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ABUNDANCE AND DIVERSITY OF ZOOPLANKTON IN THE LITTORAL ZONE OF LAKE LICHEŃSKIE

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ABSTRACT. The aim of the present study was to determine the species diversity and abundance of zooplankton as well as to describe the relationships between the thermal conditions in littoral waters and the numbers and biomass of taxocenoses. The study was conducted in a monthly cycle during the years 2001 and 2002. Thirty-five species belonging to Rotifera and 32 species representing Crustacea were identified. The mean species richness varied significantly in particular months; it was the lowest in June and the highest in September. No significant correlation was found among water temperature and species abundance and the values of the diversity index in the zooplankton community. Zooplankton diversity did not show great fluctuations and was comparable over the entire experimental period. The numbers of Rotifera, Cladocera, and Copepoda were at a similar level, whereas their biomass was highly differentiated. An increase in water temperature was followed by an increase in the abundance and biomass of Cladocera as well as by a decrease in the numbers of Rotifera. The domination of pelagic species was observed in the spring only, while littoral species later assumed the leading position.

Key words: ZOOPLANKTON, LITTORAL, SEASONAL DYNAMICS, SPECIES ABUNDANCE, DIVERSITY, HEATED LAKE

INTRODUCTION

Numerous planktonic organisms colonize the littoral zone and use macrophytes as a feeding ground, while aquatic plants significantly affect the structure of zooplankton communities (van Donk and van de Bund 2002). In shallow lakes zooplankton undertake daily horizontal migrations: they spend the day among macrophytes, where they can find refuge against predators, and at night they move to the pelagic zone (Timms and Moss 1984, Burks et al. 2002). The high level of spatial differentiation of the littoral is particularly beneficial for planktonic organisms feeding on periphyton since it ensures a great abundance of nutrients. This is why the occurrence of many planktonic organisms is closely related to the presence of macrophytes (Balayla and Moss 2003).

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The littoral zone of Lake Licheńskie has been thoroughly studied by researchers dealing with juvenile fish (Wilkońska 1988, 1994, Kapusta 2004a). However, the zooplankton community of this zone, although crucial to the growth and survival of fish larvae, has not been investigated yet. This far, specialists on planktonic fauna have focused on the effects of high temperatures and increased water flow on the production, taxonomic composition, abundance, size structure, and fecundity of zooplankton in the pelagic zone (Hillbricht-Ilkowska et al. 1976, 1988, Hillbricht-Ilkowska and Zdanowski 1978, Tunowski 1988, 1994, Bogacka-Kapusta 2007).

Lake Licheńskie is a key component of the water cooling system of the neighboring power stations. The littoral zone of the lake is overgrown with aquatic vegetation, which limits water flow, reduces the efficiency of the cooling system, and causes ecological changes. The aim of the present study was to determine the species richness and abundance of zooplankton as well as to describe the relationships between the thermal conditions in littoral waters and the numbers and biomass of taxocenoses.

MATERIALS AND METHODS

STUDY AREA

Lake Licheńskie (52°18'N, 18°20'E) is a shallow, eutrophic lake near Konin (central Poland), with a surface area 147.6 ha, a mean depth of 4.5 m, and maximum depth of 12.6 m (Fig. 1). Since 1958, the lake has been heated with waters from the cooling system of two powers stations, Pątnów and Konin (Zdanowski 1994b). Among the five lakes incorporated into this cooling system, Lake Licheńskie is characterized by the highest water temperature. From early spring to late fall the waters are mixed to the bottom. The northern and southern parts of the lake, where the degree of water heating is lower, can freeze over during severe winters (Zdanowski 1994a).

