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Late Glacial and Holocene history of vegetation in Gostynin area, central Poland

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ABSTRACT. Pollen analysis of lake and mire sediments from Lake Lucieńskie, Lake Białe and former Lake Gąsak, situated in the Gostynin Lake District, provided a continuous record of vegetation changes in the Gostynin region from ca. 11 000 BC to 1500 AD as well as the fragmentary data concerning the last centuries. The results were correlated with the palynological record from Lake Gościąż, a reference site for central Poland, located at the distance of about 10 km. Local and regional changes were distinguished, most important of which were those having a regional character. The most interesting regional changes were as follows:

– the phase of high *Pinus sylvestris* values ca. 6500–6200 BC, contemporaneous with the beginning of increased *Pteridium* values and high charcoal concentration probably connected with the activities of Mesolithic societies;

– three distinct decreases of *Ulmus* curve about 3900–3800 BC, 2850–2750 BC, and 2000–1950 BC coinciding with strong expansion of *Corylus*;

– three episodes of *Carpinus* expansion dated to ca. 1750–1500 BC, 100–60 BC, and 400–900 AD, indicating periods of weaker settlement activity near studied sites;

– an intensive spread of *Betula* from about 1730/1330 BC to the beginning of our era due to the development of secondary communities on fallow lands.

Important local characteristics include a long-term occurrence of *Vitis vinifera* ssp. *sylvestris* in the vicinity of Lake Lucieńskie; a distinctly lower frequency of *Taxus baccata*, *Tilia platyphyllos*, *Acer*, and *Fagus* in the forests of the Gostynin region compared to the surroundings of Lake Gościąż; and the intensive development of *Stratiotes aloides* ca. 10 540–9330 BC at Lake Lucieńskie.

The phases of the evolution of water reservoirs were recognized and the process of the transformation of lake into peat-bog about 190–400 AD at the site Gąsak was described.

The strongest anthropogenic influence on local vegetation was observed in Lake Białe and the weakest one in Lake Lucieńskie. The studies have shown that the clearing and thinning of forests by humans with the use of fire started as early as the Mesolithic. Anthropogenic transformations became intensified with the arrival of the first farmers in this area representing the Funnel Beaker culture. At that time, the area of thinned forest increased, with the large participation of shrubs and grassland vegetation and the evidences of cereal cultivation appeared. The later agricultural activities and settlement, particularly intensified during the development of the Trzciniec and Lusatian cultures, caused the deforestation of larger areas and favoured the spread of hornbeam and birch resulting in permanent woodland transformations. The influence of the Przeworsk culture was marked in Lake Białe by a short anthropogenic phase ca. 50 BC–180 AD. Following an intervening decline, agricultural activity increased again in the Middle Ages about the 10^{th}–11^{th} century AD.

KEYWORDS: *Vitis vinifera* ssp. *sylvestris*, palynology, history of woodland communities, post-glacial tree migrations, Holocene, Gostynin Lake District, central Poland

INTRODUCTION

Palynological investigations of the deposits filling the basins of Lakes Lucieńskie and Białe, and Gąsak peat-bog were undertaken with the following aims: to define the dynamics of vegetation changes in the Gostynin region; to find out the regional characteristics of forest communities in this microregion and local features of their taxonomic composition; to establish, together with the data obtained from Lake Gościąż, an area as to well known postglacial history of palaeoenvironment in central Poland; to illustrate changes of lake basins; to reconstruct the subfossil communities and the actual plant succession leading to the overgrowing of the lake and the formation of peat-bog. Pollen analysis resolved a very detailed record of human influence on local environment, documented also by numerous archaeological findings of well recognized chronology, within 5 km radius around palynological sites. This paper gives only a short information about the anthropogenic influence on vegetation. These problems are discussed in a separate publication (Rybicka & Wacnik 2011). An important aspect of these studies was to draw attention to the occurrence of some rare taxa on the territory of the Lake District in the Holocene, such as for instance *Vitis vinifera* ssp. *sylvestris*, *Tilia platyphyllos*, *Taxus baccata*, and *Stratiotes aloides*. The accomplishment of these aims was facilitated by the location of the studied sites near each other and not far from Lake Gościąż (Ralska-Jasiewiczowa et al. 1998).

THE REGIONAL ENVIRONMENT

According to the physico-geographic regionalisation of Poland, the Gostynin area is divided into the Płock Basin, the Kujawy Lake District, the Kłodawa Upland Plain, and the Kutno Plain. Studied sites are situated within the Płock Basin (Kondracki 2000). In geobotanical terms the region belongs to the Kujawy District of the Great Poland-Kujawy Section within the Belt of Great Valleys Subdivision of the Baltic Division (Szafer & Zarzycki 1972). The Lakes Lucieńskie and Białe and the Gąsak peat-bog are located in the Gostynin commune (Masovian province), in the Gostynin-Włocławek Landscape Park (Fig. 1).

Most of the Gostynin Lake District is covered with slightly differentiated light podsolic soils, formed from loose or slightly loamy (clayey) sands, with deep ground water table. A considerable area is covered by brown soils which develop on loamy sands. Brown earths and muds are the most fertile soils and for the greatest part are exploited agriculturally. Alluvial soils and peat soils occupy small areas

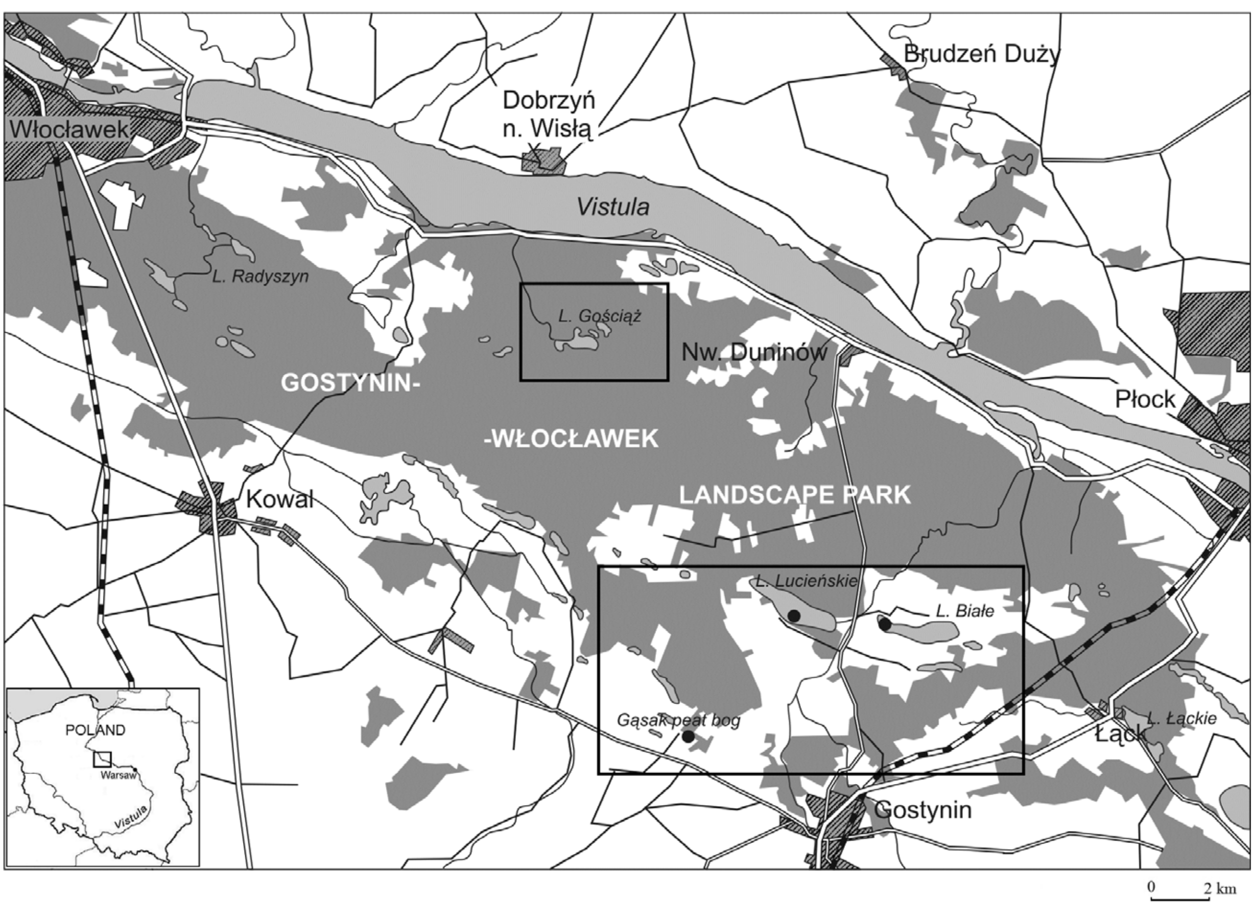

Fig. 1. Location of Lakes Lucieńskie, Białe, peat-bog Gąsak, and Lake Gościąż in the Gostynin Lake District area

in valley bottoms along water flows (Bednarek & Prusinkiewicz 1999).

The Gostynin Lake District is situated in the zone of temperate-transitional climate with a total annual precipitation 350–400 mm (reaching 550 mm only in the environs of Włocławek). The length of the vegetation period varies from 210 to 220 days. Mean annual temperature is 8.0°C, mean July temperature is 18.0°C and mean January temperature is –3.0°C (Woś 1999, Wójcik & Przybylak 1998). Forests cover 32% of the area on average.

The woodland vegetation of the Włocławek-Gostynin Landscape Park is dominated by pine and mixed oak-pine woodlands of the class *Vaccinio-Piceetea*, which grows mostly on poor sandy habitats. Among pine forests, the subcontinental pine forest *Peucedano-Pinetum* occurs most frequently. Mixed oak-pine forests grow on dune sands and sandy terraces in moist and more fertile places. These belong to two associations: the subboreal *Serratulo-Pinetum* and continental *Querco roboris-Pinetum*. Much less frequent are deciduous forests of the class *Querco-Fagetea*, represented by open oak forests *Potentillo albae-Quercetum* and subcontinental oak-hornbeam forests *Tilio-Carpinetum* that develop on fertile brown earths (Załuski & Cyzman 1994, Rąkowski et al. 2004). Alder woods and carrs develop in low-lying terrain, environs of lakes and riparian areas (Olaczek 2008). Non-forest vegetation is represented by about 70 associations of aquatic plants, reed swamps, meadows, grasslands and synanthropic plants. A characteristic feature of this area is a frequent occurrence of oligotrophic transitional peat-bogs, which develop around the dystrophic lakes and in basins surrounded by conifer forests. They are overgrown by communities of the class *Scheuchzerio-Caricetea nigrae*, such as a moss-peat with mud sedge *Caricetum limosae*, and another moss-peat with white beak-sedge *Rhynchosporetum albae*. Raised bogs can also are encountered, with a typical hummock moss-peat association *Sphagnetum magellanici* of the class *Oxycocco-Sphagnetea*, having a moss layer dominated by *Sphagnum* species. Eutrophic fens (class *Scheuchzerio-Caricetea nigrae*) are characterized by the abundant development of low sedges (Załuski & Cyzman 1994).

The flora of the Park comprises 800 species of vascular plants, including 180 rare and 52 protected species (Załuski & Cyzman 1994, Olaczek 2008).

The potential natural vegetation is made of pine forests (70%), among which the continental mixed oak-pine forests *Querco-Pinetum* would predominate over pine forests *Peucedano-Pinetum*. Hygrophilous deciduous forests, marshy alder woods of the association *Carici elongatae-Alnetum* and lowland ash-alder carr of the association *Fraxino-Alnetum* cover 20% of the area, while 10% is occupied by eutrophic subatlantic beech-oak-hornbeam forests of the association *Stellario-Carpinetum* with minor elements of Middle-European oak-hornbeam forests of the association *Galio-Carpinetum*.

Investigations of Late Glacial and Holocene changes of vegetation in the Lake District were initiated by Z. Borówko-Dłużakowa, who did pollen analytical pilot studies of sites in the vicinity of Włocławek and Płock, namely Łąck, Brzezie, Ciechomice, and DzierząPzno (Borówko-Dłużakowa 1961). However, of greatest significance for the understanding of vegetation history of this area were multidisciplinary palaeoecological investigations of annually laminated sediments of Lake Gościąż (Ralska-Jasiewiczowa et al. 1998).

STUDIES ON PREHISTORIC SETTLEMENT IN THE STUDIED MICROREGION

The history of settlement in the region of Lakes Białe and Lucieńskie and the Gąsak peat-bog was the subject of detailed archaeological surface surveys and excavations. Surface investigations were made by J. Wysocki (in the frame of Polish Archaeological Record) in the 1980's. Later his results were corroborated by K. Gowin and M. Rybicka, who discovered several settlements connected with the Mesolithic, Neolithic cultures (Funnel Beaker and Globular Amphora), Sub-Neolithic cultures (Niemen culture of the Iwno type, Corded Ware culture), Bronze and Iron Ages cultures (Trzciniec, Lusatian, and Przeworsk). Excavations such as at Huta Nowa 1, Lucień 12, Klusek Biały 7 and 28, and Budy Lucieńskie 1 and 9, were conducted in the frame of a project devoted to the study of the Neolithic and Early Bronze Age in the Gostynin Lake District (Rybicka 2004, 2011, Pelisiak et al. 2006). In 2007–2009, new investigations were undertaken in order to verify chronology and functions of settlements belonging to various cultures and to reconstruct as precisely as possible changes of local settlement patterns. These data were essential preconditions for a proper understanding of anthropogenic changes of the environment recorded in pollen diagrams. New archaeological work was concentrated in areas within a 5 km radius around pollen profiles. The first settlement traces in the area included in the present investigations originate from the Mesolithic (the exact chronology indeterminable), but the most intensive settlement developed in the Middle Neolithic. The communities of the Funnel Beaker culture were locally settled from about 3800/3600 to about 3100 BC. The most numerous settlement points (47 within 5 km radius around coring place) were revealed near Lake Białe. Among tools used by local settlers were flint sickles, axe, and quern confirming the economy based on agriculture (Rybicka 2004). The settlement situation here was different than in the Lake Gościąż area, where settlement remains were not frequent (Rybicka 2011). Then, the area was included into the range of forest zone cultures (the Niemen and the Linin-type). Its chronology is difficult to determine. Settlement of communities of the Globular Amphora and the Corded Ware cultures were weakly indicated and renewed settlement in this area was observed in the Bronze Age. The Trzciniec culture settlement (1600–1300 BC) was preceded by the Iwno culture (dated to the end of the 3rd millennium BC). After the Lusatian culture settlement (1300–300 BC), human activity declined in the area. This is confirmed by a lower number of sites of the Przeworsk culture (chronology indeterminate, ca 300 BC–400 AD). After the succeeding recession, the area was inhabited again as late as the Middle Ages. The analysis of the distribution of habitation sites indicates that the surroundings of Lake Białe and former Lake Gąsak were of greatest interest for prehistoric populations, while much less populated were those of Lake Lucieńskie, which could have been exploited by people living in the region of Lake Białe (Rybicka 2011).

MATERIAL AND METHODS

SUBJECT OF INVESTIGATIONS

Material for palynological studies comes from 3 sites: Lake Lucieńskie, Lake Białe, and peat-bog Gąsak, situated few kilometres apart and about 10 km south of Lake Gościąż (Fig. 1).

Lake Lucieńskie (52°49.8′N, 19°44.5′E) is a water reservoir with a surface of 203.3 ha, situated at an elevation of 73.1 m a.s.l. Maximal depth is 20.0 m, with the mean value of 8.4 m. The lake is 3285 m long with a maximum width of 930 m. A place located ca. 300 m SW from the deepest part was chosen for coring. Water depth at this place was 7 m. For palaeoecological studies core L/2008 was taken, which extended to the bottom of sediments at the depth 5.2 m.

Profile L/2008, sediment lithology

Depth (m)	Description of sediment
0.2–0.3	calcareous gyttja, olive-grey
0.3–1.2	clayey-calcareous gyttja, dark-olive
1.2–1.3	clayey gyttja, dark-brown
1.3–1.6	clayey-calcareous gyttja, olive-grey
1.6–3.5	calcareous gyttja, olive-grey
3.5–4.7	clayey gyttja, grey, rusty in places, laminated at 4.40–4.35 m
4.7–4.8	clayey gyttja with plant detritus
4.8–5.2	fine-grained sand with plant macrofossils

Lake Białe (52°49.5′N, 19°49.4′E) is situated at an elevation of 72.4 m a.s.l. Its length is 2975 m, with a maximal width of 775 m, and surface of ca. 150.2 ha (Jaczynowski 1929). With water depth of 31.3 m it is the deepest tunnel lake in the Lake District. It occupies a deep trough separated from Lake Lucieńskie by 1.5 km, where alluvial deposits of the Skrwa river valley accumulate (Roman 2003). Profile B/2007 was taken for investigation from the western part of the lake in its deepest part, where water depth was 7 m. The core of 8.5 m length was collected but the base of bottom sediments was not reached.

Profile B/2007, sediment lithology

Depth (m)	Description of sediment
0.05–2.2	calcareous gyttja, dark olive beige
2.2–7.4	calcareous gyttja, light olive, with abundant charcoals, charcoal pieces <1 mm long visible at the depth 5.6–5.9 and 6.5–7.5 m. At the depth 4.09–5.0 and 5.8–5.9 m the sediment is more plastic
7.4–8.5	calcareous gyttja, olive-grey, laminated at 8.2 m

Former Lake Gąsak, now transitory peat bog, lies in the watershed between the now existing Gąsak (also named Gąściąż or Gościąż) and Popówek Lakes. The peat-bog is about 100 m wide and 500 m long. The coring spot is located near the village Teodorowo (52°46.3′N, 19°39.1′E) at an elevation of ca. 81 m a.s.l. From the centre of the peat-bog, profile Gąsak II was acquired, in which 8.5 m of sediment was recovered (from the depth 10.7 to 2.2 m). The loose peat layers from the depth of 2.2–0.5 m could not be collected. In addition, at the top, a peat monolith was cut to a depth of 0.5 m.

