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CHANGES IN THE NATURAL ENVIRONMENT RECORDED IN THE SEDIMENTS OF THE KARAŚNE LAKE-MIRE COMPLEX (LUBLIN POLESIE, E POLAND)

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Abstract: This article presents results of multidisciplinary research which has been carried out in order to determine changes in the vegetation cover as well as changes in the structure of the Karaśne lake-mire complex in the Late Glacial and Holocene. In addition, human impact on the formation of the vegetation cover and the bio- and chronostratigraphy of the Late Glacial sediments is discussed.

Keywords: pollen analysis, radiocarbon dating, chemical analysis, Cladocera, Mollusca, ^{18}O and ^{13}C stable isotopes, human impact, biostratigraphy of the Late Glacial, Lublin Polesie.

1. INTRODUCTION

Lake Karaśne is one of the sites in the Lublin Polesie region, where interdisciplinary palaeoecological research is being carried out (Bałaga, 1991, 2003, 2004 and Bałaga *et al.*, 1983, 1992, 2002, 2006). The Lublin Polesie region with its 68 lakes situated circa 300 km beyond the range of the last glaciation belongs to the western part of extensive swamp areas in the Volhynia Polesie region which, in turn, is part of the peripheral area of the Eastern European platform. The top part of the pre-Quaternary basement is composed of Cretaceous rocks: marls and chalk. Their varied surface (relative heights reach 30-40 m) is masked by Quaternary formations, making this area hypsometrically undifferentiated to a large extent. The direct relation between the palaeobasin of the examined lake and the Cretaceous substratum is significant for the ongoing discussion concerning the origins of the Lublin Polesie lakes (e.g. Wilgat, 1954; Maruszczak, 1966; Wojtanowicz, 1994; Dobrowolski, 2006; Harasimiuk and Wojtanowicz, 1998 and Bałaga *et al.*, 2002). The area under discussion is also interesting with regard to the biostratigraphy of the Late Glacial as it contains pre-Alleröd sediments that are dated to more than 12 ka BP by the radiocarbon method. Last but not least, the region appears of interest because of its geobotanical location – the area of spruce disjunction beyond the continuous distribution of beech, and fir (Środoń, 1967; Boratyńska, 1983; Boratyńska and Boratyński, 1990; Tarasiuk, 1999 and Zając and Zając, 2001) – and its conservation area status (The Polesie National Park).

The purpose of the palaeoecological research is to reconstruct the vegetation cover and to determine the natural as well as prehistoric man-induced changes of the examined lake-mire complex.

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2. SITE CHARACTERISTICS

The Karaśne lake-mire complex is situated in the central part of the Łęczna-Włodawa Lake District – the Lublin Polesie subregion (**Fig. 1**). Its palaeobasin is situated on the NW slope of the Wola Wereszczyńska elevation, and was formed in Upper Cretaceous carbonate rocks. Its location in relation to the fossil and contemporary relief forms suggests a significant influence of structural conditions (Buraczyński and Wojtanowicz, 1981). The palaeobasin is hypsometrically diversified; the configuration of the substratum determines the existence of at least three basins, which are separated by narrow Cretaceous elevations (Bałaga *et al.*, 2002). The shallowest of them is the northern basin, which is marked by the most diversified relief. The maximum thickness of organogenic sediments reaches 4.5 m. They form, from bottom to top, the following sequence: clays, clayey-

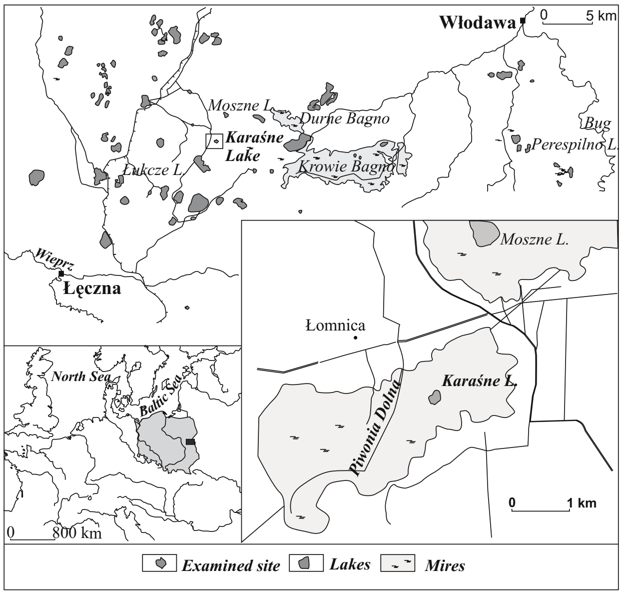

Fig. 1. *Map of Łęczna-Włodawa Lake District. Location of the examined site.*

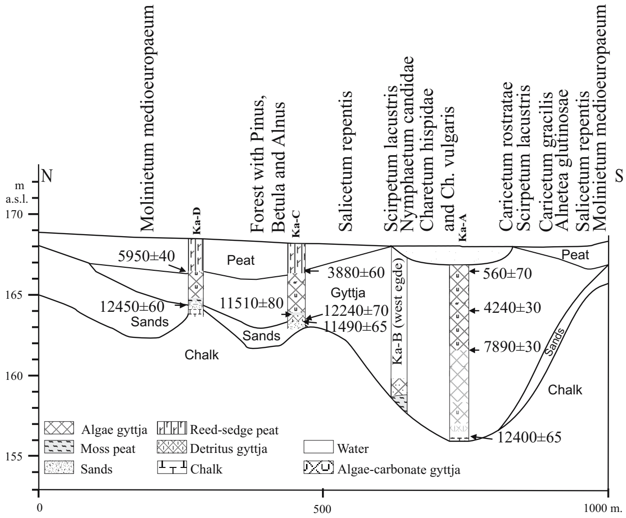

Fig. 2. *Simplified geological cross-section of the Karaśne lake-mire complex and radiocarbon dating results (BP). Location of the examined profiles. Distribution of vgetation communities after Sugier and Popiołek (1995).*

detritus-carbonate gyttja, moss peat, detritus-carbonate gyttja, moss-sedge-reed peat. The middle basin is a relatively narrow stretch of lowerings, which are up to 5.6 m deep. In the bottom part, contrary to the sediments occurring in the northern basin, the bottom limnic series is lacking therefore the biogenic accumulation is initiated by moss peat. The southern basin, where the contemporary Lake Karaśne is situated, is the central deepest part of the palaeobasin. The lithogenetic sequence of the sediments proves its similarity to the middle basin. The main difference is the lack of bottom peat on the southern slope of the basin. The maximum thickness of biogenic sediments in this part of the examined site is 13.5 m.

The contemporary Lake Karaśne (168 m a.s.l., 51°25'55"N, 23°06'30"E) is a small, overgrowing reservoir, 3.5 ha in area and 1.2 m in depth. The most common association, which shallows the lake is *Charetum vulgaris*, which takes the form of an underwater meadow occurring almost under the entire water surface of the lake (Sugier and Popiołek, 1995 and **Fig. 2**). The patches of *Charetum hispidae* occur sporadically. In the southern and western part of the lake the associations of *Nymphaetum*, mostly with *N. candida*, are plentifully developing. The water surface is surrounded by typical rush and an irregular stretch of "floating islands", which is up to 60 m wide. Typical rush consists of the following associations: *Scirpetum lacustris*, *Typhetum latifolia* and *Equisetum limosi*. "Floating islands" are formed mainly by the fen communities belonging mostly to *Caricetum gracilis, C. rostrata* and *C. paradoxeae.* Additionally, *Betula humilis* and *Salix rosmarinifolia* occur (Fijałkowski, 1960 and Sugier and Popiołek, 1995). Fragments of woodland communities containing birch, alder or pine (sporadically) have developed in the surroundings of sedge communities. In places, especially in the eastern and southern part, alder (in the form of a narrow stretch or small groupings) appears. Outside the woodland communities, on the peats filling the palaeobasin, the vegetation of hay-growing meadows develops. This situation takes place especially in the northern part, as the southern part is surrounded by small hills separated by tiny karst dolines (Bałaga *et al.*, 2002). The western part is surrounded by wider woodland areas.

3. MATERIALS AND METHODS

Four cores were taken by means of Eijkelkamp corer (10 cm in diameter) from the central part of contemporary lake (profile Ka-A), from its littoral part (profile Ka-B), from the marginal part of mire overgrown with pine forest, outside the "floating islands" surrounding contemporary lake (profile Ka-C), and from the mire used as hay-growing meadow (profile Ka-D; **Fig. 2**).

The material for pollen analysis was collected from three profiles (Karaśne A, B, C). In order to remove calcium carbonate the samples were treated with 10% HCl. Then they were heated with 10% KOH to remove organic matter. The samples containing sand or clay were put in cold 40% HF to dissolve silica. After such preliminary treatment all samples were subjected to acetolysis in order to remove cellulose matter. To calculate the concentration of sporomorphs two tablets with *Lycopodium* spores were added to each sample (Stockmarr, 1971). At least 500 pollen grains of trees and shrubs were microscopically identified in each spectrum. The obtained results were presented as percentage diagrams and total pollen concentration. The percentages of all taxa were calculated on the basis of the sum of tree, shrub, and herb pollen. Pollen of limnophyta and telmatophyta, and spores of mosses and pteridophyta were excluded from the total sum.

Macrofossils of water plants were identified in the top part of the profile Ka-A. The samples 2 cm thick were taken from the depth 2-4 m. They were washed according to the procedure of preparing material for radiocarbon dating by means of AMS method. The results were presented in a tabular form.

The samples for chemical analyses were taken from the profile Ka-A. The analyses were made in the Institute of Soil Science and Natural Environment Protection, Agricultural Academy, Lublin. The samples were dried to a constant weight, and next mineralised in a wet state in a mixture of HNO_3 and $HClO_4$ (1:1) in microwave stoves in an open system of Prolabo Microdigest 3.6. Major and minor elements (Al, B, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, Sr, Ti, V, Zn) were determined by means of emission spectrometry ICP on the Leeman Labs PS 950 apparatus. The content of mineral substances was determined by combustion in 550°C, and the content of $CaCO_3$ by means of Scheibler method in the Department of Physical Geography and Palaeogeography, Institute of Earth Sciences, Maria Curie-Skłodowska University.

Radiocarbon ages were obtained for the series of samples taken from four profiles (Ka-A, Ka-B, Ka-C and Ka-D), and additionally for one sample of peat from the lake bottom (Ka-A1). The dating was carried out in the Radiocarbon Laboratory in Poznań (15 samples) and in the Radiocarbon Laboratory of the Ukrainian National Academy of Sciences (2 samples).

Carbon and oxygen stable isotope composition was analysed for the bottom, carbonate part of the profile Ka-A by Dr T. Durakiewicz in the Institute of Physics, Maria Curie-Skłodowska University. Isotope composition was determined on the modified mass modified MI1305.

The nature of the lake and the influence of economic activities of prehistoric man were interpreted on the basis of the results of the following faunal analyses of the profile Ka-A: Cladocera – Szeroczyńska, 2003; Molluscs – Bałaga *et al.*, 2005 (analyses made by Professor S. Alexandrowicz in Kraków). The archaeological data that were used (Taras, 2005 and unpublished materials) came from the sites situated within a three-kilometre radius from the Lake Karaśne. Such a radius was selected due to a rather close vicinity of other objects (Moszne, Durne Bagno, Krowie Bagno) that were palynologically examined.

Lithology. The **c**ores were described (**Table 1-4**) applying the Troels-Smith method to distinguish deposit components and their quantities (Troels-Smith, 1955).

Radiocarbon dating. The results of radiocarbon dating are shown in **Table 5** and **Figs 2** and **3**.