The littoral of Lake Licheńskie is dominated by *Vallisneria spiralis* L. (Hutorowicz and Dziedzic 2003). This species, considered exotic in Poland, was reported for the first time in this water body at the beginning of the 1990s. *Ceratophyllum demersum* L., *Najas marina* L., *Nuphar lutea* (L.) Sibth. and Sm., *Myriophyllum spicatum* L., *Potamogeton pectinatus* L., *P. lucens* L., *P. perfoliatus* L., and *P. natans* L. can be found sporadically in Lake Licheńskie. In the shallow littoral there are phytocenoses of

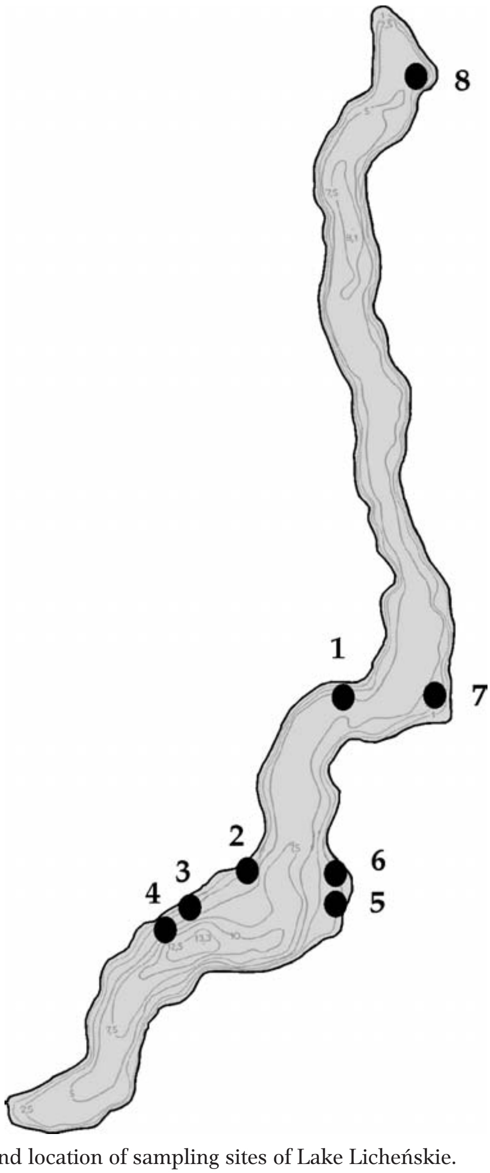

Fig. 1. Bathymetric map and location of sampling sites of Lake Licheńskie.

Phragmites communis Trin, *Typha* sp., and *Acorus calamus* L. One of the sampling sites located in the littoral zone was free of macrophytes (psammolittoral).

ZOOPLANKTON SAMPLING AND ANALYTICAL METHODS

The experimental materials were collected at monthly intervals from April to July, 2001 (8 sampling sites) and from April to September, 2002 (7 sampling sites). The research stations were located at different places, so as to reflect a wide diversity of littoral communities (Fig. 1). Zooplankton samples were taken in the littoral zone, at a depth of 0.5-1 m, with a 2.5 dm^3 Patalas sampler. A volume of 25 dm^3 of water was collected each time. The samples were poured through a 60 μm plankton net. The biological material was preserved with Lugol's solution and a 96% ethyl alcohol solution (Hillbricht-Ilkowska and Patalas 1967). Following sample condensation, the zooplankton were identified to the lowest possible taxonomic unit in a Sedwick-Rafter chamber (Flössner 1972, Kiefer and Fryer 1978, Koste 1978). The number of all taxa in a sample was determined each time, and the body length and width of individuals were measured. The total biomass of planktonic organisms was estimated using the relationships between the body weight and body length (width) of an individual (Bottrell et al. 1976, Ruttner-Kolisko 1977, Ejsmont-Karabin 1998).

An analysis of the zooplankton community structure provided the basis for determining the species richness and the Simpson diversity index. The frequency occurrence of zooplankton species in the littoral was analyzed using the occurrence constancy index, i.e., the ratio between the number of samples in which a given species was found to the total number of samples collected in the lake (Trojan 1975). Generally, this index enables determining the frequency occurrence of a given species on a four-point scale, i.e., absolutely constant species (AS) – > 75%, constant species (S) – 51-75%, accessory species (A) – 26-50%, accidental species (P) – < 25%.

