

Summer zooplankton in small rivers in relation to selected conditions

Research Article

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Abstract: The abundance and the biodiversity of summer zooplankton in the waters of the Drawa drainage (NW Poland) were studied, as was their relation to selected environmental conditions. The conditions upstream, especially in the outlets of lakes, did not affect the zooplankton communities downstream. This was also true of tributaries which had no influence on the shape of the zooplankton communities in the main river. The number of zooplankton in the outlets of eutrophic lakes was greater than in those of mesotrophic lakes. Increased vegetation cover significantly affected mainly the crustacean communities of zooplankton. Larger amounts of zooplankton were observed in rivers where the riparian zone was not covered with vegetation, but this difference was not significant. The hydrological conditions of the rivers and the Secchi depth visibility strongly impacted the composition of the zooplankton. The influence of abiotic factors was most pronounced on the abundance of cladocerans, and least pronounced on the abundance of rotifers.

Keywords: *River microfauna • Drift of zooplankton • Small rivers • Outlets*

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1. Introduction

The zooplankton communities in large rivers are relatively well known [1-3]. However, zooplankton in small rivers and streams, and especially how they are affected by biotic and abiotic conditions, have not yet been clearly explained [4,5]. Many authors report that the main sources of zooplankton in larger rivers are stagnant water bodies such as lakes, dam reservoirs or floodplains. Several hundred meters below the outlets of these waters a sharp decline in the number of zooplankton is observed [e.g. 6,7]. In smaller rivers the percentage decline of zooplankton communities is very similar [3,8,9]. In contrast, much more is known about the reduction of zooplankton communities between the outlet and downstream in large rivers than the reduction in smaller rivers or watercourses. For this reason it seems appropriate to examine the continuity of zooplankton communities throughout the main stream and discontinuities where lake outlets enter small rivers. Similarly, little is known about the effects of inflow from tributaries on the community of zooplankton in the main stream, in both large and small rivers.

The structure of the zooplankton community depends on many abiotic and biotic variables in the water [10,11]. The density of zooplankton correlates significantly with the physico-chemical conditions of a lake or the lower course of a large river, especially the inorganic nutrients and the conductivity [12,13]. The relationship between the structure of the zooplankton community and the chemical conditions in small rivers has not been observed [e.g. 5,6]. However, in outlets from strongly eutrophic lakes the impact of chemical factors on the quantity of zooplankton can be clearly observed [8]. The difference in the trophic status of lake outlets may also similarly affect the abundance of zooplankton [9]. However, many authors indicate that the river regime mainly determines the structure of the zooplankton community in rivers [14-16].

In lakes, one factor that determines the abundance of zooplankton is transparency. Estlander *et al.* [11] stated that an increase in transparency decreases the number of zooplankton, especially crustaceans. Thus, it can be assumed that in a small river this factor will also have a strong influence on the structure of the zooplankton community. In many cases, fish are the

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main factor limiting the quantity of zooplankton in rivers [5,6]. Fish can easily capture zooplankton in waters with clear visibility. Therefore, it seems that the turbidity, as well as the hydrologic conditions of the river can also affect the amount of zooplankton in small watercourses.

Vegetation can cover both the bed and riparian zone and can affect the abundance of zooplankton in rivers, as it does in lakes and ponds [11,17]. In lakes, vegetation that covers the bed plays a significant role in shaping the structure of zooplankton communities, mainly due to the many hiding places it provides zooplankton who can avoid predation by fry [e.g. 11,13,17]. In rivers with richly vegetated riparian zones, fry are more abundant than in riparian zones without vegetation [18,19]. Since more fry means greater predation on zooplankton, the vegetation in the riparian zone can affect the density of zooplankton.

Although the Drawa River is one of the wildest north-western Polish rivers it has not been the object of many biological studies. It functions as a corridor linking two important ecological centres: the Drawski Landscape Park and Drawieński National Park, and accordingly, the state of the water in this river should be carefully monitored. Our paper is the first report on drifting zooplankton in the whole Drawa drainage area.

The aim of this study was to answer the following questions: (1) Do conditions upstream, especially at the outlets of lakes, affect the zooplankton communities downstream? (2) Do small tributaries have an impact on the zooplankton community in the main stream? (3) What are the relationships between zooplankton communities and selected abiotic and biotic factors, including trophic status, vegetation in the river bed and the riparian zone, the river regime, and physico-chemical conditions?

2. Experimental Procedures

The study was performed in the catchment area of the Drawa River (GPS: 53°20'25" N; 15°46'30" E – middle Drawa), which is a 190 km long quaternary tributary of the Odra River. The Drawa River is situated in North-West Poland in the Pomeranian Lake District. The springs of the Drawa River are at an altitude of 150 m a.s.l. The mean slope of the river bed is 0.59 m km⁻¹. The catchment area of the Drawa is 3198 km². The samples were collected from 88 sites located at different points of the area as shown in Figure 1.

The samples of zooplankton to be studied were collected in July 2009. At each site 50 l of water were collected from the river drift. The water was filtered through a 25 µm mesh net, then the sample was fixed in a 4–5% formalin solution. A Glass Sedgewick Rafter

Counting Chamber was used for counting. Zooplankton were identified and counted in five subsamples. For identification, a Nikon Eclipse 50i microscope was used. Species identification was made using the keys of Wagler [20], Kutikova [21], and Harding and Smith [22].

Temperature, p H, conductivity and dissolved oxygen were measured at the sites with an oxygen content meter and a CX-401 pH meter made by Elmetron (Poland). At each site, the velocity, width, and depth were measured using an OTT electromagnetic water flow sensor (Germany) to calculate the discharge of water. At each site the macrophytes along a 50 m transect were examined. We visually estimated the total percent of vegetation coverage. Riparian zones were classified according to three types: riparian zone covered with vegetation (V), riparian zone without vegetation (NV) and concrete riparian zone (C). The water transparency in each lake from which the watercourses flowed was measured with a Secchi-disk. The trophic status of the lake was expressed in terms of the Carlson index [23]: $TSI_{SD} = 10 (6 - \log_2 SD)$, where: SD – maximum depth in meters at which the Secchi disk was visible. The list and ranges of environmental variables are shown in Table 1.

In order to examine zooplankton diversity we used the Shannon-Weaver index. Species similarity between sites was compared with the Jaccard index; abundance similarity was estimated with the Sørensen index.

Analysis of variance (ANOVA, $P < 0.05$) was used to test the statistical significance of the differences in zooplankton community abundance between sites with different riparian zone types and trophic statuses. The Duncan - *post-hoc* test was used as a pairwise test. In order to determine the influence of the environmental factors on the abundance of zooplankton, the Canonical Correspondence Analysis (CCA) was applied. Software of Vegan 1.15.1 was used to perform the analyses

	Range (units)
Vegetation coverage	0–100%
Depth	0.05–2.50 m
Width	0.1–30 m
Velocity	0.01–4 m s ⁻¹
Discharge	0.00015–22.5 m ³ s ⁻¹
Temperature	12.8–23.5°C
Dissolved oxygen	2.57–18.42 mg l ⁻¹
Conductivity	123.2–856.3 µS
pH	7.16–9.37

Table 1. List of environmental variables and their ranges and units in the waters of the Drawa River drainage in July 2009.



Figure 1. Map of sampled sites (black points) in the Drawa River drainage.

(Oksanen J., Kindt R., Legendre P., O'Hara B., Simpson G.L., Solymos P., *et al.*, The Vegan Package, 2008, 1, 15-1, available via <http://cran.rproject.org/web/packages/vegan/vegan.pdf>). To illustrate the similarities between the sites in terms of total zooplankton abundance non-metric multidimensional scaling ordination (nMDS) was used. The grouping in the nMDS ordination was based on the Bray-Curtis distances

3. Results

3.1 General composition of zooplankton

Rotifers accounted for over 71% of all zooplankton taxa identified. The percentage composition of cladocerans was 17%; copepods, 8%. All together, 123 taxa of zooplankton were identified from all the sites. 118 species were present, of which 87 were

Rotifera, 21 were Cladocera and 10 were Copepoda (Table 2). From the rotifers, the taxa present at most sites were *Bdelloidea*, *Keratella cochlearis* and *Lecane closterocerca*. The cladocerans most frequently found were *Bosmina coregoni* and *Ceriodaphnia quadrangula*. The most frequently found copepods were *Thermocyclops oithonoides* and *Eucyclops serrulatus* (Table 2). Cyclopoida nauplii were observed in over 97% of the samples.

