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Vegetation changes in the Jezioro Lake on the background of the Holocene history of forests, Woźniki-Wieluń Upland, Poland

MAŁGORZATA NITA and ARTUR SZYMCZYK

Department of Earth Sciences, Silesian University, Będzińska 60, 41-200 Sosnowiec, Poland;
e-mail: malgorzata.nita@us.edu.pl, aszymczy@us.edu.pl

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ABSTRACT. The results of pollen and macrofossil analysis of organic deposits from the Jezioro Lake site are described here. It is one of a few sites in the Silesian-Cracovian Upland where almost complete transformation of vegetation at the end of Vistulian (Younger Dryas) and Holocene were recorded (i.e. from the Preboreal to the Subboreal). Six local pollen assemblage zones record vegetation transformations from the open assemblages of Younger Dryas herbaceous, through older Holocene birch-pine, to multispecies deciduous forest vegetation of the Atlantic and Subboreal chronozones. It is also the only natural water body (apart from ox-bow lakes) in the Woźniki-Wieluń Upland that is protected by law as an ecological site. The analysis of plant macrofossils (7 local macrofossil assemblage zones) made it possible to study the development of aquatic and rush vegetation and trophic transformations. The oligotrophic character of the lake at the beginning of the Preboreal is denoted by numerous micro- and megaspores of *Isoëtes lacustris*.

KEYWORDS: pollen analysis, plant macrofossils, Holocene, Woźniki-Wieluń Upland, Poland

INTRODUCTION

The Silesian-Cracovian Upland is a region where only a few sites representative of the late Pleistocene and Holocene have been described, most of them represent sedimentary series deposited during short time intervals. Deposit series containing complete litostratigraphic sequences are particularly valuable for interpretation of environmental change throught time. In the late 1990s, the profiles from Bąków (Mamakowa 1997) and Bronów (Granoszewski 1998) were studied using pollen analysis, but the full results of these investigations have not been published yet. The only site in the Silesian Upland which contains a complete record of environment change since the Allerød is located in Jaworzno (Szczepanek & Stachowicz-Rybka 2004). At Wolbrom, in the southern part of Kraków-Częstochowa Upland, the oldest peat deposits were dated at 12 340 ± 160 ^{14}C BP (Latałowa & Nalepka 1987).

During the investigations carried out in the Woźniki-Wieluń Upland, one of the water reservoirs appeared to have a natural origin (Czylok et al. 2004). This lake is located about 80 km north of Jaworzno at Jezioro near Herby (Fig. 1). Drilling has revealed a sedimentary sequence 3.75 m thick. C^{14} dating revealed that the oldest of these sediments is late Vistulian. A preliminary analysis of plant macrofossils revealed a great floral diversity. This also showed that the lake underwent several phases of development since its initiation in the late Vistulian (Czylok et al. 2004). This started multi-field investigations aiming to reconstruct changes taking place in the environment and to explain the origin of the lake. The aim of this paper is to describe the vegetation transformations at Jezioro Lake on the basis of pollen analysis and plant macrofossil research.

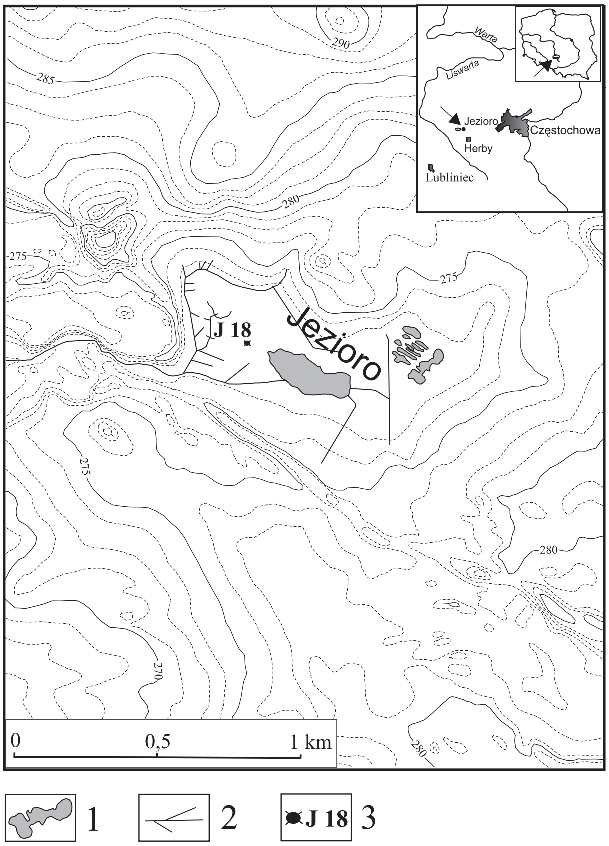

Fig. 1. Topographical map of the studied area. Explanations: **1** – water body, **2** – drainage ditch, **3** – location of profile J18

DESCRIPTION OF THE JEZIORO LAKE AND ITS SURROUNDINGS

Jezioro Lake, an inner-forest lake (18°50′E, 50°47′N) is located in the Woźniki-Wieluń Upland at the border of two geomorphological units – the Liswarta Depression and the Herby Escarpment (Kondracki 2000). It is situated in the Herby Forest, about 0.5 km west of the village Jezioro, within the catchment of the Upper Liswarta. A series of organic sediments (Tab. 1) is overlain by clayey sand with an admixture of trace amounts of organic matter. In the deposit floor, there is clay and silty clay covered by clayey silt, which contain sand intercalations 0.3–1.0 cm thick.

The neighbourhood of the Jezioro Lake (Fig. 2) is covered by gravel-sandy fluvioglacial deposits of Odranian glaciations age (Haisig et al. 1983) These are part of the fluvioglacial plain which runs along the Liswarta valley at a height of 250–280 m a.s.l. Small depressions filled with alluvium or peat considered as kettle holes occur locally within the plain (Haisig et al. 1983). Aeolian dunes 2.5–5.0 m high are present to the W, S and SE of the lake. These are of late Vistulian and Holocene (Boreal) age (Szczypek 1977).

The Jezioro Lake, apart from the ox-bow lakes, is the only natural body of standing water within Woźniki-Wieluń Upland. At the end of the Vistulian, the existing lake outlet became dammed by a parabolic dune that came from the west and stopped at the lake shore (Czylok et al. 2004). Most of the lake's catchment area was covered by forest, with this largely stabilised water balance of the lake. In the period of intensive settlement development, mostly in the 18th and 19th century, local residents tried to de-water a peatbog adjacent to the lake in order to convert it into agricultural land (Czylok et al. 2004). However, these measures failed and, in the eastern part of the peatbog, exploitation of peat for fuel use commences. A peat layer, 2.5 m thick, was excavated leaving many post-excavation holes. Afforestation was introduced in some places. Sedimentation of the former lake basin resulted in a decrease of the area of the lake's water surface which is now 12 times smaller than it used to be. It is now 2.66 ha (Czylok et al. 2004) and it is located at the height of 271.4 m a.s.l. Water is discharged from the lake by a system of artificial drainage

Table 1. Description of organic sediments acc. to Troels-Smith (1955)

