

DOI: 10.1515/cjf-2017-0013

CODEN RIBAEG ISSN 1330-061X (print),  
1848-0586 (online)

## ZOOPLANKTON IN ANCIENT AND OLIGOTROPHIC LAKE OHRID (EUROPE) IN ASSOCIATION WITH ENVIRONMENTAL VARIABLES

Orhideja Tasevska<sup>1</sup>, Maria Špoljar<sup>2\*</sup>, Dafina Gušeska<sup>1</sup>, Goce Kostoski<sup>1</sup>, Suzana Patcheva<sup>3</sup>,  
Elizabeta Veljanoska Sarafiloska<sup>4</sup>

<sup>1</sup>Department of Zooplankton, Hydrobiological Institute, Naum Ohridski 50, 6000 Ohrid, Macedonia

<sup>2</sup>Department of Biology, Zoology, Faculty of Science, University of Zagreb, Rooseveltov trg 6, 10000 Zagreb, Croatia

<sup>3</sup>Department of Phytoplankton, Hydrobiological Institute, Naum Ohridski 50, 6000 Ohrid, Macedonia

<sup>4</sup>Department of Physical and Chemical Research of Water, Hydrobiological Institute, Naum Ohridski 50, 6000 Ohrid, Macedonia

\*Corresponding Author, Email: [maria.spoljar@biol.pmf.hr](mailto:maria.spoljar@biol.pmf.hr)

### ARTICLE INFO

Received: 24 July 2017

Received in revised form: 21 August 2017

Accepted: 29 August 2017

Available online: 1 September 2017

### ABSTRACT

Zooplankton is studied in the ancient, tectonic, oligomictic and oligotrophic Lake Ohrid (Macedonia, South Eastern Europe). The main aim of this study was to assess the seasonal and spatial patterns of the zooplankton functional feeding guilds in relation to the environmental conditions. Metalimnion of the lake was detected as the most productive environment, where biomass of the phytoplankton and abundance of the zooplankton reached their maxima. Pelagial zooplankton of low abundance ( $25 \pm 22$  ind. L<sup>-1</sup>) consisted of 16 species including two endemic copepods, *Arctodiaptomus steindachneri* (Richard, 1897) and *Cyclops ochridanus* (Kiefer, 1932). Copepods obtained remarkable share (60%) in the zooplankton assemblage. Microphagous zooplankton was mainly comprised of the most abundant rotifer *Kellicottia longispina* (Kellicott, 1879) in summer, and copepod nauplii during the spring *Eudiaptomus gracilis* (Sars, 1862) and *C. ochridanus*, and autumn *C. ochridanus*. Due to their requirements for the bacterio-detritus suspension, this microphagous zooplankton occupied aphotic hypolimnion during the entire study period. Raptorial were typically represented by copepodites and adult copepods in the metalimnion, and were significantly and positively affected by temperature ( $r = 0.417$ ,  $p = 0.001$ ), dissolved oxygen ( $r = 0.463$ ,  $p = 0.0001$ ) and, particularly, phytoplankton biomass ( $r = 0.708$ ,  $p < 0.00001$ ). This is the first study in which the link between the lower and higher trophic levels is investigated in Lake Ohrid.

### Keywords:

Copepods

Rotifers

Microphagous

Raptorial

Metalimnion Oligomictic lake

### How to Cite

Tasevska, O., Špoljar, M., Gušeska, D., Kostoski, G., Patcheva, S., Elizabeta Sarafiloska, V. (2017): Zooplankton in ancient and oligotrophic Lake Ohrid (Europe) in association with environmental variables. Croatian Journal of Fisheries, 75, 95-103. DOI: 10.1515/cjf-2017-0013.

## INTRODUCTION

Zooplankton is an important link in the food webs between the primary producers and higher trophic levels in a lake. It is an efficient grazer on the suspended organic matter and phytoplankton, while also serves as food source for larger invertebrates and fish (González Sagrario and Balseiro, 2010; Špoljar et al., 2011; Compte et al., 2016; Celewicz-Goødyn and Kuczyńska-Kippen, 2017). Zooplankton species are sensitive to anthropogenic impacts, reflected in the alterations in their abundance and diversity as well as in water quality (Ejsmont-Karabin and Kuczyńska-Kippen, 2001; Jeppesen et al., 2011; Špoljar, 2013). The abundance and composition of zooplankton vary spatially and seasonally in large lakes due to both biotic and abiotic factors. The key factors are temperature (Voutilainen et al., 2016), oxygen (Ekau et al., 2010), nutrients (Conde-Porcuna et al., 2002), food resources (Špoljar et al., 2005), competition (Gilbert, 1989) and predation (Meerhoff et al., 2007; Basińska et al., 2010).

The role of zooplankton species in water bodies is generally analysed based on the variations in distribution of particular species or populations. More recently, their functional traits are considered, aggregating their species in groups (guilds) with similar roles in the ecosystems (Karabin 1985; Obertegger and Manca, 2011; Špoljar et al., 2011; Litchman et al., 2013). Various levels of zooplankton functions and types provide more detailed and complex information on functioning of natural food webs (France, 2012). Functional categories can be distinguished on the niche bases occupied by species in the food web including feeding (trophic) groups, *i.e.* bacterivorous, algivorous or predatory species (Špoljar et al., 2005, 2011), or in relation with the habitat within the water body, *i.e.* littoral species within different type of macrophytes (Celewicz-Goødyn and Kuczyńska-Kippen, 2017).