Table 1. *Description of the profile Ka-A (central part of contemporary lake).*

Depth (cm)	Deposit description
0.00-120	water
120-200	algae-carbonate gyttja, light-grey, strongly water-logged, nig. 1.5, elas. 0, strf. 0, sicc. 1, lim. 0, Ld^3 2, Lc 2
200-228	algae-carbonate gyttja, light-grey, fine-grained, nig. 1.5, elas. +, strf. +, sicc. 1.5, lim. 0, $Ld^3$2, Lc 2
228-238	algae-carbonate gyttja, olive-brown, fine-grained, nig. 2++, elas. 1, strf. 0, sicc. 2, lim. 0, Ld^3 2, Lc 2
238-262	algae-carbonate gyttja, olive-grey, fine-grained, nig. 2, elas. +, strf. +, sicc. 2, lim. 0, Ld^3 2, Lc 2, part. test. (moll.)
262-278	algae-carbonate gyttja, olive-brown, fine-grained, nig. 2.5, elas. +, strf. 0, sicc. 2, lim. 0, Ld^3 4, Lc +
278-305	algae-carbonate gyttja, light-grey, fine-grained, inserts of plant detritus, nig. 2. strf. +, elas. +, sicc. 2, lim. 0, Ld^3 2, Lc 2
305-337	algae-carbonate gyttja, olive-brown, fine-grained, with detritus and few molluscs, nig. 2++, elas. +, strf. ++, sicc. 2, lim. 0, $Ld^2$3 Lc 1, part. test. (moll.)
337-360	algae-carbonate gyttja, grey, fine-grained, nig. 2, strf. +, elas. +, sicc. 2, lim. 0, Ld^4 3, Lc 1
360-529	algae-carbonate gyttja, olive-grey, fine-grained, nig. 2, elas. +, sicc. 2, lim. 0, Ld^3 3, Lc 1, anth.
529-576	algae-carbonate gyttja, olive-brown, fine-grained, nig. 2.5, elas. 0, strf. 0, sicc. 2, Ld^4 2, Lc 2
576-582	algae-carbonate gyttja, olive-brown, fine-grained, nig. 1.5, elas. 1, strf. +, sicc. 2, lim. 0, Ld^4 2, Lc 2
582-612	algae-carbonate gyttja, olive-brown, fine-grained, nig. 1.5, elas. 1, strf. +, sicc. 2, lim. 0, Ld^4 2, Lc 2
612-696	algae-carbonate gyttja, olive-brown, fine-grained, nig. 2, elas. 1, strf. 1, sicc. 2, lim. 0, $Ld^4$2, Lc 2
696-702	algae-carbonate gyttja, olive-brown, fine-grained, nig. 2.5, elas. 3. strf. +, sic. 2, lim. 0, Ld^4 2, Lc 2
702-740	algae-carbonate gyttja, olive-brown, fine-grained, nig. 2, strf. ++, elas. 3, sicc. 2, lim. 0, Ld^4 4, Lc ++
740-763	algae gyttja, olive-brown, fine-grained, with plant detritus and numerous molluscs, nig. 2, strf. +, elas. ++, sicc. 2, lim. 0, Ld^3 4, Lc ++, part. test. (moll.)
763-1138	algae gyttja, dark-brown, fine-grained, with molluscs, nig. 3+, elas. 1, sicc. 2, strf. +, lim. 0, Ld^4 4, part. test. (moll.)
1138-1212	algae gyttja, olive-green, fine-grained, nig. 2, elas. 1, strf. 0, sicc. 2, lim. 0, Ld^4 4, Lc +
1212-1245	algae-carbonate gyttja, olive-grey, fine-grained, laminated (subhorizontally in the top part, obliquely in the bottom part), nig. 2, elas.1, strf. 3, sicc. 2, lim. 0, Ld^4 2, Lc 2
1245-1261	algae-carbonate gyttja, olive-grey, fine-grained, with plant detritus and molluscs, nig. 2, elas. 1, strf. +, sicc. 2, lim. 0, Ld^3 2, Lc 2, part. test. (moll.)
1261-1277	detritus gyttja, dark-brown, fibrous, nig. 3, elas. 1, strf. +, sicc. 2, lim. 0, Ld^3 3, Tb^4 1
1277-1287	clay, olive-grey, with admixture of medium-grained sand in the bottom part, nig. 2, elas. 0, strf. 0, sicc. 2, lim. 0, Ag 3, Ga 1
1287-1300	medium-grained sand, clayey with debris of Upper Cretaceous rocks in the bottom part, nig. 2, elas. 0, sicc. 2, lim. 0, Ga 3, Ag 1
>1300-?	clayey residuum of Upper Cretaceous rocks

Table 2. *Description of the profile Ka-B (littoral part of contemporary lake).*

Depth (cm)	Deposit description
1055-1090	algae-detritus gyttja, dark-brown, nig. 3, elas. +, strf. 0, sicc. 2, lim. 0, Ld^2 3, Th^2 1, Tb +
1090-1190	moss peat, brown, slightly decomposed, nig. 2, elas. +, strf. 0, sicc. 2, lim. 3, Tb^3 4, Th^3 +, Ld +
>1190-?	clayey residuum of Upper Cretaceous rocks

Table 3. *Description of the profile Ka-C (marginal part of mire, outside the "floating islands" surrounding contemporary lake).*

Depth (cm)	Deposit description
10-16	reed-sedge peat, dark-brown, moderately decomposed, nig. 3, elas. +, strf. 0, sicc. 2++, Th^2 (*Carex*)3, Th^2 (*Phrag.*)1
16-19	sedge-reed peat, brown, weakly decomposed, nig. 2, elas. 0, strf. 0, sicc. 2, lim. 0, Th^1 (*Phrag.*)3, Th^2 (*Carex*)1
19-33	reed-sedge peat, dark-brown, moderately decomposed, nig. 2++, elas. 0, strf. 0, sicc. 2, Th^2 (*Carex*)3, Th^2 (*Phrag.*)1
33-40	reed-sedge peat, dark-brown, more decomposed, nig. 3, elas. +, strf. 0, sicc. 2, Th^3 (*Carex*)3, Th (*Phrag.*)1,
40-47	sedge peat, brown, with few reed, strongly decomposed, nig. 2++, elas. +, strf. 0, sicc. 2, lim. 0, Th^3 (*Carex*)4, Th^2 (*Phrag.*)+
47-64	sedge-moss peat, dark-brown, moderately decomposed, nig. 3, elas. +, strf. 0, sicc. 2, lim. 0, Tb^2 3, Th^2 (*Carex*)1
64-68	sedge-reed peat, brown, weakly decomposed, nig. 2, elas. 0, strf. 0, sicc. 2, lim. 0, Th^2 (*Carex*)1, Th^2 (*Phrag.*)3
68-72	moss-sedge peat, brown, weakly decomposed, nig. 2, elas. 0, strf. 0, sicc. 2, lim. 0, Th^2 (Carex)3, Tb^2 1
72-85	sedge-reed peat, brown, weakly decomposed, nig. 2, elas. 0, strf. 0, sicc. 2, lim. 0, Th^2 (*Phrag*)3, Th^2 (*Carex*)1
85-100	sedge peat, dark-brown, strongly decomposed, nig. 2++, elas. +, strf. 0, sicc. 2, lim. 0, Th^3 3, Ld^4 1
100-120	sedge peat, brown, with few reed, moderately decomposed, nig. 2, elas. +, strf. 0, sicc. 2, Th^2 (*Carex*)4, Tb^3 +
120-130	sedge-moss peat, brown, moderately decomposed, nig. 2+, elas. +, strf. 0, sicc. 2, Th^3 1, Tb^3 1
130-150	moss-sedge peat, dark-brown, strongly decomposed, nig. 3, elas. +, strf. 0, sicc. 2, Tb^3 1, Th^3 3, Ld +
150-174	moss-sedge peat, brown, moderately decomposed, nig. 2, elas. 0, strf. 0, sicc. 2, Th^2 3, Tb^2 1
174-189	sedge-moss peat, brown, weakly decomposed, nig. 2, elas. 0, strf. 0, sicc. 2, Tb^2 3, Th^2 1
189-205	moss-sedge peat, dark-brown, strongly decomposed, nig. 3, elas. +, strf. 0, sicc. 2,Th^3 3, Tb^3 1, Ld +
205-248	coarse-detritus gyttja, black-brown, nig. 3, elas. +, strf. 0, sicc. 2, lim. 0, Ld^2 3,Th^3 (*Carex*)1, Tb +
248-288	carbonate gyttja, olive-brown, nig. 2, elas. 1, strf. 1, sicc. 2, lim. 0, $Ld^3$2, Lc 1, Th +
288-305	coarse-detritus gyttja, black-brown, nig. 3, elas. +, strf. 0, sicc. 2, lim. 0, Ld^2 3, Th^2 1, Tb +
305-316	coarse-detritus gyttja, dark-brown, nig. 2.5, elas. +, strf. 0, sicc. 2, lim. 0, Ld^2 3, Th^2 1, Lc +
316-338	algae-carbonate gyttja, grey-brown, nig. 2, elas. +, strf. 0, sicc. 2, lim. 0, Ld^3 3, Lc 1, Th^3 +
338-350	algae gyttja, brown, with dark organic interbeddings, nig. 3, elas. +, strf. 1, sicc. 2, lim. 0, $Ld^3$3, $Th^2$1, Lc +
350-370	algae gyttja, brown, nig. 2.5, elas. +, strf. +, sicc. 2, lim. 0, Ld^4 3, Th^4 1, Lc +
370-378	algae gyttja, black-brown, nig. 3, elas. +, strf. +, sicc. 2, lim. 0, Ld^4 4, Th +, Lc +
378-392	algae-carbonate gyttja, brown, nig. 2, elas. +, strf. +, sicc. 2, lim. 0, Ld^4 3, Lc 1, Th +
392 397	moss peat, brown, slightly decomposed, nig. 2, elas. +, strf. 0, sicc. 2, lim. 3, Tb^3 4, Th^3 +, Ld +
397-400	algae gyttja, black-brown, with light intergebbdins, nig. 3, elas. +, strf. 1, sicc. 2, lim. 0, Ld^4 4, Th +, Lc +
400-450	coarse-detritus gyttja, black-brown (bottom 4 cm very strongly decomposed), nig. 2++, elas. +, strf. 1, sicc. 2, lim. 0, Ld 3, Th 1
450-464	clayey gyttja, brown, nig. 2+, elas. 0, strf. 1, sicc. 2, lim. 0, $Ld^3$2, As 2, Lc +
464-490	sand, light-yellow, with organic interbeddings, nig.1.5, elas. 0, strf. 1, sicc. 2, lim. 0, Ga 1, $Ld^2$1
490-510	clayey gyttja, light-brown, compact, nig. 2, elas. 0, strf. 0, sicc. 2, lim. 0, $Ld^2$2, As 2, Lc +

Table 4. *Description of the profile Ka-D (mire – northern part of the complex).*

Depth (cm)	Deposit description
0-10	sedge peat, dark-brown, strongly decomposed, nig. 3, elas. 0, strf. 0, sicc. 2, Th^4 (*Carex*)4
10-50	sedge peat, brown, moderately decomposed, nig. 2, elas. 0, strf. 0, sicc. 2, lim. 0, Th^2 (*Carex*)4, Th^2 (*Phrag.*)+
50-56	moss-sedge peat, brown, weakly decomposed, with reed fragments, nig. 2, elas. +, strf. 0, sicc. 2, lim. 0, Th^2 (*Carex*)2, Tb^2 1,Th^2 (*Phrag.*)+
56-95	moss-sedge peat, brown, moderately decomposed, more reed, nig. 2, elas. +, strf. 0, sicc. 2, lim. 0, Th^2 (*Carex*)2, Th^2 (*Phrag.*)1, Tb^2 1
95-145	moss-sedge peat, dark-brown, moderately decomposed, nig. 3, elas. +, strf. 0, sicc. 2, lim. 0, Tb^2 1, Th^2 (*Carex*)3
145-148	sedge-moss peat, brown, weakly decomposed, nig. 2, elas. +, strf. 0, sicc. 2, lim. 0, Tb^2 3, Th^2 (*Carex*)1
148-188	moss-sedge peat, dark-brown, moderately decomposed, nig. 3, elas. +, strf. 0, sicc. 2, lim. 0, Tb^2 1, Th^2 (*Carex*)3
188-190	sedge-moss peat, brown, weakly decomposed, nig. 2, elas. +, strf. 0, sicc. 2, lim. 0, Tb^1 3, Th^2 (*Carex*)1
190-230	sedge-moss peat, brown, moderately decomposed, nig. 2, elas. +, strf. 0, sicc. 2, lim. 0, Tb^2 3, Th^2 (*Carex*)1
230-240	coarse-detritus gyttja, brown, nig. 2, elas. +, strf. 0, sicc. 2, lim. 0, Ld^2 3, Th^2 1
240-266	algae-carbonate gyttja, light-brown, with detritus, nig. 2, elas. +, strf. +, sicc. 2, lim. 0, Ld^3 3, Lc 1, Th^3 +
266-271	algae-carbonate gyttja, light-brown, more detritus, nig. 2, elas. +, strf. ++, sicc. 2, lim. 0, Ld^3 2, Lc 1, Th^3 1
271-300	algae gyttja, brown, nig. 1.5++, elas. +, strf. 0, sicc. 2, lim. 0, Ld^4 4, Lc +
300-316	moss peat, brown, weakly decomposed, nig. 2, elas. +, strf. 0, sicc. 2, lim. 3, Tb^3 4, Th^3 +, Ld +
316-340	clayey gyttja, brown, more compact, nig. 2+, elas. 0, strf. +, sicc. 2, lim. 2, $Ld^2$2, As 2, Lc +
340-350	sand, light-yellow, varigrained, with organic matter, nig. 1.5, elas. 0, strf. 1, sicc. 2, lim. 0, Ga 1, $Ld^3$1

Table 5. *Radiocarbon dates of the Karaśne profiles. Atmospheric data from Reimer et al. (2004), OxCal v. 3.10 Bronk Ramsey (2001).*