During the experimental period water temperature varied from 14.4 to 30.6°C. In April water temperature was significantly lower than in May-September. The highest water temperature was recorded in August (Fig. 2). The water oxygen content was generally high over the entire experimental period (on average 11.4 mg O_2 dm^{-3}), but significant differences were observed in this parameter between particular months (ANOVA, $P < 0.0001$). The highest oxygen concentration in the littoral was noted in April, and the lowest in June (Fig. 2).

The significance of differences between the parameters describing zooplankton communities in successive months was estimated with non-parametric ANOVA

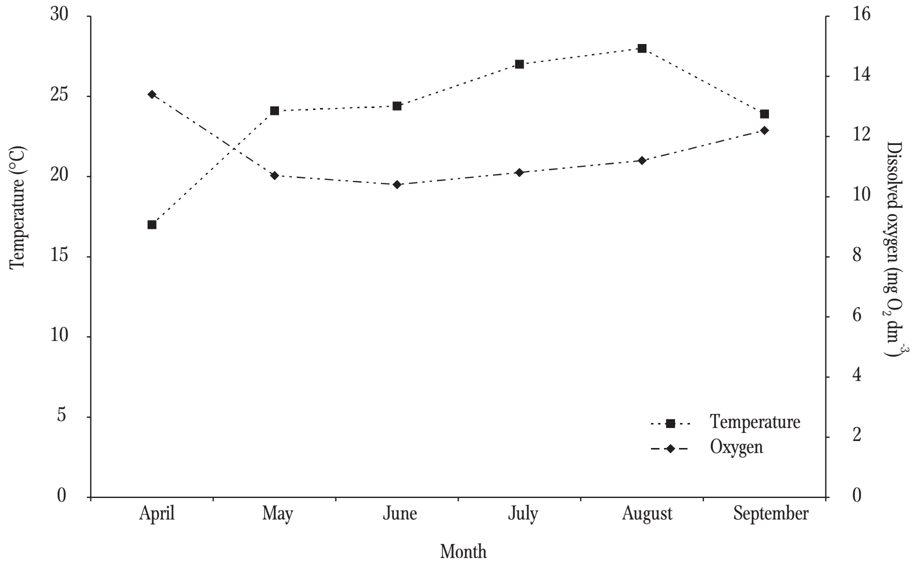

Fig. 2. Mean water temperature and mean water oxygen content in the littoral zone of Lake Licheńskie.

(Kruskal-Wallis test). Having obtained statistically significant values of the test, post hoc analysis was performed. The groups that differed from one another were determined with the Dunn test. The effect of water temperature on zooplankton abundance was estimated using the Spearman correlation.

RESULTS

In both years the zooplankton community in the littoral of Lake Licheńskie was characterized by a rich and diverse qualitative composition. Of the 67 zooplankton species identified, 64 species were recorded in 2001 and 54 in 2002 (Appendix 1). Among them 35 belonged to the Rotifera, 18 to the Copepoda, and 14 to the Cladocera. From 1 to 26 species were reported at particular research stations. The majority of them occurred irregularly, most often in low densities. Juvenile individuals, especially juvenile Cyclopoida, were present throughout the experimental period. The mean species richness varied significantly in particular months (Kruskal-Wallis test, $P = 0.015$) and was the lowest in June and the highest in September (Fig. 3). No significant correlation was found between water temperature and species abundance and the

