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RESEARCH PAPER

Seasonal Dynamics of Riverine Zooplankton Functional Groups in Turkey: Kocaçay Delta as a Case Study

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Abstract

River ecosystems are among the most affected habitats globally by human activities, such as the release of industrial, agricultural and domestic pollutants to the rivers. However, how affected zooplankton functional groups in rivers are largely unknown. In the present study zooplankton functional and taxonomic structure were investigated seasonally in relation to environmental parameters between 2013 and 2015 in Kocaçay Delta located on the South of the Marmara Region. The environmental parameters (e.g. water temperature, conductivity, dissolved oxygen, pH, chlorophyll-a and nutrients) were measured at four sampling station covering estuarine and riverine area. A total of 44 taxa of zooplankton were identified and mostly dominated by cosmopolite microphagous rotifers reflecting the proper intervals of environmental parameters for their habitat choices. Among rotifers Microcodides chlaena and Keratella serrulata were the new records for the study site and Turkish rotifer list. The only selective filter feeder was Bosmina longirostris in Kocacay Delta. The zooplankton functional group, microphagous, showed seasonal variations and affected by chlorophyll-a content. We suggested that trait-based approaches would be a useful tool to assess the degree of environmental disturbance and interaction between trophic levels.

Introduction

Rivers are important aquatic ecosystems supporting diverse life forms (Dudgeon *et al*., 2006) yet they are under intense anthropogenic disturbances such as nutrient enrichment via agricultural activities, urbanization (Parks, Quist & Pierce, 2014). In recent decades, there has been an increasing attention on the ecology of zooplankton communities in rivers regarding their abundance, diversity and spatio-temporal patterns (Lair, 2006). Zooplankton has an important role in functioning the aquatic ecosystem through energy flux (Santos-Wisniewski, Rocha, Guntzel, & Matsumura-Tundisi, 2006; Gutierrez *et al*., 2018). Thus, these organisms can be used as an indicator of eutrophication, pollution, environmental problems and global warming in cases of long-term changes (Akbulut, Akbulut, & Park., 2008; Hsieh *et al*., 2011). As well as the determinant of ecological status of a river together with ecological variables (Voutilainen, Jurvelius, Lilja, Viljanen & Rahkola-Sorsa, 2016).

Recently, several studies have documented the effect of local-scale environmental conditions on the composition and distribution of riverine zooplankton in Turkey (e.g. Göksu, Bozkurt, Taşdemir, & Sarıhan, 2005; Bozkurt & Güven, 2010; Saler, 2011; Bekleyen, Gokot & Varol, 2011; Güher, 2012; Bozkurt & Akın 2012; Dorak, 2013; Saler, Bulut, Birici, Tepe, & Alpaslan, 2015). However, to the best of our knowledge, there is no literature exist on the riverine zooplankton functional

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groups. The functional trait approach has recently increased among community ecologist due to enables the better understanding of community structure along with the environmental factors (McGill, Enquist, Weiher, & Westoby, M 2006; Díaz, Suárez Alonso, & Vidal-Abarca, 2008). Unfortunately, the trait-based approaches for zooplankton particularly for the rotifers have been done limited (Barnett, Finlay, & Beisner, 2007; Barnett & Breisner, 2007). According to the several studies regarding the feeding type of zooplankton species, the species grouped into functional guilds (Hillbricht-Ilkowska, 1983; Karabin, 1985; Špoljar, Habdija, Primc-Habdija, & Sipos, 2005; Špoljar, Tomljanović, & Lalić, 2011, Špoljar, Dražina, Habdija, Meseljević, & Grčić, 2011; Virro, Haberman, Haldna, & Blank, 2009; Bertani, Ferrari, & Rosetti, 2012). The Guild Ratio has been introduced by Smith, Ejsmont-Karabin, Hess, & Wallace, (2009) based on feeding strategies was recently modified by Obertegger, Smith, Flaim, & Wallace, (2011) as Guild Ratio (GR). The ratio allows researchers for understanding the community relations with ecological processes. The main aim of this study is to assess the variability in zooplankton functional groups together with biotic and abiotic parameters in the Kocaçay Delta that located an important agricultural area.

