Arch. Pol. Fish. (2009) 17: 221-238
DOI 10.2478/v10086-009-0016-x

RESEARCH ARTICLE

Changes in the zoobenthos structure in a system of heated lakes in central Poland

Received – 22 June 2009/Accepted – 30 September 2009. Published online: 30 December 2009; ©Inland Fisheries Institute in Olsztyn, Poland

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Abstract. The aim of the study was to identify changes in the quality and quantity structure of the zoobenthos assemblages inhabiting the lakes, channels, and basins that comprise the cooling system of a power plant in central Poland. By comparing the invertebrate fauna occurring on the freshwater clam *Sinanodonta woodiana* (Lea) and the macrophyte *Vallisneria spiralis* (L.), the significance of exotic species in the development of invertebrate macrofauna species was demonstrated. The zoobenthos inhabiting the channels was poorer quantitatively and qualitatively than was the lake zoobenthos. Factors that determined this included thermal and oxygen conditions and water flow. Elements that enriched the development of the zoobenthos and the zooperyphyton included populations of alien zebra mussel *Dreissena polymorpha* Pallas and *S. woodiana*, and assemblages of *Myriophyllum spicatum* L. and *Ceratophylum demersum* L. In comparison to thirty years ago, the quality of the bottom fauna in the system has decreased.

Keywords: heated lake, channels, zoobenthos, chironomids, substrate preferences

Introduction

Zoobenthos play an important role in aquatic environments and affect many aspects of their ecology, including habitat-forming functions, organic material transformation, and the cycling of organic elements (Covich et al. 1999). Factors that influence whether or not invertebrates settle in an aquatic ecosystem include the flow of organic and inorganic materials in the basin, temperature, oxygen content, light penetration, water flow rate, substrate type, food availability, and predation by fish and invertebrate predators (Kajak and Prus 2001). Assemblages of benthic organisms are used as bioindicators of changes in water quality (Marchese and Ezcuura de Drago 1999, Kownacki 2000, Kudelska and Soszka 2001).

The density of benthic fauna depends on environmental productivity and thermal and oxygen conditions. Higher zoobenthos biomass is noted in shallow, nutrient-rich environments that are well oxygenated. The biomass of benthos occurring in oxygen-depleted conditions in deep profundal zones is not high (Prus 1998). The biomass of invertebrate fauna occurring on submerged vegetation is comparable with that of benthic fauna, but it is several hundred times lower on emerged vegetation (Pieczyński 1977). The overall abundance of invertebrate macrofauna can fluctuate from several to even several thousand individuals per square meter (Protasov et al. 1994).

Discharges of post-cooling waters by power plants are an important factor that changes the ecological structure and functioning of aquatic ecosystems (Hillbricht-Ilkowska and Zdanowski 1988, Protasov et al. 1997). Changes in the domination and abundance of benthic fauna and variation from the characteristic structure of the zoobenthos and zooperiphyton is a

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consequence of heating waters and subsequent changes in the hydrological and trophic regimes of aquatic basins. Long-term heating usually results in the impoverishment of invertebrate macrofauna, decreased species diversity, and the reduced abundance of organisms. This can ultimately lead to the loss of many species. The niches made available by these organisms are then free to be settled by alien species, especially thermophilic ones (Wróblewski 1977).

The first investigations of the benthic fauna of the Konin heated lakes system were done in the 1960s and 1970s (Leszczyński 1976c, Wróblewski 1977). Until recently, these studies were the only source of information on the domination structure of the benthic species inhabiting this system. Protasov et al. (1994, 1997) presented changes in the quality and quantity structures of the zoobenthos and also confirmed the massive occurrence of the freshwater clam *Sinanodonta woodiana* (Lea) in the heated channels of the cooling system as well as the thermophilic macrophyte *Vallisneria spiralis* (L.).

The aim of the study was to identify changes in the quality and quantity structure of the zoobenthos assemblage in the Konin heated lakes and the channels that connect them with a focus on descriptions of the macrofauna of the lotic systems. The comparison of the invertebrate fauna occurring on *S. woodiana* and *V. spiralis* confirmed that these exotic species played significant roles in the shaping of conditions for the development of invertebrate macrofauna.

Materials and methods

Studies of the benthic fauna of the lake system, channels, and water cooling basins of the power plant were conducted in 2000-2002 (Fig. 1). Twelve basic stations were distributed among the littoral, sublittoral, and profundal zones of lakes Licheńskie and Ślesińskie, in the immediate vicinity of the discharge from the initial cooling basin, and from the bottom of the zone of the main water flow in the channels (Table 1). In 2000, samples were collected six times (January, April, June, July, September) and once in 2002 (July). Additionally, five supplementary stations were designated (Table 1) that were located in the immediate vicinity of the water discharge site from the Konin Power Plant (KPP), in the warm Licheńskie Channel, in a cold stretch of the Warta-Gopło Channel, in the Licheńsko-Pątnowskie Channel, and in the littoral zone of Lake Licheńskie. Samples were collected from these stations three times (in July 2000, 2001, and 2002). In 2001 and 2002 during the peak growing season, samples were also collected of epibiontic fauna occurring on *S. woodiana* and phytophilous fauna occurring among submerged vegetation species *V. spiralis, Myriophyllum spicatum* L., and *Ceratophylum demersum* L.

Benthic fauna samples were taken from the littoral and sublittoral zones of lakes, the initial cooling basin, and the channels in three replicates with a sediment box sampler with a grab area of 100 cm^2 according to methods described in Protasov et al. (1982). Benthos from the profundal zones of the lakes was collected in three replicates with a Kajak core sampler and an Ekman-Birge bottom sampler with a grasping area of 225 cm^2. The benthos samples collected were sieved through a metal sieve with a mesh of 0.25 x 0.25 mm, which permitted separating out the organisms that are identified as macrozoobenthos (Schlacher and Wooldridge 1996a, 1996b).

The epibiontic fauna occurring on freshwater clams and phytophilous invertebrates were collected by divers from a bottom section delineated by a frame with an area of 0.5 m^2. Vegetation was cut and placed in a drag with a 0.25 x 0.25 mm mesh size. The vegetation samples were rinsed in water and then sorted to separate the phytophilous fauna from the substrate. In the laboratory, the vegetation was dried at a temperature of 105°C. Samples of benthic, epibiontic, and phytophilous fauna were preserved in a 4% formaldehyde solution. After drying on blotting paper, the individual organisms were weighed to the nearest 0.1 mg. The abundance and biomass of the benthic fauna were recalculated to 1 m^2 of bottom area; phytophilous fauna were recalculated to 100 g wet weight of vegetation (w.v.); epibiontic fauna were recalculated to 1000 g mussel wet mass (m.w.m.).

Since the share of Chironomidae larvae in the overall abundance and biomass of invertebrate macrofauna was significant, they are described with domination and frequency indices (Kasprzak and Niedbała 1981). Species domination in this group was expressed in classes, as follows: subrecendent < 1%, recendent 1.1-2.0%, subdominant 2.1-5.0%, dominant 5.1-10.0%, and eudominant > 10.1%. The frequency of occurrence of Chironomidae larvae was determined based on sorting the organisms into classes, as follows: accidental species < 25.0%, accessory species 25.1-50.0%, constant species 50.1-75.0%, and absolutely constant species > 75.0%. Faunistic similarity coefficients were calculated for the assemblages of Chironomidae larvae as well as for those of bottom, epibiontic, and phytophilous fauna (Marczewski and Steinhaus 1959, cited in Kasprzak and Niedbała 1981).

