HOW DO THE STAGNANT AND FLOWING SYSTEMS INFLUENCE THE PRODUCTION OF ROTIFERS IN THE DANUBE DELTA?

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Abstract. The studies about the ecology of rotifers highlight their cosmopolitan character, being found among the most numerous zooplankton organisms. Due to their features of simple organisms, rotifers respond to different changes in the environment in a very short time. Consequently, the physiology and morphology of rotifers are into a permanent change due to the need for adaptation. Our results showed that the type of ecosystem influenced the dynamics of rotifers. Loricate species were better adapted to the flowing water conditions, while illoricate species preferred shallow waters (especially lakes). The depth and pH determined the spatial variations of the production of rotifers, while the temperature influenced the seasonal dynamics.

Keywords: lentic and lotic ecosystems, loricate and illoricate rotifers, Roşu Lake, secondary production.

Rezumat. Cum influențează apele stagnante și curgătoare producția rotiferelor în Delta Dunării? Studiile care urmăresc ecologia rotiferelor evidențiază caracterul lor cosmopolit, regăsindu-se printre cele mai numeroase organisme zooplanctonice. Totuși, prin trăsăturile lor de organisme simple, rotiferele sunt într-un timp foarte scurt afectate de modificările mediului, astfel fiziologia și morfologia acestora este într-o permanentă schimbare în nevoia de adaptare. Rezultatele noastre au evidențiat că tipul de ecosistem a influențat dinamica rotiferelor. Speciile loricate au avut o adaptare mai bună în condițiile de apă curgătoare, în timp ce speciile neloricate au preferat apele cu adâncimi mici (în special lacurile). Adâncimea și pH-ul au fost parametrii de mediu care au determinat variațiile spațiale ale rotiferelor, în timp ce temperatura a influențat variațiile sezoniere ale producției.

Cuvinte cheie: ecosisteme lentice și lotice, specii loricate și neloricate, Lacul Roșu, producție secundară.

INTRODUCTION

The assessment of the zooplankton biomass and production represents an important scientific concern due to their important role in biogeochemical and energy cycles, as well in aquatic ecosystem food web. Thus, the biological production highlights the importance of a population into ecosystems and their contribution in providing the necessary nutritive base to higher levels (MAKAREWICZ & LIKENS, 1979; GUTELMAKHER & MAKARTSEVA, 1990). The turnover (the production/biomass ratio) completes the production knowledge with indices of the replacement rate of a population, in terms of the existing conditions of an ecosystem. Zooplankton productivity is strongly influenced by physicochemical factors, food resources and consumer pressures (ARNOT et al., 1999).

Zooplankton communities constantly change under the influence of seasonal and spatial variations. Even if, rotifers are considered ubiquist species and are found among the most numerous planktonic organisms, nevertheless they have affinities for stagnant waters with a high coverage of macrophytes (KOSTE et al., 1982; BIELAŃSKA-GRAJNER & GŁADYSZ, 2010; NOVA et al., 2014). Their presence in lotic ecosystems is much weaker being determined mainly by the low food availability and also by the characteristic unstable conditions (CASANOVA et al., 2009). Thus, the rivers diversity is much lower compared with lake ecosystems, with few dominant species (especially with lorica) adapted to the running waters. In the Danube Delta, there are about 400 lakes, with different sizes, which communicate with each other through a complex hydrological network consisting of various channels (COOPS et al., 2008). Aquatic ecosystems are characterized by a variety of hydrogeomorphological features. These traits are reflected in the diversity and biological production.

The aim of our study was to assess the differences in terms of rotifer production depending on the lotic or lentic traits of the ecosystem. Mândra Lake is a small lake (1.47 km^2) with high vegetation, presenting the most favourable conditions for the development of rotifers. The second one, Roșu Lake represents the same type of the ecosystems, but with different features compared to the previous one (14.31 km^2). To highlight the lotic conditions, there were chosen Roșu-Împuțita channel (approx. 5.80 km) and Roșu-Puiu channel (approx. 2.70 km). The advantage of the study in the Danube Delta was represented by the opportunity to have all these types of ecosystems under similar climatic conditions.