Materials and Methods

Study Area

The Kocaçay Delta, formed by the Susurluk River and located on the southern shore of the Sea of Marmara, is consist of diverse habitats including lakes, swamps, sand dunes, and forests. It covers an area of 751 km² and flows into the Sea of *Marmara.* Kocaçay River is connected with Nilüfer Stream across the Bursa which is a densely populated city and Uluabat Stream, discharged into the Sea of Marmara from Kocaçay Delta. Susurluk River is the most important water source on the delta. Delta is one of the most important agricultural regions in Turkey. The Kocaçay Delta contains Arapçiftliği, Dalyan and Poyrazlar lagoons which are an important habitat for flora and fauna (Anonimous, 1993). The sampling was performed eight time from November 2013 to March 2015 in the 4 sampling stations in Kocaçay Delta (Figure 1, Table 1).

Sampling and Laboratory Analyses

To investigate the zooplankton species composition, samples were collected by vertical haul using a standard plankton net of 44 µm mesh size from 4 different stations (Figure 1; Table 1). Zooplankton samples were fixed in Lugol's solution (4%). The zooplankton species were identified as possible as species level under the binocular microscope (Leica DM5000B). Among zooplankton, Cladocera and Copepoda were identified according to Scourfield & Harding (1966), Kiefer (1978), Reddy Ranga (1994), Smirnov (1996), Flößner (2000), and Dussart & Defaye (2001). Rotifers were identified according to Emir, (1994), Koste, (1978), Ruttner-Kolisko, (1974), Segers, (1995), Nogrady & Paurriot, (1995), De Smet, (1996), De Smet & Pourriot, (1997), De Smet (1998). Zooplankton taxa were divided into different functional groups into feeding guilds (Barnett, Finlay, & Beisner, 2007, Obertegger & Manca, 2011; Bertani, Ferrari, & Rosetti, 2012; Lokko & Virro, 2014. The Guild Ratio was calculated as GR=(biomass raptorial-biomass

Figure 1. Sampling Area (Akbulut &Tavşanoğlu 2015).

microphagous)/(total rotifer biomass), and values range from -1 to +1. Values >0 indicated the dominance of microphagous while <0 indicated the dominance of raptorial ones (Obertegger, Smith, Flaim, & Wallace, 2011). A Functional Diversity (FD) was also calculated by using different functional groups mentioned above with the same formulae as for Shannon–Wiener diversity index.

Vertical profile of water temperature (°C), conductivity (μS cm^{-1}), salinity (‰), dissolved oxygen (mg L^{-1}), and pH was measured *in situ* using YSI Pro Plus multiprobe system. Water transparency was measured with a 20 cm diameter Secchi Disk. 1.5L of water samples were collected for chemical (major anions and cations) analysis which were measured in the Water Chemistry Laboratory of Hacettepe University (see. Akbulut & Tavşanoğlu, 2015). Chlorophyll-*a* (Chl-a) analyses were determined using by ethanol extraction method according to Jespersen & Christoffersen, 1987 and measured at 663 and 750 nm.

There were no marked differences between sampling locations thus samples from 4 different stations were pooled.

Statistical Analyses

The data of physico-chemical parameters and functional groups were tested for normality using the Kolmogorov-Smirnov test (SigmaStat 3.5), and variables with non-normal distribution were transformed (log10, log10+1). To test the seasonal differences in zooplankton functional groups, we employed one-way analysis of variance (one-way ANOVA). If the significant effects appeared, the post hoc method for pairwise multiple comparisons was performed. To evaluate the effect of environmental variables, we employed multiple regression (stepwise procedure, variables entered the analysis if p≤0.05). Among the 16 environmental parameters, we excluded 9 due to collinearity problem (VIF<10). Remained parameters as explanatory variables were: salinity, pH, Chl-a, Dissolved Inorganic Nitrogen (DIN), Mg and Ca.

In each sampling seasons, we calculated the richness of the species according to the total number of different species in each station. Species evenness is a measure of the equality in species composition in a community (Krebs, 2002). From the abundance data, we calculated Pielou's evenness (J) and Shannon–Wiener (H) diversity using the R package 'vegan' (R Core Development Team, 2011).

