DIVERSITY AND SPATIAL DISTRIBUTION OF ZOOPLANKTON COMMUNITIES OF DANUBE DELTA LAKES

LARISA FLORESCU[*], LAURA PARPALĂ[*], IOANA ENACHE[* **],
ALINA DUMITRACHE[* **], MIRELA MOLDOVEANU[*]

The high diversity of aquatic communities offers stability and resilience to the ecosystems. The zooplankton has a particularly important role in aquatic ecosystems, by up-taking the organic matter synthetized by phytoplankton and transferring it to higher consumer orders, by grazing and facilitating bacterial decomposition processes, by contributing to the enrichment with nutrients of the water and benthic layers, etc. Our study was focused on assessing zooplankton diversity, spatial distribution and particularities in 21 selected lakes located in three main lake complexes of the Danube Delta. The structural parameters with key role for zooplankton diversity were assessed by linear regressions. The most representative taxonomic groups were Rotifera and Copepoda, the highest number of species and abundance being recorded in Matiţa-Merhei lake complex (164 species, 343 ind. L^{-1}). In the same complex, the Shannon index was positively correlated with species richness and evenness. In the Roşu-Puiu complex, a negative correlation between evenness and abundance was found as a result of the high number of accidental species; also, a positive correlation between evenness and Shannon index was recorded. The highest diversity was recorded in Isac-Gorgova lake complex, characterized by a positive relationship between abundance and the number of species and between Shannon index and evenness. The correlations with phytoplankton groups indicated the importance of Chlorophyceae and Cyanobacteria for the development of rotifers and copepods. The influence of environmental variables on zooplankton diversity was further tested to explain the dissimilarities between the lake complexes.

Keywords: Copepoda, diversity indices, population dynamics, Rotifera, shallow lakes.

INTRODUCTION

The zooplankton communities play a pivotal role in aquatic food webs as they represent a significant food for planktivorous fish and invertebrate predators. They graze on algae, bacteria, protozoa, and other small invertebrates.

Diversity is a very important trait of any community in a given ecosystem. The variation of diversity may strongly influence the functionality, stability and productivity of the ecosystem (Zhang *et al*., 2012). Many authors use species richness as a measure of diversity (Stirling & Wilsey, 2001; Bock *et al*., 2007; Gotteli & Chao, 2013). But community diversity includes two main components: number of species and evenness. Hence some authors recommend to treat these two components separately in order to investigate the determinants of diversity.

Examined along an increasing gradient of trophy, the zooplankton community is represented by species like large cladocerans, diaptomids and cyclopids and small percentages of rotifers, in mesotrophic lakes, while in more eutrophic lakes, the structure is based on small species: small cladocerans, more copepod instars, and dominating rotifers (Gliwicz, 2005).

During early spring, the zooplankton community is dominated by small species, with high reproductive rates, like protozoans and rotifers, while large species, such as cladocerans and copepods, occur later; this dynamics is highly dependent on phytoplankton development and the predators pressure. Moreover, the particular conditions created by wind-induced mixing (Yoshida *et al*., 2001; Gliwicz, 2005), raise additional difficulties to anticipate the distribution of zooplankton in shallow lakes.

With the beginning of summer, the zooplankton community is restructured as a consequence of temperature increase, dynamics of phytoplankton community and fish predation pressure; small zooplankton genera, such as *Thermocyclops*, *Mesocyclops*, *Bosmina*, *Chydorus*, *Diaphanosoma*, *Ceriodaphnia*, *Moina*, and rotifers prevail. As autumn progresses, large genera, like *Daphnia* and *Eudiaptomus*, start developing again. This is an effect of both the changes occured in the phytoplankton community, when edible species have a distinct peak of development, and of the decreased predation pressure. During late autumn and winter, many zooplankton species enter a diapause phase (Sommer *et al*., 1986).

