north-western Estonia perhaps even earlier, in the Roman Iron Age (Heinsalu and Veski 2010). The relatively high frequency of *S. cereale* pollen noted in the Salęt profile (Fig. 4b) could be partly explained by *Secale* pollen dispersal by wind. This crop has higher pollen production and better dispersal potential than other cereals (Koff and Punning 2002). Vuorela (1973) studied the variation in pollen rain in the vicinity of an agricultural area surrounded by forest in Finland, and her principal conclusion was of the pollen filtering action of the forest. If the pollen of *S. cereale* is well dispersed and is found in peat-bogs and lake sediments far away from cultivated areas, then its frequencies must represent regional background values. Thus, in our investigation the *S. cereale* frequencies in the Salęt profile could reflect the regional background, which has to be taken into account when interpreting the diagram. The increased diversity of settlement and farming indicators was also observed for that period in some other sites from NE Poland, e.g. at about AD 100–650 in the surroundings of Miłki and at about AD 50–500 in the Staświny-Ruda and Lake Łazduny region (Wacnik et al. 2012). Wacnik et al. (2012) concluded that meadows and fields were that time the permanent, though not the dominant element of the local landscape.

Intensive agriculture and the broad extent of disturbed soils with high NO_3 content in the vicinity of Lake Salęt are documented by the wide presence of typical weeds (*Rumex acetosella*-type, *Artemisia* and Chenopodiaceae) from the second to the 5th century AD. The smallest particles of microscopic charcoal were present here at very high values from the second half of the 4th century AD, which suggests that fire could have served as a tool for clearing ground for cultivation and could have provided ash for fertilizing fields. In the light of our pollen data there is no record of a demographic crisis at the end of the fourth and in the early 5th century, as is suggested by some archaeological data in this region (e.g. Szymański 2005; Bitner-Wróblewska 2010).

Evidence for cattle rearing activity also comes from the fungal spore record, with the dung-inhabiting taxa (*Cercophora*-type and *Sordaria*-type). *Cercophora* comprises species which occur regularly on decaying wood, culms, stems and leaves (Ellis and Ellis 1997), but in an archaeological context this fungus can be used as an indicator for the presence of animal dung (van Geel and Aptroot 2006). The dispersal and transport of the fungal spores is less efficient in comparison with tree pollen, probably partly because of the position of fungal fruit bodies near the ground, where wind dispersal is less effective, and therefore the records of spores of coprophilous fungi can be used as indicators of the presence of animals near the sample site (van Geel et al. 2003).

The increasing human impact in the catchment area of Lake Salęt, as can be interpreted from the pollen records of human impact indicators, had its effect on the trophic conditions of this lake water. The simultaneous occurrence of NPP taxa, such as various algae (*Botryococcus*, *Tetraedron*, *Scenedesmus*, Zygnemataceae) and cyanobacteria (*Aphanizomenon*, *Anabaena*, *Gloeotrichia*) showed increasing eutrophication of the lake environment.

Some more information about the economy of West Balts tribes during the Roman Period comes from archaeobotanical and archaeozoological investigations at several sites in Masuria, for instance at Jeziorko in the Great Lakes Masurian District (Zabłocki 1950; Grezak and Piotrowska-Malecka 2007), Pieczarki (Polcyn 2000) and Wyszembork in the Mrągowo Lake District (Lityńska-Zając 1997). At the Wyszembork site, which is located close to Lake Salęt, abundant material of charred cereal grains contained *Hordeum vulgare*, *Secale cereale* and *Panicum miliaceum.* Seeds of *Cannabis sativa*, *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).

Judging from these results, *Cannabis sativa* cultivation in the close vicinity of Lake Salęt is confirmed both by the archaeobotanical data and pollen data from the Salęt profile (Fig. 4b).

