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ORIGINAL PAPER

The Late Vistulian and Holocene evolution of Jezioro Lake: a record of environmental change in southern Poland found in deposits and landforms

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Abstract Jezioro Lake is the only natural lake in southern Poland outside mountainous areas to have existed continuously since the Pleistocene. The record of environmental change in the Late Vistulian (Weichselian) and Holocene is preserved in the deposits and landforms around the lake. This paper presents the results of paleogeographical and paleoecological research that emabled us to reconstruct the history of the Jezioro Lake. At the end of the Vistulian period, the outlet of the lake was blocked by a parabolic dune moving in from the west. Limnic sedimentation was evident in the sediment core at all levels from the Holocene, with remains of Cladocera, Chironomidae larvae, and aquatic plants. The lake did not disappear at that time, although its area decreased by a factor of 12 by the end of the period. Paleobotanical research permitted the reconstruction of sequences of plant communities and changes in nutrient status and water level. An initial oligotrophic lake, as indicated by the presence of *Isoëtes lacustris* L., changed to a eutrophic lake, as indicated by the presence of *Potamogeton natans* L. and *Nuphar* sp., then the lake progressed to the present-day dystrophic lake that is surrounded by a swamp. The profile of organic deposits contains a record of environmental change at least since the Younger Dryas in southern Poland.

Keywords Lake evolution · Late Vistulian · Holocene · Vegetation history · Southern Poland

Introduction

In Central and Eastern Europe, the majority of lakes that hold a record of changes in environmental conditions from the late Pleistocene until modern times in their sediments are young glacial lakes (Błaszkiewicz 2007). Such lakes can be found from the Mecklenburg Lake District in Germany through northern Poland, Lithuania and north-western Russia to Finland. One of the best studied sediment profiles of this type of lake is from Gościąż Lake (Ralska-Jasiewiczowa et al. 1998, 2003; Goslar et al. 1999). Sediments that are also valuable from the point of view of Late Pleistocene/Early Holocene paleogeography include those of karst lakes situated north of Lublin in Poland (Bałaga 2007, 2010) and in western Belarus, as well as ox-bow lake sediments, e.g. in the Sandomierz Basin (Nalepka 1994; Kołaczek 2010), and those of single lakes left behind by mountain glaciers (Obidowicz 1996). Profiles of those lake sediments have been compared to profiles of peat bogs situated in various regions of Poland (Czyżewska 2005).

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The further south we move in Poland, the fewer natural water bodies are present. A peculiar type of lake found there is the aeolian barrier lake. These lakes formed in the late Pleistocene as a result of small valleys being blocked by dunes that moved in from the west and they preserve a rich record of environmental change in their sediments. They formed in sandy areas with poor soils and thus remained outside the settlement zone for a long time. As a result, anthropogenic impact was only reflected in their sediment records at a late stage. Most of these, usually shallow, lakes rapidly became eutrophic. Jezioro Lake on the Silesian-Kraków Upland is one of the few lakes that still remain.

Jezioro Lake is located west of Częstochowa (Fig. 1a). This splendid lake is the only such lake of non-anthropogenic origin in southern Poland outside mountainous areas (Czylok et al. 2004). It lies in forested terrain (Fig. 1b) within the "Lasy nad Górną Liswartą" ("Forests on the Upper Liswarta") Landscape Park, which is only partly used by traditional agriculture.

Earlier research, carried out in 2004, was mainly concerned with the contemporary condition of the lake. That research had an interdisciplinary character that involved surface geological and geomorphological investigations, hydrological mapping, physicochemical analyses of water, analysis of shallow lake sediments and mapping of contemporary plant communities (Czylok et al. 2004).

The present paper interprets the evolution of the lake based on a study that was carried out in 2006–2009.

The importance of Jezioro Lake deposits in providing complete information on the Late-Vistulian and Holocene transformations of the environment in southern Poland is emphasised by the fact that the nearest site from which similar organic deposits have been described lies in the area of Jaworzno (Szczepanek and Stachowicz-Rybka 2004), located 180 km to the south and this contains a slightly shorter record, reaching only down to the Younger Dryas, i.e. GS-1 according to the stratigraphic division proposed for the North Atlantic region (Björck et al. 1998).

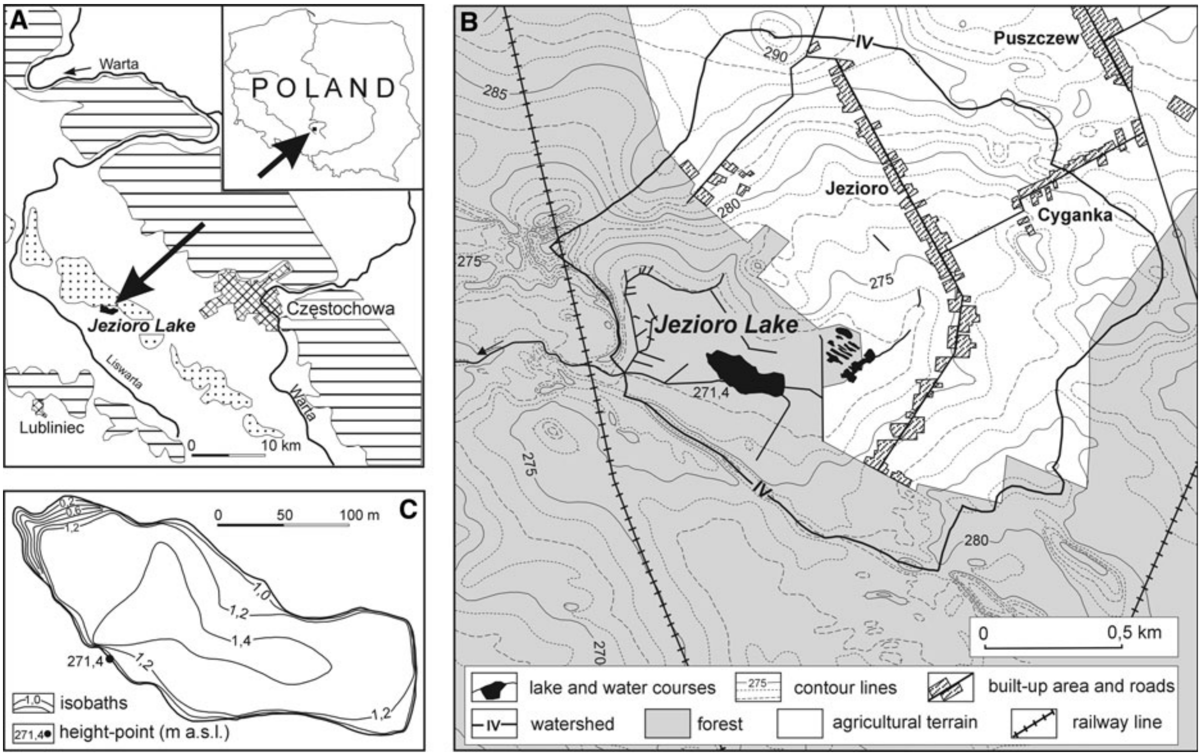

Fig. 1 Location of study site: **a** location of Jezioro Lake (limestone structural thresholds—hatched, sandstone structural threshold—dotted); **b** Jezioro Lake environs; **c** Bathymetric plan of lake

Study area

Jezioro Lake (N 50°47′ 21.33″, E 18°50′ 20.00″) is a natural water body located in the northern part of the Silesian Upland, on the margin between the Herby Ridge, formed by ferruginous sandstones of the Middle Jurassic and the Liswarta Depression formed in Lower Jurassic clays, loams and sands. The surface is formed of Pleistocene glacial, fluvioglacial, fluvial and aeolian deposits and Holocene fluvial deposits 10–20 m thick. Their thickness is locally reduced to a few metres where the Jurassic substratum is elevated (Klimek 1966; Haisig et al. 1983).

The swampy topographic depression in which the lake is located (Figs. 1b, 2a, 2b) drains into a stream that flows into the Liswarta River through a system of ditches. The lake is situated in a coniferous forest that occupies almost 1/3 of its 2.5 km^2 catchment (Fig. 1b).

Jezioro Lake is a dystrophic lake with water area of 0.027 km^2 and a total depth of 1.2–1.5 m (Fig. 1c), of which more than 0.4 m is made up of semiliquid bottom deposits (Fig. 2c). Significant amounts of humic substances in the water give it a brown hue.

