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Potamozooplankton communities in three different outlets from mesotrophic lakes located in lake-river system

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Abstract

Qualitative and quantitative composition of potamozooplankton was studied in three outlets from mesotrophic lakes. The greatest taxonomic and quantitative similarity of zooplankton occurred between the outflows of the second and third lake, located in the lake-river system. The farther the lake was located in the lake-river system, the greater was the quantity of zooplankton in the outflow. Within a short distance between the outflow and the downstream section, there was a strong reduction of cladocerans' communities, followed by copepods, while the communities of rotifers were reduced in relatively small quantities. The hydrological conditions and transparency had a strong impact on the rate of changes in the zooplankton community.

INTRODUCTION

The ecological phenomenon of drifting zooplankton in outlets of large rivers coming from floodplains, lakes and dam reservoirs is currently a subject of many studies (e.g. Davidson et al. 2000, Thorp & Mantovani 2005, Illyová et al. 2008). However, it should be noted that the zooplankton community of large rivers is much better known than the zooplankton community of small rivers or small streams. The main subject of the studies on the river zooplankton community is its ecology in the outflow and in the downstream section (Ejsmont-Karabin & Węgleńska 1996, Viroux 2002, Pithard et al. 2007). These studies are specifically related to the reduction rate of qualitative and quantitative parameters of zooplankton and to relationships between the zooplankton community and the biotic and abiotic parameters (Walks & Cyr 2004, Nielsen et al. 2005, Lair 2006, Chang et al. 2008).

Most authors investigating the zooplankton of rivers and small streams argue that the river regime is the main factor affecting the zooplankton community dynamics (Pace et al. 1992, Campbell 2002, Walks & Cyr 2004, Basu & Pick 1996, Czerniawski & Domagała 2010a, Czerniawski & Pilecka-Rapacz 2011). In addition, in the outflows of highly eutrophic lakes, even the impact of chemical parameters is visible. This is particularly true of inorganic nutrients (Czerniawski & Domagała 2010b). In effect, visible chemical parameters, being the inorganic nutrients, determine the results of a physical parameter, namely the water transparency. The transparency of the water can have a big impact on the zooplankton community in the outlet and in the downstream section. This can have a special relationship with the effective predation of fish in water with less organic matter. Water transparency is better in waters with smaller amounts of organic

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matter (Wissel et al. 2003, Estlander et al. 2009). Most authors believe that fry which feed on river zooplankton are a major factor limiting the amount of river zooplankton. Fry are observed in large quantities in outlets (Lair 2006, Chang et al. 2008). In turn, reduction of zooplankton quantities by fry may depend on physical parameters of a watercourse.

In the outflow from a mesotrophic lake, a reduction of the zooplankton community may be even a dozen times greater than in the outflow from a eutrophic lake (Czerniawski & Domagala 2010a). Nielsen et al. (2005) and Czerniawski & Domagala (2010b) also proved that different hydrological and biological conditions of small rivers differently affect the formation of a zooplankton community in the downstream section. So it appears that a reduction in a zooplankton community in the outlets and streams with different hydrological conditions may also be different, despite the same trophic status of lakes from which watercourses flow out. In view of these assumptions, a basic question arises: what is the impact of different hydrological conditions of streams flowing out from different lakes with the same trophic status on a community of drifting zooplankton in the outlets and in the downstream section?

The main aim of this study was to examine the zooplankton community in streams characterized by different hydrological conditions, which are flowing out from three mesotrophic lakes connected in a lake-river system. In order to fully achieve our objective, we decided to answer the following questions:

- (1) What is the similarity in zooplankton composition between the outflows of the three mesotrophic lakes located in the lake-river system?
- (2) Are there significant differences in some properties of the zooplankton community between the outflow of mesotrophic lakes and the lower course of the river?
- (3) What is the difference in the reduction of quantity and quality of the zooplankton community between the three morphologically and hydrologically different outflows from the mesotrophic lakes?
- (4) Do the transparency and hydrological conditions affect zooplankton biomass in outflows?

MATERIALS AND METHODS

The study was performed on three outlets of the small river Słopica from mesotrophic lakes connected in the lake-river system (GPS: N 53° 12′

30″, E 15° 50′ 17″). At each outflow, two sampling sites were selected. The first site was located right at the outflow and the second site was located 0.2 km from the outflow. The greatest zooplankton community decline is within the 0.2 km long outlet section (Chang et al. 2008, Czerniawski & Domagala 2010a). The sites on the outflow from Lake Szerokie (76.3 ha) were marked as S1, S2, on the outflow from Lake Krzywe (127.8 ha) – as K1, K2, while those on the outflow from Lake Dominikowo (70.9 ha) – as D1, D2 (Fig. 1).



Fig. 1. The study area.

The outlet from Lake Szerokie was covered with sparse vegetation; between the first (S1) and the second site (S2), the bed of the stream was regularly shaped and was sandy and gravelly, with only 5% vegetation cover. The outflow from Lake Krzywe had 10% cover of the common reed (*Phragmites communis*); between the first (K1) and the second site (K2), the bed of the stream was regularly shaped and sandy, and 10% of the bed was also covered with *Sparganium* sp. The outlet from Lake Dominikowo was not covered with vegetation except for a small section of ca. 3 m² immediately after the outflow, covered with *Veronica beccabunga*; the bed between D1 and D2 was irregular with underwater holes and large stones. We observed the fry, especially of cyprinids, in each sections (below each lake).

The samples of zooplankton to be studied were collected in 2008 and 2009 in April, June, October and December. At each site 50 l of water collected

with the 10 l bucket from the river current. The samples were concentrated to 250 ml. The water was filtered through a 25 µm mesh net, then a sample was fixed in 4–5% formalin solution. From the stirred total sample, five subsamples (2 ml) were pipetted into a glass Sedgewick-Rafter Counting Chamber. For identification, a Nikon Eclipse 50i microscope was used. Species identification was performed using the identification keys of Wagler (1937), Kutikova (1970), and Harding & Smith (1974). In each sample, the body length of at least 30 individuals from each species was measured by the Pixelink Camera Kit 4.2 software. If the number of individuals representing a given species was lower than 30, the body lengths of all individuals were measured. The body length conversion to wet mass was performed using the formulas of Ruttner-Kolisko (1977), McCauley (1984) and Ejsmont-Karabin (1998). Measurements of temperature, pH, conductivity and dissolved oxygen at the sites were made in each outlet by an oxygen content meter and pH meter CX-401 produced by Elmetron (Poland). The contents of nitrites, as well as nitrates and orthophosphates were measured by a photometer DR-850 produced by Hach Lange (USA) (Table 1). At each site (outlet and

downstream), the velocity, width and depth (Fig. 2) were measured by the electromagnetic water flow sensor OTT (Germany) to determine the discharge of water. Each month, water transparency in each lake was measured by the Secchi-disk - diameter 32 cm (Fig. 3). During the month with the lowest transparency, the trophic status of the lake was determined and expressed in terms of the Carlson index – TSI_{SD} (1977). The value of TSI_{SD} calculated for Lake Szerokie was 35.4, for Lake Krzywe it was 41.0 and for Lake Dominkowo it was 37.6, which corresponds to mesotrophic water.

