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# SPATIAL-TEMPORAL DIFFERENTIATION OF ZOOPLANKTON COMMUNITY STRUCTURE OF TWO LAKES OF DIFFERING DEGREES OF HUMAN IMPACT

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**Abstract:** The research was carried out in two zones (open water and littoral) of two lakes located within the Puszcza Zielonka, near Poznań. One of the lakes undergoes protection (Czarne lake), while the second one is open for recreational purposes Miejskie Lake. The analysis, including zooplankton community structure and the cheangeability of physical-chemical parameters, were made in three following seasons – spring, summer and autumn – of 2009.

Even though both examined lakes, situated in a forested catchment area, were neighbouring each other they differed in respect to zooplankton community structure. It was expected that lake Czarne, which undergoes protection, would be characterised by better water quality than lake Miejskie, which is a recreational lake undergoing strong human impact from late spring to early autumn. However, lake Czarne was found to be in much worse condition. This lake is a typical eutrophic water body with less diverse taxonomic structure, higher abundance on average and higher participation of eutrophic species in the total zooplankton communities compared with Miejskie lake.

**Keywords:** zooplankton, community structure, human impact, lake zones

## INTRODUCTION

Wielkopolska, which is an important agricultural region in Poland, is also covered by a number of forested areas, often accompanied by various types of water bodies. Lately, long-term changes in the water ecosystem characteristics, related to the transformation in their catchment area, have become more visible. The specificity of the catchment area outside a lake may influence the majority of processes occurring within a water body basin. It could also potentially have an impact on the physical-chemical features of water as well as on zooplankton communities inhabiting lakes of various trophic conditions, which was the main aim of the present study. Some authors (e.g. Dodson et al. 2007) have recorded a significant and adverse effect of differentiated watershed land use on zooplankton species richness. Changes in the catchment area of a lake are related to

the character of the land use, so it is particularly important to consider the level of recreation and tourism in the case of lakes located within the forested area; as is the case with both lakes undergoing the investigation. Czarne lake, which is a reserve area, has had a restricted human impact, while Miejskie lake undergoes recreation from late spring to early autumn. A very important problem which may often be observed within Poland and particularly in the Wielkopolska region is the trend of a lowering water level and drying up of water reservoirs. This problem also concerns both of the studied lakes (Olejniczak 2003)

Zooplankton is known to be a perfect tool for the biomonitoring of water quality. They are among one of the most common elements of water ecosystems. Representatives of crustaceans and especially rotifers are often used for the purpose of estimating the environmental conditions of aquatic ecosystems (Mäemets 1983; Sládeček 1983; Saksena 1987).

This work was mainly undertaken in order to (1) determine the structure of the zooplankton community in two mid-forest lakes subject to different degrees of human impact and (2) find out whether the effect of recreation has resulted in an acceleration of eutrophication in Lake Miejskie compared to lake Czarne – a reserve area.

Moreover, the present study was planned to determine the seasonal (three following seasons: spring, summer and autumn) distribution of zooplankton communities, both rotifers and crustaceans, between two locations within the two lakes – the zone of open water and a vegetated stand located within the helophyte belt. Habitat structure, especially referring to its heterogeneity, is one of the fundamental factors determining the distribution of zooplankton in various types of aquatic ecosystems. Vegetation, which is more heterogenic than the open water area, may contribute to shaping the structural environment for invertebrates (McAbendroth et al. 2005).

## MATERIAL AND METHODS

The studied lakes were located north – east of the agglomeration of the city of Poznań, in the macroregion of the Wielkopolska Lake District (Kondracki 1998) – within the area of the **Zielonka Forest Landscape Park**. This park was created in 1993 in order to prevent, protect and recultivate the greatest and almost natural forested complex of central Wielkopolska. The forest is mainly coniferous and covers the greatest part of the park (78%), while waters take up almost 4% of the area. Czarne Lake is a floristic reserve area with a surface measuring 17.75 ha. It is a typical post-glacial lake, covering a fragment of a deep post – glacial channel. Miejskie Lake is also a mid-forest lake of an area of 13.3 ha. Both lakes are a part of an endorheic sequence of lakes, having a closed drainage basin: Czarne, Pławno, Kamińskie and Miejskie (Anders 1997).