Results

Environmental Variables

Main physicochemical characteristics of Kocaçay Delta did not show clear seasonal variations (Table 2). Water temperature varied from 13.1 °C in winter to 27.9 °C in summer. Dissolved oxygen saturations were between 39.9% and 55.2%. According to the "River

Table 1. The sampling locations of Kocaçay Delta

Sampling Stations	Coordinates	
K-1	40°22'50,6"N	28°29'33,1"E
K-2	40°22'10,9"N	28°29'10,6"E
K-3	40°17'41,9"N	28°27'34,5"E
K-4	40°23'37,6"N	28°30'38,5"E

Table 2 General physical and chemical parameters of Kocaçay Delta with standard error (Mean±SE) during sampling seasons

Parameters		Spring	Summer	Autumn	Winter
	WTemp. (°C)	17.7±1.8	27.9±0.3	15.9±1.2	13.1±0.4
	DO %	39.9±9.2	40.8±15.4	49.2±3.3	55.2±6.3
	DO mg L^{-1}	3.9±0.9	3.1±1.2	4.5±0.6	5.7±0.7
	EC (mS cm^{-1})	2423.9±1135.3	4513.7±1564	895.1±137.9	3567.1±2595.5
	Salinity (‰)	1.4±0.7	2.6±0.9	0.45±0.1	2.13±1.6
	pH	8.04±0.2	8.1±0.1	7.73±0.0	7.8±0.2
	Chl-*a*	13.4±2.9	205.5±66.2	37.2±8.5	7.3±1.2
Anions	Cl$^-$ (meq L^{-1})	2.9±0.8	8.9±0.9	3.9±0.9	3.9±1.3
	DIN (meq L^{-1})	0.3±0.1	0.7±0.2	0.4±0.1	0.4±0.1
	SO^{-4} (meq L^{-1})	1.3±0.2	1.7±0.1	1.6±0.1	1.6±0.2
	HCO^{-3} (meq L^{-1})	4.5±0.3	6.6±0.9	5.1±0.2	5.1±0.4
Cations	Na$^+$ (meq L^{-1})	3.9±0.9	9.7±1.6	6.4±1.1	6.3±1.6
	K$^+$ (meq L^{-1})	0.2±0.0	0.3±0.0	0.2±0.0	0.2±0.0
	Mg$^+$ (meq L^{-1})	2.4±0.3	3.2±0.5	2.5±0.2	2.5±0.2
	Ca$^+$ (meq L^{-1})	3.5±0.2	3.5±0.2	3.3±0.2	3.3±0.3

Pollution Index" by EPA (http://wq.epa.gov.tw), Kocaçay Delta was moderately polluted based on dissolved oxygen concentrations ($4.5 \geq DO \geq 2.0$) most of the samplings (Table 2). During summer, Chl-a concentration was found to be very high reflecting the eutrophic conditions due to low-flow in the river as well as high nutrient loading arising from catchment due to agricultural activities and urbanization around the villages. Dissolved Inorganic Nitrogen (DIN) was also higher during summer than the other seasons. The mean pH values were varied from 7.7 to 8.1 reflecting the alkaline conditions. Major anions and cations did not show clear seasonal variations except for the Na^+ and Cl^- with marked a increase during summer. Accordingly, conductivity was also observed high during summer (Table 2). Although, salinity was increased during summer particularly towards the mouth of the estuary reached up to 7.9 ‰ (in July), no significant result appeared among the sampling stations.

However according to the one-way ANOVA results, no significant difference was observed among seasons for environmental variables except for chlorophyll-*a* (K-W one-way ANOVA; H=8.69, $P<0.05$) and Cl^- (K-W one-way ANOVA; H=8,1, $P<0.05$).