The deep oligotrophic lakes are characterised by low zooplankton biomass, abundance and biodiversity (Habdiija et al., 2011). In these lakes, the bottom-up control is stronger than the top-down control of the zooplankton grazing on phytoplankton (Auer et al., 2004). Due to the opportunity to escape from predators with vertical migrations to the deeper aphotic layers, fish predation pressure on zooplankton is lower in deep lakes, whereas in shallow lakes (Jeppesen et al., 1997, 2003) it is considerable.

The study of freshwater zooplankton communities in Lake Ohrid has a long history (Georgević, 1907; Stanković, 1931; Serafimova-Hadžišče, 1959, 1986; Gušeska, 1998). Although there have been numerous surveys of the lake zooplankton with records about its composition, abundance, biomass, and spatial and temporal distribution (Kostoski et al., 2004, 2005; Tasevska et al., 2008; Gušeska et al., 2013, 2014), data concerning the relationships of the zooplankton assemblages with the range of physical and chemical characteristics of the lake and biotic factors are limited

(Gušeska et al., 2005; Noveska and Tasevska, 2010; Tasevska et al., 2012a, 2012b). The aim of this study was to assess the spatio-seasonal patterns of the main zooplankton groups, Rotifera, Cladocera and Copepoda, and their relations in the functional feeding guilds with the environmental conditions.

## MATERIALS AND METHODS

### *Study site*

Lake Ohrid (41°2'19"N, 20°44'13"E) is the oldest lake in Europe and one of the oldest water systems in the world. Being formed tectonically 4 to 10 million years ago, the lake is situated in the Ohrid valley in the south-western part of Macedonia adjacent to Albanian border at an altitude of 693.17 m above the sea level. It has a surface area of 358.2 km<sup>2</sup>, a maximum depth of 288.7 m, a water volume of 58.6 km<sup>3</sup> and a shoreline length of 87.53 km. Detailed morphometric and limnological attributes of the lake were recorded in the study of Matzinger et al. (2006, 2007). A main characteristic of Lake Ohrid's ecosystem is the scarcity of nutrients and consequently a low level of primary production. Its biodiversity richness, especially in relict and endemic species - as a result of its ancient origin, geographic isolation and the stability of its ecological conditions - has given it a global significance (Spirkovski et al., 2000; Matzinger et al., 2007). Results of a comprehensive study classified Lake Ohrid as oligomictic regarding the thermal combination and stratification. It has been discovered that the top ~150 m of its water column engages in annual thermal stratification, while the lower hypolimnion is stable due to the salinity gradient. The "complete overturn" takes place only roughly once every 7 years during the cold winters (Matzinger et al., 2006). In this study, the term 'mixolimnion' will be used, common for the meromictic lakes (Kalf, 2002), for annually-mixed water column apart from the rarely- or unmixed deeper water layer.

### *Data collection and analysis*

Sampling was conducted in 2010 in the pelagic zone of Lake Ohrid, on the vertical profile above the maximum depth of 245 m, during two months of each season: winter (January, March), spring (April, May), summer (July, September), autumn (October, December). The vertical layers were divided into epilimnion (1 and 10 m), metalimnion (20 and 30 m) and hypolimnion (40, 50, 75 and 100 m).

Zooplankton was collected by a 5-liter Ruttner sampler, filtered *in situ* through a sieve (45 µm mesh-size) and preserved in 4% formalin. The specimens were quantitatively analysed under a Laica DM IRB microscope (100 to 600× magnification). Identification of the species was undertaken according to the guides provided by Koste (1978), Amoros

(1984) and Einsle (1993).

Water temperature was measured in the field using a WTW probe. Dissolved oxygen (Winkler method, APHA-Awwa-WPCF, 1998), total nitrogen, TN (Solorzano, 1969) and total phosphorus, TP (Strickland and Parsons, 1972) were analysed in the laboratory. The concentration of chlorophyll *a* (Chl *a*), as an indicator of phytoplankton biomass, was determined by spectrophotometry, following its extraction in 90% ethanol (ISO 10260, 1992; Meyns et al., 1994).

The zooplankton taxa were separated into functional feeding guilds (FFG), according to their food-collecting mechanism and size of the food particles (Karabin, 1985; Špoljar et al., 2011), as microphagous - collect multiple food particles, mainly bacterio-detritus suspension and raptorial - show an active grasping and piercing to catch food, *i.e.* algae, protozoans or microfauna (Oberteiger et al., 2011).

The obtained data were logarithmically transformed [ $\log(x+1)$ ], checked by the Shapiro-Wilk's test and, as they did not follow a normal distribution, were analysed by non-parametric tests using Statistica 13.0 software (Statsoft Inc., 2013). Kruskal-Wallis H test was conducted for the analysis of spatial and seasonal differences in the environmental parameters and zooplankton assemblage. The relationships between environmental variables and zooplankton abundance were tested by Spearman's correlations.

## RESULTS

The summarized results of analysing water temperature, concentration of dissolved oxygen, TP, TN and Chl *a* are displayed in Table 1.