Depth (m)	Description of sediment
0.15–0.40	Poorly decomposed peat with the dominance of *Eriophorum angustifolium* $Th_{Erioph}^{1}4$. Nig.2, sicc.3, elas.2, strf.0, lim. sup.1
0.40–0.68	Gyttja Ld2, Sh1, $Tb^{1}_{Sph}1$, Dg+. Nig.2, sicc.2, elas.2, strf.0, lim.sup.1
0.68–2.74	Gyttja with small detritus Ld3, Dg1, Sh+, $Tb^{1}_{Sph}+$. Nig 3, sicc.2, elas.2, strf.1, lim.sup.1
2.74–3.37	Clayey gyttja Ld3, As1, Dg+. Nig.2, sicc.2, elas.2, strf.0, lim. sup.0
3.37–3.61	Silty and clayey gyttja Ld3, Ag1, As+, Ga+, Dh+. Nig.2, sicc.2, elas.1, strf.3, lim.sup.0 with thin laminae of sand Ga4. Nig.1, sicc.2, elas.0, strf.0, lim.sup.3
3.61–3.72	Silt Ag4, Ga+. Nig. 2, sicc.2, elas.2, strf.3, lim. sup.3 with laminae of sand Ga4. Nig.1, sicc.2, elas.0, strf.0, lim.sup.3
3.72–3.75	Silty clay As3, Ag1, Ga+. Nig.2, sicc.2, elas.2, strf. 2, lim. sup.3 with laminae of sand Ga4. Nig.1, sicc.2, elas.1, strf.0, lim.sup.3

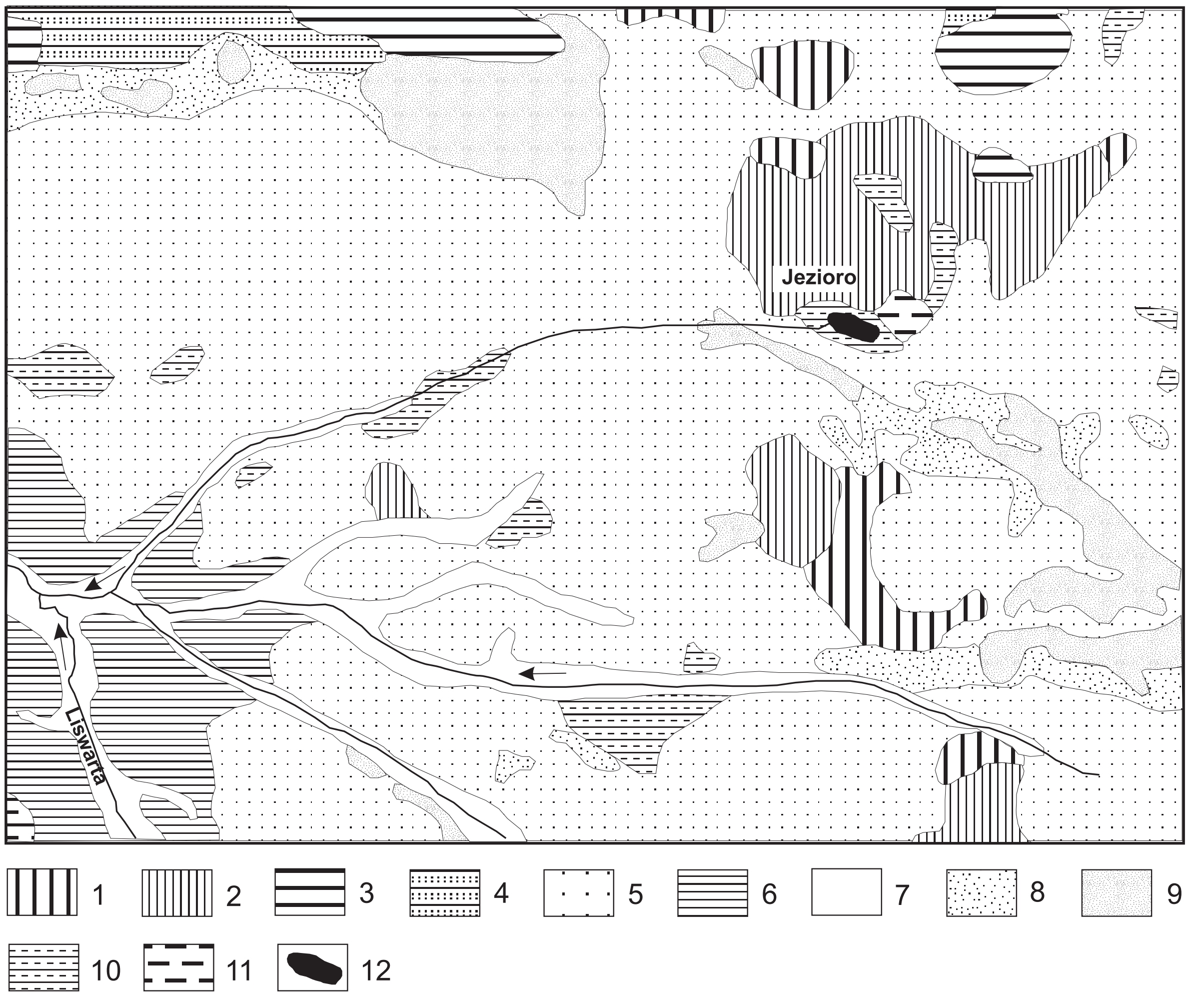

Fig. 2. Simplified geological sketch of the neighbourhood of Jezioro Lake site (acc. to Haisig et al. 1983). Explanations: **1** – till, **2** – glacial sand and gravel, **3** – silt, sand and kame gravels, **4** – kame terrace sand, **5** – fluvioglacial sands and gravels, **6** – fluvial sand and gravel of overflood terraces, **7** – fluvial sand and gravel of valley floors, **8** – aeolian sand, **9** – aeolian sand in dunes, **10** – warp, **11** – peat, **12** – water body

ditches to a tributary of the Turza river, then discharges into the Liswarta. At present, the Jezioro Lake is a shallow dystrophic pond with a well developed floating mat. Its depth at this zone is about 1 m. The upper layer of the bottom deposit is considerably hydrated. The vegetation around the lake shows a typical concentric pattern. It contains vegetation communities which are unique for the Silesian province and rare for Poland. The most valuable include patches of mesotrophic and oligotrophic peat vegetation (from the order *Sphagnetalia magellanici* (PAWŁ. 1928) MOORE (1964) 1968 and from the class *Scheuchzerio-Caricetea nigrae* (NORDH. 1937) R.TX. 1937, as well as communities *Vaccinio uliginosi-Betuletum pubescenti* LIBBERT 1993 and *Vaccinio uliginosi-Pinetum* KLEIST 1929. There are many sites of rare and protected species around the lake. Because of its natural value, the Jezioro Lake and its surrounding area are located within a Landscape Park "Forests over the Upper Liswarta"; it is also a protected ecological site. The following species are observed here: *Oxycoccus palustris, Andromeda polifolia*, *Drosera rotundifolia*, *Eriophorum vaginatum*, *E. angustifolium*, *Carex limosa*, *Rynchospora alba*, and *Ledum palustre*.

Limnic genesis of deposit series underlying a thin peat cover is documented by the permanent presence of Cladocera remains and Chironomidae larvae. An initial phase of the lake development, which represents the period of clay and silt accumulation, is of Younger Dryas age, confirmed by the character of the vegetation assemblage. Differentiation of the basal deposits with their insertions of various sand layers, suggests that deposition occurred in the environment of differentiated sedimentation conditions and with a large supply of terrigenic material, the source of which was probably aeolian deposits. Sedimentation took place in Late Glacial time (Szczypek 1977).

