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Original Research

Influence of Eutrophic Lowland Reservoir on Crustacean Zooplankton Assemblages in River Valley Oxbow Lakes

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Abstract

The aim of this study was to determine the ability of crustacean zooplankton outflowing from the dam reservoir to colonize new habitats of a river valley. Siemianówka Reservoir is a huge source of crustaceans for the outflowing Narew River and results in a 33- to 307-fold increase in summer biomass of potamozooplankton. Zooplankton samples were collected from a permanently connected oxbow lake located directly behind the reservoir and from 18 oxbow lakes 10 to 180 km from the dam. The results of our study showed that crustacean zooplankton of oxbow lakes generally showed low similarity to Siemianówka Reservoir. However, a high level of zooplankton similarity was observed among oxbow lakes themselves. This could suggest that the crustacean zooplankton of the oxbow lakes in the river valley show a metacommunity structure.

Keywords: crustacean zooplankton, reservoir, oxbow lakes, dispersal, colonization, metacommunity

Introduction

Nowadays most rivers are regulated by reservoirs, which greatly influence both the hydrology and biogeochemical functioning of a river [1, 2]. The water released by the reservoir is the main source of plankton in the outflowing river [3-5]. Patterns of spatial distribution of zooplankton communities in rivers below dam reservoirs have been described by many authors, and generally zooplankton suffers qualitative and quantitative reduction, which is most pronounced for large crustaceans [6-8]. Similar observations were described from two-year studies of crustacean zooplankton in the Narew River below the Siemianówka Reservoir, which is a great and continuous source of crustaceans [9]. The dispersal of zooplankton from a reservoir is a unidirectional and ongoing process. However, the dispersal of the active population of large cladocerans is potentially very important over relatively short distances, whereas resting eggs are most important for long-range dispersal [10].

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The idea that colonization and extinction can determine local community structure through dispersal was first incorporated in ecology through the theory of island biogeography [11], in which habitat fragments are colonized from a large "mainland" source. Local communities of zooplankton can be structured by both local interactions (competition, predation, environmental variables, etc.) and by regional interactions (dispersal of individuals between habitats). Study of zooplankton in highly interconnected ponds suggests that local environmental constraints can be strong enough to structure local communities [12]. Dispersal only limits the diversity of very young zooplankton communities [13]. The relative importance of local environmental and regional spatial processes in a metacommunity is currently hotly debated [14].

The question is: do reservoirs, which are a large source of zooplankton, affect the limnic ecosystems of the river valley? The aim of this study is to asses the role of the eutrophic lowland reservoir in creating crustacean zooplankton assemblages in oxbow lakes located at different distances from the dam. It may give information about influence of a reservoir on ecosystems of a river valley. This is very important because nowadays most rivers are regulated by reservoirs, being a continuous source of crustacean zooplankton.

Study Area and Methods

The Narew River is the largest tributary of the Vistula River in NE Poland. The hydrological regime of the upper Narew is characterized by deep low waters in summer and high water flows followed by floods in spring. The upper part of the Narew River is characterized by low flow velocity and discharge from 5 to 21 $m^3 \cdot s^{-1}$ [15]. In 1990 the shallow Siemianówka Reservoir (SR) (52º55'N, 23º50'E) was constructed on the upper course of the Narew River, near the Polish-Belarusian border. With the maximum stocking of water reaching 145 m a.s.l., the reservoir's capacity amounts to 79.5 million m^3 [16]. The reservoir and the river below the dam are highly eutrophic in terms of physical and chemical indicators [17]. As regards phytoplankton, a strong permanent dominance of potentially toxic Cyanobacteria has been observed in the reservoir from its beginning [18, 19]. The mean water residence time is relatively high, approximately 6 months, and this creates favorable conditions for development of crustacean zooplankton. Previous studies have shown that Siemianówka Reservoir was a huge source of crustaceans for the outflowing Narew River. [9].

