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REVIEW PAPER

Zooplankton structure in heated lakes with differing thermal regimes and water retention

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Abstract. The aim of the study was to determine the impact water retention time and increased water temperature had on the composition and abundance of zooplankton. Crustacea and Rotifera were examined from lakes Ślesińskie and Licheńskie, which are part of the water cooling system for the Konin and Pątnów power plants. Lake Ślesińskie is included in the cooling system periodically (from May to September) when the long cooling cycle is in operation, and its waters are heated moderately (< 25°C) with a water retention time of about two weeks. The zooplankton biomass in this basin in summer ranges from 1.5 to 4.0 mg dm^{-3} and was lower than that noted in May (< 25 mg dm^{-3}) before the lake was included in the water cooling system. In Lake Licheńskie, which is heated continuously (< 30°C) and has a water retention time of about 5 days, the zooplankton abundance (< 100 indiv. dm^{-3}) and biomass (< 0.5 mg dm^{-3}) noted was low. In addition to temperature, one of the factors that affects zooplankton development in both lakes is the short water retention time.

Keywords: heated lakes, zooplankton, Cladocera, Copepoda, Rotifera, diversity index

Introduction

The spatial distribution of zooplankton in lakes is shaped by a variety of environmental factors including water temperature, water content of dissolved oxygen, water exchange, and the productivity of the water. Changes in the species composition, trophic structure, and the productivity of the zooplankton are confirmed in basins that are transformed by anthropogenic pressure (Hillbricht-Ilkowska and Zdanowski 1978). This is why zooplankton can be excellent indicators of eutrophic change in water systems (Karabin 1985, Ejsmont-Karabin and Węgleńska 1988a), and they can also be used to monitor the ecological effects that heated water discharge has on the environment (Hillbricht-Ilkowska and Zdanowski 1988a, Zdanowski 1994a).

The primary changes in the natural environments of lakes that are used for power plant cooling systems are in the thermal and hydrological regimes of these basins (Zdanowski 1994b). Temperature is a limiting factor for the growth of organisms, and, depending on temperature range, it can affect the mortality of organisms. Different zooplankton species exhibit different abilities to tolerate increases in temperature (Tunowski 1988, Hillbricht-Ilkowska and Zdanowski 1988b), and particularly sensitive ones are eliminated. Zooplankton are also eliminated mechanically after moving across the stream condensers of the power plants. Fish feeding intensely on zooplankton has also been noted in the post-cooling water discharge area (Pinel-Alloul et al. 2004). As a result, small forms, like rotifers and smaller copepods, dominate the plankton (Hillbricht-Ilkowska et al. 1988). The zooplankton of

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lakes that are intensively heated exhibit low species diversity (Hillbricht-Ilkowska 1985, Tunowski 1994).

The aim of the current study was to identify the distribution and development of pelagic zooplankton in lakes that are heated to different degrees and have different water retention rates.

Materials and methods

Lake Licheńskie (52°19.3'N, 18°20.6'E; surface area 153.6 ha) and Lake Ślesińskie (52°23.4'N, 18°19.9'E; surface area 148.1 ha) along with lakes Pątnowskie, Gosławskie, and Mikorzyńskie, comprise the five-lake complex that is used to cool the discharged post-cooling waters from the Konin (since 1958) and Pątnów (since 1970) power plants (Table 1).

Table 1
Limnological characteristics of the Konin lakes (according to Zdanowski 1994a – adapted)

	Licheńskie Lake	Ślesińskie Lake
Area (ha)	153.6	148.1
Max. depth (m)	13.3	25.7
Mean depth (m)	4.9	7.5
Secchi depta (m)	1.6 (± 0.2)[2]	3.1 (0.3)[2]
Retention time (day)[1]	3 (2-5)[3]	14 (6-30)[3]
Trophic type	eutrophic (monomictic)	eutrophic (dimictic)

[1]Data from the 1999-2000 period. Water retention values for Lake Ślesińskie are for the period when the long cooling system is in operation
[2]Data from September 1999
[3]Mean (range)

The Konin Power Plant (KPP) discharges heated waters either through the initial cooling basin or directly into lakes Licheńskie (50% of the discharge), Pątnowskie, and Wąsosko-Mikorzyńskie. A portion of the post-cooling waters from the Pątnów Power Plant are discharged into Lake Gosławskie, while the remaining portion is deposited into the KPP discharge channel. During the summer (May-September), the long cooling cycle is put into operation, which means that water is pumped from

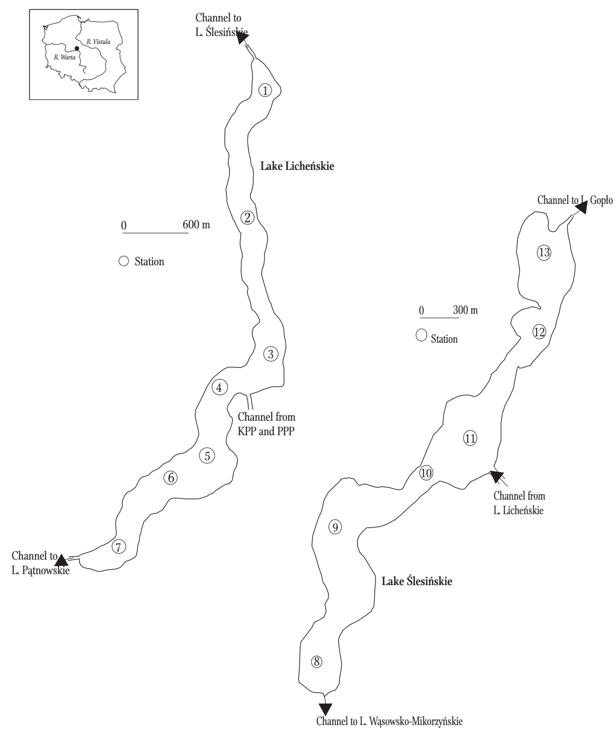

Figure 1. Zooplankton sampling sites in lakes Licheńskie and Ślesińskie in 1999. KPP – Konin Power Plant, PPP – Pątnów Power Plant.