The increase in the importance of crop farming, combined with the need for new agrarian land, could have resulted in the clearing of areas with fertile soils occupied earlier by *Alnus* stands or mixed woods with high *Alnus* content (cf. Saarse et al. 2010). The preference for *Alnus* stands as the first choice in slash-and-burn cultivation could be motivated by the fact that as an N_2-fixing tree *Alnus* can itself fertilise soil with atmospheric nitrogen (Uri et al. 2003). The use of iron tools increased the need for iron, and it is possible that *Alnus* wood was used as a fuel for iron smelting, which in turn would also diminish the *Alnus* population. *Alnus* is known as a rich pollen producer (Rasmussen 2005) thus its percentage is high in the whole diagram (Fig. 4). However, a decrease in the *Alnus* pollen curve began about AD 540, as in the other European lake sediment sequences, which registered a significant *Alnus* decline between AD 300 and 1000 (e.g. Sarmaja-Korjonen 2003; Veski et al. 2005; Saarse et al. 2010). In north-eastern Europe, *Alnus* pollen percentages diminished sharply during the Iron Age, which coincided with the start of extensive crop farming (Punning et al. 1995; Sarmaja-Korjonen 2003; Veski et al. 2005; Niinemets and Saarse 2007b; Saarse et al. 2010).

Pollen data from the Salęt profile indicate that the same land-use practices as in the Roman Period seem to have continued into the Migration Period. Settlement of the Olsztyn Group developed then in the surroundings of Lake Salęt (Fig. 2). Among palynological indicators of agricultural activity pollen grains of cereals (*S. cereale*, *Hordeum*-type, *Avena*-type) and *Cannabis*/*Humulus*-type pollen were present (Fig. 4b). In the older part of this phase the degree of anthropogenic vegetation changes declined temporarily, although the occurrence of herbs, including weeds typical of permanent fields (e.g. Chenopodiaceae) was noted regularly. Then further vegetation changes dated to about AD 600 indicate the increasing human influence on the environment around Lake Salęt. These are a high representation of ruderal plants and a continuous cereal curve and these indicate the existence of settlements and cultivated land nearby. Charcoal is a particularly useful proxy for recording the disturbance of vegetation by humans. Its peak values occured together with a pronounced drop of tree pollen and a significant rise of anthropogenic pollen (Fig. 4). It is worth mentioning that the pollen record from the eastern part of the Masurian Lakeland (Wacnik et al. 2012) showed a distinct difference between the intensity of vegetation changes caused by man in comparison with our data. The traces of economic-settlement activity recorded in those pollen diagrams indicate its decline in the vicinity of Lakes Miłkowskie, Wojnowo and Łazduny about AD 600–1000 (Wacnik et al. 2012).

In some European pollen diagrams slightly elevated percentage values of *Cannabis*/*Humulus*-type range from ca. AD 400 to 1500. This is apparent in the pollen records from Sweden (Påhlsson 1982), Finland (Sarmaja-Korjonen 2003), Denmark (Rasmussen 2005) and Lithuania (Stančikaitė et al. 2008) and correlates well with the Salęt data. In Lithuania macroremains and pollen of *Cannabis sativa* were found in sediments dated back to about AD 430–620 (Stančikaitė et al. 2008) and this suggests that this taxon may have been introduced and widely cultivated in this period. Interesting evidence comes from archaeobotanical investigations conducted in southwestern Germany showing that from the 3rd to the 6th century AD beer was made mainly from not very pure *Hordeum* malt, but with the addition of honey, and probably flavoured with *Humulus lupulus* (Rösch 2008). It is possible that in NE Poland there were also such a practice related to the Bogaczewo culture and the Olsztyn Group activity.

Among the NPPs recorded in the assemblage zone related to the Migration Period are fungal spores indicative of the presence of dung, namely *Sporormiella*-type, *Sordaria*-type and *Cercophora*-type as well as egg shells of the intestinal parasite *Trichuris*, which point to the deposition of excrement (van Geel et al. 1983). *Sporormiella*-type is also known as a strictly local grazing pressure indicator (Blackford and Innes 2006; Davis and Shafer 2006) and is commonly used for past grazing pressure reconstruction (van Geel et al. 2003; Gauthier et al. 2010). Dietre et al. (2012) confirmed the indicative power of this taxon as coprophilous fungi and documented its association with open habitats. Considerable numbers of akinetes of *Aphanizomenon* and *Anabaena* have been found at this time in the Salęt profile. These cyanobacteria can be considered as an indication of increased nutrient loading, related to the above-mentioned contemporaneous increase of human impact in the catchment area. Their dominance could be explained by an increase in phosphorus, which commonly occurs in eutrophicated waters (van Geel et al. 1994). According to our palynological data, anthropogenic changes in the environment, which started during the Migration Period, lasted until the mid 9th century.