Generally, the zooplankton diversity in Danube Delta lakes is very high, being influenced however by the natural and antropogenic drivers in the area. For instance, between 1975–1995, 562 species were recorded (Zinevici & Parpală, 2006), but their number fluctuated widely during this interval: e.g. due to a high impact of eutrophication, a drastic reduction of zooplankton diversity was recorded between 1975–1987 (53.08%) (Zinevici & Teodorescu, 1996; Zinevici & Parpală, 2000). Hence, investigations of freshwater zooplankton community structure could represent a valuable indicator for assessing aquatic ecosystem health (Rocha *et al*., 1997; Pedrozo & Rocha, 2005; Șundri, 2015).

The objectives of this study were to assess the diversity of zooplankton and its spatial distribution in selected lakes of Danube Delta, as well as the state of these communities in 2013. Such information plays a major role for the conservation efforts of Danube Delta lakes.

MATERIAL AND METHODS

Study area

The Danube Delta Biosphere Reserve, located at 45°0′N latitude, 29°0′E longitude, in the Eastern part of Romania encompasses a complex of aquatic and terrestrial ecosystems unique in Europe.

The study was conducted during 2013, in 21 lakes belonging to three lake complexes of the Danube Delta: Roşu-Puiu, Matiţa-Merhei, Gorgova-Uzlina (Fig. 1).

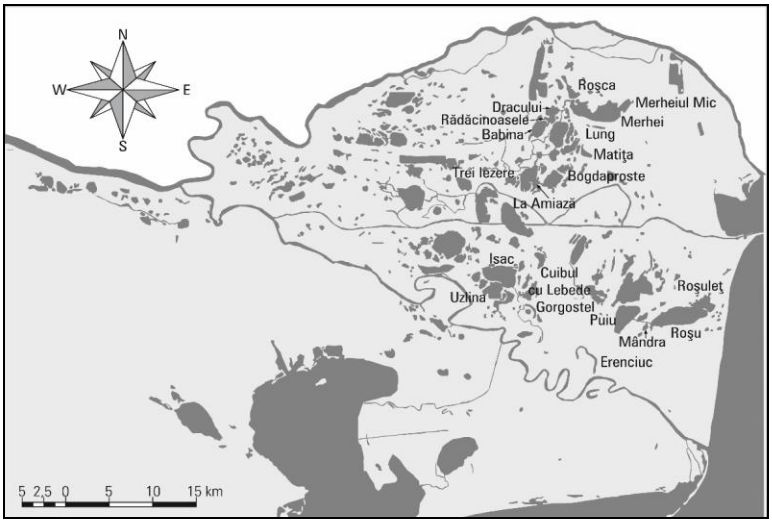

Fig. 1. The map of sampled lakes (orig.).

Table 1

List of the sampled lakes in the Danube Delta

Roșu-Puiu	**Matiţa-Merhei**	**Gorgova-Isac**
Roşuleţ	Trei Iezere	Cuibul cu Lebede
Roșu	La Amiază	Isac
Mândra	Bogdaproste	Uzlina
Erenciuc	Matiţa	Gorgostel
Puiu	Merheiul Mic	
Tătaru	Lacul Lung	
	Merhei	
	Roşca	
	Dracului	
	Rădăcinoasele	
	Babina	

Field sampling and laboratory analysis

Three sampling campaigns were carried out seasonally: in May, July and September. The sampling point was located in the centre of the lake, samples being collected on water column. The redox potential, pH, conductivity, were measured in the field with a multiparameter WTW 340i. The turbidity was measured with a Hanna Instruments turbidimeter and the water velocity was estimated using a flowmeter. The phytoplankton samples (500 ml) were taken on the water column, without filtration and conserved with formaldehyde 4% in order to estimate the abundance (cells L^{-1}). The total phytoplankton biomass and the biomass of different algal groups (expressed as chlorophyll *a* content, µg L^{-1}) were assessed *in situ* with a submersible fluorometer (Fluoroprobe III, bbe Moldaenke).

The zooplankton was sampled by filtering 50 L of water taken from the water column with a Patalas-Schindler plankton trap (5 L) and plankton nets (65 µm mesh size), concentrated in 10 ml and conserved with formaldehyde solution 4%.