The greatest values on the Shannon-Weaver index of total zooplankton were observed in the outlets of eutrophic lakes and at sites in which the bed vegetation coverage was relatively large (50 – 100%), e.g., at sites 43, 35, 30 (Table 3). Rotifers reached the greatest rates of this index in the outlets of eutrophic lakes, e.g., at sites 37, 43, 74. The greatest rates of cladoceran biodiversity also were noted either at sites with similar, large vegetation coverage or at sites at which the water velocity was relatively low (between 0.08 m s⁻¹ and 0.2 m s⁻¹), e.g., at sites 75, 64, 55. Copepods also reached the highest rates on the Shannon-Weaver index at sites characterized by relatively low velocity, between 0.02 m s⁻¹ and 0.15 m s⁻¹, e.g., at sites 29, 32, 40, 43.

At all sites the abundance of zooplankton was determined mainly by the rotifers, which usually comprised over 50% of the total, with an average of 87.4%. In many sites rotifers were the only taxonomical group of zooplankton (Table 3). The highest amounts of rotifers were found in the outlets of strongly eutrophic lakes. Small species dominated the rotifer community. These small species were mainly *Keratella cochlearis tecta* and *Pompholyx sulcata*. They made up 35% and

11%, respectively, of the total mean abundance of Rotifera at all 88 sites. Cladocerans were found in relatively small amounts; their mean abundance at all sites was almost 2.9% of the total zooplankton. The abundance of cladocerans was determined by *Ceriodaphnia quadrangula*, *Bosmina coregoni* and *Daphnia cucullata* which reached a mean of 28%, 23%, and 19% of the total number of cladocerans, respectively. The greatest abundance of cladocerans was observed in rivers which were relatively densely covered by macrophytes and in rivers characterized by low velocity, low transparency and greater depth and width, e.g., at sites 29, 31, 32. At all sites the abundance of copepods which was at least 28%, was composed mainly of Cyclopoida nauplii, with a mean of 76%. The greatest abundance of copepods was noted in rivers below outlets from eutrophic lakes. Copepoda determined 9.7% of the mean abundance of zooplankton in all sites.

3.2 Similarity between upstream and downstream areas

The continuity of zooplankton composition and abundance along the main channel of the Drawa depended on the environmental conditions in the lakes (Figure 2, Table 3). The highest abundance of each group of zooplankton was noted in the outlets of lakes characterized by high trophic status and low Secchi depth. At other sites along the Drawa the abundance of zooplankton was rather low, even in lake outlets. In the lower course of the Drawa (section 67-88), the densities of each group of zooplankton were low and comparable. In other rivers of the Drawa drainage area

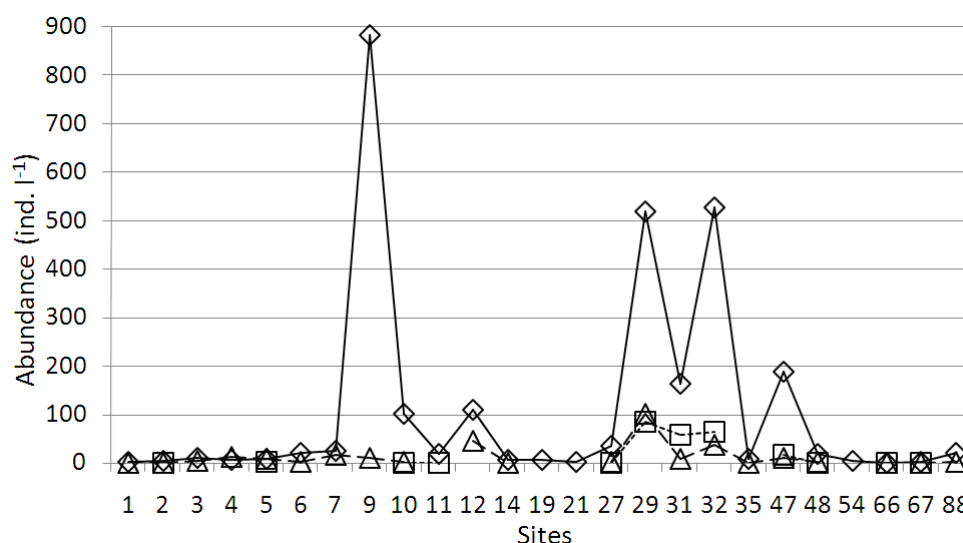


Figure 2. Abundance of zooplankton at sites along the main channel of the Drawa (low order stream). Rhombi and continuous line - rotifers, triangles and dashed line - copepods, squares and dotted line - cladocerans.