Lake Licheńskie into Lake Ślesińskie. This reduces the water retention time in the former to just a few days and in the latter to about 14 days (Stawecki et al. 2007). Water from Lake Licheńskie flows into Lake Ślesińskie through a cascade system, which causes mixing throughout the water column to depths of 20 m in the inflow zone (Zdanowski 1994a).

Zooplankton samples were collected three times in 1999 (spring (May), summer (July), early autumn (September) at seven stations (1-7) in Lake Licheńskie and at six (8-13) in Lake Ślesińskie (Fig. 1). Because there was no thermal or oxygen stratification at most of the sites, most of the zooplankton samples were collected from throughout the water column from the surface to the bottom. Only at station 8 in Lake Ślesińskie, where during summer there was full thermal stratification, were zooplankton samples drawn from the epi-, meta-, and hypolimnions. These corresponded to the 0-5, 5-10, and 10-20 m layers. Zooplankton samples were collected using a semi-automatic Toń sampler with a volume of 5 dm^3. Water (30 dm^3) was filtered from each water depth layer through a no. 25 mesh plankton net. Concentrated plankton samples were transferred to glass containers and fixed with Lugol's solution and then preserved with a 2-3% formalin solution.

Water temperature and oxygen content measurements were taken when the zooplankton samples were collected. The surface water temperature in Lake Licheńskie during the summer of 1999 did not exceed 29°C, and it did not fall below 13°C at the bottom. In Lake Ślesińskie, which was stratified, the maximum epilimnion temperature was 26.4°C, and that at the bottom was 4.6°C (Fig. 2). The thermal stratification in Lake Ślesińskie resembled that which is natural and typical of dimictic lakes in the temperate zone. However, because of the short water retention time and the high temperature of waters discharged through the channel into Lake Licheńskie, conditions in this lake were extremely changeable. Not even in summer did thermal stratification occur. Water temperature in Lake Licheńskie at the designated stations was higher than that in Lake Ślesińskie (Table 2). The opposite was noted with regard to oxygen content. According to Secchi disc measurements, water transparency in Lake Licheńskie was 2.1 m, while in Lake Ślesińskie it was up to 5 m in spring.

The abundance of taxa and the lengths of the zooplankton were determined in a Sedgwick-Rafter chamber using an optical microscope. The biomass of Rotifera and Crustacea were calculated based on the dependence between the length and the individual weight of the particular species (Hillbricht-Ilkowska and Patalas 1967, Bottrell et al. 1977). The Shannon-Weaver species diversity index was determined based on the zooplankton abundance and biomass in individual samples (Margalef 1958).

Results

Zooplankton abundance

Thirty species of planktonic organisms were confirmed in lakes Licheńskie and Ślesińskie. Seventeen species of Rotifera, 8 Cladocera, and 5 Copepoda were identified (Table 3). In Lake Licheńskie,

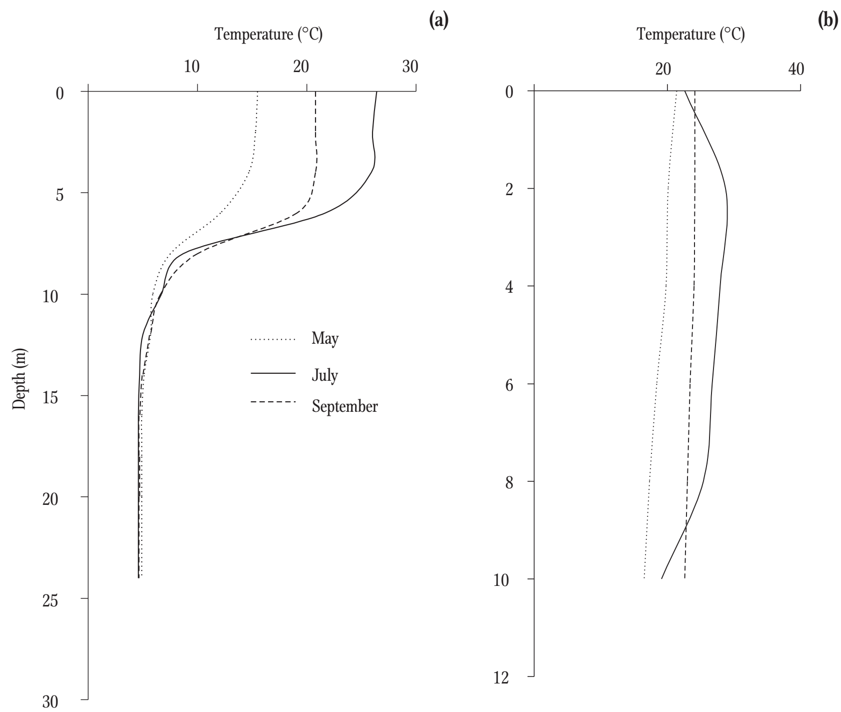

Figure 2. Vertical water temperature distribution in lakes Licheńskie (a) and Ślesińskie (b) in 1999.