Profile Gąsak II, sediment lithology

Depth (m)	Description of sediment
0.0–0.40	moss-*Scheuchzeria* peat, transition peat-bog
0.4–0.50	moss peat, hummock peat-bog
2.2–2.30	sedge-moss peat, fen peat
2.3–3.40	coarse detritus gyttja, grey-brown, lumpy
3.4–3.50	moss peat
3.5–4.50	coarse detritus gyttja, grey-brown, lumpy
4.5–5.75	coarse detritus gyttja, brown-greenish, elastic
5.75–5.85	coarse detritus gyttja
5.85–8.80	fine detritus gyttja, brown-greenish, elastic
8.8–9.37	clayey detritus gyttja, fissile, compact
9.37–9.46	strongly decayed wood of *Pinus sylvestris*
9.46–9.52	detritus gyttja, brown
9.52–9.80	muddy sand with plant detritus
9.8–10.70	fine sand, grey, with admixture of clay and plant detritus

FIELD WORK, SAMPLE PREPARATION, AND DETERMINATION OF MICROFOSSILS

In 2007 and 2008, sediment cores of 10 cm in diameter were taken from the Lakes Lucieńskie and Białe as well as the former Lake Gąsak (now peat-bog). Coring were performed from the peat surface or from the raft with a Więckowski' piston corer.

POLLEN AND MICROSCOPIC CHARCOAL ANALYSES

The volume of samples taken for pollen analysis was 1 cm^3. Samples were treated with 10% HCl solution to remove calcium carbonate, and then boiled in 10% KOH solution to remove humus compounds. Silica was eliminated by boiling in 40% HF solution for about 20 min. This pre-treatment was followed by acetolysis according to Erdtman (1960). *Lycopodium* index tablets were added for the calculation of concentration of microfossils (Stockmarr 1971, Berglund & Ralska-Jasiewiczowa 1986).

For each spectrum at least 2 slides were examined under 400× and 1000× magnification. On the average 800 pollen grains of trees and shrubs were counted as well as all accompanying sporomorphs. In a few samples pollen frequency was so low that total pollen sum was smaller, but it never fell below 250 tree pollen grains. Taxonomic identification was based on the reference pollen and spore collection of the Department of Palaeobotany, W. Szafer Institute of Botany, Polish Academy of Sciences, and standard keys such as Moore et al. (1991), Beug (2004) and atlases of Reille (1995, 1998). Charcoal microfragments were counted at same time as sporomorphs and they were classified according to two size fractions: 10–100 µm and >100 µm.

Pollen analysis of profiles Gąsak II and Lake Białe was done by M. Ralska-Jasiewiczowa, that of Lake Lucieńskie by E. Madeyska. The results are presented in tables and percentage diagrams drawn in POLPAL for Windows program (Walanus & Nalepka 1999). Pollen percentages are calculated in relation to the sum of terrestrial plants, which includes trees and shrubs (AP) as well as herbaceous plants (NAP), excluding local vascular plants and cryptogames. The percentages of each taxon of the last two groups were calculated from the same total increased by the addition of the number of sporomorphs of this particular taxon. Diagrams were divided into local pollen assemblage zones (L PAZ), the results of the ConsLink analysis being taken into consideration (Walanus & Nalepka 1999). Local pollen assemblage zones are named after the most characteristic or most numerous taxa.

THE ANALYSIS OF THE VEGETATIVE PLANT PARTS

The analysis of the botanical composition of peat was performed by M. Kloss (Centre for Ecological Research, Polish Academy of Sciences, Dziekanów Leśny). Peat was boiled in 10% solution of KOH and then washed on sieve with mesh diameter 0.2 mm. The selected remains were identified to species, as far as possible, and their percentage composition was calculated. For each sample 10 microscope slides were analysed. For identification the following keys and atlases were used: Dombrovskaya et al. (1959), Kac et al. (1965, 1977), Grosse-Brauckmann (1974), and Grosse-Brauckmann & Streitz (1992). The results allowed to identified peat types according to the classification of Tołpa et al. (1967).

CHRONOLOGY OF SEDIMENTS

The basis for the determination of the age of sediments is radiocarbon dating and the correlation of the results of pollen analysis with the reference pollen profile from Lake Gościąż. AMS radiocarbon dating was done in the Poznań Radiocarbon Laboratory; the results are presented in Table 1.

The relation depth-age and thus the ages of individual samples were calculated by A. Walanus (University of Science and Technology) using the Depth/Age computer program of the POLPAL system (see Walanus 2011). In the text calendar dates are used.

THE RESULTS OF POLLEN ANALYSIS

The results obtained from individual localities are presented in tables: Lake Lucieńskie – Table 2, former Lake Gąsak – Table 3, and Lake Białe – Table 4.

THE DEVELOPMENT OF WOODLAND COMMUNITIES IN GOSTYNIN REGION

Vegetation development during the Late Glacial of the Vistula glaciation was recorded in the sediments from Lake Lucieńskie and at the base of the Gąsak II profile.

Table 1. Results of AMS radiocarbon dating

Profile	Depth [cm]	No. Lab.	Material	^{14}C BP	Calendar age BC/AD (2σ probability)*
Lake Lucieńskie	49–51	Poz-32516	gyttja	3480 ± 35	1982 BC–733BC
Lake Lucieńskie	139–141	Poz-32518	gyttja	4770 ± 100	3769 BC–3351 BC
Lake Lucieńskie	289–291	Poz-32519	gyttja	8900 ± 100	8286 BC–7729 BC
Lake Białe	75–80	Poz-32513	gyttja	355 ± 35	1537 AD–1635 AD
Lake Białe	124–130	Poz-32514	gyttja	1610 ± 60	324 AD–583 AD
Lake Białe	225–230	Poz-32515	gyttja	2035 ± 30	116 BC–29 AD
Lake Białe	419–424	Poz-32511	gyttja	3580 ± 40	2034 BC–1869 BC
Lake Białe	600–610	Poz-32512	gyttja	4800 ± 40	3657 BC–3516 BC
Gąsak II	270–280	Poz-32505	gyttja	2195 ± 30	367 BC–181 BC
Gąsak II	380–390	Poz-32506	gyttja	3360 ± 35	1740 BC–1603 BC
Gąsak II	520–530	Poz-32508	gyttja	4720 ± 40	3468 BC–3374 BC
Gąsak II	830–840	Poz-32509	gyttja	8830 ± 50	8021 BC–7749 BC
Gąsak II	937–946	Poz-32510	gyttja	11 970 ± 60	12 049 BC–11 727 BC

* Results of date calibration; Reimer et al. 2004; OxCal v3.10 Bronk Ramsey (2005)

PHASE I

The dominance of pine and pine-birch forests

L-1 *Pinus-Betula* L PAZ (11 000–10 640 BC; Fig. 2) – corresponds to the *Pinus-Betula-Filipendula* G1/87-1 zone (10 900–10 700 BC) in Lake Gościąż (Ralska-Jasiewiczowa et al. 1998, fig. 8.22)

Pine forests with an admixture of *Betula*, *Larix*, and some *Populus* (probably *P. tremula*) were growing around Lake Lucieńskie. *Pinus sylvestris* was the main forest component as is indicated by its very high pollen percentages (up to 71%). The occurrence of numerous wood fragments of *Pinus sylvestris* in the deposits underlying pollen profile from the site Gąsak II and dated to ca. 12 049–11 727 BC (11 970±60 ^{14}C BP) indicates a much earlier presence of pine in the region. Pine needles and peryderm were found in the sediments of Lake Gościąż dated to the Allerød interstadial (Ralska-Jasiewiczowa et al. 1998). Birch played a more significant role in wet habitats where it could form more open patches together with willows and rare *Betula nana*. It was more common also in lacustrine areas. The occurrence of *Humulus lupulus*, *Urtica*, *Filipendula*, Apiaceae, and *Thalictrum* may be connected with similar habitats. In dry and well lighted places *Juniperus* was growing together with *Rumex* (*R. acetosella*-type), *Helianthemum nummularium*, and *Pleurospermum austriacum*, as well as species of *Artemisia*, Chenopodiaceae, and *Dianthus*-type. Poaceae, *Potentilla*, Rubiaceae, *Aster*-type, and Cichorioideae could occur in various habitats, in the herb layer of forests together with ferns or at the lake shore.

PHASE II

Expansion of open communities with *Juniperus*

GII-1 *Juniperus-Salix*-NAP L PAZ (one sample, ca. 10 290 BC; Fig. 3), **L-2 *Juniperus-Salix*-NAP L PAZ** (10 640–9140 BC; Fig. 2) – corresponds to the two zones G1/87-2 *Juniperus-Artemisia*-Chenopodiaceae-*Salix* (10 700–10 150 BC) and G1/87-3 *Betula-Artemisia* (10 140–9550 BC) in Lake Gościąż (Ralska-Jasiewiczowa et al. 1998, fig. 8.22)

The climatic cooling at the end of the last glaciation (e.g. Goslar et al. 1999, Mayewski et al. 2004, Ralska-Jasiewiczowa et al. 2003) caused partial withdrawal of *Pinus sylvestris* (macroscopic remains were present in Lake Gościąż sediments) and the reduction of birch trees or limitation of their pollen production. Open birch forests with pine, several willows, and *Populus* cf. *tremula* developed in the region of Gostynin. High pine pollen percentages, to a significant degree, are the result of the long distance transport. Low density of forest cover is confirmed by high representation of *Juniperus communis*, a heliophilous species growing in dry open habitats. Communities of steppe vegetation became widespread, with several species of Poaceae, *Artemisia*, and Chenopodiaceae, with *Ephedra distachya*, *E. fragilis*, and *Rumex acetosella*, and representatives of

Table 2. Lake Lucieńskie. Results of pollen analysis

L PAZ and L PASZ; depth; age	Description of zones		Phase of basin develop-ment
	Terrestrial vegetation	Aquatic and shoreline vegetation	
L-1 *Pinus-Betula*; 482–440 cm; 11 000–10 600 BC	Very high values of *Pinus sylvestris* (to 71.4%). *Betula* to 20.8%. Stable *Juniperus* to 1.7%. Frequent herbs especially Poaceae (to 8.4%), *Artemisia* (to 1.4%), and Chenopodiaceae (to 1.5%). Continuous curve of *Filipendula*, *Humulus*, and *Thalictrum*. Presence of rebeded palynomorphs in sediment at depth of 455–451 cm.	Numerous Cyperaceae (to 4.3%), *Equisetum*, and green algae (*Botryococcus* and *Pediastrum*). Constant values of *Potamogeton* and *Sphagnum*. *Ceratophyllum* leaf spines noted regularly. Single *Stratiotes*.	I 11 000– 10 740 BC
L-2 *Juniperus-Salix*-NAP; 440–370 cm; 10 600–? (sedimentological gap) 9140 BC	Bottom limit: decrease of *Pinus*, *Betula*, and rise of *Juniperus*. Very high but decreasing amount of *Pinus* (66.4%–59.5%). *Betula* to 11.2%. Increase of *Salix* (to 2.5%) and *Populus* (to 1.6%). Continuous curve of *Alnus* (<1%). Presence of *Betula nana*-t., *Ephedra distachya*, *E. fragilis*. High frequency of *Juniperus* (to 7.3%), as well as herbs e.g.: Poaceae (to 5.8%), *Artemisia* (to 2.2%), and Chenopodiaceae (to 2.1%). Rise of *Filipendula* (to 1.2%), *Thalictrum* (to 1.5%). Regular presence of *Rumex acetosella*-t., *Potentilla*-t., Rubiaceae, *Humulus*, *Urtica*, and *Aster*-t. Single *Pleurospermum*, *Helianthemum numullarium*-t. Continuous curve of Filicales.	Strong increase of *Stratiotes aloides*, Cyperaceae (to 6.9%), *Potamogeton*, and *Equisetum*. *Sphagnum* regularly in the older and *Nymphaea alba* in the younger part. In single spectra *Scheuchzeria palustris* and *Lemna*.	II 10 740– 9330 BC
L-3 *Betula-Pinus*; 370–310 cm; ca. 9140–7930 BC	Bottom limit: sharp rise of *Betula*, fall of *Juniperus* and Cyperaceae. Maximum *Betula* (45.1%) in the bottom, than decrease to 13.9%. Parallel rise of *Pinus sylvestris* (to 70.9%). Slight decrease of *Salix* and *Populus*. The end of *Juniperus* curve (0.5%). Regular presence of *Ulmus*, *Corylus*, *Alnus*, *Quercus*, and *Fraxinus*. *Corylus* to 3.8%, *Ulmus* to 1.5% in the upper part. Poaceae (to 5.8%), *Artemisia* (0.4%), *Humulus*, *Urtica*, *Filipendula*, and *Thalictrum*.	Decrease of Cyperaceae (2.1%) and *Equisetum*. Disappearance of *Stratiotes*. Continuous curve of *Thelypteris palustris* and *Potamogeton*. Regularly *Typha angustifolia / Sparganium* and *Typha latifolia*. Single spectra with *Nymphaea alba*, *Scheuchzeria palustris*, and *Sphagnum*. Regular occurrence of *Ceratophyllum* leaf spines. Low values of green algae.	III 9330–4240 BC
L-4 *Corylus-Alnus-Ulmus* (*Quercus*); 310–210 cm; 7930–5300 BC	Bottom limit: increase of *Corylus*, *Alnus*, and decrease of *Pinus*. Systematic reduction of *Pinus sylvestris* (to 53.4%). Decrease of *Betula* (17.4%–9.2%). Fast rise of *Corylus* (to 18.2%), *Alnus* (to 12%), and smaller of *Quercus* (to 5.1%), *Ulmus* (to 3%), and *Fraxinus* (to 3.3%). Beginning of constant presence of *Tilia* (to 1.3%). Appearance of *Juniperus*, *Acer*, *Juglans*, *Hedera*, and *Viscum*. Decrease of Poaceae (24.9%–2.9%), *Artemisia* (to 1%). Presence of *Rumex acetosella*-t., *Urtica*, and *Humulus*. Single finds of Cichorioideae, *Ranunculus*, and Rubiaceae.		
L-5 *Ulmus-Tilia-Fraxinus*; 210–140 cm; 5300–3610 BC	Bottom limit: strong decrease of *Corylus*, decrease of *Ulmus* and *Quercus*. The highest amount of *Ulmus* (to 6.1%). Further rise of *Alnus* (to 18.8%), *Quercus* (to 6.8%), and *Fraxinus* (to 2.9%). Decrease in the bottom, then rise of *Corylus* (to 11.5%). Reduction of *Pinus* (46.6%–34.6%). Presence of *Picea* and *Carpinus*. Single *Vitis*, *Viscum*, *Hedera*. Continuous curve of *Calluna* and *Pteridium*. Single *Triticum*-t. and Cerealia. Stable frequency of Filicales.	Small increase of *Potamogeton*. Stable frequency of Cyperaceae (to 1.6%). Regularly *Typha angustifolia / Sparganium*, *Equisetum*. Several spectra with *Thelypteris palustris*, *Stratiotes*, and *Myriophyllum spicatum*. Low values of green algae.	IV 4240–1400 BC
L-6 *Corylus-Quercus-Alnus*; 140–60 cm; 3610–2010 BC	Bottom limit: increase of *Corylus*, *Alnus*, and fall of *Pinus*. The highest frequency of *Quercus* (to 11.8%) in the upper part. Visible rise of *Alnus* to 20.9%. Decreasing tendency of *Pinus* (to 37.6%), *Betula* (to 13.7%), *Tilia* (to 2.9%), and *Ulmus* (to 4%). *Corylus* curve forms two picks at 130 cm – 15.6% and at 70 cm – 15.4%. *Fraxinus* to 3.7%. Increase of *Carpinus* to 2%. Continuous curve of *Fagus* below 1%. In the upper part single *Vitis* and *Viscum*. Among anthropogenic indicators e.g.: *Artemisia* (to 1.4%), *Rumex acetosella*-t. (to 1.5%), *Plantago lanceolata*, *Plantago major*. Stable Poaceae, *Humulus*, and *Ranunculus*. Decrease of Filicales.		
L-7 *Carpinus-Betula*; 60–21 cm; 2010–1400 BC	Bottom limit: decrease of *Corylus*, *Quercus*, rise of *Carpinus* and *Pinus*. Maximum of *Carpinus* (to 5.8%) and *Alnus* (to 26.2%). First *Quercus* decrease (10.4%–4.8%), then stable contribution. Constant fall of *Corylus* (10.8%–1.6%), *Fraxinus* (1.5%–0.1%), *Tilia*, and *Ulmus*. Increase of *Pinus* (to 41.5%) and *Betula* (to 16.3%) in the upper part. Presence of *Fagus*. Regularly *Vitis* and *Juniperus*. Strong increase of herbs. High frequency of Poaceae (to 8%), *Artemisia* (to 1.2%), *Rumex acetosella*-t. (to 2.3%), *Humulus* (to 1.1%), *Urtica* (to 2.6), *Plantago lanceolata* (0.6%), *Triticum*-t. (to 1%), and *Secale cereale* (to 2.3%).		