Profile	No. Lab.	Material	Depth (cm)	Age in years: ^{14}C (BP)	Calendar (BC/AD): 68.2% probability	Calendar (BC/AD): 95.4% probability
Ka-A	Poz-187*	macrofossils	216-218	560±70	1300AD (37.1%) 1370AD	1280AD (95.4%) 1450AD
					1380AD (31.1%) 1430AD	
	Poz-188*	macrofossils	372-374	4240±30	2900BC (41.2%) 2870BC	2920BC (51.3%) 2860BC
					2810BC (20.3%) 2780BC	2820BC (35.3%) 2750BC
					2770BC (4.0%) 2760BC	2730BC (8.8%) 2700BC
					2720BC (2.7%) 2710BC	
	Poz-1157	macrofossils	715-717	7890±90	7030BC (11.5%) 6960BC	7100BC (95.4%) 6500BC
					6950BC (3.6%) 6930BC	
					6920BC (7.6%) 6880BC	
					6840BC (45.5%) 6640BC	
	Poz-184	macrofossils	1265-1270	12400±65	13100BC (33.1%) 12600BC	13500BC (95.4%) 12100BC
					12550BC (35.1%) 12150BC	
Ka-A1	Ki-8642	peat	1325-1332	12150±150	12365-12095BC	13130-12785 BC
					11975-11910BC	12430-11875 BC
Ka-B	Ki-8641	peat	1180-1190	12180±140	12380-12105BC	13130-12790 BC
					11955-11925BC	12430-11885 BC
Ka-C	172	macrofossils	71-72	1700±35	260AD (12.8%) 280AD	250AD (95.4%) 430AD
					320AD (55.4%) 410AD	
	Poz-200	macrofossils	187-188	2760±25	970BC (0.7%) 960BC	980BC (8.2%) 950BC
					920BC (28.6%) 890BC	940BC (87.2%) 820BC
					880BC (38.9%) 830BC	
	Poz-173	macrofossils	244-245	3880±60	2470BC (68.2%) 2280BC	2500BC (93.4%) 2190BC
						2170BC (2.0%) 2140BC
	Poz-908	macrofossils	396-397	11510±80	11850BC (15.2%) 11750BC	11900BC (95.4%) 11200BC
					11600BC (45.6%) 11350BC	
					11300BC (7.4%) 11200BC	
	Poz-333	macrofossils	450-452	12240±70	13100BC (23.2%) 12700BC	13500BC (44.6%) 12600BC
					12450BC (45.0%) 12100BC	12500BC (47.1%) 12100BC
						12000BC (3.7%) 11800BC
	Poz-338	macrofossils	452-455	11490±65	11850BC (8.8%) 11750BC	11900BC (23.6%) 11650BC
					11600BC (48.7%) 11350BC	11600BC (71.8%) 11200BC
					11300BC (10.7%) 11200BC	
Ka-D		macrofossils	56-57	2800±35	1000BC (68.2%) 900BC	1020BC (95.4%) 830BC
	Poz-909	macrofossils	147-148	4350±40	3020BC (68.2%) 2900BC	3090BC (7.0%) 3050BC
						3040BC (88.4%) 2880BC
	Poz-907	macrofossils	187-190	4550±40	3370BC (20.7%) 3320BC	3490BC (1.4%) 3470BC
					3230BC (24.6%) 3170BC	3370BC (94.0%) 3090BC
					3160BC (22.8%) 3100BC	
	Poz-912	macrofossils	227-228	5950±40	4910BC (8.2%) 4870BC	4940BC (95.4%) 4710BC
					4860BC (53.3%) 4770BC	
					4750BC (6.7%) 4730BC	
	Poz-911	macrofossils	315-316	12450±60	13300BC (3.0%) 13200BC	13500BC (95.4%) 12200BC
					13000BC (65.2%) 12200BC	

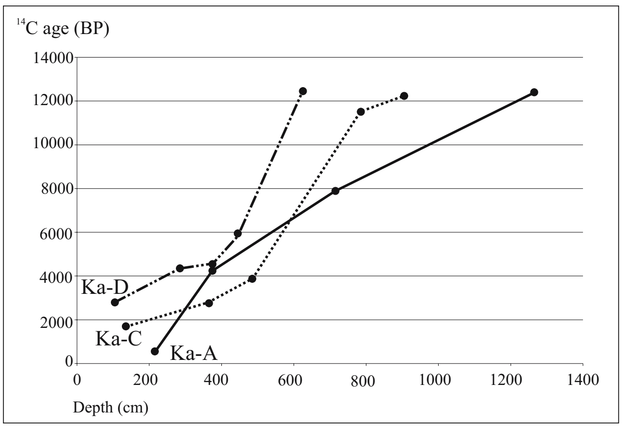

Fig. 3. *^{14}C conventional age of dated samples in relation of their depth for the profiles Ka-A, Ka-C, Ka-D.*

Pollen and chemical zones. Pollen diagrams were divided into local pollen assemblage zones (LPAZ), i.e. biostratigraphic units with characteristic composition of sporomorphs (Berglund and Ralska-Jasiewiczowa, 1986). Some of these pollen zones were divided into subzones. Boundaries of all units were determined by traditional means, i.e. taking into account the increase or decrease of the percentage curves of main trees, shrubs, and overall curve of NAP, and then compared with the results obtained by means of Conslink numerical method (Walanus and Nalepka, 2003). The names of zones and subzones derive from the predominant or typical taxa. Short descriptions of local pollen zones in individual profiles are presented in **Tables 6-8**. Their approximate ages were calculated making the assumption that sedimentation rate was constant, and additionally taking into consideration the well-dated boundaries of Younger Dryas (e.g Mangerrud *et al.*, 1974).

Based on the vertical differentiation in sediment chemistry in the profile Ka-A, six chemical zones are distinguished. They are described in **Table 6**.

Table 6. *Characterization of local pollen assemblages zones (LPAZ), subzones (LPAsubZ) and chemical zones for profile Ka-A.*

LPAZ and LPAsubZ *(Depth; Age ^{14}C)*		***Description of zones*** – ***pollen***	***chemical***
***Salix*-Cyperaceae** *(1270-1265 cm; ?- 12400 BP)*		*Salix* (25.7%) and Cyperaceae (14.2%) dominate. *Pinus* and *Betula* reach 37.2 and 7.1%, respectively. *Betula nana*, *Juniperus* and *Hippophaë rhamnoides* present. Spores of *Equisetum* frequent (4.2%). Limit: decrease of *Salix* and Cyperaceae	**Ch-1** zone (1275-1255 cm) The contents of some macroelements (Mg, K, Na and Al) and microelements (Ti, V, Pb and Cu) are high
Betula (1265-1215 cm; 12400-11800 BP)		Rise of *Betula* (up to 71.6%) and *Pinus* (up to 51.1%), decrease of Cyperaceae and *Salix* (to 0.8%). Poaceae, *Artemisia*, and Chenopodiaceae reach higher values. *Juniperus, Betula nana, Hippophaë rhamnoides*, *Menyanthes trifoliata*, *Sparganium*, *Typha latoifolia*, *Nuphar luteum*, *Stratiotes*, and *Nymphaea* (to 1.6%) present. Limit: rise of *Pinus*, decrease of *Betula*	**Ch-2** zone (1255-1175 cm) The contens of elements abundant in the previous zone decrease, and those of Ca, Fe, Mn, P, Ni and Cd increase
Pinus-Betula (1215-1145 cm; 11800-10700 BP)		*Pinus* (61.6%) still rises. Values of NAP and *Salix* (0.8-1.1%) are low. Frequencies of birch are higher (24.3%) in the younger part of the zone. *Betula nana*, *Juniperus*, and *Alnus viridis* present. Pollen of water plants is represented by *Myriophyllum*, *Nuphar*, *Stratiotes*, and mostly by *Nymphaea* (3.9-5.6%). Limit: rise of *Artemisia* and NAP	**Ch-3** zone (1175-875 cm) The contents of Ca decreased. Ca is negatively correlated with Mg, K, Al, Ti, V, Pb, Zn, Cu, Ni, and Cr
***Artemisia*-Chenopodiaceae** (1145-1070 cm)		Pollen of NAP dominates, in it of *Artemisia* Cyperaceae, Poaceae, and Chenopodiaceae. *Salix*, *Betula nana*, and *Juniperus* rise. *Hippophaë rhamnoides*, *Gypsophila fastigita*, and *Helianthemum sp.* present. Limit: decrease of *Artemisia* and NAP	
Ulmus-Betula (1070-800 cm; 10000-8400 BP)	***Filipendula*** (1070-1015 cm; 10000-9100 BP)	Rising *Betula* (up to 53.1%*), Filipendula* (up to 0.8%), and *Urtica* (up to 1.35%). Continuous curve (> 1%) of *Ulmus* appears. Decreasing *Pinus* (to 27.2%*), Artemisia,* Cyperaceae, Poaceae, and Chenopodiaceae*. Humulus lupulus, Phragmithes, Sparganium, Menyanthes trifoliata, Nymphaea alba,* and *Potamogeton* sec. *Eupotamogeton* present. Limit: rise of *Betula*, decrease of *Pinus*	
	Betula (1015-915 cm)	*Betula* reaches the highest values (71.4%). Limit: decrease of *Betula*, rise of *Pinus*	
	Pinus-Betula-Corylus (915-800 cm)	Rise of *Pinus*, decrease of *Betula*. Continuous curve of *Corylus* appears at the end of the zone. Limit: rise of *Corylus*, *Alnus* and *Quercus*	
Ulmus-Alnus-Quercus-Tilia (800-475 cm; 8400-5300 BP)	***Alnus-Corylus*** (800-665 cm; 8400-7300 BP)	Values of *Ulmus* and *Corylus* rather stable and those of *Quercus*, *Alnus, Fraxinus*, and *Tilia* gradually increase. Limit: increase of *Alnus* and *Tilia*	**Ch-4** zone (875-750 cm) The rise in the concentration of Ca is associated with the consistently decreasing contents of almost all elements negatively correlated with Ca in the previous zone
	Tilia (665-475 cm; 7300-5300 BP)	*Tilia* and *Fraxinus* reach the highest values – 1.5% and 2.6%, respectively. Limit: decrease of *Ulmus*, increase of *Carpinus*	**Ch-5** zone (750-465 cm) The increase and stabilization of the Ca content. From among the elements positively correlated with Ca the highest are the contents of Sr and Na, and the lowest – of K, Al, Ti and V
Carpinus (475-210 cm; 5300-500 BP)	***Corylus*** (475-395 cm; 5300-4400 BP)	*Carpinus* increases and values of *Corylus* are still high. Continuous curve of *Fagus* appears. Rise of *Artemisia*. First grain of *Plantago lanceolata* appears. Limit: decrease of *Corylus*	**Ch-6** zone (465-155 cm) The content of Ca increases or slightly fluctuates. The concentrations of elements negatively correlated with Ca (K, Al, Ti and V) slightly rise
	Alnus-Quercus (395-290 cm)	*Carpinus* temporary reaches high values. *Corylus*, *Tilia*, *Fraxinus*, and *Ulmus* decrease. First grains of Cerealia appear. Limit: rise of NAP, decrease of *Carpinus* and *Betula*	
	Fagus (290-210 cm; 2400-500 BP)	*Fagus* (2.3%) and *Carpinus* (8.8%) reach high values. Limit: decrease of all tree taxa, rise of NAP	
NAP-Cerealia *(210-160 cm)*		Values of NAP increase, in it those of anthropogenic indicators. Percentages of almost all AP taxa decrease	

Table 7. *Characterization of local pollen assemblages zones (LPAZ) for Profile Ka-B.*

LPAZ *(Depth; Age ^{14}C)*	**Description of pollen zones**
Cyperaceae (1185-1180 cm; 12180±140 BP)	High values of Cyperaceae (30.8%). *Betula nana*, *Salix polaris* and *Juniperus communis* present. Limit: rise of *Betula*, decrease of NAP
Pinus-Betula (1180-1100 cm)	Rise of *Pinus* (67%). Values of *Betula* fluctuate from 12.3 to 31.9%. Continuous curve of *Betula nana*. *Juniperus communis* still present in the older part of the zone. *Nymphaea alba* appears in the younger part. *Alnus viridis* present. Limit: rise of *Artemisia* and Chenopodiaceae
***Artemisia*-Chenopodiaceae** (1100-1055 cm)	*Artemisia* reaches 6.9%, and Chenopodiaceae 1.6%. Pollen of *Juniperus communis, Salix polaris* and *Gypsophila fastigiata* occurs sporadically

Table 8. *Characterization of local pollen assemblages zones (LPAZ) and subzones (LPAsubZ) for profile Ka-C.*

LPAZ *(Depth; Age ^{14}C)*		**Description of pollen zones**
***Pinus-Betula* LPAZ** (440-425 cm)		High values of *Pinus*. Limit: rise of *Artemisia* and *Chenopodiaceae*
***Artemisia*-Chenopodiaceae** (425-385 cm)		High values of NAP, in it those of *Artemisia*, Chenopodiaceae, and Cyperaceae. *Betula nana*, *Juniperus*, and *Gypsophila fastigiata* present. Limit: decrease of *Artemisia*, Cheopodiaceae, and Cyperaceae
Ulmus-Pinus-Filipendula (385-350 cm; 10000-8500? BP)		Continuous curve of *Ulmus* (4.6%) appears, *Corylus* reaches 9.1%. Limit: increase of *Alnus*, *Corylus* and *Quercus*
Ulmus-Alnus-Quercus-Tilia (350-255 cm; 8500?-4400? BP)	***Alnus-Corylus*** (350-325 cm; 8500?-7400 BP)	Values of *Ulmus*, *Quercus*, *Alnus*, and *Corylus* increase. *Betula nana* present. Limit: decrease *Alnus* and rise *Ulmus*
	Tilia (325-255 cm; 7400-4400 ? BP)	Frequencies of *Quercus*, *Alnus* and *Ulmus* rise or stabilize. *Tilia* and *Fraxinus* reach the maximum values. *Betula nana* still present, *Viscum* appeared. Limit: decrease of *Ulmus* and rise of *Carpinus*
Carpinus (255-170 cm; 4400?-2600 PB)	***Corylus*** (255-210 cm; 4400?-3200 BP)	Values of *Alnus* and *Corylus* high but with decreasing trend. Rise of *Carpinus*. First grain of *Plantago lanceolata* appears. *Betula nana* still present. Limit: rise of *Pinus* and decrease of *Corylus*
	Alnus-Quercus (210-170 cm; 3200-2600 BP)	Still high values of *Quercus* and *Carpinus*, with decreasing trend at the end of the zone. *Viscum* present. Limit: decrease of *Quercus* and *Carpinus*
Pinus **(**170-20 cm; 2600-500 BP)	***Alnus*** (170-130 cm; 2600-2300 BP)	Values of *Alnus* (7.5%) and *Quercus* (3.0%) are high in the AP sum. Frequencies of *Carpinus* are low (0.8 %). First grain of *Abies alba* appears. Limit: rise of *Carpinus*, decrease of *Quercus*
	Carpinus (130-80 cm; 2300-1800 BP)	Values of *Carpinus* rise to 2.5%. Limit: decrease of *Carpinus* and *Fagus*
	Quercus (80-20 cm; 1800-500 BP)	*Pinus* still dominates. Values of *Quercus* and *Alnus* are high. *Betula nana* appears again. Limit: rise of NAP, in it anthropogenic indicators
NAP-Cerealia (20-10 cm; 500-250 BP)	Values of NAP rise, in it those of Cyperaceae, Poaceae, Cerealia, and *Plantago lanceolata*.	