In the vicinity of the lake, plant communities are present that are unique within the region and rare in Poland. Among the most valuable are patches of mesotrophic and oligotrophic peat as well as birch wood swamp (*Betuletum pubescentis* R. Tx.) and adjacent coniferous swamp forest communities (Fig. 3).

Methods

Fieldwork

The landforms in the lake catchment were mapped using transects. The geomorphology of the deposits was examined using exploratory boreholes. The relationships between landforms and the deposits forming them were investigated through field observations, and by relating these to the Topographic map of Poland at 1:10,000 scale and the Detailed Geological Map of Poland at 1:50,000 scale. On the transect lines and at other selected points, exploratory boreholes were made to a depth of 3 m, and the macroscopic structural and textural features of the deposits were examined.

The maximum historic extent of the waterline was determined by investigating old micro-cliff and sub-cliff sediment zones. Where the relief of lake banks was less articulated, the waterline was determined by projecting the bases of the micro-cliff across the lake using land surveying equipment.

A bathymetric plan of the contemporary lake was generated using an echo-sounder and range pole. The positions of the measurements were determined by the use of a GPS receiver.

Granulometric composition of the mineral sediments was attained by using a sieve method. Analysis of roundness and degree of matting of quartz grains was conducted using the morphoscopic method of A. Cailleux as modified by Goździk (1980) on the 0.8–1.0 mm fraction. The content of calcium carbonate was determined using a field methodology involving 10 % hydrochloric acid poured on the samples. It was assumed that episodes when the mineral sediments had a better oxygen penetration were marked with an orange-reddish colour from iron compounds.

Plant macroremains and pollen analysis

Core J18 was obtained for peat and pollen analysis using an Instorf Ø 80 peat borer at a location that is presently dry but which is situated along the axis of the former lake basin (Fig. 3). The analysis of macroscopic remains was conducted from samples of 100 cm^3 taken every 5 cm along the core. Microscope slides were prepared from this material in order to identify the presence of remains of Cladocera and to identify accurately the features of the deposit. Fresh sediment was soaked with water to separate remains and then washed through a 0.2-mm mesh sieve. This permitted individual remains to be segregated and preserved in a solution of water, glycerine, and alcohol (1:1:1) and some drops of thymol. Some plant remains were washed with alcohol and dried before identification for better demonstration. Determinations were mainly made with a stereoscopic microscope. Paleobotanical keys (Berggren 1969; Cappers et al. 2006; Grosse-Brauckmann 1992; Katz et al. 1965; Velichkevich and Zastawniak 2006; Aalto 1970; Wasylikowa 1986) were used to identify macroremains. The results were compiled in the form of a diagram of macroremains.

Palynology samples were taken from the J18 core at intervals of 2–2.5 cm. Macerated samples were 1 cm^3

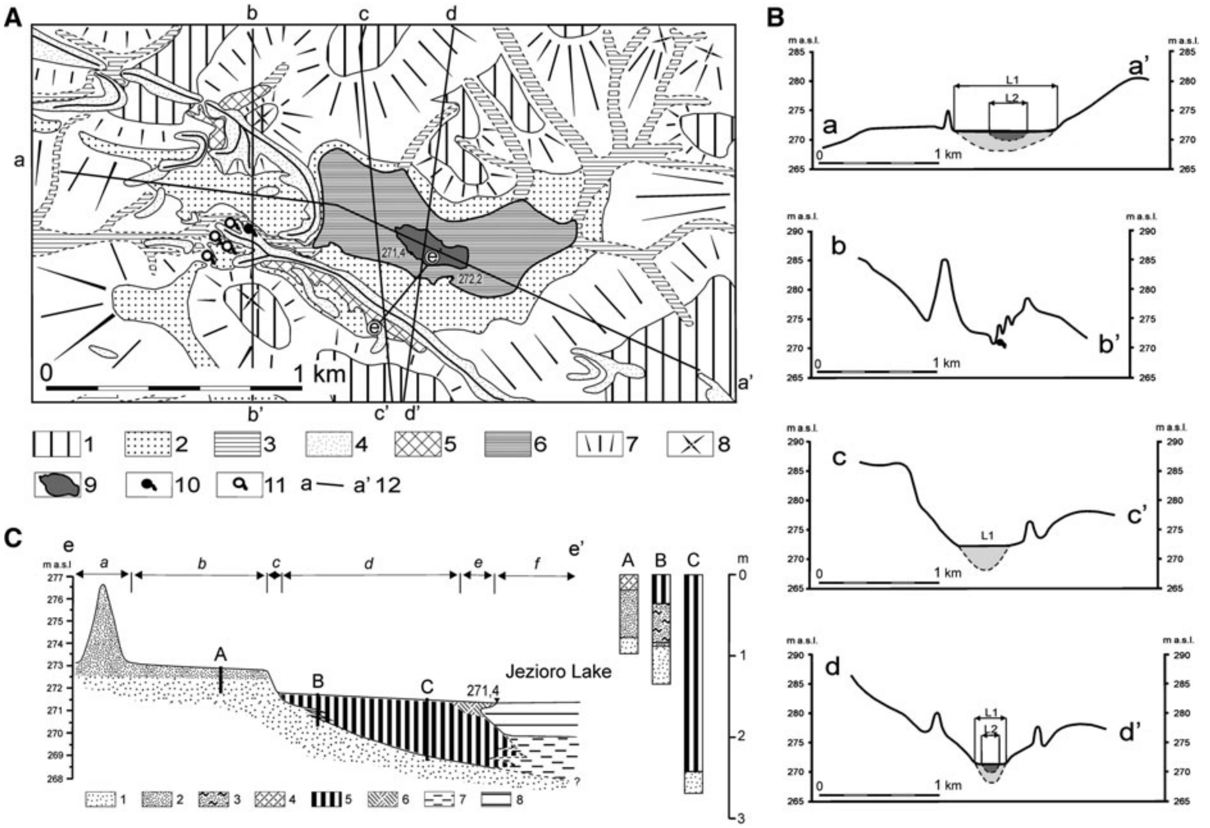

Fig. 2 Geomorphic sketch of the Jezioro Lake environs: **a** Geomorphic sketch (*1* fluvioglacial-morainic plateau and kame terrace, *2* fluvioglacial terrace with aeolian cover, *3* Holocene valley floors, *4* dunes, *5* depression without drainage, *6* organogenic plain, *7* slopes, *8* summit of elevations, *9* lake, *10* old spring niche, *11* old bog-spring, *12* topographic profile lines). **b** Schematic morphological profiles of the Jezioro Lake area; location of morphological profiles—see figure **a** (*L1* old shoreline of lake, *L2* modern shoreline of lake). **c** Schematic morpho-geological cross-section of the shore of Jezioro Lake—without horizontal scale, *e–e′* cross-section line is marked on figure **a**, after Czylok et al. (2004) (*a* dune, *b* fragment of outwash plain with aeolian sand covers with different thicknesses, *c* old lake shore with micro-cliff, *d* peat-plain, *e* floating mat, *f* open water, *1* variable-grained sand, *2* fine-grained sand, *3* sand with humus, *4* organic horizon of forest soil, *5* peat, *6* floating mat, *7* bottom deposits, *8* open water)

in volume and typically taken at 5-cm intervals. Depending on the results obtained these intervals were shorter in certain profiles of the core. Maceration agents included 10 % KOH, 10 % HCl, $ZnCl_2$ and Erdtman's acetolysis was applied (Faegri and Iversen 1989). Two tablets of *Lycopodium* were added to the samples at the beginning of the maceration process. Calculations were performed on the basis of the sum total of arboreal pollen (AP) and of land-growing non-arboreal pollen (NAP). Results of the pollen analysis are shown on a pollen diagram created using the POLPAL package (Nalepka and Walanus 2003). The main criterion for determining the limits of macrofossil assemblage zones was the appearance or disappearance of one or several species typical for a given level, or the frequent occurrence of species with similar ecological requirements. The layers identified reflect the transformation of vegetation and the phases of development of the water body and its immediate environment that followed.

The pollen diagram has been divided into 6 local pollen assemblage zones (LPAZ) according to Birks (1986) and Janczyk-Kopikowa (1987) supported by numerical analysis (ConSLink).

