Studia Quaternaria, vol. 19: 37–53.

HYDROLOGICAL CHANGES IN THE LUBLIN POLESIE DURING THE LATE GLACIAL AND HOLOCENE AS REFLECTED IN THE SEQUENCES OF LACUSTRINE AND MIRE SEDIMENTS

Krystyna Bałaga

Department of Physical Geography and Paleogeography, Maria Curie-Skłodowska University, ul. Akademicka 19, 20-033 Lublin, e-mail: kbalaga@biotop.umcs.lublin.pl

Abstract

The paleoecological research of biogenic sediments sampled in the different lake-mire ecosystems of the Łęczna-Włodawa Lake District were the basis of studies on hydrological changes during the Late Glacial and Holocene. The lithological differentiation (spatial and temporal) of lacustrine and mire sediments in the studied sites indicates that the hydrological changes were of local nature. The investigations also evidence a specific functioning of the lakes in this region. Lake basins were formed as a result of the ground ice degradation and the transformation of groundwater circulation in the Late Glacial. The total area of lakes in the Lake District was the largest from the Younger Dryas to the Subboreal chronozone. The gradual lowering of water level during the early Holocene resulted in the transformation of sedimentation process, and in the development of typologically differentiated mires and lacustrine-mire complexes.

Key words: Lublin Polesie, Late Glacial, Holocene, hydrological changes, pollen analysis

Manuscript received 17.09.2002, accepted 30.10.2002

INTRODUCTION

The nature of organic accumulation (lacustrine and mire sediments) is closely related to the changes of groundwater level. The changes of deposition conditions may have been caused by both the climate and plant cover changes as well as by an anthropogenic impact. Different research methods are used in order to estimate fluctuations of lake water level (Gaillard 1985, Digerfeldt 1972, 1986, 1988, Digerfeldt *et al.* 2000, Dearing, Foster 1986). The results of pollen, fauna and chemical analyses of the lacustrine-mire sediments in the Lublin Polesie provide evidence of water level changes in this region during the Late Glacial and Holocene.

The Lublin Polesie is situated in the eastern part of the Polish Lowlands, in the north-eastern foreland of the Lublin Upland, in the Wieprz and Bug interfluve. The Lublin Polesie is characterized by occurrence of many swamps and wetlands as well as lakes (67) which are grouped within the unit of lower rank, *i.e.* the Łęczna-Włodawa Lake District (Chałubińska, Wilgat 1954). These lakes, being so numerous, are the only such group of lakes situated outside the last ice sheet extent. It should also be stressed that this region is situated in the marginal zone of the Precambrian platform. The sub-Quaternary basement is mainly composed of the Upper Cretaceous deposits which are liable to karstification. Unlike the modern relief, which is rather flat, the sub-Quaternary surface is characterized by the relative heights reaching 90 m. Deep fossil valleys follow tectonic discontinuities; most of the lakes are associated with these valleys (Buraczyński, Wojtanowicz 1983, Liszkowski 1979).

The karst or thermokarst origin and age of the lakes have been discussed for many years. Recently, many factors are considered to affect the formation of this group of lakes, *i.e.* karst and thermokarst phenomena, action of confined groundwaters, tectonics of the area (Wilgat 1954, 1994, Wilgat *et al.* 1991, Maruszczak 1966, Buraczyński, Wojtanowicz 1983, Wojtanowicz 1994, Bałaga *et al.* 1996, 2002, Harasimiuk 1996, Dobrowolski 1998, Harasimiuk, Wojtanowicz 1998).

GEOMORPHOLOGIC-HYDROLOGIC CHARACTERISTICS OF THE ŁĘCZNA-WŁODAWA LAKE DISTRICT

The Łęczna-Włodawa Lake District is the depression situated between the Włodawa Hump from the north and the Uhrusk Ridge from the south. The modern relief of the Polesie has been strongly influenced by the Middle Polish Glaciations, especially the Odranian Glaciation (Buraczyński, Wojtanowicz 1983). The rich inventory of relief forms originating from that period consists of moraine ridges, kames, eskers, outwash fans, glaciofluvial plains, fossil valleys. The thickness of the lithogenetically differentiated Quaternary deposits reaches 40 m. The Łęczna-Włodawa Lake District is

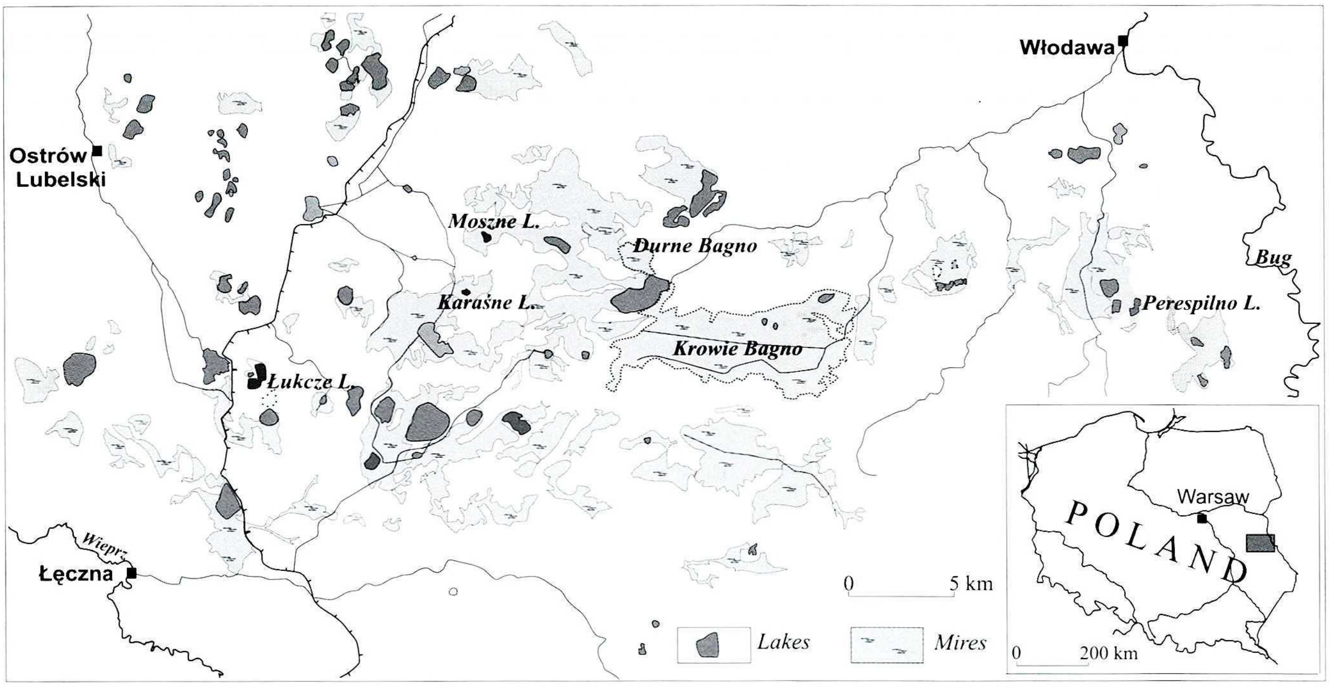

Fig. 1. The map of the Łęczna-Włodawa Lake District with the location of the examined sites.

a plain with the relative heights not exceeding 30 m. Its lowest, north-western part (near Ostrów Lubelski and Sosnowica) reaches the height of 150–160 m a.s.l. Northwards, towards the Włodawa Hump, and southwards, towards the Chełm Hills the height rises to about 180–185 m a.s.l. (Wilgat 1954, Buraczyński, Wojtanowicz 1981).

The Łęczna-Włodawa Lake District is characterised by the occurrence of shallow groundwaters. Groundwater table forms a continuous surface, and its location is conditioned by the main relief forms (Wilgat *et al.* 1991, Michalczyk 1998). In the greatest part of the examined area we find water to a depth of 2 m, especially in the areas which adjoin depressions. The water resources of the Łęczna-Włodawa Lake District consist mostly of groundwaters occurring in the Upper Cretaceous and Quaternary sediments which form one, hydraulically linked reservoir (Michalczyk 1998). Groundwaters of the first aquifer are in hydraulic equilibrium with lake waters. Groundwater table in depressions is also the local base level of the drainage of neighbouring areas. In the greater part of the Łęczna-Włodawa Lake District, unconfined groundwaters are not isolated from the ground surface by impermeable sediments (aquifuges). Therefore, the conditions for groundwater recharge by precipitation are good. However, infiltration to deeper layers and underground runoff to other areas are inhibited (Wilgat *et al.* 1991, Michalczyk 1998). The confined groundwater surface is stabilized at almost the same height as the groundwater table of the Quaternary aquifer, *i.e.* at about 160–170 m a.s.l.

The Łęczna-Włodawa Lake District covers about 1160 km^2. The total area of all lakes (nearly 3%) and wetlands constitutes 35% of the Lake District area (Wilgat *et al.* 1991, Michalczyk 1998). The capacity of individual lakes is small, usually 1–2 mln m^3. The following lakes have the greatest capacities: Białe near Włodawa – 15 mln m^3 (area – 106.4 ha; depth – 33.6 m), Piaseczno – 13.7 mln m^3 (area – 84.7 ha; depth – 38.8 m), Uściwierz – 9.2 mln m^3 (area – 284.1 ha; depth – 6.6 m).

METHODS

Lacustrine and mire sediments were investigated in the typologically differentiated lake-mire complexes of the Łęczna-Włodawa Lake District. Samples for pollen analysis were taken in all the examined sites, and samples for fauna and chemical analyses, and radiocarbon dating – only in the selected ones. Some of the obtained results were the basis of chronostratigraphy of sediments and the studies on the hydrological changes in the Polesie during the Late Glacial and Holocene. The chronostratigraphy of the sediments is illustrated on the simplified pollen diagrams. The dates ^{14}C are on the left side of pollen diagrams. ^{14}C dates were obtained in Institute of Physics, Silesian Technical University of Gliwice (Gd), Radiocarbon Laboratory of Kiev (Ki), and Poznań Radiocarbon Laboratory (Poz).

CHARACTERISTICS OF THE EXAMINED SITES AND CHRONOSTRATIGRAPHY OF THE SEDIMENTS

The location of the examined sites is presented in Fig. 1. Łukcze Lake and the adjoining mire occur in the western part of the Łęczna-Włodawa Lake District. The Moszne and Karaśne lake-mire complexes, and the Durne Bagno bog are situated in the central part of the Lake District (in the Polesie National Park). The Krowie Bagno fen occurs a little southwards, outside the Park, and Lake Perespilno (Pereszpa) – in the eastern part of the Lake District.

Łukcze lake-mire complex

Lake Łukcze (area – 56.5 ha; max. depth – 8.9 m; capacity – 2.09 mln m^3) consists of two basins: the northern one is more elongated and shallower (4 m), and the southern one is rather circular and deeper (8.9 m). These basins are joined by a narrow shallowing (to 2.4 m). Łukcze is a eutrophic lake. The swampy areas by the north-western, western and south-western lake-shores are chiefly occupied by mire communities *e.g. Sphagnetum medio-rubelli* (Bałaga 1991). The thickness of organic sediments underlain by muds and sandy muds reaches here about 4–6 m (Liszkowski 1979). The bottom sediments (about 10 m thick) in the central part of the southern basin consist of peats formed in the Alleröd chronozone, and algae gyttja accumulated during the whole Holocene (Bałaga 1991). The sediments of the adjoining mire are lithologically differentiated. Muds accumulated in the later part of the Pleniglacial (compare Ralska-Jasiewiczowa *et al.* 1999), and peat or peaty gyttja formed in the successive phases of the Late Glacial. Limnic sediments accumulated during the Preboreal chronozone, but they were found only in the shore zone of the mire (Łukcze II profile – Bałaga 1991). Sedge-moss mire has developed in the shore zone of the lake since the Boreal chronozone, but at the turn of the Atlantic and Subboreal zones the peat sedimentation was not continuous or very slow.

