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EUTROPHICATION IMPACT ON ZOOPLANKTON COMMUNITY: A SHALLOW LAKE APPROACH

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Zooplankton communities were investigated in a turbid shallow lake with an aim to analyze (i) relationships between ecological conditions and the communities and (ii) trophic state inferred from abiotic and biotic indicators. According to results emerged littoral vegetated zone increased diversity (30 taxa) in comparison to the pelagial (17 taxa). Rotifers dominated in terms of diversity and abundance in littoral and pelagial, 15 and 27 taxa, 58 and 71%, respectively. Thus, they were chosen for approximation of the system trophic level according to their feeding preferences exhibited as guild ratio. Mean guild ratios in littoral (– 0.36) and pelagial (– 0.31) suggested the prevalence of microfagous rotifers. They fed mostly on bacteria and detritus suspension, thus together with environmental parameters indicated high trophic level of the lake. It is supposed that turbidity resulted from anthropogenic eutrophication has affected biocoenosis assemblage, not only zooplankton but also the primary producers and the fishes.
Key words: transparency/turbidity, vegetation, trophic state, zooplankton.

Utjecaj eutrofikacije na zooplanktonsku zajednicu - koncept plitkog jezera. Interakcije zooplanktona istraživane su u eutrofnom, plitkom jezeru s ciljem utvrđivanja: (i) odnosa ekoloških čimbenika i zooplanktonske zajednice; (ii) stupnja trofije a obzirom na abiotičke i biotičke indikatore. Iako uska, u zoni emerzne vegetacije raznolikost svojti bila je veća (30 svojti) u odnosu na pelagičku zonu (17 svojti). Rotifera (kolnjaci) dominirali su u raznolikosti i brojnosti zooplanktona u litolarnoj i pelagičkoj zoni, a 15 i 27 svojti, odnosno udjelom od 58 i 71%. Zbog navedenog kolnjaci su izabrani za procjenu stupnja trofije ovog hidrosusatava temeljem načina prehrane izraženog kroz omjer hranidbenih skupina. Srednja vrijednost ovog omjera u litoralnoj (-0.36) i pelagičkoj (-0.31) zoni ukazivala je na dominaciju mikrofagnih vrsta. One se hrane suspenzijom bakterija i detritusa te zajedno s čimbenicima okoliša ukazuju na eutrofiju sustava. Pretpostavljamo, da je mutnoća jezera uzrokovana antropogenom eutrofikacijom utjecala na strukturu biocenoze, ne samo zooplanktona nego i primarnih producenata i riba.
Ključne riječi: prozirnost/mutnoća, emerzna vegetacija, stupanj trofije, zooplankton.

INTRODUCTION

Littoral zone of a lake is characterized by higher fluctuations of environmental factors, i.e., temperature, dissolved oxygen, nutrients, plenty food resources and presence of submerged, emerged or floated aquatic vegetation (hydrophyte communities or macrophytes) [1]. Macrophytes are defined as macroscopic photosynthetic organisms including algae, mosses and vascular vegetation which are also able to adapt to live in aquatic environments [2]. Their density influence water biochemistry and ecology of ecosystems [3]. For instance, they prevent resuspension of sediments and therefore dynamics of nutrients (mostly nitrates and ortho-phosphates) within the entire water body, and offer a shelter from predators to many organisms such as young fish, macroinvertebrates and zooplankton [4, 5]. Moreover, macrophytes serve as a food source for planktonic organisms and littoral zone inhabitants with attached detritus and epiphytic communities consisting of algae, protozoa, bacteria and microscopic metazoan [6, 7, 8].

Shallow lakes have been mostly neglected in limnological investigations as compared to the deep lakes. Formerly, it was considered that both types of lakes function in the same way [9]. Recently, many different abiotic and biotic interactions are known in these lakes, i.e., in shallow and deep lakes environmental parameters and biocoenosis are distributed horizontally and vertically, respectively [10, 11]. Wider catchment area in shallow lakes increases loading of phosphorus and nitrogen and consequently organic production. Besides natural loading of nutrients, intensive technological and agricultural progress has led to anthropogenic eutrophication. It leads to degradation of shallow lakes to the marshes and swamps and at the end to terrestrialisation. Anthropogenic influences on hydrosystems are exerted in several respects including agricultural fertilisation, industrial and municipal waste releases, irrigation, fishing and recreation [12]. Many rivers and streams are stroked by hydro-technical interventions recently. One such intervention is canalizing which has a strong impact on habitats and biodiversity.