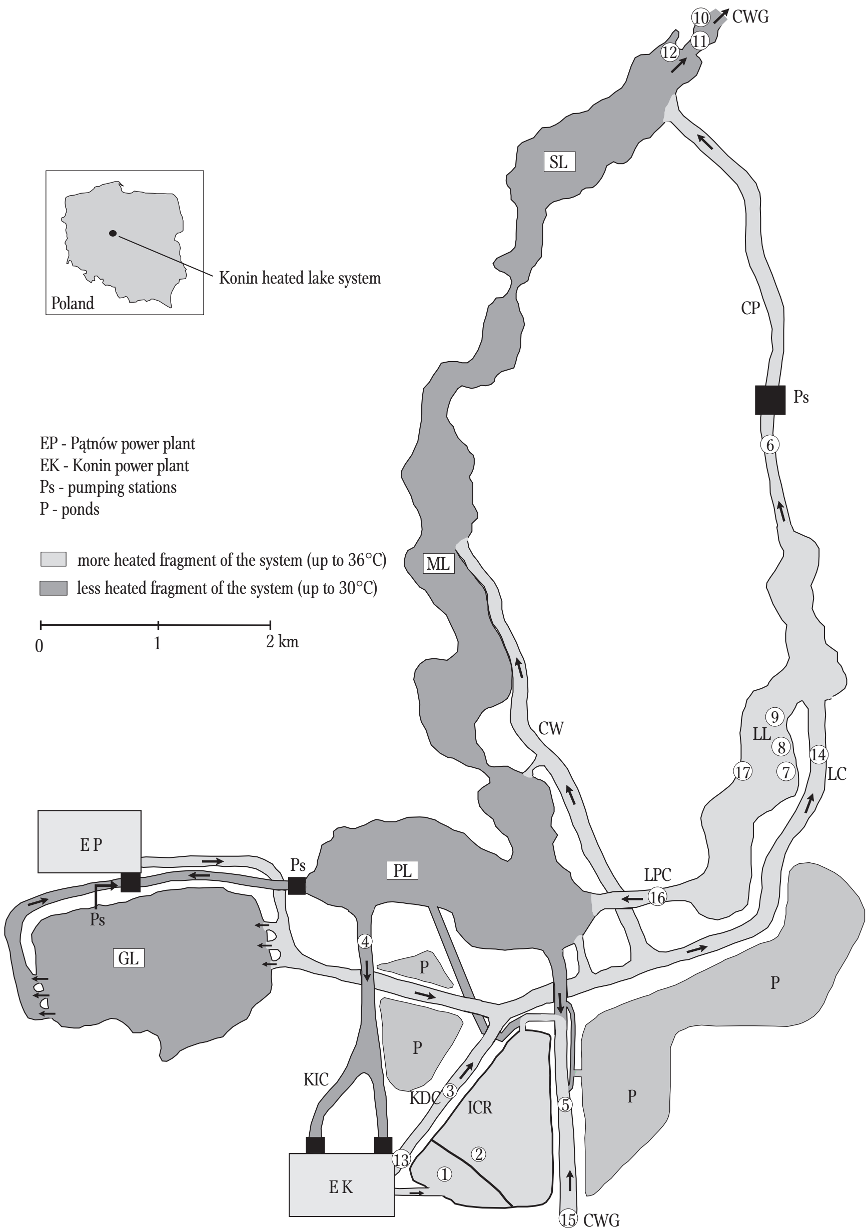

Figure 1. Location of zoobenthos sampling station in the Konin lakes system in 2000-2002. LL – Licheńskie Lake, SL – Ślesińskie Lake, PL – Pątnowskie Lake, GL – Gosławskie Lake, ML – Mikorzyńskie Lake, CP – Piotrkowicki Channel, LC – Licheński Channel, CWG – Warta-Gopło Channel, KDC – Konin discharge channel, LPC – Licheńsko-Pątnowski Channel, CW – Wąsowski Channel, KIC – Konin inlet channel, ICR – Initial coding reservoir.

Table 1
Morphological and hydrological characteristics of the basic (1-12) and supplementary (13-17) zoobenthos sampling sites in the Konin lakes system in 2000-2002

Location	Sampling station number	Depth (m)	Temperature (°C)	Oxygen content (mg O_2 dm^{-3})	Water flow rate (m s^{-1})	Substrate type	Characteristics
Initial cooling basin	1	2.0	21	9	0.03	Muddy ediments	-
Initial cooling basin	2	3.0	20	9	0.02	Muddy sediments (organic)	-
Konin Power Plant discharge channel	3	2.3	19	9	0.12	Sandy sediments covered with *S. woodiana* shells	No aquatic vegetation
Konin Power Plant inlet channel	4	3.0	14	10	0.32	Sandy-rocky sediments covered with *D. polymorpha* shells	-
Warta-Gopło Channel	5	2.5	21	7	0.10	Sandy sediments	Warm segment
Piotrkowicki Channel	6	3.1	24	8	0.05	Muddy sediments	Segment up to pumping station banks overgrown with *V. spiralis*
Lake Licheńskie (littoral)	7	0.5	18	8		Sandy sediments	Bottom covered with mats of *V. spiralis*
Lake Licheńskie (sublittoral)	8	2.5	18	8		Sandy sediments covered with *D. polymorpha* shells	Station located outside range of *V. spiralis*
Lake Licheńskie (profundal)	9	7.0	4	4		Muddy sediments	-
Lake Ślesińskie (littoral)	10	0.5	13	11		Sandy sediments	Banks overgrown with submerged and emerged vegetation
Lake Ślesińskie (sublittoral)	11	2.5	14	9		Sandy sediments covered with filamentous algae	-
Lake Ślesińskie (profundal zone)	12	15.0	4	2		Muddy sediments	Periodic oxygen depletion, detectable H_2S
Konin Power Plant discharge channel	13	2.5	20	8	0.12	Sandy-rocky sediments	Immediate water discharge area – no vegetation
Licheński Channel	14	3.2	20	7	0.17	Sandy sediments	No vegetation
Warta-Gopło Channel	15	1.5	14	5	0.01	Muddy sediments	Cold segment
Licheńsko-Pątnowski Channel	16	2.6	25	6	0.11	Muddy sediments covered with *D. polymorpha* shells	Banks overgrown with *V. spiralis* and emerged vegetation
Lake Licheńskie (littoral)	17	1.0	18	8		Sandy sediments	Bottom totally covered with *V. spiralis*

Changes in fauna abundance and biomass at sampling stations in the different years of the study were analyzed with Tukey's test. Relationships between environmental characteristics and abundance, biomass, and the number of taxa of invertebrates were estimated with canonical correlation analyses. The significance of relationships between the groupings of benthic fauna and environmental factors (water temperature, oxygen content, water flow, depth and character of substrate) were tested with analysis of covariance (ANCOVA).

Results

General characteristics of the zoobenthos

The invertebrate fauna of the Konin lakes system was represented by 75 taxa. The benthic fauna comprised 60 species, epibiontic 25, and phytophilous 49 (Table 2). The greatest diversity among the three categories of zoobenthos were exhibited by Chironomidae (18 taxa), Oligochaeta (8 taxa), and Bivalvia (7 taxa) among the benthic fauna; by Chironomidae (10 taxa), Oligochaeta (4 taxa), and Amphipoda (3 taxa) among the epibiontic fauna; and by Chironomidae (13 taxa) and Gastropoda (8 taxa) among the phytophilous fauna.