Radiocarbon dating

A total of 7 samples from the J18 cross-profile were radiocarbon dated (Table 1). The 6 samples taken from gyttja were dated at the Radiocarbon Laboratories in

Fig. 3 Distribution of the main areas of natural vegetation at Jezioro Lake

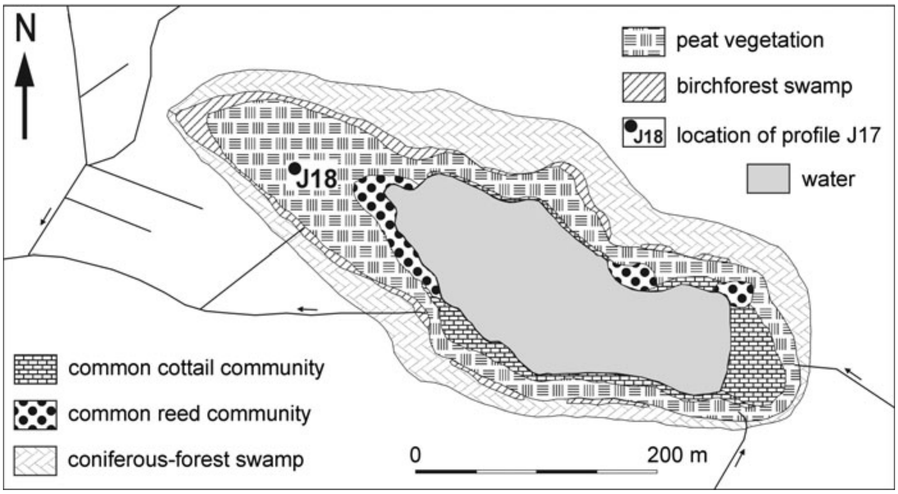

Table 1 Radiocarbon dates from profile (J 18 profile)

Lab no.	Depth (cm)	Age ^{14}C BP	Calibrated age		Material
			Range 68 %	Range 95 %	
Gd-30175	113–116	3,650 ± 230	2,400 (1.0 %) 2,380 cal BC	2,840 (0.4 %) 2,810 cal BC	Gyttja
			2,350 (67.2 %) 1,740 cal BC	2,670 (94.6 %) 1,490 cal BC	
				1,480 (0.4 %) 1,450 cal BC	
MKL-986	162–167	3,550 ± 90	2,020 (4.7 %) 1,990 cal BC	2,140 (95,4 %) 1,660 cal BC	Gyttja
			1,980 (63.5 %) 1,750 cal BC		
MKL-987	188–192	4,740 ± 80	3,640 (49.7 %) 3,500 cal BC	3,660 (95,4 %) 3,360 cal BC	Gyttja
			3,430 (18.5 %) 3,370 cal BC		
Gd-30176	226–229	8,000 ± 240	7,300 (1.7 %) 7,270 cal BC	7,520 (95.4 %) 6,450 cal BC	Gyttja
			7,260 (2.5 %) 7,220 cal BC		
			7,200 (63.6 %) 6,630 cal BC		
			6,620 (0.3 %) 6,610 cal BC		
MKL-988	278–285	9,180 ± 180	8,710 (2.6 %) 8,670 cal BC	9,200 (95,4 %) 7,800 cal BC	Gyttja
			8,660 (65.6 %) 8,220 cal BC		
Gd-30167	322–325	11,900 ± 290	12,150 (68.2 %) 11,450 cal BC	12,810 (95.4 %) 11,250 cal BC	Gyttja
Ki-13020	365–368	12,000 ± 90	12,340–11,860 BC		Clay and silt
			12,400–11,600 BC		

Gliwice and in Skała (Poland). Radiocarbon dates were calibrated with OxCal v4.0.5 (Bronk Ramsey 2001) and the IntCal04 atmospheric curve (Reimer et al. 2004). A sample of clay and silt was dated at the Radiocarbon Laboratory in Kiev (Ukraine).

The J18 profile stratigraphy was based on radiocarbon dating, palynological research and on analyses of plant remains. Chronozones were determined according to Mangerud et al. (1974).

Results

Geological and geomorphological conditions

The most significant surface deposits in the vicinity of Jezioro Lake are sandy to gravely fluvioglacial deposits from the Oder glaciation that are located on a large sandy plain stretching along the Liswarta valley at an elevation of 250–280 m a.s.l. The top

Table 2 Deposits noted in the core from borehole J18

Depth (cm)	Characteristics of deposits in the core
0–15	Living plant cover composed mainly of *Sphagnum cuspidatum* with some *Rhynchospora alba*, *Eriophorum angustifolium* and *Oxycoccus palustris*
15–40	Dark-brown peat, poorly decomposed, mainly derived from remains of *Eriophorum* sp., at a depth of 19.5–31 cm yellow-brown poorly decomposed peat mainly derived from *Sphagnum* sp. Fragments of twigs of *Pinus sylvestris* are present. The layer is strongly penetrated by roots. Testacea shells and numerous insect remains were noted
40–68	Dark brown gyttja at the top of this horizon strongly penetrated by roots does not contain mineral matter. Large contribution of amorphic material, fine (up to 1 mm) plant detritus (mainly remains of *Sphagnum* sp.). Below 50 cm fragments of *Pinus sylvestris* bark, numerous stems of *Sphagnum* sp. and remains of *Eriophorum angustifolium* are present. Numerous Bacillariophyceae frustules, Testacea shells and remains of Cladocera and Chironomidae larvae were noted
68–274	Olive gyttja, olive-brown and olive-black gyttja without admixtures of mineral matter. The change of colour is especially visible at depths of 117, 145, 186 and 235 cm. There is a large contribution of formless material and fine plant detritus throughout the whole series. At the top of the horizon there are remains of *Sphagnum* sp. (including stems). Numerous Bacillariophyceae frustules, and remains of Cladocera and Chironomidae larvae were noted throughout the whole horizon. Bryozoa were also present
274–337	Clayey gyttja, olive, dark-olive and olive-black. A change in colour is observed at depths of 280, 305 and 325 cm. A slight contribution of clay is present thoughout the whole horizon. Large contribution of formless material and fine plant detritus. Bacillariophyceae frustules and remains of Cladocera and Chironomidae larvae were noted
337–361	Clayey and silty gyttja with laminae of sand, grey-olive. Leaf-like remains of plants 1–3 cm long appear at a depth of 339 cm, and their contribution increases with depth. Distinct, darker layer at a depth of 342–345 cm, below a distinct lamination of the deposit. Particles of clay and silty are visible throughout the whole horizon and their contribution increases with depth. There is a laminae of sand 3 mm thick at a depth of 355 cm, while below 355 cm sand grains are not numerous in the deposit. Bacillariophyceae frustules and remains of Cladocera and Chironomidae larvae were noted. Bryozoa were also noted
361–372	Clay and silt with laminae of sand, grey-olive. Dispersed sand grains are present throughout the whole series of the deposit. Upper and lower contacts of the bed is delimited by laminae of sand with thicknesses of 0.5 and 1 cm. In the upper contact there is a significant contribution of leaf-like plant remains 1–3 cm in length. Bacillariophyceae frustules and remains of Cladocera and Chironomidae larvae were noted
372–375	Clay and silty clay with laminae of sand, grey. Dispersed sand grains are present throughout the whole series of clay. Bacillariophyceae frustules and remains of Cladocera and Chironomidae larvae were noted

Table 3 Local macrofossil assemblage zones (profile J18)

Depth (cm)	No. of sample	No. LMAZ	Local macrofossil assemblage zones
15–40	1–5	J18-7	*Pinus sylvestris-Eriophorum angustifolium*
40–215	6–40	J18-6	*Chara-Pinus sylvestris-Eriophorum vaginatum*
215–265	41–50	J18-5	*Chara-Potamogeton natans-Pinus sylvestris*
265–310	51–59	J18-4	*Isoëtes lacustris-Chara-Pinus sylvestris*
310–345	60–66	J18-3	*Potamogeton pusillus-Chara-Carex*
345–360	67–69	J18-2	*Potamogeton natans-Chara*
360–375	70–72	J18-1	*Chara-Potamogeton filiformis-Potamogeton praelongus*

layers of the sandy deposits are composed of coarse-grained sands, with a local admixture of gravels.