The direct impact of water pollution is reflected in disrupting the balance among aquatic community, such as plankton, benthos and nekton, i.e., fish [13, 14]. Zooplankton (Rotifera, Cladocera and Copepoda) species are considered as good indicators of water quality, due to their feeding preferences [15, 16]. These species are less studied than fish, but are important components of food webs in freshwater ecosystems. Restoration of lake systems includes creating balance between phytoplankton and zooplankton communities [17]. Changes of environmental parameters affect interactions between species, such as competition and predation, which can disbalance a hydrosystem. Our study was carried out in a highly trophic water body influenced by human activities. It can be characterized as follow: first, it is an oxbow lake originated by hydrotechical regulation of a river basin; second, it is a sport fishing site regularly used by fishermen; third, it is surrounded by agricultural fields influenced by fertilizers leaching. Its turbid state has not allowed submerged macrophytes to develop similar to other highly eutrophic lakes [18]. The main purpose of this study was to determine abundance, diversity and functional feeding guilds of zooplankton as biotic indicators of environmental changes.

STUDY AREA

This study was carried out in an oxbow lake created in the Krapina River (NW Croatia) by cutting of the mainstream meander following the construction of a highway 50 years ago. Sampling sites were located in the littoral zone with emerged macrophytes (L1) and open water zone or pelagial (P1) (Fig. 1).