When comparing the qualitative composition of zooplankton between sites, we used the Jaccard index (C_j) (Schwerdtfeger 1975):

$$C_j = J(a + b - J)^{-1}$$

where a is the number of species present in one population, b is the number of species present in the other population, and J is the number of species present in both populations. The statistical significance of the differences for morphometric and hydrological parameters of the sites and for some properties of the zooplankton community between sites was tested using the pairwise t -test for dependent samples ($P < 0.05$). In order to determine the influence of the transparency and hydrological conditions of the watercourses on the biomass of some species of zooplankton, the Canonical Correspondence Analysis (CCA) with the forward selection of environmental variables was performed using Vegan 1.15.1 (Oksanen 2009).

RESULTS

Sixty two taxa of potamo zooplankton were identified at all sites, including 57 taxa at the species level: 39 from Rotifera, 10 from Cladocera and 8

Table 1

The mean content $\pm$ SD of physical and chemical parameters in the outlets of the three studied lakes.

Lake	Temp. (°C)	pH	Cond. (µS)	O ₂ (mg l ⁻¹)	NO ₃ (mg l ⁻¹)	NO ₂ (mg l ⁻¹)	PO ₄ (mg l ⁻¹)
Szerokie	11.3 ± 8.4	8.12 ± 0.27	350.7 ± 100.1	10.22 ± 1.65	0.34 ± 0.11	0.009 ± 0.005	0.22 ± 0.05
Krzywe	11.1 ± 8.1	8.15 ± 0.37	255.1 ± 54.8	10.64 ± 1.68	0.26 ± 0.31	0.006 ± 0.005	0.07 ± 0.04
Dominikowo	11.2 ± 8.7	7.98 ± 0.28	207.4 ± 27.8	10.87 ± 1.54	0.03 ± 0.02	0.003 ± 0.002	0.05 ± 0.02

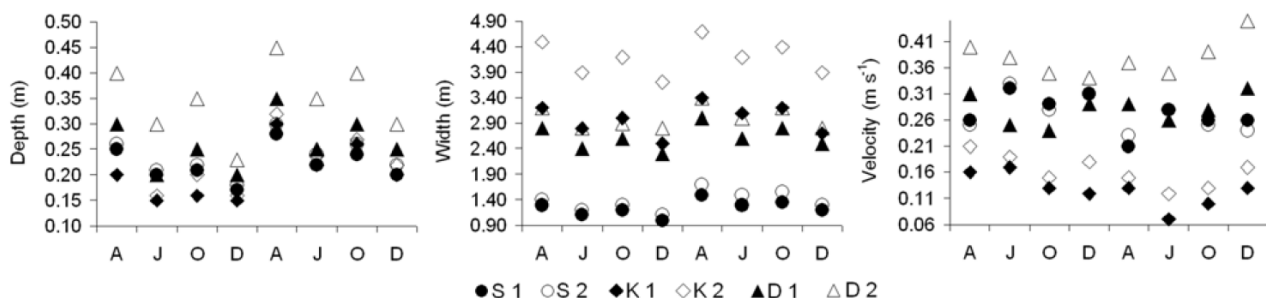


Fig. 2. Seasonal variations in the depth, width and current velocity at the studied sites in 2008-2009, A- April, J – July, O – October, D – December.

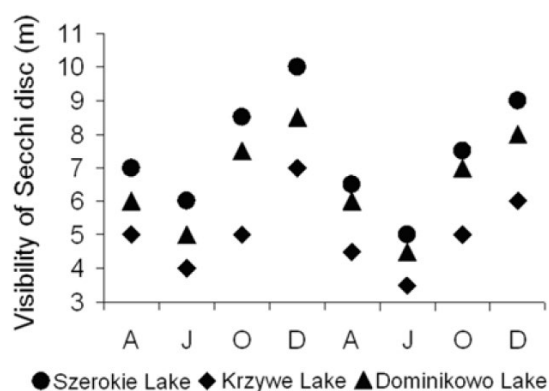


Fig. 3. Seasonal variations in the Secchi disc visibility in the studied flow-through lakes in 2008-2009. For months' symbols see Figure 2.

from Copepoda (Table 2). *Keratella cochlearis* was present each month, both at each outlet and downstream site; also the rotifer species *Polyarthra dolichoptera* had a high frequency; among Cladocera, *Bosmina coregoni* and *Daphnia cucullata* had the highest frequency, while among Copepoda – *Eudiaptomus graciloides*. Also *Cyclops vicinus* was observed at all the sites, but only in cold months. In 100% of the samples, nauplii of Cyclopoida were observed. The highest average number of taxa from all systematic groups was observed in the outlet from the second lake - Lake Krzywe (Table 3). Only in the outlet from the third lake - Lake Dominikowo, the average number of Copepoda taxa was higher than in the outlet from Lake Krzywe. The difference, however, was insignificant ($P > 0.05$). The mean number of each taxa in the outlet from Lakes Dominikowo and Krzywe was significantly higher than in the outlet from Lake Szerokie ($P < 0.05$). Jaccard index values were the highest between the outflow of the second and third lakes (K1 vs. D1) (Table 4). The rates of the index between the first lake outflow (S1) and the two other outflows were much lower.

Significant differences in the mean abundance of potamozooplankton between the outflows concerned only crustaceans (Table 3). The mean abundance of cladocerans in the outflow from Lake Szerokie (S1) was significantly lower than in the other outlets ($P < 0.05$). Also the abundance of copepods at D1 was significantly lower than at S1. Each group had the greatest abundance in April, while the lowest in December (Fig. 4). The mean biomass of total zooplankton and crustaceans from the outlet of the first lake (S1) was significantly lower than in the two other outlets ($P < 0.05$) (Table 3). Only rotifers

Table 2

Taxonomic composition, frequency (in %) and average percentage dominance of taxa in the biomass of total potamozooplankton (○<10%; ●<20%; ■<30%; ▲<40%) at the outlets and at downstream sites of Szerokie Lake (S1, S 2). Krzywe Lake (K 1, K 2) and Dominikowo Lake (D 1, D 2).