METHODS

The core (J18) was obtained with the use of a sounder Instorf Ø 80. The samples for pollen analyses (1 cm^3) were macerated with 10% KOH, 10% HCl, $ZnCl_2$ and subjected to Erdtman's acetolysis (Faegri & Iversen 1989). Two *Lycopodium* indicator tablets were added to each sample prior to maceration. The basis of calculation was the total of trees and shrubs (AP) and also herbaceous plants and dwarf shrubs (NAP). Most of the pollen spectra were counted to include at least 500 AP grains, except for 5 samples, in which, because of low frequency, the AP total was smaller, but always above 400. The results are shown on a pollen diagram, prepared with the application of a computer software POLPAL (Nalepka & Walanus 2003).

The analysis of macrofossils was carried out in samples of the volume of 100 cm^3 taken from the core every 5 cm. In order to separate the remains, the deposit was washed using a 0.2 mm sieve. The macroremains were observed using a binocular microscope. The results are presented in the form of a diagram of plant macrofossils (as the total number of specimens per sample) including 8 ranges of remains content. The species names are after Mirek et al. (1995), and the vegetation communities according to Matuszkiewicz (2001).

RADIOCARBON DATING

Five samples of organic deposits from Jezioro profile were dated by means of ^{14}C method (Tab. 2). These analyses were made in the Kyiv Radiocarbon Laboratory and Radiocarbon Laboratory, Institute of Physics in Gliwice.

POLLEN AND PLANT MACROFOSSIL STRATIGRAPHY

Pollen analysis was applied to 64 samples of organic sediments. The pollen diagram is divided into 6 local pollen assemblage zones – L PAZ (Tab. 3, Fig. 3) according to Birks (1986) and Janczyk-Kopikowa (1987) and supported by numerical analysis (ConSLink). Chronozones were distinguished on the basis of the convention proposed by Mangerud et al. (1974). In 72 sediment samples examined for macrofossil remains 61 taxa were determined, including 43 species. Seven local macrofossil assemblage zones (L MAZ) were determined (Tab. 4, Fig. 4).

VEGETATION CHANGES IN THE LATE GLACIAL AND HOLOCENE

The results of pollen and plant macrofossils analysis make it possible to reconstruct the history of terrestrial vegetation in the vicinity of Jezioro Lake and study changes of the aquatic environment there.

YOUNGER DRYAS (J-1 L PAZ; J-1 L MAZ, J-2 L MAZ, BOTTOM PART OF J-3 L MAZ)

The history of the vegetation as recorded in the organic deposits from Jezioro Lake started in the time when open communities predominated (J-1 NAP L PAZ). They mainly included herbaceous and grass communities with participation of *Artemisia* and some other heliophilous plants (e.g. *Helianthemum nummularium* t., *Rumex acetosella*, occasionally Chenopodiaceae pollen) and *Hippophaë rhamnoides*. Dry, sandy habitats were also suitable for *Juniperus* shrubs. The not very low contents of *Betula alba* t. and *Pinus sylvestris* t. pollen in the spectra evidently indicate the

Table 2. Radiocarbon dates from Jezioro Lake site: **Gd** – Radiocarbon Laboratory, Institute of Physics, Gliwice, **Ki** – Kyiv Radiocarbon Laboratory

Lab. No.	Depth [cm]	Age ^{14}C BP	Calibrated age range 68%	Calibrated age range 95%
Gd-30175	113–116	3650 ± 230	2400 (1.0%) 2380 cal BC 2350 (67.2%) 1740 cal BC	2840 (0.4%) 2810 cal BC 2670 (94.6%) 1490 cal BC 1480 (0.4%) 1450 cal BC
Gd-30176	226–229	8000 ± 240	7300 (1.7%) 7270 cal BC 7260 (2.5%) 7220 cal BC 7200 (63.6%) 6630 cal BC 6620 (0.3%) 6610 cal BC	7520 (95.4%) 6450 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

Lab. No.	Depth [cm]	Age ^{14}C BP	Age ^{14}C BC/AD
Ki-13019	342–345	12 450 ± 90	13 000–12 200 BC 13 500–12 100 BC
Ki-13020	365–368	12 000 ± 90	12 340–11 860 BC 12 400–11 600 BC

Table 3. Description of local pollen assemblage zones (L PAZ)

L PAZ		Description
J-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.
J-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.
Subzones	*Pinus*-NAP (2.925–3.365 m)	Rice in *Pinus sylvestris* t. (55%) and *Betula alba* t. (37%). Gradual decrease in Poaceae (20–7%).
	Pinus (2.62–2.925 m)	Maximum value of *Pinus sylvestris* t. (72%).
	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%.
J-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.
J-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.
J-5 *Corylus-Quercus-Alnus* (1.525–1.82 m)		Continuous pollen curve of *Carpinus betulus* with max. 3.4% and *Fagus sylvatic*a with max. 3.4%. Decrease in *Corylus avellana* pollen. The upper boundary: increase in *Carpinus betulus* and decrease in *Corylus avellana* pollen.
J-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.

presence of these trees in the landscape, what is confirmed by quite numerous macroscopic remains (J-1 L MAZ, J-2 L MAZ). The contents of pollen reaching 5% indicate the presence of *Pinus cembra*, accompanied sometimes by *Larix*. The landscape around the lake was diversified, with some growth of *Salix pentranda* and *Populus*. Near the site, patches of bush tundra with *Betula nana* and *Salix* (*S. polaris* t. and *Salix* undiff.) occurred.

Dates from ^{14}C analysis, made from deposits of floor part of the profile, are turned and therefore they do not seem to be credible. The lower date determines the age of deposits from 12 000 ± 90 BP (depth of 3.65–3.68 m), whereas the upper date determines the age to be from for 12 450 ± 90 BP (depth of 3.42–3.45 m). In the lower sample no pollen was recovered, but pollen spectrum of deposits taken from the upper sample can be correlated with the Younger Dryas, on the basis of comparison with precisely dated profile from Wolbrom (Latałowa 1989). Such correlation is also proved by similarities in the course of pollen curves from J-1 NAP L PAZ and horizons of other Polish profiles correlated with this chronozone (Ralska-Jasiewiczowa & Latałowa 1996).

In the formation time of the lake (J-1 L MAZ), its deep water was dominated by algal assemblages of the *Charion fragilis* KRAUSH 1964 alliance, typical for early stages of the succession (Matuszkiewicz 2001). The assemblage of *Potametum filiformis* KOCH 1926, with a large representation of *Potamogeton praelongus,* was a very significant stage in the development of the lake vegetation. *Potamogeton pusillus* and *Batrachium* sp. also occurred sporadically. Places with still water in the shore zone started to be colonised by *Potamogeton natans*. The decrease of the number of endocarps of *P. filiformis* and *P. praelongus,* and oospores of *Chara* sp. recorded in the younger parts of the zone suggests that phytocenoses built by these species became less important. The character of the vegetation, and especially the development of assemblages sensitive to habitat changes like *Potametum filiformis* in the older part of the horizon, suggests that the lake water was cold and mesotrophic (Kolstrup 1979, Matuszkiewicz 2001, Velichkevich & Zastawniak 2006), transparent, rich in $CaCO_3$ (Bennike et al. 1994) and had a pH >7 (Lang 1994).