Zooplankton Community Structure

A total of 44 zooplankton taxa was observed within the groups Rotifera (43taxa) and Cladocera (1 taxa). We did not find zooplankton taxa from the K-1 station thus all the analyses were run from three stations. Zooplankton fauna of the Kocaçay Delta was composed mainly of Rotifera group and was characterized mostly by the presence of cosmopolite species (Table 3). Among rotifers *Microcodides chlaena* (Gosse, 1886) and *Keratella serrulata* (Ehrenberg, 1838) were the new records for the study site and Turkish inland waters rotifer list Ustaoğlu *et al*., 2012; Ustaoğlu 2015). Among functional groups, we found 11 raptorial, 7 large microphagous, 8 medium microphagous, 17 small microphagous Rotifera species. We identified only one selective filter feeder cladoceran (*Bosmina longirostris* O.F. Müller, 1776) and one medium microphagous copepods (cyclopoid nauplii) in Kocaçay Delta (Table 3).

Throughout the sampling periods, the abundance of microphagous was observed high and showed seasonal variations (one-way ANOVA; F=3.51, $P<0.05$). According to pairwise comparisons, seasonal variations observed between summer and winter ($P<0.01$). Although selective filter feeders were found to be very low, they also showed clear increasing trends after July (Figure 2). However, we did not observe significant differences among seasons for the filter feeders ($P=0.2$). Raptorial ones were relatively high following the microphagous (Figure 2). However, no significant differences were observed among seasons for raptorial too (one-way ANOVA; F=0.87, P>0.4). The differences in abundance of all functional groups displayed similar pattern in each station (Figure 2). Furthermore, the highest zooplankton abundance was recorded in summer (July) while the lowest value was recorded during winter (February).

Accordingly, the Guild Ratio Index (GRI) was also showed the seasonal difference (K-W one-way ANOVA; H=9,63, P<0.05). Among all the pairwise comparisons, GRI was significantly different between winter and fall season (P<0.05) but from the rest of the season we did not detect the differences. The GRI had low values in

Table 3. Functional characterization of the zooplankton taxa based on several traits in Kocaçay Delta

Rotifera	Raptorial	*Asplanchna priodonta* Gosse, 1850, *Trichocerca bidens* (Lucks, 1912), *Trichocerca cylindrica* (Imhof, 1891), *Trichocerca inermis* (Linder, 1904), *Polyarthra remata* Skorikov, 1896, *Polyarthra dolichoptera* Idelson, 1925, *Polyarthra vulgaris* Carlin, 1943, *Synchaeta oblonga* Ehrenberg, 1832, *Synchaeta pectinata* Ehrenberg, 1832, *Cephalodella gibba* (Ehrenberg, 1830), *Ascomorpha ovalis* (Bergendal, 1892)
	Large Microphagous	*Brachionus calyciflorus* Pallas, 1766, *Brachionus plicatilis* Müller, 1786, *Brachionus quadridentatus* Hermann, 1783, *Brachionus urceolaris* Müller, 1773, *Euchlanis dilatata* Ehrenberg, 1832, *Brachionus bidentata* Anderson, 1889, *Conochilus unicornis* Rousselet, 1892
	Medium Microphagous	*Rotaria* sp., *Brachionus angularis* Gosse, 1851, *Lophocharis salpina* (Ehrenberg, 1934), *Bdelloid rotifer, Philodina* sp, *Adineta* sp., **Microcodides chlaena* Gosse, 1886, *Testudinella patina* (Hermann, 1783)
	Small Microphagous	*Anuraeopsis fissa* Gosse, 1851, *Anuraeopsis navicula* Rousselet, 1911, *Filinia longiseta* (Ehrenberg, 1834), *Filinia terminalis* (Plate, 1886), *Keratella cochlearis* (Gosse, 1851), *Keratella cruciformis* Thompson, 1892, *Keratella quadrata* (Müller, 1786), **Keratella serrulata* Ehrenberg, 1838, *Lecane bulla* (Gosse, 1851), *Lecane inermis* (Bryce, 1892), *Lecane luna* (Müller, 1776), *Lecane lunaris* (Ehrenberg, 1832), *Lepadella patella* Müller, 1773, *Lepadella* sp., *Colurella colurus* (Ehrenberg, 1830), *Colurella uncinata* (Ehrenberg, 1832), *Hexarthra fennica* (Levander, 1892)
Cladocera	Selective filter feeders	*Bosmina longirostris* (O.F. Müller, 1776)
Copepoda	Medium Microphagous	Cyclopoid nauplii

*New records for Turkish Rotifer Fauna

each season except for winter (> 0) reflecting the dominance of microphagous while, the highest value in winter (< 0) reflecting the dominance of raptorial rotifers (Figure 3).