**Table 1.** Range and mean  $\pm$  SD values of the environmental variables and abundances of the zooplankton groups (ind. L<sup>-1</sup>)

	Range	Mean		SD
T (°C)	6.1 – 24.6	8.67	±	0.449
O <sub>2</sub> (mg. L <sup>-1</sup> )	7.749 – 12.56	9.85	±	0.104
TP (µg. L <sup>-1</sup> )	2.48 – 11.935	6.372	±	0.279
TN (µg. L <sup>-1</sup> )	159.46 – 599.26	327.265	±	12.108
Chl <i>a</i> (µg. L <sup>-1</sup> )	0.007 – 1.78	0.654	±	0.052
Rotifera	0 – 40	7.820	±	9.167
Cladocera	0 – 9.5	1.180	±	2.206
Copepoda	0 – 66.5	15.633	±	14.856
Zooplankton total	0 – 86.5	24.633	±	22.030
Microphagous	0 – 54	14.188	±	12.252
Raptorial	0 – 47.5	10.336	±	13.050

T – temperature; O<sub>2</sub> – dissolved oxygen; TP – total phosphorus; TN – total nitrogen; Chl *a* – chlorophyll *a*

Configuration of the environmental parameters and zooplankton indices showed more pronounced spatial, *i.e.* vertical, than seasonal pattern (Table 2). Water temperature and phytoplankton biomass did not show significant seasonal oscillations (Kruskal-Wallis test,  $p < 0.05$ ). As expected, concentration of dissolved oxygen was higher during winter ( $10.1 \pm 0.7$  mg O<sub>2</sub> L<sup>-1</sup>) than in summer and autumn. Nutrients seasonality indicated a significant increase in summer so that the values of TP ( $8.64 \pm 1.56$  µg L<sup>-1</sup>) and TN ( $370.81 \pm 87.43$  µg L<sup>-1</sup>) were twice and triple their annual mean values, respectively (Table 1). In contrary, there was no significant difference in the vertical distribution of the nutrients (Kruskal-Wallis test,  $p < 0.05$ ). Water temperature and phytoplankton biomass showed strong vertical differences with the highest values in the epilimnion ( $13.71 \pm 5.1$ °C) and metalimnion ( $1.04 \pm 0.31$  µg Chl *a* L<sup>-1</sup>), respectively (Table 2).

Pelagial zooplankton consisted of 16 species, including two endemic copepods, *Arctodiaptomus steindachneri* (Richard, 1897) and *Cyclops ochridanus* (Kiefer, 1932), and rotifers as the most diverse group presented by 8 species (Table 3). Mean annual abundance of zooplankton ( $25 \pm 22$  ind. L<sup>-1</sup>) was very low (Table 1, Fig. 1). Copepods prevailed in all seasons (51% to 59%), except in summer when rotifers overtook a higher share (44%), reaching their peak with significant increase in abundance (Kruskal-Wallis test,  $p < 0.05$ , Table 1 and 2). Copepods seasonality pattern did not show significant oscillations (Kruskal-Wallis test,  $p > 0.05$ ), although displayed notable variations. They achieved their peak in spring, caused mainly by higher abundance of nauplii of the calanoid *Eudiaptomus gracilis* (Sars, 1862) and cyclopoid *C. ochridanus* with an increased abundance in autumn due to the dominance of the cyclopoid *C. ochridanus* nauplii (Fig. 1, Table 3). Within zooplankton, the abundance of cladocerans was the lowest, although their contribution to the zooplankton assemblage increased slightly in autumn (Fig. 1).

In the vertical distribution, each zooplankton group developed the most abundant populations in thermocline - metalimnion (Fig. 1, Tables 2 and 3). Copepods prevailed in the entire mixolimnion layer, with the contributions from 47% up to 55% in the vertical gradient.

Functional feeding guilds contained microphagous and raptorial zooplankters.

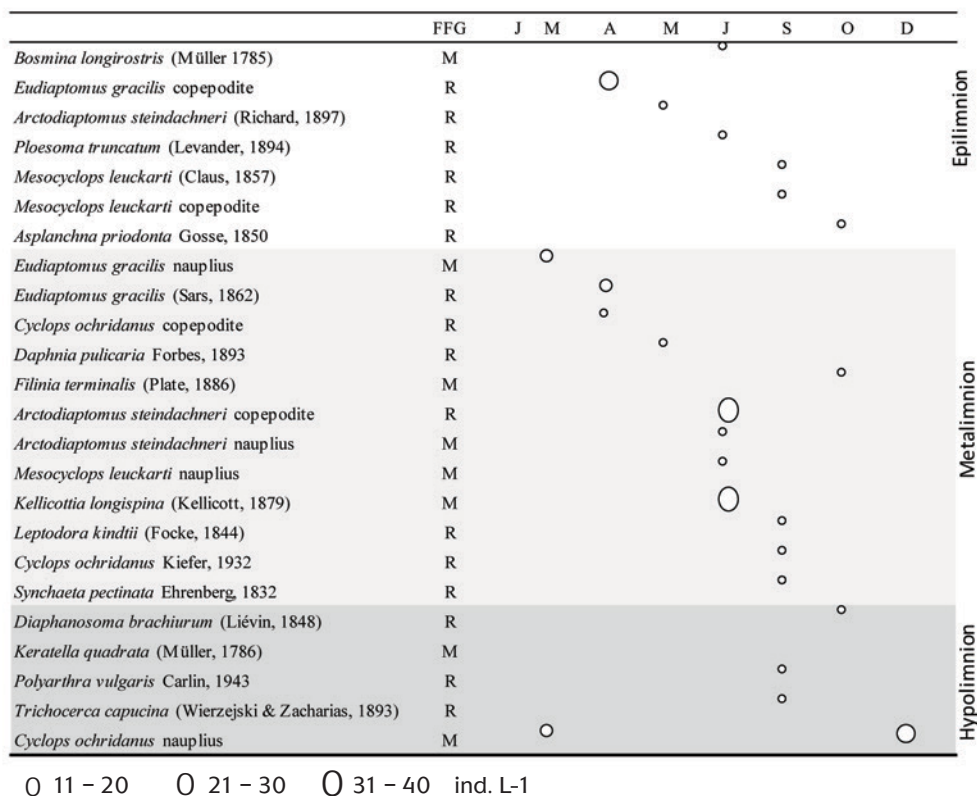
The obligate predators among cladocerans, *Leptodora kindtii* (Focke, 1844), and rotifers, *Asplanchna priodonta* Gosse, 1850 and *Ploesoma truncatum* (Levander, 1894), were present very sparsely, individually and sporadically. Abundance of the microphagous and raptorial did not show seasonal fluctuations, and their vertical oscillations fitted to general zooplankton trend, maximizing in the metalimnion (Fig. 2, Tables 1 and 2). Microfilter-feeders comprised mainly of the most abundant rotifer, *Kellicottia longispina* (Kellicott, 1879), and copepod nauplii which,

