*Studia Quaternaria*, vol. 19: 55–60.

# PALAEOHYDROLOGICAL ASPECT OF TRANSFORMATION OF LAKES INTO PEAT BOGS DURING MIDDLE HOLOCENE ON THE BASIS OF CLADOCERA ANALYSIS IN THE NORTHERN POLAND

**Krystyna Szeroczyńska, Michał Gąsiorowski**

*Institute of Geological Sciences, Polish Academy of Sciences, 00-818 Warszawa, ul. Twarda 51/55, e-mail: kszerocz@twarda.pan.pl, mgasior@twarda.pan.pl*

**Abstract**

Cladocera are a group of water animals, which are strongly dependent on environmental conditions. The ratio of planktonic to littoral Cladocera species is a widely used tool in palaeohydrological reconstruction of lakes' water level changes. Interpretation of this ratio is still unclear and requires further evidence. The simplest indicator of water level, which can be used in tracing lake-peat bog transitions, is the presence or absence of Cladocera and the character of its disappearance. In general, two models of Cladocera decline are observed. The first model is characterized by a very abrupt disappearance of all species, whereas the second one, with an intermediate stage, is characterized by domination of specific species. These two models are related to different types of terminal history of the water body. Even after a total disappearance of water in the peat bogs, there were episodes of some pioneer cladoceran species presence, correlated with periods of humid climate.

**Key words:** Cladocera remains, fossil lakes, Middle Holocene, palaeohydrology

*Manuscript received 25.09.2002, accepted 30.10.2002*

## INTRODUCTION

Character and evolution of lakes depend on geographical and hydrological settings. Lakes' basins are being filled with accumulated sediments and gradually overgrown by plants, which can lead to a complete disappearance of the lakes.

The process of lakes' extinction is very common in Poland. According to recent studies, over 60% of Polish postglacial lakes declined to the present time (Choiński 1995). Many scientists have studied the issue of water level changes for many years (Ralska-Jasiewiczowa, Starkel 1988, Korhola *et al.* 2000).

Most of the declined lakes transformed into peat bogs. Such transitions are caused by natural (*e.g.* climatic) and anthropogenic factors, which can be traced on the basis of chemical and biological analysis of lake sediments – the best archive of nature. Remains of Cladocera are one of the languages, in which this archive is written (Frey 1986).

Palaeoecological studies of cladoceran fauna have been conducted since early 60's. During many years of research activity, Cladocera appeared to be an excellent tool for the reconstruction of palaeoenvironmental factors, mainly climate, and trophic and hydrological conditions. In Poland, the first studies using the Cladocera analysis were conducted by Czeczuga *et al.* (1970), Mikulski (1978) and Szeroczyńska (1984, 1985).

Cladocera analysis was also used for the reconstruction of water level changes of many lakes (*e.g.* Alhonen 1970, Whiteside 1970, Szeroczyńska 1998, Sarmaja-Korjonen, Alhonen 1999, Sarmaja-Korjonen, Hyvärinen 1999). These reconstructions were based on the ratio of planktonic to littoral forms (p/l index). It should be noted, that the value of this index can be affected by eutrophication processes, which increase abundance of planktonic *Bosmina longirostris* and littoral *Chydorus sphaericus*. Hence, palaeohydrological meaning of the p/l index is still unclear and seems to be related rather to the changes of relative volume of pelagic and littoral zones, than to changes of water level. In spite of this, some of Cladocera taxa could serve as indicators of water turbidity, macrophytes development and other characteristics of lake, which may indirectly reflect water level changes. The best indicator of lake of disappearance is the absence of Cladocera remains.

## STUDIED SITES

Three small fossil lakes (all located in the northern Poland), which revealed a great deal of sedimentological, palaeobotanical and palaeozoological data, were chosen for cladoceran investigation. These lakes, as many other water bodies in this region, were formed after regression of the last Scandinavian ice sheet. Inorganic and organic sediments