Still and transparent lake waters favoured the development of the green alga *Pediastrum* (J-1 L PAZ). The most common were colonies built from *Pediastrum boryanum* var. *boryanum*, which, at present, can live in both

Table 4. Description of local macrofossil assemblage zones (L MAZ)

L MAZ	Description
J-1 L MAZ (3.60–3.75 m)	The most numerous endocarps of *Potamogeton filiformis* and *P. praelongus*, sporadically occur: *P. natans* and *P. pusillus* and fruits of *Batrachium* sp. Very numerous are oospores of *Chara* sp. The most numerous are nuts of *Carex* (*C.* sect. *Acuta* and *C. acuta* and also *C. canescens*). Trees are represented by remains of *Betula* and *Pinus sylvestris*. Fruits and leaf fragments of *Betula nana* are determined, as well as a leaf of *Chamaedaphne calyculata*. The upper boundary: above decrease of *Potamogeton filiformis* and below abundant appearance of *P. natans*.
J-2 L MAZ (3.45–3.60 m)	Endocarps *Potamogeton natans* predominate. Individual endocarps *P. praelongus*, *P. filiformis*, and *P. pusillus* are recorded and also remains of *Nymphaea candida.* Nuts of *Carex rostrata* predominate. Also seeds of *Menyanthes trifoliata*, *Comarum palustre* and *Schoenoplectus lacustris* were found. Remains of *Pinus sylvestris, Betula pubescens*, and *B.* sect. *Albae* are quite abundant. In the bottom part of the deposit a seed and fruit scales of *Betula nana* were determined and also a fruit of *B.* sect. *Humilis*. The upper boundary: below increase of *Potamogeton pusillus*.
J-3 L MAZ (3.10–3.45 m)	The most numerous are endocarps of *Potamogeton pusillus.* Endocarps of *P. natans*, *P. praelongus*, *P. filiformis* were also found as well as seeds and fragments of a seed coat of *Nuphar pumila, Nymphaea candida*, and individual seeds of *Myriophyllum verticillatum* and *Ceratophyllum demersum*, also a fruit of *Myriophyllum alterniflorum* and individual megaspores of *Isoëtes lacustris*. Very rare of (nuts of *Carex* and tracheids of *Equisetum fluviatile*). In the bottom individual seeds of *Rhynchospora alba* and spindles of *Eriophorum vaginatum*. Numerous fragments of a bark of *Pinus sylvestris* and rare remains of *Betula nana* and *B. pubescens*. The upper boundary: below abundant appearance of *Isoëtes lacustris* and above abundant occurrence of *Potamogeton pusillus.*
J-4 L MAZ (2.65–3.10 m)	Megaspores of *Isoëtes lacustris* are abundant. There is a considerable increase of the number of oospores of *Chara* sp. Fruits of *Batrachium* sp. are numerous. Individual endocarps of *Pamogeton natans* and *P. pusillus* are found, and in the roof *P. praelongus* occurs. Seeds of *Najas minor, Nuphar pumila*, *Nymphaea candida*, and fragments of seed coat of *N. alba* occur. Nuts of *Carex* are rare. Trees are represented by *Pinus sylvestris* (bark fragments, bud scales, a seed and a cone) and also *Betula pubescens* and *B.* sect. *Albae* (single fruits). The upper boundary: above decrease of *Isoëtes lacustris* and below increase of *Potamogeton natans* endocarps.
J-5 L MAZ (2.15–2.65 m)	Endocarps of *Potamogeton natans* and oospores of *Chara* sp. are abundant. There are individual endocarps of *Potamogeton pusillus* and *P. praelongus*, seeds of *Najas minor, Nuphar pumila*, and *Nymphaea candida* as well as fragments of seed coat of *N. alba*. The most numerous are seeds of *Schoenoplectus lacustris.* Also seeds of *Eleocharis palustris* and *Sagittaria sagittifolia* were determined. Leaves of *Scheuchzeria palustris*, spindles of *Eriophorum vaginatum*, seeds of *Rhynchospora alba* and *Menyanthes trifoliata*. There are numerous and differentiated remains of *Pinus sylvestris* and species of *Betula*. An individual bud scales of *Populus tremula* were determined. The upper boundary: above abundant occurrence of aquatic plant remains.
J-6 L MAZ (0.40–2.15 m)	Macroremains of aquatic plants are present only in the bottom part of the zone (endocarps of *Potamogeton,* including *P. natans* and oospores of *Chara* sp.). There are single nuts of *Carex limosa*, *C. canescens*, *C. acuta*, and *C. rostrata*. Numerous spindles of *Eriophorum vaginatum*, leaf remains of *Scheuchzeria palustris* and leaves of *Oxycoccus palustris*. Remains of trees: bark and bud scales of *Pinus sylvestris,* seeds and fruit scales of *Betula,* including *B. nana*. The upper boundary: below rise in number of wetland plant remains.
J-7 L MAZ (0.15–0.40 m)	Domination of *Carex* nuts, mainly *C. rostrata*. *Carex nigra*, *C. canescens*, and *C.* sect. *Paludosae* are also recorded. Numerous, mainly as leaf remains: *Scheuchzeria palustris*, *Eriophorum angustifolium*, and *Oxycoccus palustris*. Rare: bud scales of *Pinus sylvestris* and fruits of *Betula pubescens.* No upper boundary.

meso- and eutrophic lakes. *P. duplex* var. *rugulosum*, which is an indicator of vegetation-free or partly overgrown lakes (Komárek & Jankovská 2001), was a minor representative. *Pediastrum boryanum* var. *longicorne*, which prefers distrophic conditions, was abundant. According to Komárek and Jankovská (2001) this green alga may also occur in lakes of other trophy, assuming that distrophic water from more elevated peatbogs containing *Sphagnum* are part of the lake intake. In the profile from the Jezioro Lake, the representation of cenobia of this green alga is similar to that of spores of *Sphagnum*.

The shores of the lake were occupied by peatbogs which were partly separated from open water by a belt of sedge rushes represented mainly by assemblages with predomination of *Carex acuta*. The sedge rushes were probably accompanied by small tufts of *Juncus*, the occurrence of which is documented by individual seeds. Locally, the foreshore shallow waters with uncovered mineral substratum were probably occupied by small patches of

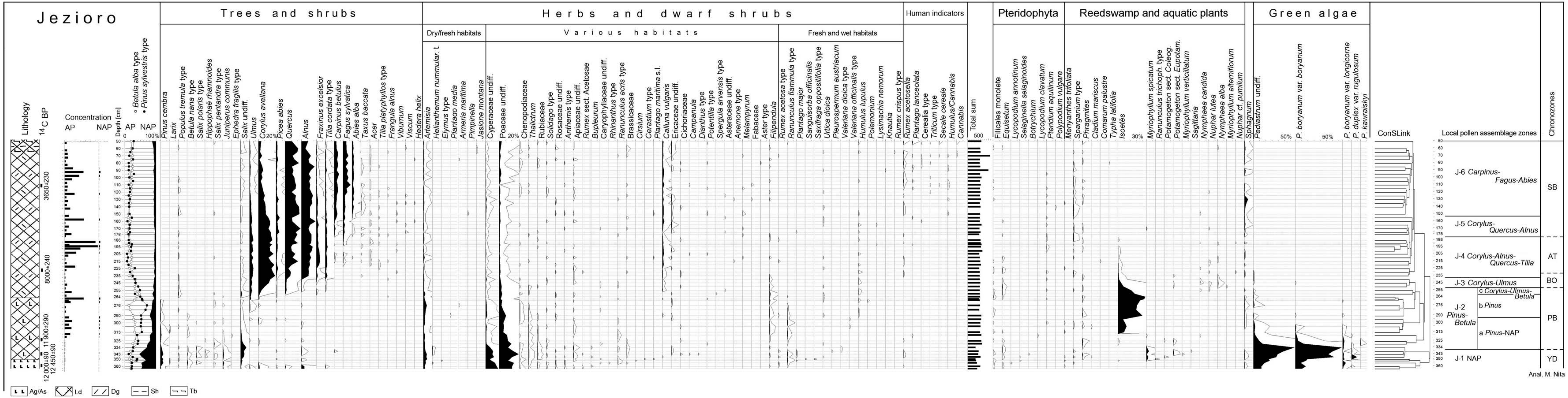

Fig. 3. Percentage pollen diagram from Jezioro Lake site. Lithology: **Ld** – limus detrituosus, **Ag/As** – argrilla granosa/argilla steatodes, **Dg** – detritus granosus, **Sh** – substantia humosa, **Tb** – turfa bryophytica