**Table 2.** Seasonal and spatial oscillations of the environmental variables and abundances of the zooplankton groups (ind. L<sup>-1</sup>), Kruskal-Wallis test (n = 64, p < 0.05) with accompanying results of the post-hoc multiple comparison test. For abbreviations see Table 1.

	Seasonal oscillations		Spatial oscillations			
	H	P	Multiple comparison test	H	P	Multiple comparison test
a) Environmental variables						
T (°C)	1.54	ns		46.22	0.0000	E, M > H
O <sub>2</sub> (mg.L <sup>-2</sup> )	16.65	0.0008	W, SP > A	12.05	0.002	M > H
TN (µg. L <sup>-1</sup> )	9.78	0.02	SU > A	0.1	Ns	
TP (µg. L <sup>-1</sup> )	40.70	0.0000	W, SP < SU, A	6.26	Ns	
Chl a (µg. L <sup>-1</sup> )	2.79	Ns		20.81	0.0000	E, M > H
b) Zooplankton groups						
Rotifera	13.85	0.003	SU > W, A	16.20	0.0003	M > H
Cladocera	6.92	ns		23.10	0.0000	M > E, H
Copepoda	0.43	ns		12.99	0.002	M > E, H
Microphagous	4.65	ns		16.35	0.0003	M > E, H
Raptorials	1.26	ns		25.25	0.0000	M > E, H

ns - nonsignificant; W - winter; SP - spring; SU - summer; A - autumn

**Table 3.** Zooplankton composition and their feeding traits according to the spatio-seasonal species maxima. FFG: Functional Feeding Guilds, M: microphagous, R: raptorials

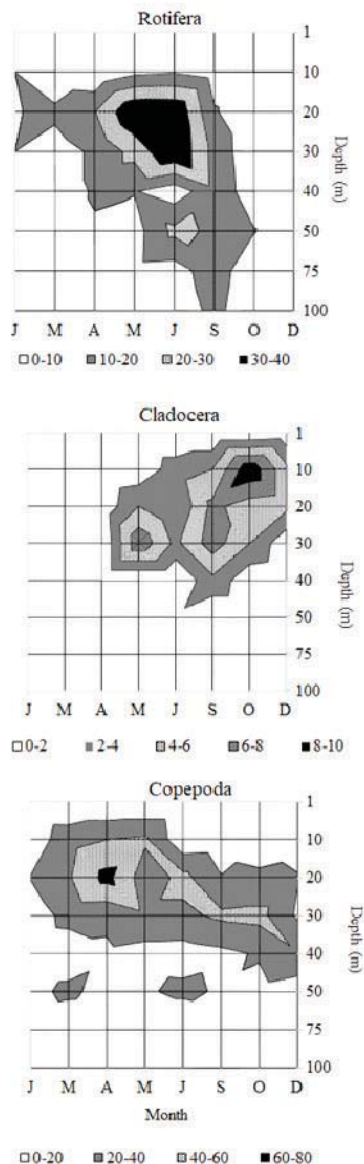




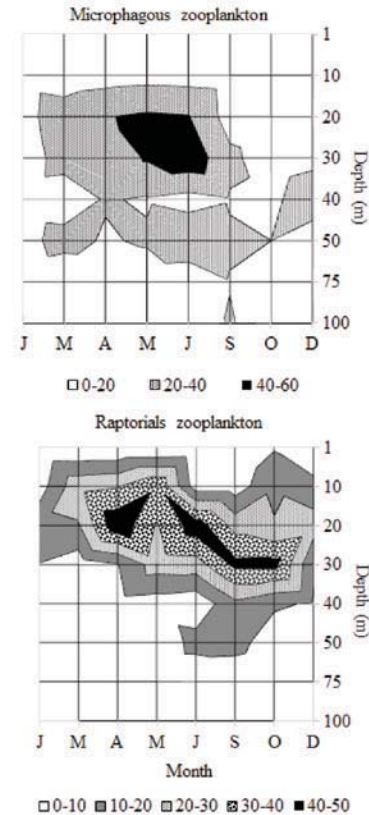
**Table 4.** Relationships between zooplankton abundances (ind. L<sup>-1</sup>) and environmental variables (Spearman correlation coefficient,  $p < 0.05$ )

	Rotifera	Cladocera	Copepoda	Microphagous	Raptorials
T (°C)			0.482		0.417
O <sub>2</sub> (mg. L <sup>-1</sup> )	0.430		0.437	0.410	0.463
Chl <i>a</i> (µg L <sup>-1</sup> )		0.531	0.652		0.708

besides metalimnion, occupied the hypolimnion (depths 40 - 75 m) during the entire study period (Fig. 2). Raptorials were represented mainly by copepodite and adult copepods and were limited to metalimnion. Microfilter-feeders were positively affected by dissolved oxygen, and raptorials by temperature, dissolved oxygen and, most significantly, by phytoplankton biomass ( $r = 0.708$ ,  $p < 0.00001$ ; Table 4). Similar interactions with environmental variables, as functional feeding guilds, also exposed the main zooplankton constituents (Table 4).