MATERIAL AND METHODS

Study site – The study was conducted between 2011 and 2013 with three sampling campaigns each year during the productive seasons (spring, summer and autumn). There were established one sampling point for Mândra Lake and 2 for the channels. In Roșu Lake, there were established five different sampling points in order to determine the variation of the hydrological regime (Fig. 1).

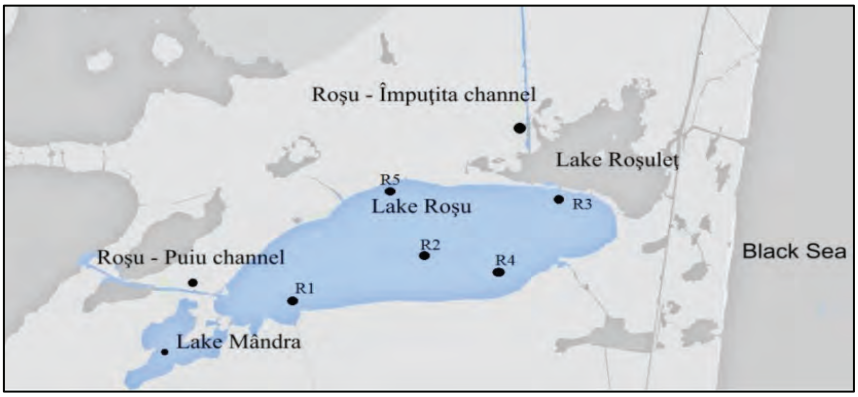

Figure 1. Study site with the sampling points (modified after Google Map).

Environmental parameters – The monitoring program includes measurements of depth, transparency, temperature and pH. The phytoplankton samples were collected without filtering, in 0.5 L bottles, preserved with 4% formaldehyde solution. The phytoplankton and zooplankton biomass was assessed by volumetric and gravimetric measurements.

Zooplankton - The zooplankton samples were taken by filtering maximum 50 L of water using Patalas-Schindler plankton trap (5 L), plankton nets (65 µm mesh size) and fixed with formaldehyde solution 4%. The rotifer species were identified and counted using a Zeiss inverted microscope and following keys: VOIGHT, 1956; RUDESCU, 1960. In order to evaluate the productivity, it was necessary to calculate de density (ind L^{-1}) (UTERMÖHL, 1958) and biomass (µg wet weight L^{-1}) (DUMONT et al., 1975; MCCAULEY, 1984). The secondary production was assessed as µg wet weight L^{-1}/24h, according to EDMONDSON & WINBERG, 1971.

Statistical analyses were performed using XLSTAT 2014 and PAST software (HAMMER et al., 2001).

RESULTS AND DISCUSSIONS

The depth of the studied ecosystems showed generally a downward trend from spring to autumn. The highest depth was recorded in Roşu-Puiu channel, about 4 m in spring, due to the flooding characteristic to this time of the year. Mândra is considered a very shallow lake, ranging from 1.87 to 1.17 m. Roşu-Impuţita channel differs from the other channel having much lower depths (1.70 - 1.57 m) (Table 1).

The delta waters generally have a slightly alkaline pH, varying in narrow limits in our ecosystems, being independent of the season. The minimum value was 8.01, in Roşu-Impuţita channel and the maximum value 8.85, in Roşu Lake. In fact, the highest pH values were found in Roşu Lake, in all three seasons (Table 1).

The water temperature was dependent on season, with high values in spring (22.35 in Roşu-Impuţita channel) and summer (26.67) in the same channel. The lowest temperatures were in autumn, about 16º C in most ecosystems (Table 1).

Table 1. The averages of the environmental variables of the study sites.