Moszne lake-mire complex

Dystrophic, shallow Lake Moszne (area – 17.5 ha; max. depth – 1.5 m) is surrounded with typologically differentiated mires. The mineral bedrock of diversified relief is composed of sandy muds, sands, and the Upper Cretaceous weathered carbonate rocks. The latter ones are found everywhere, except the western part of the mire. The bottom sediments of the lake are 10–15 m thick. They are formed with moss peats dated at the Alleröd. They are overlain by the series of algae-detritus gyttja, carbonate in places, which accumulated during the Younger Dryas and Holocene (Fig. 2B). The sediments from the mire adjoining the lake from the west (Fig. 2A) are lithologically more differentiated. They consist of the muds of the Older Dryas, algae, algae-carbonate and algae-detritus gyttja accumulated from the Alleröd to the Subboreal chronozone, and the sedge-moss-*Sphagnum* peat of the younger Holocene. The typologically differentiated peat series, which occurs over the gyttja, is about 3.5 m thick, and its thickness decreases towards the lake, where mire vegetation encroaches on the lake as a floating coating ("spleja"). In the northern part of the mire, moss peat is covered with a differentiated layer of limnic and peat sediments (Bałaga *et al.* 1995).

Karaśne lake-mire complex

Lake Karaśne (area – 3.2 ha; max. depth – 1.2 m) is one of the smallest and shallowest lakes of the region. It is surrounded with fens. The whole complex covers the area of about 72 ha, and is formed in Cretaceous rocks. In the diversified relief of the mineral bedrock, we distinguish three paleobasins which are meridionally situated and filled with the differentiated series of lacustrine-mire sediments (Bałaga *et al.* 1996, Bałaga *et al.* 1996, Bałaga *et al.* 2002). The sediments occurring under the fens are to 5 m thick, whereas the bottom sediments of the modern lake are over 13 m thick. Their bottom part consists of moss peat (the shore zone of the lake) or coarse detritus (peaty) gyttja (the central part of the lake). Pollen analysis of the profile from the central part of the lake indicates that coarse detritus (peaty) gyttja accumulated during the Older Dryas, and the overlying lacustrine sediments have accumulated since the Alleröd (Fig. 3). In the shore zone of the lake, moss-peat sedimentation (layer 90 cm thick) started at the Older Dryas and lasted till the end of the Alleröd chronozone (Fig. 3). In this profile the overlying lacustrine sediments have accumulated since the Younger Dryas.

Durne Bagno

Durne Bagno is a bog of continental type. It occupies a rather regular, oval-shaped basin about 1 km in diameter and to 8.5 m deep. The relief of mineral bedrock is diversified here, with several depressions, the deepest of which occurs in the southern part of the basin. The whole basin is formed in sandy and muddy sediments; weathered Cretaceous rocks are not found under organic sediments. Sands and muds are overlain by gyttja with the thickness of several dozen centimetres to about 4 m. The gyttja is covered by the lithogenetically differentiated peats: reed, sedge-reed, and *Shpagnum* peat at the top. Mineral gyttja accumulated in the Older Dryas chronozone, and algae gyttja – from the Alleröd till the early part of the Atlantic chronozone (Fig. 4). The lake was then shallowing and mire started to develop about 7400 years BP (Atlantic chronozone) as is recorded in the shallower parts of the basin. In its deeper parts the mire encroached on lacustrine sediments later on, *i.e.* from about 6000 years BP.

Krowie Bagno

Krowie Bagno is the largest fen in the Lublin Polesie. Four small lakes occur within the limits of it. The sandy-muddy bedrock with numerous depressions is filled with a lithogenetically diversified series (6–9 m thick) of limnic-moss sediments. The central part of the basin is filled with even more differentiated peats, covered with a series of limnic-moss sediments, overlying mineral layer. Thickness of the organogenic sediments can reach even 10 m (*e.g.* near the small Lake Lubowieżek). Pollen analysis indicates that clayey gyttja accumulated in the Older Dryas, and the sedimentation of moss peat occurred during the Alleröd and Younger Dryas (Fig. 5). A large lake existed here from the Preboreal chronozone, and algae-carbonate gyttja was deposited in it. A fen has developed since the Subboreal chronozone. Varying colours and degree of decomposition of sedge peat evidence fluctuations of the groundwater table in the younger Holocene.

Lake Perespilno

Lake Perespilno (area – 24.3 ha; max. depth – 6.2 m; capacity – 0.78 mln m^3) and two other lakes (Wspólne, Kosemiec) form a group of lakes in the eastern part of the Łęczna-Włodawa Lake District (Wilgat 1954, Wilgat *et al.* 1991).

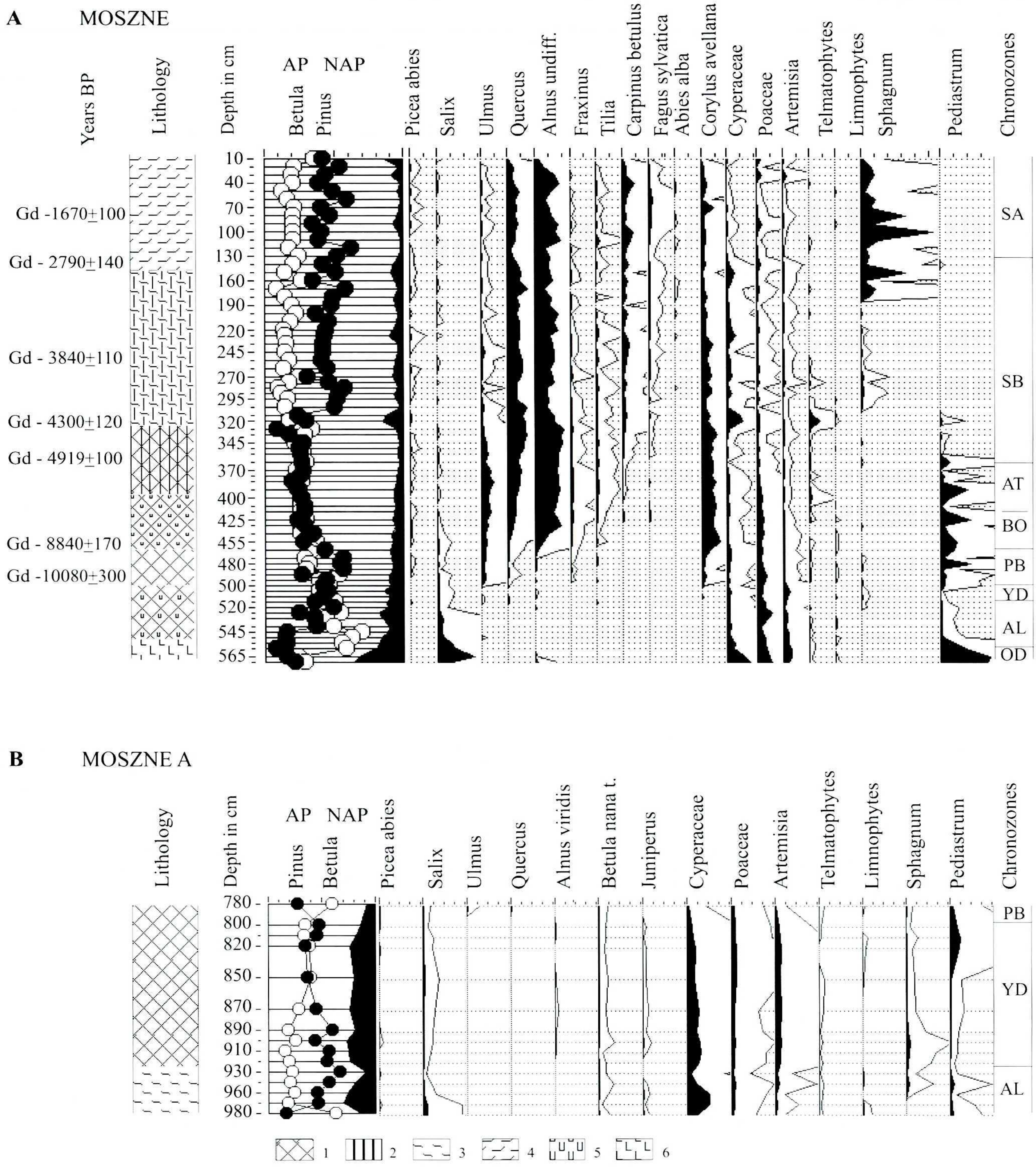

Fig. 2. Simplified percentage pollen diagrams of the sediments of the Moszne lake-mire complex: **A** – from the mire, **B** – from the central part of the lake. *1* – gyttja, *2* – sedge peat, *3* – moss peat, *4* – *Sphagnum* peat, *5* – $CaCO_3$, *6* – muds (combined symbols denote mixed composition of sediment).

However, Lake Perespilno has a separate catchment. Lake Perespilno consists of two basins (the northern one 6.3 m deep and the southern one 4.5 m deep) joint by a shallowing 2.7 m deep (Wilgat *et al.* 1991). Lacustrine-flood sands surround the lake forming rather flat surface, which rises 2–3 m over the lake water level. The depressions within these sands are filled with organic-mineral sediments 0.5–4 m thick (Marek 1965). Lake Perespilno is situated in the middle of impenetrable swamps and waterlogged forests, only the fragments of its eastern and western shores are higher and better accessible.

The sediments of Lake Perespilno consist of algae-carbonate and algae gyttja about 16 m thick. The sediments with annual lamination (Fig. 6) accumulated here from the