Table 2
Variability in temperature and oxygen content in lakes Licheńskie and Ślesińskie in 1999

Month	Lake Licheńskie			Lake Ślesińskie		
	Station	Temperature (°C)	Oxygen (mg dm^{-1})	Station	Temperature (°C)	Oxygen (mg dm^{-1})
May	1	21.1	7.9	8	16.9	8.8
	2	21.4	7.8	9	16.4	8.8
	3	21.2	7.6	10	16.8	8.5
	4	21.3	7.8	11	16.0	8.9
	5	22.4	7.6	12	15.8	8.7
	6	21.0	9.6	13	15.9	8.9
	7	20.0	8.4			
July	1	27.4	8.6	8	26.2	8.6
	2	27.9	8.1	9	26.5	7.8
	3	28.1	7.0	10	26.5	7.8
	4	28.5	7.6	11	26.5	7.2
	5	29.0	6.4	12	26.1	8.6
	6	28.5	5.9	13	25.8	8.4
	7	28.5	6.7			
September	1	21.4	7.7	8	21.5	8.0
	2	22.5	7.2	9	21.4	7.9
	3	23.5	7.1	10	21.3	7.8
	4	24.2	6.6	11	21.0	7.7
	5	25.6	6.6	12	21.5	7.7
	6	26.5	6.2	13	20.4	8.1
	7	24.5	7.3			

abundance was dominated by Rotifera and there were small shares of Cladocera and Copepoda, while Crustacea and Rotifera were equally abundant in Lake Ślesińskie. Cladocera were represented by the genus *Daphnia* and *Bosmina* and by the species *Leptodora kindti* (Focke) and *Diaphanosoma brachyurum* (Liévin). Among the copepods, there were species from the families Cyclopidae and Diaptomidae. Rotifera were most frequently represented by taxa from the families Branchionidae and Synchaetidae. Associated species included *Euchlanis dilatata* (Ehrenberg), *Filinia longiseta* (Ehrenberg), *Lecane luna* (O.F. Müller), and *Trichocerca pusilla* (Lauterborn).

Lake Licheńskie had relatively low zooplankton abundance in comparison to that in Lake Ślesińskie. In July and September 1999, fewer than 100 indiv. dm^{-3} were noted. Slightly higher zooplankton abundance was noted only in spring at stations 1 and 7, and in autumn at station 6 (Fig. 3). Rotifera contributed the largest share to the overall zooplankton, among which were small filtrators and the predatory rotifers *Synchaeta kitina* (Rousselet), *Synchaeta stylata* Wierzejski, *Synchaeta oblonga* Ehrenberg, *Brachionus angularis* Gosse, and *Brachionus calyciflorus* Pallas. Large cladocerans and copepods were the most numerous in May and July, but only in open areas of the lake (stations 2, 3, 4), which were outside the reach of the discharged water flow through the lake (Fig. 1).

During the spring, Rotifera was represented by species from the genus *Keratella* such as *K. quadrata* (O.F. Müller) and *K. cochlearis* (Gosse), as well as by *Brachionus* representatives *B. angularis* and

Table 3

Zooplankton species composition in lakes Licheńskie (L) and Ślesińskie (S) in the 1999 growing season

Taxa	May		July		September	
	L	S	L	S	L	S
Cladocera						
Bosmina coregoni coregoni (Baird)	+	+	+	+		+
Bosmina longirostris (O.F. Müller)		+			+	
Daphnia cristata Sars	+	+				
Daphnia cuculata Sars	+	+	+	+	+	+
Daphnia hyalina (Leydig)		+		+		
Daphnia longispina (O.F. Müller)		+				+
Leptodora kindti (Focke)				+		+
Diaphanosoma brachyurum (Lievin)	+	+	+	+	+	+
Copepoda						
Cyclops kolensis Lilljeborg	+	+		+	+	+
Mesocyclops leuckarti (Claus)	+	+	+	+		
Thermocyclops oithonoides (Sars)	+		+	+		+
Eudiaptomus gracilis (Sars)		+				+
Eudiaptomus graciloides (Lilljeborg)		+				+
Rotifera						
Brachionus angularis Gosse	+	+	+	+	+	
Brachionus budapestiensis Daday			+		+	
Brachionus calyciflorus Pallas	+		+	+	+	+
Brachionus diversicornis Daday					+	
Keratella cochlearis typica (Gosse)	+	+				+
Keratella cochlearis tecta (Gosse)	+	+				
Keratella quadrata (O.F. Müller)	+	+	+	+	+	
Euchlanis dilatata Ehrenberg	+					
Filinia longiseta (Ehrenberg)						+
Lecane luna O.F. Müller			+	+		
Polyarthra dolichoptera Idelson						+
Polyarthra remata Skorikov	+	+	+	+	+	+
Polyarthra vulgaris Carlin	+	+	+	+	+	+
Synchaeta kitina Rousselt	+	+	+	+	+	+
Synchaeta stylata Wierzejski	+	+		+	+	
Synchaeta oblonga Ehrenberg	+	+	+		+	
Trichocerca pusilla (Lauternborn)	+		+	+	+	+

B. calyciflorus, and the genus *Synchaeta* by *S. kitina* and *S. stylata*. Rotifers comprised a nearly 90% share of the overall zooplankton abundance, except at stations 2 and 3 where its shares were 45 and 60%, respectively. The quantitative shares of Copepoda at stations 2 and 3 did not exceed 30 and 15%, respectively, at this time, and the contribution of Cladocera was 20 and 30%, accordingly. In the summer (July), a smaller share of rotifers were noted, while those of Copepoda were higher and Cladocera were similar (Fig. 3). The quantitative share of Rotifera fluctuated from 30% at station 4 to 60% at