Influence of the dam reservoir on the crustacean zooplankton assemblages in oxbow lakes was analyzed in two sites. The first one was the permanent connected oxbow lake (OX) located just behind the dam. The oxbow lake is approximately 250 meters long, narrow (6-10 m), shallow (up to 1.2 m), and covered with aquatic vegetation dominated by *Ceratophyllum demersum*, *Elodea canadensis*, and *Potamogeton pectinatus*. Zooplankton samples were taken monthly during the vegetation season from June to September 2011 at three sampling stations: Siemianówka Reservoir near the dam (SR), an oxbow lake 300 m below the dam (OX), and the Narew River 500 m below the dam (NR) (Fig. 1).

The second site involved 18 oxbow lakes of the upper Narew valley (Fig. 1). The studies were carried out during

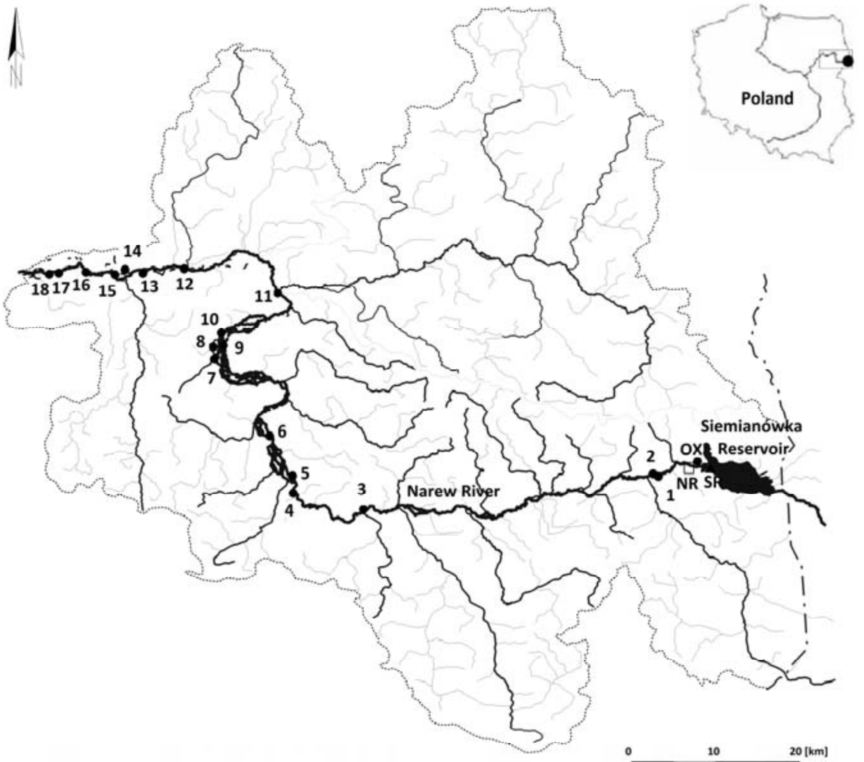

Fig. 1. Map of the study sites with the locations of the sampling stations; dot – oxbow lakes (OX, 1-18); square – Narew River below the dam (NR); triangle – Siemianówka Reservoir (SR) near the dam.

Table 1. Characteristics of the studied oxbow lakes.

Oxbow lakes	Distance from the dam [km]	Connection to the river	Character of the river
1	10	temporary	meandering
2	11	temporary	meandering
3	73	temporary	meandering
4	89	permament	meandering
5	91	temporary	anastomozing
6	100	permament	anastomozing
7	126	permament	anastomozing
8	127	permament	anastomozing
9	127	permament	anastomozing
10	130	permament	anastomozing
11	145	temporary	regulated
12	160	permament	regulated
13	168	temporary	regulated
14	170	temporary	regulated
15	172	temporary	regulated
16	177	permament	regulated
17	183	temporary	regulated
18	185	temporary	regulated

low water in July 2011. These oxbows were located between 10 and 185 km below the dam reservoir (Table 1). The Narew River below the SR is a meandering river with flooded marshes and meadows. From 90 to 130 km below the dam the river changes its character and becomes an anastomosing one and is protected as Narew National Park (NNP). Below NNP the valley is strongly altered by drainage works and the Narew River becomes regulated with a large number of oxbow lakes (Table 1).