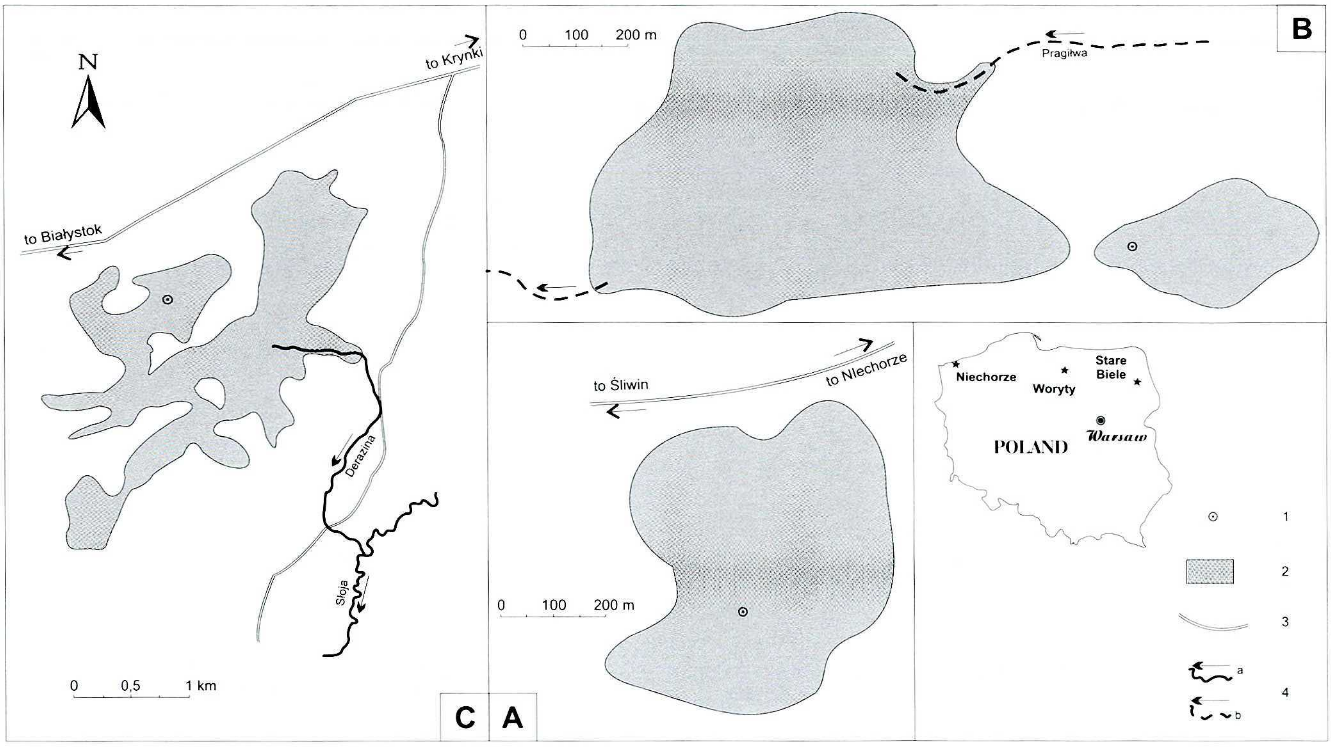


**Fig. 1.** Location of the studied sites: **A** – Niechorze fossil lake, **B** – Woryty, **C** – Stare Biele. *1* – coring sites, *2* – maximum extent of the fossil lakes, *3* – roads and paths, *4* – rivers and streams: *a* – recent, *b* – former.

were filling their basins during the Holocene, so that those lakes were ultimately transformed into peat bogs.

Niechorze fossil lake is located in northwestern Poland, 1.5 km from the present-day shore of the Baltic Sea (Fig. 1A) at an elevation of 4 m a.s.l. It was a shallow (approximately 8 m deep) lake. It occupied a depression after 'dead ice' melting. Nowadays, its basin is filled with limnic mud, gyttja and peat.

Woryty fossil lake is located in the northern Poland (Fig. 1B), in the Dobrzyń-Olsztyn Lake Districts at the elevation of 105 m a.s.l. It was a small (5 ha) and shallow (10 m) lake and was drained by Pragiłwa River. There was also another, bigger lake to the west. Lusatian settlement existed in the vicinity of the lakes. Today this terrain is a drained, cultivated grassland.

The Stare Biele Range is located in Knyszyn Forest (Fig. 1C), 25 km to NE from Bialystok (NE Poland), at the elevation of 144 m a.s.l. It is an isolated complex of moor and moss with alder and pine forest, surrounded by terminal moraine and kame hills (Czerwiński *et al.* 2000). Its basin was developed in sands and gravels of Riss glaciation and was filled by organic material during the Late Glacial and Holocene. Morphology of the basin's bedrock is very complex, with many well-like pits. The deepest part of the basin, which was the drill site, is completely filled with 10 m thick sediments.