Table 3. Former Lake Gąsak. Results of pollen analysis

L PAZ and L PASZ; depth; age		Description of zones: Terrestrial vegetation	Description of zones: Aquatic and shoreline vegetation	Phase of basin develop-ment
GII-1 *Juniperus-Salix*-NAP; 925 cm; ca. 10 490–10 200 BC		High contribution of *Pinus* (45%), *Betula* (20%), *Salix* (3.5%), and *Juniperus* (5.1%). Numerous *Artemisia* (7.1%), Poaceae (9.4%), and Chenopodiaceae (2.3%).	Frequency of Cyperaceae 3.8%. Presence of *Equisetum*, *Sparganium*-t., *Potamogeton*, *Nymphaea alba*, and *Thelypteris palustris*. Single *Typha latifolia* and *Nymphaea candida*.	I ca. 10 490–9670 BC
GII-2 *Betula-Pinus-Ulmus-Corylus*; 925–840 cm; 10 200–8200 BC		Rise of *Betula* to 63.4%. *Pinus sylvestris* first decreasing to 25%, than rising to ca. 33%. Curve of *Salix* (to 3.5%). *Populus* in several spectra. Regular presence of *Ulmus* and *Corylus*. High but decreasing herbs, e.g: Poaceae (9.4%–3%), Cyperaceae (3.8%–0.2%), *Artemisia* (7.1%–0.8%). Filicales up to 2.1%.		
GII-3 *Corylus-Alnus-Quercus*; 840–770 cm; 8200–6450 BC		Bottom limit: decrease of *Betula*, increase of *Alnus*, *Ulmus*, and *Quercus*. Slight increase of *Pinus sylvestris* in older part than fall to 13.7%. Decrease of *Betula* to 22%. Fast increase of *Corylus* (to 35%) and *Alnus* (to 17%). *Ulmus* (to 5.5%), *Quercus* (to 4.3%), and *Fraxinus* generally below 1%, with maximum in upper part (3%). *Calluna* regularly noted in each spectrum. Low percentage curves of *Artemisia* (to 1.6%), and *Humulus lupulus* (to 0.7%). High representation of Poaceae to 6.5%. Beginning of *Pteridium* curve. Numerous Filicales monolete (to 3.6%).	Decrease Cyperaceae (to 1.3%). Regular occurrence of *Potamogeton*, *Thelypteris palustris*, *Nymphaea alba*. Several spectra with *Nymphaea candida*, *Sparganium*-t., and *Equisetum*. Single *Rumex aquaticus*-t.	II 9670–5120 BC
GII-4 *Ulmus-Quercus-Fraxinus*; 770–560 cm; 6450–3790 BC		Bottom limit: increase of *Pinus*, reduction of *Alnus*, *Corylus*, and *Ulmus*. Fall of *Pinus* (46%–18%) and *Betula* (26%–14%). Maximum of *Ulmus* (14.5%) and *Tilia* (4.7%). Increase of *Quercus* (to 11.2%) and *Fraxinus* (to 4.4%). Temporary fall then rise of *Corylus* to 23%. *Picea* below 1%. Regular presence of *Acer* and *Populus*. Maximum of *Calluna* (3.8%). High *Pteridium* (to 4.1%), Poaceae (to 4.2%), and *Artemisia* (to 2%). Systematic pollen of *Thalictrum*, *Filipendula*, *Galium*-t. Maximum of Filicales (to 4.5%).		
	GII-4a *Pinus*; 770–700 cm; 6450–5600 BC	Abundance of *Pinus* (to 46.9%). Increase of *Corylus* (to 23.3%). High amount of Poaceae and *Thalictrum*. Regular presence of *Rumex acetosa*-t.		
	GII-4b *Quercus-Tilia*; 700–560 cm; 5600–3790 BC	Numerous *Alnus*, *Betula*, *Pinus*, and *Corylus*. Rise of *Quercus* and *Tilia*. Single *Tilia platyphyllos*, *Hedera helix*, and *Taxus baccata*. Increase of *Calluna* and Poaceae.	Numerous *Nymphaea alba* and *Potamogeton*. Small rise of Cyperaceae (to 2.2%). More frequent *Sphagnum* in the upper part. Presence of *Sparganium*-t., *Rhynchospora*, *Menyanthes*, and *Nymphaea candida*. In the bottom part idioblasts of Nymphaeaceae.	III 5120–2600 BC
GII-5 *Corylus-Quercus-Pinus* (*Picea*); 560–400 cm; 3790–1770 BC		Bottom limit: decrease of *Quercus*, *Corylus*, *Betula*, *Ulmus*. Increase of *Pinus*. High and stable values of *Pinus sylvestris*, except of single pick (44.3%) in the bottom. *Alnus* reaches 12–19%. Strong fluctuation of *Corylus avellana* curve (to 23.3%). Small decrease of *Ulmus*. Maximum of *Quercus* (to 13.2%). Frequency of *Tilia*, *Picea*, and *Fraxinus* ca. 1–2% . Beginning of *Carpinus* (to 6%) and *Fagus* (<1%) curves. Single *Taxus*, *Viscum*, and *Hedera* pollen. Higher representation of *Calluna* (to 1.9%), Poaceae (to 3.9%), and *Artemisia* (to 2.9%). Regular presence of *Plantago lanceolata*, *Rumex acetosella*-t., and single Cerealia (*Triticum*-t., *Hordeum*-t.), and *Plantago major*. Continuous curve of *Pteridium* (to 1.8%). Filicales monolete to 2.9%.		
	GII-5a *Corylus-Alnus-Picea*; 560–440 cm; 3790–2450 BC	Numerous *Corylus* with three picks. Increase of *Alnus* (to 19%), *Betula*, and *Fraxinus*. Slight increase of *Picea* to 2.6%.		

	GII-5b *Carpinus*; 440–400 cm; 2450–1770 BC	High values of *Carpinus* to 6%, stable *Picea* (to 1.5%), *Fraxinus* (to 2.4%). Slight increase of *Tilia* (to 1.9%) and *Ulmus* (to 2.4%). More frequent *Plantago lanceolata* and *Rumex acetosa*-t.	Higher representation of Cyperaceae, *Typha latifolia* (to 2.9%), *Menyanthes*, *Sphagnum*, and *Rhynchospora*. Frequent *Nymphaea alba* and *Potamogeton*. Presence of *Thelypteris palustris*, *Sparganium*. Single *Myriophyllum verticillatum*, *Hottonia*, and *Scirpus*.	IV 2600 BC–190AD
GII-6 *Carpinus*-*Betula*-NAP; 400–235 cm; 1770 BC–180 AD		Bottom limit: decrease of *Corylus* and rise of *Carpinus*. High values of *Pinus* up to 45.6%. After a short reduction of *Betula* to 6.9%, fast increase to 23.5%. High frequency of *Alnus* (to 20%), *Quercus* (to 9.5%), and *Carpinus* (to 15.4%). Reduction of *Corylus* (to 12.8%), *Ulmus* (to 1.6%), *Fraxinus* (to 2.4%), and *Tilia* (to 2.3%). Continuous curve of *Fagus* and *Abies*. Increase of herbs. Frequent Poaceae (to 4.2%), and anthropogenic indicators such as: *Artemisia* (to 4.8%), *Plantago lanceolata* (to 1.3%), *Rumex acetosella*-t. (to 0.7%). Regularly *Triticum*-t., *Hordeum*-t., *Plantago major*, *Rumex acetosa*-t., Cichorioideae, Apiaceae, and *Humulus lupulus*. Appearance of *Secale* and *Cannabis sativa*. Decrease of *Pteridium* and Filicales (to 2%).		
	GII-6a *Carpinus*; 400–370 cm; 1770–1520 BC	Maximum of *Carpinus* 5.4% and *Alnus* 20%. Decrease of *Corylus* (2–3%), numerous *Quercus* (to 9.5%).		
	GII-6b *Betula*; 370–280 cm; 1520–380 BC	Fast rise of *Betula* to 23.2%, parallel to reduction of *Carpinus* (15.5–6.8%), *Quercus*, *Alnus*, and *Corylus*. Increase of NAP.		
	GII-6c *Carpinus*-*Quercus*; 280–240 cm; 380 BC–180 AD	Increase of *Carpinus* (14.4%), *Betula* (23.4%), and *Alnus* (18%). Reduction of herbs: Poaceae, *Artemisia*, and *Plantago lanceolata*.		
GII-7 *Pinus*-NAP; 50–23 cm above the water layer; 1800–2000 AD ?		Bottom limit: water layer High values of *Pinus sylvestris* (to 62.3%), smaller of *Betula* (to 8.1%) and *Alnus* (to 4.9%). Low frequency of *Quercus* (to 1.6%), *Carpinus* (to 1.2%), and *Corylus* (to 1.8%). Diversity of dwarf-shrubs represented by *Vaccinium*-t., *Calluna vulgaris*, *Andromeda* cf., and *Ledum palustre*. Frequent Poaceae (to 9%), *Artemisia* (to 2.6%), *Secale cereale* (to 6.8%), *Plantago lanceolata* (to 1.4%), *Rumex acetosella*-t. (to 2.5%), and Brassicaceae (to 1.8%). Continuous curves of *Triticum*-t., *Avena*-t., *Centaurea cyanus*, and *Rumex acetosa*-t.	Abundant *Sphagnum* (to 12%) and Cyperaceae (to 43.6%) in a top of sample.	V ?–2000 AD

Table 4. Lake Białe. Results of pollen analysis

L PAZ and L PASZ; depth; age		Description of zones: Terrestrial vegetation	Description of zones: Aquatic and shoreline vegetation	Phase of basin development
B-1 *Ulmus*-*Quercus*-*Fraxinus*; 850–635 cm; 6350–3870 BC		High and stable frequency of *Betula* (to 23.8%), *Alnus* (to 22.2%), and *Corylus* (to 16.1%). Fluctuation of *Pinus sylvestris* curve (to 39.2%) with decrease in the uppermost part. Slight increase of *Quercus* (to 13.2%), *Tilia* (to 4.2%), and *Fraxinus* (to 5.2%). Maximum of *Ulmus* (to 9%). Almost continuous curves of *Picea*, *Salix*, and *Populus* (below 1%). Single *Hedera helix* and *Viscum*. Among herbs the most frequent Poaceae (to 6.5%) and *Artemisia* (to 2.2%). Numerous *Pteridium* (to 2.3%).	Cyperaceae curve to 1.2%. Regularly *Potamogeton*, *Sparganium*-t. and *Thelypteris palustris*. Single *Callitriche*, *Nymphaea alba*, and *Typha latifolia*.	I 6350–3930 BC
B-2 *Corylus*-*Quercus*-*Alnus*; 635–440 cm; 3870–2160 BC		Bottom limit: decrease of *Ulmus*, *Tilia*, *Fraxinus*, as well as strong increase of *Corylus* and *Alnus*. High amount of *Quercus* (22.6%) and *Alnus* (33.8%). Fluctuations of *Corylus* curve (to 28.3%). Decrease of *Betula* in the upper part (16.6%–6.9%). Fluctuations of *Pinus* curve (to 30.7%). *Ulmus* (to 7.6%), *Tilia* (to 5.9%), *Fraxinus* (to 4.5%), and low values of *Picea* below 1%. Beginning of *Carpinus* curve. Single *Viscum*, *Hedera*, and *Ilex*. Small decrease of herbs. Presence of anthropogenic indicators such as: *Plantago lanceolata*, *Rumex acetosa*-t., *Rumex acetosella*-t., *Triticum*-t.	Small decrease of Cyperaceae. More frequent *Sparganium*-t. and *Callitriche*. Systematic presence of *Potamogeton*. Single *Alisma plantago-aquatica*, *Cladium mariscus*, *Myriophyllum*, and *Stratiotes*. Presence of *Ceratophyllum* leaf spines and idioblasts of Nymphaeaceae in the upper part.	II 3930–1900 BC
	B-2a *Alnus*-*Quercus*-*Ulmus*; 635–510 cm; 3870–2800 BC	Maximum of *Corylus* (28.3%), followed by decrease to 6.3%. High values of *Alnus* and *Quercus*, decrease of *Ulmus*, *Tilia*, *Fraxinus*, and herbs in the upper part.		
	B-2b *Corylus*-*Carpinus*; 510–440 cm; 2800–2160 BC	Fall of *Betula*. Fast increase of *Corylus* (to 18.6%). Occurrence of *Carpinus*. Beginning of *Rumex acetosella*-t. curve.		
B-3 *Carpinus*-*Betula*-NAP; 440–25 cm; 2160 BC –1500 AD		Bottom limit: synchronous decrease of *Ulmus*, *Tilia*, *Fraxinus*, *Quercus*, and rise of *Alnus*. First increase of *Pinus sylvestris* to 37.3%, than decrease. After a short rise, decrease of *Betula*. High frequency of *Carpinus*. Decrease of *Alnus* and *Corylus*. Continuous curves of *Ulmus*, *Tilia*, *Fraxinus*, and *Fagus*, with mean values of 1–2%. High number of NAP pollen, especially Poaceae. *Plantago lanceolata*, *Artemisia*, *Rumex acetosella*-t., and Chenopodiaceae. Regular *Triticum*-t. and *Secale cereale*. Decrease of *Pteridium* in the upper part. Filicales to 2.8%.		
	B-3a *Carpinus*-*Alnus*; 440–375 cm; 2160–1450 BC	Rise of *Carpinus* (to 12.6%) and *Alnus* (to 26.3%). Increase of *Corylus* (to 17%) in the older part, than decrease (to 5%). Minimum of *Betula* (to 4.5%). Frequent *Artemisia* (to 2.9%), *Plantago lanceolata* (to 2.3%), and *Rumex acetosella*-t. (to 0.6%).	Increase of Cyperaceae. Regularly *Sparganium*-t., *Potamogeton*, *Thelypteris palustris*, *Equisetum*, and *Sphagnum*. Several spectra with *Typha latifolia*, *Callitriche*, and *Nymphaea alba*. Single *Menyanthes*, *Scirpus*, *Myriophyllum*, and *Nuphar*. Frequent *Ceratophyllum* leaf spines.	III 1900 BC–1500 AD
	B-3b *Pinus*-*Betula*-NAP; 375–275 cm; 1450–550 BC	Strong reduction of *Carpinus* (from 6.3% to 0.1%). Decrease of *Corylus*, *Quercus*, and *Alnus*. High contribution of *Pinus* (to 32.9%), *Betula* (to 22.3%), and herbs. Maximum of *Artemisia* (to 4.3%). Almost continuous curve of Chenopodiaceae.		
	B-3c *Carpinus*-*Quercus*; 275–200 cm; 550 BC–100 AD	Increase of *Carpinus* (8.4%). Frequent *Quercus* (to 17.1%). Stable representation of *Alnus* (ca. 20%). Decrease of herbs such as: *Artemisia*, Poaceae, and *Rumex acetosella*-t.		
	B-3d *Betula*-*Pinus*; 200–150 cm; 100–380 AD	Increase of *Pinus* to 33.6%. Short but high culmination of *Betula* (to 32.4%). Decrease of *Quercus* (12.8–8.3%) and *Carpinus* (8–3.4%). Visible increase of herbs e.g.: *Triticum*-t., *Artemisia* (to 2.1%), Poaceae (to 5.1%), *Plantago lanceolata* (to 1.1%), *Rumex acetosella*-t. (to 1.2%), and *R. acetosa*-t. (to 1%). Single *Plantago major* and *Agrostemma githago*.		
	B-3e *Carpinus*-*Fraxinus*; 150–75 cm; 380–1100 AD	Absolute maximum of *Carpinus* (to 23.8%), than decrease (to 6.9%). High *Quercus* (to 13.4%). Stable but lower amount of *Betula* (to 16.4%). Decreasing tendency of *Alnus* (27.2–12.2%). Slight reduction of *Fraxinus*, *Tilia*, *Ulmus*, and strong reduction of herbs.		
	B-3f *Pinus*-*Alnus*-NAP; 75–25 cm; 1100–1500 AD	Stable frequency of *Carpinus* (to 9.4%), *Quercus* (to 11%), and *Betula* (to 15.3%). Increase of *Alnus* (to 20.2%), *Pinus* (to 36.3%), and *Salix* (to 2.3%). Sharp rise of herbs. High values of Poaceae (to 7.6%), *Artemisia* (to 3.2%) and *Rumex acetosella*-t. (to 2.7%), as well as *Triticum*-t. (to 1%), *Secale cereale* (to 2.7%), and *Cannabis sativa* (to 1.5%) in the upper spectra. Single *Avena*-t., *Fagopyrum* and *Centaurea cyanus*.		

Aster-type, *Helianthemum nummularium*, and *Pleurospermum austriacum*, in the region of the former Lake Gąsak also with *Gypsophila*. In moist places, besides *Betula* trees and *Salix*, dwarf shrubs of *Betula nana* were growing and herbs such as *Urtica dioica*, *Humulus lupulus*, *Filipendula*, *Thalictrum*, and representatives of Apiaceae and Cyperaceae.

Palynological record of postglacial development of vegetation is presented in diagrams from the Lakes Lucieńskie, Białe, and Gąsak.