Benthic fauna

The occurrence and abundance of benthic macroinvertebrates at the sampling stations during the study period depended on the depth and oxygenation of the habitats (ANCOVA, $P < 0.05$). The greatest benthic fauna species richness was noted at the most oxygenated stations (> 8 mg dm^{-3}) that were moderately warm (Fig. 2). In the sublittoral of Lake Ślesińskie (station 11) and in the littoral of Lake Licheńskie (station 7) 30 and 37 taxa were noted, respectively. The lowest benthic fauna species richness was noted in the profundal zone of Lake Ślesińskie (station 12) and in the discharge channel of the power plant (station 13). There was no correlation between species richness of the benthic fauna and the degree to which the water was heated.

The abundance of benthic fauna at stations was linked to the depths at which the zoobenthos settled in different zones (ANCOVA, $P < 0.01$). The highest benthic fauna abundance (1714 indiv. dm^{-3}) was noted in the littoral zone of Lake Ślesińskie (station 10), while the lowest (39 indiv. m^{-2}) was in the profundal zone of Lake Licheńskie (station 9). The abundance of benthic fauna fluctuated greatly in the lotic zone (from 435 to 1053 indiv. m^{-2}; Fig. 3). The abundance of zoobenthos in the heated channels increased with distance from the discharge site, and the highest abundance was noted in distant segments of the discharge channels. Oligochaetes, especially those of the genus *Tubifex*, dominated quantitatively in all of the lotic zones including the sublittoral (station 8) and profundal (station 9) zones in the heated Lake Licheńskie. The majority of the zoobenthos abundance in the Konin Thermoelectric Plant inlet channel (station 4) and in the profundal zone of Lake Ślesińskie (station 12) was comprised of amphipods, represented primarily by *Corophium curvispinum* G.O Sars. However, at the lentic stations, which included the littoral zone of Lake Licheńskie (station 7) and the littoral (station 10) and sublittoral (station 11) of Lake Ślesińskie, were dominated by Chironomidae, and their abundance was determined by the mass occurrence of *Stictochironomus psamnophilus* Chernovskij.

The variation in benthic fauna biomass at stations was linked to the depths the zoobenthos inhabited in the various zones (ANCOVA, $P < 0.01$). In the littoral and sublittoral of lakes Licheńskie (stations 7 and 8) and Ślesińskie (stations 10 and 11) as well as in the distant segments of the warm discharge channel the benthic fauna biomass was higher (from 4.30 to 6.05 g m^{-2}) than it was in the other lotic zones of the initial cooling basin (from 1.21 to 3.59 g m^{-2}). The lowest benthic fauna biomass (0.15 g m^{-2}) was noted at station 9 in the profundal zone of Lake Licheńskie (Fig. 4). Usually, the biomass dominant were oligochaetes, while amphipods and chironomids dominated in terms of weight in KPP inlet channel (station 4), in the littoral of Lake Licheńskie

Table 2
Taxonomic composition of invertebrate macrofauna at sampling stations in the Konin lakes system

Benthic fauna (Station)

Taxa	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Class: Turbellaria															
Dugesia tigrina															
Class: Gastropoda															
Viviparus viviparus															
Bithynia tentaculata	+			+	+		+	+		+	+				
Physa fontinalis															
Lymnaea stagnalis															
Lymnaea sp.					+										
Anisus vortex															
Planorbarius corneus										+					
Radix ovata					+										
Class: Bivalvia															
Sphaerium corneum				+						+	+				
Pisidium amniculum				+											
P. crassum				+											
P. supinum				+											
Dreissena polymorpha	+		+	+	+	+	+	+	+	+	+				+
Unio tumidus				+	+						+				
Sinanodonta woodiana	+	+		+											
Class: Oligochaeta															
Chaetogaster sp.						+	+								
Stylaria lacustris															
Dero sp.					+		+	+	+						
Nais sp.	+				+	+	+				+			+	
Branchiura sowerbyi	+	+	+	+	+	+	+	+	+		+		+	+	+
Potamothrix sp.			+	+	+	+	+	+	+	+	+			+	
Tubifex sp.	+	+	+	+	+	+	+	+	+	+	+	+			+
Limnodrilus sp.	+		+		+	+	+	+	+	+	+			+	
Lumbriculus variegatus	+	+				+	+		+						
Class: Hirudinea															
Glossiphonia complanata											+				+
Helobdella stagnalis										+	+				
Erpobdella octoculata										+					

Epibiontic fauna (Station)

Taxa	1	2	3	4	5	6	8	11	13	14	15	16
Class: Turbellaria												
Dugesia tigrina	+	+	+	+				+				+
Class: Gastropoda												
Viviparus viviparus												
Bithynia tentaculata				+				+			+	
Physa fontinalis												
Lymnaea stagnalis												
Lymnaea sp.												
Anisus vortex												
Planorbarius corneus												
Radix ovata												
Class: Bivalvia												
Sphaerium corneum												
Pisidium amniculum												
P. crassum												
P. supinum												
Dreissena polymorpha	+	+		+	+	+	+	+		+		+
Unio tumidus												
Sinanodonta woodiana												
Class: Oligochaeta												
Chaetogaster sp.												
Stylaria lacustris												
Dero sp.												
Nais sp.												
Branchiura sowerbyi									+			
Potamothrix sp.											+	
Tubifex sp.	+			+					+			
Limnodrilus sp.									+	+		
Lumbriculus variegatus												
Class: Hirudinea												
Glossiphonia complanata								+			+	
Helobdella stagnalis												
Erpobdella octoculata												

Epiphytic fauna (Station)

Taxa	1	2	4	5	6	7	10	15	16	17
Class: Turbellaria										
Dugesia tigrina			+	+	+			+		+
Class: Gastropoda										
Viviparus viviparus			+						+	
Bithynia tentaculata			+				+			
Physa fontinalis		+								
Lymnaea stagnalis		+								
Lymnaea sp.		+		+			+	+		
Anisus vortex			+							
Planorbarius corneus		+								
Radix ovata		+	+				+			+
Class: Bivalvia										
Sphaerium corneum										
Pisidium amniculum										
P. crassum										
P. supinum										
Dreissena polymorpha		+	+		+	+	+		+	+
Unio tumidus										
Sinanodonta woodiana										
Class: Oligochaeta										
Chaetogaster sp.										
Stylaria lacustris							+	+		
Dero sp.										
Nais sp.										
Branchiura sowerbyi										
Potamothrix sp.										
Tubifex sp.										
Limnodrilus sp.										
Lumbriculus variegatus										
Class: Hirudinea										
Glossiphonia complanata			+	+			+	+		
Helobdella stagnalis								+		
Erpobdella octoculata							+			