## METHODS

Sediment cores for Cladocera analysis were collected from sites where the deposits attained their maximum thickness. The cores were subsampled every 10 or 20 cm. Samples of 1 $cm^3$ were prepared according to the standard procedure (Frey 1986). The sediment was treated with 10% HCl in order to remove calcareous material and then heated in 10% KOH for 20–30 minutes using magnetic stirrer in order to deflocculate organic material. Samples were sieved through a 33 μm screen and transferred into distilled water. Before counting, samples were colored with Safranin O glycerin solution. Minimum 250 remains of Cladocera (3–4 slides, each containing 0.1 ml of sample solution) were examined for each level and the total concentration of Cladocera per $cm^3$ was calculated. Identification of cladoceran taxa was based mainly on the papers by Frey (1958) and Flössner (1972). The results are presented on the total concentration diagrams (Fig. 2). Shannon-Wiener diversity index was also calculated. The equation of index and its interpretation were given by Frey (1986).

## CLADOCERAN STRATIGRAPHY

### Woryty fossil lake

Cladocera analysis of sediments from Woryty was done in the 80's (Szeroczyńska 1985). 37 Cladocera species belonging to 5 families, both planktonic and littoral, were found during that investigation (Fig. 2). 3 stages of cladoceran assemblages' development could be then distinguished on the concentration diagram. Stage I (7.7–4.2 m) is characterized by presence of low-trophy species. Planktonic *Bosmina coregoni* and littoral *Alonella nana* and *Chydorus sphaericus* are dominant. That stage was defined as Older Holocene. Stage II (4.2–1.6 m) is described by presence of high-trophy