Czarne Lake reserve protects the lake along with a bog of a transitional nature, educated by fouling tanks. The lake is shallow with a depth of 5 meters. It has no tributaries and only one outflow leading waters towards Kociolek Lake. Miejskie Lake is a water reservoir located in the zone of direct human impact of Kamińsko village. The lake is used recreationally; the beach is situated on the eastern side of the lake.

The research was carried out in the three following seasons – spring, summer and autumn of 2009.

Two stations were examined on each occassion – the open water zone and littoral area. In the case of Czarne lake the vegetation area, where the samples were collected, was dominated by *Phragmites australis*. There were also other macrophyte species occurring between the helophytes – representatives of *Myriophyllum* sp. and *Potamogeton natans*. In Miejskie lake the investigated area was dominated by helophytes (*Typha angustifolia* and *Phragmites australis*) and single specimens of *Utricularia vulgaris*, *Najas marina*, *Myriophyllum* sp., *Potamogeton perfoliatus* and *Chara* sp. were also recorded.

At each sampling site temperature, pH, electric conductivity and dissolved oxygen (DO) were measured. Additional samples were taken in order to estimate the concentration of phosphorus and nitrogen, which were determined in a laboratory according to Standard Methods for the Examination of Water and Wastwater (1992).

Zooplankton material was taken in triplicate at each site using a calibrated vessel from the open water area and using a plexiglass core sampler (∅ 50 mm) from among the vegetated areas. This is the method advised for studies within the littoral zone (Schriver et al. 1995). The 10 L samples were concentrated using a 45-µm plankton net and were fixed immediately with 4% formalin.

The dominating species of the zooplankton community were calculated as those which exceeded 10% of the total zooplankton abundance at each station. In order to define the species diversity of zooplankton inhabiting different habitats the Shannon–Weaver index was calculated (Margalef 1957).

The *U*-Mann test was used for statistical analysis in order to evaluate the differences in the density of the zooplankton community between particular lakes, habitats and particular seasons ($N = 36$). The relationship between particular physical-chemical parameters and zooplankton densities was measured using Pearson's Correlation Coefficient.

## RESULTS

Both examined lakes were quite similar in respect to physical parameters. Lake Miejskie was characterised by slightly higher water reactivity and slightly lower conductivity than Czarne lake. At the same time lake Czarne had

higher concentrations of nutrients and higher concentrations of chlorophyll *a* (Tab. 1).

Table 1. Mean values of physical-chemical parameters (Temp – temperature, Cond – conductivity, Transp – water transparency, TP – total phospohorus, TN – total nitrogen, chl a – chlorophyll a concentration) of two examined lakes

| Lake | pH | Temp | $O_2$ | Cond | Transp | TP | TN | chl a |
|---|---|---|---|---|---|---|---|---|
| Czarne | 7.5 | 17 | 5.89 | 389 | 2.4 | 0.020 | 0.345 | 8.25 |
| Miejskie | 7.99 | 18 | 5.74 | 352 | 2.5 | 0.018 | 0.26 | 3.51 |

As a result of the examination carried out in 2009 on two lakes – Czarne and Miejskie – 110 species of zooplankton were recorded altogether (65 of rotifers, 32 of cladocerans and 13 of copepods). Miejskie Lake was characterised by a more diverse taxonmic structure (54, 30 and 8 species, respectively) than Czarne lake (45, 20 and 10). Moreover, based on the currently available literature (Flössner 1972; Radwan et al. 2004) four species, either rare or occurring infrequently in the Polish fauna (*Euchlanis triquetra* Ehrenberg, *Acroperus elongatus* (Sars), *Chydorus gibbus* Sars and *Rhynchotalona falcata* Sars) were recorded. All of them occurred in Miejskie lake and were present only in the littoral zone. The number of zooplankton species in the open water zone slightly differed between the investigated seasons. Rotifers remained at the same level in the case of Czarne lake, while in Miejskie lake the highest diversity was attributed to the spring season. Crustaceans revealed the same decreasing pattern, from spring to autumn, of taxonomic distribution in both lakes. The littoral zone possessed much richer species composition than the open water zone and the differences between particular seasons were here less pronounced, however, being on average higher in Miejskie lake (Tab. 2).