Taxa	S 1	S 2	K 1	K 2	D 1	D 2
<i>Anuraeopsis fissa</i>			13○	13○		
<i>Ascomorpha ecaudis</i>			25○	25○	13○	25○
<i>Ascomorpha ovalis</i>	50○	50○	25○	13○	25○	13○
<i>Asplanchna priodonta</i>	38▲	38▲	88○	88○	75○	75○
<i>Cephalodella sterea</i>						13○
<i>Conochilus unicornis</i>			25○	25○		25○
<i>Conochiloides natans</i>					13○	13○
<i>Calurella adriatica</i>			50○	50○	50○	50○
<i>Calurella colurus</i>	38○	38○			13○	
<i>Filinia longiseta</i>			38○	38○	50○	38○
<i>Filinia terminalis</i>			75○	75○	25○	25○
<i>Gastropus stylifer</i>	25○	13○				
<i>Kellicotia longispina</i>	50○	38○	88○	88○	50○	50○
<i>Keratella cochlearis cochlearis</i>	100■	100■	100○	100○	100○	100○
<i>Keratella cochlearis hispida</i>			13○	13○	13○	
<i>Keratella cochlearis tecta</i>			38○	25○	13○	
<i>Keratella quadrata</i>	50○	50○	88○	88○	75○	63○
<i>Lecane closterocerca</i>	25○	25○	88○	63○	63○	38○
<i>Lecane hamata</i>			13○			
<i>Lecane luna</i>			50○	25○		
<i>Lepadella acuminata</i>	25○	25○	25○			
<i>Lepadella ovalis</i>			50○	50○		38○
<i>Mytilina crassipes</i>			13○			
<i>Notholca acuminata</i>			25○	25○		
<i>Notholca foliacea</i>			25○			13○
<i>Notholca squamula</i>			13○	13○		
<i>Polyarthra dolichoptera</i>	75○	75○	100○	100○	75○	75○
<i>Polyarthra longiremis</i>				13○	25○	13○
<i>Polyarthra major</i>	50○	50○			50○	13○
<i>Polyarthra vulgaris</i>	50○	50○	50○	50○	50○	63○
<i>Pompholyx complanata</i>	25○	25○	75○	75○	50○	50○
<i>Pompholyx sulcata</i>			50○	50○	13○	38○
<i>Synchaeta oblonga</i>	38○	25○	63○	50○	75○	50○
<i>Synchaeta pectinata</i>			50○	25○		
<i>Synchaeta stylata</i>	25○	25○		13○		
<i>Synchaeta tremula</i>	25○	25○				
<i>Trichocerca capucina</i>	63○	50○	88○	88○	38○	25○
<i>Trichocerca similis</i>	25○	25○	63○	63○	25○	25○
<i>Trichortia pocillum</i>					25○	
<i>Rotatoria non det.</i>	25○	25○			25○	
<i>Acropeus harpae</i>	13○					
<i>Alona rectangularis</i>					13○	
<i>Bosmina longirostris</i>	25○	13○	63○	25○	38○	25○
<i>Bosmina coregoni</i>	13○		100○	100○	63○	25○
<i>Ceriodaphnia quadrangularis</i>			25○	25○	25○	13○
<i>Chydorus sphaericus</i>			75○	50○	50○	38○
<i>Daphnia cucullata</i>	13○		75○	75○	75●	75○
<i>Daphnia longispina</i>			13○			
<i>Leptodora kindtii</i>			13○			
<i>Peracantha truncata</i>			13○	13○		
<i>Nauplii Cyclopoida</i>	100○	100○	100○	100○	100○	100○
<i>Nauplii Calanoida</i>			25○	13○	38○	25○
<i>Copepodites Cyclopoida</i>	75○	75○	100○	100○	100○	100○
<i>Copepodites Calanoida</i>			13○	13○	38○	25○
<i>Cyclops kolensis</i>	13○		25●	25○	50■	38■
<i>Cyclops vicinus</i>	13●	13○	25○	13○	38○	25○
<i>Diacyclops bicuspidatus</i>					25○	13○
<i>Eudiaptomus gracilis</i>			38○	25○	50●	25○
<i>Eudiaptomus graciloides</i>			75●	63●	63▲	25■
<i>Thermocyclops crassus</i>			38○	25○	38○	
<i>Thermocyclops emini</i>			13○			
<i>Thermocyclops oithonoides</i>			25▲	25●	13●	13○

reached a slightly higher biomass in the outlet from the second lake (K1) compared with the outlet from the third lake (D1), but the difference was not

Table 3

Mean values of the species number, abundance (ind. l⁻¹), biomass (µg l⁻¹) and the body size (µm) of potamozooplankton in the outlets (S 1 – Szerokie; K 1 – Krzywe; D 1 – Dominikowo) and at the downstream sites (S 2 – Szerokie; K 2 – Krzywe; D 2 – Dominikowo).

	Outlet sites			Downstream sites		
	S 1	K 1	D 1	S 2	K 2	D 2
Species number						
Rotifera	9	16	12	8	13	9
Cladocera	1	4	3	+	3	2
Copepoda	2	5	6	2	4	4
Abundance						
Rotifera	154.0	131.7	171.4	97.5	95.5	123.2
Cladocera	0.2	8.8	7.9	0.1	4.1	2.1
Copepoda	16.1	31.1	44.1	7.4	20.7	23.5
Biomass						
Rotifera	110.1	170.8	161.6	61.9	112.1	104.3
Cladocera	5.2	218.9	341.3	0.1	98.0	58.3
Copepoda	58.3	1186.7	2934.9	16.4	465.6	667.7
Body size						
Rotifera	159.9	176.1	188.2	147.8	171.6	160.4
Cladocera	220.4	481.5	662.3	38.3	444.3	428.8
Copepoda	452.2	1013.4	958.1	361.0	887.9	707.9

Table 4

Results of the Jaccard index between three outlets from different lakes (S1, K1, D1) and their downstream sites (S2, K2, D2).