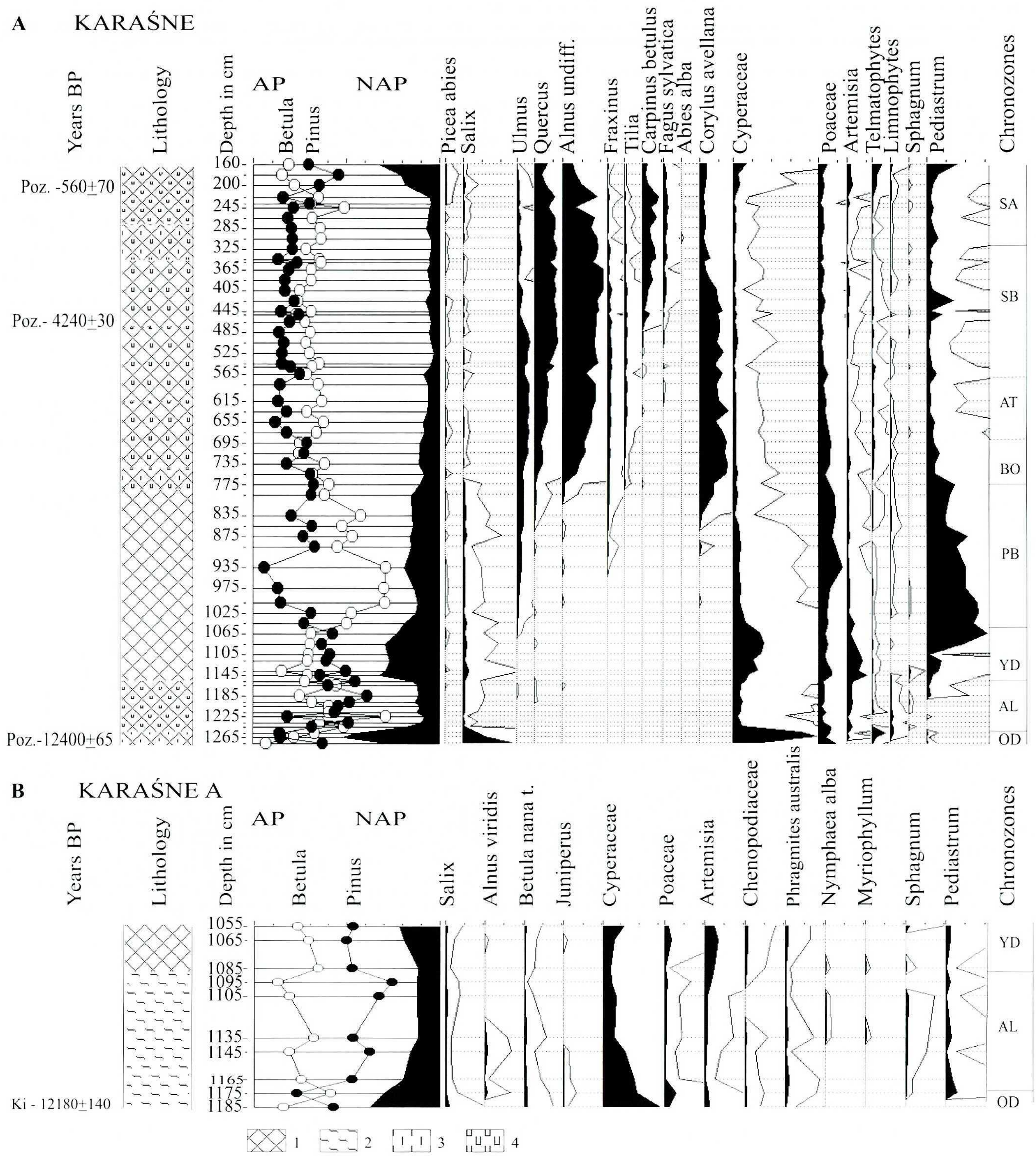

Fig. 3. Simplified percentage pollen diagrams of the sediments of the Karaśne lake-mire complex: **A** – from the central part of the lake, **B** – from the shore zone of the lake. *1* – gyttja, *2* – moss peat, *3* – detritus, *4* – $CaCO_3$ (combined symbols denote mixed composition of sediment).

end of the Late Glacial till the early phase of the Preboreal chronozone (Bałaga *et al.* 1998, Goslar *et al.* 1999). In the younger part of Preboreal, formation of laminated sediments was disturbed. The gyttja sediments accumulating during the Boreal chronozone were the richest in calcium carbonate, and then, in the early part of the Atlantic chronozone, the content of carbonate decreased (Bałaga *et al.* 2002, Fig. 7). Algae gyttja has accumulated in the lake since the middle phase of the Atlantic chronozone till now.

To sum up, it should be stressed that the nature and time of accumulation of biogenic sediments in the lakes were very differentiated. The bottom sediments of the lakes consist of

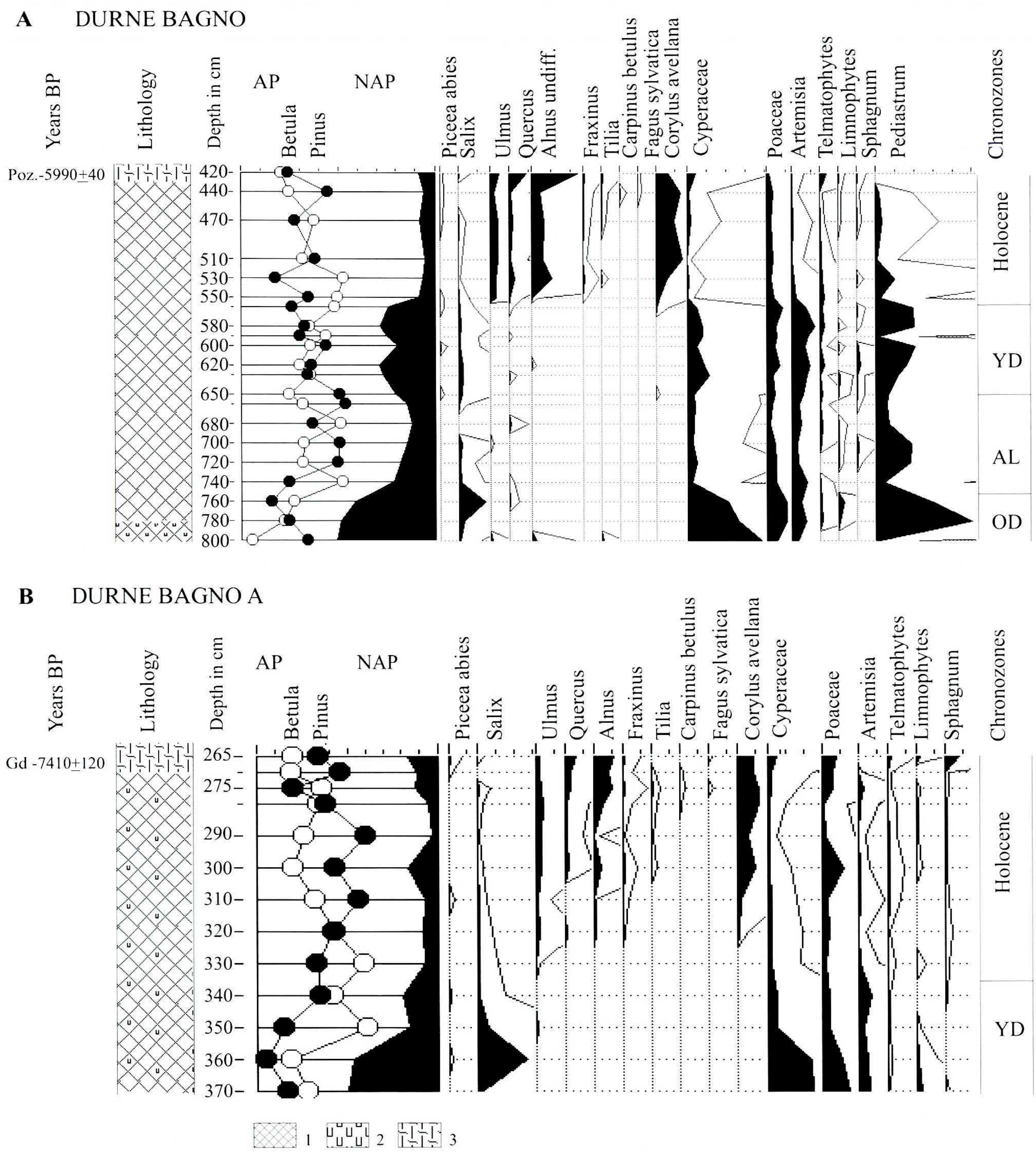

Fig. 4. Simplified percentage pollen diagrams of the sediments of the Durne Bagno bog; **A** – from the deepest part of the basin, **B** – from the shallow part of the basin, *1* – gyttja, *2* – $CaCO_3$, *3* – moss peat (combined symbols denote mixed composition of sediment).

algae or algae-carbonate gyttja. Accumulation of carbonates, which is often considered as an indicator of the depth of a lake (Niewiarowski 1995, Wojciechowski 2000), occurred in the examined lakes in different periods. The comparison of the sediments from the Perespilno and Karaśne lakes is quite instructive. Carbonates were deposited simultaneously in these lakes only during the Alleröd, Boreal and early Atlantic chronozones. In the Younger Dryas and Preboreal chronozones, and also in the younger Holocene the nature of deposition in these two lakes was different (Fig. 7 and Goslar *et al.* 1999).

WATER LEVEL CHANGES DURING THE LATE GLACIAL AND HOLOCENE

The succession of lacustrine and mire sediments, and their nature can give information about the fluctuations of lake water-level, and indirectly about precipitation and the

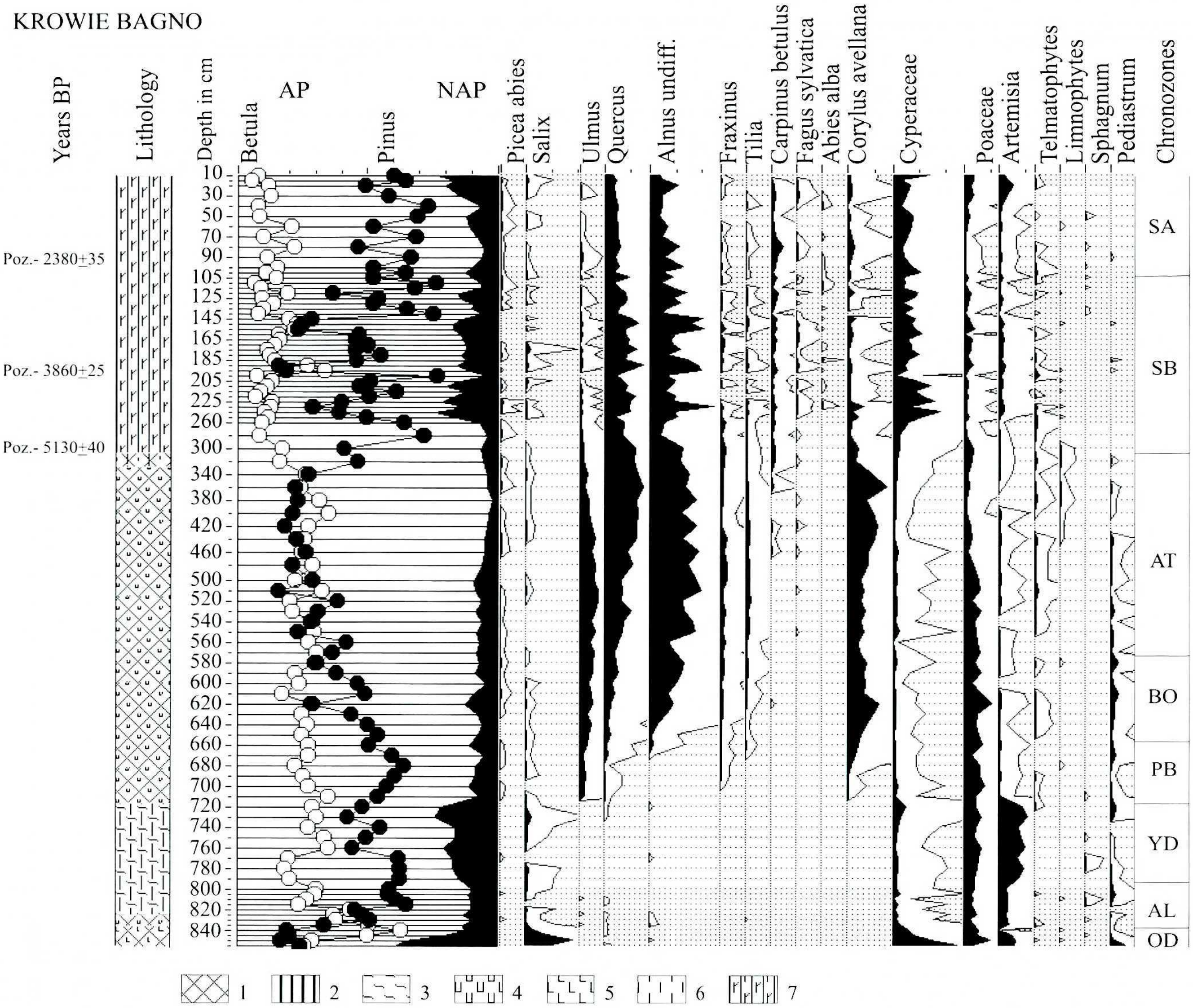

Fig. 5. Simplified percentage pollen diagram sediments of the Krowie Bagno mire; *1* – gyttja, *2* – sedge peat, *3* – moss peat, *4* – $CaCO_3$, *5* – muds, *6* – detritus, *7* – sedge peat with *Phragmites* (combined symbols denote mixed composition of sediment).

whole water balance (Ralska-Jasiewiczowa, Starkel 1988, 1991). The changes of biogenic sedimentation character in the examined sites of the Łęczna-Włodawa Lake District during the Late Glacial and Holocene are presented in Fig. 8.