Accordingly, the species richness ranged between 1 and 12 and Shannon diversity ranged between 0.36 and 2.26. The highest diversity parameters were observed on spring (March and May) while the lowest ones were observed on winter (February) (Table 4). Shannon-Wiener diversity showed significant difference among seasons (one-way ANOVA, F=5.57; *P*<0.01). According to pairwise multiple comparisons, seasonal variations observed between spring and winter (*P*<0.01) as well as between spring and autumn (*P*<0.05). For species richness, a similar pattern occurred among seasons in the Kocaçay Delta (one-way ANOVA, F=4.57; *P*<0,05). Minimum richness was observed during the winter period (Table 4). However, no significant differences appeared for Pielou's evenness among seasons (P>0.05). Furthermore, a significant positive correlation was found between Shannon–Wiener taxonomic diversity and Functional Diversity (R^2=0.32, P<0.01).

According to the Multiple regression with stepwise procedure, microphagous zooplankton was positively related to Chl-a (coefficient: 0.01; F= 10.46, *P*<0.05) and pH (coefficient: 1.23; F= 25.98, *P*<0.001), while no clear trend with the selected variables were found for both raptorials and filter-feeders in Kocaçay Delta.

Discussions

Trait-based approaches have been used to reveal the environmental disturbances. Both functional and

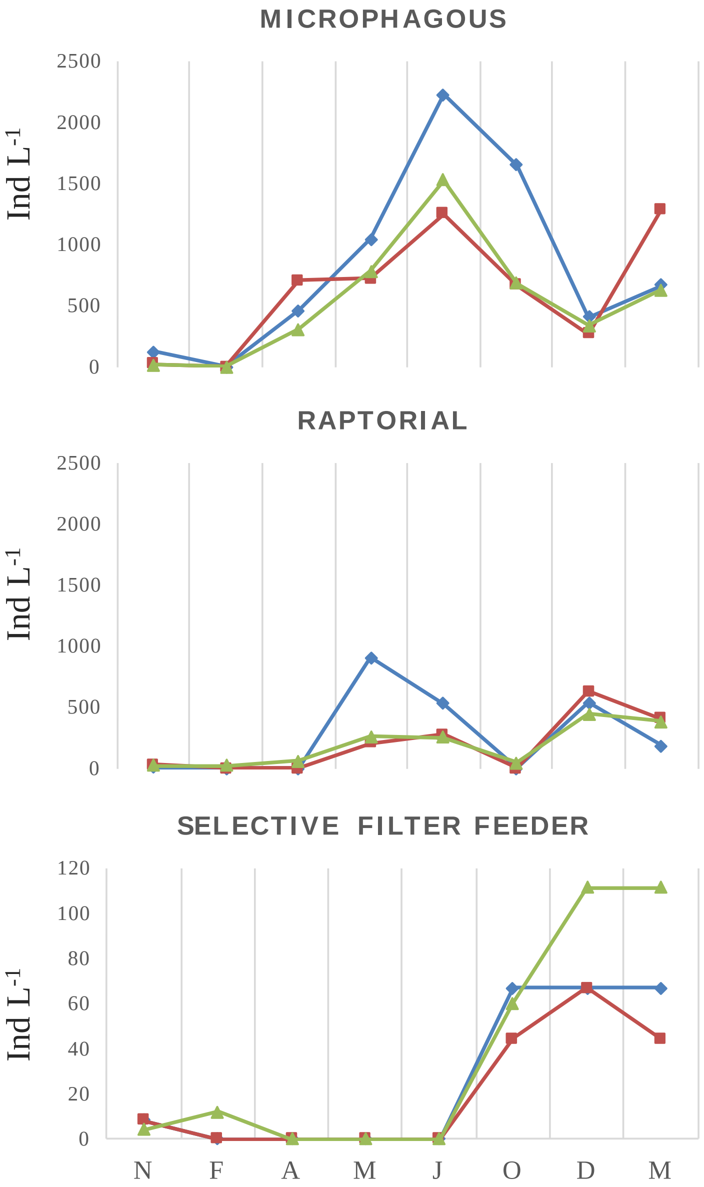

Figure 2. Bimonthly Distribution of Zooplankton functional groups in Kocaçay Delta. Symbols represented; Triangle: K2, square: K3 and diamond: K4. Please, note that the scales of y-axis are different.