4. RECONSTRUCTION OF PALAEOENVIRONMENT

Changes in the vegetation cover surrounding the examined site

The Late Glacial. The development of vegetation cover in the Late Glacial is presented in the pollen diagrams Ka-A (**Fig. 4**), Ka-B (**Fig. 5**) and Ka-C (**Fig. 6**). The distinguished of LPAZ are correlated with chronozones in accordance with the proposal of Mangerud *et al.* (1974).

The bottom sediments of ***Salix*-Cyperaceae LPAZ** (Ka-A, 1270-1265 cm) and **Cyperaceae LPAZ** (Ka-B, 1185-1180 cm) probably come from the end of the Pleniglacial (see section "Biostratigraphy…"). The total pollen concentration (**Fig. 4**) as well as high pollen values of NAP and shrubs evidence the lack of woodland vegetation. The landscape of the examined site was dominated by willow communities at the time. Shrub tundra with *Betula nana* and *Salix* (cf. *polaris*) was developing on the moist habitats surrounding the newly formed lake. Cyperaceae, *Equisetum*, *Phragmites australis* type and *Sparganium* were covering the littoral zone of the lake. On dry habitats, the grass-*Artemisia* steppe communities were spreading, among which heliophilous shrubs *Juniperus communis* and *Hippophaë rhamnoides* occurred.

The ***Betula*** **LPAZ** is distinguished only in the profile Ka-A (1265-1215 cm) and can be correlated with the beginnings of the Bölling-Alleröd complex (Bałaga, 1991) or Early Interstadial (Ralska-Jasiewiczowa *et al.*, 1999 and Bałaga, 2004). The increasing percentages of *Betula* and *Pinus* give evidence for loose birch communities, presumably with a pine admixture. The development of these forests was combined with the improvement in climatic conditions. The decreasing curve of Cyperaceae as well as the increase in the pollen values of dry habitat vegetation with Poaceae and *Artemisia* may indicate a less humid, more continental climate – notably in the

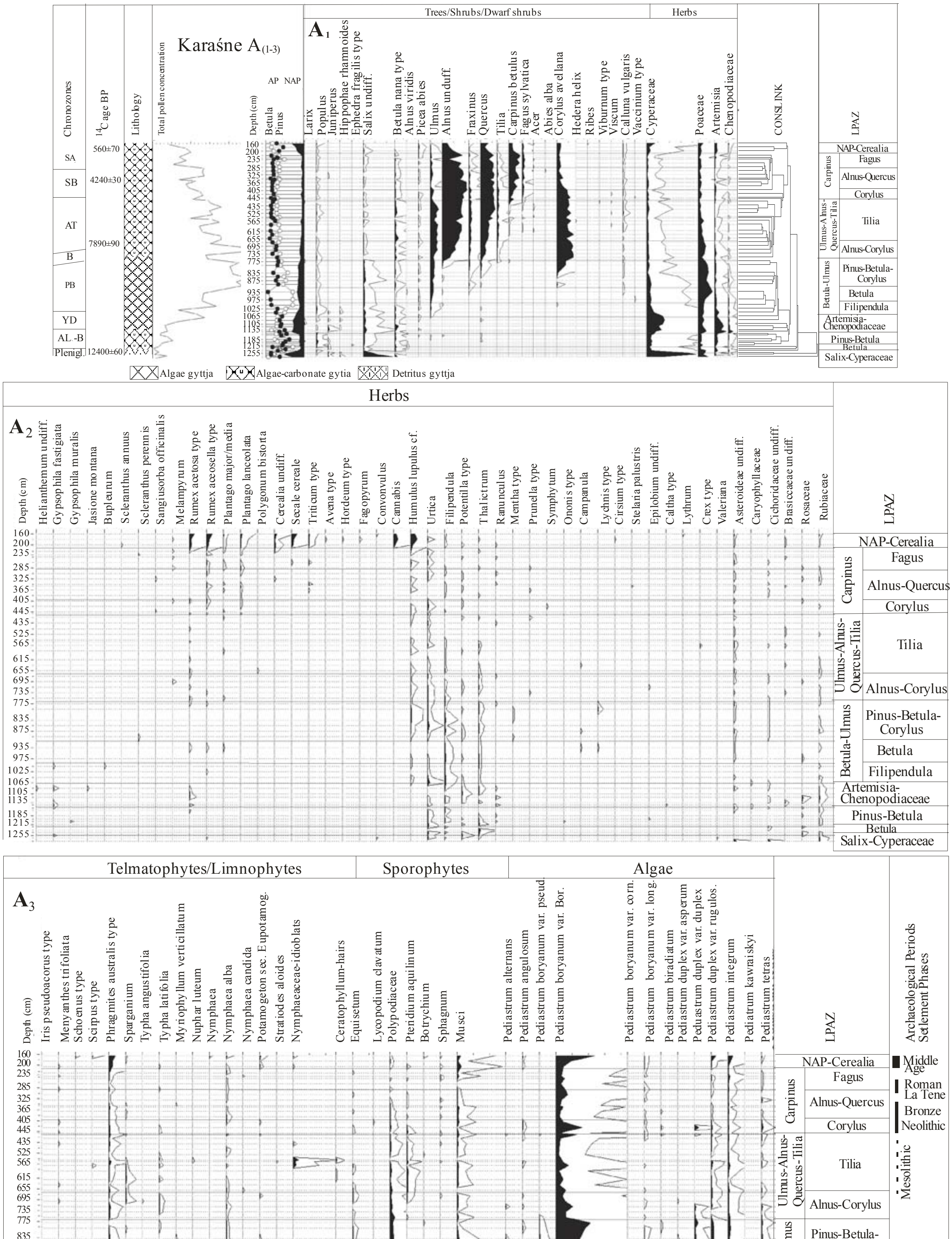

Fig. 4. *Percentage pollen diagram of the profile Ka-A.*

older part of the zone. The spread of birch excluded the presence of willow in the surroundings of the lake, which was characteristic for the former zone. The presence of *Betula nana* pollen points to the ongoing occurrence of tundra communities. *Alnus viridis*, whose pollen occurs sporadically, could have been present on fresh mineral soils.

The ***Pinus-Betula*** **LPAZ** (Ka-A, 1215-1145 cm; Ka-B, 1180-1100 cm; Ka-C, 440-425 cm) corresponds to the Alleröd chronozone. The increase in the pollen concentration indicates a more intensive development of the vegetation cover. The increasingly warming climate favoured further pine-birch forest development, where *Populus* (cf. *P. tremula*) could be present. *Populus* could also form communities with *Salix*, and such communities are similar to contemporary *Salici-Populetum*. The development of forest communities distinctly limited the spread of open vegetation cover, which resulted in the decrease in Cyperaceae, Poaceae, *Artemisia* and Chenopodiaceae. The increased pollen values of *Filipendula* cf. *ulmaria* indicate the presence of high herbaceous plants near the shore of the lake. The pollen values of *Betula nana* evidence the ongoing occurrence of wet habitat communities of tundra type. The presence of *Typha latifolia* and *Nymphaea alba* indicates that the average July temperature was not lower than 14-15°C (Iversen, 1960 and Isarin and Bohnacke, 1999).

The ***Artemisia*****-Chenopodiaceae LPAZ** (Ka-A, 1145-1070 cm; Ka-B, 1100-1055 cm; Ka-C, 425-385 cm) corresponds to the Younger Dryas chronozone. The climate cooling in the Younger Dryas led to the decrease of forest area. The vegetation of park type with *Pinus* and *Betula* developed. Single pollen grains of *Larix* may point to the presence of this tree in the vicinity of the lake, as they are not resistant to long transport. The proportion of *Populus* was distinctly lower in the forests. The landscape of lake environs was dominated by grass communities with *Artemisia*, Chenopodiaceae, *Gypsophila fastigiata*, *Helianthemum* sp. and *Potentilla* type. Heliophilous shrubs *Juniperus communis* and *Hippophaë rhamnoides* were also present in these communities. The surroundings of the lake were again covered by the communities with dwarf birch and willow. Sporadically found pollen grains of *Alnus viridis* indicate that alder could have been again present on fresh mineral soils. Thermophilous species such as *Typha latifolia* and *Nymphaea alba* disappeared.

Holocene. The development of vegetation cover in the Holocene is presented in the pollen diagrams Ka-A (**Fig. 4**) and Ka-C (**Fig. 6**).

The ***Ulmus-Betula*** **LPAZ** (Ka-A, 1070-800 cm; *Filipendula* subzone, 1070-1015 cm; *Betula* subzone, 1015-915 cm; *Pinus-Betula-Corylus* subzone, 915-800 cm) and ***Ulmus-Pinus-Filipendula*** **LPAZ** (Ka-C, 385-330 cm) are correlated with the Preboreal chronozone. The comparison of two profiles indicates that in the profile Ka-C only a small section corresponds to Preboreal. A fuller picture of the vegetation cover may be arrived at by examining the pollen spectra of the profile Ka-A as they reflect the successive development of birch-dominated (up to 70.4%) forests (*Betula* subzone). The proportion of birch decreased in the younger part of the chronozone. Elm (up to 3.7%) appeared at the beginning of the Preboreal chronozone, whereas hazel (7.6%) – at the end of this period (*Pinus-Betula-Corylus* subzone). The sporadically found pollen grains of *Picea* may signalize the rare occurrence of spruce. Low pollen values of other tree taxa point to the fact that they still didn't play any significant part in the developing forest communities. The re-