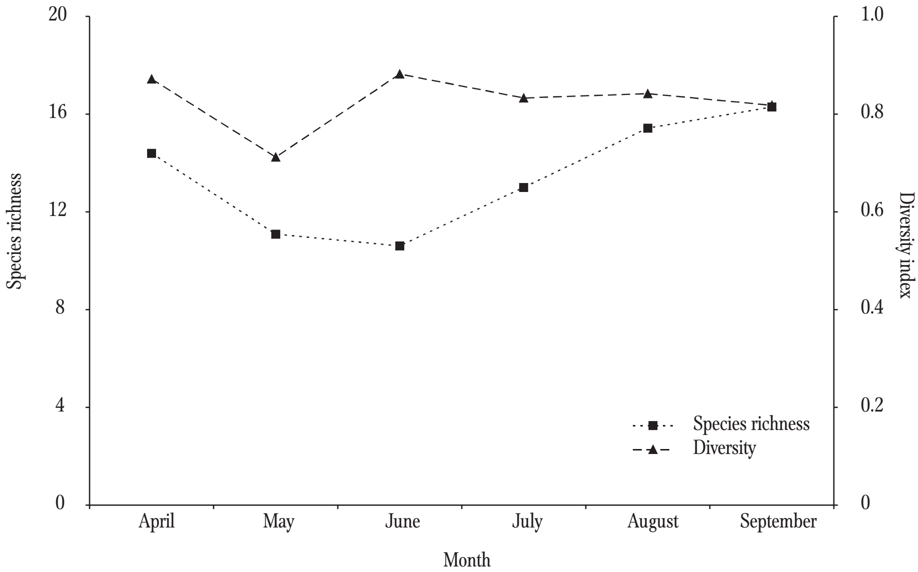

Fig. 3. Mean species richness and diversity of zooplankton in the littoral zone of Lake Licheńskie.

values of the diversity index in the zooplankton community. Zooplankton diversity did not show great fluctuations, but there were significant differences between the mean values of the diversity index in particular months (Kruskal-Wallis test, $P = 0.017$). The lowest diversity of the zooplankton community was observed in May. In June zooplankton diversity was the highest, despite the lowest species abundance. This resulted from uniform distribution of individuals representing particular species. In the subsequent months zooplankton diversity was only slightly lower than in June (Dunn test, $P > 0.05$).

The abundances of Rotifera, Cladocera, and Copepoda were at similar levels throughout the study period (Kruskal-Wallis test, $P = 0.086$, Fig. 4), whereas the biomass of particular taxonomic groups was highly differentiated (Kruskal-Wallis test, $P < 0.0001$, Fig. 5). The total biomass of Cladocera and Copepoda was comparable, but much higher than the biomass of Rotifera (Dunn test, $P < 0.05$). No significant changes were noted in the abundances and biomass of Rotifera in successive months (Dunn test, $P > 0.05$). An increase in water temperature was followed by an increase in abundance (Spearman correlation, $r = 0.317$, $P < 0.05$) and biomass ($r = 0.335$, $P < 0.05$) of Cladocera, as well as by a decrease in the numbers of Rotifera ($r = -0.213$, $P < 0.05$). In April zooplankton