**Fig 1.** Spatio-seasonal distribution of Rotifera, Cladocera and Copepoda (ind. L<sup>-1</sup>) in the pelagic zone of Lake Ohrid



**Fig 2.** Spatio-seasonal distribution of microphagous and raptorial zooplankton (ind. L<sup>-1</sup>) in the pelagic zone of Lake Ohrid

## DISCUSSION

Results of this study provide insights into the spatio-temporal distribution of the main zooplankton groups in Lake Ohrid nested within the functional-feeding guilds. In spring, the microphagous entities, consisting of the naupliar stage of *C. ohridanus* and *E. gracilis* which were not dependent upon the primary production, *i.e.* phytoplankton biomass, started to develop their populations. Abundance of the nauplii decreased in summer due to their further development to copepodite and adult stages, while in autumn the new generation gained the domination. Rotifers, as r-strategists, occupied the meta- and hypolimnion layers in summer chiefly

by the microphagous species *K. longispina*. This small rotifer was one of the rare inhabitants of the deeper hypolimnion due to the availability of suspended bacterio-detritus food resources. Transparency enhanced the phytoplankton growth, resulting in the occupation of the metalimnion by raptorial copepod species both in copepodite and adult stages throughout the study period.

The abundance of zooplankton in the metalimnion could be argued from several points of view. The peculiar environmental conditions in this transitional layer have also been observed in other studies (Cantin et al., 2011; Karpowicz and Ejsmont-Karabin, 2017). For instance, the non-significant difference in vertical distribution of the nutrients was in compliance with the orthograde regime in oligotrophic lakes. During the thermal stratification, sharp negative vertical gradient of temperature in the metalimnion increases water density and nutrient concentration. In addition, due to the sufficient light availability, this is the most productive photosynthetic layer which concomitantly promotes the zooplankton growth. This was the case for Ohrid Lake where the maximum chlorophyll *a* concentration was measured in the metalimnion ( $0.31 \pm 0.06 \mu\text{g L}^{-1}$ ). In addition, sinking to the deeper layers protects the plankton against UV irradiation, thus only few species achieve their maximum abundances in epilimnion (Compte et al., 2016). Furthermore, high abundances of visual predators, zooplanktivorous fish, *i.e.* Ohrid trout *Salmo letnica* (Karaman, 1924), belvica *Salmo ohridanus* (Steindachner, 1892) and bleak-plasica *Alburnus alburnus arborella* (de Filippi, 1844), have probably reduced zooplankton in the epilimnion (Talevski et al., 2009).

According to the survey of rotifer succession in Lake Ohrid, the microphagous *Keratella cochlearis* (Goose, 1851) and *K. longispina* alternatively dominated from the year 2000 to 2008 (Tasevska et al., 2008). In our study conducted in 2010, the most abundant rotifer species in Lake Ohrid was *K. longispina* with similar abundance ( $7 \text{ ind. L}^{-1}$ ) to that in 2008 ( $6 \text{ ind. L}^{-1}$ ) (Tasevska et al., 2008). The presence of this species in the hypolimnion could be a result of its wide tolerance to oxygen depletion and its opportunistic nature that will allow it to quickly occupy empty ecological niches after the crustaceans nauplii decrease in summer (B rzi š and Pejler, 1989). Overall, higher abundances of the microphagous species rely upon the increase in concentration of the suspended organic matter, *i.e.* production, indicated eventually at the higher trophic levels (Malekzadeh-Viayeh and Špoljar, 2012; Špoljar, 2013).

Oligotrophic lakes are generally dominated by calanoid copepods because of their competitive advantage for algae over cladocerans (Bunnell et al., 2011). Their domination is also recorded for other lakes of low trophic levels, such as that of *Eudiaptomus hadzici* (Brehm, 1939) in karst Visovac Lake in Croatia (Bukvić et al., 1999) and in the shallow lakes

of Uruguay with warmer waters (Meerhof et al., 2007). Freshwater planktonic copepods play an important role as feed for the planktivorous fish (Jeppesen et al., 2000). Cyclopoids are mostly omnivores and raptors upon algae, protozoans and small zooplankton. Calanoids, in turn, have a more algivorous diet and outcompete the early copepodite stages and cladocerans. Moreover, they have lower food threshold and are usually more abundant than cyclopoids in oligotrophic lakes (Anneville et al., 2007). Thus, low cladoceran abundance in Lake Ohrid could be the result of their competition with the copepods, while high risk of their predation by fish due to their reduced swimming velocity could also have an impact (Dodson et al., 1997).

Knowledge of nutrient flux through the complex dynamics of natural food webs can be useful for understanding the ecology of the oligomictic and oligotrophic lakes. Considering the functional role of zooplankton within the freshwater food webs, exploring their interactions with biotic and abiotic parameters can assist in the protection of water quality and biodiversity in such peculiar ecosystems such as Lake Ohrid.