	Outlet			Downstream		
	S1 vs. K1	S1 vs. D1	K1 vs. D1	S2 vs. K2	S2 vs. D2	K2 vs. D2
Rotifera	0.35	0.53	0.49	0.38	0.43	0.62
Cladocera	0.50	0.43	0.50	0.16	0.20	0.83
Copepoda	0.36	0.25	0.83	0.30	0.30	0.82

significant. This was due to the presence of *Asplanchna priodonta*, particularly in April (Fig. 4). Copepods reached the greatest biomass in December. Copepods were represented mainly by adult individuals of *Cyclops* sp. and *Eudiaptomus* sp. The dominants in the total zooplankton biomass were as follows: in Lake Szerokie – *A. priodonta* and *K. cochlearis*, in Lake Krzywe and Dominikowo – *Cyclops kolensis*, *E. graciloides* and *Thermocyclops oithonoides*. Alike abundance and biomass, the lowest mean body size of most zooplankton groups was also in the outlet from Lake Szerokie (Table 3). Crustaceans in the outlet from the third lake (D1) were significantly longer compared with crustaceans from the first lake outlet (S1). Only rotifers did not differ significantly in their body size between the

three outlets ($P>0.05$). The seasonal changes in the body size revealed that the highest value of this parameter for each taxonomical group was recorded in December (Fig. 4).

At the downstream sites (200 m below the outlets), differences in zooplankton communities between sites were similar to the differences in the outlets (Table 3). Still, the highest values of zooplankton communities were observed below the third lake. However, the difference in the species number between the downstream sites was slightly more significant than between the outlets. We found that at each site located in the downstream section, rotifers had a higher percentage contribution in the composition of the zooplankton community compared with the outlets, e.g. in the case of abundance – from 79% at K2 to 93% at S1. Also, the percentage composition of rotifer biomass at S1 increased to almost 80%, while at the other sites, the percentage composition of copepods in the total zooplankton biomass declined, at K2 even to 67%. In addition, at D2 we did not observe cladocerans in December 2008. Other seasonal changes in zooplankton communities in the downstream section were rather similar to the seasonal changes in the outlets (Fig. 4).

It was only in the case of cladocerans below Lake Szerokie and Dominikowo (Table 4) that we observed significant differences in the qualitative and quantitative composition of zooplankton between the outflow and the downstream section. The highest reduction for each parameter of cladocerans was observed between S1 and S2 ($P<0.05$) (Table 5). Significant differences in the mean decline of cladocerans abundance and biomass were also noted between D1 and D2 ($P<0.05$). Despite several significant differences in the quantitative composition of Cladocera, there was still a visible reduction in the biomass of copepods (Table 5).

The seasonal changes consisting in a reduction of rotifer communities were generally similar in the downstream sections below the outlets from all three lakes (Fig. 4). But the greatest decline occurred in the months with the highest abundance, biomass or the largest body size in the outlets (Fig. 4). For example, the abundant presence of large *Asplanchna* sp. in the downstream section below Lake Dominikowo in December caused the greatest decline in all rotifers parameters. There was a similar decline in the case of crustaceans. The greatest decline in cladocerans communities, which reached up to 100%, was recorded in the summer or winter in the downstream

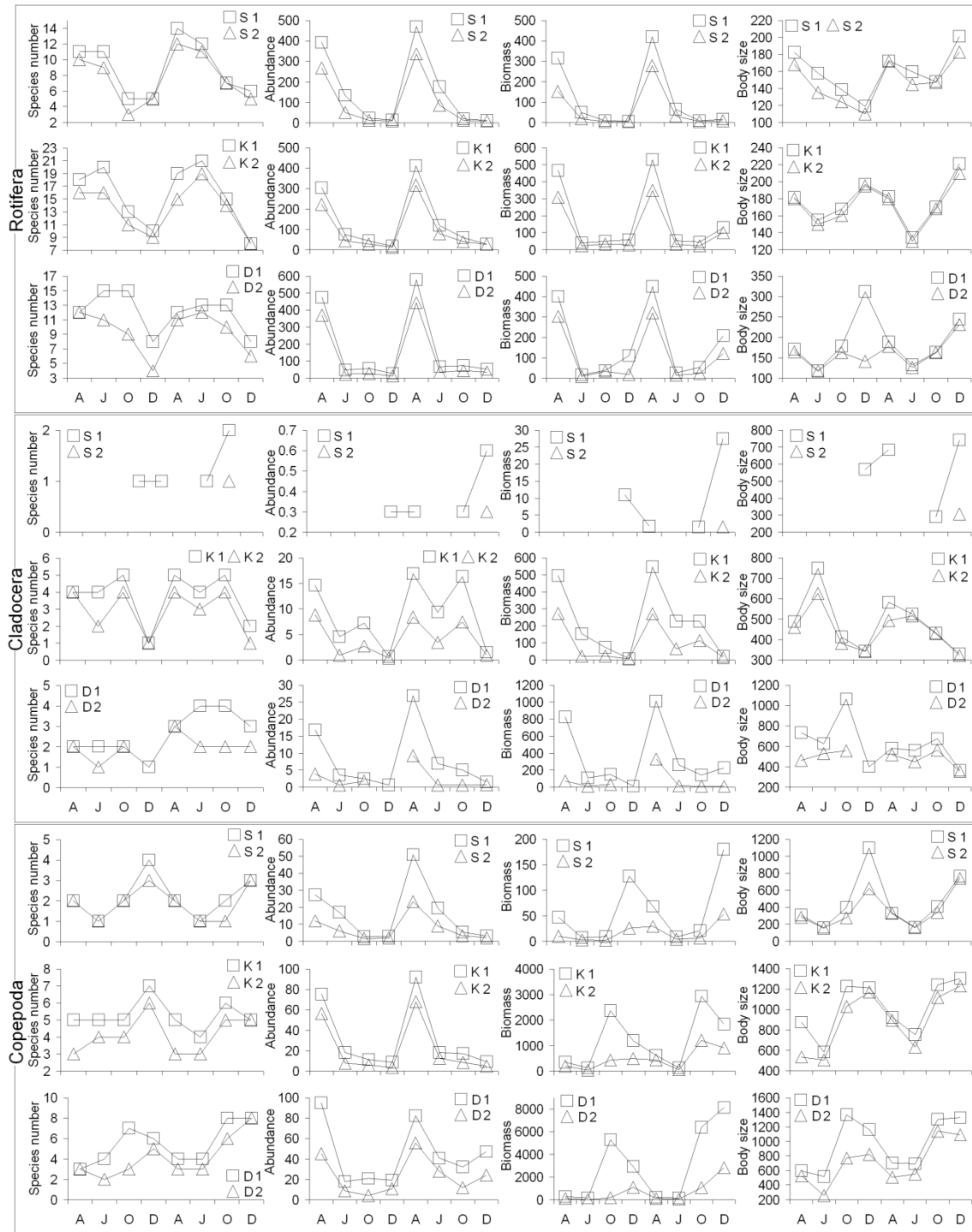


Fig. 4. Seasonal changes in the species number, abundance (ind. l^{-1}), biomass ($\mu\text{g l}^{-1}$) and the body size (μm) of Rotifera (top), Cladocera (middle) and Copepoda (bottom) in the studied lake outlets (S1 – Szerokie; K1 – Krzywe; D1 – Dominikowo) and at their downstream sites (S2, K2, D2) in 2009-2009. For months' symbols see Figure 2.