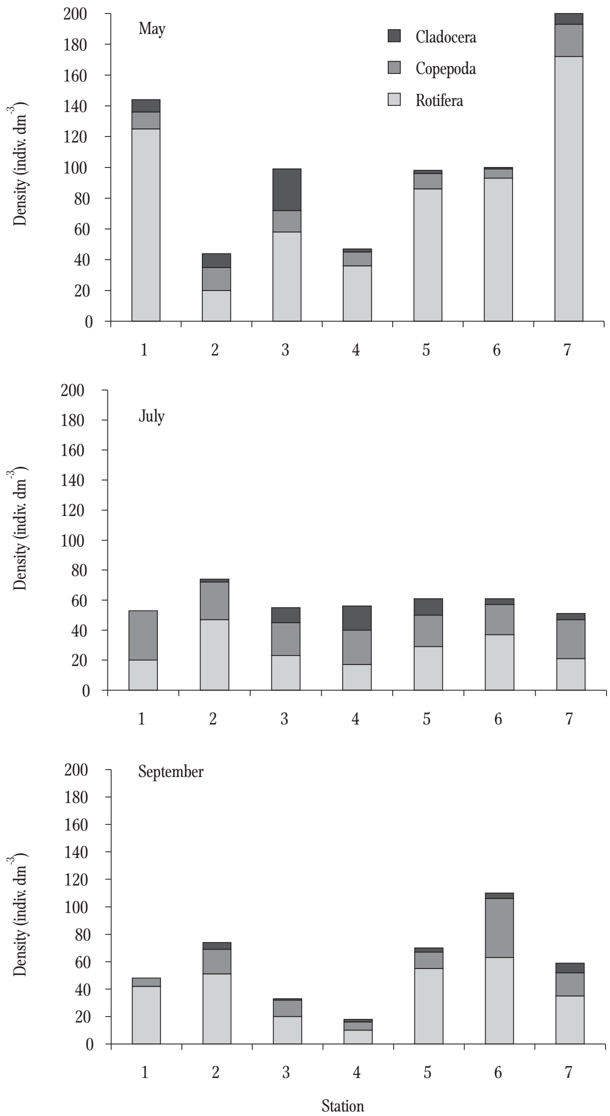

Figure 3. Zooplankton density (indiv. dm^{-3}) in Lake Licheńskie in 1999.

stations 2 and 6. The abundance of copepods in this period was from 30 to 40% of the overall abundance of zooplankton and was higher only at stations 6 and 1 (50 and 60%, respectively). The abundance of cladocerans did not exceed 20% of the overall zooplankton abundance and only at station 4 did their share increase to 30%. In fall the share of Rotifera in the overall zooplankton abundance increased again to 80% (Fig. 3). The share of Copepoda was varied at the particular stations within a range of 10 to 40%. Copepods were most often represented by juvenile stages (nauplii, copepodites), and species from the

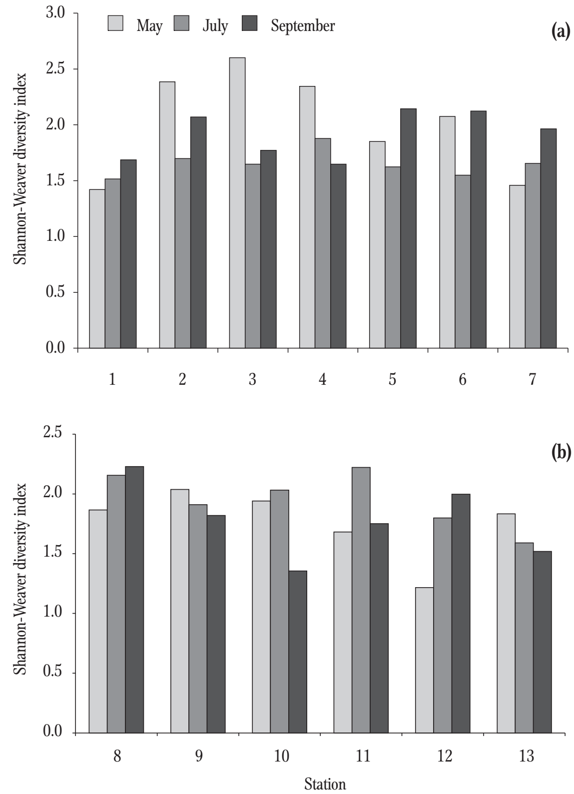

Figure 4. Shannon-Weaver zooplankton species diversity index (density) in Lake Licheńskie (a) and Lake Ślesińskie (b) in 1999.

genus *Cyclops* and *Mesocyclops* were numerous. The share of Cladocera in the overall abundance was still very low and did not exceed 10%. The most frequently noted was *D. brachyurum*, and there were single specimens of *Daphnia cucullata* Sars.

The value of the species diversity index of the zooplankton in Lake Licheńskie, calculated based on the abundance of species, ranged from 1.42 to 2.60 (Fig. 4a). The highest value of the species diversity index was noted in May at station 3, when no single species was noted as the dominant. The share of the remaining taxonomic groups was distributed quite evenly. In spring, there was greater diversity in the pelagic zone of the northern part of Lake Licheńskie (stations 2, 3, 4), and thus in the part of the lake that is outside of the main flow of the discharge waters from the power plant. In September, however, the zooplankton species diversity was higher in the southern part of the lake (stations 5, 6, 7), which remained a zone without through water flow. In July, the zooplankton species diversity was rather balanced throughout the entire lake, which could have resulted from the high water temperature (Table 2). The variability of the Shannon-Weaver species diversity index was determined by the domination of juvenile forms of Copepoda (nauplii, copepodites) that sometimes comprised as much as 60% of the overall abundance.