Sandy fluvioglacial and fluvial deposits, easily blown by wind, provided the source material for fields of aeolian sands that developed into sand dunes of different types. In addition to the plain of aeolian sands, parabolic dunes and longitudinal dunes forming long ridges occur in areas to the west, south, and southeast of Jezioro Lake (Figs. 2a, 2b). Dunes reach heights of 2.5–6 m up to 13–15 m, and the thickness of the aeolian sand cover exceeds 2 m.

Table 4 Local pollen assemblage zones (profile J18)

L PAZ	Description	Chrono-zones
J18-6 *Carpinus-Fagus-Abies* (0.50–1.525 m)	Increase in *Carpinus betulus* (to 8 %) and *Fagus sylvatica* pollen (to 12 %). Continuous pollen curve of *Abies alba* with max. 3 %. Sporadically *Triticum* t. and Secale cereale pollen are recorded. No upper boundary	SB
J18-5 *Corylus-Quercus-Alnus* (1.525–1.82 m)	Continuous pollen curve of *Carpinus betulus* with max. 3.4 % and *Fagus sylvatica* with max. 3.4 %. Decrease in *Corylus avellana* pollen. The upper boundary: increase in *Carpinus betulus* and decrease in *Corylus avellana* pollen	SB
J18-4 *Corylus-Alnus-Quercus-Tilia* (1.82–2.375 m)	Maximum content of *Corylus avellana* (27 %), *Ulmus* (6 %), *Fraxinus excelsior* (6 %) and *Tilia cordata* t. (4 %). Increase in values of *Quercus* to 21 % and *Alnus* to 18 %. The upper boundary: beginning of percentage curve of *Fagus sylvatica* and *Carpinus betulus*, decrease in *Ulmus* pollen	AT
J18-3 *Corylus-Ulmus* (2.375–2.525 m)	High values of AP. Increase in *Corylus avellana* pollen to 19 %. Decrease in *Pinus sylvestris* t. to 32 %. *Betula alba* t. 35 %, *Ulmus* 4 %. Low pollen values of *Quercus* (3 %) and *Alnus* (1 %). The upper boundary: increase in *Quercus*, *Alnus* and *Tilia cordata* t. pollen	BO
J18-2 *Betula-Pinus* (2.525–3.365 m)	Increase in tree and bush pollen (AP) to 88 %. Rise in *Pinus sylvestris* t. pollen to 72 % and *Betula alba* t. to 48 %. Presence of *Isoëtes* microspores (44 %). The upper boundary: increase in *Corylus avellana* and decrease in *Pinus sylvestris* t. pollen	PB
Subzones		
Corylus-Ulmus-Betula (2.525–2.62 m)	Increase in *Corylus avellana*, *Ulmus* and *Quercus* pollen (to 5 %, 4 % and 2 %) and *Betula alba* t. to 48 %	
Pinus (2.62–2.925 m)	Maximum value of *Pinus sylvestris* t. (72 %)	
Pinus-NAP (2.925–3.365 m)	Rice in *Pinus sylvestris* t. (55 %) and *Betula alba* t. (37 %). Gradual decrease in Poaceae (20-7 %)	
J18-1 NAP (3.365–3.63 m)	High representation of herbaceous plant pollen (NAP), max. 47 %. Predomination of pollen: Poaceae undiff. (31 %), Cyperaceae (20 %) and Artemisia (6 %). *Pinus sylvestris* t. 40 % and *Betula alba* t. 21 %. Recorded pollen: *Pinus cembra* t. (5 %), *Betula nana* t. (1 %) and *Juniperus* (2 %). The upper boundary: decrease of NAP curve	Late Vistulian

An analysis of the remains of old micro-cliffs in the south and west part of the lake revealed that the maximum water level could have reached 272.4 m a.s.l., i.e. 1 m higher than today (Figs. 2a, 2b). In the north and east the former waterline is often indistinguishable. A contour was drawn corresponding to the old waterline, which helped to estimate the maximum water surface of the lake at about 0.32 km^2, or 12 times the present surface area.

Among drillings made within the historic lake bowl that is currently filled with sediment, profile J18 (Fig. 3) was selected as the one offering the best potential for plant remains and palynological analyses.

At its lowest level the J18 well contained various-grained sands with an admixture of silt and clay, as well as trace quantities of organic matter. From a depth of 3.61–3.75 m upwards, clay and silty clay with organic matter are found. Sediments from 3.65 to 3.68 m were radiocarbon dated to 12,000 ± 90 BP, i.e. 12,400–11,600 cal. BC (Ki-13020) (Table 1). No pollen was found. Analyses of samples taken from the entire sediment did not contain any calcium carbonate. The clay and silt layers as well as gyttjas directly above them contain 0.3–1.0 cm thick sandy laminae, as well as scattered grains of sand. They are particularly numerous at depths between 3.45 and 3.75 m. The layer at the depth of 3.55 m was particularly pronounced.

The clay and silt layer becomes rusty in colour when it borders on a sandy lamina, which would suggest higher degrees of iron oxidation. Above this layer is clayey and loamy gyttja as well as fine-detritus gyttja 2.34 m thick with no mineral matter. At the top level these gyttjas are covered with a thin layer of peat formed as a result of a floating mat encroaching

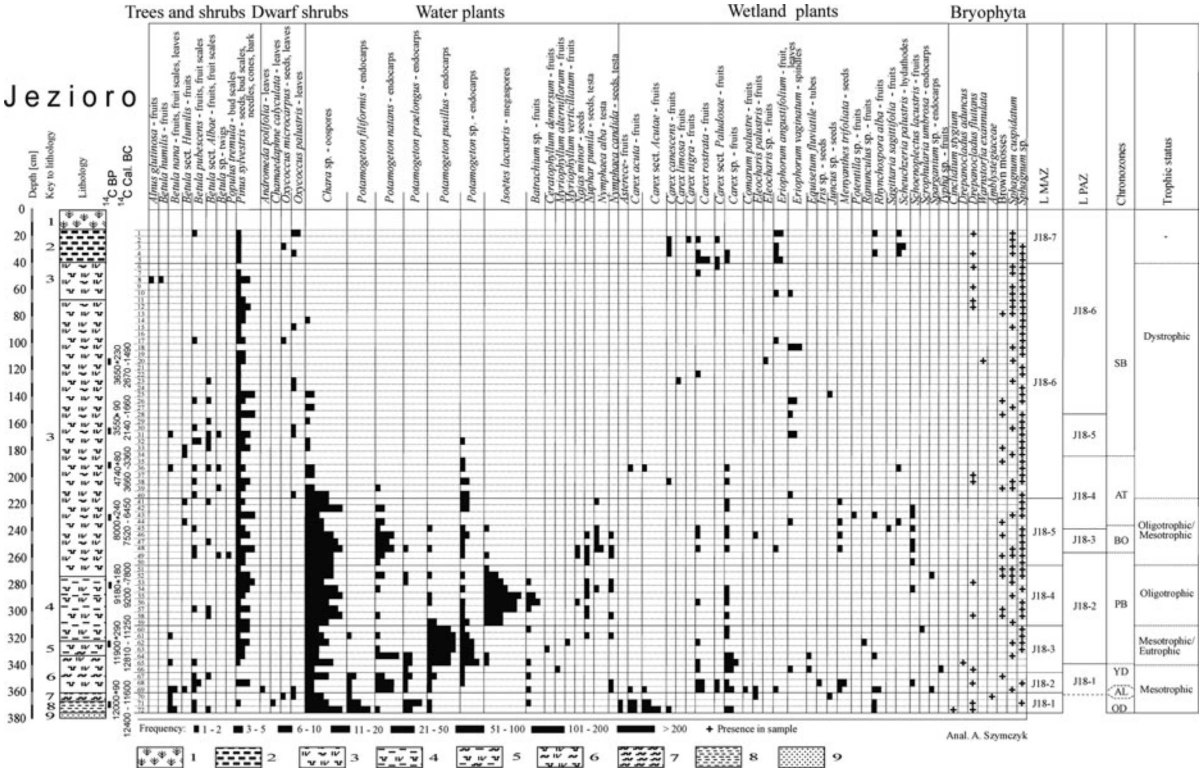

Fig. 4 Plant macrofossil diagram from Jezioro Lake (profile J18): *1* living vegetation, *2* peat, *3* gyttja, *4* clayey gyttja, *5* silty gyttja with laminae of sand, *6* clayey and silty gyttja, *7* clayey silt with laminae of sand, *8* clay and silty clay with laminae of sand, *9* sand with laminae of silt

inwards from the banks. A limnic origin is suggested for the entire deposit series found under the peat layer by the presence of remains of water vegetation and numerous remains of Cladocera and of Chironomidae larvae, which are indicators of lacustrine sedimentation.