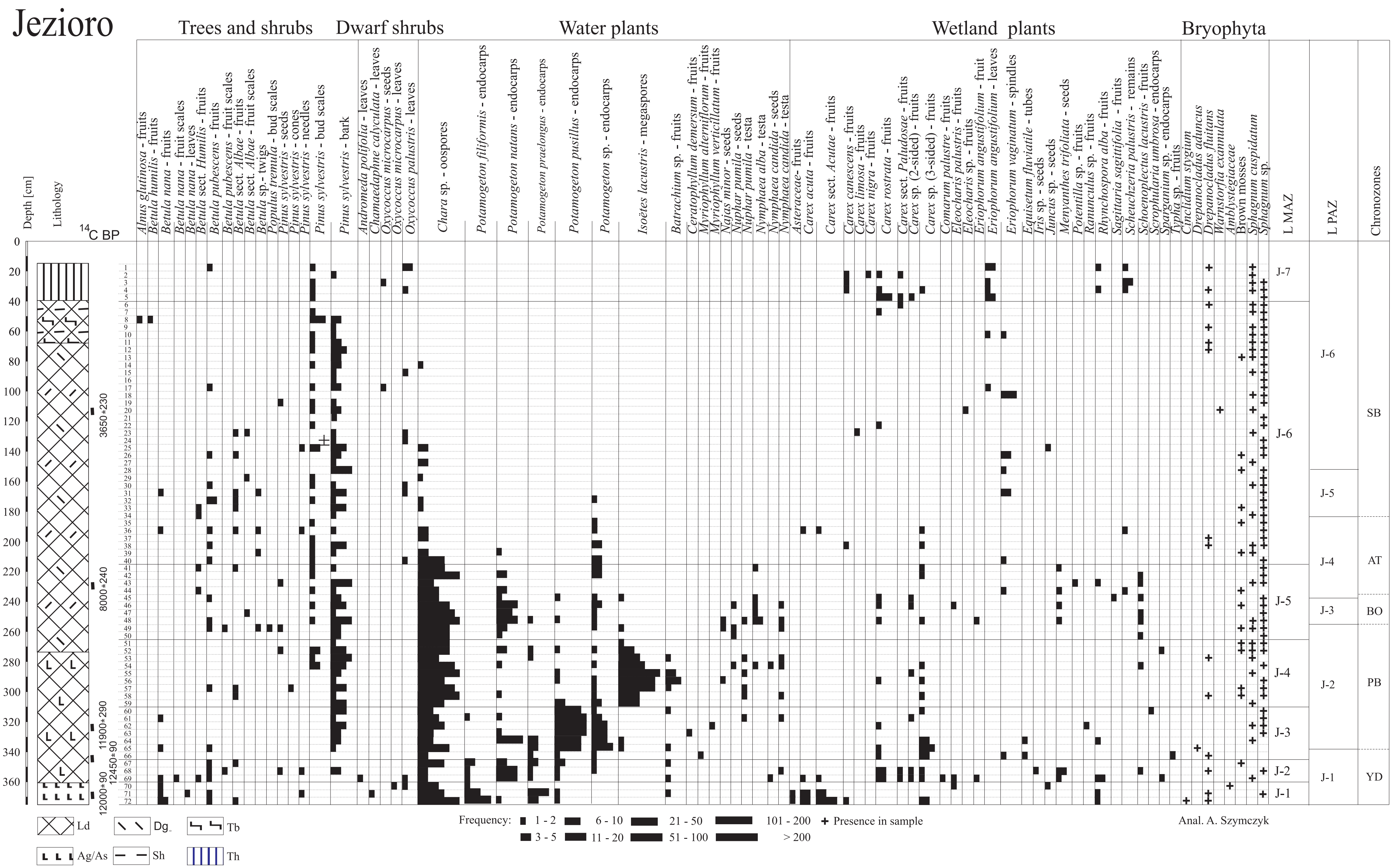

Fig. 4. Plant macrofossil diagram from Jezioro site. Lithology: **Ld** – limus detrituosus, **Ag/As** – argrilla granosa/ argilla steatodes, **Dg** – detritus granosus, **Sh** – substantia humosa, **Tb** – turfa bryophytica, **Th** – turfa herbacea

Eleocharis palustris assemblage. The peatbogs surrounded the lake showed an initial character and probably represented the complex of communities connected with moss-sedge phytocenosis of the *Scheuchzerio-Caricetea nigrae* class, and also rich in draft shrub peatbogs of the *Oxycocco-Sphagnetea* Br.-Bl. & R.Tx.1943 class. Among species developing into peatbogs *Rhynchospora alba,* represented by glumes and individual seeds, was common. *Carex canescens* occurred also here as well as mosses typical of peatbogs, such as *Drepanocladus fluitans* and the cold climate-indicator species *Cinclidium stygium* (Kłosowski & Kłosowski 2006). Draft shrubs connected with a raised peatbog were represented by *Chamaedaphne calyculata* and *Oxycoccus palustris*. Locally *Betula nana* was present (pollen and macrofossils).

With the regression of the phytocenosis built from *Potamogeton filiformis* and alga *Chara* sp. (J-2 L MAZ), an increase in the importance of assemblages of floating-leaved plants with *Potamogeton natans* and *Nymphaea candida* is evident. The regression of these communities concomitant with the expansion of *Potamogeton natans*, a species which often occurs in initial stages of eutrophication (Arts et al. 1990) suggests a small increase of water trophy. However, $CaCO_3$ supply and a pH decrease, is a more likely reason for this as confirmed by the presence of *Nymphaea candida* (macrofossils). At present, this species reaches its optimum in mesotrophic lakes deficient in calcium (Kłosowski & Kłosowski 2006). This is also confirmed by the appearance of *Menyanthes trifoliata* (pollen and seeds) and *Comarum palustre* (fruits), species which are normally associated with a shore zone of mid-peatbog lakes and with acid peatbogs (Kłosowski & Kłosowski 2006).

The rush communities also became transformed. The sedge assemblages with *Carex acuta* gave a way to a gradually expanding phytocenosis with *Carex rostrata*. In the belt of rushes, such species as *Schoenoplectus lacustris*, *Iris* sp. *Sparganium* sp., and spores of *Equisetum* sp. appeared. The peatbogs surrounding the lake transformed and their vegetation probably evolved towards moss communities, as confirmed by a greater representation of *Sphagnum* sp. remains and the appearance of *Andromeda polifolia* typical of the order *Sphagnetalia magellanici*. *Betula nana* still grew in the peatbogs, and, among the herbaceous vegetation, *Ranunculus flammula* represented by pollen, was dominant. The zone of the contact of open water and the peatbog and wet depressions therein were occupied by *Comarum palustre* and patches of *Menyanthes trifoliata*. Many different rush species dominated by *Carex rostrata* and assemblages of floating-leaved plants suggest a shallow lake basin. Owing to the presence of developing peatbogs around, its water might have undergone distrophication at that time.