The zooplankton abundance in Lake Ślesińskie was higher than that noted in Lake Licheńskie. The differences between the two lakes were especially distinct in spring, when the overall abundance of zooplankton in Lake Ślesińskie was the highest (Fig. 5). The high share of Rotifera in May, especially at station 12, was thanks primarily to the abundant occurrence of specimens from the genus *Keratella* (378 indiv. dm^{-3}) (Fig. 5). The share of Cladocera in the overall zooplankton abundance in May was from 20 to 60%, and the most abundant were individuals from the genus of *Daphnia* and *Bosmina*. The share of copepods was generally low, and they were represented by juvenile forms and *Eudiaptomus graciloides* (Lilljeborg) and *Eudiaptomus gracilis* (Sars). The abundance of Rotifera did not decrease until July when it comprised just 5 to 30% of the overall zooplankton abundance, and only at station 8 did it exceed 50%. The share of Copepoda in the overall zooplankton abundance ranged from 30 to 70%, except at station 8, where its share decreased to 20%. Cladocera were less abundant than were copepods, at a 20% share of the overall zooplankton abundance. Only at station 10 was it about 40%. Copepods were noted to dominate in autumn, when their share in the overall zooplankton abundance was the highest (50-70%) (Fig. 5). The share of Cladocera did not usually exceed 20% of the overall zooplankton abundance, and Rotifera comprised a share of just a few percent increasing to 30% only at station 8.

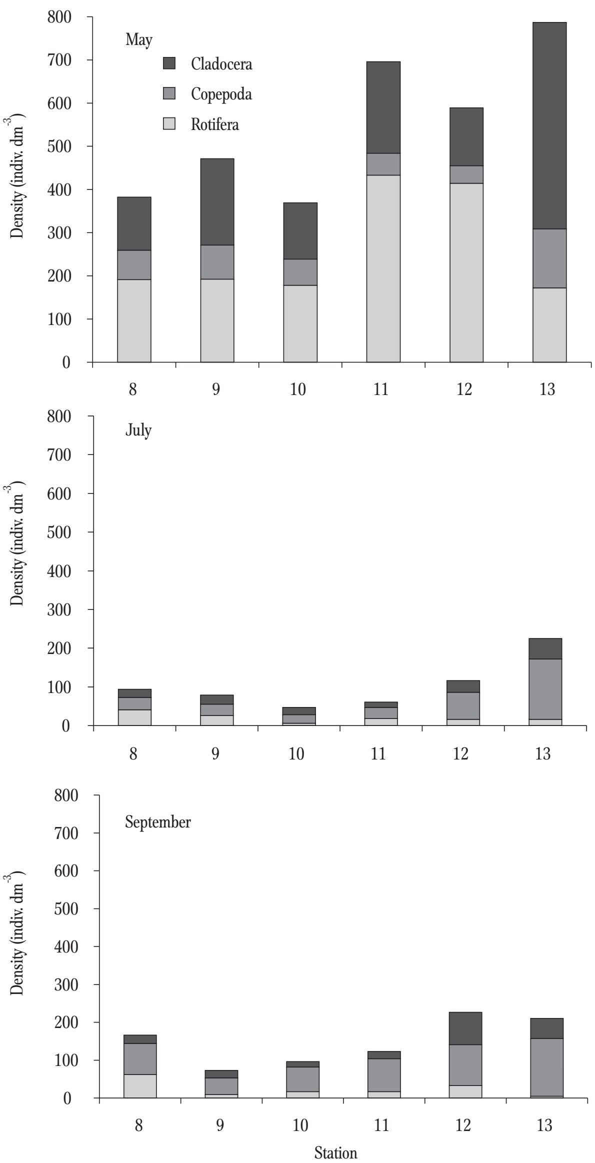

Figure 5. Zooplankton density (indiv. dm^{-3}) in Lake Ślesińskie in 1999.

The zooplankton species diversity in Lake Ślesińskie was lower than that in Lake Licheńskie. The highest value of the Shannon-Weaver diversity index were confirmed in May at station 12 and in September at station 10 (1.22 and 1.36, respectively). The highest value (2.23) of this index was noted in September at the deepest, stratified station 8 (Fig. 4b).

Zooplankton biomass

The overall zooplankton biomass in Lake Licheńskie was not great, and only during spring did it increase slightly to 1.2 mg dm^{-3} (Fig. 6). Cladocera comprised from 60-90% of the overall zooplankton biomass. The species that dominated in terms of weight included *D. cuculata*, *D. brachyurum*, *Bosmina coregoni* Baird, and *Mesocyclops leuckarti* (Claus). The highest (90%