Table 5

Mean percentage decline of the potamozooplankton communities at sites located 200 m below the outlets in the downstream section (S2 – Szerokie; K2 – Krzywe; Dominikowo – D2). The significant decline of zooplankton parameters between the outlets and downstream sites are in bold type ($P < 0.05$).

	S2	K2	D2
Species number			
Rotifera	13	15	23
Cladocera	87	23	45
Copepoda	9	22	25
Abundance			
Rotifera	40	30	41
Cladocera	98	55	80
Copepoda	47	43	51
Biomass			
Rotifera	38	39	44
Cladocera	98	56	84
Copepoda	70	57	75
Body size			
Rotifera	18	3	9
Cladocera	90	7	31
Copepoda	13	13	26

section below lakes. This is the period when large individuals of *Daphnia cucullata* were removed from lakes. The copepod communities, particularly their biomass also had the highest decline in winter or in autumn, mainly because of the presence of adult individuals.

In summary, we conclude that the greatest reductions in the qualitative and quantitative composition of zooplankton concerned crustaceans. These reductions were most visible in the lower section below Lake Szerokie and Lake Dominikowo, while the lowest reduction of all parameters for all taxonomic groups were in the lower section below Lake Krzywe.

CCA analysis of zooplankton biomass with the forward selection of environmental variables showed that the Secchi disk visibility, river width, river depth and current velocity (in order) explained the largest part of variation (Table 6). The permutation test

Table 6

Results of Canonical Correspondence Analysis of potamozooplankton biomass with the forward selection of environmental variables.

Variables	Order of integration of variables for analysis	Variance explained (%)	Permutation test	
			F	P
Secchi depth	1	35.7	10.3	0.005
Width	2	35.7	6.0	0.005
Depth	3	19.0	2.9	0.020
Current velocity	4	9.5	2.4	0.030
Discharge	5	7.1	1.4	0.210

showed that each variable except discharge has a significant impact on improving the fit of the model (Table 6). The Secchi disk visibility correlated best with the first axis, the width of rivers correlated slightly less with this axis (Fig. 5). While the width, the Secchi disk visibility and the current velocity correlated best with the second axis. Therefore, each of the physical parameters, except discharge, was

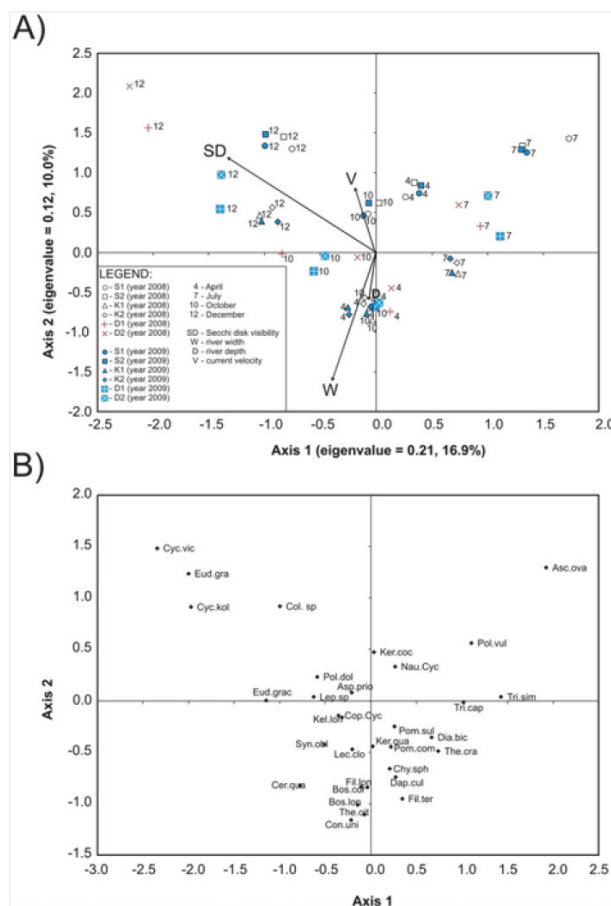


Fig. 5. Zooplankton biomass along Secchi depth and hydrological conditions: CCA ordination diagram of the samples and taxa biomass with the forward selection of variables.

Taxa: Asc. ova – *Ascomorpha ovalis*; Asp. prio – *Asplanchna priodonta*; Bos. cor – *Bosmina coregoni*; Bos. lon – *B. longirostris*; Cer. qua – *Ceriodaphnia quadrangula*; Chyd. sph – *Ch. sphaericus*; Col. sp – *Colurella* sp.; Con. uni – *C. unicornis*; Cop. Cyc – cyclopoids copepodites; Cyc. kol – *Cyclops kolensis*; Nau. Cyc – cyclopoids nauplii; Cyc. vic – *C. vicinus*; Dap. cuc – *Daphnia cucullata*; Dia. bic – *Diatomella bicuspidatus*; Eud. gra – *Eudiaptomus gracilis*; Eud. grac – *E. graciloides*; Fil. lon – *Filinia longiseta*; Fil. ter – *F. terminalis*; Kel. lon – *Kellicottia longispina*; Ker. coc – *Keratella cochlearis*; Ker. qua – *K. quadrata*; Lec. clo – *Lecane closterocerca*; Lep. sp – *Lepadella* sp.; Pol. dol – *Polyarthra dolichoptera*; Pol. vul – *P. vulgaris*; Pom. com – *Pompholyx complanata*; Pom. sul – *P. sulcata*; Syn. obl – *Synchaeta oblonga*; The. cra – *Thermocyclops crassus*; The. oit – *T. oithonoides*; Tri. cap – *Trichocerca capucina*; Tri. sim – *T. similis*.

correlated with two axes, and thus with the biomass of zooplankton species. CCA showed that the biomass values of two months (December and July) were clearly divided along the second axis, irrespective of the type of outlet and sampling site. Samples collected in December were characterized by a stronger positive correlation with the Secchi disk visibility, this variable seemed to have a positive impact on the biomass of large copepods. In contrast, biomass of zooplankton in July was characterized by a stronger negative correlation with transparency. Hence, during the two months, the biomass of zooplankton in each outlet was differently correlated with transparency. The samples collected in April and October were characterized by a stronger positive correlation with the hydrological variables. The depth and width were positively correlated with the biomass of all cladocerans, *Thermocyclops oithonoides* and *Conochilus unicornis*.

