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SUBFOSSIL OSTRACODS (CRUSTACEA: OSTRACODA) IN DEEP BOTTOM SEDIMENTS OF THE WDZYDZE LAKE SYSTEM (NORTHERN POLAND)

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Summary. Distribution of ostracods in short sediment cores from the profundal-sublittoral zones of various basins of Wdzydze lakes (N Poland), differing in trophic conditions, indicates three major assemblage types. In slightly eutrophic basins ostracod assemblages were dominated by *Candona neglecta* accompanied by *Cytherissa lacustris*, indicative of low trophy conditions. Increasing abundance of *Candona candida*, other candonids and nektobenthic eurytopic species, and gradual decline of *C. lacustris* corresponded with eutrophic conditions prevailing in most of the deepest basins. Finally, highly eutrophic basins were characterised by increasing abundance of nektobenthic species, decrease of. *C. candida* and complete disappearance of typically profundal, poly-oxyphilic species.

Key words: subfossil Ostracoda, lakes, succession, anthropogenic eutrophication

INTRODUCTION

Ostracods (Ostracoda) are small bivalved crustaceans frequently occurring in all modern aquatic habitats and are also common as microfossils, since their calcified valves easily preserve in sediments after the death of the animals [Martens and Horne 2009]. They have been, therefore, effectively used in a variety of ways to infer past environments (both marine and non-marine) in a wide range of temporal and spatial scales. Despite recent advances in applying single ostracod valves as geochemical proxies in palaeoclimatic and palaeoenvironmental reconstructions, still much information can be obtained from ostracod (palaeo-) assemblages [see reviews in: De Deckker 2002 and Boomer *et al.* 2003]. In local-scale studies of lakes, successional changes in ostracod assemblages often follow environmental shifts over recent centuries or decades, and as such may be indicative of the health of lacustrine ecosystems suffering from anthropogenically accelerated eutrophication and/or industrial and urban pollution [Danielopol *et al*. 1990, Namiotko 1995, Löffler 1997, Namiotko 1998, Griffiths and Holmes 2000].

The aims of this contribution were: a) to investigate spatial and temporal variation of ostracod assemblages in short cores taken from deep bottom sediments of a morphologically diversified postglacial lake system situated in northern Poland and consisting of basins differing in trophy level due to the impact of local tourism and agriculture, and b) to relate these local successional changes to the generalised model of the lacustrine ostracod succession previously established for the Polish lakes on the country scale [Namiotko 1995, 1998].

STUDY AREA

The system of Wdzydze lakes was formed during the last glacial period some 11 thousand years ago [Cieslewicz *et al*. 2008]. It lies between 53°56'39" – 54°01'45" N and 17°52'30" – 17°59'51" E at 133 m a.s.l. in the South Pomeranian Lake District, Northern Poland, ca. 60 km SW of Gdańsk, and belongs to the drainage basin of the Vistula river. The system of Wdzydze lakes, due to the heterogeneity in its origin as well as the morphometric and trophic conditions, is commonly considered as two separate lakes: a deeper and larger Southern Wdzydze (WDS) and a smaller, shallower and more eutrophic Northern Wdzydze (WDN) [e.g. Churski 1961, Cydzik *et al*. 1992, Jańczak 1997]. The originally oligotrophic lake has been influenced until the mid 1990' by increasing nutrient loading, but the installation of a high capacity sewage treatment plant and a number of smaller ones slowed down the anthropogenic eutrophication [Patalas 1961, Szczerbowski 1969, Sterzyński 1979, Lange 1986, Przewoźniak 2001, Machnikowski and Buliński 2001, Cieslewicz *et al*. 2008]. However, this amelioration is seen only in the southern basin so that it can now be considered eutrophic with a tendency to moderately eutrophic, while the northern basins, still suffering from advancing anthropopressure, are going to become highly eutrophic [Lange *et al*. 2001].