The anthropogenic impact on the landscape during that period, which is distinctly evidenced by the pollen diagram, is not reflected by the archaeological data. Most of the data postulate a decline of settlement from the 7th century (e.g. Kowalski 2000; Nowakowski 2000). However, this conception is based mainly on studying cemeteries and may not reflect actual depopulation, but only changes in burial practices (e.g. Wróblewski et al. 2003). Reinterpretation of the data in the context of new studies on the distribution of pottery styles suggests that here the settlement could have been maintained up to the 9th century (Paweł Szymański: personal communication). Also some historians suggest that in some regions of the Masurian Lakeland settlement was scattered but still persisted till the Early Medieval (e.g. Białuński 1999).

Local development of *Betula* in a European perspective

From the beginning of the early Iron Age, the existence of deforestation favouring the expansion of *Betula* is indicated by the increased percentages of herbaceous plants (Fig. 4). According to Lindbladh et al. (2003) human activity and fire could have been important factors for the long-term recorded dominance of *Pinus*, *Betula* and some other species in northern Europe during last 2,500 years. These authors emphasised that many *Pinus* trees can survive mild to moderate fires, whereas *Betula* is a prominent pioneer species after fires. The pollen assemblage zone representing this period in the Salęt profile (*Betula*–*Corylus*-NAP) is dominated by *Betula* pollen up to 35 %, suggesting that *Betula* was the dominant taxon among trees. It has been assumed that a minimum value of 10 % of *Betula* pollen may indicate its local presence, values larger than 25 % indicates local *Betula*-dominated woodlands, and more than 50 % reflects *Betula*-dominated woodlands which cover the landscape (Huntley and Birks 1983). Isopollen maps for 600–60 BC show the distinct increase of *Betula* pollen values to about 25 % in north-eastern Poland (Ralska-Jasiewiczowa et al. 2004). This process is also evident in the profile from Lake Dgał Wielki (Filbrandt-Czaja 2000), and slightly less clearly in Lake Mikołajskie (Ralska-Jasiewiczowa 1966). In the other profiles from the Masurian Lake District, the *Betula* pollen percentages remain on a high level (25–40 %) for a long period as is recorded in Lakes Łazduny, Miłkowskie and Wojnowo (Wacnik et al. 2012) as well as in Lake Linówek (Gałka et al. 2014). These authors mostly concluded that the reason was that the landscape was cleared repeatedly in order to prevent woodland succession within the settlement region. Systematic clearings were connected with short-lasting agricultural use of the ground, which required temporary resting. They also noted the occurrence of micro-charcoals >100 μm which indicates local intentional use of fire, probably in the course of slash-and-burn agriculture, known also as swidden or shifting agriculture (Cornell 2011). This system involves the rotation of several plots in a planting cycle and works best in low intensity agriculture, when there is enough space for fallow land. Using the traditional Fennoscandian method, the trees were cut down and left to dry 1 year before burning, while cultivation took place in the following few years. The land was then left for reforestation, or turned into pastures during the fallow periods (Sjögren and Arntzen 2013). This method was similar in other countries on the eastern coast of the Baltic Sea, where farming societies were established in Lithuania, Latvia and Finland during the Late Bronze Age at the earliest (Antanaitis-Jacobs and Girininkas 2002).

There is a general assumption that fire events during the late Holocene in Europe and western Asia can be explained by deforestation using fire, especially during the Bronze and Iron Ages (Power et al. 2008). In contrast to earlier woodland clearances, after which regeneration normally occurred, Iron Age clearances often resulted in a permanent change in the ecosystem. Implementation of iron tools, ploughing and manuring enabled people to extend the size and number of fields and to exploit less favourable areas. In addition, increases in crop and non-arboreal pollen (AP) were often accompanied by evidence of fire use in woodland clearances visible as woodland composition changes. In general, the proportions of temperate broadleaved trees and *Picea* decrease at the same time as *Betula* and *Pinus* increase. This feature is apparent in several records from Estonia, Latvia and Lithuania (Stančikaitė et al. 2006; Heikkilä and Seppä 2010). However, in some regions in Estonia the woodland composition changes took place earlier than the start of the continuous crop pollen curve and other evidence for large-scale arable farming (Veski et al. 2005; Niinemets and Saarse 2007a). High values of *Betula* pollen, up to 35 %, that were contemporary with low frequencies of charcoal particles in the pollen assemblages associated with West Baltic Barrow culture in the profile from Lake Salęt allowed us to formulate a hypothesis about the agricultural practices in this area. Tentatively we suggest that felling trees rather than burning served as a tool for clearing ground for cultivation in the investigated microregion.