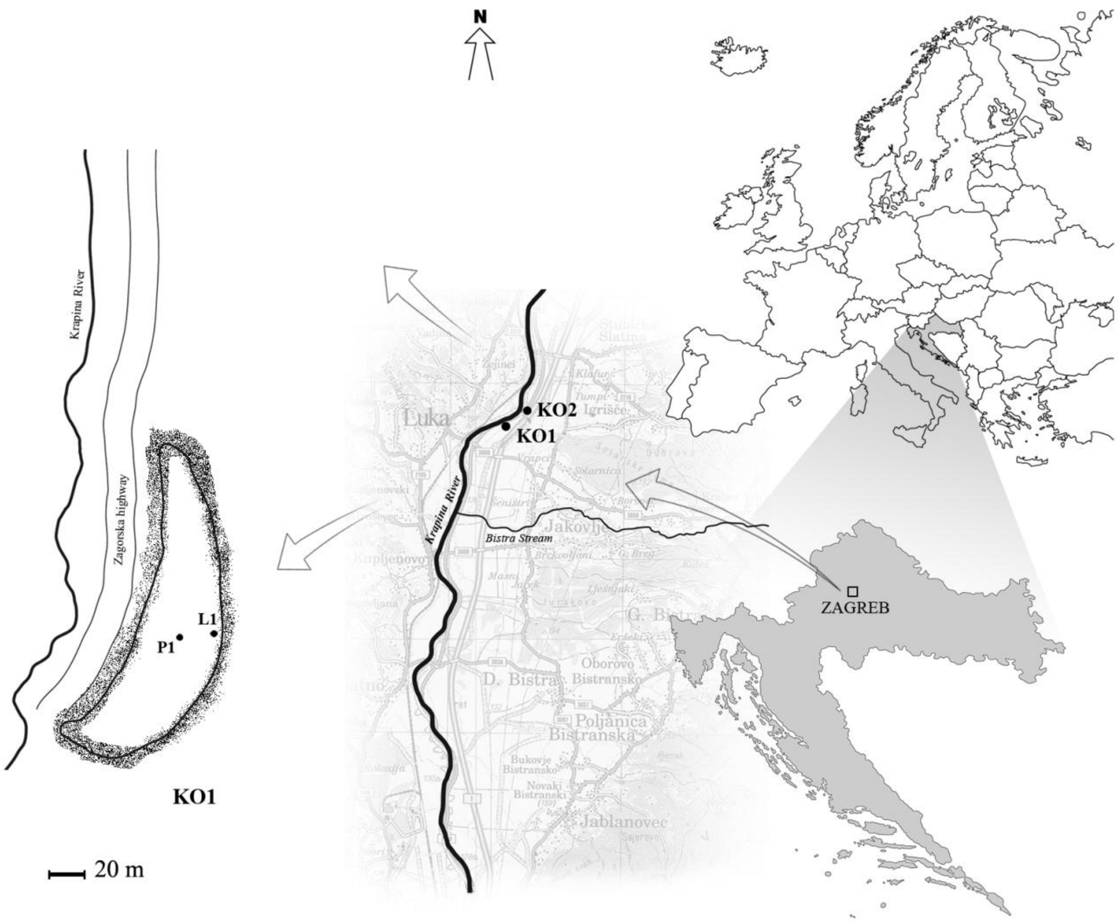

Figure 1. Map of the Krapina River and an investigated oxbow lake KO1 and study sites P1 and L1 in the Krapina River.
Slika 1. Karta Rijeke Krapine i mrtvaje KO1 te istraživanih postaja P1 i L1.

Lake morphometric features and macrophyte composition of Krapina Oxbow Lake 1 (KO1) are summarized in Table 1.

Table 1. Main morphometric features and macrophyte composition of Krapina oxbow lake KO1.
Tablica 1. Osnovna morfometrijska obilježja i sastav makrofita u istraživanoj mrtvaji Krapine KO1.

Parameters	
Coordinates	45°57'96" N; 15°50'78" E
$Length_{max}$ (m)	150
$Width_{mean}$ (m)	37
Surface area (ha)	1.7
Max. depth (m)	4.0
Shore slope	steep
Macrophyte coverage %	3.2-5.5
Surronding area	ploughed-fields
Macrophyte type	emergent
Macrophyte composition (%)	*Typha latifolia* (40%)
	Iris pseudacorus (30%)
	Carex sp. (15%)
	Sparganium ramosum (15%)

More detail desriptions are given in other publication [12]. Recorded fish species were carp (*Cyprinus carpio*), black bullhead (*Ameiurus melas*), pike (*Esox lucius*), pikeperch (*Sander lucioperca*), roach (*Rutilus rutilus*), bleak (*Alburnus alburnus*), bream (*Abramis brama*), sunfish (*Lepomis gibbosus*) and chub (*Squalius cephalus*) (personal communication with staff of Sport Fishing Association “Carp”).

METHODS

All samples were collected between April and August 2006. Two seasons were considered in the temporal analyses, i.e., spring (April–June) and summer (July–August). Sampling was performed at monthly intervals in April, May, June and August and twice in July. On each sampling occasion, zooplankton samples were collected in two different locations (Fig. 1).

At each study site, 30 L of water were filtered through a 26 µm mesh net to collect zooplankton. A second net filtered sample of 30 L from each site was used for ash free dry mass (AFDM) assessment. For the chemical analyses, 3 L of non-filtered water was collected in a bottle at the same study sites where the zooplankton was collected.

Rotifer identification was carried out on live material which was later fixed in 4%

formaldehyde solution. Rotifers were identified to species or genus level, using standard taxonomic reference [19]. Bdelloidea were counted, but not identified, and abundances of *Polyarthra dolichoptera* and *P. vulgaris* were aggregated into a single category (*Polyarthra* spp.). Similarly, Copepoda were identified to species or genus level according to Einsle [20] and Cladocera according to Margaritora [21].

For quantitative analysis, samples were concentrated by centrifugation (2000 rpm/5 min) to a volume of 15–20 mL, mixed thoroughly and then, three samples of 3 mL each were counted using a Sedgewick-Rafter cell under an Opton-Axiovert 35 inverted microscope. Rotifer and crustacean feeding guilds were assigned according to the feeding strategy of microfilter–feeders, and raptors (macrofilter–feeders and predators) [22, 16].

Biomass (dry weight) of rotifers was determined based on the length–weight relationships in up to 30 randomly selected specimens per taxon [23, 24]. The guild ratio (GR) was calculated as: GR = ∑(biomass raptorial – biomass microphagous)/ ∑ (total rotifer biomass) [16].

Temperature, dissolved oxygen, pH and conductivity were measured *in situ* using portable probes; WTW OXI 96, WTW 330i and HACH sension 5. Water transparency (z_{SD}) was determined using a Secchi disc. Procedures for estimation of water chemistry parameters (alkalinity, nitrates, orthophosphates, chemical oxygen demand, COD) and biological parameters such as algal biomass as chlorophyll *a*, Chl *a*, and particulate organic matter, POM as AFDM were determined according to procedure explained in detail in a previous publication [25, 26].