Taxa	Frequency (%)	Taxa	Frequency (%)	Taxa	Frequency (%)
Rotifera		<i>Lecane curvicornis</i>	1.1	<i>Trichocerca similis</i>	45.6
<i>Anuraeopsis fissa</i>	16.7	<i>Lecane depressa</i>	1.1	<i>Trichocerca taurocephala</i>	1.1
<i>Ascomorpha ecaudis</i>	7.8	<i>Lecane hamata</i>	14.4	<i>Trichocerca tenuior</i>	2.2
<i>Ascomorpha ovalis</i>	14.4	<i>Lecane ludwigii</i>	2.2	<i>Trichocerca vernalis</i>	1.1
<i>Ascomorpha saltans</i>	16.7	<i>Lecane scutata</i>	7.8	<i>Trichotria pocillum</i>	1.1
<i>Asplanchna brightwellii</i>	2.2	<i>Lecane stichaea</i>	1.1	Cladocera	
<i>Asplanchna priodonta</i>	7.8	<i>Lepadella acuminata</i>	10.0	<i>Alona affinis</i>	1.1
<i>Asplanchna sieboldi</i>	1.1	<i>Lepadella costata</i>	1.1	<i>Alona costata</i>	2.2
<i>Bdelloidea</i>	58.9	<i>Lepadella ovalis</i>	33.3	<i>Alona guttata</i>	4.4
<i>Brachionus angularis</i>	4.4	<i>Lepadella rhomboides</i>	2.2	<i>Alona quadrangularis</i>	1.1
<i>Brachionus calyciflorus</i>	4.4	<i>Mytilina bisulcata</i>	3.3	<i>Alona rectangula</i>	1.1
<i>Brachionus diversicornis</i>	1.1	<i>Acropeus harpae</i>	1.1	<i>Alonella nana</i>	5.6
<i>Brachionus quadridentatus</i>	4.4	<i>Mytilina crassipes</i>	5.6	<i>Bosmina coregoni</i>	20.0
<i>Brachionus urceus</i>	1.1	<i>Mytilina ventralis</i>	4.4	<i>Bosmina longirostris</i>	8.9
<i>Bryceella tenella</i>	1.1	<i>Notholca labis</i>	1.1	<i>Ceriodaphnia laticaudata</i>	1.1
<i>Cephalodella auriculata</i>	1.1	<i>Notommata copeus</i>	1.1	<i>Ceriodaphnia quadrangula</i>	17.8
<i>Cephalodella eliptica</i>	1.1	<i>Plationus patulus</i>	1.1	<i>Chydorus gibbus</i>	5.6
<i>Cephalodella catellina</i>	2.2	<i>Platylas quadricornis</i>	1.1	<i>Chydorus sphaericus</i>	12.2
<i>Colurella adriatica</i>	31.1	<i>Ploesoma truncatum</i>	1.1	<i>Daphnia cucullata</i>	13.3
<i>Colurella colurus</i>	6.7	<i>Polyarthra euryptera</i>	8.9	<i>Daphnia longispina</i>	2.2
<i>Colurella uncinata</i>	15.6	<i>Polyarthra longiremis</i>	44.4	<i>Diaphanosoma brachyurum</i>	1.1
<i>Conochilus unicornis</i>	14.4	<i>Polyarthra major</i>	1.1	<i>Graptoleberis testudinaria</i>	1.1
<i>Elosa worallii</i>	1.1	<i>Polyarthra minor</i>	6.7	<i>Leptodora kindtii</i>	1.1
<i>Euchlanis deflexa</i>	1.1	<i>Polyarthra remata</i>	21.1	<i>Peracantha truncata</i>	6.7
<i>Euchlanis dilatata</i>	6.7	<i>Polyarthra vulgaris</i>	30.0	<i>Polypherus pediculus</i>	2.2
<i>Euchlanis lyra</i>	1.1	<i>Pompholyx complanata</i>	20.0	<i>Scapholeberis mucronata</i>	10.0
<i>Euchlanis oropha</i>	1.1	<i>Pompholyx sulcata</i>	38.9	<i>Simocephalus vetulus</i>	1.1
<i>Filinia longiseta</i>	8.9	<i>Scaridium longicaudatum</i>	1.1	Copepoda	
<i>Filinia terminalis</i>	1.1	<i>Squatinella mutica</i>	2.2	<i>Nauplii Cyclopoida</i>	76.7
<i>Gastropus hyptopus</i>	5.6	<i>Synchaeta kitina</i>	23.3	<i>Nauplii Calanoida</i>	8.9
<i>Gastropus stylifer</i>	12.2	<i>Synchaeta oblonga</i>	1.1	<i>Copepodites Cyclopoida</i>	37.8
<i>Hexarthra mira</i>	1.1	<i>Synchaeta pectinata</i>	15.6	<i>Copepodites Calanoida</i>	8.9
<i>Kellicotia longispina</i>	28.9	<i>Synchaeta stylata</i>	11.1	<i>Acanthocyclops robustus</i>	5.6
<i>Keratella coch. cochlearis</i>	57.8	<i>Testudinella patina</i>	2.2	<i>Diacyclops bicuspidatus</i>	3.3
<i>Keratella coch. hispida</i>	38.9	<i>Testudinella parva</i>	1.1	<i>Eucyclops macrurides</i>	4.4
<i>Keratella coch. robusta</i>	14.4	<i>Testudinella truncata</i>	1.1	<i>Eucyclops serrulatus</i>	16.7
<i>Keratella coch. tecta</i>	58.9	<i>Trichocerca capucina</i>	11.1	<i>Eudiaptomus graciloides</i>	1.1
<i>Keratella quadrata</i>	37.8	<i>Trichocerca elongata</i>	4.4	<i>Mesocyclops leuckarti</i>	4.4
<i>Keratella ticinensis</i>	5.6	<i>Trichocerca insignis</i>	3.3	<i>Thermocyclops crassus</i>	1.1
<i>Lecane arcuata</i>	5.6	<i>Trichocerca longiseta</i>	1.1	<i>Thermocyclops dybowskii</i>	3.3
<i>Lecane bulla</i>	1.1	<i>Trichocerca pusilla</i>	18.9	<i>Thermocyclops emini</i>	1.1
<i>Lecane closterocerca</i>	52.2	<i>Trichocerca rattus</i>	2.2	<i>Thermocyclops oithonoides</i>	17.8

Table 2. Taxonomic composition and frequency (%) of all taxa identified at 89 sites of Drawa River drainage in July 2009.

Site	Shannon-Weaver index				Abundance (ind. l ⁻¹)			
	Rotifera	Cladocera	Copepoda	Total	Rotifera	Cladocera	Copepoda	Total
1	1.01	-	0.69	1.56	1.2	-	0.6	1.8
2	0.30	0.00	0.00	0.79	3.3	0.3	0.3	3.9
3	0.41	-	0.00	0.91	10.5	-	5.0	15.5
4	0.61	-	0.38	1.05	5.25	-	12.0	17.25
5	1.10	0.00	0.86	1.81	9.0	1.5	9.0	19.5
6	1.72	-	0.00	1.84	20.1	-	1.2	21.3
7	1.46	-	0.26	1.65	24.8	-	16.6	41.4
8	1.60	0.00	0.00	1.76	644.1	4.8	42.6	691.5
9	1.45	-	0.89	1.51	884.4	-	11.0	895.4
10	0.81	0.00	0.45	0.92	100.5	0.6	1.8	102.9
11	0.57	0.00	-	0.64	18.0	0.3	-	18.3
12	2.10	-	0.31	2.18	110.4	-	45.3	155.7
13	2.01	0.69	-	2.04	78.0	0.6	-	78.6
14	1.90	-	0.00	2.00	6.0	-	0.3	6.3
15	1.91	1.31	0.98	2.41	152.4	22.2	107.4	282.0
16	1.78	-	0.00	1.86	18.0	-	0.6	18.6
17	1.39	-	0.45	1.51	45.3	-	1.8	47.1
18	1.42	-	-	1.42	1.8	-	-	1.8
19	1.03	-	-	1.03	6.4	-	-	6.4
20	1.70	0.87	0.21	2.09	17.7	6.3	10.8	34.8
21	0.86	-	-	0.86	1.3	-	-	1.3
22	1.07	1.21	0.41	1.49	125.4	1.6	30.6	157.6
23	1.91	0.41	0.85	2.18	69.3	2.1	6.0	77.4
24	1.84	-	-	1.84	13.5	-	-	13.5
25	0.53	1.03	0.48	1.47	11.1	12.0	48.0	71.1
26	1.23	-	-	1.23	16.2	-	-	16.2
27	1.42	1.10	0.60	1.63	35.8	0.6	1.4	37.8
28	1.08	-	-	1.08	1.4	-	-	1.4
29	1.58	1.48	1.04	2.25	519.0	84.2	100.6	703.8
30	2.28	-	0.60	2.41	12.6	-	4.4	17.0
31	0.76	0.09	0.91	1.31	163.4	57.0	8.2	228.6
32	1.68	1.56	1.06	2.17	527.1	64.9	37.4	629.4
33	2.05	1.13	0.32	2.27	179.2	4.6	50.6	234.4
34	1.99	-	0.00	2.05	20.2	-	0.4	20.6
35	2.39	-	0.00	2.47	7.6	-	0.4	8.0
36	2.17	-	-	2.17	15.5	-	-	15.5
37	2.29	-	0.00	2.36	98.0	-	3.4	101.4
38	1.54	0.00	1.04	1.83	172.2	0.2	19.4	191.8
39	0.81	0.00	0.68	0.99	61.6	0.8	1.8	64.2
40	1.08	0.00	1.05	1.74	6.0	1	2.5	9.5
41	1.42	-	-	1.42	73.0	-	-	73.0
42	1.31	-	-	1.31	2.4	-	-	2.4
43	2.57	1.54	1.05	3.02	17.1	4.2	3.0	24.3
44	2.03	-	0.00	2.14	5.4	-	0.4	5.8
45	1.26	1.01	1.33	2.22	5.4	1.2	4.0	10.6
46	1.76	0.56	0.68	1.88	354.3	2.4	11.7	368.4
47	1.66	0.65	0.37	1.98	187.6	16.2	10.6	214.4
48	2.18	0.00	0.59	2.35	19.6	0.2	1.4	21.2
49	1.85	0.45	0.53	2.14	46.6	1.2	15.0	62.8
50	1.89	0.00	0.63	2.25	8.0	1.0	1.8	10.8

Table 3. The Shannon-Weaver index and abundance of Rotifera, Cladocera, Copepoda and total zooplankton at each site examined in the Drawa River drainage in July 2009. The data at sites of the main Drawa River are marked with bold.