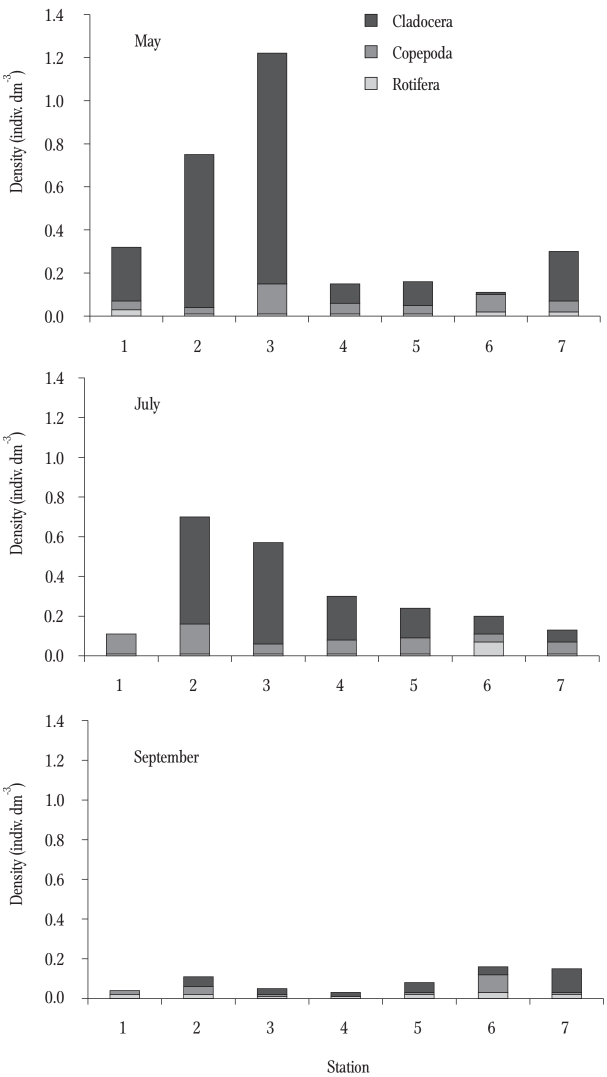

Figure 6. Zooplankton biomass (mg dm^{-3}) in Lake Licheńskie in 1999.

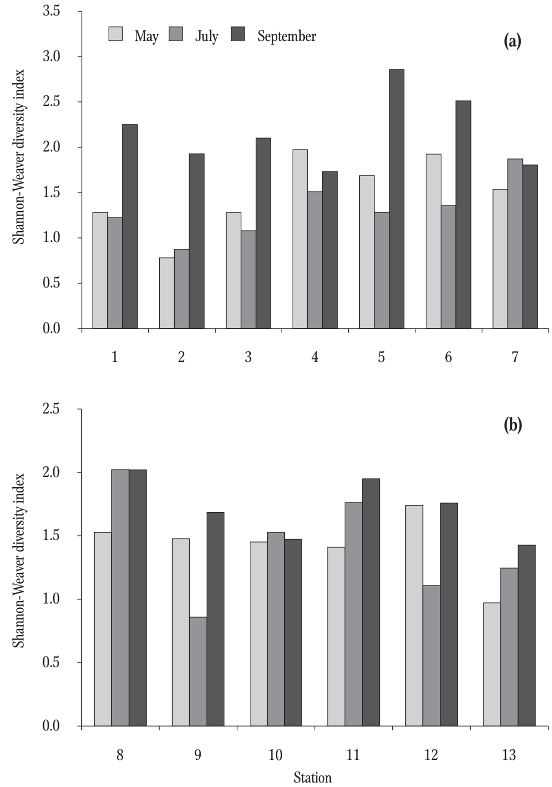

Figure 7. Shannon-Weaver zooplankton species diversity index (biomass) in Lake Licheńskie (a) and Lake Ślesińskie (b) in 1999.

share) Cladocera biomass was confirmed in spring (May) at station 3 (Fig. 6). The share of cladocerans at the other stations was within the 70-80% range, but at station 6 it did not exceed 15%. Mainly Copepoda were the decisive factor in determining overall zooplankton biomass. The biomass of Rotifera was low, and only at station 6 did it achieve a 20% share of the zooplankton biomass. The Cladocera biomass was the highest in July at station 3 (90% of the overall zooplankton biomass), but at station 1, however, they had been totally eliminated. The shares of Copepoda and Rotifera were similar to those noted in May, and the share of the former was the highest at station 1 at 70% of the total zooplankton biomass. At this station, Rotifera comprised 30% of the overall plankton biomass. In September, the share of Cladocera in the overall zooplankton biomass decreased substantially to 50-80%. Similarly to the summer, no cladocerans were noted at station 1, while at station 6 an increased share of rotifers was noted at 20 to 40% of the overall zooplankton biomass, while the share of Copepoda oscillated from 10 to 60%.

The Shannon-Weaver diversity index of species diversity calculated based on the zooplankton biomass in Lake Licheńskie during the 1999 growing season fluctuated within a wide range from 0.78 to 2.86 (Fig. 7a). The lowest diversity was noted in spring at station 2, when the species *D. cuculata* dominated at 80%. The highest diversity was confirmed in September at station 5, where the overall biomass was very low and the shares of all the taxanomic groups were equal.