DISCUSSION

Cottenie et al. (2003) claim that the connected water reservoirs have similar zooplankton communities if they are environmentally similar. In the present study, the outflows from the second and third lake had many more taxonomic zooplankton species recorded than in the first lake – Lake Szerokie. Between the outlets of these two lakes (Krzywe and Dominikowo), the frequency of some taxa, especially planktonic rotifers and many crustaceans was similar. Moreover, in these outlets the same three species of copepods were the dominants in the mean biomass of the total potamozooplankton. It is worth noting that the Jaccard similarity of copepods between the outlet from the first lake (Lake Szerokie) and the other two outlets was small. This is similar to the values of the abiotic parameters of Lake Dominikowo and Lake Krzywe. The abiotic parameters of these lakes could similarly affect the taxonomic composition of zooplankton in the lake and consequently in its outlets. In addition, these two lakes, in contrast to Lake Szerokie, were characterized by similar morphometric and biological conditions. First of all, the littoral zone of these two lakes associated with vegetation was much broader than in Lake Szerokie. Also, zooplankton occurred in greater quantities in the outlets of Lake Dominikowo and Lake Krzywe. With the increase of surface vegetation in lakes, the number of species and zooplankton abundance also increases (Kornijów et al. 2008, Estlander et al. 2009,

Kuczyńska-Kippen & Nagengast 2006).

As with the qualitative composition, the abundance and biomass of zooplankton in the outlets of the second and third lake were also different in comparison to the outlet of the first lake. This was especially true in terms of cladocerans. Guided by the above statement of Cottenie et al. (2003), it can be assumed that the similar environmental conditions of Lake Krzywe and Lake Dominikowo had an effect on the similarity of the qualitative and quantitative composition of zooplankton between the outlets of these lakes. The outlet in the last lake – Lake Dominikowo had the highest abundance and biomass of all taxonomic groups. It can be assumed that because Lake Dominikowo was located as the last one in the lake-river system, this had an effect on the increase of its trophic status and chemical parameters (Bajkiewicz-Grabowska & Zdanowski 2006). In lakes with a higher trophic status and higher content of inorganic nutrients, a larger quantity of zooplankton is noted (Karabin 1985, Żurek 2006, Dodson et al. 2009).

At the beginning of this article a series of questions were posed. To sum up, the answer to the first question is that the greatest qualitative and quantitative similarity of zooplankton occurred between the outflows of the second and third lakes located in the lake-river system. Moreover, the farther the lake was located in the lake-river system, the greater was the abundance and biomass of zooplankton in the outflow.

The results of Nielsen et al. (2005) indicate that river zooplankton differs more in terms of quantitative parameters compared to qualitative ones.

In the present study, the analysis of qualitative and quantitative composition of zooplankton also revealed minor differences between the outflow and downstream section regarding the reduction of taxa compared to reduction of quantitative parameters. The taxonomical similarity with cladocerans was small only below the outflow of Lake Szerokie, but this resulted from the presence of single individuals, or their complete absence in the downstream section. A similar trend took place below the other lakes, in which the taxonomic similarity of crustaceans was determined by the presence of single individuals of these species.

Authors investigating the reduction in zooplankton between the outflow and downstream section indicate that the highest reduction of zooplankton abundance occurs in the first section of a river, below the outflow from the lake (Ejsmont-

Karabin & Węgleńska 1996, Hoffsen 1999, Chang et al. 2008), moreover the reduction can be enhanced in the outlets from clean, mesotrophic lakes (Czerniawski & Domagała 2010a). In the present study, the reduction of quantitative parameters of Copepoda reached up to 80%. While in some months the reduction of quantitative parameters of cladocerans reached 100%. Rotifers had the lowest reduction of quantitative parameters. In the downstream section of each outlet, the percentage contribution of rotifers in the total zooplankton communities increased, while the percentage contribution of crustaceans decreased. This is typical of the lower courses of streams below the water outflows (Armitage & Capper 1976, Hoffsen 1999, Walks & Cyr 2004, Czerniawski 2008). In the lower course of each outlet, no significant reduction in the abundance, biomass or body size of rotifers was observed. In rivers, especially in their lower sections, the abundance of rotifers is usually large (Chang et al. 2008, Czerniawski & Domagała 2010b). Perhaps planktivorous fish, which mainly reduce the abundance of zooplankton (Armitage & Capper 1976, Sandlund 1982), selected larger specimens and in this way did not influence the abundance of small rotifers. Chang et al. (2008) found very small quantities of small rotifers in stomachs of fish, even at sites far from the outflow. Big rotifers (e.g. *Asplanchna* sp. or *Brachionus calyciflorus*) and crustaceans, were not very common downstream, but they could be eaten by fish (Chang et al. 2008). Also among cladocerans and copepods, only small species or nauplii were recorded in the downstream section. There were more copepods than cladocerans. This may be explained by the fact that copepods managed to avoid fry more efficiently. Gliwicz (1985) and O'Brien (1987) report that Copepoda are able to swim faster than Cladocera and can more effectively avoid the attack of predatory fish. So the stronger impact of the fry on the crustaceans communities was the likely cause of the reduction.

Back to the questions from the beginning of this article; in answer to the second question, it can be concluded that the reduction of qualitative and quantitative parameters of zooplankton was observed within the short distance between the outflow from the mesotrophic lake and the downstream section. The largest reduction affects the cladocerans, followed by copepods, while the parameters of rotifers are reduced in relatively small amounts.

Czerniawski & Domagała (2010a) stated that in the first downstream section the reduction of

zooplankton parameters largely depends on the trophic status of the lake from which the stream flows out. An example of this is the outflow from mesotrophic lakes in which the reduction of zooplankton communities is faster than in the outflow from eutrophic lakes. Additionally, the different hydrologic conditions of the stream may affect the zooplankton composition (Campbell 2002, Nielsen et al. 2005, Czerniawski & Domagała 2010b). In the present study, the reduction of zooplankton parameters was different in three outlets. This was particularly related to crustaceans. The greatest reduction in the communities of cladocerans occurred below Lake Szerokie, where the stream was characterized as having the lowest rates of morphometric and hydrological parameters. Additionally, the water in this lake was the most transparent and, as revealed by CCA, the increase of transparency in summer negatively affects the biomass of zooplankton, especially for crustaceans. Perhaps the pressure of planktivorous fish on drifting zooplankton in the streams with high velocity and small water transparency is lower. The quantitative reduction of all taxonomic groups in the stream below Lake Krzywe occurred to a lesser extent; the morphometric parameters of the lake were higher and transparency was lower. Positive correlations between adult Copepoda and the Secchi disk visibility in December can be explained by their presence only during the cold season when the transparency was better and when the fry was probably scarce or absent.