Agricultural exploitation of the study area became stronger from the second half of the 2nd century AD (Roman Iron Age). Numerous charred particles detected in sediments from this period suggest the use of fire for land clearing. This technique apparently favoured the spread of *Betula* (30–35 %). The gradual increase of *Betula* pollen during the Roman Iron Age was observed also in Lithuania, to ca. 10 % in the area of Baltija Upland (Stančikaitė et al. 2004) and to 25–30 % in the Biržuli Lake region (Stančikaitė et al. 2006), and both were interpreted as human induced vegetation changes. Several pollen diagrams from Sweden also show high frequencies of *Betula* pollen at levels dated to the Iron Age, as is evident, for example, in the pollen maps presented by Björse and Bradshaw (1998). In southern Sweden a new agro-technical system was introduced during the first centuries AD (Lagerås and Bartholin 2003). This was hay production, which presumably resulted in increased manuring and hence longer cultivation periods between fallow phases.

The new, more open spaces created during human expansion phases favoured light-demanding shrubs and trees like *Betula* and *Corylus*.

Betula expansion in the area of Lake Salęt intensified during the later stages of the Iron Age. The pollen diagram (Fig. 4a) shows fluctuating *Betula* values (25–43 %) during the Migration Period (end of the *Pinus-Carpinus*-NAP and *Pinus-Corylus*-NAP LPASZ). These fluctuations in the *Betula* pollen proportion together with the increase in the amounts of charcoal particles and cereal pollen can be interpreted as the evidence for the shrub-fallow type agrotechnical system. There are several examples of this system across Europe. In the Carpathians a 10-year cycle shrub-fallow system was used. The shrubs were cut down in the middle of the summer and allowed to dry. The next year they were burnt and the ashes worked into the soil. The first year *Hordeum* was cultivated, followed by 2 years of *Avena*, after which the fields were left to regenerate (Emanuelsson 2009). Around the North Sea different systems were used. In one of them, the grass turf was broken up, allowed to dry, and subsequently burnt (Emanuelsson 2009). In prehistory the shrub-fallow cultivation system existed in a multiplicity of variants, and it is probably not possible to find its exact analogue in recent history. Sjögren and Arntzen (2013) describe a hypothetical shrub-fallow system in which after a 5–15 year fallow period the shrubs were cut down and/or the turf broken up and allowed to dry. After burning the dried plants, the soil was reworked and cultivated for no more than 2–3 years. It is possible that this activity resulted in depletion of the soil nutrients within 5–10 cycles. Sjögren and Arntzen (2013) suggest that this forced the farm to move, or to turn previous pastureland into arable land and vice versa. Alternatively, or in addition to this, the slash-and-burn practice and the use of the ashes to provide nutrients to the soil could be employed. The main reasons for the high yields after burning are the mobilization of nutrients, the rise in pH, which makes nutrients more easily available, especially for *Triticum*, and the suppression of weeds (Rösch et al. 2004). In our investigation, high values of *Betula* pollen observed during the whole of the Iron Age could be related to secondary communities with *Betula* as the dominating taxon that invaded heavily cleared places. The possibility of using ash for manuring impoverished soils was restricted by the limited availability of wood suitable for burning, which in turn necessitated longer periods of leaving the exploited areas fallow (Rösch et al. 2004; Wacnik et al. 2011). The source of wood could be provided by quickly growing *Betula* thickets, which were common on fallow land. It should be noted here that *Betula*, the most likely taxon to colonize the fallow land, does not start to produce pollen until after about 10 years when standing alone and free, and in compact stands not before 20–25 years (Tomanek 1966). Slash-and-burn cultivation was used in many parts of Europe up to the 20th century, e.g. in South Estonia up to the end of the Second World War (Niinemets and Saarse 2006; Poska et al. 2008).