Late Glacial

The Late Glacial sediments are found in all palynologically analysed profiles of the examined sites. The alternation of lacustrine sediments and peats indicates that variable environmental conditions influenced the accumulation processes in that period. The Late Glacial sediments were usually deposited in the following succession: muds and mineral gyttja, coarse detritus gyttja, peats, algae-carbonate and algae gyttja.

In the Łukcze and Perespilno sites, which are situated at the peripheries of the examined area, the bottom layers (muds and mineral gyttja) were deposited during the last part of the Pleniglacial (compare Ralska-Jasiewiczowa *et al.* 1999). To this period we should probably relate the Older Dryas chronozone, which is distinguished in the pollen diagrams from the central part of the Łęczna-Włodawa Lake District (Figs. 2, 3, 4 and 5). However, this question needs a detailed and comprehensive discussion, so further on I use the hitherto accepted chronostratigraphic units of the Late Glacial. Accumulation of muds and mineral gyttja, which are the most frequent types in the bottom parts of the biogenic series, was associated with shallow lake basins. Their development was due to permafrost degradation which marked the beginning of the thermokarst process (Wojtanowicz 1994).

The biogenic accumulation in the Alleröd was diversified. In the Moszne complex, the Alleröd lacustrine sediments are found under the present mire, and peats of the same age – in the bottom sediments of the modern lake. The bottom sediments of Lake Karaśne are differentiated. The Alleröd peats overlain by the lacustrine sediments of Younger Dryas occur in the profile from the shore zone of the modern lake. These sediments are overlain by a layer of limnic sediments accumulated since the Younger Dryas. In the central part of the lake algae-carbonate gyttja was deposited in the Alleröd.

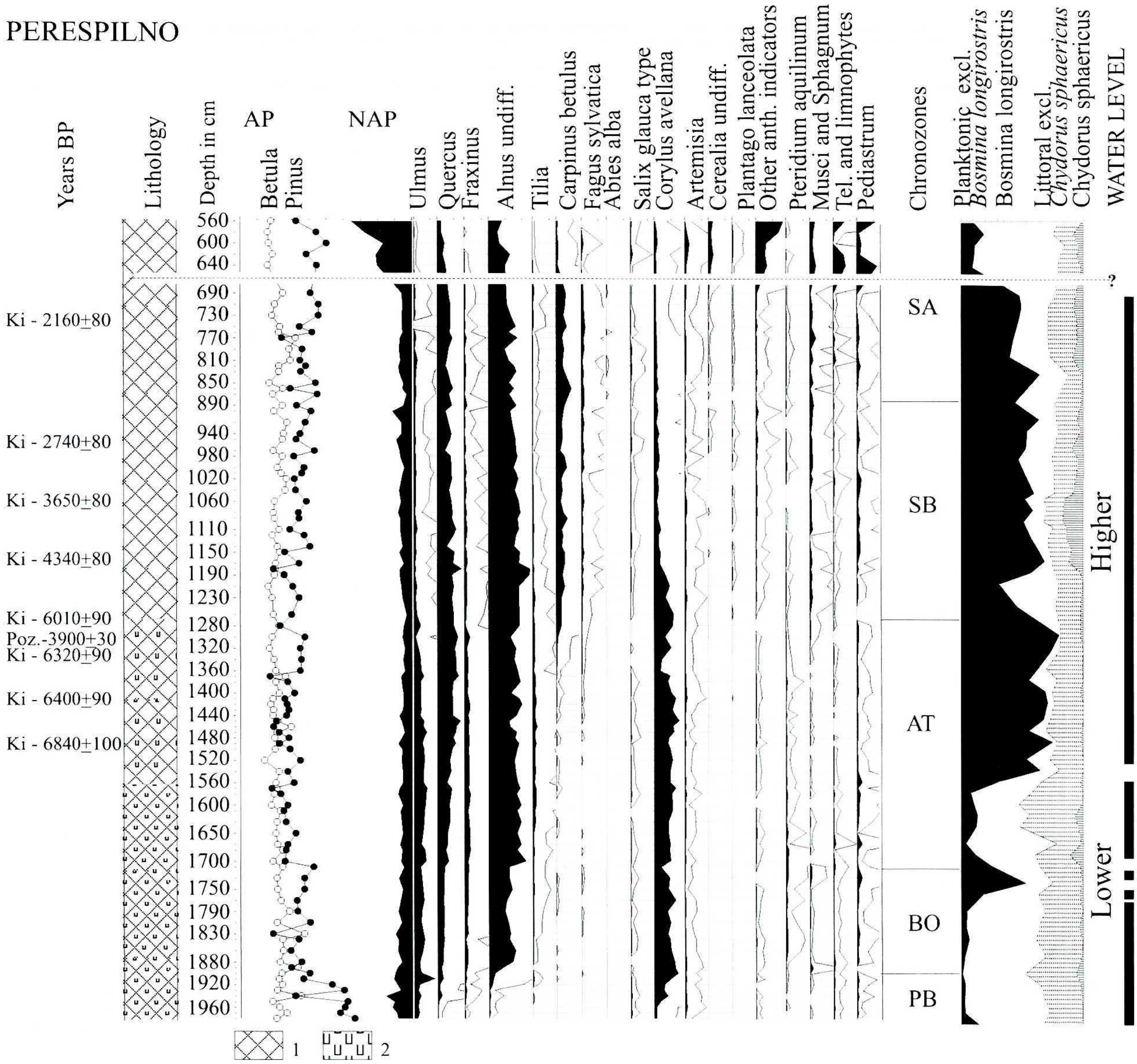

Fig. 6. Simplified percentage pollen diagram and total cladoceran diagram (after K. Szeroczyńska – Bałaga *et al.* 2002) of the Holocene sediments of Lake Perespilno; *1* – gyttja, *2* – $CaCO_3$ (combined symbols denote mixed composition of sediment).

Therefore, we can assume that the Polesie landscape during the Alleröd chronozone was characterized by development of moss and sedge moss mires and lakes. The Alleröd peats, which occur at a depth of 10–15 m under the present lakes and at a depth to 5 m in the small depressions within the mires, probably accumulated at a similar hypsometric level. Situation of the Late Glacial peats is presented in the schematic geological cross-sections of the Moszne and Karaśne complexes (Figs. 9 and 10). The peats were gradually shifted downwards during ground subsidence, probably as a result of total or partial degradation of permafrost and of melting of ground ice lenses (Wojtanowicz 1994, Harasimiuk, Wojtanowicz 1998). These phenomena were favoured by the warm climate of the Alleröd, with mean temperatures of July determined at about 14–16°C (Wasylikowa 1964), which is evidenced by the occurrence of *Nymphaea alba* and *Typha latifolia* pollen. It is possible that other factors also participated in the formation of lakes, *i.e.* the karstification of carbonate rocks, and the processes associated with the ascensive activation of groundwater vertical circulation (Dobrowolski 1998, Bałaga *et al.* 2002). The water level in the Moszne and Karaśne lakes (developing during the Alleröd chronozone) was perhaps at about 165 m a.s.l., if we assume that the peats, which consitute bottom layers of the lithologically differentiated biogenic sediments filling the depressions near the lakes, remain in their original positions and were not shifted downwards. If not (which is also probable), the lake water level may have been higher, similar to the present one. Algae-carbonate gyttja was usually formed in the lakes during the Alleröd chronozone. The carbonate content in these sediments (*e.g.* Karaśne) ranges from 40 to 90% (Fig. 7). Calcium carbonate may have precipitated during the process of biological decalcification of water rich in Ca^{2+} and HCO_3^- ions, in which planktonic algae and macrophytes took part (Stasiak 1971, Rzepecki 1985, Gąsiorowski 2001). The supply of Ca^{2+} ions was probably conditioned by the occurrence

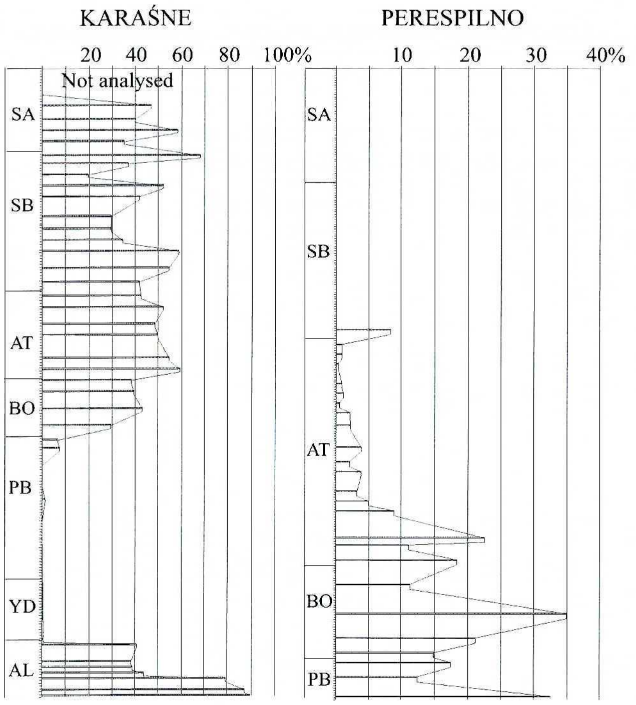

Fig. 7. The curves of $CaCO_3$ content in the sediments of Karaśne and Perespilno lakes. Carbonate content in the Late Glacial and early Preboreal sediments of Lake Perespilno described in the paper by Goslar *et al.* (1999).

of the Cretaceous carbonate rocks in the lake catchments and by biological factors existing in the lake itself.

Molluscan fauna identified by S. W. Alexandrowicz (unpublished materials) in the carbonate gyttja from the central part of the present Lake Karaśne indicates ecological conditions at a shallow lake during its first stage of development, which were favourable for lung-breathing snails (Planorbidae). The occurrence of snails tolerating periodic drying (*Planorbis planorbis*) may also suggest some changes of lake shoreline and the seasonal reduction of water sheet. The occurrence of littoral macrophytes (Fig. 3) and moss remains (*Calliergon trifarium*, *C. gigantheum*, *Drepanocladus fluitans*, *D. sendtneri*) also indicates that the sedimentation during the early part of the Alleröd chronozone preceeded in a shallow lake. An increase of water level, or rather lake deepening as a result of the subsidence of its bottom, occurred in the late phase of the Alleröd chronozone. It evidenced by the lack or very small amount of moss remnants in gyttja accumulated in the Karaśne site at that time, and also by microfauna assemblage (higher frequency of *Bosmina longirostris* at a depth of 1175 cm – the materials being prepared by K. Szeroczyńska). The occurrence of this species, however, depends not only on depth, but also on productivity of the lake. The increased pollen values of taxa occupying wet habitats provide evidence of the wetter climate during the late phase