Site	Shannon-Weaver index				Abundance (ind. l ⁻¹)			
	Rotifera	Cladocera	Copepoda	Total	Rotifera	Cladocera	Copepoda	Total
51	1.77	-	0.00	1.90	72.6	-	6.4	79.0
52	1.04	0.56	-	1.12	31.2	3.2	-	34.4
53	1.19	-	-	1.19	13.6	-	-	13.6
54	1.45	-	-	1.45	4.2	-	-	4.2
55	1.91	1.71	0.00	2.23	68.7	6.3	1.5	76.5
56	1.11	0.47	0.55	1.68	371.4	34.2	323.1	728.7
57	0.79	-	0.61	0.85	2797.6	-	32.4	2830.0
58	0.63	-	-	0.63	0.6	-	-	0.6
59	1.45	-	-	1.45	3.8	-	-	3.8
60	1.80	0.69	0.33	2.04	70.0	2.4	32.0	104.4
61	1.69	-	0.00	1.81	5.7	-	0.3	6.0
62	0.89	0.00	0.00	1.37	3.0	0.3	0.6	3.9
63	1.69	-	0.00	1.80	5.7	-	0.3	6.0
64	0.98	1.33	0.00	1.00	480.0	2.0	2.4	484.4
65	1.58	-	0.00	1.76	2.6	-	0.4	3.0
66	1.62	0.00	0.00	1.92	3.9	0.3	0.9	5.1
67	1.04	0.00	0.69	1.64	2.4	0.3	0.6	3.3
68	1.66	1.20	0.51	1.98	173.6	2.4	39.2	215.2
69	1.51	-	-	1.51	17.4	-	-	17.4
70	1.48	-	0.00	1.65	49.8	-	5.4	55.2
71	1.47	0.66	0.96	1.59	563.7	2.4	12.6	578.7
72	1.65	0.69	0.41	1.88	27.9	0.6	2.1	30.6
73	1.93	0.00	0.51	2.14	58.0	0.4	6.4	64.8
74	2.34	-	0.00	2.39	10.0	-	0.2	10.2
75	1.70	1.33	0.57	2.01	166.0	1.0	56.2	223.2
76	0.93	-	-	0.93	7.4	-	-	7.4
77	1.81	-	0.00	1.81	235.8	-	8.4	244.2
78	1.01	0.00	1.24	1.17	435.6	2.1	12.9	450.6
79	1.20	-	0.00	1.35	6.6	-	0.4	7.0
80	0.64	-	0.00	0.69	1.8	-	0.6	2.4
81	1.03	-	0.00	1.21	4.0	-	4.0	8.0
82	0.78	-	0.00	0.91	26.6	-	1.0	27.6
83	1.80	0.00	0.00	2.07	18.7	3	1.5	23.25
84	0.63	0.00	-	1.03	2.4	0.8	-	3.2
85	1.67	0.64	0.69	2.15	3.9	0.9	2.7	7.5
86	1.04	-	-	1.04	4.5	-	-	4.5
87	1.77	0.69	0.00	1.99	25.8	0.6	3.0	29.4
88	1.81	-	0.00	1.93	20.7	-	1.2	21.9

continued Table 3. The Shannon-Weaver index and abundance of Rotifera, Cladocera, Copepoda and total zooplankton at each site examined in the Drawa River drainage in July 2009. The data at sites of the main Drawa River are marked with bold.

the densities of zooplankton were also determined by the environmental conditions of the through-flow lakes. In the entire Drawa drainage we examined 15 sections (Figure 3). The sections showed little similarity between the taxonomic groups, their abundance, and the overall abundance of zooplankton (Figure 3). Copepods showed the greatest similarity, but there was only one taxon – nauplii, at all sites. In additions, copepods showed the highest taxonomic and abundance similarity in section 85-88. There was a similar result in the case of the cladocerans, represented only by *Bosmina*

coregoni in the section between sites 83 and 84. The similarity of the sites in terms of rotifers was due to the ubiquity of *Keratella cochlearis*, *Bdelloidea* and *Lecane closterocerca*. In each section, a sharp decrease in the abundance of zooplankton was observed, except for rotifers and total zooplankton in sections 14-19, cladocerans in sections 51-52 and 54-66, rotifers and copepods in sections 67-88 and all taxonomic groups in sections 84-85 (Figure 4). The greatest reductions of each taxonomic group occurred between the outlets of lakes and the next downstream section

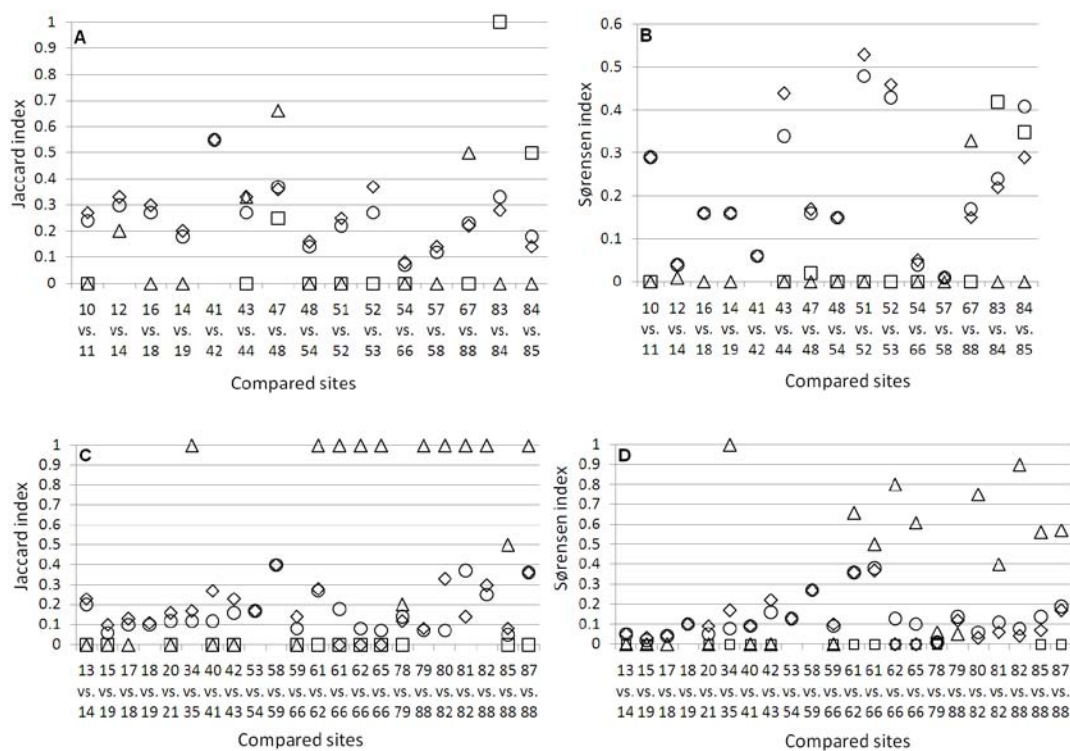


Figure 3. Taxonomic similarity (Jaccard index – A, C) and abundance similarity (Sørensen index – B, D) between upstream and downstream areas of the Drawa drainage (A, B) and between tributaries and main streams of the Drawa drainage (C, D) in July 2009. Rhombi - rotifers, triangles - copepods, squares - cladocerans, circles - total zooplankton.