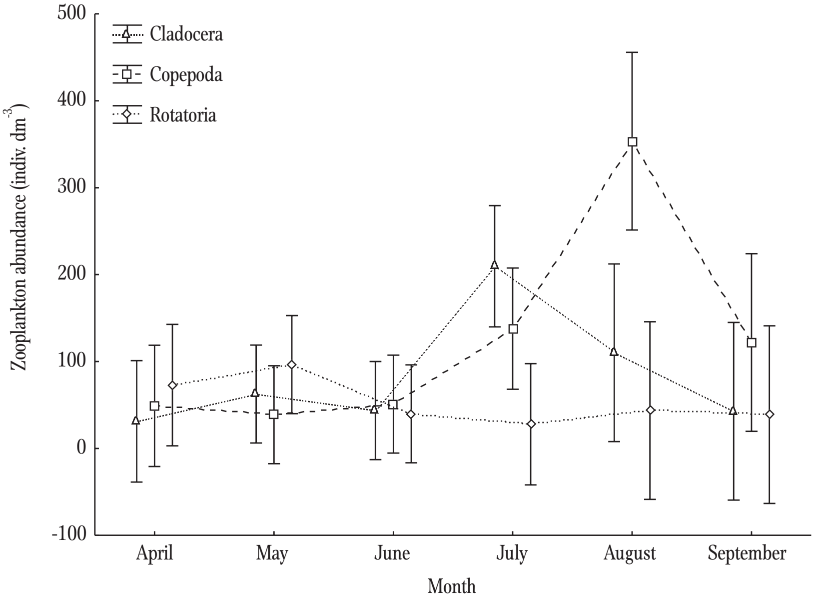

Fig. 4. Seasonal changes in zooplankton abundance (mean ± 95% range) in the littoral zone of Lake Licheńskie.

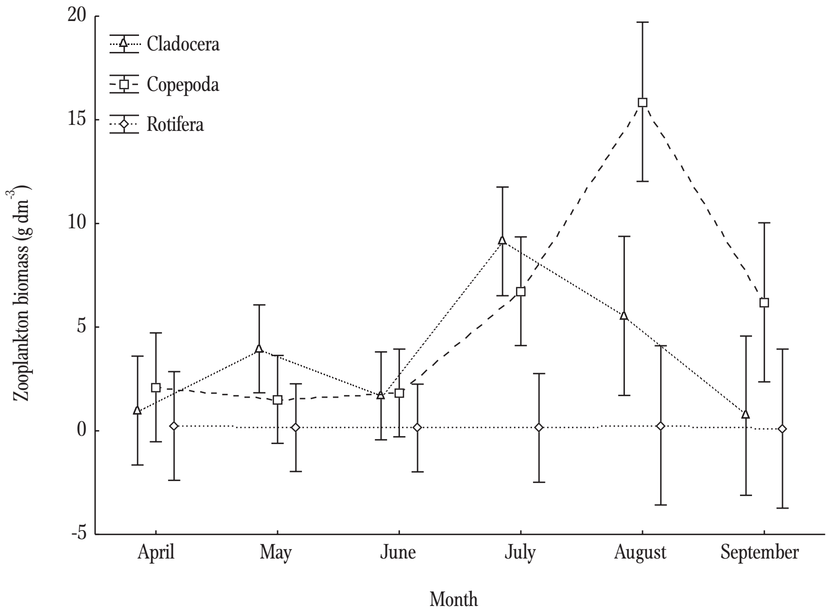

Fig. 5. Seasonal changes in zooplankton biomass (mean ± 95% range) in the littoral zone of Lake Licheńskie.