PHASE III
The development of birch- and birch-pine forests

GII-2 *Betula-Ulmus-Corylus* L PAZ (10 290–8200 BC; Fig. 3), **L-3 *Betula-Pinus* L PAZ** (9140–7930 BC; Fig. 2) – corresponds to G1/87-4 *Betula-Populus-Ulmus* (9600–8550 BC) and G1/87-5 *Pinus-Betula-Ulmus-Corylus* zones in Lake Gościąż (Ralska-Jasiewiczowa et al. 1998, fig. 8.22)

Warming at the beginning of the interglacial favoured the spread of open woodland with *Betula* as a dominating tree and more limited participation of *Salix* and *Populus tremula* (macrofossils of aspen were found in Lake Gościąż sediments). In dry habitats pine played more significant role in the forests, also *Juniperus* was present there. The herb layer flora of pine forests included *Calluna vulgaris* and ferns, for example *Dryopteris filix-mas* and sporadically *Pteridium*. Local differences were observed suggesting that in the forests surrounding the site Gąsak II birch predominated until about 8200 BC (Fig. 3), while the region of Lake Lucieńskie, after a short episode of birch dominance, already about 8530 BC was colonized by pine (Fig. 2). The difference suggests that larger areas of dry habitats which favoured pine in the competition with birch could have occurred around Lake Lucieńskie. In the vicinity of the site Gąsak *Corylus avellana* (6% of total pollen sum) and *Ulmus* (2% of total pollen sum) occurred from about 9010 BC. *Sorbus* cf. *aucuparia* appeared in the shrub layer. In the profile from Lake Gościąż differences were observed in the migration rate of hazel and elm. *Ulmus* curve increased up to several percentages around 9160 BC, while that of *Corylus* as late as around 8600 BC. Elm was expanding in moist and rather fertile places within birch forests. Hazel, due to its wider tolerance toward soil conditions, could compete satisfactorily with both birch and pine. Tallentire (2002) suggests that its migration was not limited to dry surfaces covered to a considerable degree by pine, but included also wet sites dominated by birch. Among the herbaceous plants Poaceae, *Artemisia*, *Thalictrum*, Chenopodiaceae, *Anthemis*-type, *Galium*-type, *Potentilla*, and Apiaceae were best represented.

In the herb layer of birch woods there occurred *Urtica*, *Filipendula*, *Thalictrum*, Apiaceae, *Lythrum*, *Lychnis*, *Valeriana dioica*, *Sanguisorba officinalis*, *Humulus lupulus* as climber, and Cyperaceae. *Ophioglossum* and *Botrychium* were growing on relatively poor, sandy substrate.

PHASE IV
The development of the mesophilous deciduous forests with abundant hazel and alder woods

GII-3 *Corylus-Alnus-Quercus* L PAZ (8200–6450 BC; Fig. 3), **L-4 *Corylus-Alnus-Ulmus-Quercus* L PAZ** (7930–6380 BC; Fig. 2) – corresponds to G1/87-6 *Corylus-Alnus-Quercus* (7900–6100 BC) zone in Lake Gościąż (Ralska-Jasiewiczowa et al. 1998, fig. 8.22).

Rapid expansion of hazel and the formation of new communities particularly in moist habitats, reduced the area occupied by light demanding birch. In the surroundings of Lake Gąsak the area covered by pine forests underwent no changes until about 7200 BC, and then it rapidly diminished as the deciduous trees expanded (Fig. 3). In the environs of Lake Lucieńskie pine forests were common all of the time and deciduous forests played a clearly subordinate role (Fig. 2). Birch and aspen also grew as admixtures in pine woods. In the herb layer among the other plants there occurred *Calluna vulgaris*, *Vaccinium*, and *Dryopteris filix-mas*. In moist places the frequency of hazel and elm was increasing. Shrub layer in woodland was dominated by *Corylus avellana*. High frequency of hazel indicates good light access to the forest bottom in the situation of low forest density (Tallantire 2002). Hazel pollen percentages of 26.7–35.2% about 7300–6800 BC indicate common occurrence of this shrub in the forests. Hazel thickets could develop in woodland mantles, in openings within forest stands or on sunny hill slopes (Fig. 3). *Tilia cordata*, *Quercus*, *Alnus*, and *Fraxinus* appeared in Gostynin region, *Quercus* was present locally from 8100 BC. *Quercus petraea* developed on poor habitats and easily expanded in open pine forests. *Quercus robur* favoured more fertile habitats (Szymański 2006). Oaks grow well in the company of *Tilia cordata*, which has advantageous influence on soil due to the ability to destroy dense herb cover and accelerate the decay of litter (Radoglou et al. 2008). *Tilia cordata* was present in the studied microregion from about 7700 BC (Figs 2, 3).

Around lakes and along water flows various forest communities developed which resembled modern alder woods with *Alnus glutinosa*, *Betula*, *Pinus sylvestris*, and *Salix* and/or carrs with *Alnus*, *Fraxinus*, *Ulmus*, and *Rhamnus cathartica* in the shrub layer. The analysis of isopollen maps suggests that alder expanded relatively quickly here, as in many other regions of Poland, and its postglacial migration proceeded along the Vistula river valley (Szczepanek et al. 2004). According to the data obtained from Lake Gościąż the process of alder expansion lasted in some places less than 100 years (Ralska-Jasiewiczowa et al. 1998). In the surroundings of the site Gąsak it could last longer, even a few hundred years. The representation of alder pollen (probably *Alnus glutinosa*) reached 5.9% about 8100 BC and rose to 14% about 7500 BC. Forest free areas were small, additionally they were masked in the pollen record by the presence of wind pollinated trees and shrubs known as heavy pollen producers. Several plant taxa grew in wet habitats, e.g. Cyperaceae, *Filipendula*, *Thalictrum*, *Lythrum*, *Humulus lupulus*, *Solanum dulcamara*, *Valeriana*, Poaceae, Apiaceae, *Caltha*-type, *Cirsium*-type, and *Mentha*-type. *Oxalis acetosella*, which prefers soils of low pH, appeared in the herb layer of shaded woods. Open places in the woodland communities created favorable conditions for the growth for instance of *Calluna vulgaris*, *Melampyrum*, *Pteridium aquilinum*, and other ferns. *P. aquilinum* growing in cleared forests and at forest edges could in some places form dense thickets slowing down the natural regeneration of forest stands (Humphrey & Swaine 1997). The basic mechanism of this process was that the increased shadowing was unfavourable for tree seedlings and, in addition, bracken produced phytotoxins, which limited the development of other plants in near vicinity (Dolling et al. 1994). Bracken probably favoured mature forest stands with low phosphorus content in the soil, as it does presently (de Keersmaeker et al. 2004). On dry sandy places *Artemisia*, *Jasione montana*, and *Scorzonera humilis*-type appeared.

PHASE V

The spread of multi-species deciduous forests with different species composition

GII-4 *Ulmus-Quercus-Fraxinus* L PAZ (6450–3800 BC; Fig. 3), **L-5 *Ulmus-Tilia-Fraxinus* L PAZ** (6380–4120 BC; Fig. 2)**, B-1 *Ulmus-Quercus-Fraxinus* L PAZ** (6350–3870 BC; Fig. 4) – corresponds to G1/87-7 *Ulmus-Fraxinus-Quercus* (6100–3900 BC) zone in Lake Gościąż (Ralska-Jasiewiczowa et al. 1998, fig. 8.22)

Pine forests and mixed forests with pine, birch, and oak developed on light, sandy substratum. The temporary increase of pine pollen frequency in profile Gąsak II about 6400–6200 BC seems to coincide with the intensive spread of bracken and increased concentration of microcharcoals, indicating periodical forest clearance (Fig. 3). This may reflect the temporary disturbances caused by the Mesolithic societies, the activity of which was documented by archaeological records (Rybicka 2011). The herb layer of pine forests included *Calluna vulgaris*, *Arctostaphyllos uva-ursi*, *Vaccinium*, and ferns, for instance *Dryopteris filix-mas* and *Pteridium*. On more fertile and fresh habitats multi-species deciduous forests predominated. From about 6050 BC elm was an important forest component in the vicinity of Gąsak, while in the region of Lake Lucieńskie it remained an insignificant admixture until 4500 BC (Fig. 2). Oak gained in importance from 5700/5600 BC, at the same time *Acer* appeared and slightly later *Tilia cordata* increased. Lime develops mainly in meso- and eutrophic habitats but can survive also on poor soils. It prefers fresh and moderately moist habitats. Lime can regenerate not only in the forest gaps but also under the closed canopy because it can withstand overshadowing (Lang 2003, Radoglou et al. 2008). The young seedlings can survive in strong shadow, but approximately in the 3rd–4th year they require more light (Pigott 1991). Lime grows in different communities but it is characteristic species of the alliance *Carpinion betuli* and occurs frequently in the association *Tilio-Carpinetum* (Matuszkiewicz 2007). The ability to propagate vegetatively is its survival strategy, particularly at the range limit. In unfavorable conditions lime is able to grow in shrubby form (Radoglou et al. 2008). The regions of Lake Gościąż and site Gąsak were included in the range of the other lime species *Tilia platyphyllos*. At present the northern range limit of this species runs along the July isotherm 17.0°C (Zagwijn 1996) and includes southern Poland. In Poland *T. platyphyllos* is characteristic species of lime-maple forests belonging to the alliance *Tilio-Acerion* (Matuszkiewicz 2007). According to Zając and Zając (2001) it occurs in modern vegetation of the studied region. During the climatic optimum of the middle Holocene the communities of mesophilous forests could develop in moist habitats, on slopes, dominated by *Ulmus*, *Fraxinus*, *Acer*, *Tilia cordata*, and *T. platyphyllos*. Hazel continued its growth as the main component of shrub layer together with *Viburnum opulus*, *Cornus sanguinea*, *Frangula alnus*, and *Sambucus nigra*, and in pine forests also *Juniperus*. *Fraxinus excelsior* appeared in woodlands resembling alder woods and carrs but never as co-dominating species. About 4230 BC yew (*Taxus baccata*) became a new component of the lower tree layer in forest stands near the site Gąsak II (Fig. 3). The data obtained from Lake Gościąż indicate that it was present in the region since ca. 4735 BC. Starting from the climatic optimum yew pollen was recorded in Poland within the modern range of this species (Noryśkiewicz 2006). Its frequency increased in the Subboreal (ca. 3000 BC) as it was the case in the other European sites (Krupiński et al. 2004, Deforce & Bastiaens 2007). *Taxus* is sensitive to dryness and ground frost, optimal growth conditions it finds in regions of high moisture, mild winters and summers, with mean annual temperature 9.0–10.0°C. In Europe it grows in pine forests and mixed forests with *Abies*, *Fagus*, *Carpinus*, and *Picea* (Seneta 1987), more seldom in riverside habitats. In Warmia and Mazury regions yew occurs in mixed woodland stands with birch, oak, alder, hornbeam, and spruce. It grows very well in oak-hornbeam woods (Dobrowolska & Farfał 2002). It is difficult to speculate in what community type yew was growing during the climatic optimum of the Holocene, in the vicinity of the studied sites these were certainly moist forests. Król (1975) indicates that ecological optimum for yew in the lowlands is situated between the moist forest and ash carr. Deforce and Bastiaens (2007) in their survey of yew history draw attention to the fact that in Belgium and southern Netherlands its pollen and macrofossils occur together with seeds and other macroscopic remains of plants typical for woodland with *Alnus* and *Betula* or for fen vegetation communities. They suggest that yew could grow on peat.

An important indicator of warm climate was *Vitis*, probably *V. vinifera* ssp. *sylvestris*, which was present in the neighborhood of Lake Lucieńskie about 5050 and 4250 BC (Fig. 2). This species, sensitive to water shortage, occurs in wet forests in different habitats, but mostly develops in areas periodically or permanently flooded, in temperate regions of North America and Eurasia (Arnold 2002). According to Ellenberg et al. (1991) it is a sub-oceanic taxon. The studied region is located beyond its present-day range. Southern Moravia and Ukrainian Zakarpatian region belong to the northern part of the modern range of *V. vinifera* ssp. *sylvestris* (Madera & Martinková 2002, Balyan et al. 2004). This subspecies is closely related to the cultivated *V. vinifera* ssp. *vinifera.* In certain areas of western Europe it is characteristic taxon for elm-ash carrs *Ficario-Ulmetum* (Matuszkiewicz 2007). On the other hand the investigations carried out in Romania indicate that *V. vinifera* ssp. *sylvestris* occurs also in the zone of temperate continental climate with Mediterranean influences, where mean annual temperature is between 9.0 and 11.2°C, temperature maximum oscillates from 29.6 to 42.2°C, and the absolute minimum from –20.0 to –36.4°C. In the Gostynin area the present day mean annual temperature is 8.0°C. In Rumania *Vitis* grows on sandy alluvial elevations near river terraces covered with sandy soils, in forest communities built by *Fagus*, *Alnus glutinosa*, *Robinia*, and *Quercus* (Popa et al. 2009). In the middle Holocene *Vitis* range must have been much wider that at present. It is evidenced by such records as impressions and charred pips of wild grape vine from the Neolithic of Sweden, Germany, and the Czech Republic (Lityńska-Zając & Wasylikowa 2005) and *Vitis* pollen grains from the same period (ca. 4200 BC) from Prasto in Denmark (Rausing 1990). In the Holocene deposits from Poland no macroscopic remains of *Vitis* older than the Middle Ages were discovered. Pips of cultivated grape vine were found in material e.g. from the 9–10–12th and 15th century AD on Wawel Hill in Kraków (Wasylikowa 1991), from the 13th till 18th in Kołobrzeg, Gdańsk and Elbląg (Latałowa et al. 2007). In Poland *Vitis* pollen grains were often encountered in the deposits of the Holocene climatic optimum (Granoszewski et al. 2004). The oldest records are known from Wolbrom (ca. 7100 BC or 8100 BP, the Silesia-Cracow Upland, Latałowa & Nalepka 1987), Juszek (ca. 6900 BC or 8000 BP, north Poland, Miotk-Szpiganowicz unpubl. in Granoszewski et al. 2004), Lake Błędowo (ca. 6900–5500 BC or 8000–6500 BP, middle Poland, Bińka et al. 1991) and from the mountains (but here pollen transport from the south is possible, Ralska-Jasiewiczowa 1980). In the Atlantic period the range of wild grape vine included also the Masurian Lake District (Wacnik 2009). In the Gostynin Lake District, in the regions of both Lakes Lucieńskie and Gościąż, grape vines could find the best growth conditions at the edges of wet forests in the same ecological niches as *Hedera* and *Humulus* (Ralska-Jasiewiczowa et al. 1998).

The presence of *Viscum album*, a species of continental climate, indicates warm summers with the mean temperature of the warmest month above 15.5°C, while the occurrence of blooming specimens of *Hedera helix*, an oceanic species, is evidence of mild winters with the mean temperature of the coldest month above 1.7–2.0°C (Zagwijn 1994). Ivy appeared near Lake Lucieńskie about 6660 BC, since 5250 BC it was present in the surroundings of the site Gąsak (Figs 2, 3), and since 7000 BC near Lake Gościąż. The well represented semiparasitic mistletoe (*Viscum album*) occurred in the neighborhood of the examined lakes from 6100 BC, and near Lake Gościąż from 7300 BC.

Forest clearings favoured the development of *Calluna vulgaris*, *Pteridium aquilinum*, *Melampyrum* as well as Poaceae, *Thalictrum*, Cichorioideae, Rubiaceae, and Apiaceae. Locally *Rumex acetosa*, *R. acetosella*, *Ranunculus acris*, *Potentilla*, and *Plantago media* were present. *Artemisia*, *Urtica*, and Chenopodiaceae were growing on slightly more fertile soils, in sandy places *Ornithogalum* occurred. The creepers *Humulus lupulus* and *Solanum dulcamara* developed in carrs growing on lake shores. Temporary forest disturbances were the effect of the natural forest fires and of purposeful burning by the Mesolithic hunter-gatherers.

PHASE VI

Transformations of the mixed deciduous forests; the main elm fall, the spread of hazel and oak

GII-5 *Corylus-Quercus-Pinus* (*Picea*) L PAZ (3800–1790 BC; Fig. 3), **L-6 *Corylus-Quercus-Alnus* L PAZ** (4210–2000 BC; Fig. 2), **B-2 *Corylus-Quercus-Alnus* L PAZ** (3870–2060 BC; Fig. 4) – corresponds to G1/87-8 *Corylus-Quercus-Fraxinus* (3900–1900 BC) zone in Lake Gościąż (Ralska-Jasiewiczowa et al. 1998, fig. 8.22)

The disturbances of forest communities result in changes of their composition, first of all in distinctly diminished significance of *Ulmus* about 3730 BC. The main *Ulmus* fall due to the complex causes was widely recorded across Europe about 3800–4000 BC (Parker et al. 2002, Ralska-Jasiewiczowa et al. 2003). In Lake Gościąż profile it was dated to ca. 3950 BC, in Lake Białe ca. 3900 BC (Fig. 4), and in the site Gąsak ca. 3850 BC (Fig. 3). In Lake Lucieńskie region contemporary with the elm decline alder gained in importance. In the surroundings of the former Lake Gąsak the significance of pine forests increased and pine became the main forest forming tree in this area. The decline of elm was accompanied by the temporary increased hazel frequency, caused by a more intensive pollen production due to the better light conditions and/or by the temporary spread of hazel shrubs following forest disturbance by humans. Similar phenomenon was observed in the case of oak recorded in the site Gąsak (Fig. 3). Oaks regenerate well in small gaps within tree stands where acorns falling down from nearest trees can accumulate and seedlings find better development conditions thanks to the limited competence from the other species. As it comes out from modern observations acorns disseminated by animals (mainly birds) develop particularly well under the canopy of pine trees when they reach the age of about 70 years and young oak trees successively invade wet to dry places (Pigan

& Pigan 1999, Modrzyński et al. 2006). The regeneration of oak may be hampered by animals eating acorns or browsing on seedlings and young trees, which happen first of all in places exposed to the sun (Szymański 2006, Tobisch 2010). About 2900–2700 BC the successive and final reduction of elm was recorded in the profiles from the sites Gąsak and Lake Lucieńskie (Figs 2, 3). In the Lake Lucieńskie it was followed in the next centuries by increased significance of *Corylus* and *Quercus*, documented also, but less pronounced, in the data from the site Gąsak (Fig. 3). Oak was an important component of mixed pine-oak forests and multi-species deciduous forests. According to Ralska-Jasiewiczowa et al. (2004) no exact analogues of former communities dominated by oak and hazel can be found in modern vegetation. These were probably temporary communities, which developed in response to the periodical occupation and exploitation of terrain by the Neolithic populations. Relatively numerous traces of occupation by the Sub-Neolithic cultures originate from this period (Rybicka 2011). It seems likely that these communities having park-like character were the oldest scrub forests of anthropogenic origin. They survived in the region of Lake Lucieńskie until about 2000 BC and near the site Gąsak until about 1840 BC. Successive expansion of hornbeam in deciduous forests brought about the formation of communities resembling modern oak-hornbeam forests. *Carpinus* appeared in the surroundings of the investigated lakes about 2100 BC, and about 2000 BC became an important forest tree in the region (>5% of pollen), what is confirmed by isopollen maps and by pollen record from Lake Gościąż (Ralska-Jasiewiczowa et al. 1998, 2004). Hornbeam migration was correlated with the decline of elm, lime, oak, and hazel and was closely connected with human activity. Parallel to hornbeam expansion was the elimination of hazel. This process often described in Europe from the time ca. 2500–1860 BC, according to Ralska-Jasiewiczowa should be explained as an indirect effect of human activity during the Bronze Age but not of climatic change (Ralska-Jasiewiczowa et al. 2004). It was recorded in the site Gąsak (Fig. 3) about 2200 BC, when hazel pollen rapidly decreased (23.3%–9.5%), in Lake Białe (Fig. 4) around 1900 BC, and in Lake Lucieńskie (Fig. 2) about 2100 BC. Scattered spruce trees were growing in the forests of the microregion. Alder woods and carrs were still present at lake shores. The presence of *Taxus baccata*, *Juniperus*, *Hedera helix*, and *Viscum album* was confirmed. In the neighborhood of Lake Lucieńskie again *Vitis* appeared (from ca. 2100 BC). Shrub layer in the forests became enriched in *Frangula alnus* and *Sambucus nigra*.