Samples for chemical analyses were filtered through Whatman GF/F glass fibre filters and frozen for further analyses in the lab. Nutrients were determined spectrophotometrically following a modified Berthelot method for $N\text{-}NH_4$ (Krom, 1980), Griess-Ilosvay modified method for $N\text{-}NO_2$ (Keeney & Nelson, 1982), Tartari & Mosello (1997) for $N\text{-}NO_3$, $P\text{-}PO_4$ and TP.

The phytoplankton samples were counted in the lab using Utermöhl method (1958), a Zeiss inverted microscope, and specific keys.

Zooplankton species were identified using a Zeiss inverted microscope and the following keys: for Ciliata (Grospietsch, 1972; Foissner *et al.*, 1991–1995), Testacea (Bartoš, 1954), Lamellibranchia (Marsden, 1992), Rotifera (Voight, 1956; Rudescu, 1960), Cladocera (Brooks, 1959; Negrea, 1983), Copepoda (Damian-Georgescu, 1963, 1966–1970). At the same time with species identification, the individuals were counted to assess abundance (ind. L^{-1}) (Edmonson, 1971).

Data Analysis

For statistical processing, PAST (Hammer *et al.*, 2001) and XLSTAT software were used. The zooplankton diversity was evaluated by species richness, Shannon index and Evenness. A log transformation of zooplankton abundances, phytoplankton and physical-chemical data was applied for multivariate statistical analysis.

RESULTS AND DISCUSSION

The diversity assessment is based on species richness, abundance and also by the distribution of individuals in populations (Magurran, 1988; Legendre & Legendre, 1998; Vădineanu, 2004).

In our study, the highest value of species richness (164 species) was found in Matița-Merhei Lake complex and the lowest (117) in Gorgova-Isac complex (Table 2). The highest zooplankton abundance (343 ind. L^{-1}) was recorded also in Matița-Merhei complex, while the lowest abundance (216 ind. L^{-1}) was noticed in Gorgova-Isac.

Most of the zooplankton species belong to rotifers, ciliates and cladocerans (Table 2). In freshwater ecosystems, rotifers are known to be the dominant group, both, as species number and abundance (Berzins & Pejler, 1987; Barrabin, 2000; Saler, 2004).

Table 2

Species richness recorded in the three lake complexes of the Danube Delta in 2013

Taxa	**Roșu-Puiu**	**Gorgova-Isac**	**Matița-Merhei**
Ciliata	23	15	23
Testacea (Testate amoebae)	5	3	4
Lamellibranchia	1	1	1
Gastrotricha	1	1	1
Rotifera	78	80	103
Cladocera	22	12	20
Copepoda	3	4	11
Ostracoda	0	1	1
Total zooplankton	133	117	164

Also, in our study rotifers were the most abundant group, while cladocerans were not so well represented in abundance. The abundance of copepods (Crustacea) was very high, even if the number of species was low, due to the high number of juvenile stages (Table 3). The copepod communities are frequently dominated by juvenile instars (Pourriot *et al*., 1997).

Table 3

Annual abundance (ind. L^{-1}) of the zooplankton communities
(1– Ciliata; 2 – Testacea; 3 – Lamellibranchia; 4 – Gastrotricha; 5 – Rotifera; 6 – Cladocera; 7 – Copepoda; 8 – Ostracoda)

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Roșu-Puiu complex								
Roşuleţ	4.35	10.69	7.14	0.00	33.16	28.05	52.43	0.00
Roşu	16.95	35.76	6.91	0.00	94.55	8.56	39.69	0.00
Mândra	7.19	67.77	6.00	0.41	126.95	13.16	104.40	0.00
Erenciuc	4.67	57.00	0.00	0.21	45.79	1.49	73.17	0.00
Puiu	10.22	70.64	0.09	0.37	173.42	4.85	66.86	0.00
Tătaru	3.46	13.24	0.00	1.12	10.35	122.32	237.16	0.00
Gorgova-Isac complex								
Cuibul cu Lebede	1.51	7.46	0.00	0.26	26.17	0.36	14.14	0.00
Isac	2.40	2.42	0.10	0.00	29.24	1.66	236.03	0.00
Uzlina	3.16	5.87	1.27	0.00	129.12	0.99	102.15	0.28
Gorgostel	10.00	20.41	0.00	0.84	157.42	41.43	70.32	0.00