MATERIAL AND METHODS

Six short (≤ 40 cm) sediment cores were obtained with a Kajak-corer (a tube 56 cm-long, 4.4 cm in diameter). Two replicate 26 cm and 40 cm long cores (WDS65) were collected on 7 November 1992 from the 65 m deep bottom of the central deepest basin of Southern Wdzydze (approx. coord. 53°59'01" N, 17°54'51" E). The remaining cores were collected on 16 October 1993. A 32-cm long core (WDS25) was collected from a shallower bottom (25 m depth) of Southern Wdzydze close to the south-eastern shore of Ostrów Wielki, the largest island of the lake (53°58’54” N, 17°54’28” E). Three other cores were recovered from the deepest zones of the three basins of Northern Wdzydze. A 24 cm long core (WDN12) was collected from the depth of 12 m in the Radolne basin (54°00’58” N, 17°54’17” E), another 24 cm core (WDN17) from the depth of 17 m in the Jelenie basin (54°01’21” N, 17°55’21” E), and the shortest 20 cm core (WDN14) from the depth of 14 m in the Gołuń basin (54°00’28” N, 17°56’03” E).

Following standard methods [Griffiths and Holmes 2000], ostracods were examined throughout the recovered profiles, continuously at 4 cm intervals. Fresh sediment samples of 4 cm-thickness (61 cm^3) were washed with tap water, sieved to a mesh size of 125 μm, dried to a constant weight, and then all ostracod valves from the remaining sediment residue were hand-picked, counted and identified under a stereo microscope at 25–100× magnification. Species identifications were aided largely by the use of keys of Sywula [1974], Griffiths and Holmes [2000] and Meisch [2000], with the taxonomy and systematic nomenclature following the latter monograph [Meisch 2000]. Ostracod abundance was expressed as a total number of valves per 100 cm^3 of fresh sediment and as relative percentage species/taxa abundances (averaged for two replicate cores WDS65), and finally presented on stratigraphic diagrams plotting abundances vs. depth using C2 v. 1.5 programme [Juggins 2007]. The ostracod palaeofaunal sequences were compared by an UPGMA (Unweighted Pair Group Mean Average) clustering based on species/taxa standardised counts (percentages) and Bray-Curtis similarity coefficient, the procedure run on PRIMER ver. 6.1.10 software [Clarke and Gorley 2006].

Additionally, on 27 March 1993, a qualitative dredge sample (WDS20D) was collected from the depth of 20 m near the south-western slope of the so-called Lipa peninsula of Southern Wdzydze and close to the village of Wdzydze Kiszewskie on the eastern lake shore. The sample was fixed in the field with 4% formaldehyde, and then in the laboratory washed with pressurised tap water, sieved to 125 μm and preserved in 75% ethanol. Ostracods were hand-picked and identified to species on the basis of both limbs and carapace-based characters under a stereo microscope at 25–100× magnification and a light transmission microscope at 40–400× using keys of Sywula [1974] and Meisch [2000].

RESULTS AND DISCUSSION

Ostracod valves were reasonably well preserved and the presence of both adults and juveniles of the dominant species suggests that the studied assemblages were autochthonous. 41 individual sediment samples differed in the number of recovered ostracod valves, with total absolute abundances varying between 2 and 611 valves (mean = 66). Overall, 2687 valves were obtained (711 valves from WDS and 1976 from WDN), of which 83% could be identified to the species level. The immature and/or fragmentary nature of the remaining valves led to uncertainties about some of the identifications, and as such most of this material was assigned to genus only.

In total, 17 species were recovered: *Candona candida* (Müller, 1776), *Candona neglecta* Sars, 1887, *Candona weltneri* Hartwig, 1899 f. *obtusa* Müller, 1900, *Fabaeformiscandona fabaeformis* (Fischer, 1851), *Fabaeformiscandona levanderi* (Hirschmann, 1912), *Fabaeformiscandona protzi* (Hartwig, 1898), *Pseudocandona compressa* (Koch, 1838), *Cyclocypris laevis* (O.F. Müller, 1776), *Cyclocypris ovum* (Jurine, 1820), *Cypria ophtalmica* (Jurine, 1820), *Physocypria kraepelini* G.W. Müller, 1903, *Ilyocypris decipiens* Masi, 1905, *Cypridopsis vidua* (Müller, 1776), *Potamocypris villosa* (Jurine, 1820), *Limnocythere inopinata* (Baird, 1843), *Limnocytherina sanctipatricii* (Brady & Robertson, 1869) and *Cytherissa lacustris* (Sars, 1863). The most dominant species in the whole material appeared to be *C. candida* (24.6%), *L. sanctipatricii* (9.1%), *C. vidua* (8.9%), *C. neglecta* (8.8%) and *F. levanderi* (7.8%). Six of species (*F. levanderi*, *F. protzi*, *C. laevis*, *C. ovum*, *C. vidua* and *P. villosa*) were found alive in the dredge sample WDS20D in which, in addition, empty valves of other seven species were recorded (*C. candida*, *C. neglecta*, *F. fabaeformis*, *P. compressa*, *Cyclocypris* sp. juv., *L. sanctipatricii*, and moreover *Herpetocypris reptans* (Baird, 1835), not found in the core sediments).