The characteristics of the deposits in core J18 are presented in Table 2, and Figs. 4 and 5.

Analysis of plant macroremains

In total, 72 samples were analysed in which 61 plant taxa were recognized. It was possible to identify 43 of these plant taxa down to species (including 5 bryophyte species).

The list of plant macroremains (Fig. 4) enabled the researchers to distinguish 7 local macrofossil assemblage zones (L MAZ) (Table 3).

Within the J18-1 L MAZ level, endocarps of *Potamogeton filiformis* Pers. (26 in sample No. 72) and *P. praelongus* Wulfen were the most numerous among aquatic plant remains. Oospores of *Chara* sp. were also very frequent (more than 900 specimens in sample No. 72). Among rush plant remains, *Carex* nuts were the most numerous. Within this level, trees and shrubs were represented by *Betula* remains (including B*etula nana* L.) and *Pinus sylvestris* L. Fragments of a *Chamaedaphne calyculata* (L.) Moench leaf were also found.

Within the J18-2 L MAZ level, *Potamogeton natans* L. endocarps were the most frequent aquatic plant remains. There were very few *P. praelongus*, *P. filiformis* and *P. pusillus* L. endocarps. Remains of *Nymphaea candida* C. Presl. testa and *Batrachium* sp. fruits were also found. Among rush plant remains, *Carex rostrata* Stokes nuts dominated. *Menyanthes trifoliata* L., *Comarum palustre* L. and *Schoenoplectus lacustris* (L.) Palla seeds were also present. Trees and shrubs were represented by remains of *Pinus sylvestris* and *Betula pubescens* Ehrh. (and *B.* sect. *Albae* L.). A *Betula nana* seed and fruit scale as well as a single *B.* sect. *Humilis* Schrank fruit were also found.

Within the J18-3 L MAZ level, *Potamogeton pusillus* endocarps were the most frequent aquatic plant remains (76 in sample No. 63). *P. natans*, *P. praelongus*, *P. filiformis* endocarps, *Nuphar pumila* (Timm) D.C and *Nymphaea candida* seeds and testa fragments, single *Myriophyllum verticillatum* L., *Myriophyllum alterniflorum* DC. and *Ceratophyllum demersum* L. fruits as well as single *Isoëtes lacustris* L. megaspores were also found. Rush plants were few and mostly represented by *Carex* nuts. Trees were represented by numerous *Pinus sylvestris* bark fragments and *Betula nana* and *B. pubescens* fruits and fruit scales. Single *Rhynchospora alba* (L.) Vahl seeds and *Eriophorum vaginatum* L. spindles were also found.

The J18-4 L MAZ level was made distinct by the presence of numerous *Isoëtes lacustris* megaspores (more than 300 in sample No. 55) and the increase in the number of *Chara* sp. oospores (more than 900 in sample No. 55). Among the remains of vascular aquatic plants, *Batrachium* sp. fruits and single endocarps of *Potamogeton natans*, *P. pusillus* and *P. praelongus* were present. *Najas minor* All., *Nuphar pumila* and *Nymphaea candida* seeds and *Nymphaea alba* L. testa fragments were present as well. Rush plants were represented by *Carex* nuts. Trees were represented by *Pinus sylvestris* bark fragments, bud scales, one *Pinus sylvestris* seed and one *Pinus sylvestris* cone as well as by single *Betula pubescens* and *B.* sect. *Albae* fruits.

Within the J18-5 L MAZ level, numerous *Potamogeton natans* endocarps and *Chara* sp. oospores were found. Single *Potamogeton pusillus* and *P. praelongus* endocarps and *Najas minor*, *Nuphar pumila*, *Nymphaea candida* and *N. alba* seeds were found. Among rush plant remains, *Schoenoplectus lacustris* seeds were the most numerous. *Eleocharis palustris* (L.) Roem. and Schult and *Sagittaria sagittifolia* L. fruits as well as *Carex* nuts, including *C. rostrata*, were also found. Peat plants were, *inter alia*, represented by *Scheuchzeria palustris* L. leaves, *Eriophorum vaginatum* spindles, *Rhynchospora alba* fruits and *Menyanthes trifoliata* seeds. Trees were represented by diverse and numerous *Pinus sylvestris* and *Betula* remains. A single *Populus tremula* L. bud scale was also found.

Within the J18-6 L MAZ level, aquatic plant macroremains were only present in the bottom part. These were *Potamogeton* (among others *P. natans*) endocarps and *Chara* sp. oospores. Rush plants were represented by single *Carex limosa* L., *C. canescens* L., *C. acuta* L. and *C. rostrata* nuts. Among peat plant macroremains, numerous *Eriophorum vaginatum* spindles, *Scheuchzeria palustris* L. leaf remains and *Oxycoccus palustris* Pers. leaves were found. Trees were represented by numerous *Pinus sylvestris* bark fragments and bud scales and *Betula* (including *B. nana*) seeds and fruit scales.

Within the J18-7 L MAZ level, no aquatic plant remains were found. Among macroremains, *Carex* (mainly *C. rostrata*) nuts generally prevailed. *Carex nigra* Reichard, *C. canescens* and *C.* sect. *Paludosae* G. Don nuts were also found. Among peat plants, *Scheuchzeria palustris*, *Eriophorum angustifolium* Honck and *Oxycoccus palustris* leaf remains were found. Trees were represented by rare *Pinus sylvestris* bud scales and *Betula pubescens* fruits.

Pollen analysis

Within the J18-1 L PAZ level, herbaceous and grass communities with *Artemisia*, *Helianthemum nummularium* (L.) Mill. type, *Rumex acetosella* L. were found, sometimes with Chenopodiaceae pollen and *Hippophaë rhamnoides* L. In sandy areas, which are common in the vicinity, *Juniperus* shrubs were found, but also *Betula alba* type and *Pinus sylvestris* type In all 5 % of the pollen found was *Pinus cembra* L., sometimes accompanied by *Larix*. In diverse habitats in the vicinity of the lake, *Salix pentranda* L. and *Populus*, *Betula nana* and *Salix* (*S. polaris* type and *Salix* undiff.) were present (Table 4).

Within the J18-2 L PAZ level, in *Pinus*-NAP subzone a, the percentage of forest species sporomorphs (*Pinus sylvestris* type and *Betula alba* type) increases, while the percentage of open grass communities falls and *Juniperus* disappears. Poaceae and *Artemisia* are still present to some extent.

Within the J18-3 L PAZ level, in *Pinus* subzone b, pine forest dominated in the vicinity, while *Betula alba* type was a sporadic element in the forest. Its percentage only rose in *Corylus*-*Ulmus*-*Betula* subzone c, while the percentage of *Pinus* decreased. *Ulmus* gradually appeared and reached 4 % of pollen in the late *c* subphase.

Within the J18-3 L PAZ level, more significant changes can be seen in the vicinity of Jezioro Lake. Forest species dominate—first *Pinus sylvestris* type and *Betula alba* type, but with *Corylus avellana* L. subsequently becoming increasingly significant, gradually reaching a percentage of 27 %. *Ulmus* also appears with a percentage of more than 6 % alongside *Quercus*.

Within the J18-4 L PAZ level, mixed forest species are present with *Quercus*, *Tilia* (*T. cordata* type and *T. platyphyllos* type), *Ulmus*, *Acer*, *Corylus*, *Fraxinus excelsior* L. and *Alnus*. *Taxus baccata* L. is sporadic. *Corylus* has a significant representation, while there is little *Pinus sylvestris* type and *Betula alba* type pollen (2–3 % in the younger part of the level).

Within the J18-5 L PAZ level, no major changes in vegetation are recorded. *Quercus* is present alongside *Tilia cordata* type, *Taxus*, *Fraxinus*, *Acer*, *Ulmus*, *Alnus* and an admixture of *Corylus*. New components reaching percentages of pollen of respectively 2 and 2.5 % are *Carpinus betulus* L. and *Fagus sylvatica* L. *Picea abies* (L.) H. Karst. constitutes 5 % of pollen.