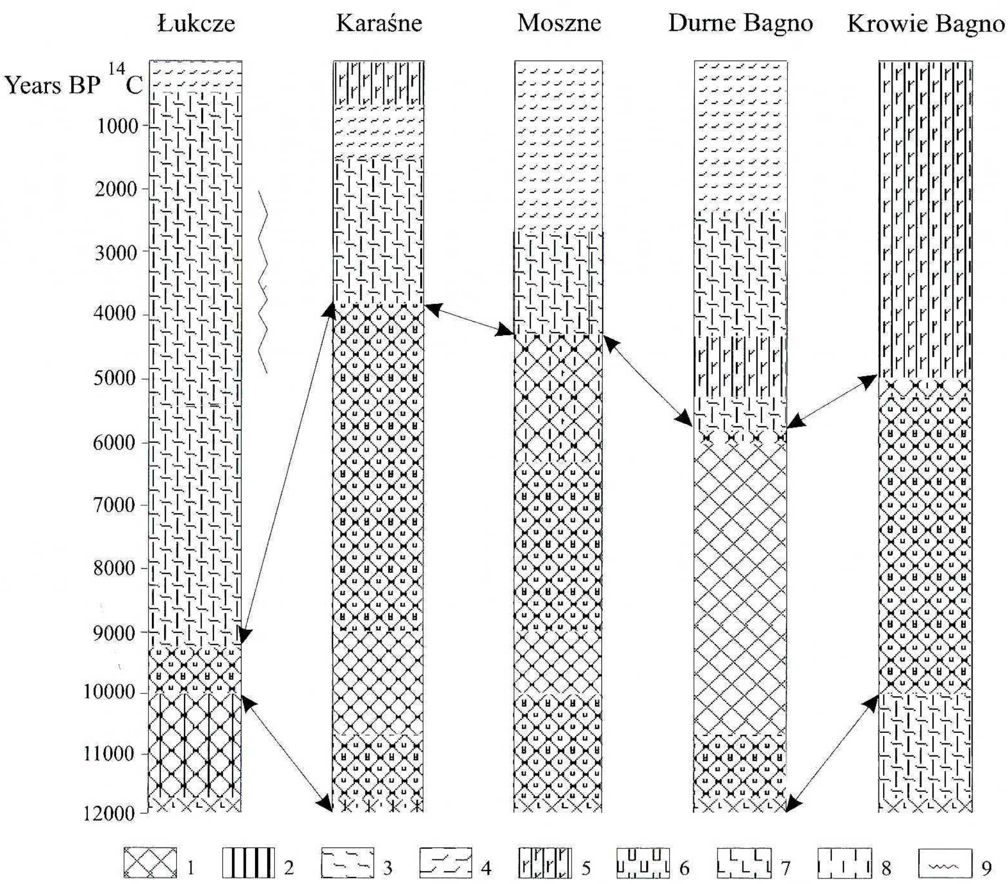

Fig. 8. The profiles illustrating the lacustrine phase (in the temporal scale) in the evolution of the lacustrine-mire ecosystems; *1* – gyttja, *2* – sedge peat, *3* – moss peat, *4* – *Sphagnum* peat, *5* – sedge peat with *Phragmites*, *6* – $CaCO_3$, *7* – muds, *8* – detritus, *9* – hiatus and low rate of sedimentation (combined symbols denote mixed composition of sediment).

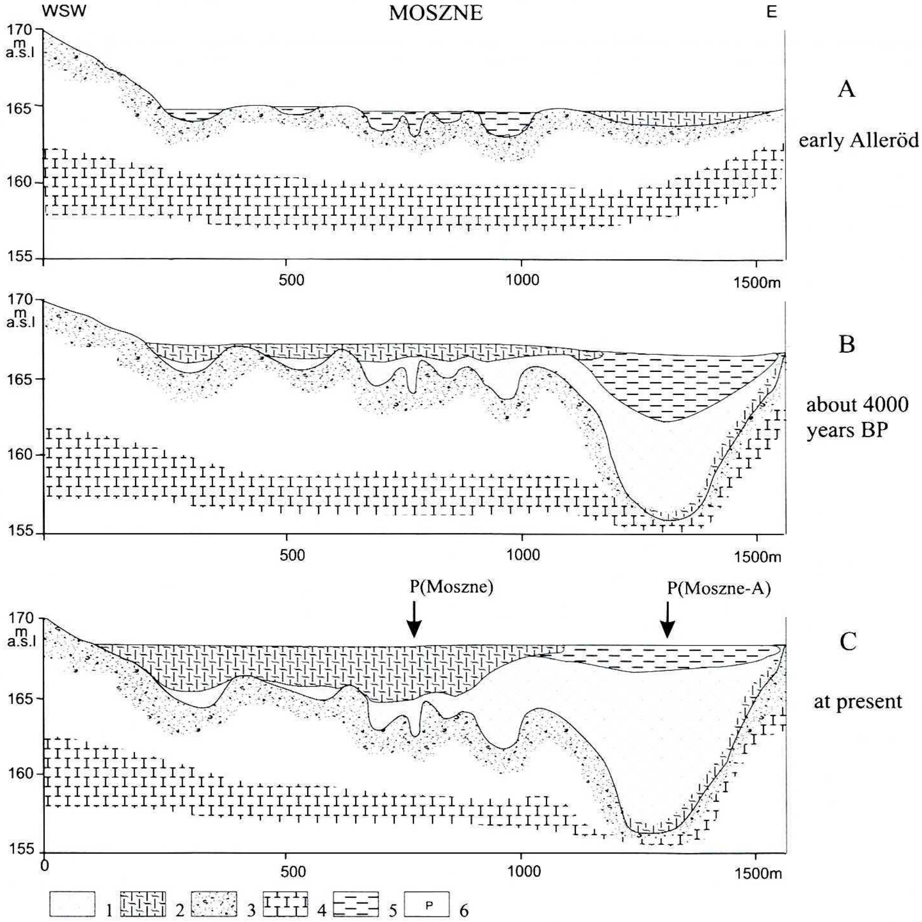

Fig. 9. The schematic geological section of the Moszne lake-mire complex presenting the development of peat and the probable water level; **A** – in early Alleröd chronozone, **B** – in Subboreal chronozone (about 4000 years BP), **C** – at present (after Bałaga *et al.* 1995, simplified), *1* – gyttja, *2* – peat, *3* – sand and muds, *4* – limestones and marls, *5* – water, *6* – palynological profile.

of the Alleröd (Fig. 3). Poor snail fauna reflects the different (from the earlier phase) environmental conditions which were unfavourable for snails.

During the Younger Dryas, the algae-gyttja or peaty gyttja (in the Łukcze site) sediments accumulated in most of the examined sites. Sedge-moss peat was found only in the Krowie Bagno site. Carbonate-free gyttja formed in the Karaśne and Durne Bagno sites. The change of sedimentation (from carbonate gyttja into carbonate-free one) in Lake Karaśne at the turn of Alleröd and Younger Dryas is especially worth noting as the Cretaceous carbonate rocks occur in the lake vicinity. The sharp boundary between the mentioned sediments provides evidence of the abrupt change of accumulation. The nature of this change is illustrated by the curve of $CaCO_3$ content (Fig. 7). Such a differentiation of sediments indicates that hydrological changes in the Łęczna-Włodawa Lake District during the Younger Dryas were local in nature. The development of water basins on the peats formed in the Allerod (site Moszne and Łukcze I) suggests an increase of water level in the Younger Dryas. The interdisciplinary researches of the sediments from Lake Perespilno, on the contrary, indicate a fall of lake water level at the time (Goslar *et al.* 1999). The accumulation of the peat in the Krowie Bagno site does not provide evidence for high water level as well. The climate of this chronozone was cold and dry. In the described region it is evidenced by high values of *Artemisia* recorded in the pollen percentage diagrams from all the examined sites. Winter precipitation probably could have conditioned a rather high water level. A high water level in the Alleröd and possibly in the Younger Dryas is also noticeable in other examined lakes of Poland (*e.g.* Goslar *et al.* 1998). Hence, the interrelations between the processes of activating of the groundwaters, permafrost degradation and local geological conditions might have been the factors influencing the water system of the Łęczna-Włodawa Lake District. A gradual subsiding of the bottoms of the lakes cannot be excluded.

Holocene

Preboreal chronozone

Pollen analysis indicates that the beginning of Holocene has been recorded in lacustrine sediments under most of the present mires in the Polesie region. Peat sedimentation occurred in the environs of the described sites only locally (Bałaga 1991). In the profile near Lake Perespilno, a simultaneous appearance of the continuous curves of thermophilous trees is observed directly after the Late Glacial decrease of the NAP and *Artemisia* pollen values (Fig. 11). This phe-

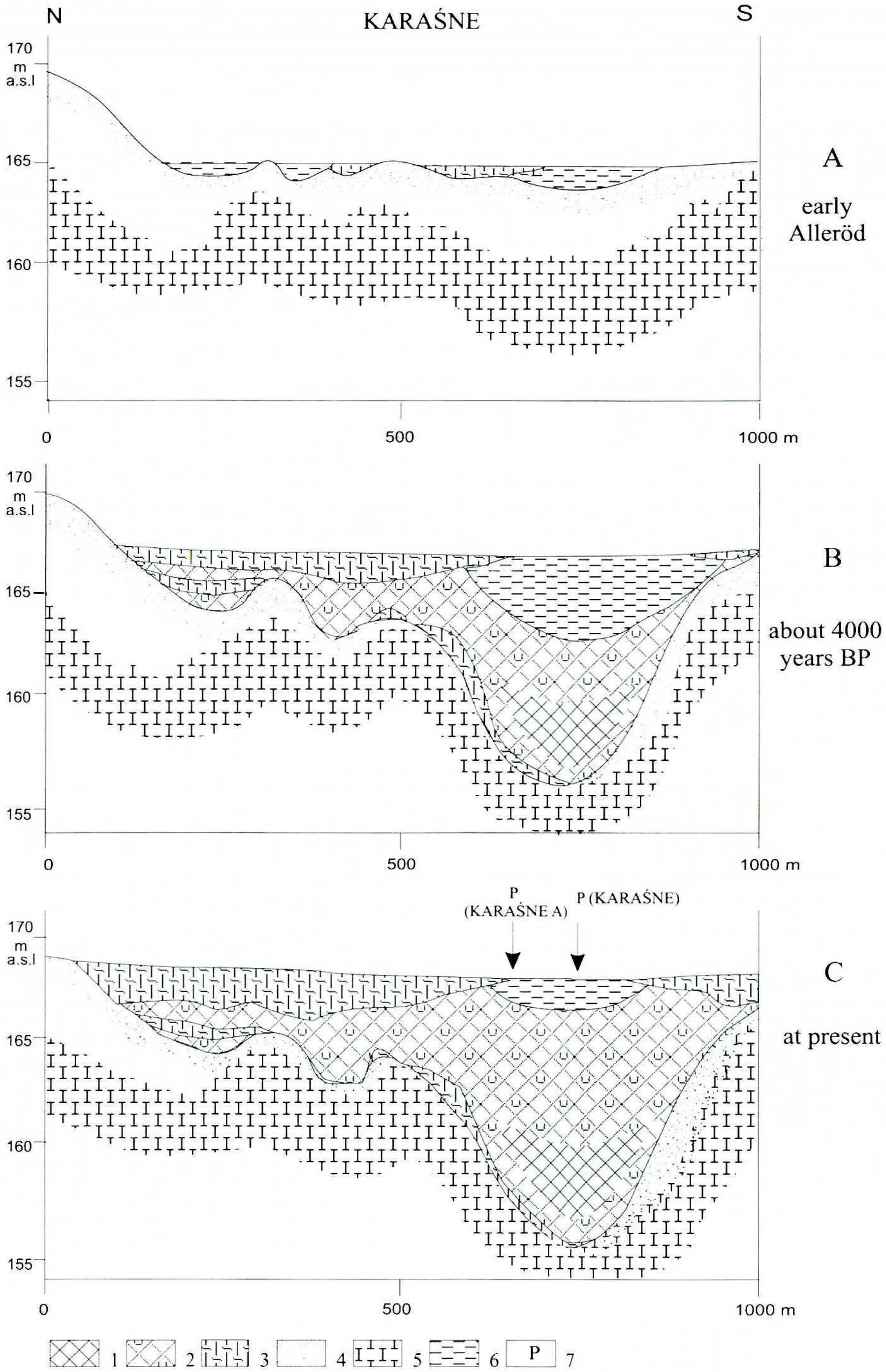

Fig. 10. The schematic geological section of the Karaśne lake-mire complex presenting the development of peat and the probable water level; **A** – in early Alleröd chronozone, **B** – in Subboreal chronozone (about 4000 years BP), **C** – at present (after Bałaga *et al.* 2002, simplified), *1* – gyttja, *2* – gyttja with $CaCO_3$, *3* – peat, *4* – sand and muds, *5* – limestones and marls, *6* – water, *7* – palynological profile.

nomenon probably evidences a hiatus or a very slow rate of accumulation during the Preboreal chronozone resulting from the low groundwater table. Low groundwater level in the early Holocene is confirmed by the results of Cladocera analysis in Lake Perespilno (Bałaga *et al.* 2002 and Fig. 6). The predominance of littoral Cladocera and occurrence of wide macrophyte zone provide evidence of a shallow eutrophic lake in the Preboreal chronozone.