Table 3 (continued)

Matiţa-Merhei complex								
Trei Iezere	1.27	11.93	0.00	0.76	23.92	4.07	16.37	0.00
La Amiază	4.09	13.44	0.00	0.00	146.99	2.25	54.07	0.00
Bogdaproste	2.79	16.89	0.00	0.82	120.93	1.18	86.26	0.00
Matiţa	3.47	3.59	0.60	0.00	186.24	25.68	104.04	0.00
Merheiul Mic	19.01	12.61	0.07	0.28	257.62	12.27	61.00	0.13
Lacul Lung	1.19	17.03	0.00	0.00	21.92	10.36	78.66	0.40
Merhei	6.52	8.30	0.00	0.56	356.17	47.36	71.12	0.00
Dracului	11.50	8.33	0.00	0.82	656.67	14.80	126.83	0.00
Rădăcinoasele	9.33	3.79	0.00	0.00	342.75	11.15	92.68	0.00
Babina	1.73	2.05	0.00	0.11	113.45	3.77	219.97	0.00

Although the highest values of species richness and abundance were recorded in the lakes of Matiţa-Merhei complex, the Shannon-Wiener and evenness indices were lower than in other complexes. The highest diversity was recorded in Gorgova-Isac complex (Fig. 2).

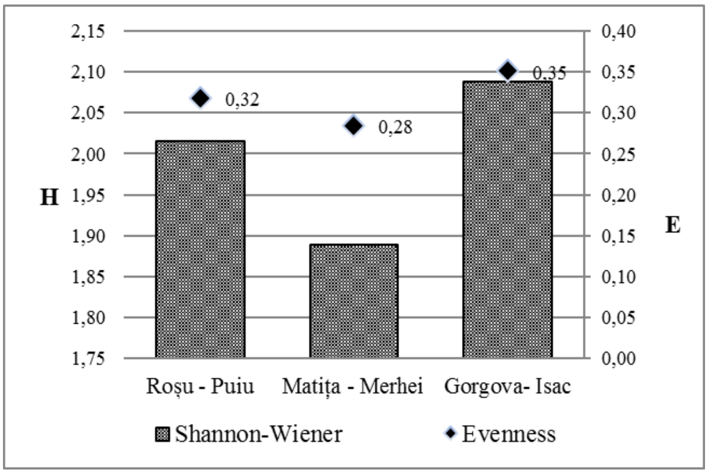

Fig. 2. Shannon-Wiener diversity index and evenness
of the three investigated lake complexes.

In order to establish which structural parameter (species richness or abundance) had a decisive role in defining diversity, linear regressions were performed.

In Matiţa-Merhei complex, the Shannon-Wiener index was significantly influenced by the number of species in ecosystems (Table 4) while between abundance and evenness a negative relationship was found. Also, between Shannon-Wiener and evenness indices a positive correlation was noticed. In addition, the evenness presented the lowest value in comparison with the other complexes.

Table 4

The relationship among diversity indices and abundance in Matița-Merhei complex

	R			**p-values:**
	Species richness	Abundance	Shannon	Evenness
Species richness		0.004	0.0001	0.39
Abundance	0.5		0.29	0.05
Shannon	0.73	0.2		0.01
Evenness	-0.16	-0.36	0.48	

All this explains that, even if the number of species and abundance was higher in Matița-Merhei comparing with Roșu-Puiu and Gorgova-Isac complexes, the individuals were not evenly distributed in the lakes. Some species were dominant or were concentrated in few lakes of the complex, which reduced the evenness and diversity. This was confirmed using Simpson's Index of dominance (D) that showed higher values, ranging between 0.59 and 0.72 in almost half of the lakes of the complex (Babina, Bogdaproste, Dracului, Matiţa, Lung, Merhei lakes).

In Gorgova-Isac, the complex with the highest diversity, a positive relationship was recorded between species richness and abundance (Table 5). As new species occurred, the abundace increased significantly, accompanied by evenness, in benefit of the diversity.