The discharge or current velocity is the most important factor influencing the zooplankton parameters (Vranovský 1995). Campbell (2002) claims that high flow rate and high current speed favor the growth of plankton. In addition, Estlander et al. (2009) showed that high transparency has a strong impact on zooplankton communities. According to Wissel et al. (2003), smaller abundance of zooplankton can be a consequence of increased water transparency, as the latter facilitates predation by fish. This may be due to the fact that faster drifting and less visible zooplankton are more difficult for fish to catch. It is also important to note that benthic organisms in these waters may have lesser impact on the reduction of zooplankton. Zooplankton is a high quality food for benthic macroinvertebrates, especially for mussels (Malmqvist & Brönmark 1984, Richardson 1992). Stronger quantitative reduction of all taxonomical groups in the stream below Lake Dominikowo than

in the stream below Lake Krzywe can also be attributed to the width of the watercourses. The stream below Lake Krzywe was wider than the stream below Lake Dominikowo. Moreover, the riparian zone of the stream below Lake Dominikowo was densely covered with vegetation. The dense vegetation constitutes refuges for planktivorous fishes, which are found in higher numbers in streams whose riparian zones are covered with vegetation (Jones et al. 1999, Gergel et al. 1999). Additionally, higher reductions in zooplankton biomass in the watercourse below Lake Dominikowo occurred in different months than in the case of Lake Krzywe. This variation may be due to a relatively higher biomass of large plankters, e.g. *Asplanchna* sp., *Brachionus calyciflorus*, *Daphnia cucullata* or adult copepods in the outlet of Lake Dominikowo. Separation of December and July samples along the second axis of CCA shows the different effect of transparency on zooplankton biomass in these two months. So, it is possible that seasonal changes of another unmeasured biotic and abiotic parameters had a significant impact on the zooplankton community. Hence, the presence of fry in July could have a more negative effect on the biomass of zooplankton in waters with higher transparency, while the increase of transparency and the lack of fry in December induced an increase in the biomass of zooplankton in the outlets.

In the second year of the present study, reductions of zooplankton community were lower in comparison to the first year. In 2009, more intensive discharge into the streams had been observed. Therefore, the values of all hydrological parameters were increased, including the depth, which according to CCA also positively influenced the zooplankton biomass. More water with greater width and depth causes floodplains and slack waters, which are a source of zooplankton in the river current (Saunders & Lewis 1998, Nielsen et al. 2010). Thus, the more slack waters connected with a river, the more quantity of zooplankton in the river current.

Back to the questions again; in order to answer the third and fourth question, the differences in the reduction of qualitative and quantitative parameters of zooplankton were analyzed between the downstream sections of all the outflows. With this analysis it can be concluded that transparency and all of the morphometric and hydrological conditions had a strong impact on the rate of changes in the zooplankton community. Crustaceans were affected by the greatest changes. These crustacean changes

occurred in the watercourse characterized by the smallest rate of morphometric parameters and the greatest water transparency.

The overall conclusion is that the differences in zooplankton communities between the outlets are attributed to their different environmental characteristics or differences in the environmental characteristics of the lakes, which support different zooplankton communities. So, despite the same trophic status, even small abiotic differences between the lakes can cause changes in zooplankton communities in the outlets. Moreover, different transparency, morphometric and hydrological conditions of the outlets can have different effects on zooplankton structure in the downstream section.

REFERENCES

- Armitage, P.D. & Capper, M.H. (1976). The numbers, biomass and transport downstream of micro-crustaceans and Hydra from Cow Green Reservoir (Upper Teesdale). *Fresh. Biol.* 6, 425-432.
- Bajkiewicz-Grabowska, E. & Zdanowski, B. (2006). Phosphorus retention in lake section of Struga Siedmiu Jezior. *Limnol. Rev.* 6, 5-12.
- Basu, B.K. & Pick, F.R. (1996). Factors regulating phytoplankton and zooplankton biomass in temperate rivers. *Limnol. Oceanogr.* 41, 1572-1577.
- Campbell, C.E. (2002). Rainfall events and downstream drift of microcrustacean zooplankton in a Newfoundland boreal stream. *Can. J. Zool.* 80, 997-1003.
- Carlson, R.E. (1977). A trophic state index for lakes. *Limnol. Oceanogr.* 22, 361-369.
- Chang, K.H., Doi, H., Imai, H., Gunji, F. & Nakano, S.I. (2008). Longitudinal changes in zooplankton distribution below a reservoir outfall with reference to river planktivory. *Limnology*, 9, 125-133.
- Cottenie, K., Michels, E., Nuytten, N. & De Meester, L. (2003). Zooplankton metacommunity structure: regional vs. local processes in highly interconnected ponds. *Ecology*, 84, 991-1000.
- Czerniawski, R. (2008). The effect of flow-through reservoirs on zooplankton of the Plonia river. *Pol. J. Natur. Sc.*, 3, 23, 583-597.
- Czerniawski, R. & Domagała, J. (2010a). Zooplankton communities of two lake outlets in relation to abiotic factors. *Cent. Eur. J. Biol.*, 5, 240-255.
- Czerniawski, R. & Domagała, J. (2010b). Similarities in zooplankton community between River Drawa and its two tributaries (Polish part of River Odra). *Hydrobiologia*, 638, 137-149.
- Czerniawski, R. & Pilecka-Rapacz, M. (2011). Summer zooplankton in small rivers in relation to selected conditions. *Cent. Eur. J. Biol.* 6, 659-674.
- Davidson, N.L.Jr., Kelso, W.E. & Rutherford, A.D. (2000). Characteristics of cladoceran and copepod communities in floodplain habitats of the Atchafalaya River Basin. *Hydrobiologia*, 435, 99-107.
- Dodson, S.I., Newman, A.L., Will-Wolf, S., Alexander, M.L., Woodford, M.P. & Van Egeren, S. (2009). The relationship