Cont. Table 2

Taxa	Benthic fauna															Epibiontic fauna												Epiphytic fauna									
	Station																																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1	2	3	4	5	6	8	11	13	14	15	16	1	2	4	5	6	7	10	15	16	17
Order: Amphipoda																																					
Gammarus pulex	+	+	+		+	+	+			+	+		+			+	+		+	+	+		+			+	+		+	+				+			
Corophium curvispinum	+	+	+	+	+	+	+		+		+	+	+	+		+	+		+	+	+	+	+		+		+	+	+	+	+	+	+	+		+	
C. robustrum				+	+		+			+						+	+		+	+	+	+	+				+		+	+							
C. mucronatum				+		+	+							+																							
Order: Isopoda																																					
Asellus aquaticus																										+								+			
Family: Chaoboridae																																					
Chaoborus crystallinus															+																						
Family: Ceratopogonidae																																					
Sphaeromias pictus								+	+	+	+																										
Bezzia sp.																																		+			
Hydracarina:																																					
Hydrachna sp.											+																										
Limnesia sp.		+									+																										
Unionicola sp.	+									+	+																							+	+		
Mideopsis sp.		+						+			+																								+		
Order: Ephemeroptera																																					
Beatis sp.																													+								
Caenis horaria				+	+		+	+	+	+	+			+			+					+				+									+		
C. macrura	+	+				+	+		+	+	+																				+			+			
Caenis sp.							+	+		+	+			+															+						+		
Order: Odonata /Zygoptera/																																					
Platycnemis pennipes					+																													+	+		
Coenagrion pulchellum							+																						+						+		
Calopteryx virgo																														+					+		
Calopteryx sp.																																			+		
Order: Megaloptera																																					
Sialis lutaria					+																					+											
Order: Trichoptera																																					
Ecnomus tenellus	+	+	+	+	+	+	+				+		+	+		+	+	+	+	+	+	+			+	+	+	+		+		+	+	+	+	+	
Polycentropus flavomaculatus		+																																			
Limnephilus flavicornis							+			+																									+		

Cont. Table 2

Taxa	Benthic fauna															Epibiontic fauna												Epiphytic fauna									
	Station																																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	1	2	3	4	5	6	8	11	13	14	15	16	1	2	4	5	6	7	10	15	16	17
Order: Coleoptera																																					
Platambus maculatus																																		+	+		
Hyphydrus ovatus																																		+			
Family: Chironomidae																																					
Procladius sp.	+	+			+	+	+	+	+	+	+	+		+	+							+						+	+					+			
Clinotanypus nervosus																																			+		
Ablabesmyia monilis							+																						+					+			
Cricotopus sp.	+	+									+																										
Isocladius silvestris					+																																
Psectrocladius sp.		+	+			+				+													+					+		+	+		+	+			+
Chironomus plumosus		+			+	+	+	+	+	+	+	+			+											+			+					+	+		
Cryptochironomus defectus		+			+	+	+	+	+	+	+			+												+			+	+		+	+	+			+
C. pararostrachus		+			+	+		+		+	+															+			+	+	+	+	+	+			+
Dicrotendipes tritomus	+				+						+							+											+								
Dicrotendipes sp.											+																		+								
Endochironomus tendens	+		+		+		+	+		+	+			+																	+	+	+	+		+	+
E. albipennis	+				+	+	+	+	+	+	+			+		+	+			+		+				+		+	+					+			+
Glyptotendipes gripekoveni							+	+																					+			+					
Pollypedillum sp.	+				+		+		+		+							+								+			+			+					
Microtendipes chloris						+	+				+												+						+					+			
Strictochiron. psamnophilus							+		+	+	+																										
Tanytarsus sp.						+	+				+																										
Micropsectra praecox						+					+															+											
Order: Lepidoptera																																					
Nymphula sp.										+																				+				+			

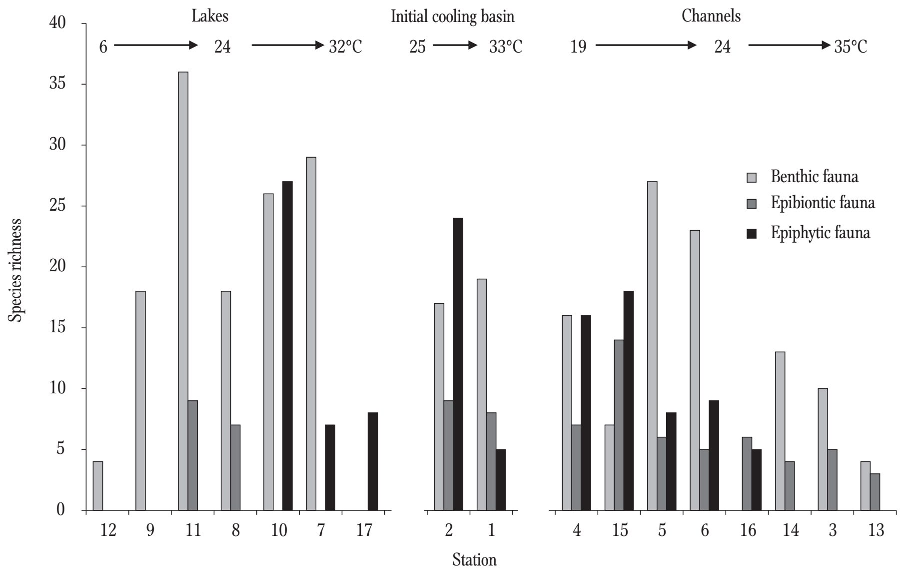

Figure 2. Species richness of the benthic, epibiontic, and phytophilous fauna at sampling stations in the Konin lakes system in 2000-2002. Stations sorted according to main habitat type and thermal characteristics.

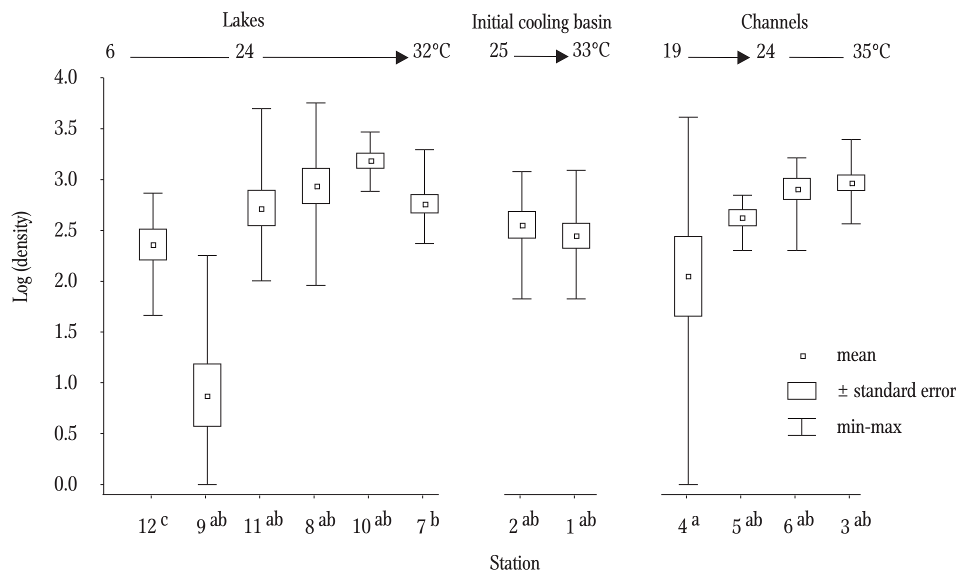

Figure 3. Abundance of benthic fauns in the Konin lakes system. Statistically significant variations in means are denoted with different letter superscripts (P < 0.05).

(station 7), and the littoral and sublittoral of Lake Ślesiński (stations 10 and 11).