All these ostracod species are known from either profundal or littoral lacustrine habitats of lakes in both modern Europe [Meisch 2000] and European Quaternary sediments [Griffiths 1995]. Some of these species, namely *Cyclocypris laevis*, *C. ovum*, *Cypria ophtalmica*, *Cypridopsis vidua*, and to a lesser extent *Physocypria kraepelini*, are considered to be generalists, widely distributed nektobenthic forms, in lakes preferring shallow zones but inhabiting almost every type of inland water bodies, often doing well in stressed environments, including highly organically polluted, hypoxic and acidic waters [Sywula 1974, Meisch 2000]. *Candona weltneri* f. *obtusa*, *F. fabaeformis*, *P. compressa*, *I. decipiens*, *P. villosa*, represented in the recovered material only by a few valves each (≤ 5), as well as slightly more frequent *L. inopinata* (63 valves in total), are not capable of swimming (excepting *P. villosa*) and are typical of the meiobenthos of shallow limnic habitats, showing a preference for lacustrine littoral conditions, generally found in depths of less than 10 m [Sywula 1974, Meisch 2000]. At least some of these valves most probably drifted in from shallow water deposits and thus may be allochthonous in the profundal. However, environmental requirements of the rest of the species recovered from the cores (dominant in most of the studied sediment layers) definitely reflect the conditions of deeper zones of slightly to highly eutrophic European postglacial lakes [Sywula 1974, Namiotko 1995, 1998, Meisch 2000]. Recorded temporal changes in the relative abundances and species composition of the subrecent ostracod assemblages from the recovered cores as well as biostratigraphic equivalence of the assemblages of different cores allowed interpreting the environmental changes during the recent past of the lake. Three major assemblage types were recognised based on species composition, abundances and the modern autecological data.

Sediment samples of core WDS25 yielded between 3 and 166 valves per 100 cm^3 of fresh sediment (mean = 37), however, with some exceptions, the data showed a gradual decrease in the total abundance of ostracod remains from the core top to the base (Fig. 1). This may suggest some species-specific preservational bias and thus hinder palaeo-environmental reconstruction. Despite some variations between the faunal record in particular sediment layers of this core (partly due to the low sample size), it seems that in the recent past this area of the bottom of Southern Wdzydze has been inhabited by just one type of ostracod assemblage, clearly dominated by *Candona neglecta* having in the entire sequence high relative percentages (62% on average). This species was associated in the interval of 20–0 cm with subdominant *Cytherissa lacustris* (mean percentage = 22%), a poly-oxyphilic, inbenthic ostracod species which avoids sulphidic and organically enriched sediments [Danielopol *et al.* 1990, Geiger 1993] (Fig. 1). Such an assemblage with dominating *Candona neglecta* and *C. lacustris* accompanied by other profundal lacustrine species (*F. protzi*, *F. levanderi*, *L. sanctipatricii*, *C. candida*) is, according to Namiotko [1998], indicative of high mesotrophy to low eutrophy conditions.