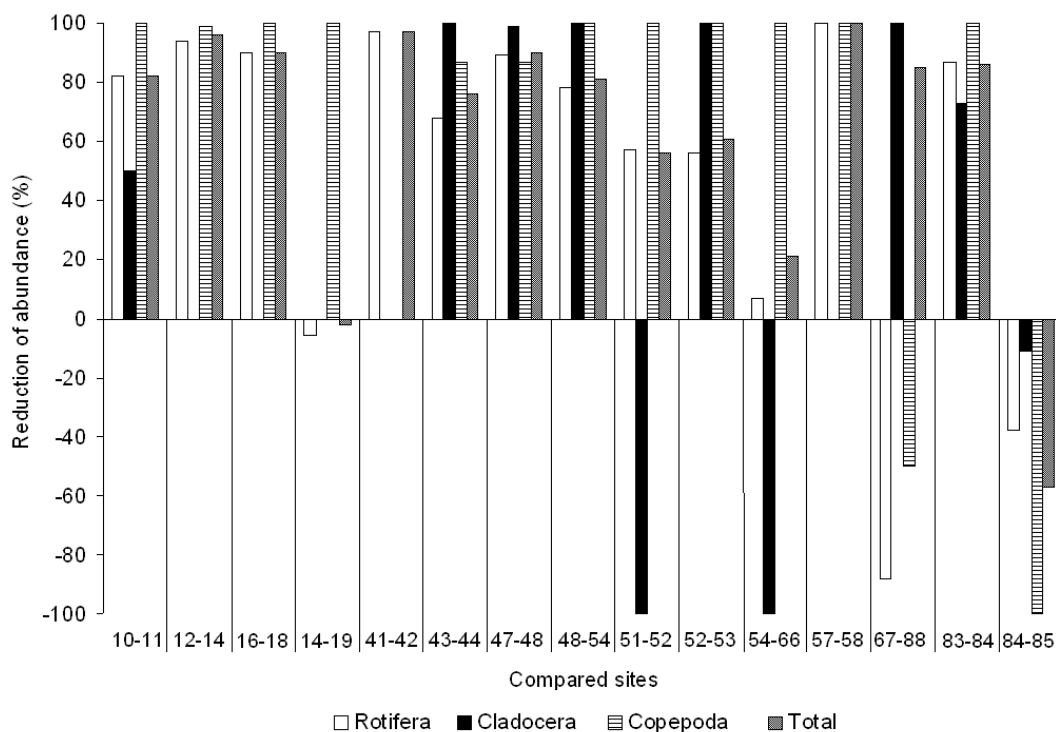


Figure 4. Reduction of zooplankton abundance (%) between upstream and downstream sites in the Drawa drainage in July 2009.

where they were sampled, although the reductions in the lower sections of rivers were also high. Generally, rotifers were characterized by the smallest reduction in abundance. Crustaceans, especially cladocerans, showed the greatest reduction in abundance. The greatest decrease of rotifer abundance – almost 100% – occurred between the outlet of the lake (site no. 57) and the next downstream section (site 58). In a few cases cladocerans were not observed even in upstream areas. Their abundance even decreased 100% in sections 43-44, 48-54, 52-53 and 67-88 (Figure 4). Copepods almost always showed a 100% decrease in abundance, except in sections 43-44 and 47-48 where they decreased by 87%. The 100% increase in abundance in downstream areas as compared to upstream areas was due to a lack of individuals upstream and very small abundances downstream (Table 3).

3.3 Similarity between tributaries and main channel

The effect of inflow from the tributaries on the zooplankton community in the main channel of the Drawa was small and characterized by the occurrence of ubiquitous taxa at the sites compared. Thus, in the whole course of the Drawa, the tributaries did not visibly impact zooplankton communities, which is similar to observations made on other rivers. In the entire drainage of the Drawa, we examined 22 sections (Figure 3). In these sections, the similarity of taxa and of abundance was also low in both each taxonomic group and in the entire zooplankton community (Figure 3). As was found in the relationships between upstream and downstream areas, the greatest taxonomic and abundance similarity

between the tributaries and the main channel was seen in the copepods, but this similarity was caused only by the occurrence of nauplii in both sites. Generally the smallest taxonomic and abundance similarity was seen in crustaceans, although the similarity of rotifers was also small. Between the tributaries and the main channel no taxonomic and abundance similarity of cladocerans were observed. Copepods, except the cases of the same taxa occurrence characterized by small community similarity. The highest Sørensen index was noted between sites 85 and 88. The highest rates of community similarity were caused by the presence of taxa, which were noted most frequently. NMDS analysis revealed high similarity in zooplankton abundance only between sites that were environmentally similar, but not between upstream and downstream areas, or between tributaries and the main channel (Figure 5).

3.4 Trophic status effect

No significant differences were observed in the Shannon-Weaver index of each taxonomical group between the outlets from eutrophic and mesotrophic lakes ($P>0.1$) (Table 4). However, in the outlets of eutrophic lakes, the species diversity of all the zooplankton, and of each taxonomic group, was higher than in the outlets from mesotrophic lakes, except for Copepoda (Figure 6). ANOVA statistical analysis revealed no significant differences in total zooplankton abundance, nor in the abundance of each taxonomic group between the outflows from the eutrophic and mesotrophic lakes ($P>0.1$) (Table 5). However, in the outflows of eutrophic lakes the average total zooplankton abundance and the abundance of each taxonomic group were higher than

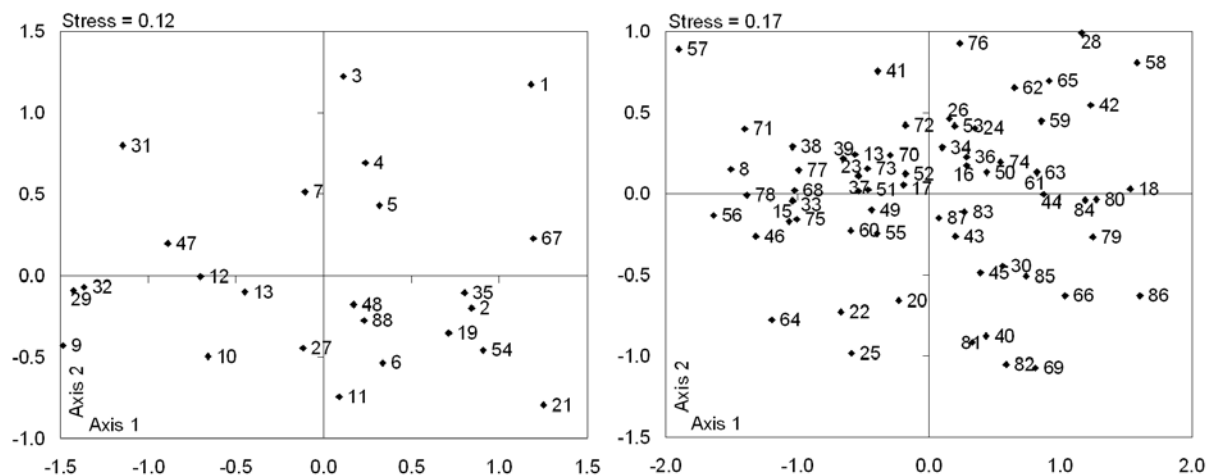


Figure 5. nMDS ordination for total zooplankton abundance at sites in the main channel of the Drawa (left) and sites in tributaries of the main channel of the Drawa (right). The grouping in the nMDS ordination was based on the Bray-Curtis distances.

in outlets from mesotrophic lakes (Figure 7). The largest differences in abundance between the outflows from lakes of different trophic status were seen in the total number of zooplankton and the number of rotifers. In the case of crustaceans, the differences in the values of the ANOVA test were much smaller than for rotifers.

3.5 Riparian zone effect

In relation to riparian zone type, no significant differences for the Shannon-Weaver index were observed between sites. Cladocerans showed the greatest difference in Shannon-Weaver index values from one type of riparian zone to another, with a greater value in rivers with a vegetation-free riparian zone (NV) than in rivers where the riparian zone is covered with vegetation (V) ($P < 0.05$) (Figure 6, Table 4). However, the most significant differences in the abundance of zooplankton were related to the riparian zone character (Figure 7, Table 5). Both the entire zooplankton community and the

rotifers were significantly more abundant in rivers with a concrete riparian zone and in rivers with vegetation-free riparian zones than in rivers with a vegetated riparian zone; $P < 0.05$ in both cases. Both cladocerans and copepods were most abundant in rivers characterized by vegetation-free riparian zones and a concrete riparian zone (Figure 7). It should be noted that abundance of cladocerans and copepods in rivers with a vegetation-free riparian zone (NV) was significantly higher than in rivers with a vegetated riparian zone ($P < 0.1$). Both the entire zooplankton community and each group showed the most abundance and taxonomical diversity in watercourses with riparian zones without vegetation (Figure 6, 7).