The nature of the sediments formed in Lake Karaśne at that time is worth noting. The 3m-thick series of algae carbonate-free gyttja accumulated then at a rate of 1.5 mm/year. A large amount of *Pediastrum* evidences eutrophic conditions of the shallow lake at that time. The assemblage of Cladocera, without deep-water species, also indicates that Lake Karaśne was rather shallow. The nature of sediments was probably determined by the biological processes going on in the lake.

During the Preboreal chronozone the lake water level in the Polesie region was generally low. A rise in temperature, low precipitation, and evapotranspiration probably also con-

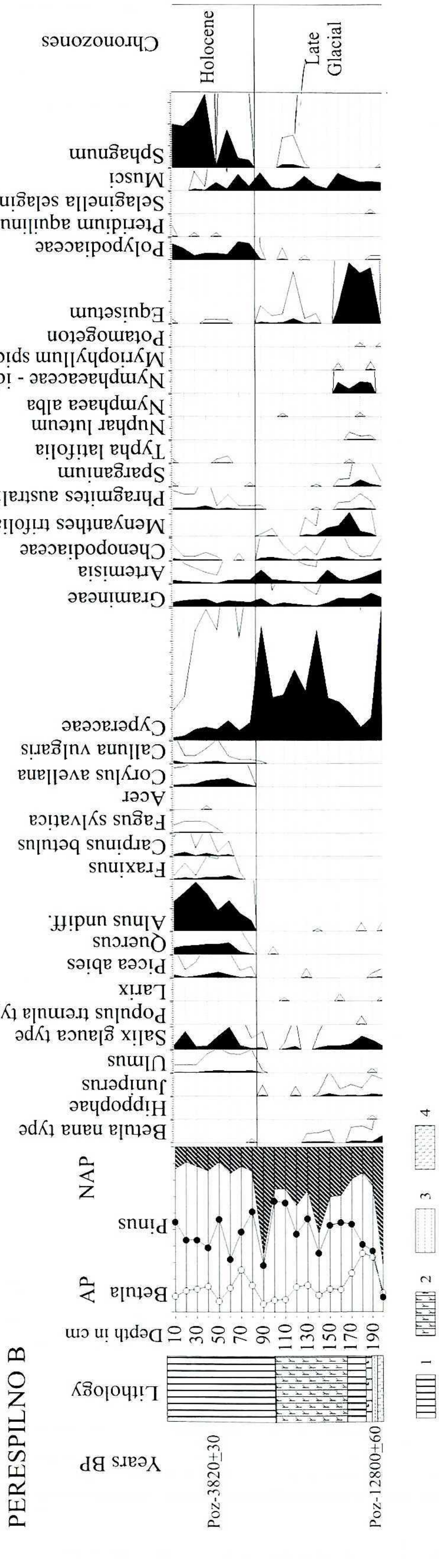

Fig. 11. Simplified percentage pollen diagram of the peat from the environs of Perespilno Lake; *1* – sedge peat, *2* – sedge peat with pieces of wood, *3* – moss peat, *4* – muds.

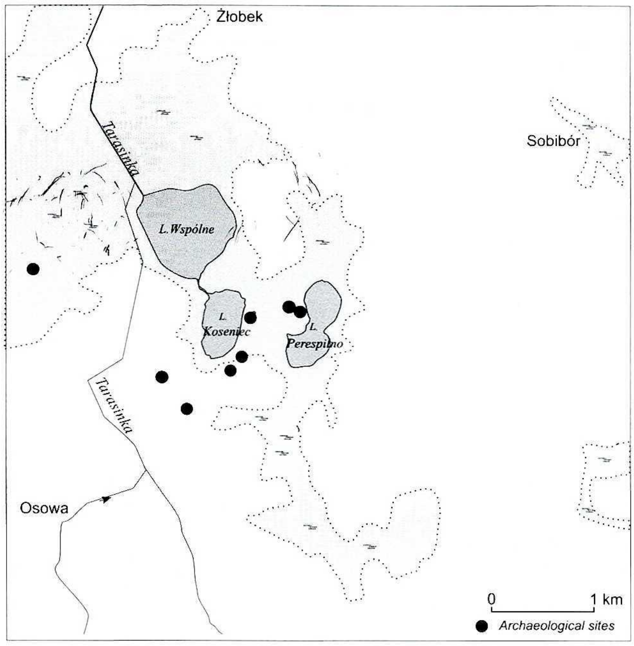

Fig. 12. The location of the Mesolithic sites in the environs of Lake Perespilno.

tributed to slowdown or even interruption of peat accumulation (registered in eastern part of Lake District) at the beginning of the Holocene. However, in the western part of the Lake District, accumulation of carbonate gyttja in the Łukcze II site was probably associated with rising water level in that lake. In the same way one can explain the accumulation of carbonate gyttja in the Krowie Bagno profile at the beginning of Holocene, when peats (or peaty gyttja) were being overlain by limnic sediments. Such local differences might have also been caused by a selective lowering of the lake bottom.

Boreal chronozone

Development of alder communities in the earlier phase of the Boreal chronozone, recorded by the maximum pollen values of *Alnus* (about 9000–8600 year BP), can indicate that the groundwater table rose and wet habitats formed which were favourable for alder (compare Jørgensen 1963). The high groundwater level probably stimulated also peat accumulation in shallow depressions near Lake Perespilno (Fig. 11). However, occurrence of the Mesolithic archaeological sites between the Perespilno and Koseniec lakes (Fig. 12) indicates that the area was accessible to man, so the lake water level must have been rather low. The increases of *Pteridium aquilinum* in the Boreal chronozone were recorded in the lacustrine sediments of Lake Perespilno (Fig. 6). This species prefers open and scorched places, so its occurrence might have been related to the presence of Mesolithic people.

In the western part of the Lake District, in the profiles of the shore zone of Lake Łukcze's mire, sedimentation of peat over carbonate gyttja provides evidence of water level lowering in the Boreal chronozone. This is also confirmed by the sedimentation change (from algae gyttja into carbonate-detritus one) in Lake Karaśne situated in the central part of the Lake District. Carbonate gyttja accumulated also in the

Krowie Bagno and Moszne sites. It seems that carbonate sediments were accumulated in shallow lakes in this region. The results of Cladocera analysis in the sediments of Lake Perespilno (Bałaga *et al.* 2002, Fig. 6) and of Lake Karaśne (K. Szeroczyńska, unpublished) and the existence of plants from the limnophyta and telmatophyta groups also indicate that the lakes were shallow with wide littoral zones. The lack of a distinct rise of lake water level in other regions of Poland at that time was explained by the evapotranspiration effects of dense mixed forests (Ralska-Jasiewiczowa, Starkel 1991).

Atlantic chronozone

In the Atlantic chronozone the sedimentation in Lake Perespilno changed into a carbonate-free one. The results of Cladocera analysis show that the lake was the deepest at the time, with the predominance of planktonic Cladocera species (Bałaga *et al.* 2002). The low amount of littoral macrophytes, and of algae from *Pediastrum* genus, also suggests the rise of water level (Fig. 6). Carbonate-free sedimentation took place also in Lake Łukcze, and lasted there through the whole Holocene. We can suppose that in warm and wet conditions of climatic optimum these two lakes were the deepest, just like today. On the contrary, in the lakes of the central part of the Lake District the accumulation of carbonate gyttja was prevailing. Preliminary Cladocera analysis in the sediments of Lake Karaśne indicates that it was a shallow and eutrophic lake. In the discussed chronozone, a different tendency of water lowering appeared in the Durne Bagno site, where peats (dated at about 7400 year BP) developed over lacustrine sediments in the shallower parts of the lake. Its deeper parts were overgrown gradually for about 1400 years (Fig. 4). In the profile from the Moszne mire, the water level lowering started in the second part of the Atlantic chronozone, as recorded by the change of algae gyttja into coarse detritus one.

In the pollen diagram from the Krowie Bagno mire we observe a distinct fall in the Cyperaceae percentages, and the appearance of plant species from limnophyta group in the latter part of the Atlantic chronozone, *i.e.* from 6900 to 5200 years BP. These observations suggest temporary rise of water level in the shallowing lake, additionally confirmed by the occurrence of branchiate snails in the sediments. Disappearance of the lake and development of mire were dated at 5100 years BP (Fig. 5).

Subboreal chronozone

The change of climatic conditions (cooling and moistening of climate) in the older part of the Subboreal chronozone probably caused the change in Cladocera assemblage in the algae gyttja sediments of Lake Perespilno (Bałaga *et al.* 2002). The predominance of *Chydorus sphaericus* and *Bosmina coregoni* indicates that the productivity decreased, and the water level was still high. The high values of *Alnus*, *Phragmites* and *Sphagnum* in the pollen diagram from the shallow depression near Perespilno (Fig. 11) are dated at about 3800 years BP, and were probably associated with a higher water level and wetter climate.

However, the total area of lakes in the Łęczna-Włodawa Lake District was strongly reduced during the Subboreal. Till about 3880±60 years BP the water sheet of Lake Karaśne covered the similar area to the present lake together with "spleja" (about 17.5 ha), and its water level was at the altitude of 166 m a.s.l. (Fig. 10). The successive sedimentation of sedge and sedge-moss peats occurred in the Krowie Bagno fen. The shallowing and overgrowing of Lake Moszne was still continued. Mire has been developing here since 4300 years BP, and "spleja" has been overgrowing the lake at a rate of about 0.85 mm/year (Bałaga *et al.* 1995).

Fluctuations of the water level in the mires are reflected by the different rates of accumulation and decomposition of peats, and probably also by hiatuses (compare Bałaga *et al.* 1983, Bałaga 1991). Interbeddings of coarse detritus gyttja in the peat profiles are found only sporadically (Bałaga *et al.* 2002). Thus, the peat accumulation was probably synchronous with the rise of water level, which might have resulted from climate moistening.

The rise in pollen values of taxa of wet habitats can be interpreted as an indicator of the climate moistening. Therefore, the phases of climate moistening were distinguished on the basis of the maximum pollen values of *Alnus*, *Sphagnum*, and the sum of telmatophyta found in the Moszne and Krowie Bagno mires (Table 1). They were compared with the record of wet/thermal phases distinguished on the basis of calcareous tufa formation in the spring mires of the Chełm Hills (Dobrowolski *et al.* 1999) and with the wet phases recorded in fluvial systems of Poland (Starkel 2002).

In the Subboreal chronozone, the synchronic character of wet phases distinguished on the basis of palynological analyses and changes in fluvial systems is noticeable. In the sedimentation of calcareous tufa at that time, however, no distinct lithological zones were distinguished.