The densities of zooplankton, especially rotifers, were on average higher in lake Czarne and differed between stations and seasons. The seasonal abundance of rotifers was quite stable in both zones of the two studied lakes (averaging between 90 and 483 ind $\times$ $l^{-1}$) with one exception in Czarne lake during the autumn, when rotifers reached their peak of 3749 ind $\times$ $l^{-1}$. This was due to the massive dominance of species such as *Synchaeta lakowitziana* and also *Anuraeopsis fissa*, *Keratella cochlearis* and *Polyarthra remata* (Tab. 2 and 3). Crustaceans, similarly to the taxonomic structure, revealed the same decreasing pattern, from spring to autumn, of their density distribution in both lakes. However, in all cases helophytes were characterised by higher abundance compared with the open water (Czarne lake – $Z = -2.3842$, $p < 0.05$; Miejskie lake – $Z = -3.6742$, $p < 0.01$). In Miejskie lake the densities of crustaceans within the littoral zone were higher than those in Czarne lake (Tab. 2).

Table 2. Mean values of the number of species, zooplankton densities and Shannon–Weaver index in the examined lakes

| Lake | Czarne | | | | | | Miejskie | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Season | spring | | summer | | autumn | | spring | | summer | | autumn | |
| Station | Wat | Hel | Wat | Hel | Wat | Hel | Wat | Hel | Wat | Hel | Wat | Hel |
| **Rotifera** | | | | | | | | | | | | |
| Number of species | 14 | 22 | 14 | 25 | 15 | 25 | 25 | 25 | 9 | 24 | 17 | 27 |
| Densities [ind × l$^{-1}$] | 429 | 416 | 303 | 265 | 3749 | 380 | 483 | 153 | 90 | 292 | 159 | 138 |
| % mesotrophic species | 3 | - | 9 | - | 1 | - | 7 | - | 0 | - | 22 | - |
| % eutrophic species | 12 | - | 31 | - | 33 | - | 10 | - | 4 | - | 8 | - |
| Shannon–Weaver index | 0.93 | 1.32 | 1.63 | 2.12 | 1.65 | 2.24 | 1.68 | 2.25 | 0.83 | 2.46 | 1.91 | 1.55 |
| **Crustacea** | | | | | | | | | | | | |
| Number of species | 6 | 17 | 4 | 16 | 3 | 18 | 8 | 24 | 4 | 13 | 3 | 25 |
| Densities [ind × l$^{-1}$] | 33 | 294 | 32 | 34 | 9 | 160 | 22 | 1090 | 6 | 65 | 5 | 600 |
| % eutrophic species | 31 | - | 50 | - | 22 | - | 5 | - | 67 | - | 20 | - |
| Shannon–Weaver index | 1.39 | 1.69 | 1.13 | 2.21 | 1 | 2.15 | 1.62 | 1.81 | 1.33 | 1.79 | 0.95 | 1.62 |

Three zooplankton species were associated with a particular type of habitat. Two were pelagic-associated (*Collotheca mutabilis* (Hudson): Czarne lake – $Z = 2.0817$, $p < 0.05$; Miejskie lake – $Z = 2.1947$, $p < 0.05$ and *Pompholyx sulcata* (Hudson): Miejskie lake – $Z = 1.9639$, $p < 0.05$). Only one species was macrophyte-associated (*Ceriodaphnia quadrangula* (O.F. Müller): Miejskie lake – $Z = -2.0299$, $p < 0.05$) (Fig. 1).

The participation of species characteristic for eutrophic conditions was on average higher in the case of Czarne lake, especially in the case of rotifers. Only in the summer season did eutrophic crustaceans prevail in Miejskie lake (Tab. 2), however, the densities of these species were low. Also in the case of Miejskie lake there was also a higher participation of mesotrophic species in the open water zone, where such species occur.