		Lentic systems		Lotic systems	
		Roşu	**Mândra**	**Roşu -Împuţita**	**Roşu-Puiu**
Depth	Spring	2.49	1.87	1.70	3.90
	Summer	2.29	1.47	1.73	3.07
	Autumn	2.20	1.17	1.57	2.67
Transparency	Spring	1.44	1.43	1.70	1.67
	Summer	0.47	0.67	0.63	0.63
	Autumn	0.84	0.43	1.17	0.48
Temperature	Spring	21.75	20.90	22.35	21.30
	Summer	26.01	25.47	26.67	24.83
	Autumn	16.31	16.07	17.03	16.03
pH	Spring	8.36	8.08	8.03	8.15
	Summer	8.85	8.63	8.07	8.16
	Autumn	8.53	8.52	8.01	8.49

The phytoplankton biomass recorded high values, especially in summer, in all the studied ecosystems. The values exceeded up to 8 times (in Roşu Lake and Roşu-Puiu channel) the algal bloom threshold of 5 mg L^{-1} established by OLTEAN, 1985. In fact, the maximum values were registered in these systems and the lowest was found in Mândra and Roşu-Impuţita channel (Table 2). It was noticed a variation dependent on the season because in autumn, when temperatures have minimum values, the phytoplankton biomass values were the smallest.

Table 2. The seasonal averages of phytoplankton biomass (mg wet weight L^{-l}) in the two different systems.

	Lentic systems		Lotic systems	
	Roşu	**Mândra**	**Roşu -Împuţita**	**Roşu-Puiu**
Spring	40.88	11.07	1.11	45.50
Summer	33.03	22.07	15.04	43.85
Autumn	33.66	10.10	6.44	10.21

The seasonal averages of rotifer production showed higher values in Mândra, 59.21 µg wet weight L^{-1}/24 h (Table 3), compared to Roșu, while Roșu - Împuțita (the long channel) presented a much higher production than the other ecosystems. In most ecosystems, the lowest values of rotifer production were registered in autumn, while the summer was the season with high values in most systems.

Table 3. The seasonal averages of rotifer production (µg wet weight L^{-1}/24h) of the study period.

	Lentic systems		**Lotic systems**	
	Roșu	**Mândra**	**Roșu -Împuțita**	**Roșu-Puiu**
Spring	26.91	59.21	12.02	34.21
Summer	56.91	50.53	87.37	33.51
Autumn	12.46	32.94	38.09	9.69

During the 3 years of the study a number of 106 species were registered, varying in the two types of ecosystems as follows: Roșu Lake (80 sp.), Mândra Lake (63 sp.), Roșu-Impuțita channel (71 sp.) and Roșu-Puiu channel (62 sp.). Of this sum, 76 species were loricate and 30 soft-bodied species (illoricate). The high percentage of loricate species was reflected by the secondary production of rotifers (Fig. 2).