Within the J18-6 L PAZ level, *Quercus* still dominates and percentages of *Carpinus betulus* and *Fagus sylvatica* increase, while that of *Abies alba* Mill is maintained. *Alnus* is present with a slight downward trend in the upper part of the level. The percentage of *Corylus* decreases, there is little *Ulmus* and *Tilia* (*T. cordata* type) pollen, and the percentage of NAP increases slightly in the upper part of the profile.

Discussion

History of the environmental changes in Jezioro Lake

The results obtained from the analysis of the cores of organogenic sediment and from the geomorphological studies allowed us to reconstruct the Late Vistulian and Holocene history of Jezioro Lake.

An analysis of the bottom sediments found in J18 reveals that they may have begun to accumulate intermittently, but that the Jezioro Lake never entirely disappeared, although its area has decreased by a factor of 12 between its formation and the present day. The water level in the lake was probably lowered as a result of the construction of drainage ditches, not earlier than the end of the eighteenth century, during the period of the so-called Fryderycjanska colonization.

Late Vistulian period

During the Late Vistulian period, two stages of increased aeolian activity in the Older Dryas (i.e. GI-1d) and Younger Dryas (i.e. GS-1) played a considerable role in the development of the land relief in the Liswarta Depression and beyond in the Silesian Upland and in an eastern part of the Silesian Lowland (Szczypek 1977; Waga 1994). During the Older Dryas period, very strong northwestern winds created sand dunes, some of which moved up valleys that opened to the west. Numerous small valleys became blocked and their drainage hampered. This is likely to have been the case with the basin-shaped valley where the Jezioro Lake is found.

The age of layers at 3.65–3.68 m was determined as 12,400–11,600 cal. BC (Ki-13020) (Fig. 4), which indicates that the initial phase of lake development, i.e. the period of clay and partly silty clay accumulation, could reach as far back as the end of the Bölling or the beginning of the Older Dryas. The varied character of the deposits at the base of the core, sand and admixtures of finer mineral material, suggests that its deposition occurred in an environment of variable supply of terrigenous matter. The sources of this material were fluvioglacial and fluvial sediments of the Liswarta Depression, assisted by aeolian processes of the Late Glacial. This is indicated by the abrasion of quartz grains in medium- and fine-grained sands at the base of the sediment. A significant contribution of rounded and matted grains (RM)—14–26 % and transitional grains of EM type—60–68 % is typical. The predominance of grains of RM and EM types, indicates brisk aeolian activity and short sand transport during the period of sedimentation at the base of the profile.

In the early stages of lake development (J18-1 L MAZ; 3.60–3.75 m) (Fig. 4), *Chara* sp., *Potamogeton filiformis* and *Potamogeton praelongus* algae were abundant and *Potamogeton pusillus*, *Potamogeton natans* and *Batrachium* sp. were scarce. The drop in the count of the *P. filiformis* and *P. praelongus* endocarps at a later stage shows that phytocenoses composed of these species declined. The presence, especially in the older profiles, of *Potamogeton filiformis* suggests that the lake was cool and mesotrophic (Velichkevich and Zastawniak 2006; Kolstrup 1979; Matuszkiewicz 2001) with clear water, abundant in $CaCO_3$ (Bennike et al. 1994) and with a pH higher than 7 (Lang 1994).

In lakes situated in areas where carbonates are abundant in sediments (e.g. mesozoic limestone or morainic clays), cycles of increasing concentration of calcium carbonate in profiles usually coincide with warm and wet periods and with intensive development of aquatic vegetation (De Klerk et al. 2008; Lauterbach et al. 2011). In the case of the Jezioro Lake, calcium carbonate is scarce in local sandy-gravelly fluvioglacial and glacial sediments originating from the Oder glaciation. Carbonates are easily removed from this type of sediment (Bukowska-Jania and Pulina 1999). On the other hand, the presence of $CaCO_3$ within the water body is recorded in the composition of aquatic plant species that grew in the lake in the Older Dryas. This apparent chronological anomaly may be explained by the fact that carbonates only began to be supplied in abundance to the water body during the "stormy", cold period of the Old Dryas. They came from soil layers near the surface that underwent soil formation processes during the Bölling period (Kowalkowski 1991). Organic soil particles were probably redeposited at the same time, which may explain the presence of material dated to 12,000 ± 90 BP, i.e. 12,400–11,600 cal. BC (Ki-13020) in the sediments of the J-18 profile (correlated with Older Dryas). A similar phenomenon whereby carbonates were redeposited has been observed in Lake Perespilno in eastern Poland. An increase of $CaCO_3$ content in the early Younger Dryas section of the sediments from the lake was an effect of the drop in the groundwater level which stimulated the oxidation of soils in the lake catchment (Goslar et al. 1999). During the late Older Dryas/early Alleröd period the phase when sediments were enriched with $CaCO_3$ was more clearly recorded, inter alia, in Karaśne Lake sediments in eastern Poland (Bałaga 2007).

The water clarity of Jezioro Lake is evidenced by the development of chlorophyta of the genus *Pediastrum*. At the time, the most numerous were colonies of *Pediastrum boryanum* var. *boryanum* (Turp.) Meneghini, characterised by its wide ecological spectrum. Two other species, i.e. *P. duplex* var. *rugulosum* Raciborski, considered indicative of large and sparsely vegetated lakes (Komárek and Jankovská 2001), and *Pediastrum boryanum* var. *longicorne* Reinsch, known to prefer dystrophic waters (Komárek and Jankovská 2001), were less numerous.

A complex of moss and sedge communities, probably still of an initial nature, developed on the banks. Among the species present, the major role was played by *Rhynchospora alba* represented mainly by numerous bracts and far fewer seeds. Other plants included *Carex canescens* and mosses, including *Cinclidium stygium* Sw. noteworthy for its cold-climate associations (Kłosowski and Kłosowski 2006). Subshrubs were represented by *Chamedaphne calyculata* (L.) Moench and *Oxycoccus palustris*. Isolated stands of *Betula nana* could also be found. Reedbeds consisted mainly of *Carex acuta.* There were also some minor phytocenoses of *Eleocharis palustris* and clumps of *Juncus* on the banks.

The decline of phytocenoses consisting of *Potamogeton filiformis* and of the *Chara* sp. algae (J18-2 L MAZ; 3.45–3.60 m) correlated with a growth in importance of *Potamogeton natans* and *Nymphaea candida*. A regression of *Potamogeton filiformis* with a simultaneous broad expansion of *Potamogeton natans*, a species that often appears at the onset of eutrophication (Arts et al. 1990), would suggest a slight trend towards more eutrophic conditions. However, the most likely cause of the change observed was a drop in $CaCO_3$ concentration and a decline of pH. Within the Jezioro Lake catchment, which mostly includes varieties of silicate, the carbonates that could be leached and subsequently redeposited were exhausted relatively quickly. This is corroborated by the presence of *Nymphaea candida* which is known in modern times to reach its optimum in mesotrophic water bodies low in calcium, and the appearance of species often associated with the littoral zone of inter-bog lakes and with acid bogs, including *Menyanthes trifoliata* and *Comarum palustre* (Kłosowski and Kłosowski 2006).

In reedbed communities the dominating *Carex acuta* began to give way to the spreading *Carex rostrata.* New reedbed species included *Schoenoplectus lacustris*, *Iris* sp., *Sparganium* sp. and *Equisetum* sp., the existence of the latter supported by the presence of its spores. The proportion of remains of *Sphagnum* sp., which is higher than at lower levels, and the presence of *Andromeda polifolia* L. together with the presence of *Betula nana* suggest a continued development of fen in the banks of the lake. The occurrence of mixed-species reedbeds, including *Carex rostrata*, and the development of floating-leaved plants would suggest a shallow lake, the waters of which might become humified as a result of the surrounding fens.

In the youngest profile of J18-2 L MAZ there is a change to the species composition in the lake vegetation that suggests a change in the habitat conditions.