The appearance of *Ilex aquifolia* in two pollen spectra from Lake Białe, dated to ca. 3140 and 2880 BC (Fig. 4), causes problems for interpretation. In the Holocene sediments from Poland *Ilex* was hitherto recorded only in Lake Racze from Wolin, in spectrum dated to about 950 BC (Latałowa 1992), and in the youngest deposits of Lake Świętokrzyskie (cf. *Ilex*, Makohonienko 2000). In all other cases its presence was explained by the redeposition (e.g. Wacnik 2009). *Ilex* was relatively abundant in the younger Tertiary and occurred, though less frequently, in interglacial floras (including Eemian interglacial). In Europe, as it is evidenced by the investigations in Ireland and Great Britain, *Ilex* pollen is encountered in the Holocene sediments from about 3800 BC (5000 BP). The northern part of the range of this species includes north Germany, Denmark, south Norway, and south Sweden. Walther et al. (2005) have shown that the northern limit of *Ilex* range in the past (historical documents) followed the January isotherm of 0°C as it is the case also at present time. *Ilex* is an indicator of mild climate because it occurs in areas of mild winters and not too dry summers. It grows scattered in beech and beech-fir forests, occurs also in fresh oak-hornbeam and oak-birch forests. According to Zagwijn (1994) the nearest to Poland localities with *Ilex* pollen dated to about 3650–2400 BC (4900–3900 BP) can be found in Denmark. In the pollen profile from Lake Solsø (Denmark) the oldest pollen grain of *Ilex* was recorded about 2800 BC (Odgaard 1994). In the case of the Lake Białe there are no unequivocal arguments for counting *Ilex* pollen among the redeposited material (no other taxa from secondary bed were found, pollen preservation was very good), although the increased erosion is indicated by higher content of heavy metals in the sediments from this period (Woszczyk & Spychalski 2011). Long distance transport is also rather unlikely. *Ilex* is poor pollen producer and as insect pollinated species is characterized by the limited pollen dispersion (Walter et al. 2005).

The occurrence of *Ephedra distachya* pollen in the materials from Lake Lucieńskie (about 2900 BC) is interesting. It was recorded also several times in Lake Gościąż sediments (ca. 5300, 3800, 2600 BC, and 1500 AD). At present this species grows in southern Europe and the nearest to Poland localities occur in Ukraine (Bezus 1999). In south Slovakia *Ephedra* was growing on sandy dunes still before the World War II (Martin 2003, Baranec et al. 1994). Its pollen may also come from the long distance transport. The ability of *Ephedra* pollen to disperse over great distances was often observed in NW North America and China (Birks 1981, Zhao et al. 2007, Makohonienko 2009). However, the possibility cannot be excluded that extremely dry sandy areas existed in the studied microregion, suitable for the survival of steppe elements (perhaps including *Ephedra distachya*). Also today the Lake District is characterized by the high representation of plants of steppe character (Paul 2010).

In the herb layer of thinned forests *Calluna vulgaris*, *Pteridium aquilinum*, and other herbaceous plants were still frequent. The number of human indicators increased. In the site Gąsak II this was manifested about 2850 BC (Fig. 3) by the increased frequency of Poaceae, *Artemisia*, Cyperaceae, *Plantago lanceolata*, as well as the appearance of *Plantago major* and first of all of *Triticum*-type pollen. Pollen of *Hordeum*-type was noted since 2350 BC. In the other profile from the same locality (profile Gąsak I) a single pollen grain of *Triticum*-type occurred much earlier, already ca. 3800 BC. In the vicinity of Lake Lucieńskie Cerealia pollen was recorded about 4000 BC, whereas the frequency of *Artemisia*, *Plantago lanceolata*, Cyperaceae, and *Rumex acetosella* increased about 3300 BC (Fig. 2). The appearance of these indicators was connected with agricultural activities initiated about 3800/3600 BC by the population of the Funnel Beaker culture and continued, with varying intensity, by people of the Sub-Neolithic cultures. The settlement of the Funnel Beaker culture left the most numerous occupation traces in the region of the studied lakes, particularly in the environs of Lakes Białe and Gąsak (Rybicka 2011). The use of fire for clearing of forests and manuring cultivated fields with ash was reflected in the increased concentration of charcoal microfragments in both sites.

PHASE VII

The development of oak-hornbeam forests, intensification of forest clearings

GII-6 *Carpinus-Betula*-NAP L PAZ (1790 BC –190 AD, top of lake sediment; Fig. 3), **L-7 *Carpinus-Betula* L PAZ** (2000–1400 BC, top of the profile; Fig. 2), **B-2 *Carpinus-Betula*-NAP L PAZ** (2060 BC–1500 AD, top of the profile; Fig. 4) – corresponds to G1/87-9 *Carpinus-Betula*-NAP (1900 BC–1000 AD) zone and G1/87-10a *Pinus*-NAP (1000–1525 AD) subzone in Lake Gościąż (Ralska-Jasiewiczowa et al. 1998, fig. 8.22)

The role of *Corylus* in the forests finally diminished (pollen percentages <5%). Fast reduction of hazel in deciduous forests was followed by the expansion of *Carpinus betulus*. As in several other pollen diagrams from the territory of Poland also here three phases of the more intense hornbeam development in the forests were observed (Ralska-Jasiewiczowa & Latałowa 1996). The first one was dated to 1900–1500 BC in Lake Lucieńskie (Fig. 2), to 1730–1900 BC in former Lake Gąsak (Fig. 3), and to 1900–1500 BC in Lake Białe (Fig. 4). At the same time the decreases of lime, spruce, ash, and elm, and in the Lake Lucieńskie region also of oak were observed, which coincided with increased alder significance and the appearance of beech. The deforestation was connected with the settlement of the Trzciniec culture population. Hornbeam is a pioneer species which can quickly colonize new terrains thanks to the ability to fast regeneration. It regenerates well on wet soil in favorable light conditions created in forest gaps. In such conditions it can successfully compete for instance with oak (Tobisch 2010). Due to great ability to form offshoots from the trunks or stumps hornbeam was the main component of oak-scrubs. It grows well on wet soils and avoids dry areas, for this reason it belongs to the components of periodically inundated carrs. It probably formed oak-hornbeam forests with the participation of other trees such as lime, maple, and birch. Beech could appear in such communities sporadically, but its percentages not exceeding 1.4% suggest that it was not growing in the near surroundings of the site Gąsak. *Fagus sylvatica* exceeded the threshold value of 1% about 1550 BC. In the neighborhood of Lake Białe it could grow since 1500 BC. From 1900 to 150 BC the frequency of oak became distinctly reduced in the forests possible in consequence of selective cutting of this tree and difficulties with its regeneration in woodland stands. In the case of extensive deforestation the natural regeneration of oak becomes much weaker than for instance that of hornbeam. According to observations of modern woodland, oak is weaker competitor than hornbeam in invading larger forest gaps (wider than the length of individual tree), while the opposite is true in the case of smaller gaps, drier and better lighted, where the competitive ability of hornbeam becomes weaker (Tobisch 2010). In some oak-hornbeam forests (*Tilio-Carpinetum*) *Tilia cordata* and *Carpinus betulus* regenerated well in gaps of different size, whereas the regeneration of *Quercus robur* was either very poor or almost completely stopped (Babiec 2007). In the shrub layer besides *Corylus*, *Juniperus*, and *Frangula alnus*, also *Lonicera xylosteum* appeared. The regular records of *Abies alba* pollen (from ca. 2300 BC) are connected with the phase of strong anthropogenic changes of vegetation, which made possible pollen transportation from longer distances, probably from the south. At present the Gostynin area lies beyond the range of fir. The highest percentages of its pollen up to 1.2% recorded in the first centuries AD were probably an effect of distant pollen transportation. In the peat-bog Żabieniec, situated 60 km south of the studied microregion, during the period 0–900 AD fir pollen attains the highest values of 2.6% suggesting its local occurrence (Balwierz 2010, Lamentowicz et al. 2009). From about 1100 BC the areas overgrown by hornbeam diminished. Economic and settlement activities of the Lusatian culture societies (numerous traces of settlements within the 5 km radius from pollen sites, Rybicka 2011) left deforested and strongly cleared places, which were invaded by secondary communities with birch as the dominating species. This suggests the short lasting use of individual land pieces and leaving them fallow after impoverishment. The possibility to use ash for manuring impoverished soils was restricted by the limited availability of wood suitable for burning, which in turn necessitated longer periods of leaving the exploited areas as fallows (Rösch et al. 2004, Wacnik & Rybicka 2011). The source of wood could be birch coppices developing on fallow lands. Their modern counterpart can be the semi-natural community dominated by *Betula pendula* with the participation of *Populus tremula*, which is considered the pre-forest phase in the development of vegetation in poor habitats (Wojterska 1990, Młynkowiak & Krutyna 2009). The fragments of bark and wood of *Pinus sylvestris* found in the sediments from the site Gąsak are evidence of pine growth on the lake shore. The strongest hornbeam decline occurred about 890–560 BC in the surroundings of site Gąsak (Fig. 3) and about 600 BC near the Lake Białe (Fig. 4). This was the time of the intensive local activity of the Lusatian culture population (Rybicka 2011). After this episode the renewed regeneration of hornbeam forests took place, which lasted from about 400 BC to 20 AD near the Lake Białe (Fig. 4) and from about 480 BC to 100 AD in the vicinity of the site Gąsak (Fig. 3). At the same time pine pollen concentration decreased in the diagrams, which probably reflects diminished pollen transportation from longer distance due to the higher density of forests around the lakes. The significance of oak increased and yew was present in the region of Lake Białe. These new major forest clearances were connected with the settlement of the Przeworsk culture at the beginning of our era. Four settlement sites of this culture were discovered at the distance of a few hundred metres from the shore of Lake Białe, near the coring site, and within the radius of 5 km there were 14 settlements (Rybicka 2011). Farming and settlement building caused strong deforestation of the area, which is evidenced by high percentages of such plants as *Triticum*, *Rumex acetosella*, *R. acetosa*, *Plantago lanceolata*, and Poaceae. The third period of expansion of forest communities with hornbeam took place about 400–900 AD in the environs of Lakes Białe and Gościąż (Ralska-Jasiewiczowa et al. 1998). No sediments of this age were recovered in the other sites studied.

The periods of oak-hornbeam forest recession were characterized by the rise of the frequency of plants indicating the increasing anthropogenic disturbance of vegetation and a significant thinning of neighboring forests. From about 800 BC in the site Gąsak, in addition to cereal pollen of *Triticum* and *Hordeum* types, *Cannabis sativa* appeared and about 450 BC also *Secale cereale* (Fig. 3). In the profile from Lake Białe pollen grain of *Triticum* was recorded about 1900 BC and slightly later that of *Hordeum* (Fig. 4). *Secale cereale* appeared in local cultivations about 20 AD and *Cannabis sativa* about 350 AD. The area neighboring the lake was permanently deforested in the Middle Ages (since 1300 AD). At that time the importance of cultivated plants confirming intensive soil tillage increased. Pollen of *Avena* and *Fagopyrum* as well as of weeds *Centaurea cyanus* and *Polygonum aviculare* appeared. This phase ends the continuous record of vegetation changes.

PHASE VIII

The overgrowing of the lake and the formation of the peat-bog Gąsak. The development of pine woods and the deforestation of the site region

GII-7 *Pinus*-NAP L PAZ (the section of inexact chronology, probably the last centuries, depth 40–23 cm; Fig. 3) – corresponds to the younger section of the G1/87-10b *Pinus*-NAP subzone in Lake Gościąż dated to 1520–1985 AD (Ralska-Jasiewiczowa et al. 1998, fig. 8.22)

Pine forests with small admixture of birch expanded in the surroundings of the overgrown lake. The frequency of pine pollen above 60% confirms the absolute dominance of *Pinus sylvestris* in the neighborhood of the new formed Gąsak peat-bog. *Calluna vulgaris* was growing in the herb layer of the neighboring forests. Macrofossils of *Vaccinium uliginosum*, Ericaceae, and *Ledum palustre*, as well as pollen of cf. *Andromeda polifolia* document their occurrence as the components of peat-forming vegetation.

Only small patches of alder woods and probably also of oak-hornbeam forests persisted in the vicinity of the peat-bog because their habitats were exploited as arable fields or meadows. Cereals were cultivated not far from the site, including *Secale*, *Triticum*, *Hordeum*, and *Avena*. *Solanum nigrum* pollen type may suggest the introduction of potato cultivation (*Solanum tuberosum*). In the profile from Lake Gościąż the oldest pollen grains of this type were dated to about 1840 AD. The occurrence of cereal weed *Centaurea cyanus* additionally confirms that the deposit accumulated in the last centuries. The continuous occurrence of *Centaurea cyanus* was recorded in Lake Gościąż since 1525 AD (Ralska-Jasiewiczowa et al. 1998). Abundant representatives of field and ruderal weeds include *Artemisia*, Chenopodiaceae, *Rumex acetosella*-type, *R. crispus*-type, and *Plantago lanceolata*. There appeared also new taxa, such as *Polygonum aviculare*, *Convolvulus arvensis*, *Vicia*-type, and *Centaurea cyanus* mentioned before. Numerous meadow plants, for instance Poaceae, *Rumex acetosa*-type, *Centaurea jacea*, and *Scleranthus perennis* indicate the exploitation of meadows.

THE CHANGES OF AQUATIC AND TELMATHIC VEGETATION

LAKE LUCIEŃSKIE

Four phases were distinguished in the development of the lake (Fig. 5).

Phase I (11 000–10 740 BC)

In the lake shore zone patches of bog vegetation were growing with *Sphagnum* (regular occurrence of spores in the deposit) and Cyperaceae and reed swamps with *Equisetum*, *Scheuchzeria palustris*, and *Typha angustifolia* and/or *Sparganium*. Nearby grew limnophyte communities included *Nymphaea alba*, *Potamogeton*, and *Stratiotes aloides*. The presence of *Ceratophyllum* was recorded, the species of which grow mainly in shallow or moderately deep reservoirs with eutrophic and standing water (Podbielkowski & Tomaszewicz 1996). The colonies of two genera of chlorophytes *Pediastrum* and *Botryococcus* developed in open water.