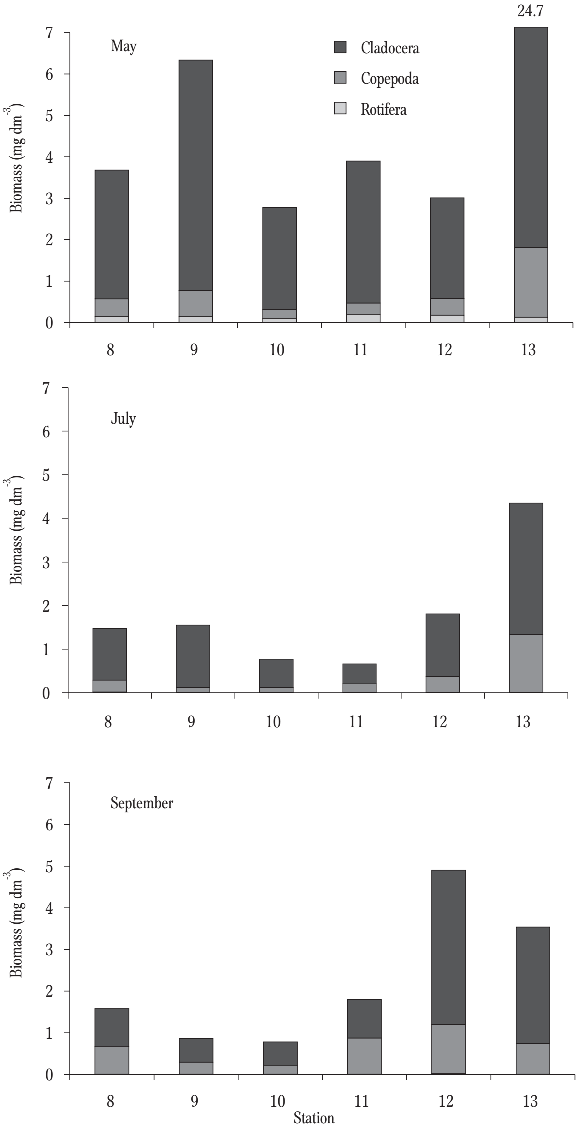

Figure 8. Zooplankton biomass (mg dm^{-3}) in Lake Ślesińskie in 1999.

The highest zooplankton biomass was noted in Lake Ślesińskie in spring after the lake was included into the power plant cooling system. In comparison to that in Lake Licheńskie, the overall zooplankton biomass was much higher (from 1 to 6 mg dm^{-3}). The Cladocera biomass was the highest in the spring when it comprised more than 80% of the total zooplankton biomass. At station 13, which is in the isolated northern section of the lake, the Cladocera biomass was as high as 25 mg dm^{-3} (Fig. 8). The decided biomass dominants there were the Cladocera species *D. cuculata* (18.5 mg dm^{-3}) and *Daphnia longispina* O.F. Müller (3.25 mg dm^{-3}). The share of Copepoda did not exceed 10% and that of Rotifera was not more than 6%. Among Copepoda, numerous juvenile and adult specimens from the family Diaptomidae were noted (*E. gracilis* and *E. graciloides*). However, their biomass did not exceed 0.6 mg dm^{-3}. Among Rotifera, the most frequently noted genus was Keratella. The decided domination of Cladocera (*B. coregoni, D. cucullata, D. brachyurum*) in the overall zooplankton biomass was also confirmed in summer. The weight share of Copepoda fluctuated from 10 to 30%, while Rotifera did not exceed 1% of the overall zooplankton biomass.

The value of the Shannon-Weaver diversity index calculated based on the zooplankton biomass in Lake Ślesińskie ranged from 0.86 to 2.02 (Fig. 7b). The highest value of this index was noted at station 8 in July and September and at station 11 in September. The lowest variation was observed in July at station 9, while high diversity indices were noted at all stations in September. During the other periods, the value of this index fluctuated substantially, and it was particularly evident in July (stations 8 and 9).

Discussion

The occurrence of zooplankton in the Konin lakes is shaped by the particular hydrological, thermal, and trophic conditions in this system (Zdanowski 1994a, 1994b, Hillbricht-Ilkowska and Zdanowski 1988a, 1988b, Pyka et al. 2007, Stawecki et al. 2007). This is linked to the quantity and quality of the post-cooling waters discharged into the system of channels and lakes, the degree to which they are heated, their retention time, and pollution from the drainage area and point sources.

Studies of the impact the discharge of power plant post-cooling waters has on zooplankton taxonomic diversity, spatial distribution, abundance, biomass, and production have been conducted for many years (Patalas 1970, Hillbricht-Ilkowska and Zdanowski 1978, Tunowski 1988). Studies have also been performed in lakes with altered thermal and hydrological regimes to identify and describe changes in primary production

(Zdanowski 1976, 1988, Hillbricht-Ilkowska 1985), and to evaluate changes in the relation of thermal and oxygen regimes and chemical composition of waters, which have significant impacts on the metabolism of planktonic organisms in these basins (Zdanowski and Prusik 1994).

Lake Licheńskie had the highest abundance of rotifers at the end of the 1980s (Tunowski 1994). This assemblage comprised from 90 to 95% of the overall zooplankton abundance. The main dominants then were species from the genus *Synchaeta*, *Polyarthra*, *Brachionus*, and *Trichocerca*, especially *K. cochlearis*, which always achieved maximum biomass in spring (up to 1600 indiv. dm^{-3}) and *S. kitina*. The high abundance of rotifers has also been noted in recent years. The abundance of planktonic crustaceans in this lake was very low and did not exceed 30 indiv. dm^{-3}, as it had in previous study periods. The dominants were *D. cuculata* and *D. brachyurum*. The development of this group of organisms was still limited by excessive water temperatures and probably also by herbivorous fish that had been introduced into the lake (Ciepielewski 2000). In Lake Ślesińskie zooplankton abundance was characterized by a higher share of planktonic crustaceans in comparison to that in Lake Licheńskie. This was doubtless influenced by the lower temperature of the discharge waters that were present only in the growing season. The cladoceran species *B. longirostris* and *D. cuculata* dominated the abundance and biomass (Tunowski 1994). Evaluating the zooplankton based on studies conducted in 1995 and 1996 indicate that the species composition, abundance, and biomass of this fauna was strictly dependent on water temperature in the various periods of the growing season (Tunowski and Siergiejeva 1998). It was confirmed that when the water temperature in Lake Licheńskie was lower by 4.4°C in the summer of 1996 than it had been in the previous year, the zooplankton biomass increased nearly threefold. Substantial increases in the temperature of aquatic ecosystems during the growing season can halt the development of some organisms, and even the entire plankton biocenosis (Patalas 1956, 1970, Evans et al. 1986, Siergiejeva et al. 1991). Water temperature influences zooplankton post-embryonic development, lifespan, and variation in size and growth rates (Węgleńska 1970). Heated waters in a basin can lead to increased numbers of zooplankton generations (Strangenberg 1975, Hillbricht-Ilkowska and Zdanowski 1978). Increased water mixing in heated basins and the associated increased productivity and small phytoplankton development should create advantageous feeding conditions for cladocerans (Hillbricht-Ilkowska and Zdanowski 1978). When warming is excessive, water movement is inhibited, and this can lead to the development of cyanobacteria, which is noted periodically in the Konin lakes (Spodniewska 1984, Socha 1998). The excessive development of Cyanobacteria, which contains and excretes toxic substances, can inhibit the development of filtrating crustaceans (Arts et al. 1992) and rotifers (Gilbert 1994). The various species that inhabit basins that are subjected to long-term heating develop adaptive mechanisms to cope with the changing environment (Goss and Bunting 1976, Goss 1980). The qualitative and quantitative distribution of zooplankton is largely dependent on the development of phytoplankton (Karabin 1985). Large algal networks limit the occurrence and disturb the feeding of large cladocerans (Węgleńska 1970), and above all they lower the rate at which food can be filtered. They can also damage cladoceran filtration apparatuses (Kajak 1979).