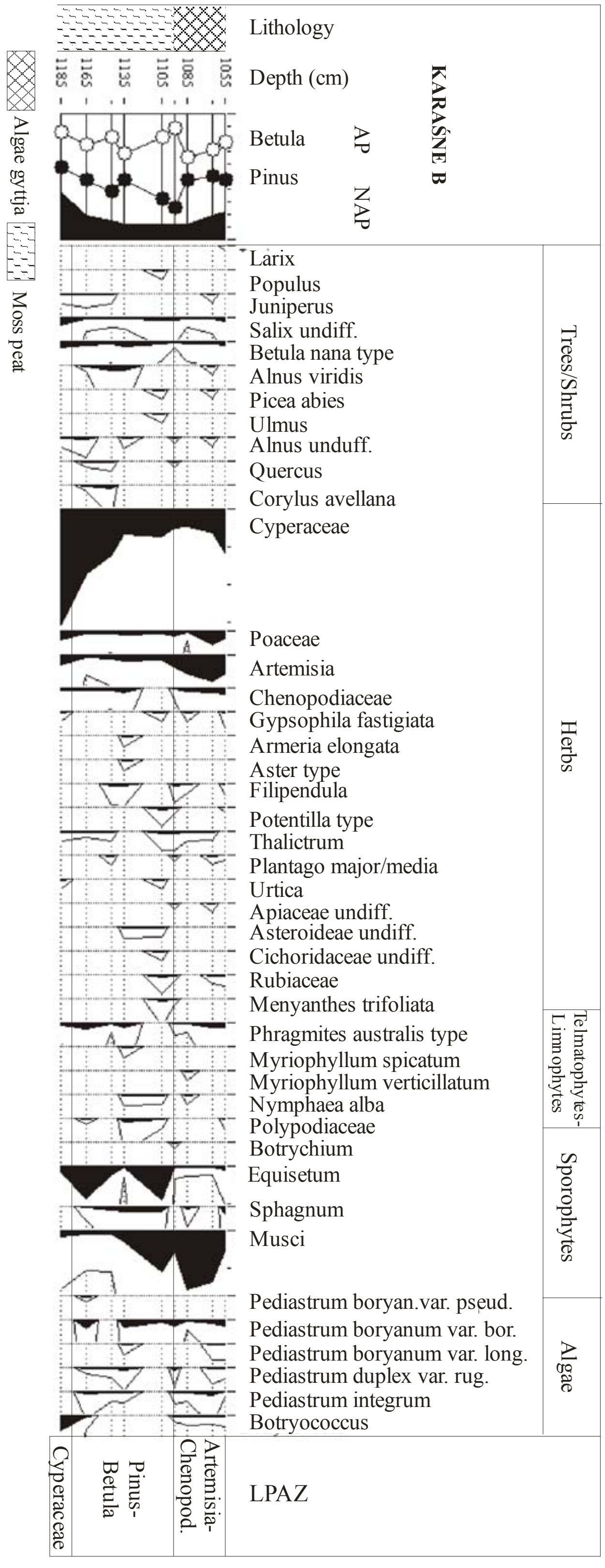

Fig. 5. *Percentage pollen diagram of the profile Ka-B.*

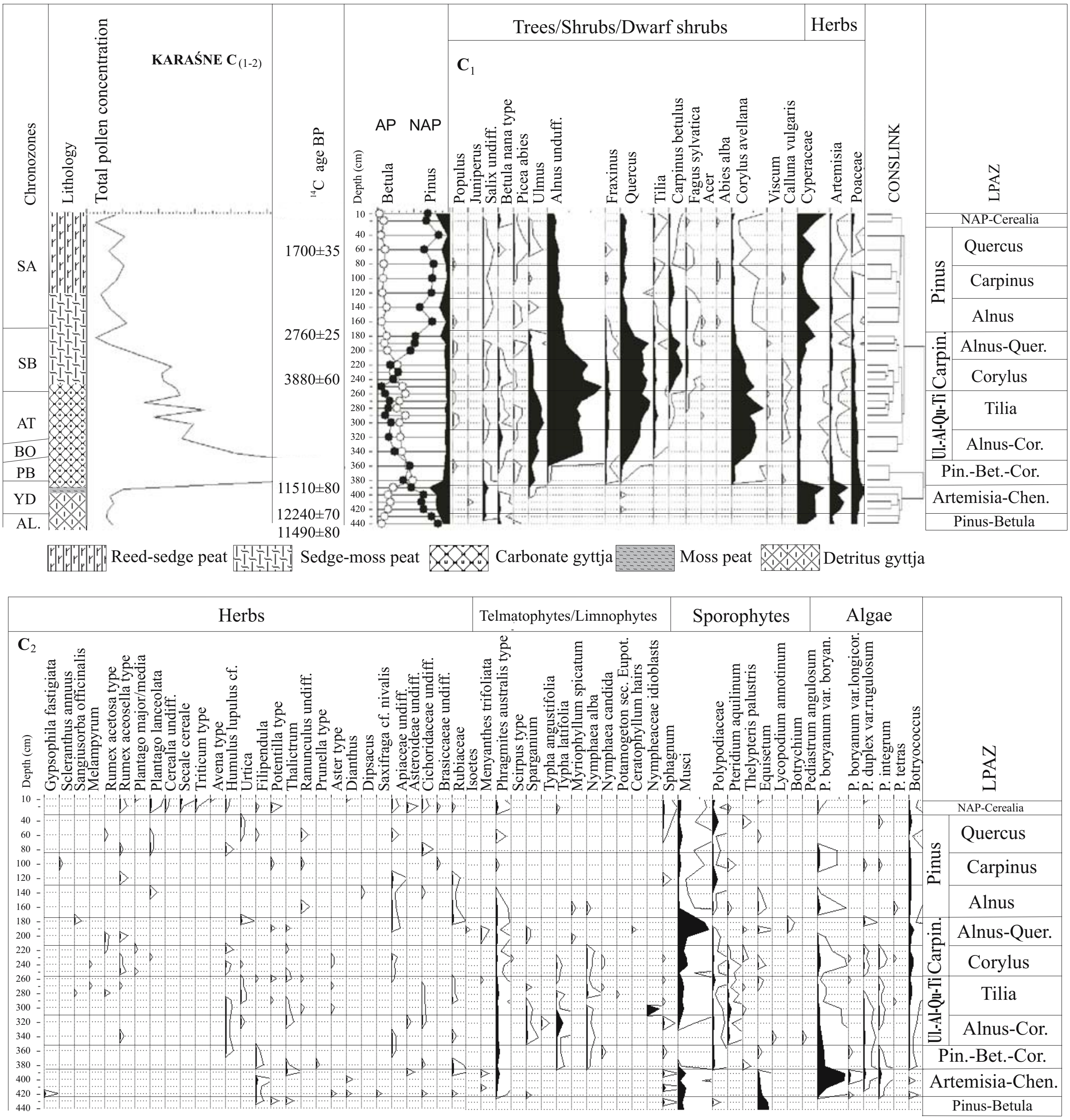

Fig. 6. *Percentage pollen diagram of the profile Ka-C.*

occurrence of *Populus* pollen and still relatively high values of *Salix* may be associated with the presence of wetland *Salici-Populetum*. The appearance of species with higher thermal requirements such as *Typha latifolia* and *Nymphea alba* reflects an increasingly warming climate at that time.

The ***Ulmus-Alnus-Quercus-Tilia*** **LPAZ** (Ka-A, 800-475 cm; Ka-C, 350-255 cm) is correlated with the Boreal and Atlantic chronozones. Two subzones are distinguished: *Alnus-Corylus* subzone (Ka-A, 800-665 cm; Ka-C, 350-325 cm) and *Tilia* subzone (Ka-A, 665-475 cm; Ka-C, 325-255). The *Alnus-Corylus* subzone is correlated with the Boreal chronozone as well as with the older part of the Atlantic chronozone. It is distinguished in both profiles but it has a somehow different picture in the profile Ka-C, as the phase with maximum values of *Corylus* preceding the maximum values of *Alnus* is lacking. The high values of hazel preceding the culmination of *Alnus* are characteristic for the diagrams of the Polesie region and should be correlated with the Boreal chronozone. Supposedly, this phase is absent from the profile Ka-C either because of a hiatus or because of the fact that the profile represents local conditions of pollen deposition. The latter option, however, is not confirmed in the percentage curves of other taxa. Both the sediments deposited in the profiles Ka-A and Ka-C represented the still extensive lake.

Pine-birch forests persisted in the landscape of the examined site in this subzone. The pollen values of the respective components were changing, but the dominating character of birch may be spotted. The values of *Ulmus*, *Alnus, Quercus* and *Fraxinus* were increasingly higher, and the forest communities increasingly more varied respective of the occupied habitats. The increasing values of *Corylus* up to 14.3% indicate the intensive spread of hazel. This photophilous shrub was a component of forest understorey, but was also able to form independent communities. In the examined site the development of these communities was gradual and then they were rather stable. During the first culmination of the *Alnus* curve there is no distinct decrease in the *Corylus* pollen frequency.

The *Tilia* subzone which corresponds to the middle and last phase of the Atlantic chronozone is characterized by the maximum development of deciduous forests composed of oak, elm, alder, ash and lime. Lime is the last of the thermophilous species, which appeared in the forests of climate optimum. It was a component of oak forests as well as of riverine communities (with elm and ash). Its pollen frequency in the examined profiles does not exceed 2%, which is similar to other sites in the Polesie region (values >2% are sometimes noted in Moszne, Łukcze, Perespilno sites). The continuously increasing frequency of *Fraxinus* pollen points to the fact that ash was a significant component of the forest, presumably forming communities resembling the modern ash-elm and ash-alder forests. An increasing role of oak may also be noted. On the poorer habitats, oak and pine were forming mixed coniferous forests, whereas on the more fertile ones, oak woods with elm, ash and lime. Low *Pinus* frequencies indicate that in the period of climatic optimum, pine forests were occupying solely the poor, sandy soils. In such loose pine forest, dwarf shrubs *Calluna vulgaris* and *Pteridium aquilinum* were developing, which is shown by their continuous curves. The predominance of birch pollen over pine pollen testifies to the abundance of birch forests in the vicinity of the lake, which distinguishes this site (Bałaga, 1991, 2004 and Bałaga *et al.*, 1983, 1992, 2006). The continuing sporadic occurrence of *Picea* pollen indicate that spruce was a likely component of the widespread alder carr communities though the different pollen values may be accepted as evidence for the presence of spruce in forest (Środoń, 1967; Huntley and Birks, 1983; Hicks, 1994 and Latałowa *et al.*, 2006). Interestingly, nowadays, in the Polesie region spruce occurs only outside its continuous distribution (Środoń 1967 and Zając and Zając, 2001). The discontinuous distribution of spruce in Poland has been given much attention over the years (compare Bałaga, 1991). The stable pollen frequencies of *Corylus* (10.4%) indicate that the understorey of the forests was composed of hazel. The pollen indicators of climatic optimum, *Viscum* and *Hedera helix,* were also present.

The ***Carpinus* LPAZ** (Ka-A, 475-210 cm; Ka-C, 255-170 cm) corresponds to the Subboreal chronozone (*Corylus* subzone – Ka-A, 475-395 cm; Ka-C, 255-210 cm, and *Alnus-Quercus* subzone – Ka-A, 395-290 cm; Ka-C, 210-170 cm), and to the Subatlantic chronozone (*Fagus* subzone – Ka-A, 290-210 cm).

In the *Corylus* subzone, which corresponds to the early phase of the Subboreal chronozone, a decrease in elm frequencies continues in the vicinity of the lake. The reasons for such a decrease, which is characteristic for the transition of the Atlantic/Subboreal chronozone, may be climatic, anthropogenic or pathogenic factors (e.g. Iversen, 1960; van Groenman-Waateringe, 1983 and Peglar, 1993). In the analysed diagrams, the decrease in the frequency of this pollen is connected with a continuously increasing curve of *Carpinus*, *Pinus* (Ka-C) and *Artemisia* as well as with a decrease in *Tilia* and *Fraxinus*. The increasing frequencies of *Plantago major/media*, *Rumex*, *Urtica* evidence the changes in the forest structure which were induced by human economic activity. A layer of peat in the Ka-C profile, which represents a decrease in elm and an increase in *Carpinus* is dated for as late as 3880±60 PB. It may indicate a hiatus in the accumulation of sediments, an observation which seems to be confirmed by the localization of the profile in the shore zone of the overgrowing lake. Similar hiatuses (at the turn of the Atlantic and Suboreal chronozones) have been reported in the profiles collected at the peat bog adhering to Lake Łukcze (Bałaga, 1991). Another, however less probable, reason for this fact may be a very low sedimentation rate in the period between the first distinct decrease in elm values (at the depth of 270 cm) and the appearance of the continuous hornbeam curve. The diagram Ka-C shows that the introduction of hornbeam - a new component of the forests - into the surroundings of the examined site was relatively slow, comparable to that of the Durne Bagno site (Bałaga *et al.*, 2006 and 2007). From the profile Ka-C, which reflects the local conditions, it can be deduced that the maximum proportion of hornbeam in forests occurred from 3500-2700 BP. The development of shady hornbeam forests continuously impeded the development of hazel communities. In the diagram K-A a decrease (to 5%) in hazel frequencies is estimated at about 4350 BP. Therefore, it is not synchronous with the diagram Ka-C, where a similar decrease is dated for 3050 BP. The early Subboreal period in the history of our country is often characterized by predominance of oak woods. Oak was a component of varied communities e.g. it formed forests of the contemporary open oak wood type (*Querco-Potentilletum albae*), which may be anthropogenic in origin (Matuszkiewicz, 2002; Ralska-Jasiewiczowa *et al.*, 2003 and Milecka *et al.*, 2004). In the vicinity of Karaśne Lake, both in the early and late Subboreal chronozone (*Alnus–Quercus* subzone) oak was quite a stable component of forests as the frequency of its pollen does not exhibit major fluctuations. The significant part of elm and ash in the moderately humid forests is emphasized by the stable, amounting to several percent values of the pollen of these trees. The constantly low pollen values of *Picea* indicate that spruce still could occur sporadically in alder carr forests.

In the Subatlantic chronozone the pollen spectra in the examined profiles are different. As mentioned above, in the profile Ka-A the Subatlantic is represented by the *Fagus* subzone (***Carpinus* LPAZ**). In the profile Ka-C the Subatlantic corresponds to the *Alnus*, *Carpinus* and *Quercus* subzones (***Pinus*** **LPAZ**, 170-20 cm). The youngest part of the Subatlantic chronozone in both analysed profiles is represented by the **NAP-Cerealia LPAZ** (Ka-A, 210-160 cm; Ka-C, 20-10 cm).

The curves of *Pinus*, *Betula* and *Carpinus* are quite different in the two analysed pollen diagrams. The high frequency of *Pinus* (84%) in the profile Ka-C is presumably local in character, it may come from a pine forest which was locally growing at the edge of the mire (Jensen *et al.*, 2002). The profile taken from the central part of the lake (Ka-A) shows that birch communities were still developing intensively. It also shows, contrary to the diagram Ka-C, that forests with oak and hornbeam were developing likewise. The frequencies of these components (especially of hornbeam) in the profile Ka-C are relatively low though about 2160 BP there was a short increase in the hornbeam values (up to 2.5%). At the same time in the central profile (Ka-A) the maximum frequencies of *Carpinus* reached up to 8.3%. In Subatlantic forests, there was a continuous decrease in lime, elm and ash proportions. Periodically high beech frequencies (up to 2.3% in Ka-A, and 1.1% in Ka-C) indicate that it may have been a local component of the nearby forests (Huntley and Birks, 1983; Huntley *et al.*, 1989 and Woods and Davis, 1989). Nowadays, no occurrences of beech tree are noted in the Łęczna-Włodawa Lake District (Fijałkowski, 1957 and Tarasiuk, 1999). Also, north-eastern limit of continuous beech distribution does not reach the Lublin Polesie region (Boratyńska and Boratyński, 1990 and Zając and Zając, 2001). *Abies alba* pollen appears sporadically in low values (0.2%) in this zone; fir, nowadays does not participate in the forest of the studied area (Fijałkowski, 1957 and Boratyńska, 1983) neither. The problem is discussed at length in Bałaga (1991). Recent research on contemporary pollen dispersion in the Roztocze region situated south of the examination site, where beech and fir occur continuously show that a considerable amount of these species pollen found in Tauber`s traps comes from short distances: up to 5000 m for beech and around 500 m for fir (Poska and Pidek, 2007).

The development of the earliest Holocene forests (**NAP-Cerealia LPAZ**) was influenced by human economic activity, which is reflected in the sections of pollen diagrams presenting the situation since the early Middle Ages.

The impact of human economic activity on vegetation cover

The analysis of the relation between human economic activity and natural environment was based on three kinds of data: occurrences of pollen established as indicators (Behre, 1981), changes of the forest cover in the examined area determined by AP/NAP ratio, and the density of settlement in the prehistoric times and Middle Ages. The location of the archaeological sites within the 3 km radius (including a part of the area of Lake Moszne) has been shown in the maps (**Fig. 7**) The traces of prehistoric settlement are quite numerous in the vicinity of these two lakes; the chronology of the majority of the archaeological findings, however, cannot be unequivocally established (Taras, 2005). Near Lake Karaśne, mainly the sites of smaller area are found.