abundance was low. Rotifera formed the largest group in the littoral of Lake Licheńskie, dominated by small organisms typical of the pelagic zone, such as *Keratella cochlearis*, *K. quadrata*, *Brachionus angularis,* and larger ones, i.e. *Asplanchna priodonta, Polyarthra dolichoptera*, *P. euryptera*. Among the crustaceans, the most common were *Bosmina coregoni*, *Chydorus sphaericus*, and juvenile Copepoda. The mean zooplankton biomass was the lowest in April at 3.3 mg dm^{-3}. The copepods dominated in terms of weight, accounting for over 60% of the total biomass of the zooplankton community. In May the rotifers were the most numerous. Apart from the species recorded previously, an increase in the densities of *Synchaeta litoralis* was also observed. This species is characteristic of the littoral zone. The mean zooplankton biomass increased at that time to 5.6 mg dm^{-3}. Cladocera dominated in terms of weight, constituting over 70% of the total zooplankton biomass. The most common species among the cladocerans was *B. coregoni*. In June the total abundance and biomass of zooplankton decreased slightly due to low densities of Rotifera and Cladocera, and the abundance of Copepoda increased. At that time the most common species were *Lecane luna*, *B. coregoni*, *Ceriodaphnia quadrangula*, *Ch. sphaericus*, *Acroperus harpae*, and juvenile copepods. In July the densities and biomass of planktonic crustaceans increased significantly, whereas the numbers and biomass of the rotifers in the littoral were comparable with those noted in the spring. Cladocera dominated, accounting for over 55% of the total biomass and abundance of the zooplankton community. As in June, a substantial increase was recorded in the proportion of species typical of the littoral zone. The dominant species was *C. quadrangula*. Significant changes were found in the taxonomic structure of the rotifers. *P. euryptera* and *B. angularis*, which had also been abundant in the previous months, were accompanied by higher densities of species typical of the littoral zone like *Colurella colurus*, *S. litoralis*, and *L. luna*. In August the numbers and biomass of Cladocera decreased considerably as compared with those in July (Dunn test, $P < 0.05$). The opposite was observed in the case of Copepoda. The densities and biomass of the copepods were the highest in this month. The total zooplankton biomass was also the highest in August at 21.7 mg dm^{-3}. The contribution of the copepods to the total zooplankton biomass and abundance was 70%. The dominant group among them were juvenile Copepoda and Harpaticoida (*Macrocyclops albidus)* found among aquatic plants. *C. quadrangula* was the most common among the cladocerans. The abundance and biomass of all taxonomic groups decreased in September (Fig. 4 and 5). The copepods were the most common, constituting nearly 60% and 88% of the zooplankton community in terms of numbers and weight respectively. In this month the dominant species were *Acanthocyclops vernalis*, *C. quadrangula*, *A. harpae*, and *B. quadridentatus*.

DISCUSSION

Examinations of the littoral zone of Lake Licheńskie revealed a relatively high species richness in the zooplankton community. Thirty-five species belonging to Rotifera and 32 species representing Crustacea were identified in the experimental materials. In the summer (July-September) the crustacean community was characterized by a higher species richness than the rotifer community. However, the low number of Rotifera species could have been caused by the fact that a 60 μm plankton net was used in the study. The development of macrophytes was accompanied by changes in the structure of the zooplankton community. The contribution of pelagic species decreased, and the proportion of littoral species increased. However, species typical of the pelagic zone (*A. priodonta*, *K. cochlearis*, *B. angularis, B. coregoni*) were present in the littoral zone throughout the study period. The occurrence of pelagic organisms in the littoral zone is a common (Timms and Moss 1984, Rodrigo et al. 2003), and it might be a result of the contact between these two environments, i.e., the interactions between the open water zone and the littoral zone, enabling species penetration from one to the other, or daily horizontal migrations undertaken by planktonic organisms in shallow lakes (Burks et al. 2002, Cerbin et al. 2003, Romare et al. 2003).

The pelagic zones of lakes are usually dominated by eurytopic species, which is not always true for the littoral zone. In Lake Licheńskie the domination of pelagic species was limited to the springtime, when macrophytes covered a small part of the lake bottom only. In addition, the high values of the diversity index confirmed the importance of low-frequency species in the zooplankton community. Only juvenile stages of Copepoda were absolutely constant in the littoral, and only the occurrence frequency of *A. priodonta*, *B. coregoni*, and *Ch. sphaericus* exceeded 50%. A key factor influencing the occurrence of particular species in the littoral zone and, in consequence, the diversity of communities colonizing this zone, is the availability of diverse habitats (Balayla and Moss 2003).