## Sažetak

### ZOOPLANKTON U DREVONOM I OLIGOTROFNOM JEZERU OHRID (EUROPA) U INTERAKCIJI S UVJETIMA OKOLIŠA

Analiziran je sastav zooplanktona u geološki starom, tektonskom Ohridskom jezeru (Makedonija, jugoistočna Europa). Glavni cilj rada bio je utvrditi sezonske i prostorne značajke funkcionalnih hranidbenih skupina zooplanktona i njihovu povezanost s uvjetima okoliša. Najveća produkcija zooplanktona utvrđena je u metalimniju, u kojem su biomasa fitoplanktona i brojnost zooplanktona postigle najveće vrijednosti. Utvrđeno je 16 pelagičkih vrsta od kojih dvije endemične: *Arctodiaptomus steindachneri* (Richard, 1897) i *Cyclops ochridanus* (Kiefer, 1932). Zooplankton pelagijala bio je zastupljen s niskom brojnošću,  $25 \pm 22 \text{ ind. L}^{-1}$ , a najveći udio, 60 %, postigli su veslonošci. Unutar trofičke skupine mikrofaga, prevladavali su tijekom ljeta kolnjaci s vrstom *Kellicottica longispina* (Kellicott, 1879), a naupliji veslonožaca prevladavali su u proljeće *Eudiaptomus gracilis* (Sars, 1862) and *C. ochridanus* i jesen *C. ochridanus*. Ova trofička skupina hrani se suspenzijom bakterija i detritusa, te je tijekom istraživanog razdoblja zauzimala afotički hipolimnion. Predatori su uglavnom bili zastupljeni s kopepoditima i odraslim veslonošcima u metalimniju. Na njihove populacije su značajno i pozitivno utjecali: temperatura ( $r = 0.417$ ,  $p = 0.001$ ), otopljeni kisik ( $r = 0.463$ ,  $p = 0.0001$ ) te najizraženije biomasa fitoplanktona ( $r = 0.708$ ,  $p < 0.00001$ ). Ovo istraživanje među prvima razmatra zooplankton Ohridskog

jezera kao važnu kariku unutar hranidbene mreže ovog oligotrofnog ekosustava.

**Ključne riječi:** veslonošci (Copepoda); kolnjaci (Rotifera); mikrofagi, predatori, metalimniji, oligomiktičko jezero

## ACKNOWLEDGEMENT

Coauthors congratulate to our colleague dr. Dafina Gušeska on 40 years of prosper work and contribution to the study of Ohrid Lake and global knowledge of zooplankton.

## REFERENCES

- Amoros, C. (1984): Crustacea cladoceres. Bulletin Mensuel de la Société Linnéenne de Lyon 3/4, 1-63.
- Anneville, O., Molinero, J. C., Souissi, S., Balvay, G., Gerdeaux, D. (2007): Long-term changes in the copepod community of Lake Geneva. Journal of Plankton Research, 29, 49-59.
- APHA-AWWA-WPCF (1998): Standard methods for the examination of water and wastewater. 20th ed., Washington DC.
- Auer, B., Elzer, U., Arndt, H. (2004): Comparison of pelagic food webs in lakes along a trophic gradient and with seasonal aspects: influence of resource and predation. Journal of Plankton Research, 26, 697-709.
- Basińska, A., Kuczyńska-Kippen, N., Świdnicki, K. (2010): The body size distribution of *Filinia longisetata* (Ehrenberg) in different types of small water bodies in the Wielkoposka region. Limnetica, 29, 171-182.
- Bērziņš, B., Pejler, B. (1989): Rotifer occurrence in relation to oxygen content. Hydrobiologia, 183, 2, 165-172.
- Bukvić, I., Kerovec, M., Mihaljević, Z., (1999): *Eudiaptomus hadzici* (Brehm) (Crustacea, Copepoda) from the Dinarid karstic area. International Review of Hydrobiology, 84, 23-31.
- Bunnell, D. B., Davis, B. M., Warner, D. M., Chrisinske, M. A., Roseman, E. F. (2011): Planktivory in the changing Lake Huron zooplankton community: Bythotrephes consumption exceeds that of Mysis and fish. Freshwater Biology, 56, 7, 1281-1296.
- Cantin, A., Beisner, B. E., Gunn, J. M., Prairie, Y. T., Winter, J. G. (2011): Effects of thermocline deepening on lake plankton communities. Canadian Journal of Fisheries and Aquatic Sciences, 68, 260-276.
- Celewicz-Goldyn, S., Kuczyńska-Kippen, N. (2017): Ecological value of macrophyte cover in creating habitat for microalgae (diatoms) and zooplankton (rotifers and crustaceans) in small field and forest water bodies. PLoS ONE 12, 5, e0177317.
- Compte, J., Montenegro, M., Ruhí, A., Gascón, S., Sala, J., Boix, D. (2016): Microhabitat selection and diel patterns of zooplankton in a Mediterranean temporary pond. Hydrobiologia, 766, 201-213.
- Conde-Porcuna, J. M. E., Ramos Rodriguez, E., Perez-Martinez, C. (2002): Correlations between nutrient concentrations and zooplankton populations in a mesotrophic reservoir. Freshwater Biology, 47, 1463-1473.
- Dodson, S. I., Tollrian, R., Lampert, W. (1997): *Daphnia* swimming behaviour during vertical migration. Journal of Plankton Research, 19, 969-978.
- Einsle, U. (1993): Crustacea: Copepoda: Calanoida und Cyclopoida. Süßwasser fauna von Mitteleuropa (eds. J. Schwoerbel, P. Zwick), Gustav Fischer Verlag, Berlin, Germany.
- Ejsmont-Karabin, J., Kuczyńska-Kippen, N. (2001): Urban rotifers: structure and densities of rotifer communities in water bodies of the Poznań agglomeration area (western Poland). Hydrobiologia, 446, 165-171.
- Ekau, W., Auel, H., Portner, H. O., Gilbert, D. (2010): Impacts of hypoxia on the structure and processes in pelagic communities (zooplankton, macro-invertebrates and fish). Biogeosciences, 7, 1669-1699.
- France, R. L. (2012): Omnivory, vertical food-web structure and system productivity: stable isotope analysis of freshwater planktonic food webs. Freshwater Biology, 57, 787-794.
- Georgević, Z. (1907): Les organismes planctoniques des grands lacs de la peninsule Balkanique. Memoires de la Societe zoology de France, 20, Paris.
- Gilbert, J. J. (1989): Competitive interactions between the rotifer *Synchaeta oblonga* and the cladoceran *Scapholeberis kingi* Sars. Hydrobiologia, 186/187, 75-890.
- González-Sagrario, M. Á., Balseiro, E. (2010): The role of macroinvertebrates and fish in regulating the provision by macrophytes of refugia for zooplankton in a warm temperate shallow lake. Freshwater Biology, 55, 2153-2166.
- Gušeska, D. (1998): Seasonal dynamic of the pelagic copepods of Lake Ohrid during 1997. In: Proceedings of the 1<sup>st</sup> Congress of Ecologists of the Republic of Macedonia. (In Macedonian with an abstract in English), 1, 226-234.
- Gušeska, D., Mitic, V., Kostoski, G., Tasevska, O., Patceva, S. (2005): Mutual relation of phytoplankton and zooplankton in Lake Ohrid pelagic zone. The 34<sup>th</sup> Annual Conference of the Yugoslav Water Pollution Control Society. "Water 2005" Conference Proceedings, Kopaonik, Yugoslavia, p. 275-282.
- Gušeska, D., Tasevska, O., Kostoski, G., Guseski, D. (2013): Biomass of the pelagic Crustacea: Cladocera in the Lake Ohrid (Macedonia) for the period 2000-2009. Natura Montenegrina, 12, 3-4, 855-862.
- Gušeska, D., Tasevska, O., Kostoski, G., Guseski, D. (2014): Zooplankton abundance and diversity in Lake Ohrid, Macedonia. International Journal of Ecosystems and Ecology Sciences (IJEES), 4, 3, 333-340.