Possibly owing to a change of biotopic conditions, in the youngest part of the zone, great changes in the composition of vegetation occupying the lake took place. In the lake, there was a renewed expansion of assemblages built from *Chara* sp. Simultaneously, the importance of assemblages of floating leaved plants decreased. As revealed by pollen analysis, the flora of the lake contained sporadically occurring *Myriophyllum spicatum* and *Isoëtes lacustris*. Macroremain analysis revealed that *Potamogeton praelongus* and *Myriophyllum alterniflorum* also occurred here. The presence of *M. alterniflorum* – generally considered to be an indicator of water acidity (Vöge 1988, 1993, Arts 1990, 2002, Arts et al. 1990, Eriksson et al. 1983) – shows, that the lake water at that time was deficient in $CaCO_3$, and its pH was below 6 (Brandrud 2002). The change of species composition of vegetation developed in the lake and a lack of macroremains of rushes and peatbog vegetation in this part of the profile suggests that a rapid deepening of the lake basin occurred at that time. This resulted in a reduction of shallow-water assemblages of floating leaved plants together with rush and peatbog vegetation. This change might have also resulted in trophy decrease.

PREBOREAL CHRONOZONE (J-2 L PAZ; J-3 L MAZ, J-4 L MAZ, WITH BOTTOM PART OF J-5 L MAZ)

Birch and pine forests expanded as a result of climatic amelioration at the beginning of the Holocene (J-2a *Pinus*-NAP subzone). Forest communities were already dominant though not forming a continuous cover. This is clear from the fairly high NAP values and the large variety of taxa of herbaceous plants. Near the lake, there were still patches of open grass communities with participation of *Artemisia.* Gradually, the importance of these communities decreased and their habitats became occupied by pine forests (*Pinus sylvestris* t.). In the forest thinning, *Juniperus* still occurred. *Ephedra fragilis* (*E. fragilis* t.) and *Hippophaë rhamnoides* also survived from the previous period.

By contrast, in the younger part of the Preboreal, forest growth was much denser. The importance of pine (J-2b *Pinus* subzone) increased and clearly it dominated the landscape around the Jezioro Lake. Birch (*Betula alba* t.) was then probably only a sporadic element of forest communities, but later, its importance increased and birch forests again expanded around the lake (J-2c *Corylus-Ulmus-Betula* subzone). *Ulmus* appeared some time later, and at the end of the subzone in the pollen diagram its curve exceeds 4%. Elm probably expanded into wet habitats in the valleys of nearby water courses. In these places, willow (*Salix pentandra* t., *Salix* undiff.) and poplar (*Populus tremula*) occurred, as well as *Humulus lupulus* and *Urtica dioica*.

In the younger part of the Preboreal chronozone, *Corylus avellana* appeared, but its pollen content was very low (max. 5%). However, hazel (*Corylus avellana*) grew undoubtedly in the area of site because the contribution of pollen above 2% indicates its presence in situ (Miotk-Szpiganowicz et al. 2004). Similarly low values of hazel pollen are noted in the profile from Wolbrom (Latałowa 1989).

We conclude that the ^{14}C date (11 900 ± 290 BP) made for deposits from the depth 3.22–3.25 m is not reliable. On the basis of comparison of pine-birch pollen spectra from this depth with similar pollen spectra in profile Wolbrom (Latałowa 1989) and Jęzor-Jaworzno (Szczepanek & Stachowicz-Rybka 2004), it is possible to correlate this part of profile from Jezioro Lake with the Preboreal chronozone.

In the lake at this time, significant changes also occurred. In the older part of the Preboreal chronozone (J-3 L MAZ) phytocenosis with *Potamogeton pusillus* predominated. In the clear water of the lake, they were initially accompanied by assemblages of *Myriophyllum spicatum*, as evidenced by the increase of its pollen representation. *Potamogeton praelongus* also stated here. Later, however, a decrease in the representation of *Myriophyllum spicatum* pollen indicates that its phytocenoses lost their importance and became replaced by assemblages in which, as shown by increasing number of endocarps in the deposit – *Potamogeton natans* and *P. pusillus* dominate. Assemblages with *Potamogeton pusillus* reached their maximum at that time. *Ceratophyllum demersum* also appeared (fruits). The predomination of *Potamogeton pusillus*, the presence of *Ceratophyllum demersum*, and the earlier expansion of *Potamogeton natans,* suggest that trophy of the water increased and was probably the highest in the entire history of the lake. In the younger part of the horizon (J-3 L MAZ), many species which reach their optimum in mesotrophic water were observed. These included the first *Myriophyllum verticillatum* represented by pollen, then *Nymphaea candida* and *Nuphar pumila*, which occupied the shallower parts of the lake. This change suggests a decrease of trophy of the lake water. In earliest Preboreal time, numerous colonies of *Pediastrum*, mainly *P. boryanym* var. *boryanym* survived, but later their importance decreased quite suddenly (Fig. 3).

After the earlier regression, rush communities at the lake shores started to re-form. They were, however, floristically poorer than in the previous period and their species composition changed. In the oldest part of the horizon, sedges including *Carex rostrata* predominated (Fig. 4). The shallow foreshore areas were occupied by patches of plants with *Equsetum fluviatile*. Among species which were of secondary importance in the rush belt were *Typha* sp., *Phragmites australis*, and *Cladium mariscus*. The appearance of *C. mariscus*, a phytocenosis which at present usually occurs in mesotrophic lakes and only rarely in oligo- or distrophic lakes (Kłosowski & Kłosowski 2006), suggests a decrease of trophy of the lake water in the younger part of the horizon. In the older part of the horizon the peatbogs surrounding the lake were poorly developed, which is evidenced by the poor representation of *Sphagnum* and lack of remains typical for draft shrubs (Figs 3, 4). In the younger part of the horizon, in the peatbogs, mosses became more important.

Significant changes in the biocenosis of Jezioro Lake took place in the younger part of the Preboreal chronozone (J-4 L MAZ). In the older part of this horizon, phytocenosis with *Potamogeton pusillus* retreated and this species reoccurred only sporadically. Simultaneously, *Isoëtes lacustris* (mega- and microspores) expanded rapidly, and reached its maximum number in the middle part of the horizon. *Pediastrum* became replaced by *Isoëtes lacustris*.

Alga (*Chara* sp.) became much more important in the vegetation. The deeper parts of the lake at that time were occupied by rare *Potamogeton praelongus*, *Najas minor*, and *Batrachium* sp. In the shallows, small vegetation patches from the alliance *Nymphaeion* OBERD. 1953 occurred, built by such species as *Potamogeton natans*, *Nuphar pumila*, *Nymphaea candida*, and also in the younger part of the horizon *Nymphaea alba* was observed.

The expansion of *Isoëtes lacustris* evidences the decrease of water trophy and indicates that the lake transformed into a fresh-water oligotrophic reservoir. Its pH was probably similar to contemporary lakes with a similar phytocenosis, i.e. 5.0–6.5 pH (Arts 2002). In the youngest part of this horizon, the population of *Isoëtes lacustris* collapsed whereas assemblages with *Potamogeton natans* expanded. These transformations suggest a further change of biotopic conditions at the turn of Preboreal and Boreal chronozones.