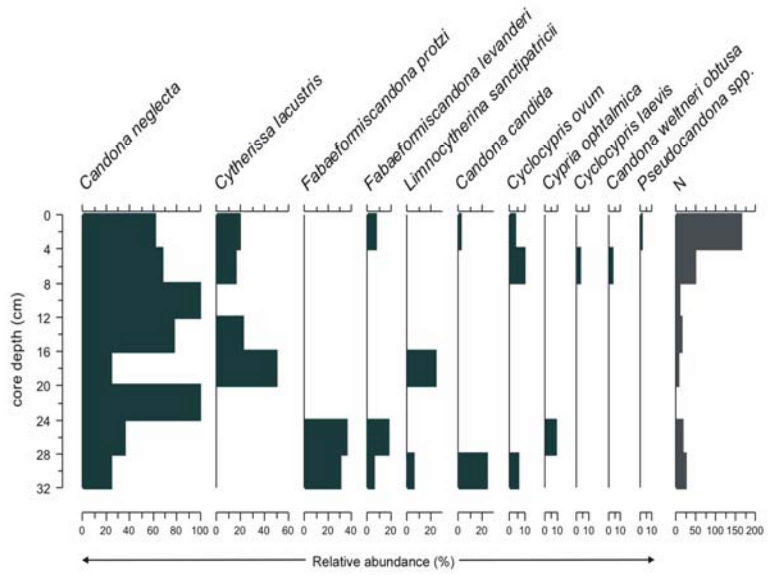

Fig. 1. Succession of ostracod assemblages in core WDS25 from Southern Wdzydze expressed by relative species abundances (%) and total number of valves in 100 m^3 of fresh sediment (N)

Mean abundance of the ostracod valves in the sediment samples of core WDS65 was also not high, amounting to the mean value of 50 valves per 100 cm^3 (range of 23–110 valves per 100 cm^3) (Fig. 2). In all samples of this core three candonid species predominated, *C. candida* (mean percentage = 27%), *F. levanderi* (20%) and *F. protzi* (12%), while *C. lacustris* and *L. sanctipatrici*, both more sensitive to the degradation of deep lacustrine environment, occurred in low frequencies (Fig. 2). Also accompanying eurytopic and littoral species, such as *C. ovum*, *L. inopinata* and *C. vidua*, have to be mentioned as they appeared relatively abundantly throughout the profile (Fig. 2). Such species composition and relative abundances of the ostracod assemblage correspond well with eutrophic lacustrine conditions [Namiotko 1998].

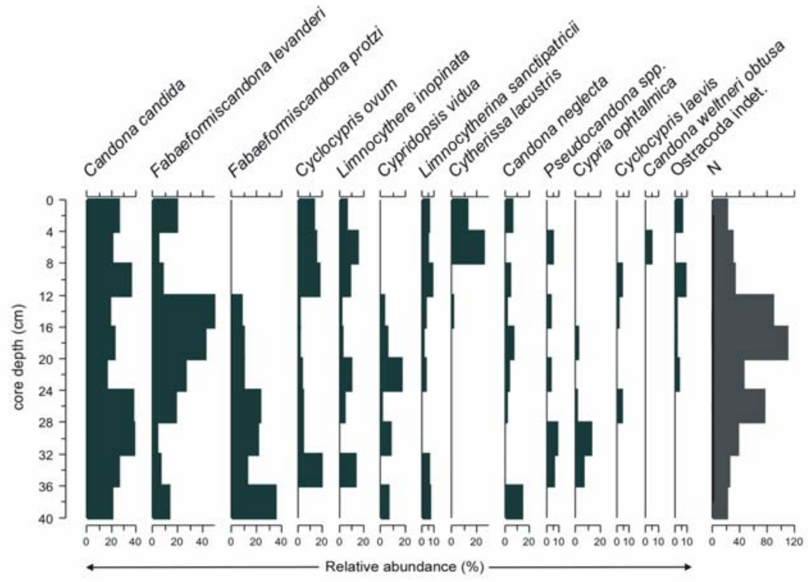

Fig. 2. Succession of ostracod assemblages in core WDS65 from Southern Wdzydze expressed by relative species abundances (%) and total number of valves in 100 m^3 of fresh sediment (N)

Also in the ostracod assemblages of WDN14 and WDN12, two cores collected from Northern Wdzydze, the most important species was *C. candida*, having in the entire sequences high counts and nearly constant relative percentages (mean = 28 and 42%, respectively) (Fig. 3 and 4). In core WDN14 *C. candida* was accompanied mainly by *C. vidua* (mean percentage = 13%), *L. sancipatricii* (12%), *C. ovum* (9%) and *C. neglecta* (9%), whereas in core WDN12 – mainly by *C. ophtalmica* (11%), *F. protzi* (8%), and also *C. neglecta* (7%) and *C. ovum* (6%) (Fig. 3 and 4). Remarkably, *C. lacustris* was sparse in core WDN14, and absent in the WDN12. It should also be noted that in both of these cores, WDN14 and WDN12, a gradual decrease in the total abundance of ostracod valves from the top to the base is seen, analogously to core WDS25. The collection of the valves recovered from the uppermost sediment layers of these cores was the richest comparing with the other studied cores, amounting to almost 1000 valves per 100 cm^3 in the 4–0 cm interval of WDN14 and to 480 in the 8–4 cm interval of WDN12 (Fig. 3 and 4).