Macrophyte coverage (%) was estimated from the ratio of transect length occupied by macrophytes to total transect length at five locations [27]. Species similarity between samples from pelagial and littoral zones was calculated using the Sørensen index. Spatial and temporal differences of biotic and abiotic parameters was analysed by Mann-Whitney U test. Spearman correlation coefficient was used to analyse the linkage between environmental parameters and biotic factors (abundance and diversity).

RESULTS AND DISCUSSION

According to the Mann-Whitney U test, there was not significant differences in the values of environmental parameters between sampling sites P1 and L1 (Fig. 2).

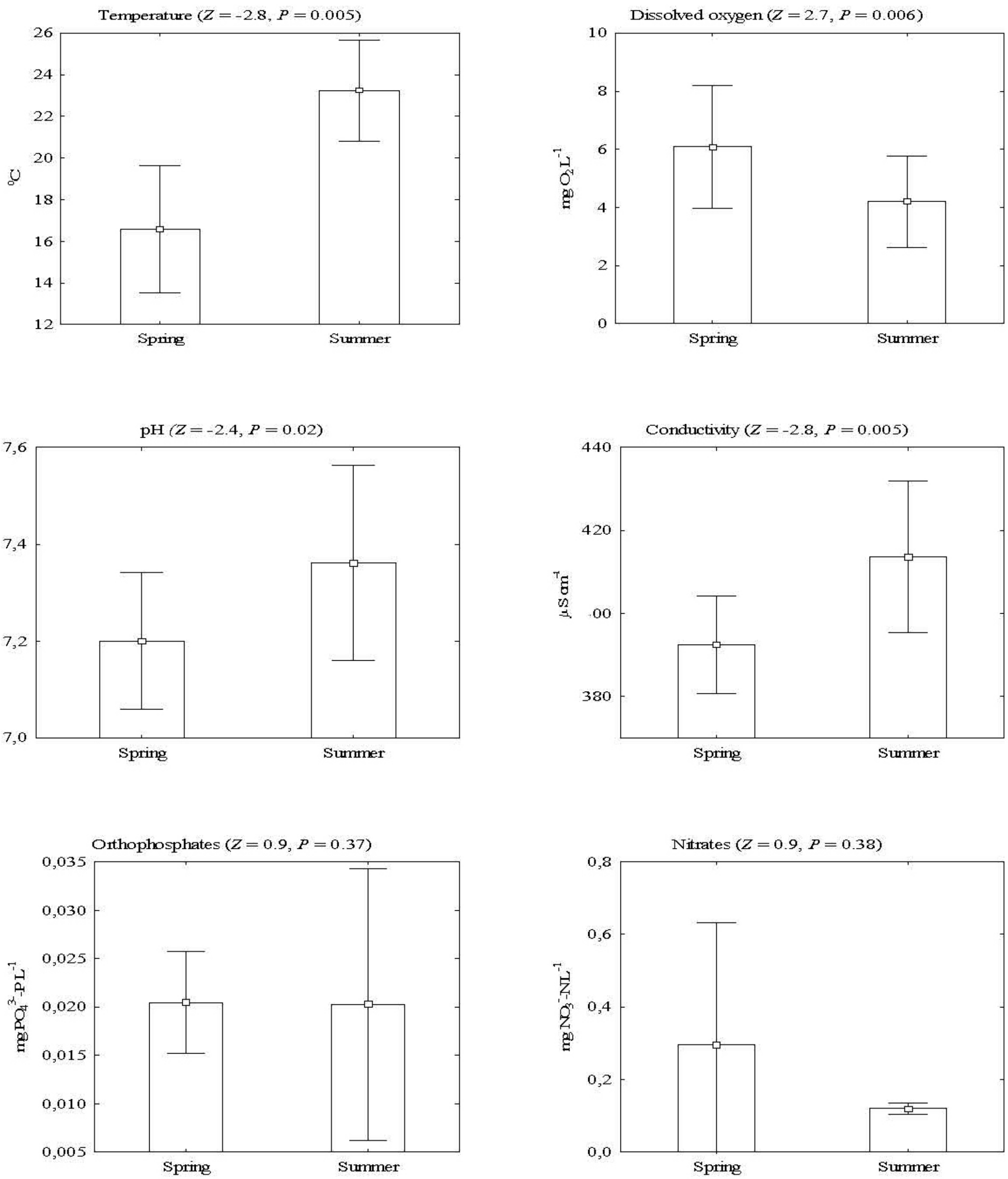

Figure 2. Mann-Whitney U test of seasonal values of physical, chemical parameters and food resources (P >0,05). ▫ Mean, ⌶ SD.