The economic activities of prehistoric man may have also influenced water conditions; deforestation may have contributed to the rise of water level. However, the low values of anthropogenic indicators in the pollen diagrams from the Polesie region suggest that man activities did not considerably influence water balance during the Subboreal chronozone (Bałaga *et al.* 2002, Fig. 6).

Subatlantic chronozone

The next cooling and moistening of climate happened at the beginning of the Subatlantic chronozone. Development of bogs in the Moszne and Durne Bagno sites (dated at 2790±140 and about 2200 years BP, respectively) was probably associated with that wet phase. The mires lost connection with the groundwater then and their supply system became ombrophilous, probably also as a result of higher precipitation.

The subsequent wet phases, reflected in the increased pollen values of *Alnus*, *Sphagnum* and telmatophyta, occurred in the periods from 2500 to 1400 years BP and from 1240 to 250 years BP, that is partly consistent with the phases distinguished in fluvial systems and calcareous tufa formation (Table 1).

Human influence on plant cover of the Polesie region has increased since the Middle Ages as evidenced by the higher values of anthropogenic indicators in the pollen diagrams. This period is best recorded in the bottom sediments of the

Table 1

Wet phases recorded in the peat profiles in the central part of the Łęczna-Włodawa Lake District during the Neoholocene (the last 5000 years BP after Starkel 1977, 1991). The numbers denote ages in years BP

Moszne		Krowie Bagno		Phases of calcareous tufa formation (Dobrowolski *et al.*, 1999)	Wet phases (Starkel, 2002)
Max. *Alnus*	*Sphagnum*	Max. *Alnus*	Telmatophytes		
980–290	780–290	1240–780	510–250	1000–650	10–11 and 17–18 century
2040–1740	1970–1370	2380–1440	2530–2000	2500–1700	2200–1800
2790–2340	3040–2190	2890–2680		lack of discrete calcareous tufa layers (of dispersed character)	2800–2700
3290–3120	3500–3290	3270–3050	3420–3270		3500–3000
3760–3420	3955–3710	3760–3640			
			3910–3560		
>4380		4520–4100	4690–4140		4500–4000

shallow Lake Karaśne. The top part of these sediments, about 0.5 m thick, represents the last 700 years and is characterized by the molluscan fauna typical of strongly overgrown lake. Deep-water species are not found among the remnants of Cladocera. These data do not evidence any distinct changes of lake water level. Nevertheless, occurrence of the sedge-*Sphagnum* peats over the sedge-moss ones in the top layer of the bog near Lake Łukcze indicates a rise of the lake water level in this time. However, it should be stressed that many mires, situated near lakes, keep up high water level due to high water-storage capacity of peat (Harasimiuk 1996), and the action of confined waters favours continual presence of wet areas, even during low precipitation periods (Michalczyk 1998). The radical changes of water conditions and forest cover occurred only in the last century, and were caused by agricultural drainage and the construction of the Wieprz-Krzna Channel (*e.g.* Wilgat *et al.* 1991).

DISCUSSION

In the light of the paleoecological analysis presented above, hydrological changes in the Lublin Polesie appear to be very complex. The water balance was dependent not only on climatic factors (regional in nature), but, to a greater extent, on local conditions. The lakes at Lublin Polesie, together with the surrounding mires, constitute an integrated hydrological complex. Their water balance is conditioned by three factors: precipitation, evapotranspiration and underground waters exchange. The interrelations between lacustrine, surface and underground waters are presented by Wojciechowski (1991a), who argued that distinguishing one uniform feature of these relations in the Lublin Polesie was not feasible. It was, however, possible to distinguish several types of relations between lakes and their surroundings. These diversified relations between lakes and their catchments were supposedly responsible for differentiated sedimentation of calcium carbonate. Variations of calcium carbonate content in lacustrine sediments are considered to indicate climatic changes as well as changes of the lake's depth. However, this indicator is not applicable when the lakes of the Polesie are concerned. All the phenomena mentioned above are extremely complex; they require further examination and a more detailed discussion.

The analyses of ^{13}C isotope in authigenic carbonates of Lake Perespilno indicate that an opposite tendency of the $\delta^{13}C$ curve in the periods Younger Dryas when compared to other Polish lakes (Kuc *et al.* 1996). This is supposedly caused by an interaction of the assimilation and decomposition of organic material inside the lake. Similarly, the analysis of water balance (the intensity of water exchange) of the selected lakes provides evidence concerning the discrete character of water circulation system of the Łęczna-Włodawa Lake District (when compared with other Polish lakes). Five of six sites examined in this district exhibited the water turnover time exceeding 6 years (7–86 years), whereas in almost all Polish lakes this time is less then 6 years (Wojciechowski 1991b).

Over the Postglacial, the total area of lakes in this Lake District was the largest between the last cold Postglacial phase and the Neoholocene. However, the lakes were probably the deepest at the older phase of the Alleröd. The depth of the examined lakes (from over 20 to several m) was conditioned by various processes (among others karst and thermokarst phenomena) forming the lake basins. These processes were influenced both by climatic and local (tectonics of the area, the nature of fault surfaces of the Upper Cretaceous massif) factors, which also had an impact on the size and character of depressions and the role of confined waters. As the bottom of lake basins became more stable, the sediments started to accumulate. In many Polish (Niewiarowski 1995, Starkel *et al.* 1998, Wojciechowski 2000) as well as southern Scandinavian sites (Gaillard 1985, Digerfeldt 1988), during the warm and dry early Holocene, low level of lakes was registered. However, the phases of a low water level distinguished in these sites are not always synchronous. This situation is similar to that of southern Sweden, where changes in water balance lagged behind those in south-central Sweden by 1000–2000 years (Almquist-Jacobson

1995). In the Polish Lowlands, the phases of the low water level occurred at 10000–9500 and 9200–9300 BP (Ralska-Jasiewiczowa, Starkel 1988). As far as the Lublin Polesie is concerned, the low water level was noticeable in its eastern part at that time. The gyttja accumulation, in turn, evidences the rise of the water level in the western and central parts of the Łęczna-Włodawa Lake District. These changes could have been instigated by a selective lowering of the bedrock.

The hydrological changes leading to the shallowing of the lakes in the central part of the Łęczna-Włodawa Lake District provide evidence for periodical fluctuations of the water level in the middle Holocene. This is also confirmed by the analyses of calcareous tufa in the mires of a neighbouring region – the Chełm Hills (Dobrowolski *et al.* 1999). The escalation of tufa sedimentation, favoured by warm and wet climate, is dated at 6700–6500 and 6000–5700 BP. Low water levels of Lake Gościąż (Starkel *et al.* 1998) and Lake Biskupińskie (Niewiarowski 1995) in the Atlantic chronozone were caused by the development of deciduous and mixed forests communities in the climatic optimum. The increased evapotranspiration was supposedly the factor modifying local water systems. The deepening of Lake Perespilno, occurring after the mid-Holocene is worth noting (Bałaga *et al.* 2002, Fig. 6). Similarly, in the Atlantic chronozone, a high water level was noted in the lakes of southern Sweden (Harrison, Digerfeldt 1993).

In the Neoholocene, hydrological changes in the Lublin Polesie were related to the successive shallowing and overgrowing of the lakes. Mires and present lacustrine-mire complexes were forming then. As the flow of enriched waters was limited, bogs fed by precipitation waters were formed. As the human impact was negligible, these changes were mainly brought about by climatic conditions.

The intended comparison of the profile from the central part of Lake Karaśne with the profiles from the mire surrounding the lake should provide some further information concerning the changes of water level in the selected site (Bałaga *et al.* 2002). The results of the palynological, Cladocera and chemical composition analyses together with radiocarbon dates are bound to provide the data for the detailed reconstruction of water-level fluctuations in the lake.

CONCLUSIONS

The biostratigraphic analysis of the lacustrine and mire sediments in the examined sites indicates that biogenic accumulation was different in the particular sites and in the successive chronozones of the Late Glacial and Holocene. The differentiation of biogenic accumulation was conditioned by local factors (geological-geomorphological conditions, biological processes occurring in lakes), and also by climatic changes.

Hydrological changes during the Late Glacial were caused by ground subsidence resulting from permafrost degradation and melting of ice lenses. The ascensive activation of groundwater vertical circulation was also conditioned by those phenomena. The most prominent changes occurred in the Alleröd chronozone where the basins of the present lakes were formed.

The total area of lakes in the Polesie region was the largest from the Younger Dryas to the Subboreal chronozone, though several lowerings of lake water level occurred.

The slow overgrowing of some lakes was observed in the Atlantic chronozone as a result of water-level lowering. The lake in the Durne Bagno site had been totally overgrown in the period from 7400 to 6000 years BP, and the modern bog (the greatest in the Polesie region) started to develop there. However, some other lakes (*e.g.* Lake Perespilno) were still deep then.

The radical changes, *i.e.* the lowering of lake water level and the development of mires on lacustrine sediments, occurred during the younger Holocene. The lakes transformed then into large mires (*e.g.* Krowie Bagno) or their area was largely reduced.

Fluctuations of groundwater level conditioned the rates of accumulation and decomposition in the Subboreal and Subatlantic peat bogs. The wet phases indicated by the maximum pollen values of *Alnus*, *Sphagnum* and sum of telmatophyta, are partially consistent with those distinguished in fluvial systems (Starkel 2002) and in the spring mires (Dobrowolski *et al.* 1999)

The economic activity of prehistoric man, recorded by the occurrence of anthropogenic indicators in the pollen diagrams, had no noticeable influence on the water level. The cosiderable changes of vegetation cover and distinct eutrophication of lakes have occurred only since the Middle Ages.

The conditions of calcium carbonate precipitation in the lakes of the Polesie region are an important and difficult problem. Algae-carbonate gyttja was accumulated in rather shallow lakes as a result of the process of biological decalcification of water rich in Ca^{2+} and HCO_3^- ions.

The obtained results indicate that the lake water level during the Late Glacial and Holocene (*e.g.* at Moszne and Karaśne sites) was at about 165–168 m a.s.l.

Acknowledgements

The studies of the sediments were partially supported by Grant No 6PO4E 02517 from the Polish State Committee for Scientific Research.

REFERENCES

Almquist-Jacobson H. 1995. Lake-level fluctuations at Ljustjärnen, central Sweden and their implications for the Holocene climate of Scandinavia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 118, 269–290.

Bałaga K. 1991. The development of Lake Łukcze and changes in plant cover of the south-western part of the Łęczna-Włodawa Lake District in the last 13 000 years. *Acta Palaeobotanica* 30, 77–146.

Bałaga K., Buraczyński J., Wojtanowicz J. 1983. Geological Structure and Development of the Krowie Bagno Peatland (Polesie Lubelskie). *Annales UMCS* Sec. B 35/36, 37–62 (in Polish with English summary).

Bałaga K., Dobrowolski R., Harasimiuk M., Rodzik J. 1996. The problem of genesis and evolution of the Łęczna-Włodawa Lake District lake and peatbog reservoirs versus conditions of their functioning. In Radwan S. (ed.), *Funkcjonowanie ekosystemów wodno-błotnych w obszarach chronionych Polesia*, UMCS, Lublin, 9–15 (in Polish with English summary).

Bałaga K., Dobrowolski R., Rodzik J. 1995. Paleogeographic Conditions of the Development of Lakes and Mires of the Polesie

National Park and Its Protection Zone. *Annales UMCS* Sec. B 48, 1–18 (in Polish with English summary).

Bałaga K., Dobrowolski R., Rodzik J. 1996. From Studies of the Bottom Sediments of the Karaśne Lake in Polesie National Park. *Annales UMCS* Sec. B 51, 77–86 (in Polish with English summary).