The importance of *Chara* sp. increased again at the expense of floating-leaved plants. At the time, according to pollen analysis, the lake floristic diversity increased with the occurrence of *Myriophyllum spicatum* L. and *Isoëtes lacustris*. A lack of macro-sized remains of reedbed and fen plants indicates that their phytocenoses had undergone a considerable regression. This change suggests rising water level together with increasing oligotrophy.

At 3.55 m a thin layer of sand appears confirming a restart of more intensive aeolian processes. During the Younger Dryas, numerous old dunes were blown out. Newly formed dunes often stopped at vegetation barriers (Waga 1994). This could explain the raising of the water level in the Jezioro Lake.

In addition this part of the J18 profile (the upper profile of the J18-1 NAP L PAZ; 3.365–3.63 m) was correlated with the Younger Dryas in the palynological record (Figs. 4, 5) due to the occurrence of pine and birch pollen spectrums with *Betula nana* type, *Salix polaris* Wahlenb. type and *Juniperus*, as well as a high concentration of Poaceae, Cyperaceae and *Artemisia* comparable with well dated cores from Wolbrom (Latałowa 1989) and Jaworzno (Szczepanek and Stachowicz-Rybka 2004) nearby. Also noteworthy is a high proportion of chlorophyta of the genus *Pediastrum*, which is characteristic of late glacial sediments (Leroy et al. 2000; Komárek and Jankovská 2001; Sarmaja-Korjonen et al. 2006).

The boundary between the Late Glacial (Younger Dryas) and the Holocene (Preboreal chronozone) periods is identified by a drop in non-arboreal pollen (NAP) and *Betula nana* type pollen and an increase in pollen counts of *Pinus sylvestris* type and *Betula alba* L. type. Criteria adopted in identifying this boundary are compatible with criteria adopted for other Polish core profiles (Ralska-Jasiewiczowa and Latałowa 1996).

Preboreal chronozone

Sediments of the J18-2 L PAZ *Pinus-Betula* level (2.525–3.365 m) were correlated with the Preboreal chronozone (Fig. 5), as pine-birch pollen spectra, containing also small proportions of Poaceae and *Artemisia*, are typical for the period (Ralska-Jasiewiczowa and Latałowa 1996, Latałowa 1989). In the initial phase of sediment accumulation in the bottom section of the J-18 profile, older humus, which contained little plant pollen, could have been brought in from adjacent areas by wind or water. For these reasons the radiocarbon dating (11,900 ± 290 BP, i.e. 12,810–11,250 cal BC) carried out for fine-detritus sediments found at 3.22–3.25 m was regarded as controversial and was excluded from the paleoecological analysis (Nita and Szymczyk 2010). The age of sediments in this level, at a depth of 2.78–2.85 m, is better described as 9,180 ± 180 BP, i.e. 9,200–7,800 cal BC.

During the early Preboreal chronozone (the middle and upper profile of J18-3 L MAZ; 3.10–3.45 m) the lake was dominated by phytocenoses with *Potamogeton pusillus*, although initially their contribution was small. At the time, phytocenoses consisting of *Myriophyllum spicatum* played the leading role as evidenced by the increased occurrence of its pollen. There was also *Potamogeton praelongus*, as well as *Myriophyllum alterniflorum* regarded as an indicator of water acidity (Vöge 1988, 1993; Arts 2002; Arts et al. 1990; Eriksson et al. 1983). Its presence indicates a water low in $CaCO_3$ with a pH below 6 (Brandrud 2002).

A subsequent drop in the occurrence of *Myriophyllum spicatum* pollen indicates that its phytocenoses declined in significance as they were replaced by communities including *Potamogeton natans* and then *P. pusillus*. *Ceratophyllum demersum* also appeared in the lake. The dominance of *Potamogeton pusillus* and the presence of *Ceratophyllum demersum*, as well as the expansion of *Potamogeton natans* earlier on, make it plausible that the level of nutrients in the lake became probably the highest in the lake's history. Species which are typical for mesotrophic lakes, e.g. *Myriophyllum verticillatum*, *Nymphaea candida* and *Nuphar pumila*, appear in the youngest profile of the horizon. These species would suggest that the lake water became more oligotrophic again. Numerous colonies of *Pediastrum*, primarily *P. boryanym* var. *boryanym*, continue to be present in the lowest profile attributed to the earliest period of the Preboreal chronozone, but then their significance declined rapidly. Reedbed communities began to re-establish themselves along the banks, but their species composition changed and diversity decreased. In the lowest profile of the horizon *Carex* species, including *Carex rostrata*, played a significant role, while only a minor role was played by *Typha* sp., *Phragmites australis* (Cav.) Trin. ex Steud., *Equisetum fluviatile* and *Cladium mariscus* (L.) Pohl. The occurrence of

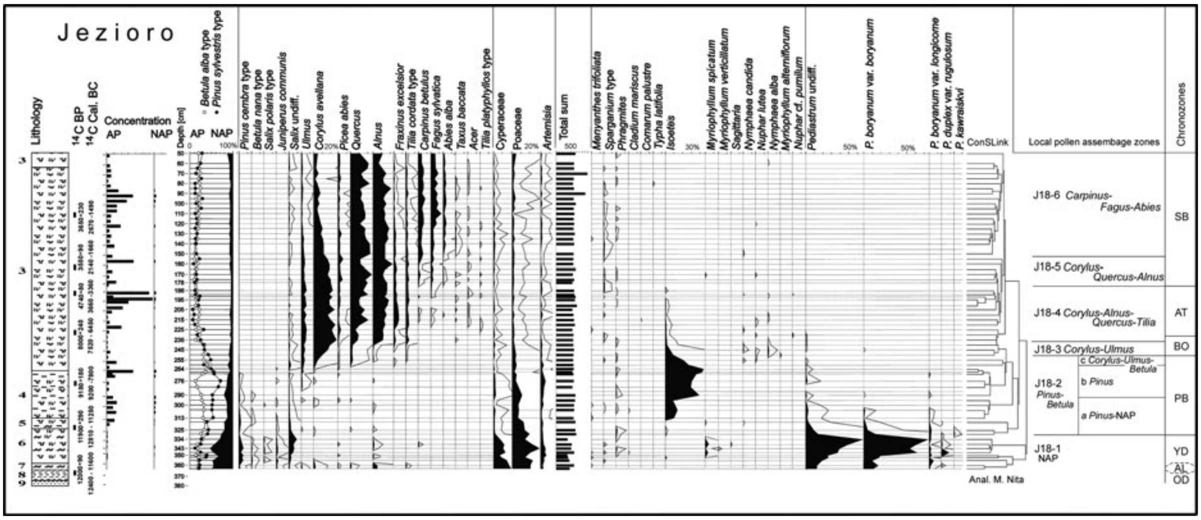

Fig. 5 Simplified pollen diagram from Jezioro Lake (profile J18). Key to lithology as on Fig. 4

C. mariscus, which is currently normally found in reedbeds of mesotrophic lakes and less frequently in oligotrophic or dystrophic lakes (Kłosowski and Kłosowski 2006), may confirm a lower water level at that stage. The appearance on the banks of more temperature demanding species such as *Typha* sp. (Kolstrup 1979; Isarin and Bohncke 1999) indicates better climatic conditions.

Initially, the fen surrounding the lake consisted primarily of *Eriophorum vaginatum* and *Rhynchospora alba*. The lack of *Sphagnum* remains and of characteristic subshrubs in the oldest section of the horizon may mean that the fens were of loose, clump-like nature. Mosses only appear to gain in significance in the fen in a younger profile of the level.

Significant changes to the Jezioro Lake biocenosis occurred in the oldest profile of the level (J18-4 L MAZ; 2.65–3.10 m). Phytocenoses with *Potamogeton pusillus* declined while *Isoëtes lacustris*, a species represented here by mega and micro spores, expanded rapidly. It reached its maximum count in the middle of the horizon. The advent of *Isoëtes* brought with it a disappearance of *Pediastrum* and an increased role of *Chara* sp. algae. Small numbers of *Potamogeton praelongus*, *Najas minor* and *Batrachium* sp. were found, and in shallower sections *Potamogeton natans*, *Nuphar pumila*, *Nymphaea candida*, were also found as well as, at a later stage, *Nymphaea alba.*

The expansion of *Isoëtes lacustris* suggests a trend towards oligotrophy and the beginning of a soft-water oligotrophic lake phase. The water could have had an acidity similar to modern-day lakes with similar phytocenoses at 5–6.5 pH (Arts 2002). In the youngest profile of the horizon there was a breakdown in the population of *Isoëtes lacustris* and an expansion of *Potamogeton natans*. This signifies yet another change in the habitat conditions at the end of the Preboreal and beginning of the Boreal periods.