Aquatic vegetation considerably affects the spatial structure of littoral zones, and the species diversity of water plants leads to the formation of heterogeneous microhabitats, colonized by different zooplankton communities (Kuczyńska-Kippen and Nagengast 2003). During the years 2001-2002, the shallow littoral zone (12.2 ha) of Lake Licheńskie was 92% overgrown with plant communities dominated by *V. spiralis* (Hutorowicz and Dziedzic 2003). Such a high proportion of this exotic macrophyte may be disadvantageous to the development of zooplankton. *V. spiralis* inhibits the occurrence of other macrophytic species, which is followed by a decrease in habitat diversity. Moreover, periodical oxygen deficits are recorded in this lake at night (Kapusta 2004b). However, no negative effect of *V. spiralis* on the zooplankton community was observed. The species abundance and diversity of zooplankton increased along with macrophyte development. The densities of zooplankton were comparable to those noted earlier in the pelagic zone, and their biomass was higher (Hillbricht-Ilkowska et al. 1976, 1988, Tunowski 1988, 1994). The biomass structure of taxocenoses was also similar. The crustaceans dominated, and the contribution of rotifers exceeded 5% in April only. The quantitative structure of the taxonomic groups of zooplankton in the littoral and pelagic zone was different. In earlier studies the pelagic zooplankton community was dominated by Rotifera, which comprised from 70 to 90% of the total zooplankton abundance (Tunowski 1994). In the littoral zone the domination of rotifers was limited to the spring only (April-May), when they accounted for almost 50% of the total zooplankton abundance. This situation was caused by environmental changes. The rotifers that occurred in great numbers in the spring were adapted to low temperatures and high oxygen concentrations (*P. dolichoptera*). An increase in water temperature stimulated the growth of thermophilous species, and indirectly, through the development of macrophytes, of those connected with aquatic vegetation. The growth of macrophytes considerably limits water flow, thus promoting zooplankton development (Basu et al. 2000). In addition, the gradual increase in water temperature, noted in Lake Licheńskie, corresponded to the increase in zooplankton densities (Żmudziński et al. 1990, Paturej et al. 2000). The copepods, present in great numbers in the summer, feed on rotifers, so they considerably reduced the size of their population. Moreover, the copepods used macrophytes as refuge against predators – planktivorous fish (Alajärvi and Horppila 2004).

As in the pelagic zone, the composition and abundance of zooplankton in the littoral zone of Lake Licheńskie are also affected by a variety of limiting factors. The results of previous studies demonstrated that elevated temperatures and increased water flow impacted the taxonomic composition and abundance of zooplankton in the pelagic zone (Hillbricht-Ilkowska et al. 1988, Tunowski 1988, 1994). Different rates of population growth under various turbulent and thermal conditions, as well as the specific resistance of particular species to the limiting factors, impacted the abundance and taxonomic composition of pelagic zooplankton. In the littoral zone, in addition to the factors above, aquatic vegetation also had a profound effect on the zooplankton community. The rapid development of *V. spiralis* was associated with changes in the zooplankton structure and with an increase in the proportion of littoral species.

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STRESZCZENIE

OBFITOŚĆ I RÓŻNORODNOŚĆ ZOOPLANKTONU W LITORALU JEZIORA LICHEŃSKIEGO

Celem pracy było określenie bogactwa gatunkowego i obfitości fauny planktonowej oraz relacji pomiędzy termiką wód litoralu i zawartością tlenu a liczebnością i biomasą badanych taksocenoz. Badania prowadzono w cyklu miesięcznym w latach 2001-2002. W materiale badawczym oznaczono 35 gatunków należących do Rotifera i 32 do Crustacea (Appendix 1). Stwierdzono istotne zróżnicowanie średniego bogactwa gatunkowego w kolejnych miesiącach (rys. 3). Najmniejsze było w czerwcu, a największe we wrześniu. Nie stwierdzono istotnego związku pomiędzy temperaturą wody a bogactwem gatunkowym i wartościami indeksu różnorodności zooplanktonu. Różnorodność zooplanktonu nie podlegała większym fluktuacjom i była podobna w całym okresie. Liczebność Rotifera, Cladocera i Copepoda utrzymywała się na podobnym poziomie (rys. 4), natomiast biomasa była wysoce zróżnicowana (rys. 5). Wzrost temperatury wody korespondował ze wzrostem liczebności i biomasy Cladocera oraz spadkiem liczebności Rotifera. Dominacja gatunków pelagicznych ograniczała się do okresu wiosennego, które później ustępowały na korzyść gatunków litoralowych.