- Habdija, I., Primc-Habdija, B., Špoljar, M., Sertić Perić, M. (2011): Ecological determinants of rotifer vertical distribution in a coastal karst lake (Vrana Lake, Island Cres, Croatia). *Biologia (Bratislava)*, 66, 1, 130-137.
- ISO 10260 (1992): Water quality – measurement of biochemical parameters – spectrometric determination of the chlorophyll a concentration, ISO, Geneva
- Jeppesen, E., Jensen, J. P., Søndergaard, M., Lauridsen, T., Junge Pedersen, L., Jensen, L. (1997): Top-down control in freshwater lakes: the role of nutrient state, submerged macrophytes and water depth. In: Kyfel, L., Prejs, A., Rybak, J. I. (eds), *Shallow Lakes 95'*. *Hydrobiologia*, 342/343, 151-164.
- Jeppesen, E., Jensen, J. P., Søndergaard, M., Lauridsen, T., Landkildehus, F. (2000): Trophic structure, species richness and biodiversity in Danish lakes: changes along a phosphorus gradient. *Freshwater Biology*, 45, 201-213.
- Jeppesen, E., Søndergaard, M., Jensen, J.P., Lauridsen, T.L. (2003): Recovery from eutrophication – global perspective. In: Kumagai, M. and W. F Vincent (eds.). *Freshwater Management- Global versus Local Perspectives*, Springer Verlag, Tokyo: 135-152.
- Jeppesen, E., Nøges, P., Davidson, T. A., Haberman, J., Nøges, T., Blank, K., Lauridsen, T., Søndergaard, M., Sayer, C., Laugaste, R., Johansson, L. S., Bjerring, R., Amsinck, S. L. (2011): Zooplankton as indicators in lakes: a scientific-based plea for including zooplankton in the ecological quality assessment of lakes according to the European Water Framework Directive (WFD). *Hydrobiologia*, 676, 279-297.
- Kalff, J. (2002): *Limnology*. Prentice-Hall, USA.
- Karabin, A. (1985): Pelagic zooplankton (Rotatoria + Crustacea) variation in the process of lake eutrophication. Modifying effect of biotic agents. *Ekologia Polska*, 33, 617-644.
- Karpowicz, M., Ejsmont-Karabin, J. (2017): Effect of metalimnetic gradient on phytoplankton and zooplankton (Rotifera, Crustacea) communities in different trophic conditions. *Environmental Monitoring and Assessment*, 189-367.
- Koste, W. (1978): *Rotatoria. Die Radertiere Mitteleuropas. Überordnung Monogononta. Ein Bestimmungswerk, begründet von Max Voigt. 2. Auflage neubearbeitet von Walter Koste. 2 Bände. Textband: VIII, 673 S., ISBN 3-443-39071-4 II Tafelband: II, 476 S., 234 Taf.*
- Kostoski, G., Gušeska, D., Tasevska, O. (2004): A day-night and seasonal periodicity in the distribution of the zooplankton from Lake Ohrid. BALWOIS – Conference of water observation and information system for decision support, Ohrid, 2004, www.balwois.org.
- Kostoski, G., Gušeska, D., Tasevska, O. (2005): Zooplankton research in the Lake Ohrid pelagic region. *Plankton investigations*. Hydrobiological Institute, Ohrid, *Limnological investigations of Ohrid and Prespa lakes*, 3, 4, 79-87.
- Litchman, E., Ohman, M. D., Kiørboe, T. (2013): Trait-based approaches to zooplankton communities. *Journal of Plankton Research*, 35, 473-484.
- Malekzadeh-Viayeh, R., Špoljar, M. (2012): Structure of rotifer assemblages in shallow water bodies of semi-arid northwest Iran differing in salinity and vegetation cover. *Hydrobiologia*, 686, 1, 73-89.
- Matzinger, A., Spirkovski, Z., Patceva, S., Wüest, A. (2006): Sensitivity of ancient Lake Ohrid to local anthropogenic impacts and global warming. *Journal of Great Lakes Research*, 32, 158-179.
- Matzinger, A., Schmid, M., Veljanoska-Sarafiloska, E., Satceva, S., Guseska, D., Wagner, B., Müller, B., Sturm, M., Wüest, A. (2007): Eutrophication of ancient Lake Ohrid: Global warming amplifies detrimental effects of increased nutrient inputs. *Limnology and Oceanography*, 52, 1, 338-353.
- Meerhoff, M., Iglesias, C., Teixeira de Mello, F., Clemente, J. M., Jensen, E., Lauridsen, T. L., Jeppesen, E. (2007): Effects of habitat complexity on community structure and predator avoidance behaviour of littoral zooplankton in temperate versus subtropical shallow lakes. *Freshwater Biology*, 52, 1009-1021.
- Meyns, S., Illi, R., Ribi, B. (1994): Comparison of chlorophyll-a analysis by HPLC and spectrophotometry: Where do the differences come from? *Archiv fur Hydrobiologie*, 132, 2, 129-139.
- Noveska, V., Tasevska, O. (2010): Preliminary investigations of mutual relations between rotifers and organotrophic bacteria in Lake Ohrid. BALWOIS – Conference of water observation and information system for decision support, Ohrid, 2010, www.balwois.org
- Obertegger, U., Smith, H. A., Flaim, G., Wallace, R. L. (2011): Using the guild ratio to characterize pelagic rotifer communities. *Hydrobiologia*, 662, 157-162.
- Obertegger, U., Manca, M. (2011): Response of rotifer functional groups to changing trophic state and crustacean community. *Journal of limnology*, 70, 2, 231-238.
- Serafimova-Hadžišče, J. (1986): Proučivanja vrz zooplanktonot na Ohridskoto Ezero za periodot 1970-1983. *Izveštaj na Hidrobiološki zavod, Ohrid*, 63-72.
- Serafimova-Hadžišče, J. (1959): II Contribution a la connaissance de la repartition horizontale du zooplankton dans le Lak D`Ohrid. *Recueil des travaux, Station Hydrobiological, Ohrid*, 7, 3, 1-23 (in Macedonian).
- Solorzano, L. (1969): Determination of ammonia in natural waters by the phenolhypochlorite method. *Limnology and Oceanography*, 14, 799-801.
- Spirkovski, Z., Krstanovski, Z., Selfo, L., Sanxhaku, M., Puka, V.I. (2000): The monitoring programme of the Lake Ohrid conservation project, pp. 41-53. In: Ganoulis J. et al. (eds), *Transboundary Water Resources in the Balkans*, Kluwer Academic Publishers.
- Špoljar, M., Habdija, I., Primc-Habdija, B., Sipos, L. (2005):