The rush flora was probably poorly developed at that time and there was no dense marginal belt. Assemblages built from *Phragmites australis* and various species from the genus *Carex* were then the most important floral elements. In places, seeds of *Sparganium* sp. and *Schoenoplectus* were noted. Patches of peatbog developing at the lake shores were still very poor, as evidenced by a dearth of remains of vascular plants.

BOREAL CHRONOZONE (J-3 L PAZ BOTTOM PART OF J-4 L PAZ; MIDDLE PART OF J-5 L MAZ)

The landscape around the site was changing gradually (J-3 *Corylus-Ulmus* L PAZ). The forests were dense and closely surrounded the lake. In the older part of the Boreal chronozone, these were mainly pine (*Pinus sylvestris* t.) and birch (*Betula alba* t.) forests, but the importance of both trees consequently decreased. *Corylus avellana* entered the pine communities and grew on more fertile habitats. At first its representation was small, but a very marked and continuous increase of its pollen indicates that, at the end of the period, it had become an essential element of forest undergrowth. It probably also grew plentifully at non-forested glades and in forest clearances. The contribution of this pollen, reaching 27%, indicates that it was one of the main species, being a part of contemporary forest communities (Huntley & Birks 1983). Values of hazel pollen noted in the Jezioro site are slightly higher from those noted in that period in the Wolbrom profile (Latałowa & Nalepka 1987). *Quercus,* which probably also entered the pine communities, became a new component of the forests. The importance of *Ulmus* increased and the representation of its pollen was as much as 6%.

At the end of the Boreal chronozone, pine was no longer an essential component of the forest communities, but it still grew in the area of the site studied. Its presence, apart from pollen representation (max. 34%) is also confirmed by macroscopic remains. Birch was still important. The radiocarbon date of 8000 ± 240 BP (the depth of 2.26–2.29 m), on account of large error, can raise certain doubts. But the grow in contribution of pollen *Quercus* and *Alnus* in the sample located directly lower in the profile (depth 2.30 m), suggests that these deposits belong to the Atlantic chronozone. Therefore, it seems that this date can be reliable.

The accumulation of homogenous fine-particle gyttja lacking an admixture of terrigenic matter (J-5 L MAZ) indicates the stabilisation of sedimentary conditions in the lake. *Isoëtes lacustris* occurred only in small concentrations. The expansion of assemblages with *Potamogeton natans* and others floating-leaved plants, such as *Nuphar pumila*, *N. lutea* (pollen), *Nymphaea alba*, and *N. candida* may have been one of the reasons for the regression of *Isoëtes lacustris* assemblages. The development of these communities resulted in a shallowing of the lake's shallow parts which probably eliminated *I. lacustris* from its previously occupied habitats. Among the submerged macrophytes, *Potamogeton pusillus*, *P. praelongus*, and *Najas minor* only occurred rarely. Simultaneously, growth of species typical of oligotrophic (*Isoëtes lacustris*) and mesotrophic (*Najas minor*, *Nuphar pumila*, *Nymphaea candida*) conditions, which have a wider ecological spectrum (*Potamogeton pusillus*, *Nymphaea alba*) and the ratio of macroremains of these plants, all suggest that the lake water at that time was mesotrophic and was poor in calcium carbonate.

In the Boreal chronozone, a significant development of rushes occurred. They gradually covered larger areas. The rushes were mainly composed of *Phragmites australis*, *Schoenoplectus lacustris*, and sedges including mainly *Carex rostrata*. The shallower parts of the lake were occupied by assemblages of *Eleocharis palustris*, *Sagittaria sagittifolia, Equisetum* sp., and *Sparganium* sp. determined in pollen analysis. The expansion of variable rush assemblages correlated with the development of assemblages of floating-leaved plants, suggests that the lake became quite shallow. This probably resulted from an intensive sedimentation of gyttja, which, in turn, favoured further expansion of *Nymphaea alba* and *Nuphar lutea*.

ATLANTIC CHRONOZONE (J-4 L PAZ WITHOUT BOTTOM PART; UPPER PART OF J-5 L MAZ, AND BOTTOM PART OF J-6 L MAZ)

Typical mixed forests with *Quercus*, *Tilia* (*T. cordata* t. and *T. platyphyllos* t.), *Ulmus*, *Acer*, and *Corylus* expanded (J-4 *Corylus-Alnus-Quercus-Tilia* L PAZ). *Taxus* is also sporadic. Compared with the previous period, *Corylus* decreased significantly; this genus probably represented an important component of the undergrowth of these communities. Despite low representation of *Pinus sylvestris* t. and *Betula alba* t. pollen, the presence of quite numerous macroscopic remains of pine and birch indicate the presence of both trees around the lake. However, it is not known whether *Picea abies* was already present in the study area. The representation of its pollen (2–3%) recorded in the younger part of Atlantic chronozone is very low. In the forest undergrowth numerous bushes *Viburnum, Frangula alnus*, and *Hedera helix* occurred. *Viscum* occurred in the tree-crowns. In wet habitats, alder communities occurred with *Fraxinus* in undergrowth.

In the younger part of the zone J-5 L MAZ (correlated with Atlantic chronozone), aquatic vegetation became impoverished. The floating-leaved plants such as *Potamogeton natans*, *Nymphaea alba*, and *Nuphar lutea* dominated but, apparently, were not extensive. *Chara* became important in the plant community.

In the younger part of the zone, such species as *Rhynchospora alba*, *Scheuchzeria palustris*, and *Eriophorum vaginatum* appeared, being indicative of the development, around the lake, peatbogs vegetation, including *Menyanthes trifoliata* and *Potentilla* sp. In the oldest part of the zone J-6 L MAZ, representing Atlantic chronozone, further regression of the aquatic vegetation communities occurred. By contrast, the peatbogs were expanding, as evidenced by the presence of *Oxycoccus palustris*. The appearance of assemblages with *Menyanthes trifoliata,* probably in the contact zone of the peatbogs and the open water, as in the case of modern mid-peatbog ponds (Kłosowski & Kłosowski 2006) suggests that, at the end of this horizon, the peatbogs adjacent to the lake expanded, floating mat developed and that this resulted in gradual distrophication of the lake.

SUBBOREAL CHRONOZONE (J-5 L PAZ, J-6 L PAZ; J-6 L MAZ WITHOUT THE BOTTOM PART, J-7 L MAZ)

Compared to the Atlantic in the earlier part of Subboreal chronozone (J-5 *Corylus-Quercus-Alnus* L PAZ), the forest landscape in the surroundings of the Jezioro Lake did not change significantly. In the multispecies mixed deciduous communities, *Quercus* still dominated, accompanied by *Tilia* (*T. cordata* t.), *Ulmus, Taxus*, *Acer*, and in the undergrowth, *Corylus* predominated. The significance of hazel in the forest assemblages decreased at the turn of Atlantic and Subboreal chronozones. *Carpinus betulus* and *Fagus sylvatica* became new components of the multispecies deciduous forests, but a low representation of pollen of both trees (2.0 and 2.5%) indicate that they were minor constituents (Ralska-Jasiewiczowa et al. 2004). The increase in *Picea abies* pollen up to 5% indicates that spruce had already been established in the surrounding of the lake. Alder forests retained their previous significance, but *Fraxinus* representation diminished.

The changes in the forest communities which occurred in the younger part of the Subboreal chronozone (J-6 *Carpinus-Fagus-Abies* L PAZ) were mainly associated with an increase of the significance of *Carpinus betulus* and *Fagus sylvatica*, and the appearance of *Abies alba*. *Quercus* still predominated in the multispecies forests, but the role of *Corylus* decreased gradually, and *Ulmus* and *Tilia* (*T. cordata* t.) occurred only sparsely. A marked decrease in *Alnus* pollen at the end of the zone J-6 suggests a decreasing representation of alder forests.