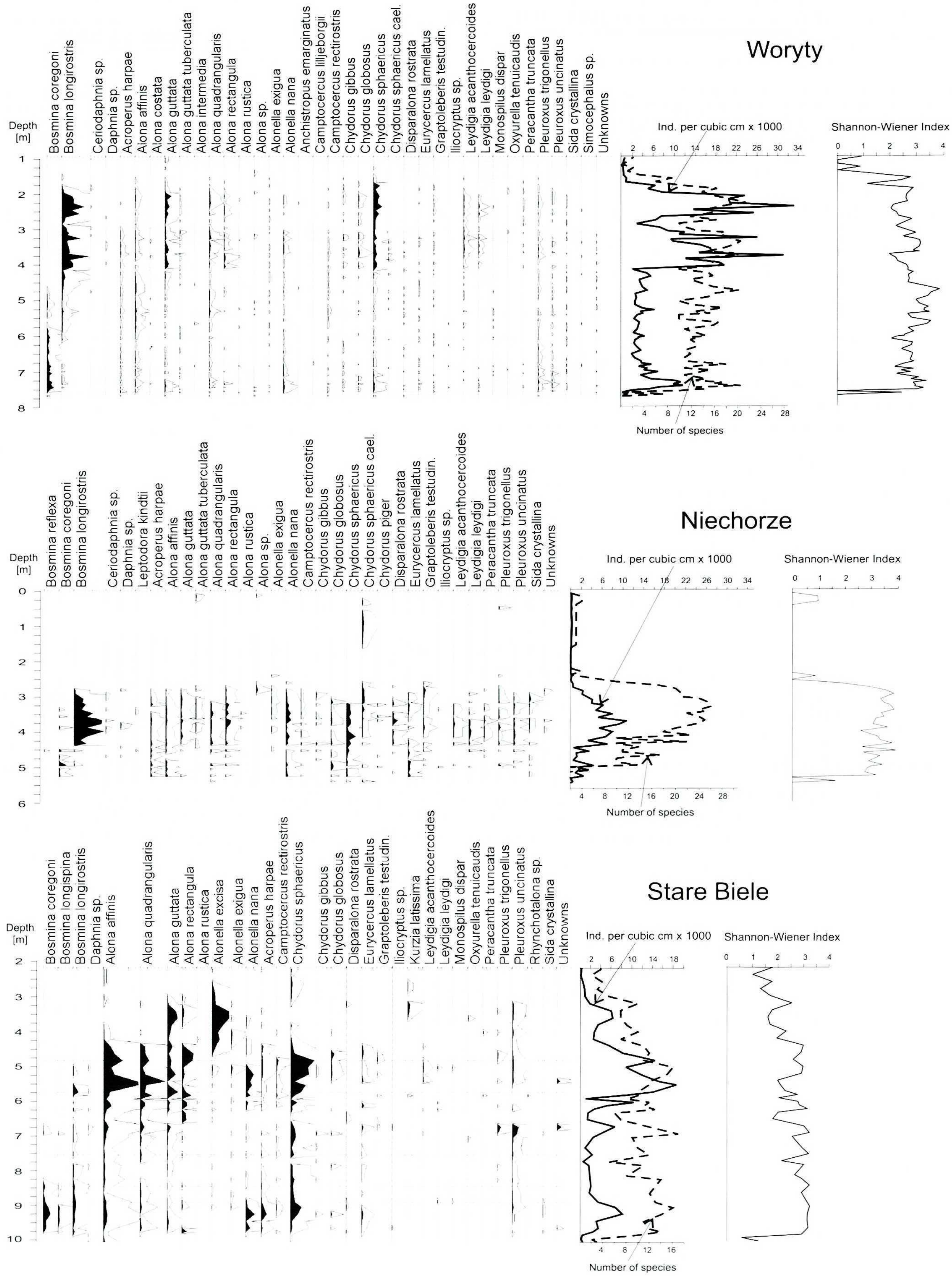


**Fig. 2.** Concentration diagrams, diversity index, number of species and individuals number of Cladocera from Woryty, Niechorze and Stare Biele fossil lakes.

species, particularly planktonic *Bosmina longirostris* and littoral Chydoridae: *Chydorus sphaericus*, *Alona guttata*, *A. rectangula*, *Leydigia acanthocercoides* and related to macrophyte density *Alona affinis*. Sediments accumulated during that stage (Subboreal and part of Subatlantic period) are mainly swamp peat with gyttja. The sediment type and the Cladocera species indicate high eutrophication and gradual decline of the lake. These processes resulted from climatic changes as well as human activity. The sediments of Stage III (above 1.6 m) are very poor in Cladocera remains. The lake was probably completely transformed into a peat bog and water level was so low, that Cladocera could no longer exist.

### Niechorze fossil lake

Cladocera analysis of profile Niechorze (IV) was also conducted during earlier investigation (Szeroczyńska 1985). 35 Cladocera species belonging to 5 families, all very well preserved were found. Cladocera remains were encountered in the sediments from 5.5 m depth up to the beginning of peat sedimentation. As in Woryty, three stages of Cladocera development were distinguished. Stage I (5.5–4.5 m) is characterized by low diversity and low frequency of Cladocera remains and accumulation of till and silt with molluscan shells. Environmental conditions were unsuitable for Cladocera then. Stage II (4.5–3.0 m; Boreal and Atlantic) is the period of maximum development of this lake. Gyttja with molluscan shells and plant debris was accumulated during this time. High-trophy species (*Bosmina longirostris*, *Alona rectangula*, *Leydigia* spp., *Chydorus sphaericus*, *Alona affinis*, *A. quadrangularis*, *Acroperus harpae*) were dominant. Stage III (above 3.0 m) was a period of peat accumulation and very low, sporadic Cladocera appearances.

### Stare Biele fossil lake

31 species belonging to 4 families were found in the sediments of this lake. Stages I and II of Cladocera development are similar as in the Niechorze profile. However, stage III where gyttja was replaced by peat is characterized by continuous presence of very few species (*Alona affinis*, *A. guttata* var. *tuberculata*, *A. rectangula*, *Alonella excisa*, *Chydorus sphaericus* and *Kurzia latissima*), which tolerate specific conditions as low pH and high density of plants. Above 2.2 m no cladoceran remains were noticed.