Phase II (10 740–9330 BC)

The lake was densely overgrown by limnophytes. The shallowing of the basin is indicated by the high representation of *Stratiotes aloides* (water soldier) pollen in the period 10 200–9400 BC. Bennike and Hoek (1999) suggest that *Stratiotes* "spread to Poland and the Netherlands by the Late Glacial, whereas it probably did not arrive in Fennoscandia until the early Holocene". The seeds of this species rarely occur in the sediments dated to the beginning of the Holocene, an example may be the site Złotoria in north-east Poland (Stachowicz-Rybka, pers. com.). Its microfossils, leaf spines and pollen, were found in Late Glacial and/or early Holocene deposits in several sites, for instance Żabinko (Bohncke et al. 1995), Kluki (Tobolski 1987), and Kraśne (Bałaga 2007). From the western and central Poland the remnants of *Stratiotes* are known

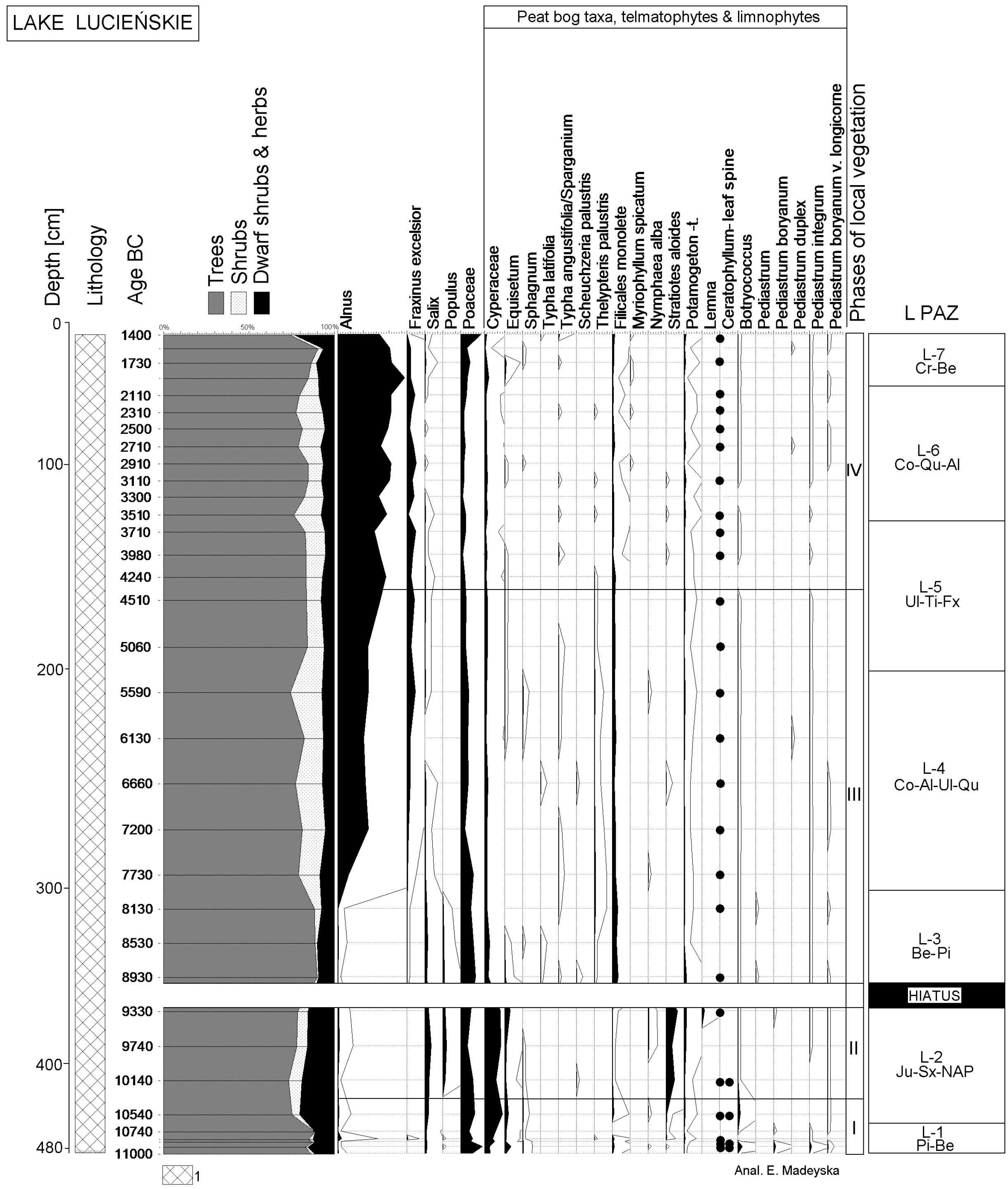

Fig. 5. Lake Lucieńskie. Percentage pollen diagram of selected taxa showing the development of telmathic and aquatic vegetation. Abbreviations see Fig. 2

from the Subboreal period in the site Giecz 2 and from the Holocene (no precise age determination is given) in Giecz 1, Mirowice and the environs of Lake Skrzynka in Bory Tucholskie Forest (Gałka 2010 and the literature cited). Nowadays *Stratiotes* develops mainly in shallow basins with stagnant water and thick layer of organic sediments at the bottom. There it grows in dense populations, sometimes forming periodically inundated "meadows". It propagates mainly vegetatively. The occurrence of *Stratiotes* is an indicator of the last stadium of aquatic plants preceding the development of reed swamps (Matuszkiewicz 1984). In the Gostynin Lake District it grows in the association *Hydrocharitetum morsus-ranae* (Załuski & Cyzman 1994).

Stratiotes was accompanied by *Nymphaea* *alba*, *Potamogeton*, *Ceratophyllum*, and *Lemna*. In the shore zone having the most shallow water or being periodically flooded, sedge bogs with Cyperaceae, *Scheuchzeria palustris*, and *Equisetum* developed. Undoubtedly at that time the lake was becoming shallower.

Phase III (9330–4510 BC)

In the shore zone Cyperaceae, *Thelypteris palustris*, and *Scheuchzeria palustris* were growing as well as reed swamp patches with *Typha latifolia*, and *Typha angustifolia* and/or *Sparganium*. At the border of phases II and III, sedges became distinctly reduced, *Equisetum* was also less frequent. *Nymphaea alba* was recorded, the representation of *Potamogeton* diminished, *Stratiotes* almost disappeared. *Ceratophyllum* as well as green algae *Pediastrum* and *Botryococcus*, which were probably freely floating in open water, were recorded regularly. At that time lake water level increased.

Phase IV (4510–1400 BC)

The composition of reed swamp communities changed. The frequency of *Thelypteris palustris*, *Typha angustifolia* and/or *Sparganium*, and *Equisetum* decreased, *Typha latifolia*, *Scheuchzeria palustris*, and *Nymphaea alba*, which were earlier recorded, now

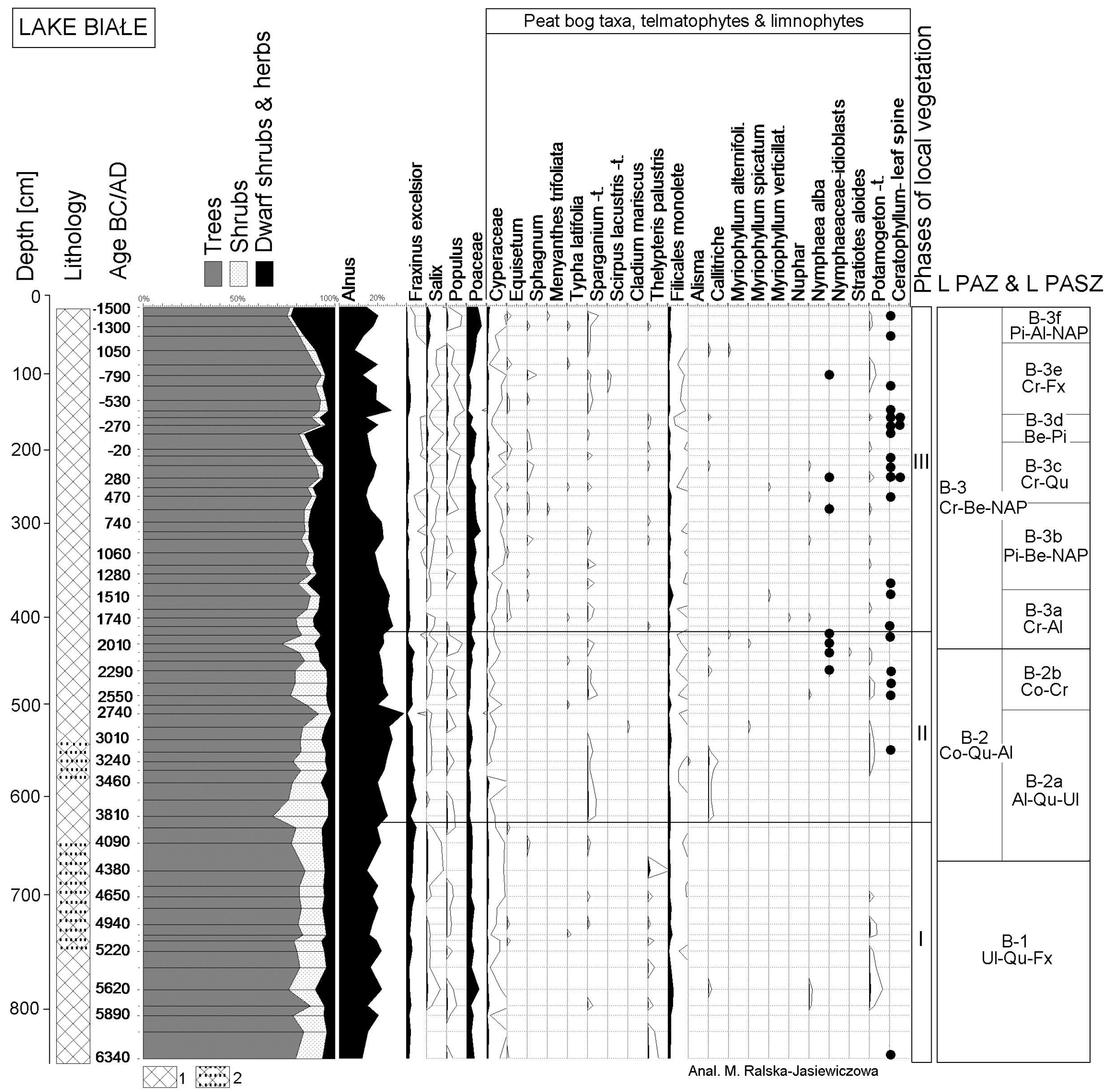

Fig. 6. Lake Białe. Percentage pollen diagram of selected taxa showing the development of telmathic and aquatic vegetation. Abbreviations see Fig. 4

disappeared. Instead, *Myriophyllum spicatum* and again *Stratiotes* appeared. The frequency of Cyperaceae was low, similar to that in the preceding phase. Relatively abundant was *Potamogeton*, also *Ceratophyllum* was present. The frequency of chlorophytes slightly decreased.

LAKE BIAŁE

In the period between 6350 and 1500 BC three phases of lake development were distinguished (Fig. 6).

Phase I (6350–3930 BC)

In the vicinity of alder woods and carrs reed swamps developed with *Typha angustifolia* and/or *Sparganium* and infrequent *Typha latifolia*. In the shore zone grew Cyperaceae, *Thelypteris palustris* (the majority of *Filicales* spores may come from *Thelypteris*), *Nymphaea alba*, and *Equisetum*. *Potamogeton* and *Callitriche* developed in slightly deeper water.

Phase II (3930–1900 BC)

The characteristic feature of the period between 3930 and 3150 BC was the very intensive development of *Callitriche* and *Typha angustifolia* and/or *Sparganium*. In the younger sediments numerous remains of *Potamogeton*, *Ceratophyllum*, *Myriophyllum alternifolium*, *M. spicatum*, *Stratiotes aloides*, and *Nymphaea alba* (idioblasts of Nympheaceae) were preserved. Reed swamp communities were changed. *Thelypteris palustris* and *Equisetum* completely disappeared, instead in addition to the earlier recorded *Typha angustifolia* and/or *Sparganium* and *Typha latifolia* new elements *Cladium mariscus* and *Alisma plantago-aquatica* sporadically appeared (ca. 3200 BC).

Phase III (1900–1500 BC)

In some places the shore zone was covered by peat bog. Communities were present with Cyperaceae, *Thelypteris palustris*, *Equisetum*, *Menyanthes trifoliata*, and *Sphagnum*. Also reed swamps developed, with *Typha latifolia*, *Typha angustifolia* and/or *Sparganium*, and *Scirpus lacustris*, which penetrated the zone occupied by plants with floating leaves represented by *Nuphar* and *Nymphaea alba*. The group of submerged plants included *Potamogeton*, *Ceratophyllum*, *Callitriche*, *Myriophyllum verticillatum*, and *M. alternifolium*.

FORMER LAKE GĄSAK

For the most part of the Holocene the sedimentation basin functioned as a small lake. As late as about 190 AD it became overgrown by peat-forming communities. Vegetation changes are divided in five phases (Fig. 7).

Phase I (10 500–9670)

In the shore zone, in addition to the numerous Cyperaceae and *Equisetum*, *Thelypteris palustris*, *Typha angustifolia* and/or *Sparganium* and *Sphagnum* occurred. The zone of plants rooted in the bottom was well developed, with abundant *Nymphaea alba* and rare *N. candida*. Idioblasts of Nymphaeaceae recorded in the sediment confirm the development of this group of plants *in situ*. In relatively shallow water *Potamogeton* and *Ceratophyllum* occurred.

Phase II (9670–5120 BC)

In the neighborhood of intensively developing alder woods and carrs reeds wamps occurred built by Cyperaceae, *Thelypteris palustris*, and *Equisetum*. Reed swamp communities with *Typha angustifolia* and/or *Sparganium* became enriched by the appearance of *Typha latifolia* and *Rhynchospora*. Locally there grew also *Scheuchzeria palustris*, *Menyanthes trifoliata*, and *Carex lasiocarpa*, identified on the basis of scattered tissue fragments dated to about 6750–6450 BC (Żurek et al. 2009). In the lake shore zone mosses *Drepanocladus* sp. and *Calliergon trifarium* appeared. *Nymphaea alba* was rather frequent. The presence of *Nuphar* was recorded and at the beginning of the zone (before 6760 BC) also of *Nymphaea candida*. In deeper part of the lake *Potamogeton* grew abundantly.

Phase III (5120–2600 BC)

The greatest taxonomic diversity of the telmathic zone was recorded in this phase. *Typha angustifolia* and/or *Sparganium*, *Typha latifolia*, *Rhynchospora*, *Cladium mariscus*, *Ranunculus flammula*, *Thelypteris palustris*, *Polygonum amphibium*, and *Triglochin* were growing at the lake shore. From the sediments dated to about 4900–4700 BC tissue fragments (Tab. 5) were identified belonging to *Carex lasiocarpa*, *Carex rostrata*, *Scheuchzeria palustris*, and a *Sphagnum* section *Sphagnum* and *S.* section *Cuspidata* (see also Żurek et al.

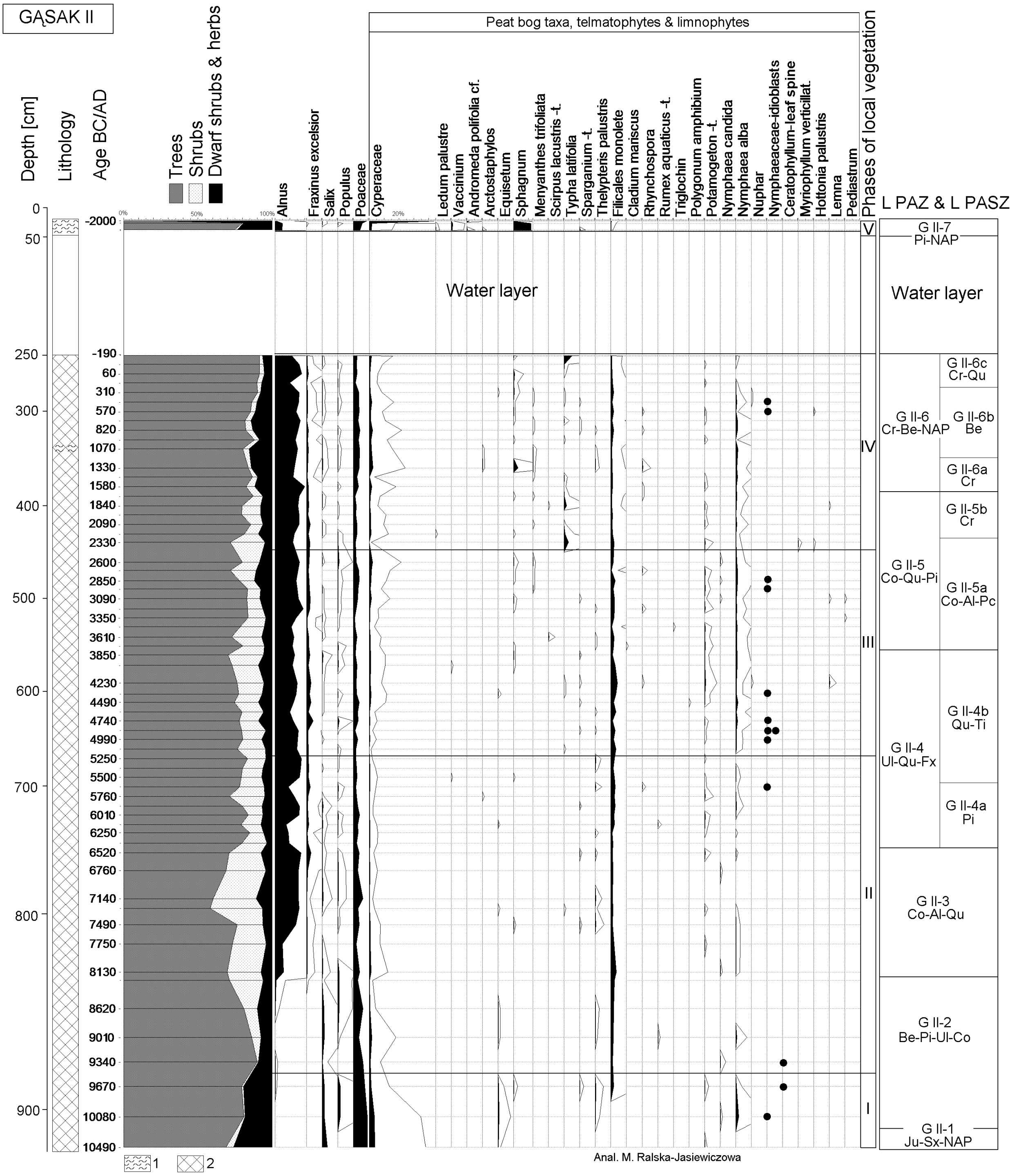

Fig. 7. Former Lake Gąsak, profile Gąsak II. Percentage pollen diagram of selected taxa showing the development of telmathic and aquatic vegetation. Abbreviations see Fig. 3

2009). The slight increase of *Sphagnum* representation (spores) from about 4000 BC is evidence that some places at the shore were converted into peat-bog. With the development of lake shallowing process from about 3000 BC the presence of *Menyanthes trifoliata* pollen is connected. In shallow water, patches of communities composed of plants with floating leaves, *Nymphaea alba*, *N. candida*, and *Nuphar*, developed abundantly. *Potamogeton* and *Lemna* also occurred there.