Six zooplankton species were found to differ significantly between the two examined water bodies. *Anuraeopsis fissa* ($Z = 2.5414$, $p < 0.05$), *Keratella cochlearis* f. *tecta* (Lauterborn) ($Z = 2.3544$, $p < 0.05$), *K. quadrata* (O.F. Müller)

Table 3. Dominating species in particular stations (Wat – open water, Hel – littoral zone) in the examined lakes

| Lake | Czarne | | | | | | Miejskie | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Season | spring | | summer | | autumn | | spring | | summer | | autumn | |
| Station | Wat | Hel | Wat | Hel | Wat | Hel | Wat | Hel | Wat | Hel | Wat | Hel |
| **Rotifera** | | | | | | | | | | | | |
| *Anuraeopsis fissa* (Gosse) | | | x | x | x | x | | | | | | |
| *Ascomorpha ecaudis* (Perty) | | | | | | x | | | | | x | |
| *Collotheca mutabilis* (Hudson) | | | | | | | | | | | x | |
| *Kellicottia longispina* (Kellicott) | | | | | | | | x | | | | |
| *Keratella cochlearis* (Gosse) | x | x | x | x | x | x | x | x | x | x | x | x |
| *Polyarthra remata* (Skorikov) | | | | | x | | x | | | | x | |
| *Synchaeta lakowitziana* Lucks | | | | | x | | | | | | | |
| *Trichocerca similis* (Wierzejski) | | | x | x | | | | | | | | |
| **Crustacea** | | | | | | | | | | | | |
| *Acroperus harpae* (Baird) | | | | | | | | | | x | | |
| *Alonella excisa* (Fischer) | | | | | | x | | | | | | x |
| *Bosmina coregoni* Baird | | | x | x | | | | | x | | | |
| *Bosmina longirostris* (O.F. Müller) | | | x | | | | | | | | | |
| *Ceriodaphnia pulchella* Sars | | x | | | | | | x | | | | x |
| *Ceriodaphnia quadrangula* (O.F. Müller) | x | x | | | | | x | | | | x | |
| *Ceriodaphnia reticulata* (Jurine) | | | | | | | | x | | | | |
| *Chydorus sphaericus* (O.F. Müller) | x | | | | | | | | x | x | | |
| *Scapholeberis mucronata* (O.F. Müller) | | | | | | | | x | | | | x |
| *Sida crystallina* (O.F. Müller) | | | | | | | | x | | | | |
| *Cyclops scutifer* Sars | | | | | x | x | | | | | | |
| *Mesocyclops oithonoides* Sars | x | | x | x | | | x | | | x | | |

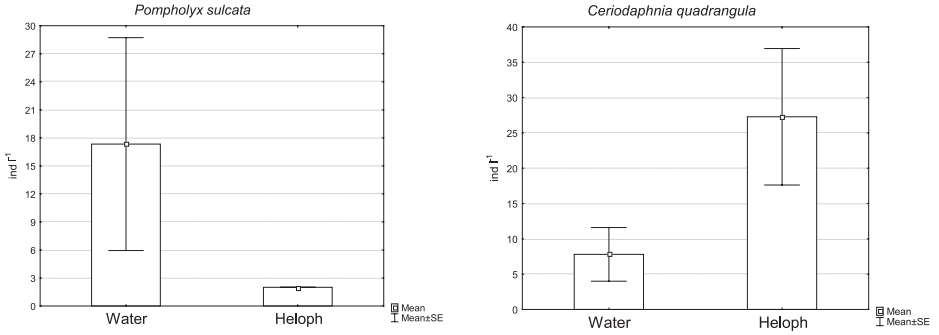


Fig. 1. Habitat preferences of particular zooplankton species [ind × $l^{-1}$] towards particular habitat (Water – open water, Heloph – littoral zone)

($Z = 2.0608$, $p < 0.05$) had significantly higher abundance in Czarne lake, while *Ceriodaphnia pulchella* Sars ($Z = –2.6617$, $p < 0.01$), *C. reticulata* (Jurine) ($Z = –2.1213$, $p < 0.05$) and *Scapholeberis mucronata* (O.F. Müller) ($Z = 2.1958$, $p < 0.05$) prevailed in Miejskie lake.

The mean Shannon–Weaver biodiversity index values ranged from 1.65 (Czarne lake) to 1.78 (Miejskie lake) for rotifers and 1.52 (Miejskie lake) to 1.59 (Czarne lake). The lowest values were found within the open water, while the littoral zone had higher values in both lakes. Additionally, an increasing trend in the seasonal distribution of biodiversity was observed in the case of lake Czarne (for rotifers in the open water zone.and for rotifers and crustaceans in the littoral area), while in Miejksie lake the biodiversity pattern of distribution was much more disturbed (Tab. 2).