Reedbed vegetation was probably poorly developed and did not form a continuous strip. The prime roles were played by *Phragmites australis* and *Carex* sedges. The lack of any remains of fen-specific vascular plants means that the fen lobes existing at the time on the banks of the lake had severely deteriorated.

In the upper profile of the horizon (subhorizon J18-2c L PAZ *Corylus-Ulmus-Betula*) pollen of *Corylus* increased to 5 % and of *Ulmus* to 4 %, which suggests that the sediments date back to the transition between the Preboreal and Boreal chronozones (Miotk-Szpiganowicz et al. 2004).

Boreal chronozone

Accumulation of homogenous fine-detritus gyttja without any soil-forming admixture (J18-5 L MAZ; 2.15–2.65 m) (Fig. 4) reflects stabilised sedimentation conditions in the lake. At this horizon *Isoëtes lacustris* was only sporadic. One of the possible causes for its regression could be an expansion of communities involving *Potamogeton natans* and other floating-leaved plants (*Nuphar pumila*, *N. lutea* Sm., *Nymphaea alba* and *N. candida*). As they grew, they left the bottom in the shallow parts of the lake in their shadow thus possibly eliminating *I. lacustris* from its previous habitats. Submergent macrophytes were sparsely represented by *Potamogeton pusillus*, *P. praelongus* and *Najas minor*. The presence in the lake of species typical of oligotrophic waters (*Isoëtes lacustris*), mesotrophic waters (*Najas minor*, *Nuphar pumila* and *Nymphaea candida*) and plants with wider ecological spectrums (*Potamogeton pusillus* and *Nymphaea alba*) leads to the conclusion that the lake water was low in calcium carbonate and mesotrophic.

Reedbeds were expanding with *Phragmites australis*, *Schoenoplectus lacustris* and *Carex* plants playing a significant role. Other species included *Eleocharis palustris*, *Sagittaria sagittifolia* together with the *Equisetum* sp. and *Sparganium* sp. found in pollen analysis. The expansion of varied reedbed communities and the growth of floating-leaved plants may indicate a shallowing phase in the lake, possibly as a result of gyttja sedimentation.

A comparison of pollen curves from the J18-3 L PAZ *Corylus-Ulmus* profile and the floor profile of the J18-4 L PAZ *Corylus-Alnus-Quercus-Tilia* (1.82–2.375 m) with the curves from Wolbrom (Latałowa 1989) and Jaworzno (Szczepanek and Stachowicz-Rybka 2004) helps to correlate the former two with the Boreal chronozone. The evidence that leads to this conclusion mainly includes the high pollen counts of *Corylus* (27 %) in the J18-3 L PAZ horizon and the existence of continuous pollen curves of *Quercus* and *Alnus* in the single percentage range.

The boundary between the Boreal and Atlantic chronozones in the profile studied is marked by the radiocarbon date of 8,000 ± 240 BP (at a depth of 2.26–2.29 m) and by a marked increase in the pollen of *Quercus*, *Alnus* and *Tilia cordata* Mill. type in an underlying sample at 2.35 m. A comparison with other Polish sites (Latałowa 1989; Ralska-Jasiewiczowa et al. 2004) would suggest that these sediments belong to the Atlantic chronozone.

Atlantic chronozone

In a younger part of the zone J18-5 L MAZ (2.15–2.65 m), correlated with the Atlantic chronozone (Fig. 4), the lake plant life is clearly less abundant. The only phytocenoses of high significance include those composed of the *Chara* sp. algae accompanied with sparse occurrence of *Potamogeton natans*, *Nymphaea alba* and *Nuphar lutea*.

The surrounding fen grew extensively, as is evident from the existence of species such, as *Rhynchospora alba*, *Scheuchzeria palustris*, and *Eriophorum vaginatum*. Other species included *Menyanthes trifoliata*, *Comarum palustre* and *Potentilla* sp. The appearance of *Menyanthes trifoliata* communities, probably in the contact zone between the fen and the lake water, suggests that towards the end of the accumulation of this horizon the fen expanded, by the extension of floating mats, and the lake underwent a process of progressive dystrophy. The dating of the sample from the depth of about 1.90 m (4,740 ± 80, i.e. 3,660–3,360 cal BC) suggests that these sediments had already accumulated during the Subboreal chronozone.

According to palynological assessment, the boundary between the Atlantic and Subboreal chronozones, which coincides with the upper boundary of the J18-4 L PAZ Corylus-Alnus-Quercus-Tilia (1.82–2.375 m), is marked by a decline in the pollen of *Ulmus* and the beginning of a continuous percentage curve of *Carpinus* and *Fagus* (Nita and Szymczyk 2010), similar to that occurring in other profiles from this part of Poland (Latałowa 1989; Szczepanek and Stachowicz-Rybka 2004).

Subboreal chronozone

Palynological analysis and an analysis of macro-sized remains show that during the Subboreal chronozone (J18-6 L MAZ excluding the oldest profile; 0.40–2.15 m) (Fig. 4), the shallowest profile of the lake was only populated by communities containing *Nuphar lutea* and phytocenoses based on *Chara* sp. A growing proportion of remains of *Sphagnum* sp. and the occurrence of species such, as *Carex limosa*, *Eriophorum vaginatum*, *E. angustifolium*, *Scheuchzeria palustris* and *Oxycoccus palustris* attests to a continued development and expansion of fen phytocenoses and the growth of floating mats that gradually encroached on the lake. This is also confirmed by the decline of reedbed communities composed of *Phragmites australis*, *Sparganium* sp. and *Typha latifolia* L. which are underrepresented here. The expansion of fen was accompanied by a progressive dystrophy of the lake.

The correlation of the J18-6 L PAZ *Carpinus-Fagus-Abies* (0.50–1.525 m) with the Subboreal chronozone proposed by Nita and Szymczyk (2010) is confirmed by radiocarbon dating of sediments at about 1.65 m (at 3,550 ± 90, i.e. 2,140–1,660 cal BC) and at about 1.20 m (at 3,650 ± 230, i.e. 2,670–1,490 cal BC).

Sediments of the youngest horizon (J18-7 L MAZ; 0.15–0.40 m), represented by peat, show that in the part of the lake where the profile was taken, the expanding floating mats filled the lake completely and fen flourished with species, such as *Eriophorum vaginatum*, *E. angustifolium*, *Rhynchospora alba*, *Scheuchzeria palustris*, *Oxycoccus microcarpus* Turcz. ex Rupr. and *O. palustris*.

Conclusions

The rich fossil material, including pollen and macro-sized plant remains, demonstrates that the accumulation of deposits in the Jezioro Lake has continued ever since its beginning in the Late Glacial period. Research carried out on macroremains allows demonstrated 7 phases of development of Jezioro Lake, depending on the composition of the phytocoenoses present on the site, degree of eutrophication, and pH-reaction.

The lake sediments also contain a record of extreme geomorphologic activity, i.e. two periods of aeolian activity. The accumulation of sands at the mouth of the valley made the original development of the lake possible. The existence of sandy layers on the bottom of the existing water body and the presence of a sizable parabolic dune retaining the lake to the west seem to point to the cause of the increase in the water level during the Younger Dryas.

The lithological and paleobotanical record found in the sediments, which is continuous since the Younger Dryas, makes this site important for the history of the Holocene in southern Poland and beyond.

During the Holocene, the Jezioro Lake watershed was not deforested, and the water balance of the lake did not change at least until the so-called Fryderycjanska colonization (late eighteenth century). The transformation related to colonisation was limited, however, because no significant traces of anthropogenic influence have been found in the profiles, perhaps because settlement in the vicinity proved unsuccessful.

Throughout the Holocene, the forest and the fen that surrounded the lake played an important role from the point of view of its water and shores, forming biogeochemical buffers that enabled certain species to survive for a long time, *inter alia Isoëtes lacustris* (until the end of the Atlantic chronozone) and *Betula nana* (until the beginning of the Subboreal chronozone). The dystrophication process affecting the lake started during the Atlantic chronozone.

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