Slika 2. Sezonske razlike istraživanih fizičko-kemijskih čimbenika i izvora hrane. Značajnost razlika prikazana je Mann-Whitney U testom. ▫ Srednja vrijednost Mean, ⌶ SD.

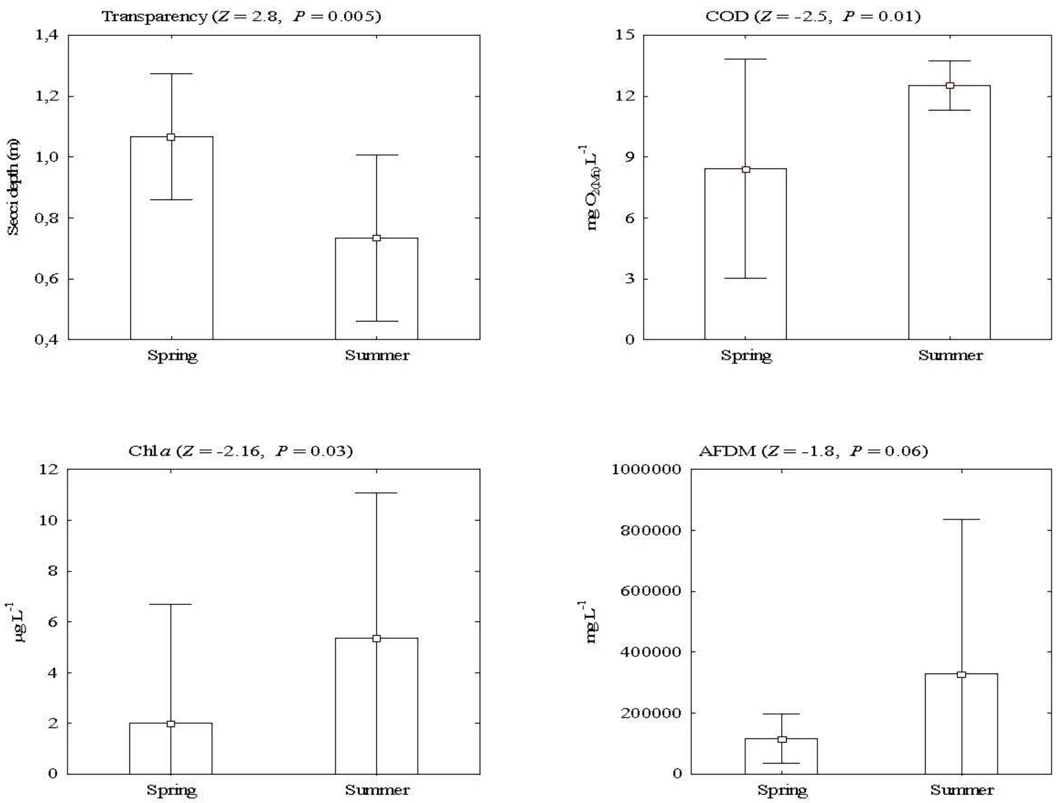

Figure 2. Continuum.
Slika 2. Nastavak.

Due to small area and low depth, water column in shallow lakes is regularly mixed by wind [28] and bioturbation [17]. Other authors also did not observe any significant differences in environmental conditions between littoral and pelagic zones in shallow lakes [29, 26].

The values of measured physical and chemical parameters and food resources were higher in summer, except transparency and dissolved oxygen (Fig. 2). According to environmental indicators of water quality, transparency (0.5 to 1 m), dissolved oxygen (3 to 6 mg O_2 L^{-1}) and COD (7 to 12 mg $O_{2(Mn)}$ L^{-1}) classified investigated oxbow lake to eutrophic system [30, 31].