Zooplankton was sampled by a bucket and material was condensed on a plankton net of 50 µm mesh size, transferred into bottles and fixed with formalin. Crustaceans were determined to species and counted in subsamples equal to 1 litre. The material was then elaborated upon according to methods described in Bottrell et al. [20].

Zooplankton communities in: SR, NR, and OX were compared using the Bray Curtis similarity matrix based on agglomerative hierarchical cluster analysis (AHC) for each month while the similarity between study objects in the Valley of the Upper Narew River were estimated by Kulczynski's similarity index. Canonical correspondence analyses (CCA) was performed in order to detect the spatial relations between the zooplankton communities of the oxbow lakes and the reservoir. The differences between samples were tested with a non-parametric Kruskal-Wallis test. Probability levels of ≤ 0.05 were considered significant and the groups were separated using the Conover-Inman test ($P<0.05$) [21]. All analyses were performed with Biodiversity Pro: Free Statistics Software for Ecology and XLSTAT (Addinsoft).

Results

The crustacean community in the SR was strongly dominated by planktonic species. More than 90% of the summer biomass formed: *Mesocyclops leuckarti* (Claus), *Chydorus sphaericus* (Müller), *Daphnia cucullata* Sars, *Diaphanosoma brachyurum* (Lievin), *Bosmina longirostris* (Müller), and *Bosmina coregoni* Baird. Zooplankton in the river below the dam (NR) was dominated by planktonic organisms from the reservoir. At the same time the oxbow lake behind the dam (OX) was dominated by littoral-periphytic species: *Simocephalus vetulus* (Müller), *Ceriodaphnia reticulata* (Jurine), *Scapholeberis mucronata* (Müller), *Acroperus harpae* (Baird), *Eurycercus lamellatus* (Müller), and *Eucyclops macruroides* (Lilljeborg). Total number of species (Fig. 2A) in the oxbow lake (OX) was significantly higher than in the SR ($p=0.005$) and NR ($p=0.001$). Shannon index (Fig. 2B) in the oxbow lake (OX) was significantly higher than in the SR ($p=0.041$) and NR ($p=0.05$). Total zooplankton abundance (Fig. 2C) in the oxbow lake was significantly lower than in the SR ($p=0.016$). The AHC analysis revealed high similarity between the reservoir (SR) and the river below (NR) it throughout the study period (Fig. 3).

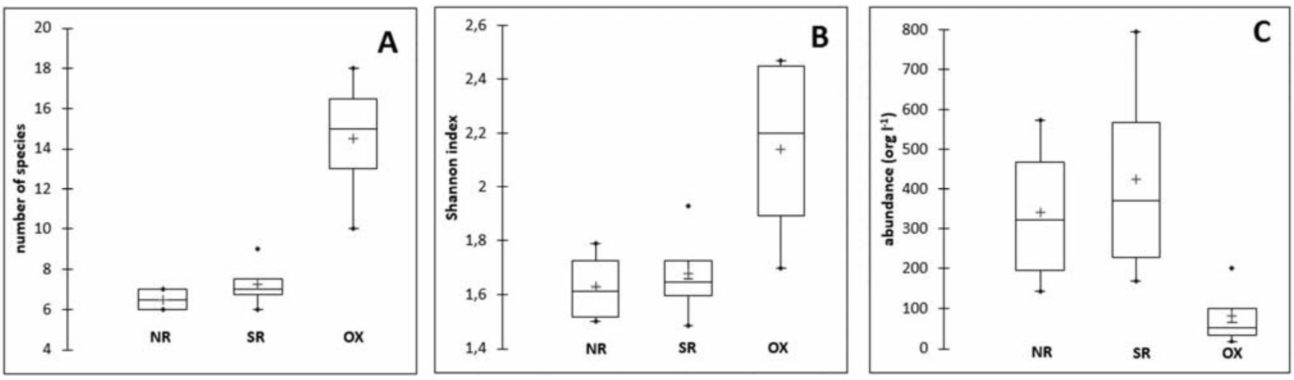

Fig. 2. Number of species (A), Shannon index (B), and abundance (ind·l^{-1}) of crustacean zooplankton in: Siemianówka Reservoir (SR), Narew River below the dam (NR), and oxbow lake behind the reservoir (OX).