- between zooplankton community structure and lake characteristics in temperate lakes (Northern Wisconsin, USA). *J. Plankton. Res.*, 31, 93–100.
- Ejsmont-Karabin, J. (1998). Empirical equations for biomass calculation of planktonic rotifers. *Pol. Arch. Hydrobiol.*, 45, 523–522.
- Ejsmont-Karabin, J. & Węgleńska, T. (1996). Changes in the zooplankton structure in the transitory river – lake – river zone. The River Krutynia system, Mazurian Lake District. *Zesz. Nauk. Kom. „Człowiek i Środowisko”*, 13, 263–289. (in Polish)
- Estlander, S., Nurminen, L., Olin, M., Vinni, M. & Horppila, J. (2009). Seasonal fluctuations in macrophyte cover and water transparency of four brown-water lakes: implications for crustacean zooplankton in littoral and pelagic habitats. *Hydrobiologia*, 620, 109–120.
- Gergel, S.E., Turner, M.G. & Kratz, T.K. (1999). Scale-dependent landscape effects on north temperate lakes and rivers. *Ecol. Appl.*, 9, 1377–1390.
- Gliwicz, Z.M. (1985). Predation or food limitation: an ultimate reason for extinction of planktonic cladoceran species. *Ergebn. Limnol.*, 21, 419–430.
- Harding, J.P. & Smith, W.A. (1974). *A key to the British freshwater cyclopoid and calanoid copepods*. FBA Far Sawrey, Cumbria: Special Publication. *Fresh. Biol. Assoc.*, 18.
- Hoffsen, P.O. (1999) Distribution on filter-feeding caddisflies (Trichoptera) and plankton drift in a Swedish lake-outlet stream. *Hydrobiologia*, 33, 377–386.
- Illyová, M., Bukvayová, K. & Némethová, D. (2008). Zooplankton in a Danube River Arm near Rusovce (Slovakia). *Biologia*, 63, 566–573.
- Jones, E.B.D., Helfman, G.S., Harper, J.O. & Bolstad, P.V. (1999). Effects of riparian forest removal on fish assemblages in southern Appalachian streams. *Conserv. Biol.*, 13, 1454–1465.
- Karabin, A. (1985). Pelagic zooplankton (Rotatoria + Crustacea) variation in the process of Lake Eutrophication. I. Structural and quantitative features. *Pol. J. Ecol.*, 33, 567–616.
- Kornijów, R., Vakkilainen, K., Horppila, J., Luokkanen, E. & Kairesalo, T. (2005). Impacts of a submerged plant (*Elodea canadensis*) on interactions between roach (*Rutilus rutilus*) and its invertebrate communities in a lake littoral zone. *Fresh. Biol.*, 50, 262–276.
- Kuczyńska-Kippen, N. & Nagengast, B. (2006). The influence of the spatial structure of hydromacrophytes and differentiating habitat on the structure of rotifer and cladoceran communities. *Hydrobiologia*, 559, 203–212.
- Kutikova, L.A. (1970). *The rotifer fauna of USSR, Key of the fauna of USSR* (pp.744). Leningrad: Nauka. (In Russian)
- Lair, N. (2006). A review of regulation mechanisms of metazoan plankton in riverine ecosystems: aquatic habitat versus biota. *River. Res. Appl.*, 22, 567–593.
- Malmqvist, B. & Brönmark, C. (1984). Functional aspects of a lake outlet versus a springfed stream ecosystem. *Verh. Inter. Verein. Limnol.*, 22, 1992–1996.
- McCauley, E. (1984). The estimation of the abundance and biomass of zooplankton in samples. In Downing, J.A. & Rigler, J.A. (Eds.), *A Manual on Methods for the Assessment of Secondary Productivity in Fresh Waters* (pp.228–265). London: Blackwell Scientific Publication.
- Nielsen, D., Watson, G. & Petrie, R. (2005). Microfaunal communities in three lowland rivers under differing flow regimes. *Hydrobiologia*, 543, 101–111.
- Nielsen, D., Gigney, H. & Watson, G. (2010). Riverine habitat heterogeneity: the role of slackwaters in providing hydrologic buffers for benthic microfauna. *Hydrobiologia*, 638, 181–191.
- O'Brien, W.J. (1987). Planktivory by freshwater fish: thrust and parry in the pelagial. In Kerfoot, W.C. & Sih, A., (Eds.), *Predation. Direct and Indirect Impacts on Aquatic Communities* (pp.3–16). Hanover and London: University Press of New England.
- Oksanen, J., Kindt, R., Legendre, P., O'Hara, B., Simpson, G.L., Solymos, P., Stevens, M.H.H. & Wagner, H. (2008). *The Vegan Package*, 1, 15–1. available via <http://cran.r-project.org/web/packages/vegan/vegan.pdf>
- Pace, M.L., Findlay, S.E.G. & Lints, D. (1992). Zooplankton in advective environments: the Hudson River community and a comparative analysis. *Can. J. Fish. Aquat. Sci.*, 49, 1060–1069.
- Pithart, D., Pichlová, R., Bílý, M., Hrbáček, J., Novotná, P. & Pechar, L. (2007). Spatial and temporal diversity of small shallow waters in river Lužnice floodplain. *Hydrobiologia*, 584, 265–275.
- Richardson, W.B. (1992). Microcrustacea in flowing water: experimental analysis of washout times and a field test. *Fresh. Biol.*, 28, 217–230.
- Ruttner-Kolisko, A. (1977). Suggestion for biomass calculation of plankton rotifers. *Arch. Hydrobiol.*, 8, 71–76.
- Sandlund, O.T. (1982). The drift of zooplankton and microzoobenthos in the river Strandaelva, western Norway. *Hydrobiologia*, 94, 33–48.
- Schwerdtfeger, F. (1975). *Ökologie der Tiere. Band 3, Synökologie* (pp. 678). Hamburg-Berlin: Paul Parey Verlag.
- Thorp, J.H. & Mantovani, S. (2005). Zooplankton of turbid and hydrologically dynamic prairie rivers. *Fresh. Biol.*, 50, 1474–1491.
- Viroux, L. (2002). Seasonal and longitudinal aspects of microcrustacean (Cladocera, Copepoda) dynamics in a lowland river. *J. Plankton Res.*, 24, 281–292.
- Walks, D.J. & Cyr, M. (2004). Movement of plankton through lake – stream systems. *Fresh. Biol.*, 49, 745–759.
- Wagler, E. (1937). *Crustacea (Crustaceans). The animals of Central Europe, II, 2a* (pp.224). Leipzig. (in German)
- Wissel, B., Boeing, W.J. & Ramcharan, C.W. Effects of water color on predation regimes and zooplankton assemblages in freshwater lakes. *Limnol. Oceanogr.*, 48, 1965–1976.
- Žurek, R. (2006). Response of rotifers to hydrochemical and biotic factors. *Oceanol. Hydrobiol. St.*, 2: 121–139.