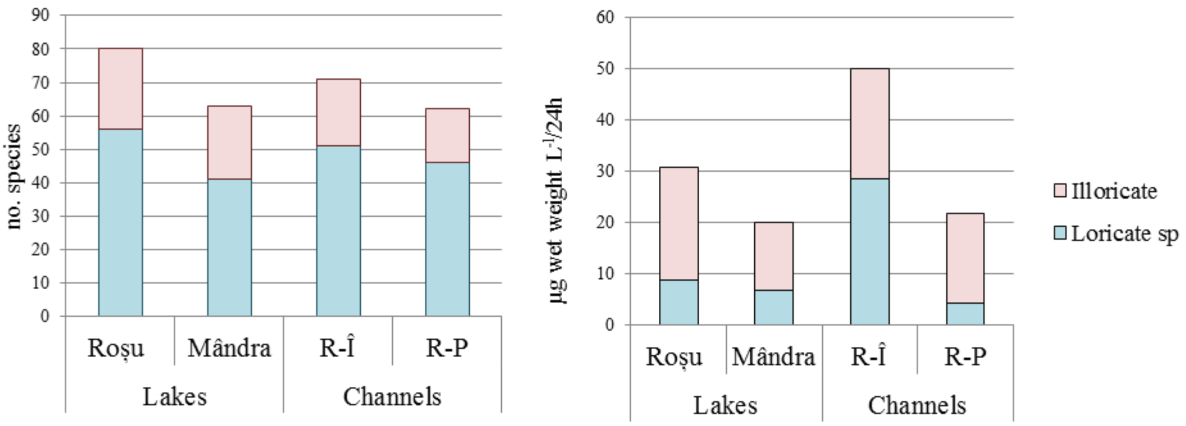

Figure 2. The variation of the two types of rotifer species in the study sites (number of species and production).

The distribution of loricate and soft-bodied species in the two types of ecosystems was explored using Detrended Correspondence Analysis (DCA). Most of the loricate species showed no preference for a particular type of ecosystem and highlighted a distribution due to the connectivity of ecosystems (Fig. 3). With regard to the soft-bodied species, it can be observed differences in distribution between the lentic and lotic ecosystems.

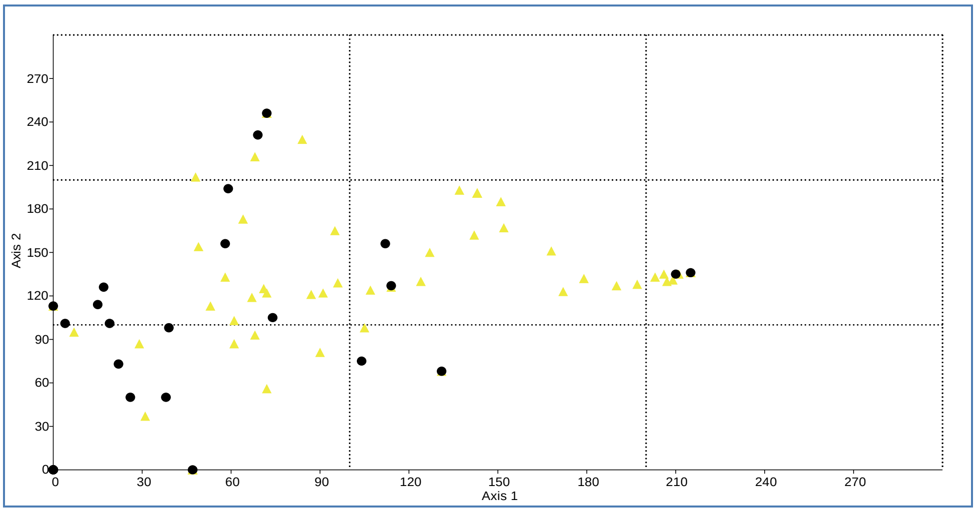

Figure 3. DCA analysis of the rotifer community distributions in the four studied ecosystems (triangles – loricate species, points – soft-bodied species).

The highest similarity was found between Roșu Lake and the short channel, Roșu-Puiu (Fig. 4). This reflects the communication between the two ecosystems and loricate species adaptability to conditions of rivers. In the case of soft-bodied species, the highest resemblance was observed between lentic ecosystems, while between the lotic ones, there were found clear differences.