Table 2. The occurrence of dominant species from Siemianówka Reserovir (SR) in the studied oxbow lakes (1-18).

	SR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Diaphanosoma brachyurum	x																		
Daphnia cucullata	x																x		
Bosmina coregoni	x												x						
Bosmina longirostris							x					x	x	x					
Chydorus sphaericus	x	x				x	x	x		x	x	x	x			x	x	x	x
Mesocyclops leuckarti	x	x	x	x			x		x		x	x	x	x	x		x	x	

Relatively high similarity of zooplankton community between SR and oxbow lake (OX) was observed only in June, when highest value of flow below the dam was observed (Fig. 3). Then in OX was observed a large share of planktonic species from the reservoir (Fig. 4). From July to September a very low similarity of crustacean communities was noted between SR and OX (Fig. 3), and zooplankton in the oxbow lake was dominated by the littoral-periphytic crustaceans and planktonic species from the reservoir were found occasionally (Fig. 4).

Subsequently the influence of the reservoir on spatial patterns of crustacean zooplankton assemblages in 18 oxbow lakes 10 to 180 km from the dam was analyzed. The zooplankton communities of oxbows were characterized by low zooplankton similarity to that of the dam reservoir (Fig. 5A). Surprisingly, the zooplankton structure of more distant oxbow lakes (121-180 km) showed higher similarity to the SR than oxbow lakes located closer (Fig. 5A). The highest similarity of zooplankton communities to the dam reservoir were found in oxbow directly behind the dam (OX), and in the most distant object (No. 18). The taxonomic similarity of crustacean communities in permanent and temporarily connected oxbow lakes were not significantly different (p=0.49) from the SR. As a rule, the higher level of zooplankton similarity was observed for oxbow lakes themselves (Fig. 5B) than with the dam reservoir (Fig. 5A). Species from the reservoir most frequently observed in oxbow lakes were common eurytopic species: *Mesocyclops leuckarti* and *Chydorus sphaericus* (Table 2). At the same time *Diaphanosoma brachyurum* was not found in oxbow lakes and *Daphnia cucullata* was noted only in oxbow lake No. 16 (Table 2).

Canonical correspondence analysis divided the crustacean communities of SR and oxbow lakes. Two axes of the ordination defined by the selected three community variables explained collectively 86.2% crustacean taxa distribution (Fig. 6). The second axis clearly distinguishes planktonic and littoral-periphytic species. Planktonic organisms were positively correlated with the second axis while the first axis divided planktonic species from SR and oxbow lakes (*Ceriodaphnia* species, *Daphnia pulex*). Littoral-periphytic species were strongly negatively correlated to the second axis. Only *Scapholeberis mucronata* was weakly negatively correlated to the second axis (Fig. 6), but this species is associated with littoral areas and hyponeuston of lakes, ponds, and rivers.