3.6 The effect of physical and chemical variables

CCA of the samples and taxa from sites in the main channel of the Drawa revealed that width, depth, vegetation coverage, pH, and Secchi depth visibility

Variable	Main effect	Pairwise comparison		
	Riparian zone type			
		V vs. NV	V vs. C	NV vs. C
Rotifera				
F	0.8738			
P	0.4210	0.3173	0.5747	0.6123
Cladocera				
F	1.6576			
P	0.2028	0.1543	0.7991	0.2078
Copepoda				
F	1.3741			
P	0.2604	0.3795	0.1487	0.5093
Total				
F	0.9948			
P	0.3740	0.2788	0.6401	0.4913
	Lake trophy status			
	Meso vs. Eu			
Rotifera				
F	3.2552			
P	0.0761	0.0762		
Cladocera				
F	0.0241			
P	0.8823	0.8825		
Copepoda				
F	1.0623			
P	0.3073	0.3076		
Total				
F	0.9887			
P	0.3253	0.3255		

Table 4. Results of statistical analysis (ANOVA as main effect and the Duncan test as pairwise comparison) for the Shannon-Weaver index at sites with different riparian zones and trophic status. For symbols see Figure 6.

Variable	Main effect	Pairwise comparison		
		Riparian zone type		
		V vs. NV	V vs. C	NV vs. C
Rotifera				
F	5.6443			
P	0.0049	0.2671	0.0018	0.0290
Cladocera				
F	2.5613			
P	0.0831	0.0871	0.3118	0.4112
Copepoda				
F	2.4228			
P	0.0947	0.0891	0.5247	0.2420
Total				
F	5.7963			
P	0.0043	0.1791	0.0019	0.0528
		Lake trophy status		
		Meso vs. Eu		
Rotifera				
F	2.0339			
P	0.1587	0.1588		
Cladocera				
F	1.5400			
P	0.2192	0.2193		
Copepoda				
F	1.2714			
P	0.2637	0.2638		
Total				
F	2.4115			
P	0.1254	0.1256		

Table 5. Results of statistical analysis (ANOVA as main effect and the Duncan test as pairwise comparison) for the abundance of zooplankton at sites with different riparian zones and trophic status. For symbols see Figure 6.

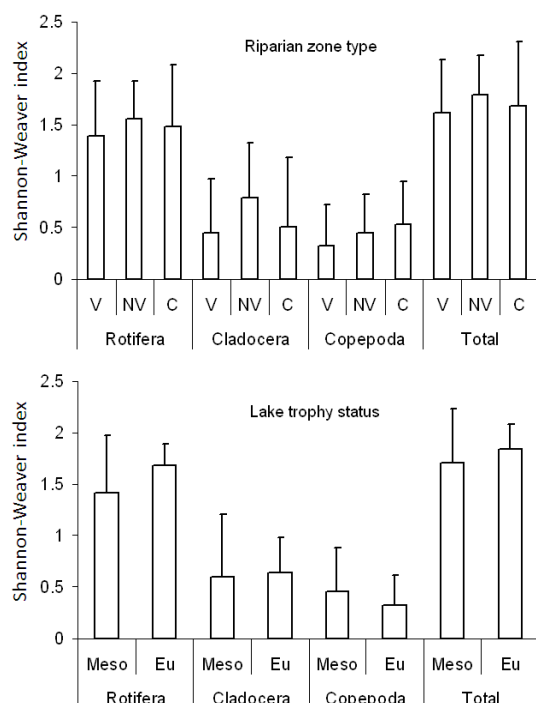


Figure 6. Mean value and SD of the Shannon-Weaver index for zooplankton at sites characterized by different riparian zones and trophic status. V – riparian zone covered with vegetation (n=53); NV – riparian zone without vegetation (n=22); C – concrete riparian zone (n=13); Meso – mesotrophic lake (n=14); Eu – eutrophic lake (n=51).

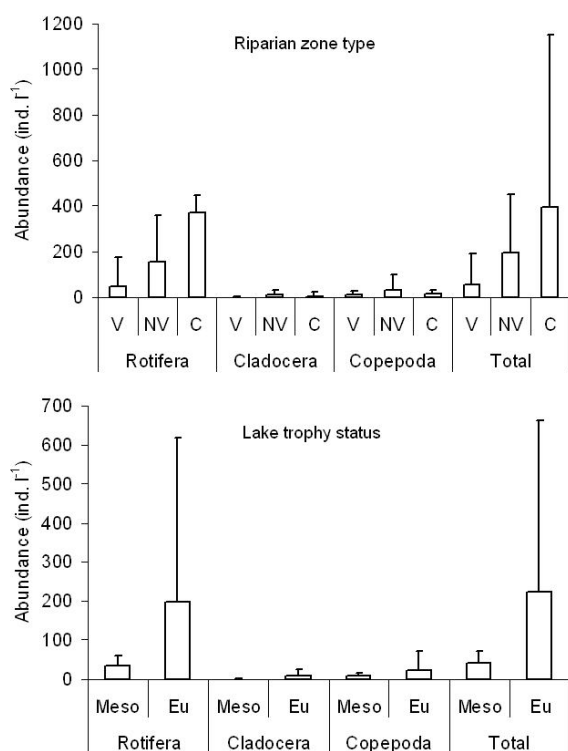


Figure 7. Mean value and SD of zooplankton abundance in sites characterized by different riparian zones and trophic status. For symbols see Figure 6.

correlated best with the first axis. Discharge correlated a little less with this axis. Temperature correlated best with the second axis (Figure 8). In the Drawa River, the abundance of cladocerans, adult copepods and *Synchaeta sp.* showed a significant positive correlation with the hydrological parameters of the river, such as depth, width and discharge, and also with vegetation coverage (randomization test, $P < 0.05$). The strongest correlation was shown by Daphnidae. The Secchi depth, dissolved oxygen content and pH were negatively related to an increase in the abundance of most plankters, particularly to the abundance of large crustaceans. Only the abundance of small rotifers such as *Kellicotia sp.*, *Keratella sp.* and *Pompholyx sp.* was positively related to chemical parameters. The abundance of small rotifers showed the weakest correlation with the hydrological parameters of the river. *Synchaeta sp.* was the only species among the rotifers whose abundance correlated with parameters similar to those of the crustaceans. As far as the tributaries of the Drawa River are concerned, the CCA revealed that their widths and depths correlated best with the first axis. Conductivity and pH correlated more poorly with this axis. The Secchi depth, temperature and conductivity correlated best with the second axis (Figure 8). Similar to observations in the main channel river, the highest abundance of zooplankton was noted in the widest and deepest streams of the tributaries. Additionally, these sites were characterized by the smallest Secchi depth. NMDS ordination indicated the greatest similarity in zooplankton abundance between sites that have very similar environmental conditions, both in the main river and in tributaries (Figure 5).

4. Discussion

In each taxonomical group the small plankters were observed to have the greatest variety of species and to be most abundant. These taxa are often seen in river plankton and their percentage contribution to the abundance of their taxonomical group was well over 50%, and in some cases, e.g., *Keratella cohclearis*, even over 90% of all zooplankton [e.g. 24]. The abundance of these taxa is probably related to the nutritional selectivity of planktivorous fish. Such fish are not interested in small species [1,25]. Jack and Thorp [25] observed that fish predation reduces the population growth rates and densities in the larger cladoceran and copepod taxa, while not affecting the population growth rates of the smaller zooplankton, such as rotifers. This fact may be related to size-selective predation by planktivorous fish [e.g. 26,27].