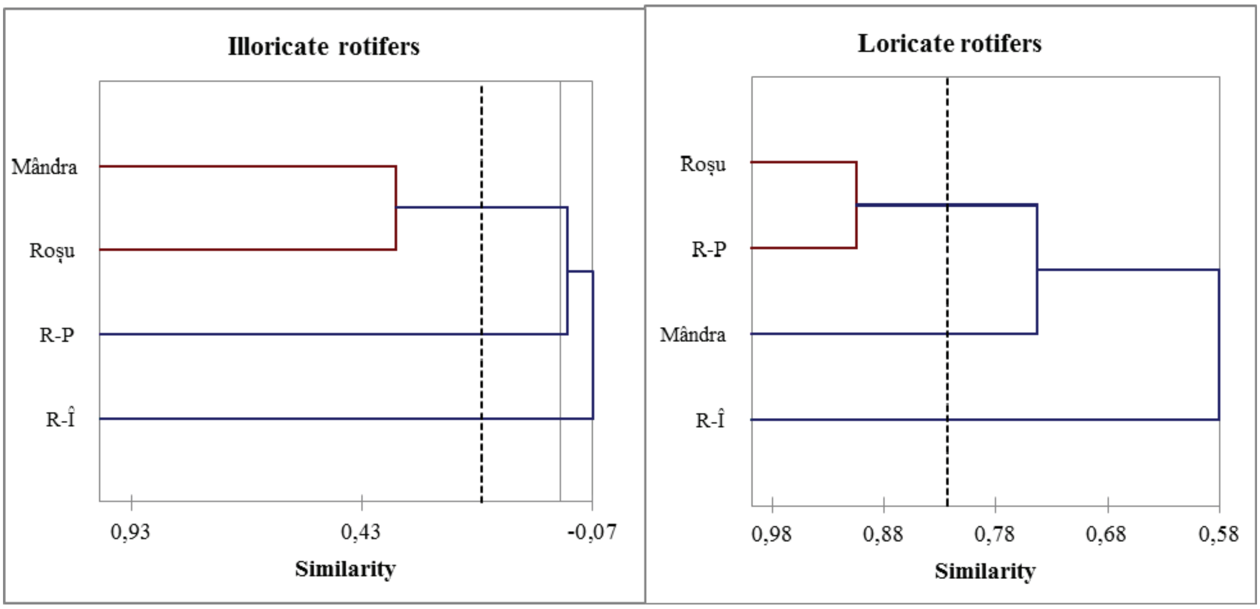

Figure 4. Agglomerative hierarchical clustering (AHC) based on similarity matrix.

An analysis of the influence of environmental parameters on the species in the 2 types of ecosystems, revealed a different pattern of responses. In the lentic ecosystems, pH and transparency were the significant parameters, while in case of channels, depth influenced the 12 species of rotifers (Table 4).

Table 4. The species number influenced by environmental parameters ($p<0.05$) depending on ecosystem type.

	Depth	Transparency	Temperature	pH
Lentic systems	0	6	4	14
Lotic systems	12	2	1	5

The organisms respond differently to environmental conditions, depending on the type of ecosystem. For instance, 7 species of rotifers that were found in both categories were influenced by depth in lotic systems and pH in the lentic ones (Table 5).

Table 5. The R values of the significant correlations between rotifers and environmental parameters ($p<0.005$).

	Rotifer species	Depth	Transparency	Temperature	Ph
Lakes					
	Anuraeopsis fissa (Gosse 1851)		-0.614		0.537
	Epiphanes clavulata (Ehrenberg 1832)		0.514		
	Filinia maior (Carlin 1943)			0.499	0.784
	Trichocerca dixton- nuttali (Jennings 1903)				0.494
	Trichocerca rattus (Müller 1776)				0.762
	Trichocerca ruttneri (Donner 1953)				0.855
	Trichocerca similis (Wierzejski, 1893)				0.468
Channels					
	Anuraeopsis fissa (Gosse 1851)	0.530			
	Epiphanes clavulata (Ehrenberg 1832)				0.985
	Filinia maior (Carlin 1943)	0.563			
	Trichocerca dixton- nuttali (Jennings 1903)	0.583			
	Trichocerca rattus (Müller 1776)	0.534			
	Trichocerca ruttneri (Donner 1953)	0.525			
	Trichocerca similis (Wierzejski, 1893)	0.617			

The transparency is an important factor influencing indirectly the zooplankton components through phytoplankton distribution (their main food source) (BERNER-FRANKHAUSER, 1987). In our study, the transparency had a negative influence on most species of rotifers. The rotifers do not show a pronounced positive phototaxis, as some species are independent of it (WILLIAMSON et al., 1996). However, rotifer studies mention a negative reaction to sunlight of these populations explaining the avoidance of intense lit superficial layer. Also, in the case of phytoplankton, there were recorded negative effects on Cyanobacteria ($R = -0.38$, $p = 0.02$) and Chlorophyceae ($R = -0.48$, $p = 0.005$). In fact, seasonal variations of light and temperature are important factors influencing life cycles of organisms, their production and productivity (VOPEL, 1999).