In Miejskie lake abundance of two crustacean species – *Acroperus harpae* Baird ($r = –0.8651$; $p < 0.05$) and *Chydorus sphaericus* (O.F. Müller) ($r = –0.8269$; $p < 0.05$) – revealed a strong negative correlation with chlorophyll *a* concentration with total phosphorus concentration ($r = –0.9295$; $p < 0.01$ and $r = –0.9295$; $p < 0.01$, respectively). Moreover, a positive relationship between two other species – *Gastropus stylifer* Imhof ($r = –0.9295$; $p < 0.01$) and *Kellicottia longispina* (Kellicott) ($r = –0.8123$; $p < 0.05$) – and water transparency, measured as Secchi disc visibility, was also found. Also in the case of Czarne lake a positive correlation between water transparency and *Tichocerca similis* (Wierzejski) ($r = –0.8269$; $p < 0.05$) and *Bosmina coregoni* Baird ($r = – 0.8269$; $p < 0.05$) abundance was found.

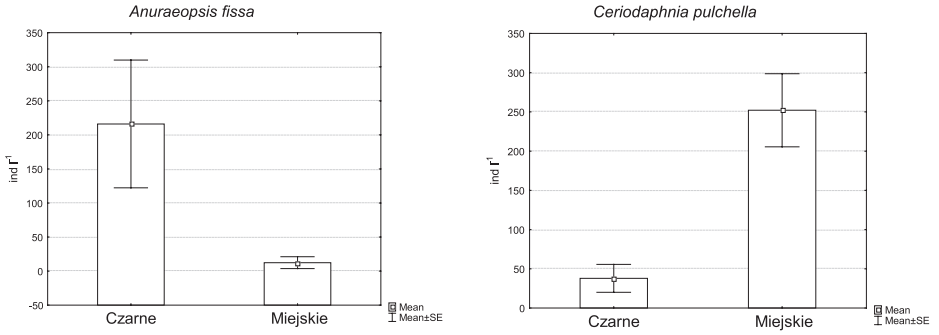


Fig. 2. Preferences of particular zooplankton species [ind × $l^{-1}$] towards particular lake

## DISCUSSION

The composition of physical-chemical features of water, depending on the type of land use in the nearest neighbourhood, the kind of soil in the catchment area, input of mineral elements with the surface waters or the content of underground waters may influence the functioning of animal plankton communities (Wetzel 2001; Radwan 2003; Moss 2007). The physical-chemical composition of water, especially concentration of nutrients such as nitrogen and phosphorus, which are frequently a consequence of human activity in the catchment area of a water body, may have an important impact on the abundance and richness of microinvertebrate communities (Castro et al. 2005). Both of the examined lakes, located within the forested catchemnt area, were similar considering physical parameters. However, they differed in respect to chemical features. Even though Czarne lake underwent almost no human impact as it is a reserve area, it was characterised by higher concentrations of nutrients in its water. The presence of biologically available mineral elements may have stimulated a development of algae, which was reflected in higher concentrations of chlorophyll *a* in lake Czarne. This was reflected in the less diverse taxonmic structure in this lake compared to Miejskie lake where four rare species in the Polish fauna () occurred. *Euchlanis triquetra*, *Acroperus elongatus*, *Chydorus gibbus* and *Rhynchotalona falcata* were recorded in the littoral zone, which confirms those species' preferences towards vegetated zones, as has been previously noted by several authors (e.g. Flössner 1972; Adamczuk 2004; Radwan et al. 2004; Kattel et al. 2006).

Worse environmental conditions in the protected lake Czarne were also reflected by highest numbers of zooplankton on average, reaching 3749 ind × $l^{-1}$ in the open water during the autumnal sampling, that were recorded in this lake. In