Table 5

The relationship among diversity indices and abundance in Gorgova-Isac complex

	R			**p-values:**
	Species richness	Abundance	Shannon	Evenness
Species richness		0.03	0.01	0.69
Abundance	0.62		0.99	0.08
Shannon	0.71	0.003		0.01
Evenness	0.13	-0.53	0.73	

The Shannon-Wiener diversity index from Roșu-Puiu complex was significantly influenced only by the evenness (Table 6). The abundance presented a positive correlation with species richness, while a negative relation was found with evenness. The output of these correlations supports the fact that abundance was the main parameter influencing the diversity, but this was reflected only for few species and in few lakes. As an example, 13% of the total number of species were present only once during the survey.

Table 6

The relationship among diversity indices and abundance in Roșu-Puiu complex

	R			**p-values:**
	Species richness	Abundance	Shannon	Evenness
Species richness		0.0008	0.11	0.07
Abundance	0.73		0.91	0.01
Shannon	0.40	-0.03		0.03
Evenness	-0.44	-0.60	0.52	

The diversity assessed in the 3 complexes reflects the environmental conditions existing in the ecosystems and also the functionality of the organisms forming the zooplankton communities. In our study, zooplankton was represented by eight taxonomic groups who contributed to diversity in various degrees, both through species richness and abundance. To assess the importance of different groups to the overall diversity of zooplankton community, Simper Analysis (similarity percentage analysis) was used. The results show that, in all the three studied complexes, Rotifera and Copepoda had the largest contribution (77.04 %) (Table 7).

Table 7

Results of SIMPER test indicating the contribution of major groups to zooplankton diversity

			Averages		
Taxa	**Av. dissim**	**Contrib. %**	**Roșu-Puiu**	**Gorgova-Isac**	**Matița-Merhei**
Rotifera	23.57	48.79	80.7	85.5	223
Copepoda	13.64	28.25	95.6	106	91.1
Testacea	4.94	10.22	42.5	9.04	9.8
Cladocera	4.46	9.23	29.7	11.1	13.3
Ciliata	1.07	2.21	7.81	4.27	6.09
Lamellibranchia	0.53	1.1	3.36	0.34	0.07
Gastrotricha	0.08	0.16	0.35	0.28	0.34
Ostracoda	0.02	0.03	0	0.07	0.05

The development of these groups was primarily based on the existing physical-chemical conditions and on the availability of the food resources. For zooplankton, there are two main food sources: phytoplankton communities and secondary detrito-bacterial particles/aggregates (Kim *et al*., 2000; Freese & Martin-Creuzburg, 2013; Zinevici *et al*., 2015).

During our investigation, a common trait of the three lake complexes was the fact that Rotifera consumed total phytoplankton, while copepods seem to prefer cryptophyte algae, confirming the results of other studies (Antajan & Gasparini, 2004) (Tables 8–10). There is a big resemblance between the food sources used by zooplankton in Roșu-Puiu and Matița-Merhei complex. Although the rotifers and copepods groups prefer green algae and diatoms, in agreement with results for similar ecosystems (Work & Havens, 2003), in the Danube Delta they seem also well adapted to cyanobacterial consumption (Tables 8–9) even if these organisms could be inedible or even become toxic in certain conditions, especially in Roșu-Puiu complex, affected by a long-term eutrophication (Postolache, 2006). Also, the diaptomids are able to use their long antenna and break the cyanobacterial filaments to consume them (Moriarty *et al.*, 1973). The third lake complex, Gorgova-Uzlina, shows a different pattern of biodiversity, due to different environmental factors (Table 10).