Ever since the Late Glacial the Polesie region was inhabited by people groups equipped with flint tools. This Palaeolithic population's economy was based on hunting (mainly reindeers and elks), people were leading a relatively mobile lifestyle and as such didn't induce major changes in the vegetation cover of the Alleröd and Younger Dryas periods.

In the younger and middle Holocene the Mesolithic populations of Komornicka, and then Janisławicka Cultures started to settle down in the Polesie region. Mesolithic economy was based mainly on exploitation of woodland, hunting, gathering and fishing (Tymczak, 1998). The sites dated for the Mesolithic are rare in the examined area (**Fig. 7**). In the analysed pollen diagrams, the major influence of Mesolithic hunters on vegetation cover is not noticeable. The continuous curve of *Pteridium aquilinum*, a species well developing in cleared forests or conflagration sites, occurs in the diagram Ka-C and is accompanied by an increasing pollen frequencies of thermophilous trees (PB/BO). In the profile Ka-A, *Pteridium aquilinum* pollen appears later, i.e. at about 7700 BP. At the same time the first pollen grain of *Melampyrum* was noted, which also indicates forest clearings. The pollen frequency of another indicative taxon, *Urtica*, which may be connected with the occurrence of nettle in alder carr communities or on nitrophilous habitats (cf. *Urtica urens*) in the vicinity of human settlements, is low but constant. Its small increase, synchronous with slightly higher pollen values of *Artemisia* and a decrease in *Alnus*, *Quercus*, *Tilia* and *Ulmus* is dated for about 6300 BP. The increase in the frequencies of *Bosmina longirostris*, *Pediastrum* and idioblasts of Nymphaeaceae may point to more eutrophic lake water, which may in turn indicate a more intensive human exploitation of the lake catchment.

The first pollen grain of *Plantago lanceolata* occurs at the depth of 450 cm, straight after the easily noticeable decrease in *Ulmus* and correlates with the increase in *Artemisia* and *Pediastrum* coenobia. This level may be dated for 5100 BP and correlated with Neolithic cultures impact. The most numerous archaeological artefacts from this area are associated with the Funnel-Beaker Culture. There are about 130 sites of the sort, they are organized into smaller or bigger groups covering the whole of the Łęczna-Włodawa Lake District (Taras, 2005). In the examined area, the sites of this culture are shown in **Fig. 7**. The population of the Funnel-Beaker Culture acquired farming land by means of a burning technique, which is confirmed by the presence of charcoals at the depth of 529-360 cm. The occurrence of new meadow and ruderal taxa (*Rumex acetosa*, *R. acetosella*, *Plantago major*/*media*) may confirm the presence of clearings or deforested areas. The proportions of mesophilous trees in forests successively decreased, whereas hornbeam slowly started to take over the deforested areas.

The first Cerealia pollen (*Triticum* type), evidencing cereal cultivation, is found at the depth of 365 cm (Ka-A) so it appeared about 4200 BP. The fact that the younger Neolithic people continued settling down in the examined area accounts for the spread of *Artemisia*, Chenopodi-

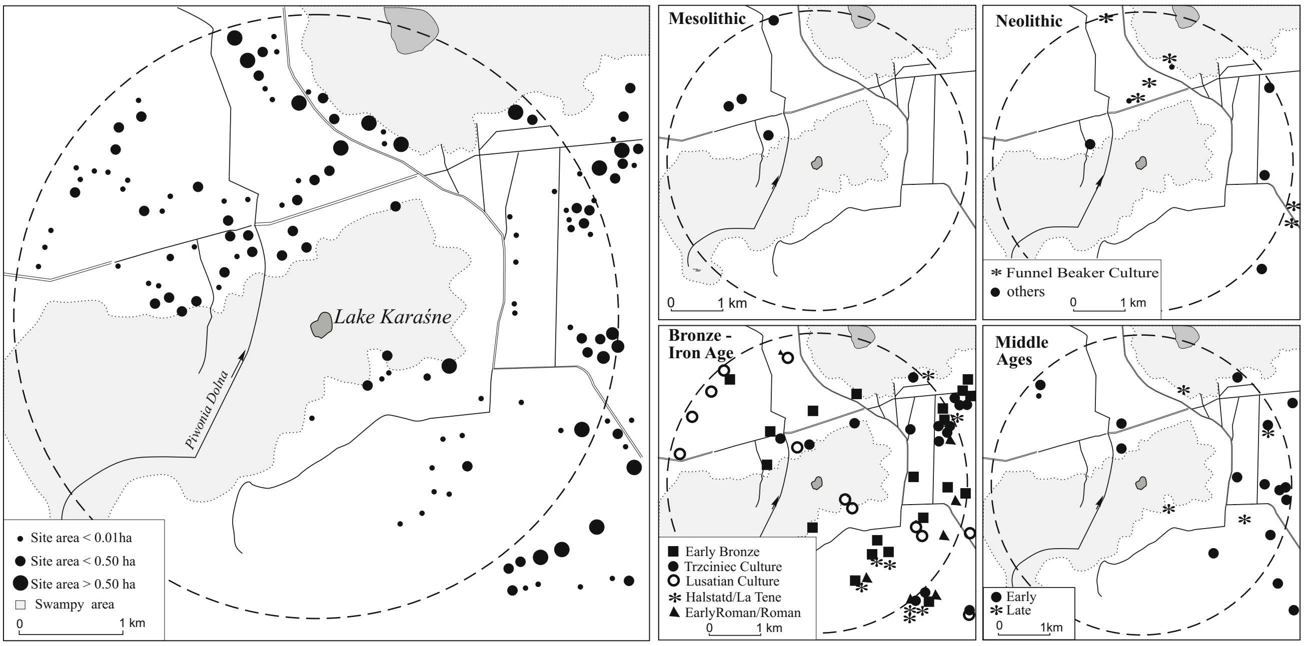

Fig. 7. *Distribution of the archaeological sites in the vicinity of Lake Karaśne.*

aceae, *Plantago lanceolata* and *Urtica* (cf. *Urtica dioica*). A slight decrease in *Fagus* and *Carpinus* pollen may be noted at this stage. In the younger Neolithic period small, short-lasting and dispersed settlements were formed. Small burial grounds or single graves of the Globular Amphorae and Corded Ware Cultures also date from that period. The majority of the settlements of the latter culture are defined by stone axes, which were found in the area (Bronicki, 1991). In the surroundings of Lake Karaśne there are 6 sites which are connected with populations of Globular Amphorae and Corded Ware Cultures (**Fig. 7**). The populations of these cultures were leading a nomadic existence and their economy was based on pasturing. Although changes induced by Neolithic man in the natural environment are not yet reflected in the AP/NAP ratio, the fluctuations of the tree curves may be considered indicative of changes in forest composition. The surface of the fields under cultivation was probably small, and, additionally, pioneering forest vegetation tended to cover the frequently lying fallow fields, which may be evidenced by increasing pollen values of birch and ash. Subsequently, hornbeam communities tended to regenerate.

At the beginning of the Bronze Age dispersed settlement of the Mierzanowicka and later Strzyżowska Cultures appeared in the examined area. These were not long-lasting forms of colonization, however, contrary to the settlements of the Trzciniecka culture which are observed in the central part of the Lake District. Barrows also date from that time (Taras, 1995 and Bronicki, 1991). Nine sites are related with the Trzciniecka Culture, and fifteen are dated to the early Bronze Age (**Fig. 7**). The pollen values of anthropogenic indicators are stable or slightly higher at this time, the pasture indicators*,* however, are predominant. The frequencies of cereal pollen are very low. This kind of economic activity lasted until the Middle Ages, that is throughout the period where Polesie was inhabited by the population of Lusatian Culture, and later by La Téne and Roman populations. The presence of numerous Lusatian Culture sites is reflected in greater deforestation and a decrease in the hornbeam curve (at about 2700-2300 BP), which were stated in both of the examined profiles (compare Ralska-Jasiewiczowa *et al.*, 2004). The presence of anthropogenic indicators is not always synchronous with a decrease in hornbeam pollen frequencies (**Fig. 4**). The first occurrence of *Secale cereale* pollen was accompanied by an increase in *Carpinus* at about 1760 BP (that is, in the Roman Period), and should be analysed in relation to direct rye cultivation.

The pollen spectra relating to the first and the beginnings of the second millennium A.D. give a different picture of the vegetation cover. In the profile Ka-A, high pollen frequencies (up to 8.5%) of hornbeam persist, and they do not decrease until 1300 BP (to 4.6%). In the profile Ka-C, in contrast, the value of hornbeam is stable and does not exceed 1%. In this period a low frequency of anthropogenic indicators is noted in both profiles, but the situation changes at about 1300 BP, when it starts to increase gradually (Ka-A). Other changes, visible in the significant increase of the NAP sum (including anthropogenic indicators), are dated for 600 BP (Ka-A, Ka-C). Numerous archaeological sites (12) from the early Middle Ages indicate that the intensive deforestation of the area began at that time, but it was not until the late Middle Ages when the transfer from a two-field system into a three-field system (resulting in cultivation intensification) had a clear reflection in the AP/NAP ratio. The development of the feudal land ownership system led to the establishment of more rigid field-forest boundaries (Maruszczak, 1988), which resulted in an increase in anthropogenic indicators in the top samples of the examined profiles. Among the cultivated plants, apart from cereals, high pollen frequencies of *Cannabis* and *Humulus*, as well as the presence of *Fagopyrum* (Ka-A) have been noted. As for weeds, the most intensive development was noted in species characteristic for acid soils, such as *Rumex acetosella*.

Development of the lake-mire complex

Pre-Bölling-Alleröd chronozone: The oldest biogenic sediments (coarse detritus gyttja – profile Ka-A), deposited in the central part of the lake and representing the *Salix*-Cyperaceae zone, are correlated with the end of the Pleniglacial (12400±65 BP). This zone should be also correlated with bottom layers of moss peat found in different parts of the bottom of the contemporary lake and radiocarbon dated for 12180±140 BP (Ka-B) and 12150±150 BP (Ka-A1) (**Figs 2** and **3**, **Table 5**). A similar age of accumulation is established in the profiles taken from the contemporary mire (Ka-C, 12240±70 BP; Ka-D, 12450±60 BP). Accumulation of these sediments took place in shallow, wet depressions holding water thanks to the presence of permafrost in the substratum (Dobrowolski, 2006). Their depth determined whether the accumulation was limnic or telmatic in character. Therefore, varied geomorphologic conditions were shaping a mosaic water-mire landscape of the examined area. The Cladocera analysis of the lowermost layers of bottom sediments (Ka-A) indicates that the waters were cold and inhabited by "arctic species" (Szeroczyńska, 2003). The sediments are characterised by a large proportion of chemical elements associated with erosion (**Fig. 8**). The upper boundary of this chronozone is also marked by distinct peaks on the curves of carbon and oxygen stable isotopes.

Bölling-Alleröd chronozones: The type of the various biogenic accumulation initiated in the former period continued in the analysed site. In the shore zone of the contemporary lake (Ka-B) peat was sedented, whereas in the central part there was a clear change into the carbonate gyttja accumulation. In the northern zone of the lake, in the profiles Ka-C and Ka-D, precipitation of $CaCO_3$ intensified in certain periods (see profile description). A different type of accumulation in the neighbouring depressions was still connected with a different depth of numerous original sedimentation basins and with a varied rate of permafrost degradation. The malacological analysis of carbonate gyttja (*Betula* pollen zone; profile Ka-A) has shown that it was a phase of the development of a shallow lake where the ecological conditions conducive for lung-breathing snails (Planorbidae) were met (Bałaga *et al.*, 2005). The presence of snails tolerating periodical drying out (*Planorbis planorbis*) may indicate that the shoreline of this lake changed. The presence of macrophytes of the littoral zone points to the fact that sedimentation in the early phase of the Bölling-Alleröd chronozones (*Betula* zone) took place in a shallow lake. The curves of stable isotopes in these deposits exhibit two phases (**Fig. 9**). The older phase is characterized by low values of $\delta^{18}O$ and high values of $\delta^{13}C$. The amplitude of the subsequent changes of $\delta^{18}O$ (towards positive values) and of $\delta^{13}C$ (towards negative values) is 4-5‰ (compare Kuc *et al.*, 1996 and Bałaga *et al.*, 1998). The older isotope phase corresponds to higher pollen frequencies of *Artemisia* and Chenopodiaceae accompanied by the increasing curves of *Betula* and *Pinus*, whereas the younger phase corresponds to the maximum values of *Betula*.