## TWO MODELS OF CLADOCERAN COMMUNITIES DECLINE

Cladocera communities in the studied fossil lakes present two models of development. The first steps of development, from the initial period to the maximum of diversity, are the same in both models (Fig. 3, steps 1–3). At the very beginning of lakes' history, only a few Cladocera taxa are recorded (Fig. 2). These are species of wide ecological tolerance of major environmental factors (temperature, turbidity, feeding manner) *i.e. Chydorus sphaericus*, *Alona affinis*, and *Alona quadrangularis*. After the initial stage, other Cladocera species, both planktonic and littoral, quickly appear. Among planktonic species, *Bosmina coregoni* has significant share in the early stages, but it is soon replaced by the other species

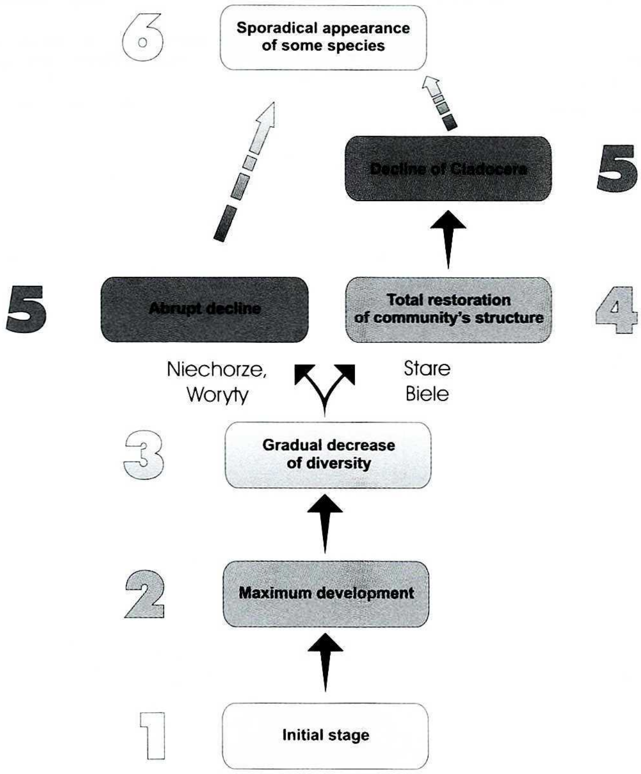


**Fig. 3.** Schematic representation of two ways of cladoceran assemblages evolution.

– *Bosmina longirostris*. This change is caused by quick eutrophication of these shallow lakes and the diminish of pelagic zone. The differences between the lakes appear after the start of cladoceran assemblages' decline. The first model, found in the Niechorze and Woryty fossil lakes, presents abrupt disappearance of all species (Fig. 3, step 5). The second one, noted in Stare Biele, is characterized by total restoration of species structure (Fig. 3, step 4), a low value of the diversity index (Fig. 2) and a strong domination of very few Chydoridae species (*Alona guttata*, *Alonella excisa* and *Kurzia latissima*). *Alonella excisa* and *Alona guttata* and especially *Alona guttata* var. *tuberculata*, seem to be related to low pH and development of macrophytes. The total disappearance of Cladocera took place after this relatively long stage.

In the following period some species with the widest ecological tolerance (eg. *Alona guttata*, *Chydorus sphaericus*) reappear sporadically (Fig. 3, step 6). These appearances are clearly correlated with the periods of the most humid climate.

## CLADOCERA AND PERIODS OF HUMID AND ARID CLIMATE

During the Holocene Periods of humid and arid climate occurred alternately. Changes of precipitation and evaporation rates strongly influence of lakes' environment. Some of the episodes of very low precipitation could cause disappearance of lakes. On the other hand, transformation of lakes into peat bogs occurred in warm and humid periods. In such a