Table 8

Significant relationships of zooplankton, phytoplankton and environmental variables in Matița-Merhei ($p<0.05$)

Variables	Ciliata	Testacea	Lamellibranchia	Gastrotrichia	Rotifera	Cladocera	Copepoda	Ostracoda
Bacillariophyceae (μg chl *a* L^{-1})					0.384	0.498	0.493	
Chlorophyceae (μg chl *a* L^{1})					0.477		0.427	-0.363
Chryptophyceae (μg chl *a* L^{-1})		0.440			0.364		0.703	
Total chl. *a* (μg chl *a* L^{-1})					0.583	0.678	0.493	
Cyanobacteria (cells L^{-1})		0.471			0.600	0.483	0.734	
Pyrrophyceae (cells L^{-1})		0.492		0.375				0.480
Chrysophyceae (cells L^{-1})						0.354		
Bacillariophyceae (cells L^{-1})			-0.522				0.457	
Chlorophyceae (cells L^{-1})	0.398	0.437			0.686	0.526	0.780	
T (C)					0.361		0.548	
T (C) sediment		0.693		0.415	0.608	0.732	0.694	
pH		0.390			0.505		0.670	
pH sediment		0.689		0.413	0.633	0.748	0.705	
Cond. (μs/cm)							0.395	
Turbidity (NFU)		0.596			0.485	0.620	0.561	
Light intensity (lx)					0.345			
Water flow (counts\min)		0.669		0.436	0.648	0.643	0.614	
Water velocity (m/s)		0.462		0.394	0.526	0.664	0.544	
NH_4^+ (μg N L^{-1})		0.535			0.549	0.559	0.779	
NO_3^- (μg N L^{-1})							0.492	
PO_4^{3-} (μg P L^{-1})		0.517			0.481	0.406	0.537	
TP (μg P L^{-1})		0.384			0.425		0.585	

Table 9

Significant relationships of zooplankton, phytoplankton and environmental variables in Roșu-Puiu ($p<0.05$)

Variables	Ciliata	Testacea	Lamellibranchia	Gastrotrichia	Rotifera	Cladocera	Copepoda	Ostracoda
Cyanobacteria (µg chl *a* L^{-1})	0.553	0.471			0.633		0.514	
Chlorophyceae (µg chl *a* L^{-1})		0.567					0.509	
Chryptophyceae (µg chl *a* L^{-1})		0.511					0.511	
Total chl. *a* (µg chl *a* L^{-1})	0.609	0.812			0.504		0.644	
Cyanobacteria (cells L^{-1})	0.576	0.550			0.722		0.744	
Euglenophyceae (cells L^{-1})			0.528					
Pyrrophyceae (cells L^{-1})	0.538			0.548			0.566	
Bacillariophyceae (cells L^{-1})		0.504			0.671		0.737	
Chlorophyceae (cells L^{-1})	0.513				0.750		0.796	
D (m)					0.490			
T (m)		-0.501						
T (C)					0.491		0.473	
T (C) sediment		0.626		0.471		0.494		
pH					0.640		0.617	
pH sediment	0.480	0.655					0.501	
Cond (µs/cm)					0.544		0.576	
Light intensity (lx)					0.541		0.535	
Water flow (counts\min)		0.652			0.469			
Water Velocity (m/s)		0.614						
NH_4^+ (µg N L^{-1})		0.493						
PO_4^{3-} (µg P L^{-1})				0.579			0.486	
TP (µg P L^{-1})					0.585		0.649	

The environmental parameters are key drivers for the dynamics of biological communities, influencing both phyto- and zooplankton populations (Basu & Pick, 1997; Heneash *et al*., 2015). Although there is no general agreement regarding all the factors regulating phytoplankton and zooplankton communities in different aquatic ecosystems (Reynolds, 1988), evidence shows that light, water velocity, temperature, nutrients, and xenobiotics modulate the development of plankton communities and interspecific competitions.

Table 10

Significant relationships of zooplankton, phytoplankton and environmental variables in Gorgova-Isac ($p<0.05$)

Variables	Ciliata	Testacea	Lamellibranchia	Gastrotrichia	Rotifera	Cladocera	Copepoda	Ostracoda
Chryptophyceae (µg chl *a* L^{-1})							0.591	
Total chl. *a* (µg chl *a* L^{-1})		0.643			0.694	0.688		
Cyanobacteria (cells L^{-1})				0.561				
Euglenophyceae (cells L^{-1})	0.716				0.678			
Pyrrophyceae (cells L^{-1})								
Chrysophyceae (cells L^{-1})								
Bacillariophyceae (cells L^{-1})	0.605							
pH							0.596	
NO_3^- (µg N L^{-1})							-0.772	

The investigations carried out in the three lake complexes emphasized that pH was a common factor influencing the development of copepods (Tables 8–10), but the other physical and chemical parameters modulating zooplankton communities had a different influence in each lake complex: while in Gorgova-Isac only nitrates influenced copepods development, in the other two complexes TP and temperature influenced both rotifers and copepods (Tables 8–10). In Matița-Merhei complex, rotifers, cladocerans, copepods and also testaceans are influenced by turbidity, water velocity and NH_4^+ content (Table 8).