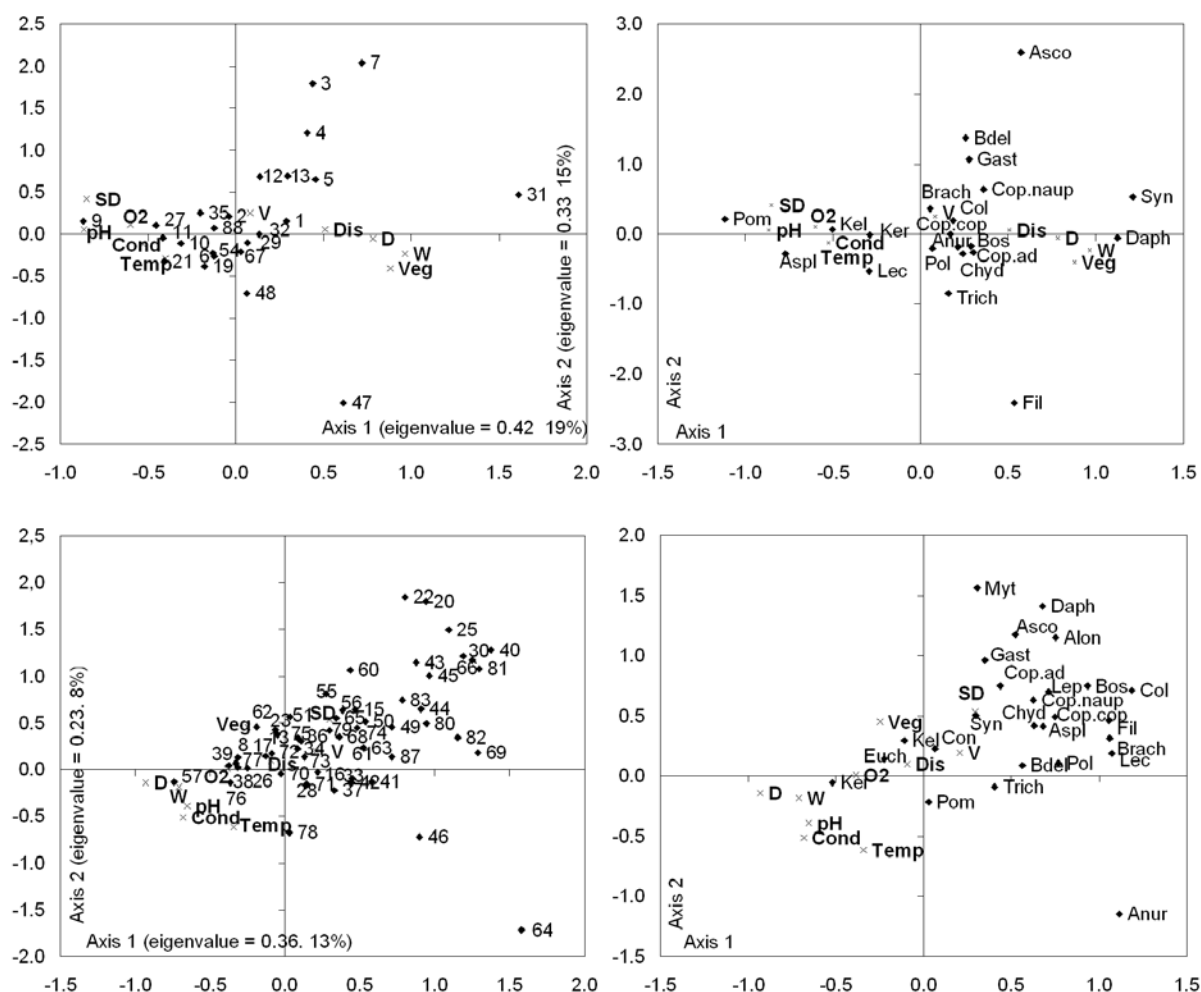


Figure 8. CCA constrained ordination of the samples and taxa from sites in the main channel of the Drawa (top) and from sites in tributaries of the Drawa (bottom). Numbers indicate the sites. Environmental variables: SD – Secchi depth, Veg – vegetation coverage; V – velocity; Dis – discharge; W – width, D – depth, Temp – temperature; Cond – conductivity; O2 – dissolved oxygen. Taxa: Anur – *Anuraeopsis* sp., Asco – *Ascomorpha* sp., Aspl – *Asplanchna* sp., Bdel – *Bdelloidea*, Brach – *Brachionus* sp., Col – *Colurella* sp., Con – *Conochilus* sp., Euch – *Euchlanis* sp., Fil – *Filinia* sp., Gast – *Gastropus* sp., Kel – *Kellicotia* sp., Ker – *Keratella* sp., Lec – *Lecane* sp., Lep – *Lepadella* sp., Myt – *Mytilina* sp., Pol – *Polyarthra* sp., Pom – *Pompholyx* sp., Syn – *Synchaeta* sp., Trich – *Trichocerca* sp., Alon – *Alonidae*, Bos – *Bosminidae*, Chyd – *Chydoridae*, Daph – *Daphnidae*, Cop. naup – *Nauplii* Copepoda, Cop.cop – *Copepodites*, Cop. ad – adult Copepoda.

In the present study the abundance of large cladocerans, e.g., *Daphnia*, *Ceriodaphnia* or *Diaphanosoma*, and adult copepods was generally small. Large riverine crustaceans, particularly *Daphnia*, showed a low abundance which often did not exceed 1.0 individuals per liter (ind. l⁻¹) or they were simply not present in the rivers [5,9]. The highest abundance of large crustaceans was only noted downstream of outlets from strongly eutrophic lakes, in the shallow and large floodplains of the Drawa River (sites 29, 31, 32). This relatively high abundance of large crustaceans could be due to a very high production of large crustaceans in shallow floodplains. The large crustaceans are a sufficient food source for planktivorous fish gathering

upstream of the outlets [1,5]. In shallow floodplains, very low transparency and high turbidity exist [28], which together may limit the ability of planktivorous fish to capture large zooplankton individuals (the effect of transparency and turbidity is discussed below). The shallow riverine lakes or shallow floodplains are rich in zooplankton and large cladocerans [e.g. 23,29]. The phenomenon of zooplankton production in stagnant riverine water bodies is very important for the well known reason that these water bodies are a major source of zooplankton in the river-lake systems [e.g. 6,29,30].

River plankton ecologists are also interested in how the river zooplankton community in the main channel is modified by the inflow from the slackwaters [4,16],

floodplains [28] connected reservoirs [24,29,30] and tributaries [8]. How much the zooplankton communities are reduced between upstream and downstream sections, especially below lake outlets, [3,5,9,29] is another major point of interest. Between the outflow of these water bodies and areas downstream there are reductions in the density of zooplankton in only the first section below the outflow. In particular, the number of large crustaceans declines [5-7,9]. Based on these authors' reports, it can be concluded that several hundred meters below the outflow the effect of stagnant water bodies on the zooplankton communities of large and relatively large rivers is rather small. In the present study, low results on the Jaccard index or the Sørensen index were observed between lake outlets and downstream areas. The nMDS analysis showed similar results. These results may also indicate the low impact lakes have on the shape of the zooplankton community downstream. Such an impact is probably due to a strong reduction of zooplankton by juvenile fish just behind the outflow [5,7]. The largest reductions of up to 100% were for crustaceans, especially cladocerans. There were exceptions; in some cases in downstream sites we observed a higher abundance of some groups than in the upstream. This fact can be explained by the occurrence of fish ponds in the section above these downstream sites. Zooplankton were able to move to the main channel from these ponds.