The absence of submerged macrophytes in the lake KO1 is presumed to be the consequence of light attenuation and dispersion and reduced transparency caused by dissolved (r = –77, $P < 0.05$) and particulate (algae r = – 0.83, $P < 0.05$; POM r = – 0.64, $P < 0.05$) organic matters [14].

A total of 34 taxa were determined in KO1: rotifers dominated with 30 taxa, while cladocerans and copepods were presented with 3 and 1 taxa, respectively. More taxa were observed in the littoral (30 taxa) less in pelagial zone (17 taxa). An explination of such distributon of diversity may be that narrow belt of emerged macrophytes (*Iris pseudacorus*) plays role of a refuge, and area of higher food and microhabitat diversity [32, 12].

In other studied water bodies these effects are especially exhibited if vegetated littoral zone comprises of complex architecture platns, i.e., *Chara*, *Myriophyllum*, which ensure better refuge and a broad spectrum of food availabilities through periphyton and surrounding water [6].

Zooplankton abundance reached higher values in P1 (748 ind L^{-1}) than in L1 (443 ind L^{-1}). Rotifers share was high in both stations: P1 58% and L1 71%, respectively (Fig. 3).

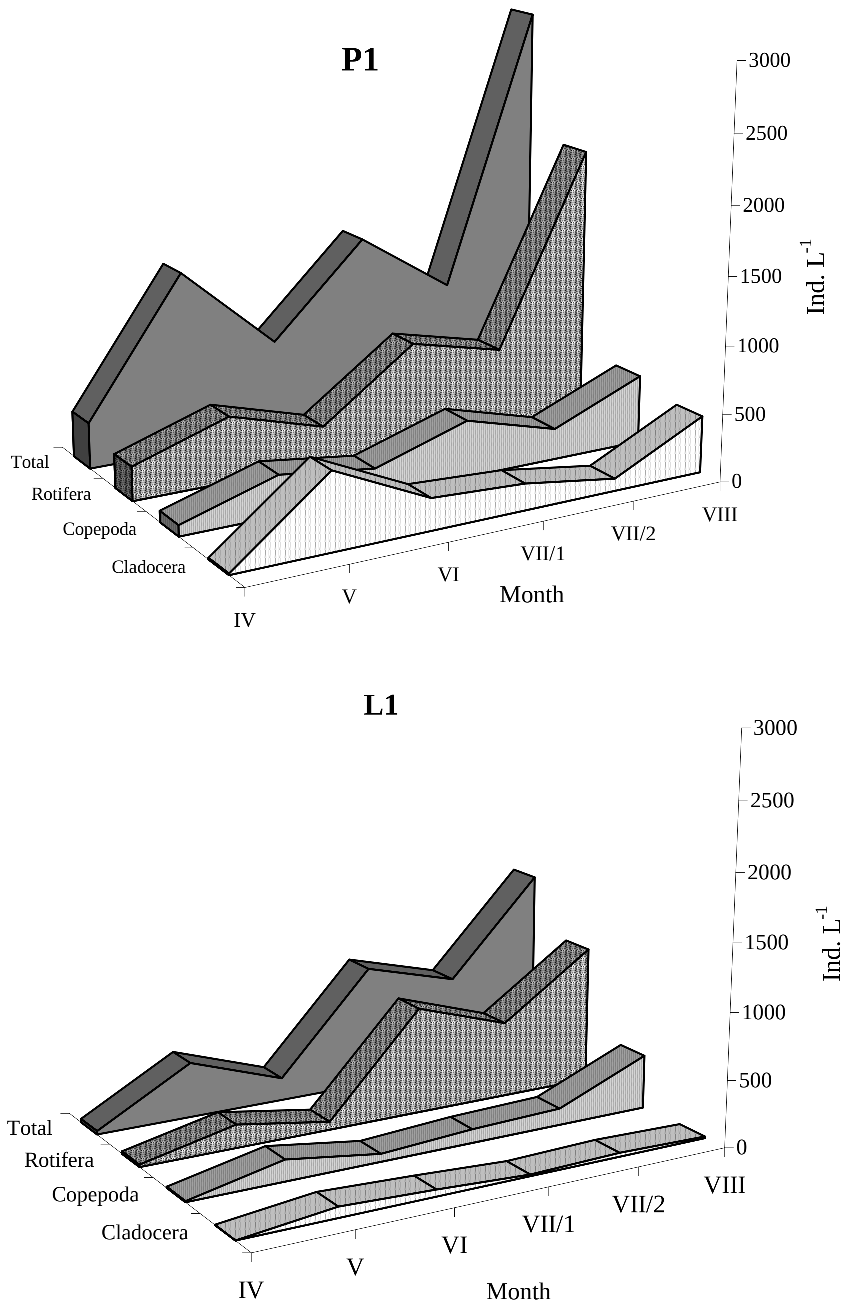

Figure 3. Seasonal variations of total zooplankton and its main groups: Rotifera, Cladocera and Copepoda abundance at sites P1 and L1. Roman numerals represent the months of the year.
Slika 3. Sezonske promjene abundancije ukupnog zooplanktona i njegovih glavnih skupina, Rotifera (kolnjaci), Cladocera (rašljoticalci) i Copepoda (veslonošci) na istraživanim postajama P1 i L1. Rimski brojevi označavajumjesece u godini.

Dominant species were rotifer *Keratella cochlearis* and cladoceran *Bosmina longirostris*. They are common inhabitants of highly trophic lakes; and the latter is a typical in plankton of hypertrophic ponds [32, 33, 34]. Decreasing trend of horizontal zooplankton abundance was noticed also in same oxbow lake during 2008, but then abundance was approximately twofold higher at each site in comparison to the year 2006 [26]. Rotifers domination, in terms of diversity and abundance, in lake KO1 accord with observations in typical lakes of higher trophic level [35, 18]. Abundance may be a more sensitive indicator of changes in trophic level than species composition [36]. Both biotic indicators, species composition (i.e. rotifer species *K. cochlearis*, *Filinia longiseta*, *Brachionus* spp. and *Hexarthra mira*) and abundance, suggested an increase in trophic level in KO1 within two years. Higher zooplankton abundance in pelagial than in littoral zone can be explained by two arguments. First, we presume that low transparency has obstructed visual predators i.e., fish, to catch the prey organisms, large–bodied and small–bodied cladocerans, respectively. Thereby small-bodied cladocerans (body size < 1 mm) of genera *Bosmina* and *Ceriodaphnia* could develop significantly higher abundances in pelagic waters, P1 (Tab. 2) [18].