- Impact of environmental variables and food availability on rotifer assemblage in the karstic barrage Lake Visovac (Krka River, Croatia). *International Review of Hydrobiology*, 90, 5-6, 555-579.
- Špoljar, M., Dražina, T., Habdija, I., Meseljević, M., Grčić, Z. (2011): Contrasting zooplankton assemblages in two ox-bow lakes with low transparencies and narrow emergent macrophyte belts (Krapina River, Croatia). *International Review of Hydrobiology*, 96, 2, 175-190.
- Špoljar, M. (2013): Microaquatic communities as indicators of environmental changes in lake ecosystems. *Journal of Engineering Research*, 1, 1, 29-42.
- Stanković, S. (1931): Sur les particularités limnologiques des lacs Égéens. *Verhandlungen der International Vereinigung für Theoretische und Angewandte Limnologie*, 5, 158-190.
- Statistica 13.0 (2013): StatSoft Inc., Tulsa, Oklahoma.
- Strickland, J. D. H., Parsons, T. R. (1972): *A Practical Handbook of Seawater Analysis*. Fisheries Res. Board of Canada, Ottawa, 310 pp.
- Talevski, T., Milošević, D., Marić, D., Petrović, D., Talevska, M., Talevska, A. (2009): Biodiversity of ichthyofauna from Lake Prespa, Lake Ohrid and Lake Skadar. *Biotechnology & Biotechnological Equipment*, 23, 400-404.
- Tasevska, O., Kostoski, G., Gušeska, D. (2008): Composition and dynamics of planktonic rotifers in Lake Ohrid, Macedonia; *Hydrobiological Institute, Review*, 41, 1, 109-115.
- Tasevska, O., Gušeska, D., Kostoski, G. (2012a): Comparison of pelagic rotifer communities in three natural Macedonian lakes. *Acta zoologica bulgarica, Suppl.* 4, 159-165.
- Tasevska, O., Jersabek, C. D., Kostoski, G., Gušeska, D. (2012b): Differences in rotifer communities in two freshwater bodies of different trophic degree (Lake Ohrid and Lake Dojran, Macedonia). *Biologia (Bratislava)*, 67, 3, 565-572.
- Voutilainen, A., Jurvelius, J., Lilja, J., Viljanen, M., Rahkola-Sorsa, M. (2016): Associating spatial patterns of zooplankton abundance with water temperature, depth, planktivorous fish and chlorophyll. *Boreal Environment Research*, 21, 101-114.