Although the reduction of zooplankton communities below outlets of stagnant water bodies is relatively well known, the effect of tributaries on the shape of zooplankton structure in the main river is poorly understood. On the basis of the results from the present study, we can also state that the zooplankton river community in the main channel is not modified, or is modified in only a small way, by the inflow tributaries. The results of the Jaccard index, the Sørensen index and the distances between sites in nMDS analysis indicate the low quantitative and taxonomic similarity between the tributaries and the main channel. Czerniawski and Domagała [8] observed that tributaries that are characterized by regular bed and faster current velocity minimally affect the zooplankton community in the main river. The tributaries almost did not affect the shape of the zooplankton communities in the main river. As mentioned above, the influence of tributaries on the zooplankton communities in the main river is not yet sufficiently understood; the same can be said about the outlets [5,15]. So, it seems reasonable to conduct further research to better understand the relationships shaping the structure of zooplankton between outflows and downstream or between the tributaries and the main channel.

Despite the lack of statistically significant differences in zooplankton abundance between the outlets of lakes of different trophic status, relatively large differences were observed. The greatest abundance of zooplankton was in the eutrophic lake outlets; whereas lesser abundance was seen in mesotrophic lake outlets. There are two main reasons for this. Firstly, the production of zooplankton in eutrophic lakes is much greater than in mesotrophic lakes [10]. It follows that in the outlets from eutrophic lakes, the zooplankton abundance would be higher than in the outlets from mesotrophic lakes. Secondly, the water removed from the eutrophic lakes is characterized by a greater amount of organic matter and suspended solids. For this reason zooplankton may be less visible to planktivorous fish. Additionally, CCA revealed that a decrease of Secchi depth visibility favored potamoplankton abundance. Czerniawski and Domagała [9] stated that in the outlet of a mesotrophic lake with high Secchi depth, the reduction of the zooplankton community, particularly the biomass of zooplankton, was higher than in the outlet of a eutrophic lake. In the case of Cladocera, the biomass was almost 20 times greater.

Analyzing the vegetation cover of the bed we observed that greater species richness and abundance of crustaceans occurred in waters with more vegetation coverage. This richness and abundance of crustaceans is probably because crustaceans, especially adult copepods, are able to escape from fish into the dense vegetation of macrophytes [31,32]. According to most of the authors working in the field, one of the major roles of macrophytes is thought to be the refuge that they provide for grazing zooplankton, especially crustaceans, from planktivorous fish that are visual predators [11,13]. Manatunge *et al.* [33] stated that the foraging efficiency of planktivorous fish decreased significantly as plant density increased. In the present study, there was a smaller correlation between crustacean abundance and surface vegetation in the tributaries of the Drawa than in the main channel. This correlation allows us to conclude that the impact of macrophytes on the abundance of zooplankton can be similar both in lakes and in larger rivers. In small streams though, a vegetation bed cover probably has less effect on zooplankton communities than in lakes.

Some sites were not densely covered with macrophytes and had lower rates of current velocity. At these sites, a low abundance of adult copepods in the waterflow volume was observed. The adult copepods' swift movements may have helped them to avoid fish predation by escaping from the flow to vegetation [31,32]. The richness of small species may be caused by their inability to resist water currents. As mentioned above, the low values of velocity provide

a higher chance for the presence and movement of crustaceans even in the watercourse flow. The majority of microfauna are unable to move at a velocity above 10 cm s^{-1} [1,34].

Riparian zone character was the variable which caused the most differences in zooplankton communities. The greatest abundance and richness of species were observed in rivers with a vegetation-free riparian zone and a concrete riparian zone. This may also be related to the number of planktivorous fish. Fish are found in higher numbers in streams whose riparian zones are covered with vegetation [35,36]. River/land ecotones with vegetation greatly influence the stream ecosystem. These ecotones shelter many species of fish fry [18,19]. The results of Jones *et al.* [37] suggest that riparian forest removal leads to shifts in the structure of fish communities due to decreases in the number of fish species. It can be concluded that riparian zones may also provide a hiding place for many fishes which prey on zooplankton. On the other hand, Dodson *et al.* [38], and Xu *et al.* [39] showed a high positive influence of riparian zones on the abundance and biodiversity of lake zooplankton. Hence, the precise causes of the greater abundance of zooplankton in rivers with vegetation-free riparian zone are difficult to explain, especially because the standard deviation of the abundance of each group of zooplankton was relatively high. It seems that the most likely reason for the differences between rivers with differing riparian zones was the varying abundance of planktivorous fish in these zones.

Most authors indicate a strong correlation between the hydrological conditions of rivers and the abundance of zooplankton [2,5,6]. The results of the CCA analysis of the present study showed similar relationships, especially in the main channel of the Drawa. The number of large plankters showed a significant positive correlation with the depth, width and discharge of the river. The small plankters such as small species of rotifers and Cladocera or Cyclopoida nauplii showed the smallest correlations with these factors. Czerniawski and Domagała [8,9] also observed this phenomenon in small rivers, where the physical conditions of the rivers only had an influence on large crustaceans and large rotifers. Hydrological parameters correlated strongly with the abundance of zooplankton, particularly cladocerans. In the tributaries of the Drawa (which are shallower and narrower streams than the Drawa) the width and depth were also the most important factors in determining the abundance of zooplankton. So, both in the Drawa River and in its tributaries the highest abundances of zooplankton were recorded in the widest and deepest streams. For this reason, it can be supposed that in watercourses with greater depth and width and higher

velocity, the faster current and greater volume of water made it difficult for planktivorous fish to capture plankters, although it is difficult to prove this supposition without checking the contents of fish stomachs.

Nonetheless, as mentioned above, in large rivers where width and depth are greater, crustaceans are much more abundant than in small rivers and streams. This was especially true of large cladocerans [e.g. 1,5]. However, in deep, wide rivers, it is difficult to prove that depth and width are negative factors for fish trying to catch plankton-prey. Macroinvertebrate predators may have difficulties similar to those of planktivorous fish. Additionally, Chang *et al.* [5] stated macroinvertebrates only play a very small role in the reduction of zooplankton densities. Another reason for the positive impact of the width and depth on the abundance of zooplankton is the widening of the river. The greater the width and depth of the river, the more small floodplains and slackwaters there are, which play a very important role in zooplankton reproduction. These small water bodies also help move the zooplankton to the main channel [1,15,16]. Nielsen *et al.* [16] have observed that the abundance of adult microcrustaceans even exceeded 180 ind. l^{-1} in slackwaters. The scouring of microfauna from slackwaters results in increased similarities between communities in slackwaters and flowing habitats [4,16]. It seems that the width of the river has more of an influence on the production of zooplankton in slackwaters and thus on the presence of zooplankton in the river. However, river width has less of an influence on zooplankton reduction, due to capture by planktivorous fish or macroinvertebrates.

The abundance of the majority of crustacean taxa was negatively related to the Secchi depth. The highest densities of zooplankton were noted in sites with low Secchi values. Hydrological parameters and transparency could affect fish feeding activity. Also, higher values of transparency may facilitate attacks by planktivorous fish. According to Wissel and Benndorf [26], a smaller abundance of zooplankton can be a consequence of increased water transparency as the latter facilitates fish predation.

In the present study we observed few significant correlations between chemical parameters and small rotifer abundance. Czerniawski and Domagała [8] stated that in small watercourses rotifer abundance may correlate significantly with chemical conditions, but this applied to outlets from strongly eutrophicated lakes. Moreover, Kobayashi *et al.* [3] observed strong positive correlations between the potamoplankton community and the conductivity or total phosphorus in the Havkesbury-Nepean River.

In summary, upstream areas, especially outlets, did not affect the zooplankton communities in downstream areas. This was also true of tributaries which had no influence on the shape of zooplankton communities in the main river. In the outlets of eutrophic lakes, a greater amount of zooplankton and of species diversity was observed than in the outlets of mesotrophic lakes. Increased vegetation coverage mainly affected the abundance of crustaceans. On the basis of the results of this study and other authors' studies, we

stated that the influence of the riparian zone on zooplankton communities in small rivers could not be verified. A decrease in Secchi depth increased potamozooplankton abundance. On the basis of all these results, it can be concluded that hydrological conditions had the greatest impact on the taxonomic composition and density of zooplankton in small rivers. The influence of abiotic parameters was most pronounced on cladocerans communities, while rotifers were the least affected.

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