all cases rotifers dominated over crustaceans here, which is often characteristic of eutrophic lakes and may be connected with the food availability. Zooplankton prefer planktonic algae in their diet, however, they also feed willingly on detritus, bacteria and also periphyton (**Pourriot 1977**; Vanni & Lampert 1978; Becker & Boersma 2003). In eutrophic lakes the presence of blue-green algae, inedible for zooplankton, numerous bacteria and detritus stimulate the development of small forms of zooplankton – rotifers. Also the dominating species of Czarne lake, with often occurring *Anuraeopsis fissa,* which occurred in high abundance both in summer and autumn, indicated the eutrophic character of this lake (Karabin 1985; Mäemets 1983; Saksena 1987). Furthermore, the participation of typically eutrophic species in the total abundance of zooplankton community structure was usually much higher in the case of Czarne lake, which confirms its highly eutrophic state, even though this lake has no human impact. At the same time the participation of species characteristic for water of lower trophy (e.g. *Kellicottia longispina*) was higher in Miejskie lake, which is used recreationally from the late spring to early autumn. Moreover, the preferences of particular species of zooplankton confirmed the advanced state of eutrophy of Czarne lake. There were three rotifer species (*Anuraeopsis fissa*, *Keratella cochlearis* f. *tecta* and *K. quadrata*) found to have significantly higher abundance in Czarne lake compared with Miejskie lake and all of those species are indicators of eutrophy in lakes in temperate climates (Karabin 1985).

Macrophytes play a very important role in the structuring of freshwater communities, especially by influencing the interactions between predators and prey and also acting as a nutritonal source (Jeppesen et al. 1998). A spatial differentiation between the littoral area and the open water zone was found in the case of zooplankton, particularly crustaceans. Stands located within the dominating helophytes were characterized by much richer communities and crustacean abundance was found to be much higher among the vegetated areas in both examined lakes. The higher abundance of cladocerans and copepods within the more heterogeneous habitat reflects more advantageous refuge conditions within the complex macrophyte stand in the lake with fish predation. So, it can be suggested that the differentiation of the zooplankton numbers between the investigated habitats may have been the result of predation but also of the different nutritional sources present at different stations. Moreover, one single species – *Ceriodaphnia quadrangula* – revealed significant differentiation between the studied stations in Miejskie lake, with its highest densities among vegetation and much lower in the open water area.

In temperate lakes ubiquitous and eurytopic plankton species prevail, however, there are numerous organisms that occur during certain seasons, in particular kinds of water body or in specific zones within a lake. Habitat selectivity is known to concern zooplankton species (e.g. Pennak 1966). It may often be a result of alternative food sources to grazers occurring in different habitats,

different concealment conditions among various habitats and competition between Crustacea and Rotifera, which may also have an influence on the domination structure of the zooplankton communities in freshwater ecosystems (Gilbert & MacIsaac 1989; Basu et al. 2000; Tessier et al. 2004). There were also two other species that were associated with the pelagic zone – *Collotheca mutabilis* and *Pompholyx sulcata* (Koste 1978; Radwan et al. 2004). Pelagic species may remain in the zone of open water as they are known to have evolved special features such as e.g. gelatinous sheaths (*C. mutabilis*), which could reduce the probability of predator success (Pejler 1995; Williamson 1987).

Another important problem that arose when analysing the zooplankton community structure of two neighbouring lakes of different human impact was a seasonal differentiation. The analyses of seasonal abundance distribution revealed two different patterns for the two groups of zooplankton communities. It was noticed that crustacean densities, as well as their taxonomic diversity, decreased from spring to autumn. At the same time seasonal abundance of rotifers was quite stable in both zones of the two lakes, with one exception in Czarne lake, where especially *Synchaeta lakowitziana* built abundant communities. This species may often occur in numbers in waters of low temperatures and prefers neutral waters (Radwan 2004).

A great proportion of rotifer and crustacean species reveal a wide range of tolerance to environmental features. However, the occurrence of many organisms may be conditioned by physical and chemical factors as well as by biotic parameters (Semenchenko et al. 2007), among which predation and competition between particular organisms belong to the most important (Hurtado-Bocanegra et al. 2002). In Miejskie lake densities of two crustacean species (*Acroperus harpae* Baird and *Chydorus sphaericus*) negatively correlated with chlorophyll *a* concentration which suggests that in this lake zooplankton was able to control phytoplankton biomass. Such a negative relationship between zooplankton densities and the rates of primary production, measured as chlorophyll *a* content, has also been recorded by other authors (e.g. Irfanullah and Moss 2005). Moreover, there was a large group of species in both lakes that revealed a positive relationship between their abundance and water transparency. Among them were typical mesotrophic species (*Gastropus stylifer* and *Kellicottia longispina*), whose occurrence depends on the level of water transparency.