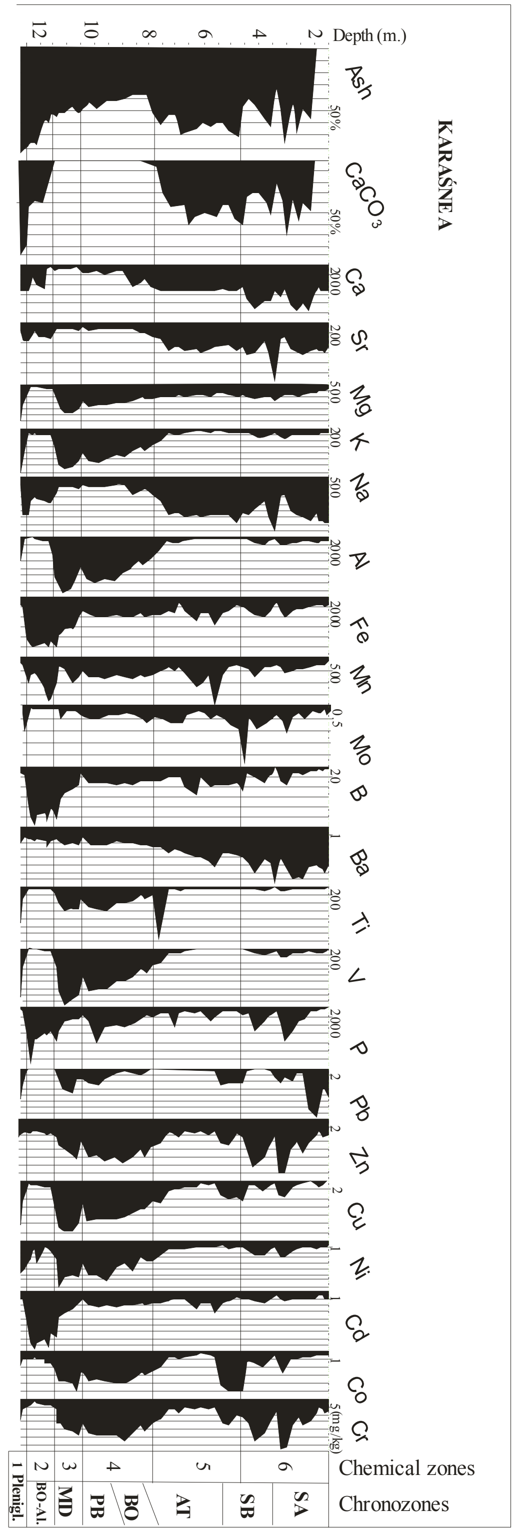

Fig. 8. *Chemical composition of the deposits from the profile Ka-A.*

A higher water level, and to be more specific, the deepening of the lake is correlated with a late phase of the Bölling-Alleröd complex that is the Alleröd chronozone (*Pinus-Betula* pollen zone). The occurrence of Bosminidae points to a higher water level (Szeroczyńska, 2003). The presence of *Bosmina longirostris* is also indicative of the increasing trophy in the lake at this time. The deepening of the lake supposedly contributed to the impoverishment of the snail fauna (**Table 9**). The stable change of δ^{18}O towards negative values and of δ^{13}C towards positive values by 1 and 2‰ respectively, was switched at the end of the pollen zone by a similar value (depth 1175-1155 cm).

The basic development phase of the extensive lake is estimated at the turn of the Alleröd and the Younger Dryas. Sedimentation of limnic deposits took place on mire (profile Ka-B, Bałaga *et al.*, 2002). This change is not as connected with a high rise of groundwater table as it is with the morphogenetic transformation of the area and the formation of the edges of the basin proper. As a result of the complete (or at least major) permafrost degradation at the end of the Alleröd the groundwater circulation was entirely reformed, and, subsequently, a rapid subsidence of substratum occurred (Bałaga *et al.*, 2002, 2006 and Dobrowolski, 2006). The change of thermal and humidity conditions is observed in the isotope composition of δ^{18}O and ^{13}C. The δ^{13}C jumped towards negative values (by over 3‰), and δ^{18}O (by over 4‰) towards positive values. Trend of δ^{13}C change is similar as in Lake Perespilno and trend of δ^{18}O change is inverse (Kuc *et al.*, 1996 and Bałaga *et al.*, 1998). A special mention deserves a change in the character of sedimentation (from carbonate to non-carbonate) in the lake basin almost directly formed in the carbonate deposits at the AL/YD turn.

Younger Dryas chronozone: It originates the stage of limnic sedimentation in the entire examined basin, which was marked by accumulation of black-brown algae

Table 9. *Comparison of the palynological, faunal (Szeroczyńska 2003, Bałaga et al., 2005) and chemical elements in deposits of the profile Ka-A.*

Chronozones	Pollen zone	Pollen subzone	Short characteristic of phases: Cladocera	Mollusca	Chemical
Plenigl.	***Salix-Cyperaceae*** (1275-1265 cm)		**I (1275-1250 cm)** Species from "arctic" group present. *Alona quadrangularis* and *Grabtoleberis testudinaria*, i.e. species preferring warmer conditions, appear at the end of the phase	Planorbidae outnumber Valvata. *Gyraulus laevis*, *Pisidium lilieborgi*, and *Planorbis planorbis* present.	High contents of erosion indicators
OD-Al	***Betula*** (1265-1215 cm)		**II (1250-1150 cm)** Rich fauna. Species of littoral and pelagic zone present. More eutrophic species (*Bosmina longirostris* and *Alona rectangulata*) and thermophilous *Graptoleberis testudinaria* reach high frequencies	Well preserved but poor fauna, typical of a small, eutrophic and overgrowing lake	High content of $CaCO_3$
OD-Al	***Pinus-Betula*** (1215-1045 cm)				
YD	***Artemisia*-Chenopodiaceae** (1145-1070 cm)		**III (1150-1070 cm)** Decrease of Cladocera fauna. Species of colder periods prevail. Species preferring warmer conditions occur sporadically	(1100-1150 cm); very poor fauna; shell fragments of *Valvata piscinalis* (represented in the whole profile). Lack of shells and opercula of *Bithynia tentaculata*	$CaCO_3$ absent
PB	***Ulmus-Betula***	***Filipendula*** (1070-1015 cm)	**IV (1070-825 cm)** Maximum development of zooplankton. *Alona rectangulata* and *Chydorus sphaericus* prevail in Chydoridae. *Disparaloma rostrata*, *Leydigia leydigii*, *L. acanthocercoides*, and *Monospilus dispar* reach maximum development.	(1100-700cm); fauna absent	
PB	***Ulmus-Betula***	***Betula*** (1015-915 cm)			
PB	***Ulmus-Betula***	***Pinus-Betula-Corylus*** (915-800 cm)			
BO	***Ulmus-Alnus-Quercus-Tilia* zone**	***Alnus-Corylus*** (800-665 cm)	**V (825-640 cm)** Worse conditions for plankton development – almost complete lack of Bosminidae species. Increase of *Allona excisa* – species preferring low pH of water	(700-200 cm; with hiatus from 600 to 650 cm); fauna consists only of *Bithynia tentaculata* opercula; unfavourable conditions for fauna development and shell preservation (shells are considerably easier and faster dissolved by water with low pH than opercula)	$CaCO_3$ present
AT	***Ulmus-Alnus-Quercus-Tilia* zone**	***Tilia*** (665-475 cm)	**VI (640-450 cm)** a) Complete lack of pelagic species and those of higher thermal requirements. Few individuals of littoral species; b) *Bosmina longirostris* appears; c) Decrease of *Bosmina longirostris*, increase of *Alona excisa* and *Monospilus dispar* (less eutrophic conditions and slight decrease of water pH)		
SB	***Carpinus***	***Corylus*** (475-395 cm)	**VII (450-385 cm)** Rise of *Alona rectangulata, Chydorus sphaericus* and *Bosmina longirostris* – species living in eutrophic water		
SB	***Carpinus***	***Alnus-Quercus*** (395-290 cm)	**VIII (385-205 cm)** *Bosmina longispina*, *B. coregoni*, and *Chydorus piger* dominate; a) Coexistence of *Bosmina longispina* and *Bosmina coregoni*		
SA	***Carpinus***	***Fagus*** (290-210 cm)	b) Complete lack of *Bosmina longispina*		
SA	***Pinus*-NAP-Cerealia** (210-160 cm)		**IX (205-155 cm)** Occurrence of species associated with shallow water and water plants – worse conditions for Cladocera development due to lake shallowing	(200-150cm); fauna of a small, strongly overgrown lake (four species of snails and one taxon of molluscs)	Slight increase of K, Al

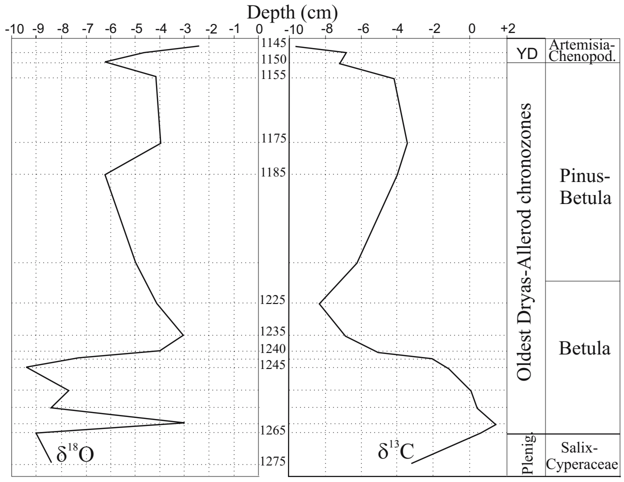

Fig. 9. *The changes in the curves of δ18O and δ13C compared with the palynological data. Values of δ18O and δ13C are given in ‰ relative to PDB standard.*

gyttja (deposited in a relatively deep lake). The cool and dry climate of the Younger Dryas (*Artemisia*-Chenopodiaceae pollen zone; Karaśne A, B, C) in this part of the country is indicated by high frequencies of *Artemisia* (Makohonienko *et al.*, 2004). According to Prentice *et al.* (1992) Artemisia steppe vegetation predominates in climates characterized by very cold winters, intensive winter precipitation, and summer drought. The cooling of the climate is also indicated by the composition of Cladocera (Szeroczyńska, 2003) as well as the malacofauna impoverishment (**Table 9**). A more abundant development of *Pediastrum* is observed in the younger phase of the chronozone with the predominance of cosmopolitan *Pediastrum boryanum* var. *boryanum* (Komarek and Jankowska, 2001). In the chemical composition of the sediments there is a decrease in Ca, Fe, Mn, B and Cd and an increase in Mg, K, Al, Ti, V, Zn, Cu, Ni, Co and Cr contents. Higher contents of macroelements are probably connected with erosion processes in the open landscape (Polański and Smulikowski, 1969 and Perelman, 1971). Increasing contents of microelements (especially in the younger part of this chronozone) should be connected with an increase in the biomass production in the lake, which is marked by a higher frequency of algae (*Pediastrum* genus) and Cladocera fauna (depth 1045 cm). In the profile Ka-C a peat layer, radiocarbon dated for 11510±80 BP, dividing the gyttja deposits (palynologically dated for the Younger Dryas) should be connected with the transfer of the Alleröd peat fragments to the lake, and subsequent sinking in younger sediments. Such thin peat interlayers in gyttja are also frequent in other sites of the Łęczna-Włodawa Lake District (e.g. in the profile Łukcze I – Bałaga, 1991).

Holocene

Preboreal chronozone: Non-carbonate algae gyttja and later carbonate gyttja were deposited at the bottom of the lake in the Preboreal chronozone (*Ulmus-Betula*, Ka-A; *Ulmus-Pinus-Filipendula*, Ka-C). In the lithology of these sediments there is no distinct boundary between Late Glacial and Holocene accumulation. The thickness of the Preboreal gyttja layer in the profile Ka-A is 180 cm while in the profile Ka-C it is as low as 30 cm. The succession of Cladocera fauna (Ka-A) is registered as the maximum development of zooplankton of meso-eutrophic type. The abundance of *Pediastrum* is also indicative of an increase in the trophy of the lake (Komarek and Jankowska, 2001). Apart from cosmopolitan *Pediastrum boryanum* var. *boryanum* the following species had high frequencies: *P. duplex* var. *duplex*, *P. duplex* var. *rugulosum*, *P. integrum*, *P. boryanum* var. *longicorne* and *P. tetras*. Almost exclusively in this zone there are found *P. alternans*, *P. boryanum* var. *pseudoglabrum*, *P. duplex* var. *asperum* and *P. biradiatum*. The frequency of plankton forms in the fauna of Cladocera indicates that the examined lake was relatively deep at the time (Szeroczyńska 2003). The malacofauna is missing completely (**Table 9**). The type of sediments was probably determined by biological processes in the lake. They are characterized by still high (although decreasing) contents of chemical elements (Mg, K, Al, V, Zn, Cu, Ni, Co and Cr), which are negatively correlated with Ca. It is not until the *Pinus-Betula-Corylus* subzone, however, that their decrease occurred, accompanied by an increase in Ca and calcium carbonate, which may be a result of the lowering of the water level. The presence of $CaCO_3$ in the lake sediments of the Lublin Polesie region is typical of shallower lake basins (Bałaga, 1991, 2003).

Boreal chronozone: In the initial phase (*Corylus-Alnus* subzones) of the *Ulmus-Alnus-Quercus-Tilia* zone, a carbonate sedimentation persisted (algae-carbonate gyttja). The analyses of Cladocera point to the lowering of water level, disappearance of Bosminidae species and a decrease in the frequencies of both Cladocera and algae of *Pediastrum* genus. In the sediment the chemical elements correlated negatively with Ca reach minimum values, whereas the elements positively correlated with Ca (especially Sr, Na and Ba) reach higher values.

Atlantic chronozone: In the younger phase of the *Corylus-Alnus* subzone and in the *Tilia* subzone of *Ulmus-Quercus-Alnus-Tilia* zone the maximum area of lake water surface (about 72 ha) existed till about 6000 BP as evidenced by the accumulation of algae-carbonate gyttja in the profile Ka-D. In the profile Ka-A the frequencies of Cladocera fauna and *Pediastrum* coenobia are still low. The low water level is confirmed by the development of the macrophytes (with *Sparganium*, *Typha latifolia*, *T. angustifolia* and *Nymphaea alba*) as well as by the lack of *Bosmina longispina* and *B. coregoni*. In the middle phase of this chronozone, *B. longirostris* had higher frequencies, which may be compared with a slight increase in *Pediastrum*, *Artemisia*, *Urtica* and *Pteridium* frequencies and associated with a higher trophy of lake waters.