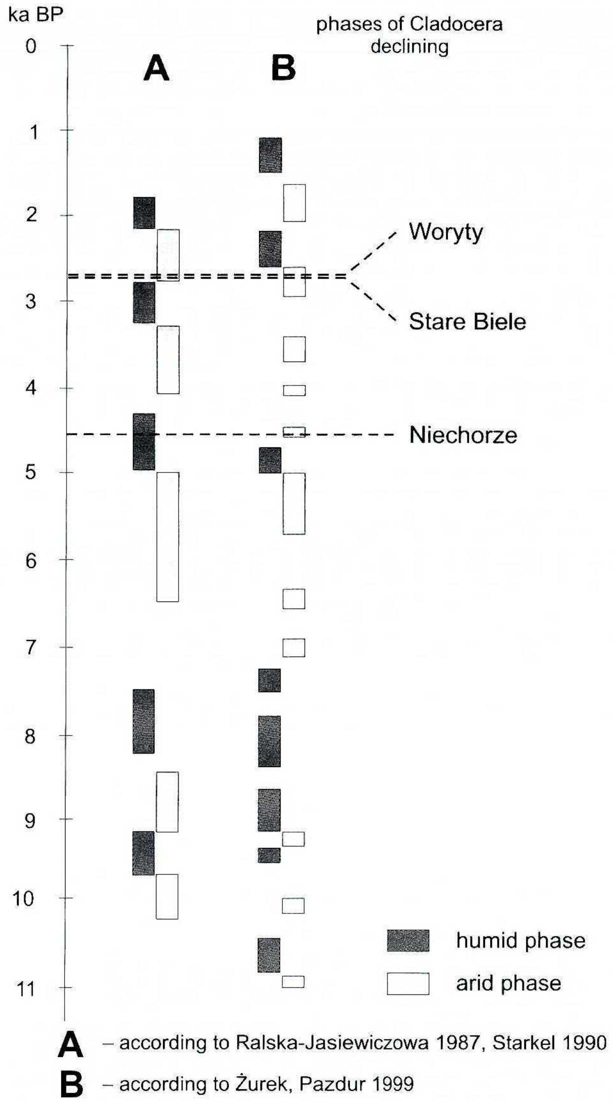


**Fig. 4.** Correlation of Cladocera disappearance in the studied fossil lakes with humid and arid periods of Holocene derived from sedimentological (Starkel 1990, Żurek, Pazdur 1999) and palaeobotanical data (Ralska-Jasiewiczowa 1987).

case, the process of lake's disappearance was related to the development of macrophytes and complete infilling of lake's basin by sediments.

In the studied sites, disappearance of zooplankton is dated to *ca.* 4500 years BP in Niechorze (Szeroczyńska 1985) and to 2800 years BP in Woryty (Szeroczyńska 1985) and Stare Biele (Czerwiński *et al.* 2000). All these dates fall into the limits of the Subboreal period. However, the zooplankton did not disappear simultaneously in all these lakes, that was caused by different morphometry and infilling rate of the lake basins. In the Stare Biele peat bog, the "declining stage" was relatively long and was characterized by specific ecological conditions (low pH of water, strong development of macrophytes). The decreases of water level recorded in Cladocera remains, followed by disappearance of the lakes, are well correlated with other data, which documented this process (Fig. 4). Sedimentological and pollen analysis recorded the same trends in other lakes and peat bogs in northern Poland (Ralska-Jasiewiczowa 1987, Starkel 1990). Results of Cladocera analysis are fine correlated with data obtained from analysis of peat bogs (Żurek, Pazdur 1999) as well as small lakes (Sarmaja-Korjonen, Alhonen 1999). Decrease of water level in Subboreal period (specially *circa* 4500 and 2600 years BP) is also recorded in other Polish lakes (even sufficiently deep), for *e.g.* Gościąż Lake (Starkel *et al.* 1998a, 1998b). However, changes of water level, sometimes followed by total disappearance of lake, seem to have many reasons and different scale (from local to global trends). In some cases, even studies conduct on close located lakes could give different results (Dąbrowski 2002). It demonstrates strong relation between water level changes and individual feature of lake and its catchment. Special attention should be put on the size and depth of the lake – a smaller lake react faster to even slight changes, so the record in the sediment is clearer.

## Acknowledgements

We thank Professor Sławomir Żurek for providing the Stare Biele sediment's samples and Professor Leszek Starkel and Professor Tomasz Goslar for critical and helpful comments to the manuscript.

## REFERENCES

Alhonen P. 1970. On the significance of the planktonic/littoral ratio in the cladoceran stratigraphy. *Commentationes Biologicae* 35, 1–9.

Choiński A. 1995. Physical limnology of Poland (Original: Zarys limnologii fizycznej Polski – in Polish), *Adam Mickiewicz University Press Publications*, 1–298.

Czeczuga B., Gołębiewski Z., Kossacka W. 1970. The history of Lake Wiżajny in the light of chemical investigations of the sediments and Cladocera fossils. *Schweizerische Zeitschrift für Hydrologie* 32, 284–299.

Czerwiński A. 2000. Habitat and peat bog vegetation changes in the Stare Biele range in Knyszyn Forest. Politechnika Białostocka. Rozprawy Naukowe Nr 70. Białystok. 1–225. (Original: Przemiany siedlisk i roślinności torfowisk uroczyska Stare Biele w Puszczy Knyszyńskiej. – in Polish with English summary).