Effects of climate change on agriculture and population of prehistoric Balts

The Bronze/Iron Age transition in Europe has long been recognized as a period of climate deterioration, corresponding approximately to changes in peat sequences defining the Subboreal/Subatlantic transition in the Blytt-Sernander scheme for division of the Holocene (Sernander 1908), reflecting a shift from warm/dry to relatively cool/wet conditions. Whether this change in atmospheric circulation patterns was primarily triggered by changes in solar activity (e.g. van Geel et al. 1999) or by changes in the thermohaline circulation (e.g. Bond et al. 1997) is still debatable. Despite the abundant evidence for widespread climate change in the late Bronze and early Iron Age, and archaeological indications of settlement abandonment at some sites, it is unclear how significant this change was for human settlement and land use (Dark 2006). The cooling of climate and increase in precipitation between 800 and 600 BC was a time when the glaciers in the Alps were growing (Holzhauser et al. 2005) and accumulation on the peat bogs increased (Gałka et al. 2013). On the basis of oxygen isotope records from Greenland ice-cores, Tinner et al. (2003) indicated that warm periods existed among others at around 650–450 BC. This was when the most significant changes in the cultural landscape of north-eastern Poland occurred, West Balt Barrow culture appearing in Masuria (e.g. Hoffmann 2000). In the pollen profile from Lake Salęt noticeable peaks in Cerealia-type and *Plantago lanceolata* pollen (ca. 1–2 %) are dated to ca. 441 BC–AD 86, and express intensified agriculture around this site. According to Büntgen et al. (2011) in central Europe, construction activity increased during the Iron Age, from ca. 300 BC to AD 200, and the maximum deforestation occurred around AD 250.

In north-eastern Poland continuous and increasing pressure on vegetation, including formation of arable plots and pastures, began from the Late Bronze Age and increased considerably during the Roman Iron Age (e.g. Wacnik 2009, Wacnik et al. 2012), when the Bogaczewo culture developed in the Masurian Lakeland (e.g. Szymański 2005; Karczewski 2011). Archaeologically documented innovations in agriculture, like iron tools (e.g. sickles) and efficient ox-pulled ploughs increased agricultural productivity during the Iron Age and this coincided with changes in the pollen of cultivated plants. The adoption of these innovations is likely to be responsible for the increasing long-term trends observed in our data. Similarly, the Roman Iron Age in Sweden was a period of agrarian expansion, intensification and innovation when the new agro-technical systems were introduced (cf. Lagerås and Bartholin 2003). According to the pollen data from the Salęt profile (Fig. 4b), at about AD 540–590 a short lasting decline of non-AP frequencies took place, particularly a sharp decrease in pollen of cultivated plants and weeds. Then a reforestation of open fields occurred with *Betula* and *Corylus* as well as broad-leaved species, i.e. *Quercus* and *Carpinus*, in the later stages. This could have been caused by the abandonment of settlements as well as by migration of some groups of people. However, the overall impression from archaeological studies implied that a presumably small human population was living there and so did not significantly influence the regional environment. The settlement regression could also be identified as the result of extensive dispersion of earlier concentrated intensive activity of Bogaczewo culture people (Szymański 2005), and it is possible that this was related to environmental changes.

The existence of important climate changes that affected the Baltic area and neighbouring European regions in the 5th–6th centuries AD is shown by many palaeoecological investigations. For example, oxygen isotope records from Greenland show a general decreasing temperature trend after AD 400 (Tinner et al. 2003). Furthermore, there are a number of wet/cold records during the period at ca. AD 450–550, noted in the bogs of England, Scotland, Ireland, Denmark and the Netherlands (Hughes et al. 2000; Barber et al. 2004), which suggest general climatic deterioration in northern Europe. Moreover, in the eastern Baltic Sea region, high-resolution palaeoecological studies of Männikjärve bog in Estonia have provided evidence of a higher surface water table ca. AD 400 as a response to cooler climate (Sillasoo et al. 2007, 2009). These phenomena coincide with the biggest central European historical crisis, the Migration Period, a time marked by lasting political turmoil, cultural change and socioeconomic instability, when exceptional climate variability is reconstructed (Büntgen et al. 2011). At the same time, hemispheric-scale cooling occurred that has been linked with an explosive near-equatorial volcanic eruption in AD 536 followed by the first pandemic of Justinian plague that spread from the eastern Mediterranean in AD 542–543 (Kausrud et al. 2010). Rapid climate changes together with frequent epidemics had the overall capacity to disrupt the food production of agrarian societies (e.g. de Menocal 2001; Haug et al. 2003). Precipitation and temperature began to increase from the end of the 6th century AD and reached climate conditions comparable to those of the Roman Period in the early 9th century AD (Büntgen et al. 2011). In many regions of northern Germany and neighbouring areas a general decline of settlement activities started from ca. AD 400 to 500 (Dörfler 1992; Karge et al. 2000; Beug 2011), and archaeological and palaeobotanical indicators of settlement activities almost disappeared between AD 500 and 900 (Müller-Wille et al. 1988). To some extent, the changes noted around these times do not have to be seen as confined only to central Europe. In Scandinavia, around AD 500 there is a drastic decline in cereal pollen. In the 6th century many settlements seem to have been completely abandoned and expanded again only in the late Viking Age (Liedgren 1992; Brink 1994; Löwenborg 2012). However, recent investigations in Lithuania (e.g. Bliujienė 2003; Simniškytė et al. 2003; Stančikaitė et al. 2013) have demonstrated rather high ongoing settlement activity, including agriculture practices, in particular areas of the Eastern Baltic during the Migration Period. Archaeological data representing this time interval attest to changing site occupation systems when hill forts were abandoned and low-lying settlements were enlarged (e.g. Stančikaitė et al. 2013).