Among the chironomid benthic fauna, there were 18 taxa (Table 3). The majority occurred sporadically and only two species, *Procladius* sp. and *Chironomus plumosus* L., occurred more frequently, and the latter was also the dominating species. *S. psamnophilus* also had a high domination index (40%), as it occurred in summer in the littoral of lakes Licheńskie (station 7) and Ślesińskie (station 10).

Epibiontic fauna

The species richness of epibiontic fauna ranged from three to 14 taxa (Fig. 2). No more than three taxa were noted at the warmest stations (represented mainly by oligochaetes), while the highest species

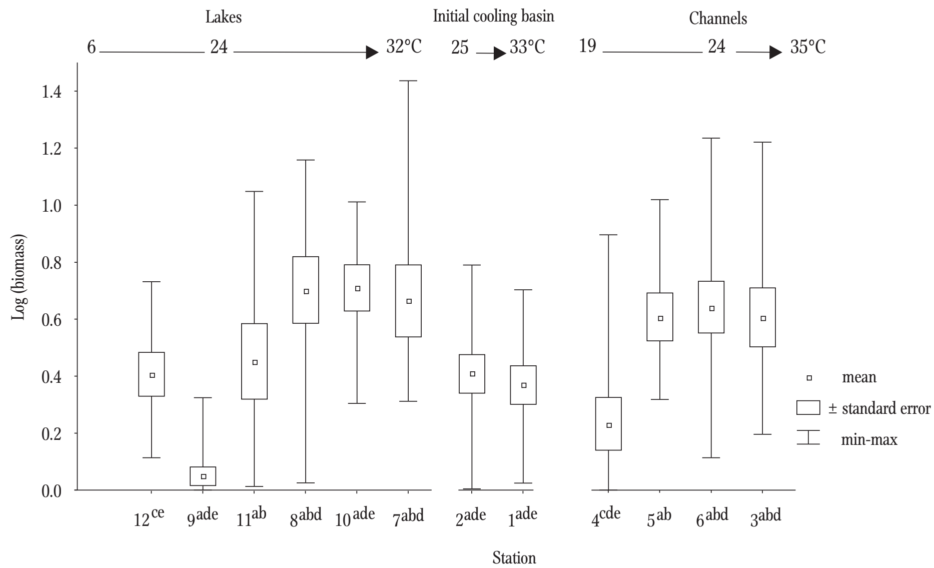

Figure 4. Biomass of bottom fauna in the Konin lakes sytem in 2000-2002. Statistically significant variations in means are denoted with different letter superscripts (P < 0.05).

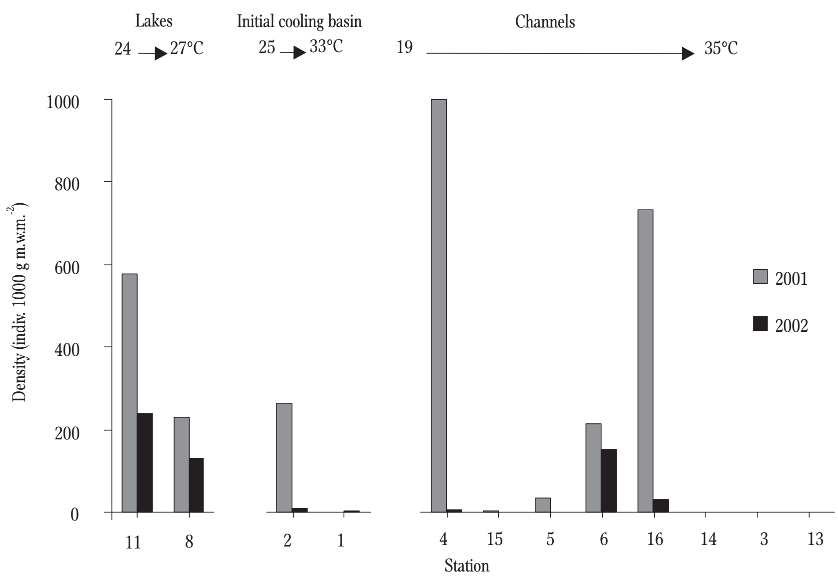

Figure 5. Mean density of epibiontic fauna in the Konin lakes system in 2001-2002.

richness of epibiontic fauna was noted in the cold segment of the Warta-Gopło Channel (station 15). The depth of the zones inhabited by macroinvertebrates, water temperatures, and oxygen conditions all had a significant influence on the species composition, abundance, and biomass of the epibiontic fauna at the stations sampled and in the periods studied (ANCOVA, P < 0.05). Species diversity in the epibiontic species assembly grew with increasing habitat depth, but decreased with increasing water temperature.

The abundance of epibiontic fauna on *S. woodiana* fluctuated from 10 indiv. in the Licheńskie Channel (station 14) to 9852 indiv. 1000 g m.w.m.$^{-1}$ in the water uptake channel of the KPP (station 4, Fig. 5). The dominating species was *Dreissena polymorpha* Pallas, which comprised as much as 50% of the epibiontic fauna inhabiting station 4. There were more

Table 3
Frequency and domination of larval Chironomidae in the benthic (a), epibiontic (b), and phytophilous (c) fauna in the Konin lakes system in 2000-2002

	Frequency			Domination		
Taxa	a	b	c	a	b	c
Procladius sp.	31	15	21	10	<1	9
Clinotanypus nervosus (Meigen)	-	5	-	-	<1	-
Ablabesmyia monilis (L.)	<1	10	-	<1	<1	-
Cricotopus sp.	8	-	8	2	-	9
Isocladius silvestris (Fabricius)	2	-	-	<1	-	-
Psectrocladius sp.	5	40	8	2	8	5
Chironomus plumosus (L.)	27	15	8	11	46	5
Cryptochironomus defectus (Kieffer)	21	35	17	9	8	5
C. pararostrachus (Harnisch)	11	45	8	3	6	9
Dicrotendipes tritomus (Kieffer)	2	20	4	2	2	5
Dicrotendipes sp.	<1	-	-	<1	-	-
Endochironomus tendens (Fabricius)	14	55	-	5	13	-
E. albipennis (Meigen)	11	25	33	4	8	32
Glyptotendipes gripekoveni (Kieffer)	3	15	-	<1	3	-
Pollypedillum sp.	11	10	8	4	2	14
Microtendipes chloris (Meigen)	4	-	4	8	-	5
Strictochiron. psamnophilus Chernovskij	14	-	-	37	-	-
Tanytarsus sp.	4	10	-	1	1	-
Micropsectra praecox (Meigen)	2	-	8	<1	-	5