The hydrogeomorphological features of the ecosystems have also key role in defining the development of plankton communities, habitat heterogeneity influencing the distribution of zooplankton individuals. The distribution of zooplankton communities in the three investigated complexes was analyzed based on Detrended Correspondence Analysis (DCA). The results show that although rotifers did not seem affected by the hydrogeomorphological characteristics, being widely spread in all the lake complexes, crustaceans (Cladocera and Copepoda) were found especially in Roșu-Puiu and Gorgova-Isac complexes (Fig. 3).

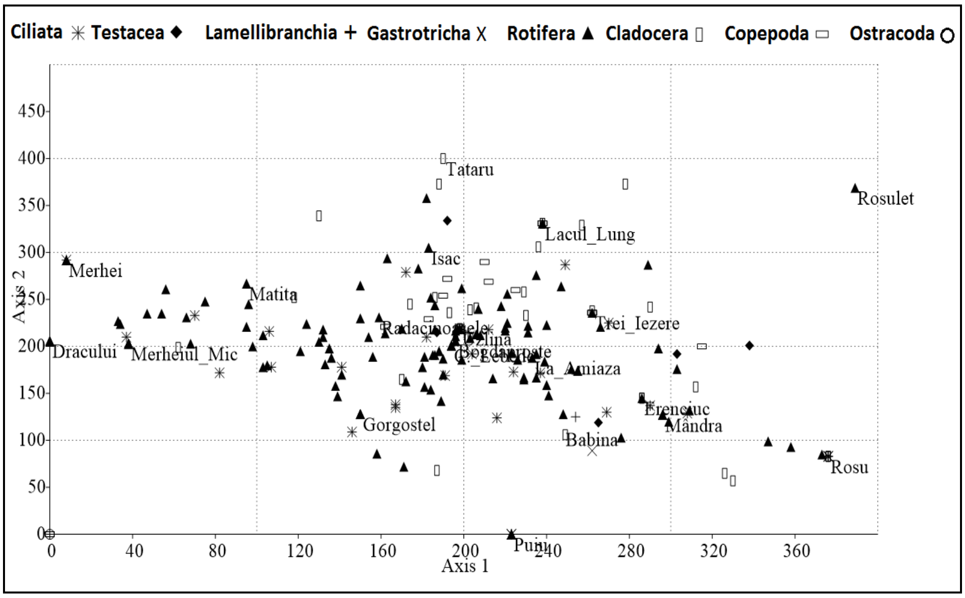

Fig. 3. Detrended correspondence analysis (DCA) of the zooplankton species distribution in the Danube Delta lakes.

CONCLUSIONS

Diversity is an important tool to assess the complexity of a community and its stability. In our study, the zooplankton diversity was assessed based on species richness and evenness. In lake complexes exhibiting a negative correlation between evenness and abundance, a higher presence of accidental species was found, determining a decrease of diversity indexes.

Taxonomic groups with significant role in defining traits of diversity were rotifers and copepods. Their role depended on both, community structure and spatial distribution. Water velocity, pH, temperature, turbidity, and nutrients modulated the development of zooplankton communities during the investigated period.

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[*] *Institute of Biology Bucharest of Romanian Academy, 296 Splaiul Independenței, 060031, Bucharest PO-Box 56-53, Romania*
e-mail: larisa.florescu@ibiol.ro

[**] *University of Bucharest, Department of Systems Ecology and Sustainability, 91–95 Spl. Independenței, Bucharest, Romania*
e-mail: ioana.enache_n@yahoo.ro