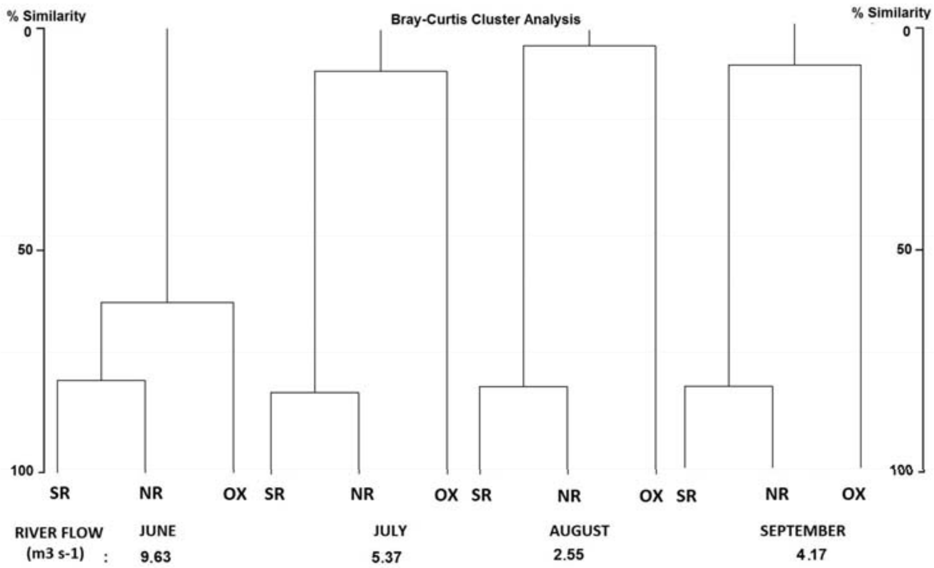

Fig. 3 Bray-Curtis similarity matrix based on agglomerative hierarchical cluster (AHC) analysis indicating the similarity of zooplankton community between Siemianówka Reservoir (SR), Narew River below the dam (NR), and oxbow lake (OX) separately for June to September; with flow below the dam ($m^3 \cdot s^{-1}$).

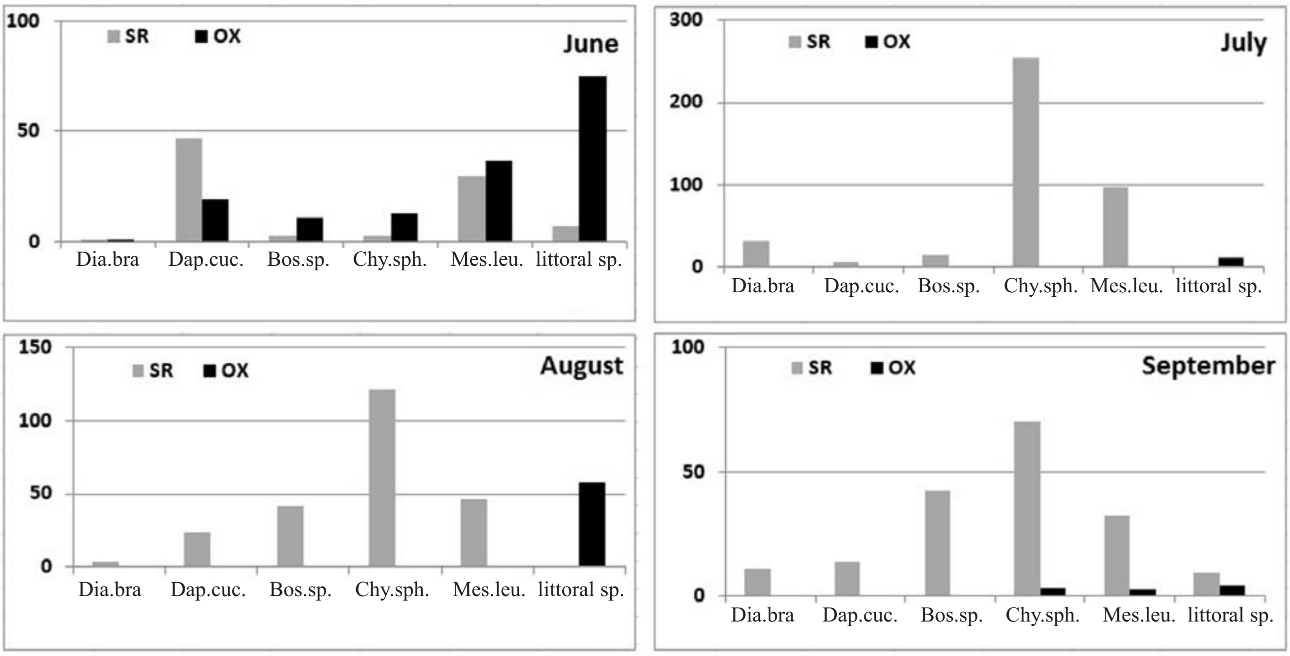

Fig. 4. The abundance of dominant crustacean species ($ind \cdot l^{-1}$) in the oxbow lake behind the dam (OX) and in Siemianówka Reservoir (SR) from June to September. The taxa shown are: Dia.bra. – *Diaphanosoma brachyurum*, Dap.cuc. – *Daphnia cucullata*, Bos.sp. – *Bosmina* species, Chy.sph. – *Chydorus sphaericus*, Mes.leu. – *Mesocyclops leuckarti* and littoral species.