The altered environment of the heated lakes caused a decrease in the species diversity among the zooplankton. The prevailing conditions of the Konin lakes meant that different zooplankton domination structures existed in lakes that differed with regard to water temperature and mixing. Small differences in the values of the species diversity index that were noted at various time intervals might indicate that the environment still offers a fairly wide spectrum of trophic possibilities (Ejsmont-Karabin and Węgleńska 1988a, 1988b). The species diversity in lakes Ślesińskie and Licheńskie was fairly low in 1999, which is evidence that the lakes have been transformed significantly and that their current functioning is also significantly different from what it would be under natural conditions. The sampling stations in stagnant areas of the open waters and those in areas with strong water flow differed with regard to the degree to which particular species dominated. The different water mixing conditions shaped very different zooplankton structures in the lakes.

The discharge of heated waters through a cascade system into the cooler Lake Ślesińskie when the long cooling cycle was in operation caused variable thermal conditions, especially at the stations that were subjected the most to the impacts of discharged waters (Tunowski 2009). This had a substantial impact on the abundance of zooplankton at the different stations of the lake. The very strong domination of Crustacea, with high individual biomass, was observed at isolated stations in the north of the lake. The stations in the south tended to have lower densities of both rotifers and crustaceans. This is confirmed by the negative impact that water flow of the cooling system has on the development of zooplankton populations. Simultaneously, in places where there is intense crustacean development a drastic decrease in the abundance of rotifers is noted, and this could have been caused by inter-specific interactions between rotifers and cladocerans. An abundance of species from the genus *Daphnia* can eliminate populations of Rotifera (Gilbert 1985, Schneider 1990). Similar tendencies were observed in Lake Licheńskie, where smaller crustacean abundance, especially of cladocerans, were observed at stations where there is a higher flow of post-cooling waters. The abundance of Cladocera decreased in the southern part of the lake in May, while in July and September they disappeared at some stations in the north of the lake that are under the immediate influence of discharged waters. The zooplankton species diversity index fluctuated, and there were higher values of it lake areas were there was no water flow.

Conclusions

1. The taxonomic composition of the zooplankton of the Konin lakes was very poor with 25 taxa noted in Lake Licheńskie and 30 in Lake Ślesińskie in 1999.
2. Rotifera dominated the abundance of the zooplankton in both lakes. In Lake Licheńskie, *S. kitina* occurred most commonly, while in Lake Ślesińskie it was *K. quadrata*. Among the Crustacea, the dominants were juvenile stages of Copepoda. The overall abundance of zooplankton in Lake Licheńskie, which was warmer, was usually threefold lower (18-200 indiv. dm^{-3}) than in Lake Ślesińskie (47-787 indiv. dm^{-3}).
3. The maximum zooplankton biomass was about 25 times lower in Lake Licheńskie (1.23 mg dm^{-3}) than in Lake Ślesińskie (24.87 mg dm^{-3}). This was because of the development of larger Crustacea forms in Lake Ślesińskie, and the domination of small Rotifera in Lake Licheńskie.
4. The primary factor influencing the abundance and biomass of the individual taxa was the water temperature and the length of the water retention period. The low species diversity index values obtained at stations that were most exposed to the discharge of heated waters are confirmation of this.

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Streszczenie

Struktura zooplanktonu w podgrzanych jeziorach o zróżnicowanej termice i retencji wód

Celem pracy było określenie wpływu retencji i podwyższonej temperatury wody na skład i obfitość zooplanktonu. Zbadano skorupiaki i wrotki jezior Ślesińskiego i Licheńskiego, wchodzących w skład systemu chłodzącego Elektrowni Konin i Pątnów. Jezioro Ślesińskie włączane okresowo (maj-wrzesień) w cykl dużego obiegu wód pochłodniczych charakteryzuje się umiarkowanym stopniem podgrzania (< 25°C) i kilkunastodniową retencją wód (ok. 14 dni). Biomasa zooplanktonu wahała się latem w tym zbiorniku od 1,5 do 4,0 mg dm^{-3} i była niższa od notowanej w maju (< 25 mg dm^{-3}), przed włączeniem jeziora w system schładzania wód pochłodniczych. W Jeziorze Licheńskim, stale podgrzewanym (< 30°C) o 5-dniowej retencji wód, notowano niską liczebność (< 100 osobn. dm^{-3}) i biomasę (< 0,5 mg dm^{-3}) zooplanktonu. W obu jeziorach, oprócz temperatury, czynnikiem modyfikującym rozwój zooplanktonu była niska retencja wód w zbiornikach.