Phase IV (2600 BC–400 AD)

The characteristic features of this phase were quickly developing reed swamps, in which *Typha latifolia*, *Rhynchospora*, and

Menyanthes trifoliata grew abundantly with some admixture of *Thelypteris palustris*, *Typha angustifolia* and/or *Sparganium*, and *Hottonia palustris*. The last mentioned species prefers muddy substratum in eutrophic and mesotrophic stagnant water. The communities similar to *Nupharo-Nymphaeetum* were well developed. About 1200–1100 BC probably the distinct lowering of lake water level took place, which is marked by the occurrence of peat layer within gyttja at the depth of 350–340 cm. Peat analysis (Tab. 5) showed that it was made up by peat-forming communities which included *Scheuchzeria palustris*, *Menyanthes trifoliata*, *Equisetum limosum*, numerous mosses such as *Drepanocladus aduncus*, *Messia triquetra*, *Calliergon trifarium*, *Sphagnum magellanicum*, *S. fallax*, *S. cuspidatum* and various members of the family Cyperaceae, e.g. *Carex lasiocarpa*, *C. limosa*, *C. rostrata*, *Eleocharis palustris*, *Rynchospora*, and *Eriophorum vaginatum* (see also Żurek et al. 2009). In slightly deeper water *Nymphaea alba*, *Potamogeton natans*, and rarely *Nuphar* were growing.

Phase V (ca.?–2000AD)

This is the terminal phase of lake overgrowing and the time of the peat-bog formation. Limnophytes were completely absent. Extremely numerous were pollen grains of sedges (up to 43.6% at the top of the profile), which took part in peat formation as it was shown by tissue analysis. In the initial stage loose peat layers were separated by intercalations of water, the compact peat layer being formed only at the very top. Peat analysis showed that the first peat-forming communities were dominated by sedges, such as *Carex lasiocarpa*, *Carex* sp., *C. rostrata*, and *Scheuchzeria palustris*, which built the layer of fen peat (*Bryalo-Parvocarpicioni*). Mosses *Drepanocladus aduncus* and *Calliergon trifarium*, *Sphagnum* species, and *Equisetum limosum* were less numerous (Fig. 8; see also Żurek et al. 2009). At the depth of 50 cm the temporary sedge-moss peat changed into moss peat (*Ombro-Sphagnioni*). In its formation mainly sphagnum mosses took part (*Sphagnum* spores up to 11.9%) such as *Sphagnum fallax*, *S. magellanicum*, *S. cuspidatum*, and *S. teres*. The participation of species from the sedge family was lower, they were represented mainly by *Carex limosa*, *C. rostrata*, *Carex* sp., and *Eriophorum vaginatum*. Dwarf shrubs of *Oxycoccus palustris*, *Ledum palustre*, and *Vaccinium uliginosum* constituted a characteristic group. Taking into consideration the local development of communities built by several sphagnum species (mainly

Gąsak II	Percentage values of plant tissues																																		
Depth [cm]	Sphagnum magellanicum	Sphagnum s. Sphagnum	Sphagnum fallax	Sphagnum cuspidatum	Sphagnum s. Cuspidata	Sphagnum s. Acutifolia	Oxycoccus palustris	Ledum palustre	Vaccinium uliginosum	Ericaceae	Eriophorum angustifolium	Carex limosa	Carex lasiocarpa	Carex rostrata	Carex sp.	Scheuchzeria palustris	Menyanthes trifoliata	Warnstorfia fluitans	Drepanocladus aduncus	Drepanocladus sp.	Straminergon stramineum	Meesia triqueta	Pseudocalliergon trifarium	Aulacomnium palustre	Bryopsida	Typha angustifolia	Eleocharis palustris	Utricularia sp.	Potamogeton natans	Nuphar sp.	Polypodiales	Equisetum limosum	Pinus sylvestris (bark)	Pinus sylvestris (wood)	Varia
20-30	15	+	45	+	+		+	+			3	10		5	3	12		1			+			+	1							+	+	+	3
35-40	10	+	60	+	+		2	+	+		+	5		+	3	15					+				+							+	+		4
40-50	50	+	35	+	+	+	3	+			+	5		+	1	2																			3
220-230		2	3		+						+	+	50	5	5	7			2				10		+	+	+	+				1	+		15
230-240		1	1		+								35	5	+	8			1				3		1	+	+	+		+			+		45
300-310						+							+	+	+	+	+		+			+	+		+				+				+	+	
340-350	8	+	5	+						+	5	10	6	2	2	15	+		5				30		5			+				+			5
630-640		+			+								+	+		+									+					+			+	+	
760-770													+			+	+			+			+							+			+	+	
930-940																																		100	
940-946																																		+	

Anal. M. Kloss

Fig. 8. Results of plant tissues analysis from former Lake Gąsak deposits (acc. to Żurek et al. 2009)

Table 5. Comparison of regional and local phenomena noted in the pollen records from Gostynin Lake District area

No.	Phenomenon/event	Territorial range (type)	Description of phenomena/events in the pollen diagrams			
			Lake Gościąż	Former Lake Gąsak	Lake Lucieńskie	Lake Białe
1	Early Holocene phase of high *Betula* frequency	Regional	From 9400 to 8650 BC, several culminations and the highest maximum of 70% at ca. 9160 BC	From 10 080 to 8620 BC, single maximum of 63% at ca. 9340 BC	Presence of hiatus, in a single pollen spectrum 45% *Betula* value, imprecise chronology	No sediment
2	Early Holocene phase of high *Pinus sylvestris* representation	Regional	From ca. 8600 to 8200 BC with maximum of 53%	Not register	From ca. 8530 to 8130 BC with maximum of 71%	No sediment
3	Short-lasting phase of high *Pinus sylvestris* at ca. 6500–6100 BC	Probably regional (anthropogenic)	From ca. 6497 to 6397 BC (max. 46%), coincident with *Ulmus*, *Corylus*, and *Alnus* fall	From ca. 6390 to 6160 BC (max.47%), with strong *Corylus*, *Ulmus*, and *Alnus* decrease	At ca. 6130 BC increase of *Pinus* to 50%, low resolution of analyses	No sediment
4	Early Holocene maximum of *Corylus*	Regional	At ca. 7200 BC (32%)	At ca.7270 BC (35%)	Not register, low resolution of analyses	No sediment
5	Beginning of continuous *Pteridium* curve with values exceeding1%	Regional	At ca. 6500 BC	At ca. 6130 BC	At ca. 6130 BC	At ca. 6350 BC
6	Early and middle Holocene (9600–5000 BC) mean values of *Pinus*	Local	ca. 35%	ca. 30%	ca. 50%	ca. 25%
7	Presence of *Tilia platyphyllos*	Local	Numerous pollen, almost continuous curve between 6044 and 2660 BC	Regular pollen presence between 4200 and 200 BC at Gąsaku I profile	Not register	Not register
8	Time of appearance and frequency of *Acer*	Local	Present from ca. 7490 BC, more frequent from 5550 BC	Not numerous pollen grains from 5760 BC	Not numerous from 5590 BC	Not numerous from 4650 BC
9	Time of presence and frequency of *Taxus*	Local	Noted from 4600 BC and 1500 AD. Quite frequent between 3100 and 2700 BC	Single from 4230 to 2700 BC, frequent from ca. 3000 BC	Not register	Single between 2900 BC and 200 AD
10	Main *Ulmus* fall	Regional (changes of other taxa accompanied the elm fall are of local character)	At ca. 3900 BC, coincident with *Quercus* increase. *Corylus* expansion initiated from ca. 4150 BC proceeded main elm fall	At ca. 3850 BC, coincident with culmination of *Corylus* and fall of *Betula*.	At ca. 3980 BC, coincident with slight fall of *Betula* and increase of *Pinus*, *Corylus*, and *Quercus*	At ca. 3810 BC, together with small rise of *Quercus*, maximum of *Corylus* and fall of *Pinus*
11	High amount of *Corylus* at ca. 3850 BC	Regional (anthropogenic)	3850–3650 BC	3850–3610 BC	3500 BC	3810 BC
12	Presence of *Vitis*	Local	Single at ca. 3400 BC and at 19th/20ve cc AD	Not register	Regular from ca. 5060 to 1400 BC	Not register
13	First phase of *Ulmus* regeneration	Regional	3300–3150 BC	3230–3090 BC	Not register	3240–3140 BC

14	Second *Ulmus* fall	Regional (changes of other taxa accompanied the elm fall are of local character)	At ca. 2750 BC, together with increase of *Corylus*, *Quercus*, and *Alnus*	At ca. 2850 BC accompanied by *Quercus* increase	At ca. 2800–2710 BC together with rise of *Corylus*	At ca. 2740 BC, with strong decrease of *Tilia*, *Corylus*, *Fraxinus*, and rise of *Quercus* and *Alnus*
15	Subboreal maximum of *Corylus* and final *Ulmus* fall	Regional	At ca. 1950 BC with drops of *Tilia* and *Quercus*	At ca. 1970 BC together with *Tilia* fall	At ca. 2310 BC early culmination is a specific feature of site	At ca. 2010 BC with *Tilia* and *Fraxinus*
16	Beginning of continuous curve of *Fagus*	Local	From ca. 2800 BC	From ca. 3000 BC	From ca. 6130 BC unreliable result, low resolution of analyses	From ca. 2400 BC
17	First maximum of *Carpinus*	Regional	ca. 1600–1500 BC	ca. 1710–1580 BC	ca. 1910–1730 BC	Ca. 1650–1510 BC
18	The lowest Holocene frequency of *Betula*	Local	Values of 1–2% at ca. 2160–1900 BC	Value of 7.4% at ca. 3850 and 9.2% at ca. 1720 BC	Not register	Value of 4.5% at ca. 1900 BC
19	Second maximum of *Carpinus*	Regional	At ca. 100 BC	At ca. 60 BC	No sediment	At ca. 100 BC
20	Beginning of the late Holocene expansion of *Betula*	Local (anthropogenic background)	From ca. 1660 BC	From ca. 1330 BC	From ca. 1730 BC	From ca. 1510 BC
21	Third maximum of *Carpinus*	Regional	At ca. 650 AD	No sediment	No sediment	Between ca. 400 and 900 AD

Sphagnum fallax), dwarf shrubs, sedges, and particularly high participation of *Scheuchzeria palustris* we may suggest that in the top part transitory moss-sedge peat was formed (Fig. 8; see also Żurek et al. 2009).

COMPARATIVE ANALYSIS OF THE HOLOCENE VEGETATION CHANGES IN THE REGIONS OF GOSTYNIN AND LAKE GOŚCIĄŻ

The most interesting point in the investigations carried out in the Gostynin region was to confirm the regional character of certain phenomena, which could be used as chronological markers and to indicate local changes specific for the environment in the surroundings of individual sites. The results of comparative analysis are presented in the form of diagrams (Figs 9, 10) and table (Tab. 5).

CONCLUSIONS

The correlation of the results based on the profiles studied allowed to obtain continuous palynological record from about 11 000 BC to 1500 AD. For the last centuries only fragmentary data were available from the top of the profile Gąsak.

The oldest material dated to the end of the Allerød interstadial was found at the bottom of the core from Lake Lucieńskie. Pollen analysis from this site showed that the sedimentation stopped about 1400 BC and that younger material was probably washed out. The sedimentation at the site Gąsak began at the Late Glacial/Holocene transition. Here also the youngest sediments were lacking and the continuous pollen record ended about 190 AD, when the floating mat covered the whole water surface. The profile from Lake Białe provided the information about environmental changes from about 6340 BC to the end of Middle Ages (ca. 1500 AD). This is also the most detailed record of the youngest period in the history of natural environment in the Gostynin region, of greatest significance from the local anthropogenic changes point of view.

Palynological investigations made possible the reconstruction of changes of forest communities in the environs of Gostynin. The comparison of the results indicated the predominance of regional phenomena, which occurred approximately at the same time in most of the studied profiles. This statement concerns the character of the dominating communities, their taxonomic composition and succession of changes. These are:

– the phase of high *Pinus* values ca. 6500–6200 BC, contemporary with declines of *Ulmus*, *Corylus*, and *Alnus*, the beginning of high *Pteridium* values and high charcoal concentration. This phase was connected with deforestations by fires caused probably by local activity of Mesolithic societies;

– three *Ulmus* falls, the main one dated to ca. 3900–3800 BC, the second one to ca. 2850–2750 BC, and the third one to ca. 2000–1950 BC (exceptionally to 2300 BC in Lake Lucieńskie) and the intense development of *Corylus*, which coincided with elm falls;

– three expansions of *Carpinus* indicating periods of weaker settlement activity in the region of the studied sites, dated to ca. 1750–1500 BC, 100–60 BC, and 400–900 AD;

– the phase of *Betula* spread in the younger Holocene from about 1730/1330 BC to the beginning of our era, possibly caused by the type of farming, which included the use of tree ash for manuring;

Several phenomena of local character were also discovered. These were for instance:

– the greatest importance of pine in forests in the Lake Lucieńskie region in the early Holocene;

– the occurrence of *Vitis vinifera* ssp. *sylvestris* in the vicinity of Lake Lucieńskie from 5060 to 1400 BC.

– in the Gostynin region lower percentages of *Taxus baccata*, *Tilia platyphyllos*, *Acer*, and *Fagus* than in Lake Gościąż.

An interesting phenomenon, but susceptible of various interpretations, was the occurrence of *Ilex* pollen in the sediments of Lake Białe dated to about 3200–3000 BC and *Ephedra distachya* in the middle Holocene sediments from Lakes Białe (ca. 2300 BC) and Lucieńskie (ca. 2900 BC).

Considering the periods of low water levels, the phases of water reservoirs development were recognized. The process of the shallowing of the former lake and the formation of peat-bog Gąsak about 190–400 AD was described. In the history of Lake Lucieńskie, which came into existence in an interstadial, the phase of low water level characterized by the abundant development of *Stratiotes aloides* was recorded about 10 540–9330 BC. In Lake Białe the aquatic and telmathic vegetation showed small changes.

The surroundings of the sites studied by pollen analysis were inhabited from the Mesolithic to the period of Roman influences. People exploited most intensively the region of Lake Białe, most weakly that of Lake Lucieńskie. The oldest disturbances of woodland communities, indicating small deforestations and clearings with the use of fire by the Mesolithic hunter-gatherers were recorded in the profile Gąsak about 8130 BC.

The intensity of anthropogenic changes of vegetation increased with the arrival of farmers belonging to the Funnel Beaker culture, which is represented by the greatest number of settlements in the studied microregion. The mosaic of forest communities was formed at that time composed of thinned forests, shrubby forests, and patches of grasslands. Clearing was done mostly with fire. A connection was observed between the formation of small gaps in forest stands, for instance due the disturbances caused by the Neolithic populations, and the spread of *Quercus*. Local changes in woodland communities were stabilized by the agricultural activity and settlement of the Trzciniec culture. The deforestation of larger areas promoted the spread of hornbeam.

Lusatian settlement which appeared about 1300/1200 BC occupied different areas than the preceding settlement. The use of fields for cultivation was probably short-lasting, perhaps periodical. Waste lands were invaded by secondary communities with birch, which is why the phase of birch expansion characteristic for this period was recorded in the profiles from Lake Białe and site Gąsak (ca. 1500–1350 BC).

The later settlement of the Przeworsk culture, which manifested itself in the strong though short-lasting anthropogenic phase in the profile from Lake Białe between about 50 BC and 180 AD (Fig. 4), was confirmed by archaeological discoveries. After the recession, agricultural activity increased again in the Middle Ages around the 10^{th}–11^{th} century AD.