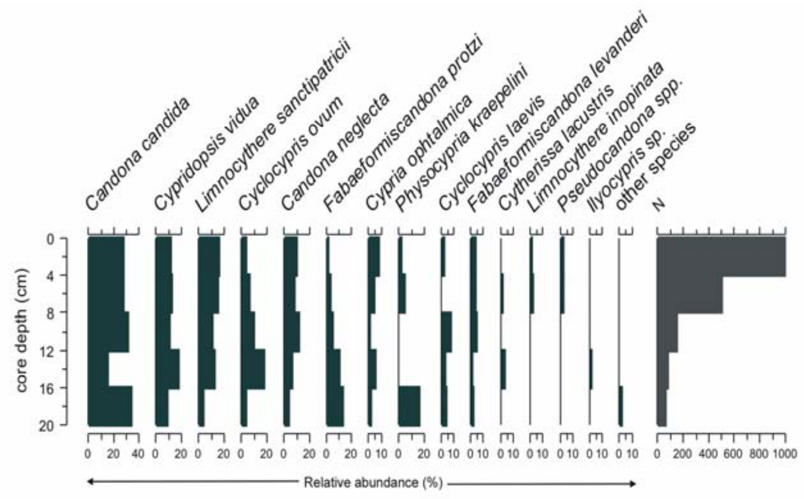

Fig. 3. Succession of ostracod assemblages in core WDN12 from the Radolne basin of Northern Wdzydze expressed by relative species abundances (%) and total number o f valves in 100 m^3 of fresh sediment (N)

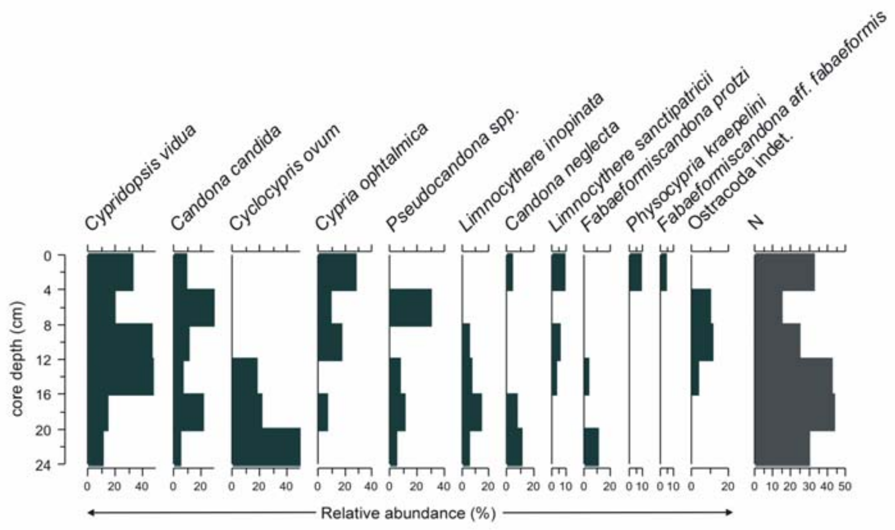

Fig. 4. Succession of ostracod assemblages in core WDN14 from the Gołuń basin of Northern Wdzydze expressed by relative species abundances (%) and total number of valves in 100 m^3 of fresh sediment (N)

The assemblages from cores WDS65, WDN12 and WDN14, with apparent domination of *C. candida*, strong increase of eurytopic species and often complete extinction of *C. lacustris*, seemed to follow in natural succession the more primal assemblage recovered from the core WDS25 corresponding to lower trophy conditions. The last stage of these successive changes in composition and structure of subrecent ostracod fauna of the system of Wdzydze lakes is represented by the assemblage of core WDN17, sampled from the most eutrophic part of the Wdzydze lakes. This assemblage was deprived of species distinctive of the profundal conditions occurring in modern lakes before the onset of eutrophication caused and accelerated by human activities, such as *C. lacustris*, *L. sanctipatricii* and *F. levanderi*, present in the previously described cores (Fig. 5). The deepest and least exposed to the wind influence, the Jelenie basin of WDN, has the highest rate and the greatest extent of oxygen deficits in the bottom waters during summers. Predominant *C. vidua*, accompanied here by numerous *C. ovum* and *C. ophtalmica*, are littoral nektobenthic species that swim actively just above the bottom, hence potentially less sensitive to oxygen deficits in the water/sediment interface than true inbenthic ostracods, not capable of sustained swimming within the water column. However, laboratory experiments show that *C. vidua* may have rather a low tolerance for poorly oxygenated waters [Danielopol 1991]. Moreover, some of the valves of these species preferring littoral conditions might well have been subjected to post-mortem transport from shallow water deposits and thus would be allochthonous in the profundal.