Table 2. Spearman correlations ($P < 0.05$) between biotic components and food resources, algae (Chl *a*) and detritus or particulate organic matter (AFDM) in the investigated sites, P1 and L1.
Tablica 2. Spearman-ov koeficijent korelacije (P < 0.05) između biotičkih čimbenika, izvora hrane, algi (Chl a) i detritusa ili usitnjene organske tvari (AFDM) na istraživanim postajama P1 i L1.

P1	*r*	*P*
	Chl *a*	
Total zooplankton abundance	0.8703	0.0242
Rotifera abundance	0.8612	0.0276
Copepoda abundance	0.9357	0.0061
Rotifera biomass	0.8737	0.0229
Rotifera microphagous biomass	0.9120	0.0113
Rotifera raptors biomass	0.8525	0.0310
	AFDM	
Total zooplankton abundance	0.9507	0.0036
Copepoda abundance	0.8492	0.0324
Rotifera abundance	0.9974	0.0000
Rotifera biomass	0.9295	0.0073
Rotifera microphagous biomass	0.9667	0.0016
Rotifera raptors biomass	0.9187	0.0096

L1	*r*	*P*
	AFDM	
Total zooplankton abundance	0.8679	0.0250
Copepoda abundance	0.9306	0.0071
Rotifera biomass	0.9447	0.0045
Rotifera microphagous biomass	0.8647	0.0262
Rotifera raptors biomass	0.8530	0.0308

Second, due to their small sizes, rotifers are not very susceptible to fish predation. Thus, having high reproduction rates, they can develop numerous populations in P1 [14, 26]. Rotifer abundance and biomass, as well as their feeding guilds were notably governed by food resources (Tab. 2). Temporary, the highest zooplankton abundance was observed in summer ($Z = -2.5$, $P = 0.03$), possibly by positive correlation with higher food availability. This is in agreement with results of other authors [12] as well as published data about KO1 for the year 2008 [26].
For better assessment of the community functional approach, we used guild ratio based on functional feeding strategy of rotifers and their biomass as the most numerous and diverse group of the lake zooplankton [37, 16]. Biomass assigns better judgement of rotifer consumption capacity and its position in food webs, according to its body size and constitutions [38]. In P1, biomass of both microphagous and raptor rotifers significantly and positively correlated with algal biomass, represented as Chl *a*. In both sites significantly positive correlation between both rotifers feeding guilds and particulate organic matter was determined (Tab. 2). Our results showed that GR values were mostly < 1, in both littoral and pelagial zones, indicating microphagous dominance over raptors (Fig. 4).