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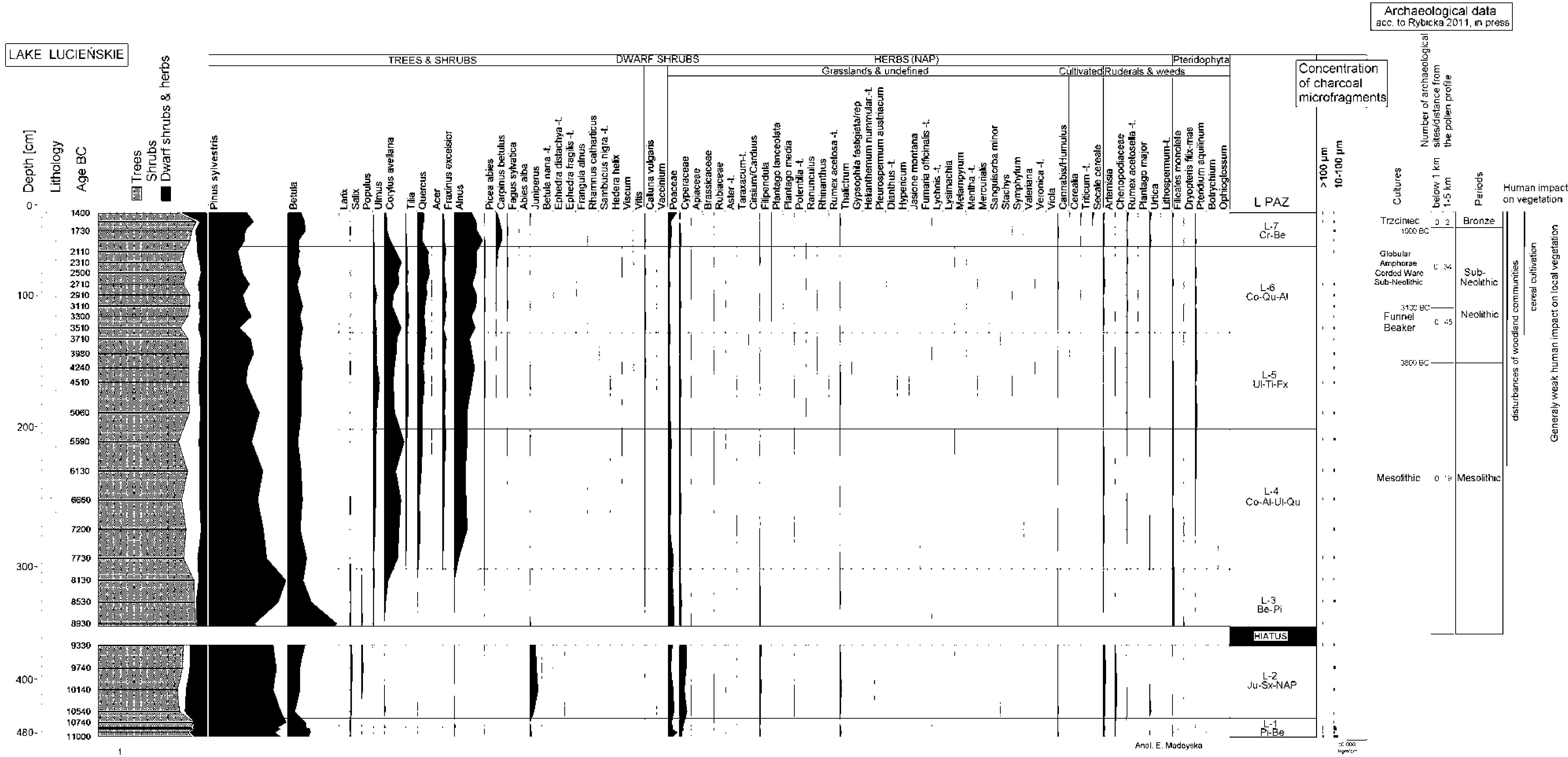

Fig. 2. Lake Lucieńskie. Percentage pollen diagram of selected taxa showing the development of terrestrial vegetation. 1– gyttja. Abbreviations: Pi-*Pinus sylvestris*, Be-*Betula*, Ju-*Juniperus*, Sx-*Salix*, NAP-herbs, Ul-*Ulmus*, Co-*Corylus*, Al-*Alnus*, Qu-*Quercus*, Fx-*Fraxinus*, Ti-*Tilia*, Cr-*Carpinus*

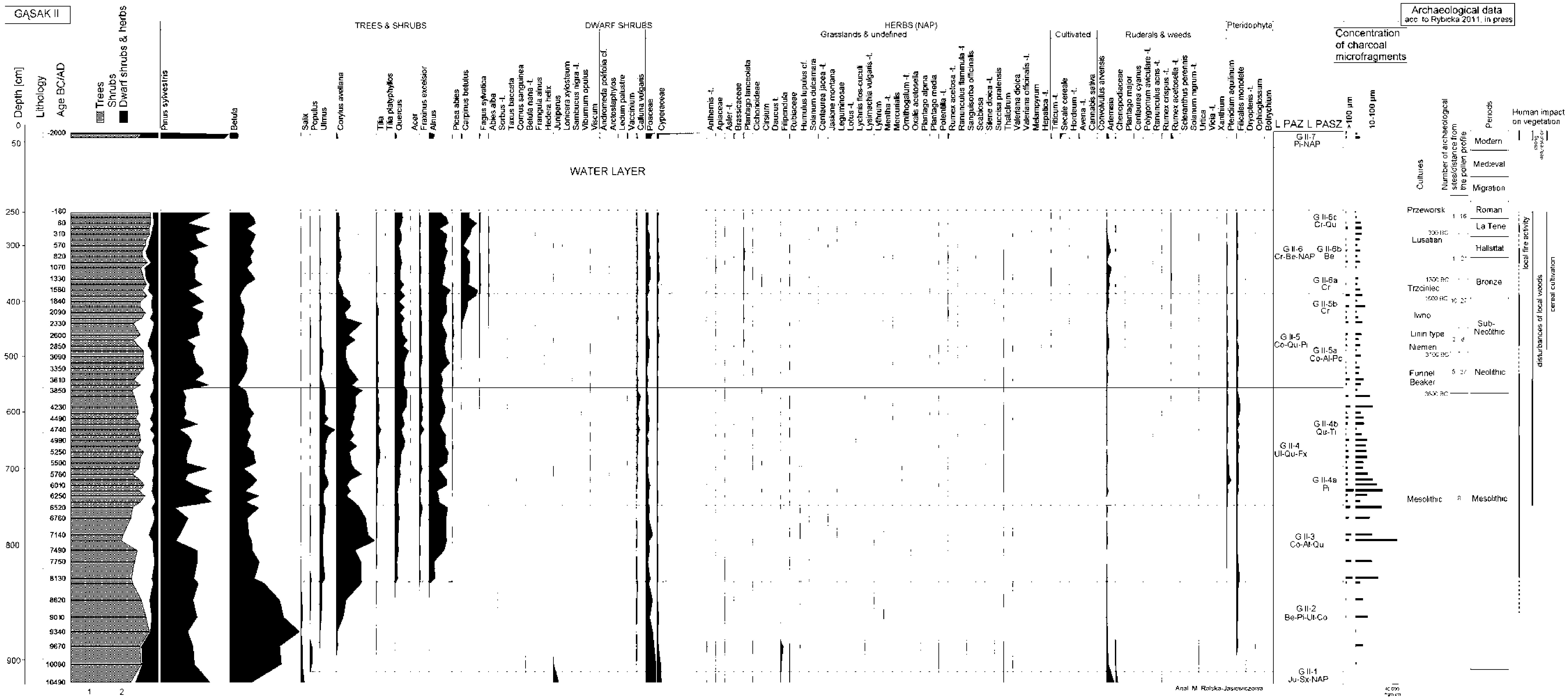

Fig. 3. Fossil Lake Gąsak, profile Gąsak II. Percentage pollen diagram of selected taxa showing the development of terrestrial vegetation. 1– gyttja, 2– peat. Abbreviations: Ju-*Juniperus*, Sx-*Salix*, NAP-herbs, Be-*Betula*, Pi-*Pinus sylvestris*, Ul-*Ulmus*, Co-*Corylus*, Al-*Alnus*, Qu-*Quercus*, Fx-*Fraxinus*, Ti-*Tilia*, Pc-*Picea*, Cr-*Carpinus*

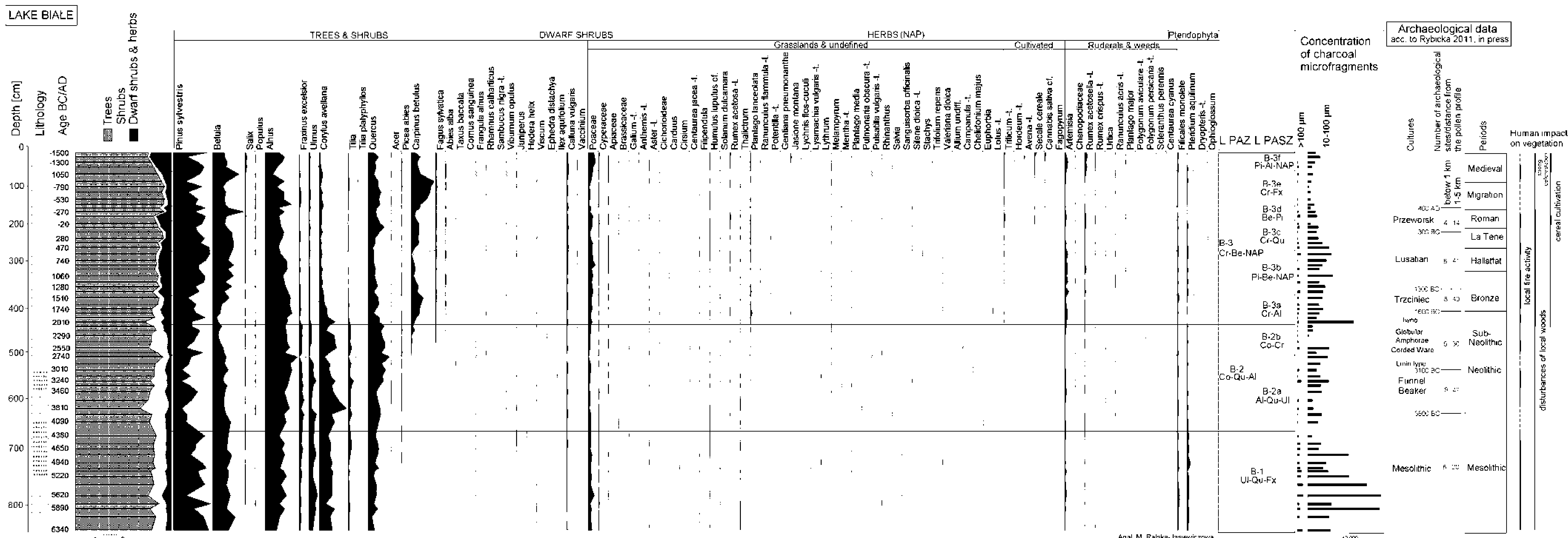

Fig. 4. Lake Białe. Percentage pollen diagram of selected taxa showing the development of terrestrial vegetation. **1**– gyttja, **2**– gyttja with macroscopic charcoal fragments.
Abbreviations: Ul-*Ulmus*, Qu-*Quercus*, Fx-*Fraxinus*, Be-*Betula*, Pi-*Pinus sylvestris*, Co-*Corylus*, Al-*Alnus*, Ti-*Tilia*, Cr-*Carpinus*, NAP-herbs

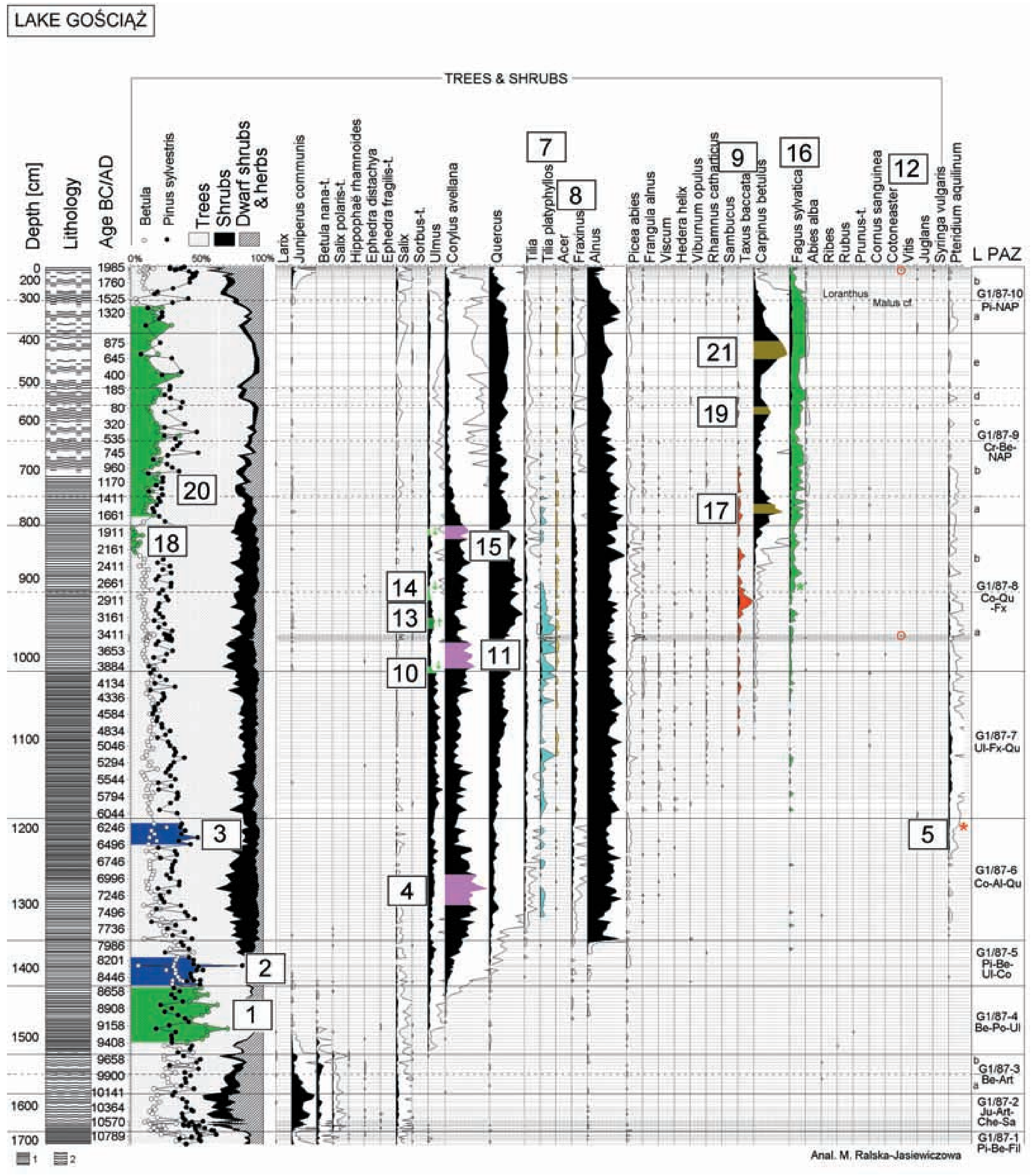

Fig. 9. Simplified pollen diagram from Lake Gościąż (acc. to Ralska-Jasiewiczowa et al. 1998) with local and regional phenomena marked on the profile. **1**–regularly laminated gyttja, **2**– irregularly laminated gyttja. Numbers 1–21 marked on the diagram follow numbers in the Table 5.

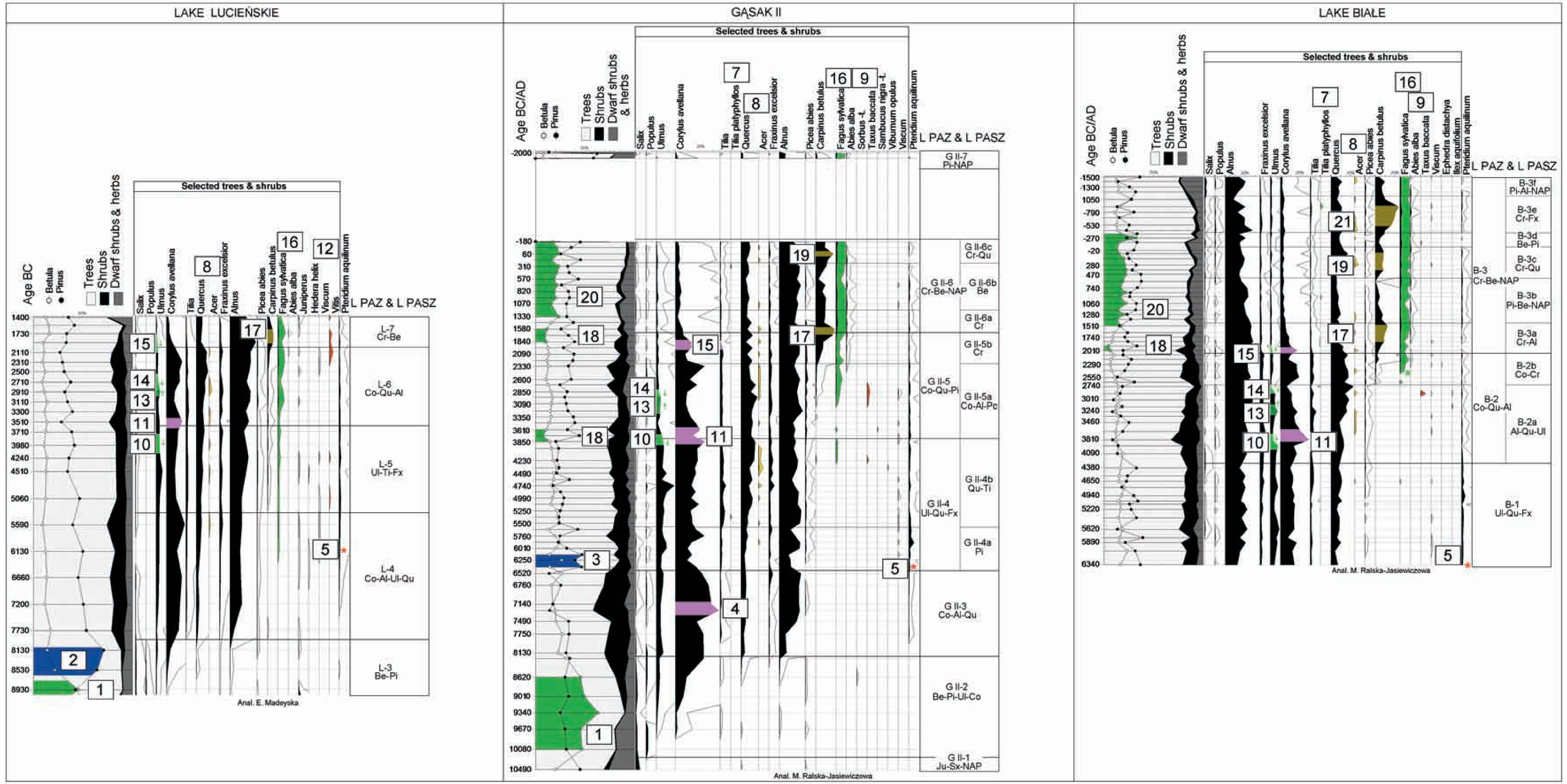

Fig. 10. Simplified pollen diagrams from Lake Lucieńskie, Gąsak II and Lake Białe with local and regional phenomena marked on the profile. Numbers 1–21 drawn on the diagram follow numbers in the Table 5