Bałaga K., Dobrowolski R., Rodzik J. 2002. Lithostratigraphic record of the development of Lake Karaśne (Lublin Polesie, E. Poland) in the Late Glacial and Holocene. *Limnological Review* 2, 5–14.

Bałaga K., Goslar T., Kuc T. 1998. A comparative study on the Late-Glacial/early Holocene climatic changes recorded in laminated sediments of the Lake Perespilno – introductory data. In Ralska-Jasiewiczowa M., Goslar T., Madeyska T., and Starkel L. (eds.), *Lake Gościąż, central Poland, A Monographic Study, Part 1*, Szafer Institute of Botany, Kraków, 175–180.

Bałaga K., Szeroczyńska K., Taras H., Magierski J. 2002. Natural and anthropogenic conditioning of the development of Lake Perespilno (Lublin Polesie) in the Holocene. *Limnological Review* 2, 5–27.

Buraczyński J., Wojtanowicz J. 1981. The explanations for a detailed geological map of Poland 1:50 000, sheet Orzechów Nowy (original: Objaśnienia do Szczegółowej Mapy Geologicznej Polski 1:50 000, ark. Orzechów Nowy). Wydawnictwa Geologiczne, Warszawa, 1–87 (in Polish).

Buraczyński J., Wojtanowicz J. 1983. The effect of the Middle-Polish Glaciation on the relief of Southern Part of Polesie Lubelskie. *Annales UMCS* Sec. B 35/36, 63–79 (in Polish with English summary).

Chałubińska A., Wilgat T. 1954. The physiographic division of the Lublin Voivodship (original: Podział fizjograficzny województwa lubelskiego). Przewodnik Ogólnopolskiego Zjazdu PTG. UMCS, Lublin, 3–44 (in Polish).

Dearing J. A., Foster I.D.L. 1986. Lake sediments and palaeohydrological studies. In Berglund B.E. (ed.), *Handbook of Holocene Palaeoecology and Palaeohydrology*, J. Wiley & Sons, 67–90.

Digerfeldt G. 1972. The post-glacial development of Lake Trummen. Regional vegetation history, water level changes and palaeolimnology. *Folia Limnologica Scandinavica* 16, 1–87.

Digerfeldt G. 1986. Studies on past lake-level fluctuation. In Berglund B.E. (ed.), *Handbook of Holocene Palaeoecology and Palaeohydrology*, J. Wiley & Sons, 172–143.

Digerfeldt G. 1988. Reconstruction and regional correlation of Holocene lake-level fluctuations in Lake Bysjön, South Sweden. *Boreas* 17, 165–182.

Digerfeldt., Olsson, S., Sandgren P. 2000. Reconstruction of lake-level changes in lake Xinias, central Greece, during the last 40 000 years. *Palaeogeography, Palaeoclimatology, Palaeoecology* 158, 65–82.

Dobrowolski R. 1998. Structural conditions of recent karst relief development in the middle Wieprz and Bug interfluve. UMCS, Lublin, 1–88 (in Polish with English summary).

Dobrowolski R., Alexandrowicz S., W., Bałaga K., Durakiewicz T., Pazdur A. 1999. Studies of tufa within spring peat-knoll in eastern Poland (orginal: Badania martwic wapiennych w obrębie źródliskowych torfowisk kopułowych we wschodniej Polsce) In Pazdur A., Bluszcz A., Stankowski W., Starkel L. (eds.), *Geochronometria górnego Czwartorzędu Polski w świetle datowania radiowęglowego i luminescencyjnego*, WIND, J. Wojewoda, Wrocław,179–197 (in Polish).

Gaillard M.J. 1985. Postglacial palaeoclimatic changes in Scandinavia and Central Europe. A tentative correlation based on studies of lake level fluctuations. *Ecology Mediterraneum* 11, 159–175.

Gąsiorowski M. 2001. Lacustrine chalk deposition in Lake Kruklin (NE Poland) as a result of decalcification of the lake catchment. *Studia Quaternaria* 18, 17–24.

Goslar T., Bałaga K., Arnold M., Tisnerat N., Kuźniarski M., Chróst L. Walanus A., Więckowski K. 1999. Climate-related variations in the composition of the Late Glacial and early Holocene sediments of Lake Perespilno (eastern Poland). *Quaternary Science Reviews* 18, 889–911.

Goslar T., Ralska-Jasiewiczowa M., Starkel L., Demske D., Kuc T., Łącka B., Szeroczyńska K., Wicik B., Więckowski K. 1998. Discussion of the Late Glacial recorded in Lake Gościąż sediments. In Ralska-Jasiewiczowa M., Goslar T., Madeyska T., and Starkel L. (eds.), *Lake Gościąż, central Poland, A Monographic Study, Part 1*, Szafer Institute of Botany, Kraków, 171–175.

Harasimiuk M. 1996. Geological and geomorfological conditions of water circulation in the area under restoration in the Łęczyńsko-Włodawskie Lake District (area of lakes Rogóźno and Uściwierz). In Chmielewski T. J, Harasimiuk M., Radwan S. (eds.), *Renaturalizacja ekosystemów wodno-torfowiskowych na Pojezierzu Łęczyńsko-Włodawskim*, UMCS, Lublin, 7–13 (in Polish with English summary).

Harasimiuk M., Wojtanowicz J. 1998. Geological structure and the relief of the Łęczna-Włodawa Lake District. In Harasimiuk M., Turczyński M. (eds.), *Jeziora Łęczyńsko-Włodawskie, Monografia przyrodnicza*, UMCS, Lublin, 41–53 (in Polish with English summary).

Harrison S.P., Digerfeldt G. 1993. Europaean lakes as palaeohydrologic and palaeoclimatic indicators. *Quaternary Sciencies Reviews* 12, 233–248.

Jørgensen S. 1963. Early Postglacial in Aamosen. *Danmarks Geologiske Undersogelse* 2, 37, 1–79.

Kuc T., Różański K., Duliński M. 1996. Some problems of isotopic record as indicators of palaeoclimatic changes derived from lake sediments. *Zeszyty Naukowe Politechniki Śląskiej, Geochronometria* 13, 181–193 (in Polish with English summary).

Liszkowski J. 1979. The explanations for a detailed geological map of Poland 1:50 000, sheet Ostrów Lubelski (original: Objaśnienia do Szczegółowej Mapy Geologicznej Polski 1:50 000, ark. Ostrów Lubelski). Wydawnictwa Geologiczne, Warszawa, 1–87 (in Polish).

Marek S. 1965. Biology and stratigraphy of the alder bogs in Poland. *Zeszyty Problemowe Postępów Nauk Rolniczych* 57, 5–303 (in Polish with English summary).

Maruszczak H. 1966. The problem of the genesis and age of lakes between Łęczna and Włodawa in Eastern Poland. *Folia Societatis Scientarium Lubliniensis* D 56, 31–37 (in Polish with English summary).

Michalczyk Z. 1998. Water conditions of the Łęczna-Włodawa Lake District (original: Stosunki wodne Pojezierza Łęczyńsko-Włodawskiego). In Harasimiuk M., Michalczyk, Z., Turczyński M. (eds.), *Jeziora Łęczyńsko-Włodawskie, Monografia Przyrodnicza*, UMCS, Lublin, 55–70 (in Polish).

Niewiarowski W. 1995. Fluctuations of water level in Biskupin (Biskupińskie) Lake and its reasons. In Niewiarowski W. (ed.), *Zarys zmian środowiska geograficznego okolic Biskupina pod wpływem czynników naturalnych i antropogenicznych w późnym glacjale i holocenie*, Turpress, Toruń, 215–234 (in Polish with English summary).

Ralska-Jasiewiczowa M., Goslar T., Bałaga K. 1999. Biostratigraphy of the Lateglacial in the lowland of Poland based on the calendar time scale. *Terra Nostra* 99/10, 66–71.

Ralska-Jasiewiczowa M., Starkel L. 1988. Record of the hydrological changes during the Holocene in the lake, mire and fluvial sediments of Poland. *Folia Quaternaria* 57, 91–127.

Ralska-Jasiewiczowa M., Starkel L. 1991. Changes in climate and water systems in the Holocene (original: Zmiany klimatu i stosunków wodnych w holocenie). In Starkel L. (ed.), *Geografia Polski. Środowisko Przyrodnicze*, Państwowe Wydawnictwo Naukowe, 177–182 (in Polish).

Rzepecki P. 1985. Lacustrine calcareous sediments of Northern Poland between Łyna and Brda rivers. *Zeszyty Naukowe AGH* 11, 5–78 (in Polish with English summary).

Starkel L. 1977. Palaeogeography of Holocene (original: Paleogeografia holocenu), Państwowe Wydawnictwo Naukowe, Warszawa (in Polish).

Starkel L. 1991. The role of the Holocene in environmental evolution and Holocene stratigraphy of (original: Rola holocenu w ewolucji środowiska i jego stratygrafia). In Starkel L. (ed.), *Geografia Polski. Środowisko Przyrodnicze*, Państwowe Wydawnictwo Naukowe, 105–106 (in Polish).

Starkel L. 2002. Change in the frequency of extreme events as the indicator of climatic change in the Holocene (in fluvial systems). *Quaternary International* 91, 25–32.

Starkel L., Pazdur A., Wicik B., Więckowski K. 1998. Lake-level changes and palaeohydrological reconstructions during the Holocene. In Ralska-Jasiewiczowa M., Goslar T., Madeyska T., and Starkel L. (eds.), *Lake Gościąż, central Poland, A Monographic Study, Part 1*, Szafer Institute of Botany, Kraków, 225–229.

Stasiak J. 1971. Sedimentation rate of calcareous gyttja sediments. *Zeszyty Problemowe Postępów Nauk Rolniczych* 107, 121–167 (in Polish with English summary).

Wasylikowa K. 1964. Vegetation and climate of the Late Glacial in Central Poland based on investigations made at Witów near Łęczyca. *Biuletyn Peryglacjalny* 13, 267–417 (in Polish with English summary).

Wilgat T. 1954. Lakes between Łęczna and Włodawa. *Annales UMCS* Sec. B 8, 37–122 (in Polish with England summary).

Wilgat T. 1994. Discussion concerning the of Łęczna – Włodawa (orginal: Spory wokół jezior Łęczyńsko-Włodawskich) In Wilgat T. (ed.), *Ogólnopolski Zjazd Polskiego Towarzystwa Geograficznego*, TWWP, Lublin, 122–129 (in Polish).

Wilgat T., Michalczyk Z., Turczyński M., Wojciechowski K. H. 1991. The Łęczna Włodawa Lakes. *Studia Ośrodka Dokumentacji Fizjograficznej* 19, 23–140 (in Polish with English summary).

Wojciechowski A. 2000. Palaeohydrological changes in the Central Wielkopolska lowland during the last 12 000 years on the basis of sediments of the Kórnik-Zaniemyśl Lakes. Wydawnictwa Naukowe UAM, Poznań (in Polish with English summary).

Wojciechowski K. H. 1991a. Changes of lake water balance directly influenced by hydrotechnic works (original: Przemiany bilansu wodnego jezior pod bezpośrednim wpływem ingerencji hydrotechnicznej). *Studia Ośrodka Dokumentacji Fizjograficznej* 19, 101–106 (in Polish with English summary).

Wojciechowski K. H. 1991b. Connections between lake waters and other surface and undeground waters (original: Powiązanie wód jeziornych z wodami powierzchniowymi i podziemnymi). *Studia Ośrodka Dokumentacji Fizjograficznej* 19, 95–101 (in Polish with English summary).

Wojtanowicz J. 1994, On Thermokarst Genesis of the Łęczna-Włodawa Lakes. *Annales UMCS* Sec. B 49, 1–18 (in Polish with English summary).