Discussion

Water released by reservoirs is one of the main factors regulating the concentration of zooplankton downstream [3]. Previous studies have shown that Narew River zooplankton below the dam is mainly composed of planktonic species from the SR. Then a decreasing share of reservoir dominants along the river and increasing importance of littoral and benthic species [9]. A similar reduction in the abundance of zooplankton below the reservoir was described by many authors [22-24]. However, the crustacean species from the SR were still observed as far as 100 km downstream [9]. Dispersal of the active population of large cladocerans is potentially very important over relatively short distances, whereas dispersal of resting eggs is most important for long-range distances [10]. This allows the large cladocerans from the reservoir effectively to colonize distant habitats in the river valley.

Many publications have proven that oxbow lakes can function as "lairs" of life for rivers after flooding [25]. But could planktonic species outflowing from reservoir effectively colonize lentic shallow water bodies in the river valley? This study demonstrates the low impact of outflowing zooplankton from the dam reservoir on crustacean communities in oxbow lakes. Even permanently connected oxbow lakes just below the dam showed low similarity of crus-

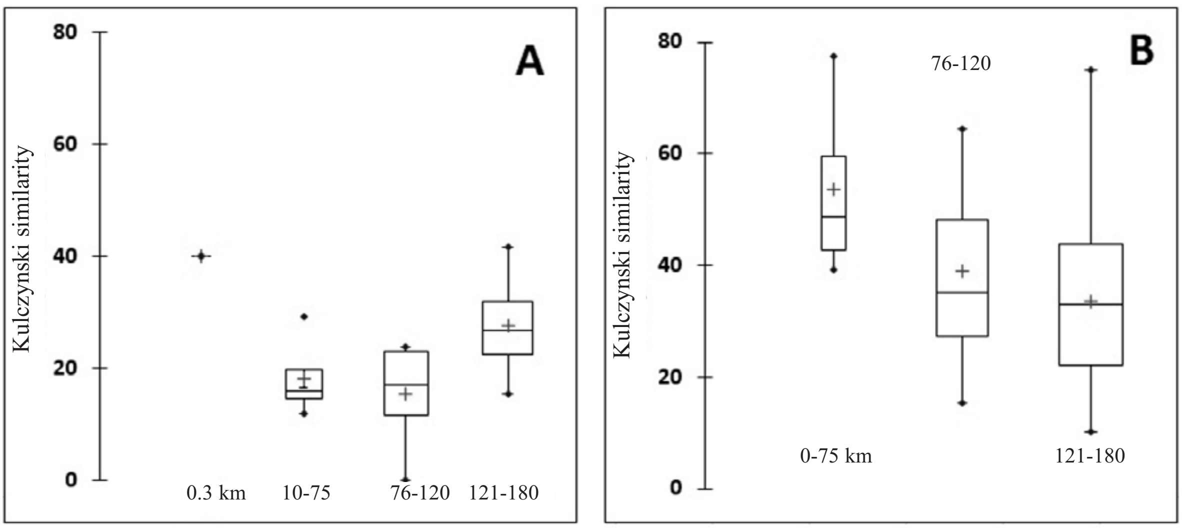

Fig. 5. Boxplot of Kulczynski similarity index of crustacean zooplankton communities from oxbow lakes (OX, 1-18) to Siemianwka Reservoir (A), and internal zooplankton similarity between oxbow lakes (B).