Conclusions

Pollen, NPPs, charcoal and geochemical analyses were conducted on sediments from Lake Salęt being the central point of the settlement microregion. The investigations were restricted mainly to the Iron Age, and covered the period from the second half of the 7th century BC to the beginning of the 10th century AD. The palaeoecological data, together with a well established chronology, made it possible to correlate local environmental changes with archaeological finds of human settlements, and confirmed the long-lasting existence of the West Balt tribes in the Mrągowo Lake District.

The results obtained provided new data to assess the dynamics of settlement and economic changes of the prehistoric inhabitants of the Mrągowo Lake District (NE Poland). The whole Iron Age in the studied region was characterized by the almost continuous existence of the West Balt tribes, which was connected with the West Balt Barrow culture, and then with the Bogaczewo culture and the Olsztyn Group. Correlation of palaeoecological data with the local archaeological data was a reliable basis for the interpretation of man-environment interactions.

The diversification of the use of the environment by humans is quite clearly marked in particular periods of the Iron Age. In the early Iron Age (West Balt Barrow culture) the mainstay of the economy was animal husbandry, and cultivation was of rather less significance (probably mainly *Triticum* was grown). In the Roman Period (Bogaczewo culture) animal husbandry and cultivation were of more or less similar economic importance, and *Secale* cultivation was introduced on a large scale. Slash-and-burn cultivation developed, particularly in the middle part of the Roman Period, after ca. AD 200. In the Migration Period (Olsztyn Group) the economic activity of the Roman Period was continued and judging from the pollen record, human impact on vegetation persisted until the 9th century. Regeneration of woodlands, mainly *Betula* woodlands and *Alnus* woods took place only in the period after ca. AD 830, and was accompanied by a decrease of all indicators of agriculture. This observation is not in accordance with the most of archaeological data about the diminishing of the settlement activity in the Salęt microregion as early as the 7th century AD.

The most characteristic feature of the studied area during the whole Iron Age was a high representation of semi-natural *Betula* woodlands which was probably linked with the shifting agriculture. However, strong reduction in *Betula* took place between ca. 650 and 450 BC and was connected with the appearance of the West Balt Barrow culture.

Plausibly, climate changes were a major factor shaping changes in settlement and land-use patterns in the Iron Age. Broadly, at around 400 BC there was a marked increase in the number of Balts settlements in the area around Lake Salęt connected to climate warming. Moreover, the economic and societal crisis at about AD 540–590 might have been aggravated by climate deterioration in the Migration Period.

Acknowledgments We are especially indebted to Małgorzata Latałowa for valuable suggestions. We would like to express our gratitude to Dorota Nalepka and Adam Walanus for their valuable support. We are grateful to Felix Bittmann and an anonymous reviewer for comments on the manuscript. We would like to cordially thank Daniela Czerniawska for help with sample preparation. We acknowledge the financial support provided by the Ministry of Science and Higher Education/National Science Centre of Poland (Grant No. N N 304 280540), and by the Institute of Biology, University of Białystok, through statutory funds.

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