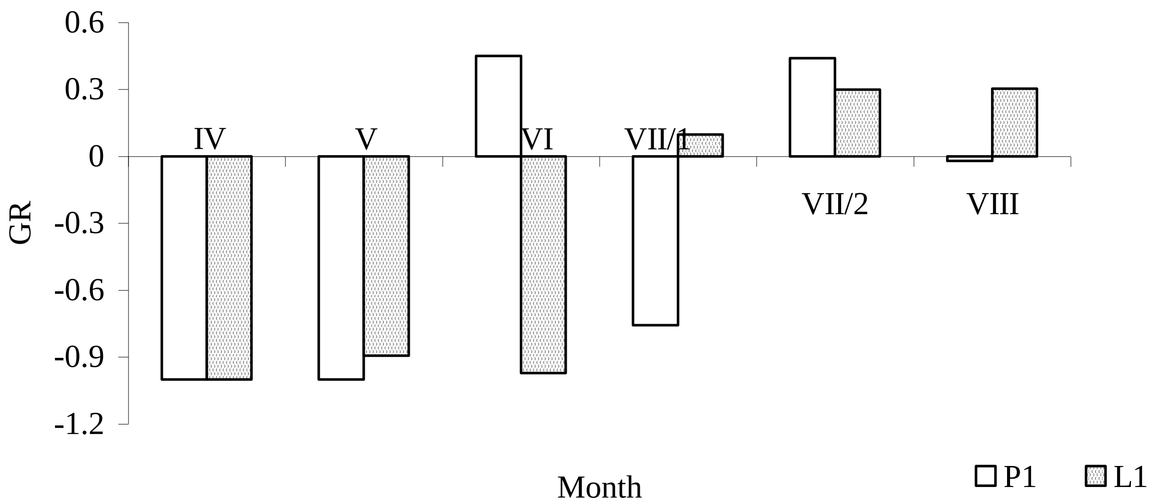

Figure 4. Seasonal changes in guild ratio (GR) of rotifers in the study sites P1 and L1. Roman numerals represent the months of the year.
Slika 4. Sezonske promjene omjera hranidbenih skupina kolnjaka na istraživanim postajama P1 i L1. Rimski brojevi označavajumjesece u godini.

These results suggest that the dominant rotifers consume minute size fractions (no larger than 15 to 20 μm) consisting mostly of bacteria, detritus suspension and small algae. Systems with high proportion of detritus and net algae, for instance KO1, will gain higher trophic level [10]. Some advantages of using GR in community analyses are: independence from species–level identification, robustness across various sampling regime and ability to predict influence of environmental changes on community structure [39, 16].

CONCLUSIONS

Zooplankton assessment is an important indicator of aquatic community structuring and water conditions. Water turbidity in the studied lake could be reduced by monitoring of fish which increase concentrations of dissolved and particulate organic matter and consequently, turbidity [14]. It is presumed that the absence of large–bodied cladocerans (>1 mm) can be a result of their predation by fish. These cladocerans play a pivotal role in phytoplankton removal and turbidity reduction [14, 17].

On the other hand, such conditions would allow growth of submerged vegetation and increase in biodiversity and density of large–bodied cladocerans which find day–time refuge in the macrophytes stands. Controlling of nutrients (phosphorous and nitrates) input i.e., antropogenic eutrophication, is the first step to improve water quality and accompanying communities. Making balance among zooplanktivorous, benthivorous (impact by bioturbation and plants destroying) and piscivorous fish would contribute to water transparency and would have mutual benefits for entire community [17]. Turbidity had a pronounced effect on aquatic community and biotic interactions among algae, aquatic macrophytes, zooplankton and fish.

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