Subboreal chronozone: In this chronozone (*Carpinus* pollen zone, Ka-C), the complete (reaching the contemporary shore zone of "floating islands") shallowing of the peripheral parts of the lake was documented. According to radiocarbon data, throughout about 2000 years the water surface was reduced to about 17.5 ha. The change of sedimentation into sedentation in the profile Ka-C (radiocarbon dated for 3880±60 BP) does not fully correspond to the palynological dating. Considering the location of the profile (the shore zone of the lake) the presence of a sedimentation hiatus cannot be excluded. Therefore, one must take into account the lack of deposits of undefined type (gyttja or peat). If the peats were damaged, we can suppose that the lake was overgrown even earlier.

At the beginning of this chronozone, in the lake sediments the content of Ca increased, as well as the contents of K and Al (so far negatively correlated with Ca). Both in the frequencies of Cladocera and *Pediastrum*, the fluctuations indicating the changes in the depth and trophy of the water are observed. It should be emphasized that the curves of these bioelements correspond with Cr, Zn and Pb curves (depth 425 cm). The synchronous character of the frequencies of Zr, Cr, and Cladocera is observed also in the Durne Bagno site (Bałaga, 2007).

The occurrence of *Bosmina coregoni* and *B. longispina* may indicate a higher water level at the end of this chronozone. Their presence is correlated with the disappearance of Characeae oospores (**Table 10**). In the lake the fauna of molluscs (*Bithynia tentaculata*) reappears.

Subatlantic chronozone: In the older part of this chronozone there was still a relatively high water level; *Bosmina coregoni*, *B. longispina*, and rather abundant *B. longirostris* occurred. A considerable shallowing of the lake is observed (NAP-Cerealia zone), which is indicated by numerous oospores of Characeae, seeds of *Najas flexilis*, coenobia of *Pediastrum* and fauna of molluscs and Cladocera. The increasing values of Musci and Cyperaceae point to the development of the "floating islands" surrounding the lake and a further reduction in the water surface.

5. DISCUSSION ABOUT BIOSTRATIGRAPHY OF PRE-YOUNGER DRYAS SEDIMENTS

A series of radiocarbon dates from the bottom deposit layers in the Karaśne site indicates that they are older than 12 ka BP, i.e. biogenic accumulation started before Older Dryas. We assume that the results are not overestimated by hard water effect because dated material was very different (gyttja, peat, terrestrial macroremnants). Similar ages of bottom deposits were also obtained in other sites of the Lublin Polesie (Bałaga, 1991, 2004; Goslar *et al.*, 1999 and unpubl. material) and Volhynia Polesie (Zernickaya, 1997 and Dobrowolski, 2006). The Late Glacial pollen diagrams from the Polesie sites are generally similar, with two distinct cold phases, which should be correlated with the Older Dryas and Younger Dryas. They were separated by an interstadial warming, sometimes with weak signs of cooling or continental climate features (compare Bałaga, 2004). Rapid expansion of birch occurred at the beginning of this warming. In most of the palynologically examined profiles the pollen frequencies of *Betula* exceed 50%, and *Hippophaë rhamnoides* is still present. However, the deposit layer with the maximum pollen values of birch has differentiated thickness. The *Betula* maximum is best recorded in the following sites: Łukcze (Bałaga, 1991), Krowie Bagno (Bałaga *et al.*, 1983), and Perespilno (Bałaga *et al.*, 1998 and Bałaga 2004). In the Łukcze and Krowie Bagno sites it is correlated with the Bölling interstadial warming and in the Perespilno profile of laminated deposits, documented by many radiocarbon dates, it is related to the Early Interstiadial – a part of the Meiendorf phase (Ralska-Jasiewiczowa *et al.*, 1999 and Bałaga,

Table 10. *Macrofossils of water plants and charcoal of the top part of the profile Ka-A; + (1-5), ++ (6-10), +++(<10 specimes).*

Depth (cm)	Characeae	Najas marina	Najas flexilis	Najas minor	Nymphaea	Charcoal
208	+++	+	+	+	-	
214	+	+	+			
216	+++		+	+		
218	++					
228	+++	+	+	+++		
244		+				
246	+	+		+		
248	++	+				
302		+				
304		+	+	+		
306		+				
308		+		+		
310		+	+			
312		++			+	
314		+		+		
316		++		+		
318			+	+++		+
320			++	++		+
322			++	+		
324		+++				
326		+++		+		
328			++			
330		++		+		
332		+				
334		+		+		
336					+	
338			++	+		
340			++			
342		+		+		
344		+		+		
346		+				
348		+		+		
350						++
352		+				
354		++		+		
356		++		+		
358		+	+			
360			+			
362	+	++	+			
364	+	+			+	
366		++	++			
368	+			+	+	
370	+		++		++	
372		+	+	+		
374	+	+	+			
376	+	+	+	+		
378	+	+	+			
380		+	+	+		
382	+	+	+	+		
384	+	+	+	+	+	
386	+			+		
488	+	+	+	+		
390	+++					+++
396	+	+	+	+		
398	+	+	+	+		
400	+	+	+	+		

2004). Correlation and synchronization of the pre-Younger Dryas pollen zones in these two sites is presented in **Fig 10**. In the Karaśne site the discussed birch maximum is determined at 14390-13660 cal BP (**Fig. 10**). In terms of age, it corresponds to the Oscillation Period distinguished in the laminated deposits from the Lake Perespilno. Pollen picture in the Karaśne site is rather poor but climatic changes at that time are recorded in oxygen and carbon stable isotope composition. The main changes in the curves of $\delta^{13}C$ and $\delta^{18}O$ may be correlated with ca. 13830 cal BP and 13100 cal BP. We cannot unambiguously say that accumulation in the examined site was discontinuous. Perhaps unvaried pollen spectra resulted only from deposit compression and sparse sampling. However, in this karst area, the processes connected with permafrost degradation (Dobrowolski, 2006) strongly influenced not only the formation of lake basins but also the character, and especially the continuity of accumulation. In respect of geology and geomorphology the area was differentiated at that time, many depressions occurred, and accumulation of biogenic deposits was conditioned by the depths of depressions and water level changes. The latter depended not only on climate but also local factors, i.e. different degree of permafrost degradation, substratum subsidence, and action of ascending groundwater. Local conditions of biogenic accumulation are reflected in pollen spectra and in the results of radiocarbon dating; both Late Glacial and Holocene vegetation succession is recorded in thin deposits of shallow, and even very shallow depressions occurring near deep lakes (e.g. Bałaga, 1991). Disturbances of accumulation are also evidenced by the inversion of radiocarbon ages in the bottom layers of the profile Ka-B, and the occurrence of the Alleröd peat layer within the gyttja bed of the Younger Dryas age. Therefore, the occurrence of hiatuses cannot be excluded, especially at the sharp contacts of different deposits. The problem of disturbances during the initial phase of the development of lakes is discussed at length in the monograph on the Durne Bagno peat bog (Bałaga, 2007). To sum up, the deposits of the *Salix*-Cyperaceae zone in the Karaśne site, as those in the Perespilno profile, can be related to the end of Pleistocene, and point to a similar period of the Lake Karaśne formation. The *Betula* and *Pinus-Betula* pollen zones represent the period from the Early Interstadial to Alleröd (Late Interstadial) inclusive. The environmental changes, which happened at the transition Alleröd/Younger Dryas, are very clearly recorded in the deposits of the compared sites.

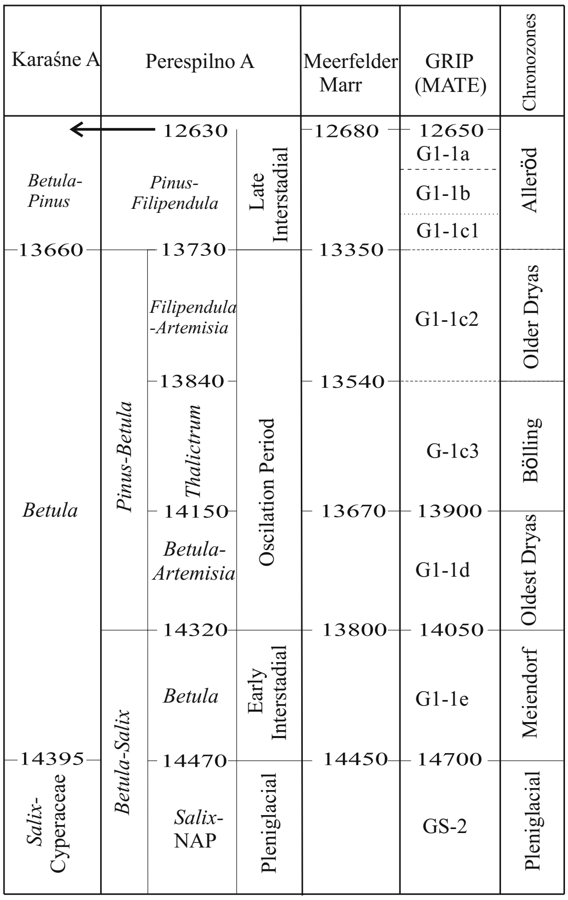

Fig. 10. *Comparison of biostratigraphy and chronostratigraphy of the pre-Younger Dryas sediments of Lake Karaśne, Lake Perespilno (Bałaga, 2004), Meerferlder Marr and GRIP(MATE) after Litt* et al. *(2001).*

6. CONCLUSIONS

Pollen analysis of the deposits from the Karaśne lake-mire complex permits us to reconstruct the history of plant communities, which developed in that area in the Late Glacial and Holocene, and evidences both the influence of climate and human activities on natural environment.

Diverse pollen record in the analysed diagrams stresses the role of local vegetation in pollen deposition. Strong influence of local vegetation on palynological picture is visible in pollen spectra obtained for the core Ka-C taken at the edge of the mire. The spectra from deposits taken in profundal zone represent vegetation of over-local character. Especially important differences are found in the curves of *Pinus*, *Betula*, and *Carpinus*. *Pinus* and *Betula* were local elements occurring in the vicinity of lake. *Carpinus* was numerous in the forests growing in a considerable distance, and it occupied elevations surrounding the depression.

The compared results of pollen analysis obtained for the examined profiles revealed also a discontinuity of accumulation – the occurrence of hiatuses, usually at the lithologic contact of different layers. Older deposits occurring within the younger ones, i.e. peat layers in gyttja, are also found.

The beginning of biogenic accumulation, gyttja sedimentation or peat sedentation, is dated in the described depression at the end of the Pleistocene. Accumulation type was conditioned by local geomorphologic conditions, original depth of depression, the degree of permafrost degradation and substratum subsidence. A mosaic, water-mire nature of the described depression lasted till the end of Alleröd. In the Younger Dryas the large palaeobasin was almost completely filled with water. Peat sedentation was replaced by limnic accumulation, in other cases limnic carbonate sedimentation by limnic carbonate-free one. The latter one occurred mainly in the zone of contemporary lake. Algae gyttja and mostly algae-carbonate gyttja accumulated in shallower zones. Numerous fauna of Cladocera and algae of *Pediastrum* genus occurred in the lake, especially in the Preboreal chronozone, and molluscs disappeared. The character of the Late Glacial vegetation cover near the examined site was similar to that at other sites in the Lublin Polesie region.

At the end of the Preboreal chronozone, carbonates were deposited in the whole lake. The lake remained large till about 6000 BP. Since that time, the palaeobasin has been consistently overgrown by sedge-reed-moss communities. In the Early and Middle Holocene the forests developing near the palaeobasin were generally similar to those described in the other sites of the Lublin Polesie (Bałaga, 1991, 2004 and Bałaga *et al.*, 1983, 1992). The main difference was the predominance of birch in the Karaśne site. During the next 2000 years the area of the lake decreased over three times. About 4000 BP water covered the area of contemporary lake and surrounding "floating islands". Forests with birch, alder, and pine successively encroached on mire areas within the palaeobasin. Alder and birch prevailed but pine occupied fragments of mire as evidenced by the pollen diagram Ka-C. Basic changes of vegetation cover near the palaeobasin started from about 5000 BP. The proportions of elm, and to the lesser extent of lime and ash, decreased. New components appeared, i.e. hornbeam, then beech and plants indicating human economic activities. The expansion of hornbeam was rather slow, similarly as in the Durne Bagno site. Pollen of *Carpinus* reached higher values only about 4300 BP. On the basis of the diagram Ka-C, we find that the highest proportion of hornbeam in the forests surrounding the examined site occurred between 3500 and 2700 BP. Simultaneously with the rising frequency of *Carpinus* pollen, the values of *Fagus* pollen also increased up to 2.3%. These values can suggest that beech grew sparsely on more favourable habitats, and its eastern limit occurred further to the east than in our times. Spruce was the second interesting species in the examined area. Pollen of *Picea* appears in the Late Glacial deposits, and its frequencies do not exceed 1% in the deposits of the entire Holocene indicating that spruce occurred only as single trees. The next distinctive tree was fir – species absent in this region in our times. However, only single pollen grains of *Abies* found in the examined cores may evidence rather sparse occurrence of fir in the vicinity of the palaeobasin in comparison with other sites of the Polesie region. The occurrence of the above-mentioned species was discussed in detail by Bałaga (1991).

The archaeologically confirmed human settlement near the examined site at the end of Palaeolithic and in Mesolithic is weakly reflected in pollen diagrams. The occurrence of taxa indicating nitrophilous habitats near settlements or small clearings in forests can be probably related to the presence of Mesolithic people. Higher pollen values of anthropogenic indicators and depressions in tree curves are dated at about 6300 BP. Human economic activities clearly influenced vegetation cover at the beginning of Subboreal chronozone. Indicators of pasturage appeared first. The occurrence of first cereals is dated at about 4200 BP. Human influence on vegetation cover from the Neolithic to the Middle Ages is not considerably reflected in the AP/NAP ratio. The change of this ratio is distinct only in the Middle Ages. Such a picture, typical of the Lublin Polesie region, is related to the changes in management forms.

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