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## REFERENCES


Adamczuk M., 2004: *Groups of planktonic crustacea (Cladocera, Copepoda) in lakes of different trophy*. Teka Kom. Ochr. Kszt. Środ. Przyr., 1, 21–26.

Anders P., 1997: *Puszcza Zielonka*. Wielkopolska Bibl. Krajoznawcza, 17.

Basu B.K., Kalff J., Pinel-Alloul B., 2000: *The influence of macrophyte beds on plankton communities and their export from fluvial lakes in the St Lawrence River*. Freshwat. Biol., 45, 373–382.

Becker C., Boersma M., 2003: *Resource quality effects on life histories of* Daphnia. Limnol. Oceanogr., 48, 700–706.

Castro B.B., Antunes S.C., Pereira R., Soares A.M., Gonçalves F., 2005: *Rotifer community structure in three shallow lakes: seasonal fluctuations and explanatory factors*. Hydrobiol., 543, 221–232.

Dodson S.J., Everhast W.R., Jandl A.K., Krauskopf S.J., 2007: *Effect of watershed land use and lake age on zooplankton species richness*. Hydrobiol., 579, 393–399.

Flössner D., 1972: *Krebstiere, Crustacea.* Kiemen-und Blattfüßer, Branchiopoda Fischläuse, Branchiura, 478 pp.

Gilbert J.J., MacIsaac H.J., 1989: *Competition between rotifers cladocerans of different body sizes*. Oecologia, 81, 295–301.

Hurtado-Bocanegra M.D., Nandini S., Sarma S.S.S., 2002: *Combined effects of food level and inoculation density on competition between* Brachionus patulus *(Rotifera) and the cladocerans* Ceriodaphnia dubia *and* Moina macrocopa. Hydrobiol., 468, 13–22.

Irfanullah H., Moss B., 2005: *Effects of pH and predation by* Chaoborus *larvae on the plankton of a shallow and acidic forest lake*. Freshwat. Biol., 50, 1913–1926.

Jeppesen E., Søndergaard Ma., Søndergaard Mo., Christoffersen K., 1998: *The structuring role of submerged macrophytes in lakes*. Springer, Berlin–New York.

Jeppesen E., Søndergaard Ma., Søndergaard Mo., Christoffersen K., Theil-Nielsen J., Jürgens K., Bosselmann S., Schlüter L., 1998: *Cascading trophic interactions in the littoral zone of a shallow lake*. [In:] E. Jeppesen Doctor's Dissertation, *Ecology of Shallow Lakes – Trophic Interactions in the Pelagial*. Ministry of Environment and Energy. Nat. Environmental Res. Inst. Techn. Report No. 247, 207–220.

Kattel G.R., Mackay A.W., Battarbee R.W., 2006: *Variation in patterns of composition and abundance of cladocerans in littoral and open water habitats of Loch Coire Fionnaraich, Scotland. Internat.* Journ. Lakes Riv., 1, 35–50.

Kondracki J., 1998: *Geografia Polski – mezoregiony fizyczno-geograficzne* [Geography of Poland. Physico-geografical mesoregions]. Wyd. Nauk. PWN, Warszawa, 348 pp.

Koste W., 1978: *Rotatoria. Die Rädertiere Mitteleuropas*. Gebrüder Borntraeger, Berlin, Stuttgart, 673 pp.

Mäemets A., 1983: *Rotifers as indicators of lake types in Estonia*. Hydrobiol., 104, 357–361.

Margalef R., 1957: *Information theory in ecology*. Gen. Syst., 3, 36–71.

McAbendroth L., ORamsay P.M., Foggo A., Rundle S.D., Bilton D.T., 2005: *Does macrophyte fractal complexity drive invertebrate diversity, biomass and body size distribution?* Oikos, 111, 279–290.

Moss B., 2007: *Ecology of fresh waters. Man and medium, past to future*. Third Edition. Blackwell Publishing.

Olejniczak M., 2003: Warunki hydrogeologiczne Parku Krajobrazowego „Puszcza Zielonka". M.Sc. Thesis. Manuscript. WNGiG UAM, Poznań.

Pejler B., 1995: *Relation to habitat in rotifers*. Hydrobiol., 313/314, 267–278.