Dąbrowski M. 2002. Changes in water level of lakes in northeastern Poland. *Limnological Review* 2, 85–92.

Frey D.G. 1958. The late-glacial cladoceran fauna of a small lake. *Archiv für Hydrobiologie* 54, 209–275.

Frey D.G. 1986. Cladocera analysis. In: Berglund B.E. (ed.), *Handbook of Holocene palaeoecology and palaeohydrology*, 667–692. John Wiley & Sons.

Flössner D. 1972. Krebstiere, Crustacea. Kiemen- und Blattfüßer, Branchiopoda Fischläuse, Branchiura. Die Tierwelt Deutschlands 60. (Lyh. Tierwelt Dtl.). Veb Gustav Fischer Verlag, Jena.

Korhola A., Olander H., Blom T. 2000. Cladoceran and chironomid assemblages as quantitative indicators of water depth in subarctic Fennoscandian lakes. *Journal of Paleolimnology* 24, 43–54.

Mikulski J.S. 1978. Man impact upon Gopło Lake as reflected in Cladocera community remains in sediments. *Polskie Archiwum Hydrobiologii* 25, 291–295.

Ralska-Jasiewiczowa M. 1987. Poland: vegetational, hydrological and climatic changes inferred from IGCP 158 B studies, *Lundqua report* 27, 35–38.

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

Sarmaja-Korjonen K., Alhonen P. 1999. Cladoceran and diatom evidence of lake-level fluctuations from a Finnish lake and the effect of aquatic-moss layers on microfossil assemblages. *Journal of Paleolimnology* 22, 277–290.

Sarmaja-Korjonen K., Hyvärinen H. 1999. Cladoceran and diatom stratigraphy of calcareous lake sediments from Kuusamo, NE Finland. Indications of Holocene lake-level changes. *Fennia* 177, 55–70.

Starkel L. 1990. Hydrological and palaeogeographical changes within the Vistula catchment against the background of Central Europe. In: Starkel L. (ed.), *Geographical Studies, special issue* 5, 189–198.

Starkel L., Pazdur A., Pazdur M. F., Wicik B., & Więckowski K. 1998a. Lake-level changes and palaeohydrological reconstructions during the Holocene. In: Ralska-Jasiewiczowa M., Goslar T., Madeyska T., Starkel L. (eds.), *Lake Gościąż, Central Poland. A monographic study*, 225–229.

Starkel L., Goslar T., Ralska-Jasiewiczowa M., Demske D., Różański K., Łącka B., Pelisiak A., Szeroczyńska K., Wicik B., Więckowski K. 1998b. Discussion of the Holocene events recorded in the Lake Gościąż sediments. In: Ralska-Jasiewiczowa M., Goslar T., Madeyska T., Starkel L. (eds.) *Lake Gościąż, Central Poland. A monographic study*, 239–251.

Szeroczyńska K. 1984. Cladocera analysis of some Tatra Mts. Lake, (Original: Analiza Cladocera w osadach niektórych jezior tatrzańskich – in Polish). *Prace i Studia Geograficzne* 5, 93–102.

Szeroczyńska K. 1985. Cladocera as ecological indicator in late Quaternary lacustrine sediments in Northern Poland (Original: Cladocera jako wskaźnik ekologiczny w późnoczwartorzędowych osadach jeziornych Polski Północnej. – in Polish with English summary). *Acta Palaeontologica Polonica* 30, 3–69.

Szeroczyńska K. 1998. Anthropogenic transformation of nine lakes in Central Poland from Mesolithic to modern times in the light of Cladocera analysis. *Studia Geologica Polonica* 112, 123–165.

Whiteside M.C. 1970. Danish Chydorid Cladocera: modern ecology and core studies. *Ecological Monographs* 40. 79–118.

Żurek S., Pazdur A. 1999. Record of palaeohydrological changes in development of peat bogs in Poland (Original: Zapis zmian paleohydrologicznych w rozwoju torfowisk Polski – in Polish), In: Pazdur A. *et al.* (eds.), *Geochronology of the Upper Quaternary in Poland in the light of radiocarbon and luminescence dating*, 215–228. WIND-J. Wojewoda, Wrocław.