APPENDIX 1

Species composition and occurrence constancy of zooplankton in the littoral zone of Lake Licheńskie. Frequency of occurrence of particular species on a four-degree scale: absolutely constant species (AS) – > 75%, constant species (S) – 51-75%, accessory species (A) – 26-50%, accidental species (P) – < 25%.

	2001	2002
Anureaopsis fissa (Gosse)	P	-
Asplanchna priodonta Gosse	A	S
Brachionus angularis Gosse	A	A
Brachionus calyciflorus Pallas	P	P
Brachionus quadridentatus Hermann	P	A
Brachionus urceolaris (Müller)	-	P
Cephalodella sp.	P	P
Colurella colurus (Ehrenberg)	P	P
Euchlanis dilatata Ehrenberg	P	P
Filinia longiseta (Ehrenberg)	P	-
Keratella cochlearis Gosse	A	A
Keratella quadrata (Müller)	P	P
Lecane bulla (Gosse)	P	P
Lecane luna (Müller)	P	A
Lepadella sp.	A	P
Notholca acuminata (Ehrenberg)	P	P
Notholca squamula (Müller)	P	P
Philodina sp.	P	-
Polyartha dolichoptera Idelson	A	P
Polyarthra euryptera Wierzejski	A	A
Polyarthra major Burckhardt	P	P
Polyarthra remata Skorikov	P	P
Polyarthra vulgaris Karlin	P	P
Pompholyx sp.	A	A
Proales sp.	P	P
Synchaeta kitina Rousselet	A	P
Synchaeta litoralis Rousselet	P	A
Synchaeta oblonga Ehrenberg	P	-
Synchaeta pectinata Ehrenberg	P	-
Testudinella patina (Hermann)	P	P
Trichocerca capucina (Wierzejski et Zacharias)	P	P
Trichocerca elongata (Gosse)	P	-
Trichocerca pusilla (Lauterborn)	P	P
Trichocerca rousseleti Voigt	P	-
Trichotria sp.	P	-
Acroperus harpae (Bard)	A	A
Alona quadrangularis (Müller)	A	P
Alonella nana (Bard)	P	P
Bosmina coregoni Baird	A	S
Bosmina longirostris (Müller)	A	P

Ceriodaphnia quadrangula (Müller)	P	A
Chydorus sphaericus (Müller)	A	S
Daphnia cucullata Sars	P	P
Daphnia longispina Müller	P	P
Daphnia magna Straus	P	P
Diaphanosoma brahyurum (Liévin)	A	A
Eurycercus lamellatus (Müller)	P	P
Iliocryptus sordidus (Liévin)	P	-
Leptodora kindti (Focke)	P	-
Moina micrura Kurtz	P	A
Pleuroxus uncinatus Baird	P	-
Polyphemus pediculus (L.)	P	-
Sida crystallina (Müller)	P	-
Cladocera (juv.)	P	P
Acanthocyclops robustus (Sars)	P	P
Acanthocyclops vernalis (Fischer)	P	P
Cyclops furcifer (Claus)	P	P
Cyclops insignis (Claus)	-	P
Cyclops kolensis (Lilljeborg)	A	A
Cyclops strenuus (Fischer)	P	P
Cyclops vicinus (Uljanin)	P	P
Eucyclops macrurus (Sars)	P	P
Eucyclops serrulatus (Fischer)	P	P
Harpaticoida	P	A
Macrocyclops albidus (Jurine)	P	P
Mesocyclops leuckarti (Claus)	P	A
Thermocyclops crassus (Fischer)	P	P
Thermocyclops oithonoides (Sars)	-	P
Copepoda (copepodit)	S	AS
Calanoida (naupli)	AS	S
Cyclopoida (naupli)	AS	AS