Pennak R.W., 1966: *Structure of zooplankton populations in the littoral macrophyte zone of some Colorado lakes.* Trans. Amer. Microsc. Soc., 85(3), 329–349.

Pourriot R., 1977: *Food and feeding habits of rotifers*. Archiv für Hydrobiologie Beiheft Ergebnisse der Limnologie, 8, 243–260.

Radwan S., 2003: *Przyrodnicze podstawy ochrony i odnowy ekosystemów wodno-torfowiskowych w obszarze funkcjonalnym Poleskiego Parku Narodowego na tle antropologicznych przekształceń środowiska przyrodniczego*. Act. Agrophys., 90, 76–86.

*Radwan S., Bielańska-Grajner I., Ejsmont-Karabin J., 2004: Wrotki Rotifera. Fauna słodkowodna Polski* [Rotifers *Rotifera*. Freshwater fauna of Poland]. Ofic. Wyd. Tercja, 447 pp.

Saksena D.N., 1987: *Rotifers as Indicators of Water Quality*. Act. Hydrochim. et Hydrobiol., 15, 481–485.

Schriver P.J., Bøgestrand E., Jeppesen E., Søndergaard M., 1995: *Impact of submerged macrophytes on fish-zooplankton-phytoplankton interactions: large scale enclosure experiments in a shallow eutrophic lake*. Freshwat. Biol., 33, 255–270.

Semenchenko V.P., Razlutskij V.I., Feniova I.Y., Aibulatov D.N., 2007: *Biotic relations affecting species structure in zooplankton communities*. Hydrobiol., 579, 219–231.

Sládeček V., 1983: *Rotifers as indicators of water quality*. Hydrobiol., 100, 169–201.

*Standard Methods for Examination of Water and Wastwater*, 1992: American Public Health Association, New York, 1137 pp.

Tessier C., Cattaneo A., Pinel-Alloul B., Galanti G., 2004: *Biomass, composition and size structure of invertebrate communities associated to different types of aquatic vegetation during summer in Lago di Canada (Italy)*. Journ. Limnol., 63, 190–198.

Vanni M.J., Lampert W., 1992**:** *Food quality effects on life-history traits and fitness in the generalist herbivore* Daphnia. Oecolgia, 92, 48–57.

Wetzel R.G., 2001: *Limnology. Lake and River Ecosystems*. Third Edition. Oxford Acad. Press.

Williamson C.E., 1987: *Predator-prey interactions between omnivorous diaptomid copepods and rotifers: the role of prey morphology and behaviour*. Limnol. and Oceanograph., 31, 393–402.

## PRZESTRZENNE I CZASOWE ZRÓŻNICOWANIE STRUKTURY ZBIOROWISK ZOOPLANKTONU DWÓCH JEZIOR O ZRÓŻNICOWANYM WPŁYWIE ANTROPOPRESJI

### Streszczenie

Streszczenie: Badania prowadzono w dwóch strefach (otwarta toń wodna i litoral) dwóch jezior zlokalizowanych na terenie Puszczy Zielonki, w okolicach Poznania. Jedno z jezior (jezioro Czarne) jest prawnie chronione, podczas gdy drugie (jezioro Miejskie) jest użytkowane rekreacyjnie. Analizy, włączając strukturę zbiorowisk zooplanktonu oraz zmiany parametrów fizyczno-chemicznych wody, prowadzono w trzech sezonach – wiosną, latem i jesienią 2009 roku. Mimo że oba jeziora usytuowane były w zlewni leśnej oraz sąsiadowały ze sobą różniły się znacznie w odniesieniu do struktury ugrupowań zooplanktonu. Spodziewano się, że jezioro Czarne, które podlega ochronie prawnej, będzie charakteryzować się lepszą jakością wód w stosunku do jeziora Miejskiego, które wykorzystywane jest rekreacyjnie i podlega silnej antropopresji od okresu późnowiosennego do wczesnojesiennego. Jednakże wykazano, że jezioro Czarne cechowało się zdecydowanie gorszymi parametrami. W porównaniu do jeziora Miejskiego jezioro to było typowym zbiornikiem eutroficznym o uboższej strukturze taksonomicznej, wyższych średnich liczebnościach oraz o wyższym udziale procentowym gatunków eutroficznych w całkowitej liczebności zbiorowisk.