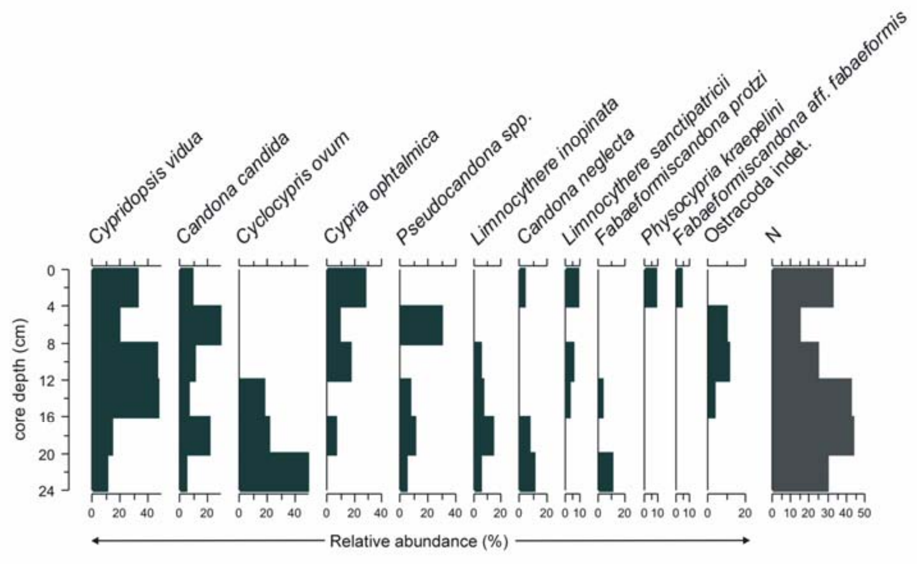

Fig. 5. Succession of ostracod assemblages in core WDN17 from the Jelenie basin of Northern Wdzydze expressed by relative species abundances (%) and total number of valves in 100 m^3 of fresh sediment (N)

CONCLUSION

The recorded ostracod sequences in the short cores of Wdzydze lakes reflected well three more-or-less predictable and orderly successive stages of deep lacustrine ostracod succession established for the Polish lakes by Namiotko [1998]. These stages corresponded well with the trophic diversity in the various parts of Wdzydze lakes, confirming and consolidating inferences based on previously published data on other trophy indices from this lake system [Lange *et al.* 2001].

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SUBFOSYLNE MAŁŻORACZKI (CRUSTACEA: OSTRACODA) GŁĘBOKIEGO DNA KOMPLEKSU JEZIORA WDZYDZE (POLSKA PÓŁNOCNA)

Streszczenie. Rozmieszczenie szczątków Ostracoda w krótkich rdzeniach osadów profundalu i sublitoralu ze zróżnicowanych pod względem trofii basenów kompleksu jeziora Wdzydze wskazuje na występowanie trzech głównych typów zgrupowań tych skorupiaków w niedawnej przeszłości tego akwenu. W zgrupowaniach z najmniej zeutrofizowanych plos dominowała *Candona neglecta*, której zwykle towarzyszyła wskaźnikowa dla warunków niskiej trofii *Cytherissa lacustris*. Wzrastająca abundancja *Candona candida*, innych gatunków z rodziny Candonidae oraz eurytopowych gatunków nektobentonicznych wraz ze stopniowym spadkiem udziału *Cytherissa lacustris* korespondowała z warunkami eutroficznymi przeważającymi w najgłębszych basenach jeziora. Wreszcie dla najbardziej zeutrofizowanych partii dna kompleksu jeziora Wdzydze charakterystyczny był wzrost abundancji gatunków nektobentonicznych, spadek udziału *Candona candida* i całkowity zanik typowo profundalowych gatunków polioksyfilnych.

Słowa kluczowe: subfosylne Ostracoda, jeziora, sukcesja, antropogeniczna eutrofizacja