The use of rotifers as bioindicators was often regarded with scepticism but the opinions have changed with the accumulation of data over time (KARABIN, 1983). Regarding the effect of pH on rotifers it was found that most are neutrophils but there are some species adapted to alkaline environment (DHURU et al., 2015, CASANOVA et al., 2009).

Temperature was the significant factor determining the total production of rotifers in lakes (R = 0.533; p = 0.023). Temperature is an important limiting factor, affecting the abundance, age structure, the rate of development, the longevity of rotifers (GALKOVSKAJA, 1987). Although rotifers are well adapted to low temperatures, they are more productive in warm seasons.

In order to detect the influence of the environmental factors on plankton groups, a Canonical Correlation Analysis (CCorA) was performed. The tested environmental parameters explained significantly the variation of plankton (82.24 %). Temperature affected directly the rotifer productions and some phytoplankton groups, like Chlorophyceae, Euglenophyceae, Pyrrophyceae, while transparency had a negative influence. For Cyanobacteria and Bacillariophyceae, the most important factor was depth (Fig. 5).

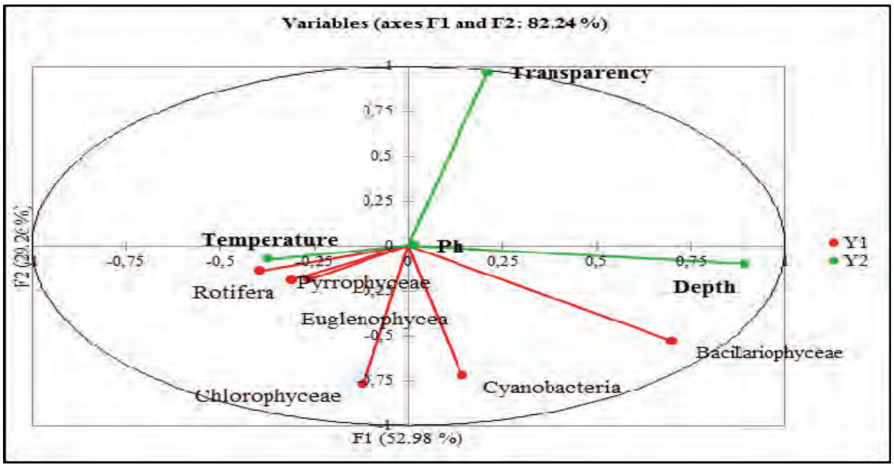

Figure 5. The influence of the environmental factors on plankton groups.

Even if rotifers are considered easily adaptable organisms, they are among the most sensitive to environmental changes in the zooplankton communities. Thus, in our study we found differences between areas in terms of rotifer production using Anosim test (R = 0.07; p = 0.057). The results have also shown the most significant differences between Roşu Lake and Roşu-Impuțita channel (Table 6).

Table 6. The Anosim test (R values in grey; p- values in white) for ecosystem differences in rotifers distribution.

	Roşu	**Mândra**	**Roşu -Împuțita**	**Roşu-Puiu**
Roşu		-0.08	**0.21**	0.12
Mândra	0.87		0.07	0.05
Roşu -Îmuțita	**0.02**	0.18		0.07
Roşu-Puiu	0.06	0.20	0.18	

CONCLUSIONS

The type of ecosystems determines the level of rotifer production in the Danube Delta

Most of the loricate species show no preference for a particular type of ecosystem and highlight a distribution due to the connectivity of ecosystems.

The soft-bodied species have differences in distribution between the lentic and lotic ecosystems preferring the lentic ones.

Temperature affects directly the rotifers productions and some phytoplankton groups, while transparency has a negative influence.

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