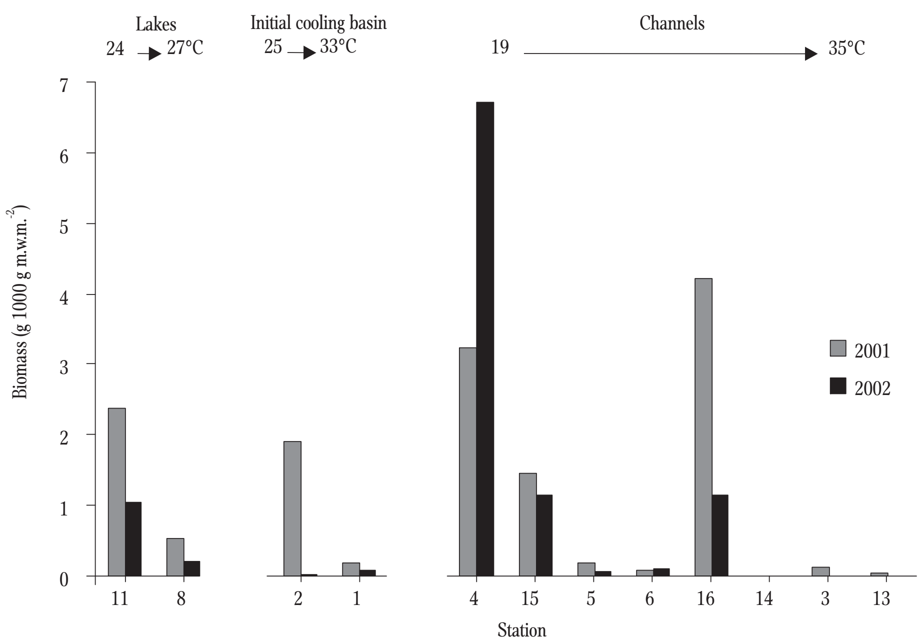

Figure 6. Mean biomass of epibiontic fauna in the Konin lakes system in 2001-2002.

advantageous developmental conditions for epibiontic fauna in the lotic zones of the system and in the water uptake channel for the KPP. The highest epibiont densities were noted in these locations, while at the stations located near the heated water discharge epibiont mortality was accompanied by a distinct decrease in the abundance of *D. polymorpha*. Higher epibiontic fauna biomass was also confirmed in the most oxygenated environments (8-10 mg dm^{-3}), with the maximum value (999 g 1000 g m.w.m.$^{-1}$) noted in the cold uptake channel of the KPP (station 4, Fig. 6). The epibiont biomass was extremely low in the immediate vicinity of the water discharge zone of the KPP (station 3) and in the Licheńskie Channel (station 14) at 0.05 and 1.25 g 1000 g m.w.m.$^{-1}$, respectively. *D. polymorpha* was the decided dominant in the lotic and lentic zones that were moderately heated, while Trichoptera and Oligochaeta were the dominants in the water discharge channel (station 3) and in the cold segment of the Warta-Gopło Channel (station 15). If Mollusca is excluded from the epibiontic fauna weight structure, then the dominant group becomes the Amphipoda.

The chironomid larval assemblage occurring on *S. woodiana* was comprised of 13 species (Table 3). Most of these occurred sporadically, with the exception of the following four species: *Psectrocladius* sp.; *Cryptochironomus defectus* (Kieffer); *Cryptochironomus pararostrachus* (Harnisch); *Endochironomus tendens* (Fabricius). Only *Ch. plumosus* was a dominating species.

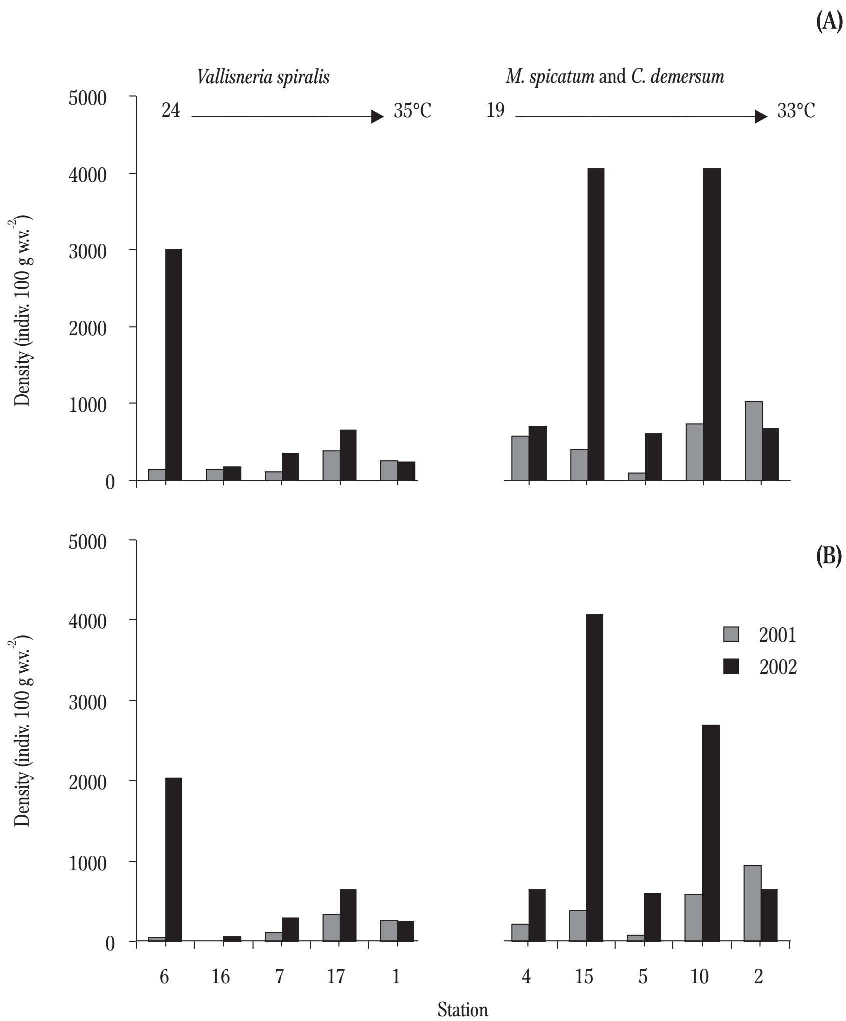

Figure 7. Mean abundance of phytophilous fauna in the Konin lakes system in 2001-2002. A – density of all phytophilous species, B – density of all phytophilous fauna without Chironomidae.

Epiphytic fauna

The greatest invertebrate species richness occurring on *M. spicatum* and *C. demersum* was noted at stations 10 and 1, which were the littoral of Lake Ślesińskie (27 taxa) and the initial cooling basin (24 taxa, Fig. 2). Slightly fewer phytophilous species were noted in the water inlet channel of the KPP (station 4) and the cold segment of the Warta-Gopło Channel (station 15) at 16 and 18 taxa, respectively. Distinctly fewer zoobenthos species settled on *V. spiralis* (from 5 to 9). Species from the genus Chironomidae occurred most frequently on assemblages of *M. spicatum* and *C. demersum* (12 stations), as well as on *V. spiralis* (5 stations). The highest taxonomic differentiation among phytophilous fauna was confirmed at stations with moderate water temperatures (< 20°C).