Apparently, the floral landscape in the direct neighbourhood of the site was only slightly transformed by human impact. A very high representation of tree and bush pollen (AP) indicates no significant deforestation in the area adjacent to Jezioro Lake. However, the activity of man in this area is evidenced by individual pollen grains of cereals (*Secale cereale, Triticum* t., and Cerealia t.) and weeds (*Centaurea cyanus*), and traces of pasture farming (*Plantago lanceolata* and *Rumex acetosella*) in the profile. In the neighbourhood of this site, archaeological investigations have not been conducted.

The correlation of pollen zone J-6 with the Subboreal chronozone is confirmed by the ^{14}C date (3650 ± 230 BP) obtained from deposits at the depth of 1.13–1.16 m.

Pollen analysis and analysis of plant macrofossils show that, in the Subboreal chronozone (J-6 L MAZ, without the oldest part), the vegetation of the shallow part of the lake created only assemblages with *Nuphar lutea* and *Chara*. The growing representation of remains of *Sphagnum* and the occurrence of such species as *Carex limosa*, *Eriophorum vaginatum*, *E. angustifolium*, *Scheuchzeria palustris*, and *Oxycoccus palustris* indicates the expansion of peatbog phytocenosis and, probably also the increase of floating mat which gradually covered the open water area. This thesis confirms also the regression of rush communities. Only reed rushes remained in the form of small isolated patches. *Sparganium* sp. and *Typha latifolia* occurred sporadically as suggested by the pollen content. They probably formed small concentrations within peatbogs or entered shallow parts of the lake occupied by assemblages with *Nuphar lutea*. The process of distrophication of the lake proceeded during this period. This was probably accelerated by the permanent presence of *Pinus sylvestris* (macroremains). In the older part of the horizon, *Betula nana* grew sporadically on the peatbogs surrounding the Jezioro Lake.

The youngest zone (J-7 L MAZ) is represented by peat deposits. In that part of the lake where the profile is located, the open water became totally covered by outgrowths of floating mat and peatbog development. This is documented by increasingly more numerous remains of *Sphagnum* sp. and also those of *Eriophorum vaginatum, E. angustifolium*, *Rhynchospora alba*, *Scheuchzeria palustris*, *Oxycoccus microcarpus*, and *O. palustris*. *Carex rostrata, C. nigra*, and *C. canescens* also grew on the peatbogs. The species composition of this horizon is similar to that observed at present on the peatbog.

CONCLUSIONS

Jezioro Lake near Herby is the only natural water body in the area of the Woźniki-Wieluń Upland. The neighbourhood of Jezioro Lake hitherto, was not deforestated and this probably caused the stabilisation of its water balance (Czylok et al. 2004).

Results of pollen analysis from profile J18 indicate that accumulation of biogenic deposits commenced during the Younger Dryas and in this part of reservoir lasted up until the Subboreal chronozone. In the area of the Jezioro site, forest communities underwent transformations which are typical for this part of Poland (Ralska-Jasiewiczowa et al. 2004). These transformations are also very similar to plant succession from the Wolbrom site (Latałowa 1989).

Macroscopic remains of *Betula nana*, determined in deposits of profile Jezioro and correlated with the Subboreal chronozonem, indicate that most probably the dwarf birch in this area managed to survive the period of climatic optimum. *Betula nana* also survived untill the Atlantic period at the peatbog in Wolbrom (Latałowa & Nalepka 1987), located approximately 80 km to the south-east from Jezioro site. It also survived in the Konopiska site near Częstochowa, situated only about 15 km away from Jezioro (Latałowa & Nalepka 1987). The statement of its occurrence in the Subboreal period can be as it was similarly suggested for peatbogs in Wolbrom by Latałowa and Nalepka (1987), as a trace of relict species at this site. The presence of dwarf birch remains in three sites, located close to each other, can prove favorable for this plant habitat conditions, occurring in the Atlantic period in this part of Poland. At the present time *Betula nana* occurs in Poland only in three relict sites. They are located in the Sudety Mts.: peatbog “Pod Zieleńcem”, peatbog “Izerskie” and peatbog “Linie”, situated in the Chełmno Lakeland. The closest contemporary place for the occurrence of *Betula nana* is in the “Torfowisko pod Zieleńcem” reserve which is about 180 km away from Jezioro Lake. Populations of this species range from two up to three thousand individuals (Kruszelnicki & Fabiszewski 2001).

Well preserved, numerous plant macroscopic remains document transformations of local aquatic and near-shore vegetation. They result in succession progression leading from relatively oligotrophic reservoir into dystrophic lake covered with floating peat mat. The described transformation type is characteristic for inland lakes functioning in catchments, which are overgrown with coniferous forests.

Among aquatic plants *Isoëtes lacustris* deserves special attention. Its very numerous macro- and microspores (more than 30%) occur in deposits correlated with younger part of the Preboreal chronozone. At the turn of the Preboreal/Boreal chronozones the contribution of these spores drastically decreases. However, continuous curve of *Isoëtes* microspores remains almost up until the end of the Atlantic chronozone, suggesting it have persisted in the water body despite gradual dystrophication of the reservoir. During the last glaciation *Isoëtes lacustris* appeared in Poland in the late glacial. It occurred in lakes, located in the area of Bory Tucholskie (Tuchola Forest), among others Gacno Wielkie and Moczadło (Hjelmroos-Ericsson 1981, Milecka 2005). It was also stated in the south of Poland in reservoir near Jaworzno (Szczepanek & Stachowicz-Rybka 2004), located about 80 km away from the site Jezioro. Investigations carried out in the area of Bory Tucholskie indicate that in the Gacno Wielkie and Moczadło lakes, despite changes in climatic conditions, this species was present for the whole Holocene (Milecka 2005). In the period of climatic optimum spores of *Isoëtes lacustris* were also stated in the deposits of Nierybno Lake and in one from reservoirs in the "Jeziorka Dury" reserve (Kowalewski, Milecka 2003, Milecka 2005). The reservoir in Jaworzno at the turn of the Late Glacial and Holocene underwent in-filling, therefore, to date it has not been known if this species survived the period of climatic optimum in the south of Poland.

The period of climatic optimum was generally unfavorable for plant communities that included *Isoëtes lacustris.* According to Milecka (2005, 2006), in the Bory Tucholskie lakes these communities survived climatic optimum because a number of factors including the small sizes of individual lakes, the lack of inflows, location in pine coniferous forests, settling poor acid soils and the development of peatbogs in the littoral zone. These factors also existed in the Jezioro Lake. Very essential for the occurrence of *Isoëtes lacustris* in the Atlantic period was here probably progressing slow process of Jezioro Lake dystrophication. This species suggests that despite the small increase in trophy, it was still a soft-water reservoir. The small forest catchment and surrounding peatbog, additionally acting as biogeochemical barriers, provided the reservoir with inflow of humus acids. These acids, binding phosphorus and nitrogen into non-available complexes for plants, prevented Jezioro Lake eutrophication and ensured the proper reaction of water. Paradoxically, the progressing dystrophication and significant decrease in water transparency, caused by the growth in content of humus acids in water, could be one of the main reasons of *Isoëtes lacustris* disappearance in Jezioro Lake towards the end of the Atlantic chronozone.

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