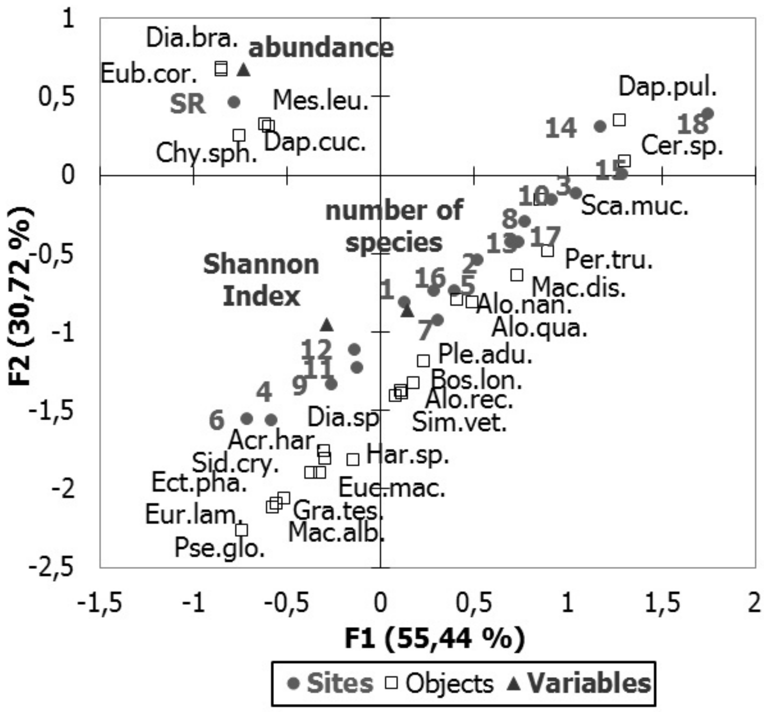

Fig. 6. CCA-constrained ordination of the crustacean zooplankton taxa, study objects (SR and 18 oxbow lakes), and community variables (abundance, number of species, Shannon Index). The taxa shown are: Acr.har. – *Acroperus harpae*, Alo.rec – *Alona rectangula*, Alo.qua – *Alona quadrangularis*, Alo.nan. – *Alonella nana*, Bos.lon. – *Bosmina longirostris*, Bos.cor. – *Bosmina coregoni*, Cer.sp – *Ceriodaphnia* species, Chy.sph. – *Chydorus sphaericus*, Dap.cuc. – *Daphnia cucullata*, Dap.pul. – *Daphnia pulex*, Dia.bra. – *Diaphanosoma brachyurum*, Dia.sp. – *Diacyclops species*, Ect.pha. – *Ectocyclops phaleratus*, Euc.mac – *Eucyclops macruroides*, Eur. lam. – *Eurycercus lamellatus*, Gra.tes. – *Graptoleberis testudinaria*, Har.sp. – *Harpacticoida species*, Mac.alb. – *Macrocyclops albidus*, Mac.dis. – *Macrocyclops distinctus*, Mes.leu. – *Mesocyclops leuckarti*, Per.tru. – *Peracantha truncata*, Ple.adu. – *Pleuroxus aduncus*, Pse.glo. – *Pseudochydorus globosus*, Sca.muc. – *Scapholeberis mucronata*, Sid.cry. – *Sida crystallina*, and Sim. vet. – *Simocephalus vetulus*.

tacean communities to that in the reservoir. The habitat template theory may help to understand this phenomenon. The level of favorability for organisms in a habitat is variable along time and space, showing different heterogeneous patterns [26]. Among factors that may structure crustacean communities in shallow and macrophyte dominated lakes, the level of a habitat heterogeneity, which is reflected in the architecture of plant beds, plays an essential role [27, 28]. The relationship between habitat and their matched species traits has been studied in aquatic ecosystems with more emphasis in the last decade, and recent studies have shown that even in distant regions, species traits converge in the same habitat [29]. Dispersal from the large source of zooplankton to local communities is a very important process, but local factors such as habitat heterogeneity, water quality, and community interactions can affect the survival and reproduction of individuals once they reach new habitat [30-32]. Crustacean communities of more distant, larger, and deeper oxbow lakes of the Narew River showed significantly higher similarity to the SR than shallow oxbow lakes closer the dam. This suggests that local environmental constrains can be strong enough to decide on the structure of local crustacean communities. Similar results were observed in highly interconnected ponds where local environmental variables had a strong impact on the zooplankton community [33]. However, a high level of similarity in crustacean zooplankton was observed among oxbow lakes themselves and could be evidence of zooplankton metacommunity structure in the oxbow lakes in the river valley.

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