Species richness and abundance of phytophilous fauna depends to a significant degree on the water thermal regime (ANCOVA P < 0.01). The highest phytophilous fauna abundance developing on *V. spiralis* was confirmed at station 6 in the Piotrkowickie Channel (3002 indiv. 100 g^{-1} w.v.), and on assemblages of *M. spicatum* and *C. demersum* in the cold segment of the Warta-Gopło Channel (station 15) and in the littoral zone of Lake Ślesińskie (station 10) at 4061 and 4065 indiv. 100 g^{-1} w.v., respectively; Fig. 7). The highest density of

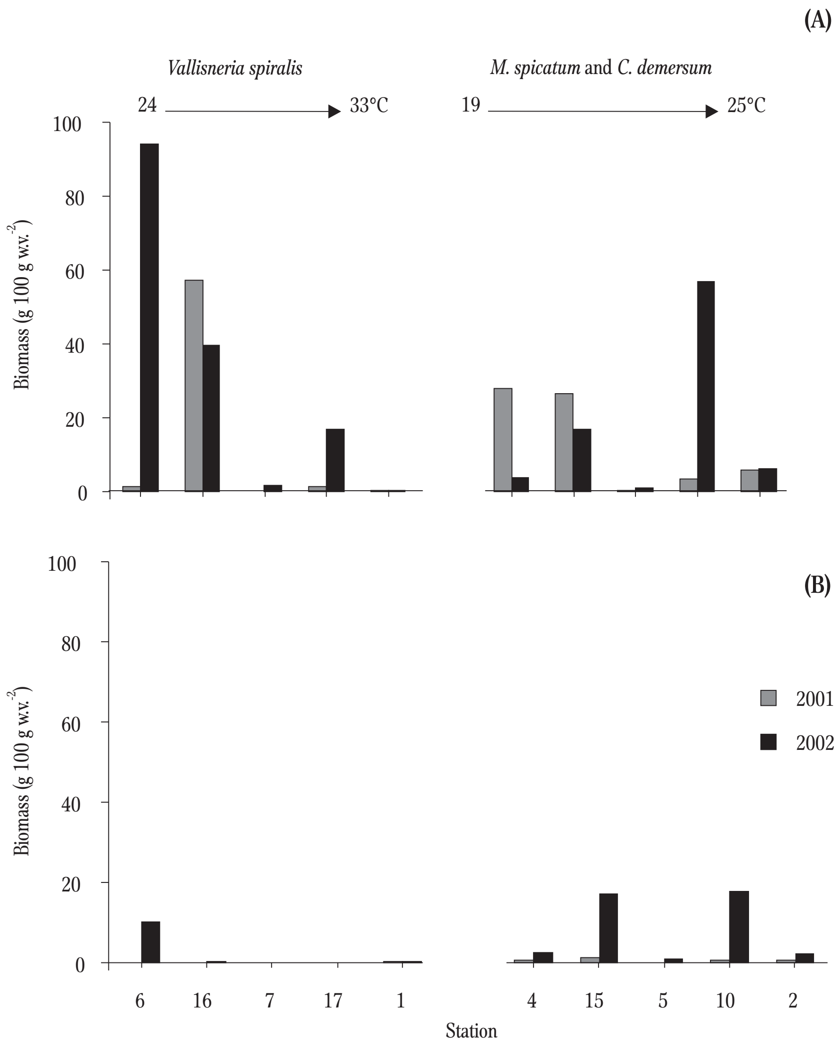

Figure 8. Mean biomass of phytophilous fauna in the Konin lakes system in 2001-2002. A – biomass of all phytophilous species, B – biomass of phytophilous fauna without Chironomidae.

phytophilous fauna developing on both *V. spiralis* and *M. spicatum* and *C. demersum* was noted in the littoral of Lake Licheńskie (station 7) at 117 and 90 indiv 100 g^{-1} w.v., respectively.

The biomass of phytophilous fauna differed significantly among the sampling stations (ANCOVA, $P < 0.05$). In assemblages of *V. spiralis* it ranged from 0.1 to 94 g 100 g^{-1} w.v. (at stations 7 and 6, respectively; Fig. 8). While in assemblages of *C. demersum* and *M. spicatum*, the lowest biomass of phytophilous fauna 0.25 g 100 g^{-1} w.v. was noted at station 5, while the highest at 57 g 100 g^{-1} w.v. was noted in the littoral of Lake Ślesińskie (station 10).

In terms of numbers, the phytophilous fauna was dominated by Chironomidae, which developed intensely especially in assemblages of *V. spiralis*, while in terms of weight (and because of the high individual weight) Mollusca dominated. After excluding Mollusca from the overall biomass, Chironomidae dominated the phytophilous fauna in assemblages of *V. spiralis,* while Amphipoda did so in assemblages of *M. spicatum* and *C. demersum. Endochironomus albipennis* (Meigen) contributed the greatest share of chironomid larvae to the phytophilous fauna zoocoenosis (Table 3).

Faunistic similarities

The taxanomic composition of the zoobenthos in the initial cooling basin (station 1; in front of the stone barrier) and the sublittoral zone of Lake Ślesińskie (station 11; Fig. 9a) was similar. Analogous similarities were noted with regard to the warm segment of the Warta-Gopło Channel (station 5) and the initial cooling basin (station 2; beyond the stone barrier), as well as in the littoral and profundal zones of Lake Licheńskie (stations 7 and 9) and the final segment of the Licheńskie Channel (station 14).

The presence and habitat-creating role of *D. polymorpha* settling on *S. woodiana* also had a significant impact on the similarity of stations inhabited by epibiontic fauna, despite the various environmental conditions prevailing in these locations. The quality of the epibiontic fauna of the

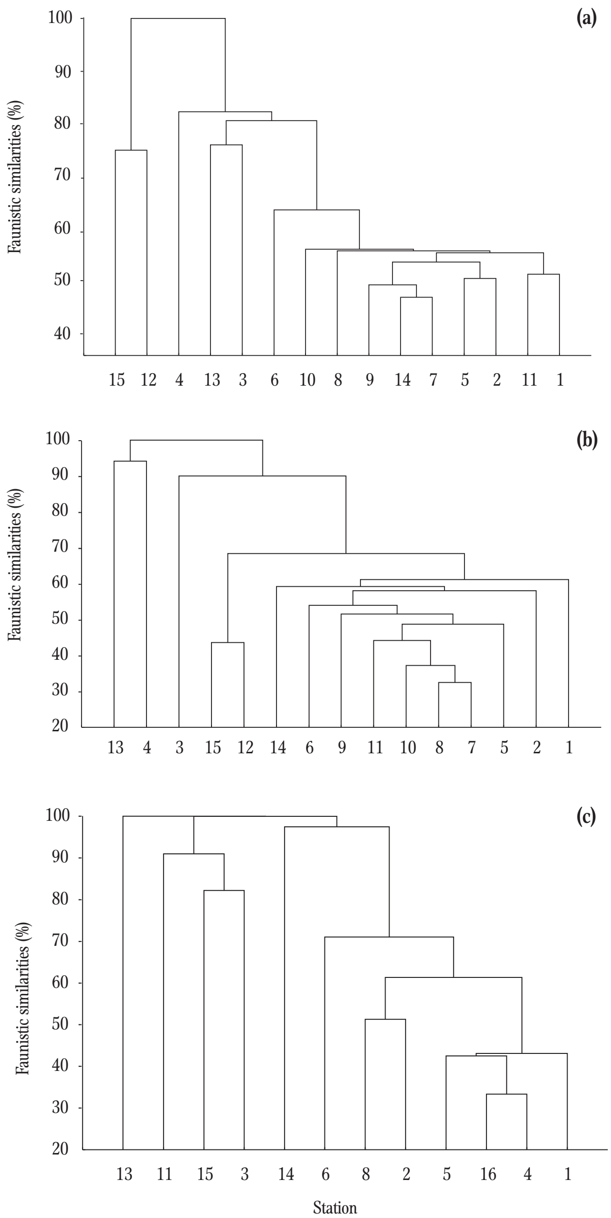

Figure 9. Faunistic similarities among benthic fauna (a), epibiontic fauna (b), and phytophilous fauna (c) in the Konin lakes system in 2000-2002.

Licheńsko-Pątnowski Channel (station 16) and the water uptake channel for the KPP (station 4) was similar (Fig. 9b). The fauna of the initial cooling basin (station 1) and the warm segment of the Warta-Gopło Channel (station 5) were slightly less similar.

The phytophilous fauna was similar taxonomically at two stations – the Piotrkowickie Channel (

station 6) and in the littoral zone of Lake Licheńskie (station 7; Fig. 9c).

Discussion

In comparison with the results of studies from the 1960s (Leszczyński 1976a, 1976b, 1976c), 1970s (Biesiadka 1977a, 1977b, Kasprzak 1977a, 1977b, Mielewczyk 1977a, 1977b, Sywula 1977, Berger and Dzięczkowski 1977), and 1990s (Protasov et al. 1994, 1997) that describe the macrofauna of the Konin lakes system, those of the current study from the 2000-2002 period indicate that the macrofauna is poorer both qualitatively and quantitatively. These differences might not be as significant as they appear and could stem from different methodological approaches. In the current study, the lotic components of the system (which are usually poorer in fauna) were studied in detail. However, areas omitted included the densely overgrown shallow areas of lakes Gosławskie and Pątnowskie, ecotone habitats, ponds located near the lakes, and parts of the littoral that are isolated by rushes and outside of the immediate reach of system water currents.

In comparison to basins with natural thermal regimes, the macrofauna of the Konin lakes in the 2000-2002 period exhibited much poorer species richness. This observation was true of nearly all of the taxonomic groups analyzed. The diversity of Chironomidae at the selected stations in the 2000-2002 period was generally lower than that reported by Leszczyński (1976a) in the 1960s, and lower than that observed in unheated basins (Zięba 1996, Jabłońska and Koszałka 2000). The number of Gastropoda taxa was also lower in the Konin lakes system than in basins with a natural thermal regime (Dusoge et al. 1990, Włosik-Bieńczak 1997). More snail species (34) were only noted by Berger and Dzięczkowski (1977) only in the initial period of heating. Protasov et al. (1994, 1997) reported that the species diversity of Gastropoda was declining in lakes Pątnowskie and Gosławskie and in Lake Wąsosko-Mikorzyńskie in the mid 1990s. Progressive declines in species richness have also been reported among Bivalvia (Protasov et al. 1994, 1997). The main representative of this class in moderately heated waters (< 28°C) was *D. polymorpha*, while in the strongly heated zones (> 28°C) the dominant was *S. woodiana*. Native Unionidae clam species preferred the cooler parts of the system (Lake Ślesińskie, the northern part of Lake Wąsosko-Mikorzyńskie, and the inlet channel for the KPP). Impoverishment in species diversity was also noted in the following taxonomic groups: Hirudinea, Isopoda, and Hydrachnidia. In the 1960s, 13 Hirudinea species occurred, but in the 1970s this had decreased to seven taxa (Kasprzak 1977b), and then just three in the 2000-2001 period. The diversity of Hydrachnidia was decidedly lower than that noted in basins with a natural thermal regime (Zawał 1992, Cichocka 1996); this was also confirmed in the 1970s by Biesiadka (1977a, 1977b).

The primary deciding factor in the qualitative and quantitative changes in the zoobenthos of the Konin lakes system was water temperature. Increases in it could have changed not only the overall rate of primary production (Wigert and Fraleigh 1972), but it could also have accelerated the development of organisms, or increased trophic reactions. This, in turn, could have shortened the life cycle, increased the number of generations occurring in one season, and increased the amount of organic material produced or accumulated on the bottom sediments (Kraska 1988). Transformations in the quantitative structure of the zoobenthos could have been a consequence of morphological changes in the organisms, and, thus, more frequent dwarfism and lower mean individual biomass (Wellborn and Robinson 1996). The benthic fauna of the zones that were heated most intensely, which were also, as a rule, those with the fastest currents, were the poorest. The only organisms that occurred here were those associated with the bottom, mainly Oligochaeta, which are more resistant to high temperatures. The development of macrofauna was more intense in the environments that had better oxygenation (> 8 mg dm^{-3}), thus, the littoral and sublittoral areas of lakes and the cooler segments of channels were where they developed. As the quantity of oxygen decreased in the near-bottom waters, the abundance and diversity of the macroinvertebrate fauna deceased. A similar trend was observed in basins with natural thermal regimes (Dusoge et al. 1990, Protasov et al. 1994). In addition to water oxygen content and temperature, water flow rate is another important factor influencing the quality and quantity structures of invertebrate fauna (Grzybowska and Dukowska 2001). The highest density of macrofauna was noted in the non-flowing littoral and sublittoral zones of lakes Licheńskie and Ślesińskie.

The epibiontic fauna on *S. woodiana* was formed, above all, by periphyton colonies of *D. polymorpha*. In the zone where these two species dominated, the growth of the zoobenthos was the highest. A consequence of the increased temperature to above 28°C was the mass mortality of *D. polymorpha*, as well as drastic reductions of other components of the epibiontic fauna. Phytophilous fauna, represented mainly by Chironomidae, expanded more readily in assemblages of *C. demersum* and *M. spicatum* than in assemblages of *V. spiralis*. This might have been because of limited access to food (Kornijów 1989, Pieczyńska 2002) and the morphology of the spiraled leaves of *V. spiralis* (Dudley 1988).

The Konin lakes system offers greater possibilities for the development of fauna, thanks to the occurrence in it of various microhabitats and different morphometric and morphological conditions, than do strong flowing, regulated rivers and dam reservoirs that serve as cooling systems for nuclear power plants (Protasov and Sinicyna 1993, Wellborn and Robinson 1996). Such ecologically diversified ecosystems should be protected from degradation caused by anthropogenic pressure, as well as that which is caused by the introduction of alien flora and fauna species (Hillbricht-Ilkowska and Zdanowski 1988).

Conclusions

1. The invertebrate macrofauna of the lotic channel network was generally poorer in both quality and quantity than was the lentic zone of the lakes. The fauna selection factors in the channels were temperature and water flow. The occurrence of fauna in the lentic environment of the lakes was determined by the thermal and oxygen conditions in the layer above the sediments.
2. The development of zobenthos and zooperiophyton fauna in the Konin lakes is supported by the intensely developing populations of *D. polymorpha* and *S. woodiana*.
3. Phytophilous fauna in assemblages of *V. spiralis* was poorer than in indigenous assemblages of *M. spicatum* and *C. demersum*.
4. The quality of benthic fauna in the system, similarly to abundance and biomass, is seemingly decreasing. It is possible that benthic fauna could develop more intensely in habitats that are isolated from the main stream of flowing discharge waters and ecotone zones.

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Streszczenie

Zmiany struktury zoobentosu w systemie podgrzanych jezior w centralnej Polsce

Przeprowadzono badania struktury jakościowej i ilościowej bezkręgowców jezior i kanałów systemu konińskiego. Fauna makrobezkręgowa zasiedlająca kanały były uboższa pod względem ilościowym i jakościowym niż fauna makrobezkręgowa jezior. Czynnikami determinującymi taki stan były warunki termiczne i tlenowe oraz przepływ wody. Elementem wzbogacającym rozwój zoobentosu i zooperyfitonu okazały się populacje zawleczonych do systemu małży *Dreissena polymorpha* Pallas i *Sinanodonta woodiana* (Lea) oraz zbiorowiska *Myriophyllum spicatum* L. i *Ceratophylum demersum* L. W porównaniu z okresem sprzed 30 lat nastąpiło zubożenie jakościowe fauny dennej w systemie.