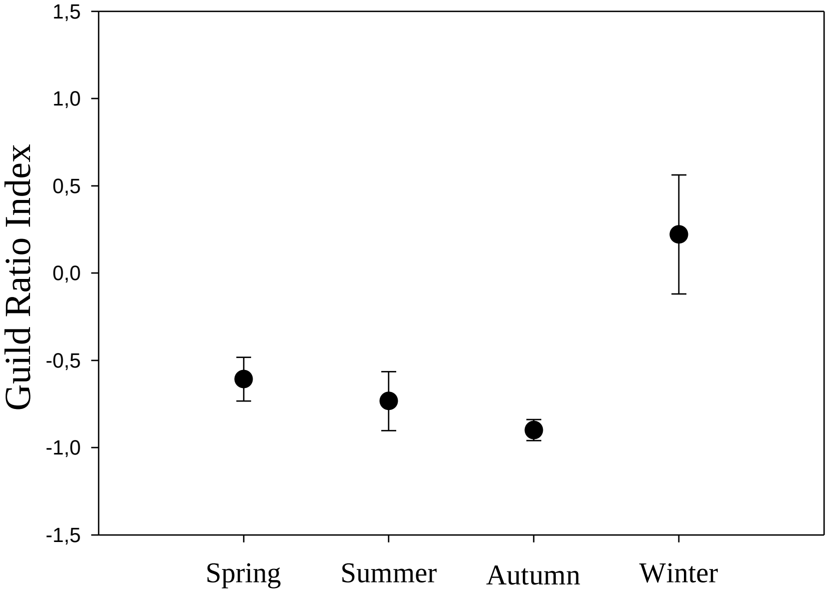

Figure 3. Variations in the Guild Ratio Index during sampling seasons.

Table 4. Species diversity (*H*), Richness (*S*), Evenness (*J*) and Functional diversity (FD) in each stations with standard error (Mean±SE) during sampling seasons

	Spring	Summer	Autumn	Winter
Shannon Diversity	2.12±0.1	1.5±0.0	1.2±0.3	1.04±0.4
Species Richness	10.6±1.2	6.7±0.3	5.5±1.8	4.7±1.8
Pielou's Evenness	0.9±0.0	0.8±0.0	0.7±0.1	0.5±0.2
Functional Diversity	0.51±0.1	0.48±0.3	0.62±0.2	0.56±0.18

taxonomic approaches are providing similar information about ecosystem functioning (Heino, 2008; Ding *et al*., 2017; Gutierez *et al*., 2018). Although several types of researches have conducted trait-based approaches for phytoplankton (see Reynolds, Huszar, Kruk, Naselli-Flores, & Melo, 2002; Kruk, *et al*. 2010), for macrophyte (Grime, 1973; Nielsen, 2003), for invertebrate (Heino, 2008), little has been done for zooplankton (Barnett *et al*. 2007; Barnett & Beisner, 2007). In the present study, zooplankton community consisted of microphagous feeding mode reflecting the favorable conditions for their development in terms of resource availability in Kocaçay Delta. Microphagous species prefer to ingest ~15-20 µm in size of multiple food sources while raptorial prefer larger particles (Pourriot, 1977; Karabin, 1985). Although we had no neither phytoplankton data nor gut content data in the present study to evaluate the food size, the positive relationship between chlorophyll-*a* and microphagous would confirm the existence of available food sources for microphagous. Furthermore, the negative GRI value in each season except for winter indicate eutrophic state. While during fall, zooplankton community underwent a dramatic increase in selective-feeding mode coherent with shifting non-polluted conditions according to “River Pollution Index” due to increased dissolved oxygen concentration.

Similar patterns appeared from the taxon-related metrics that high species richness and Shannon-Wiener diversity observed during the end of spring sampling. Due to the positive correlation between taxonomic diversity and functional diversity, we suggested that FD may be suitable in ecosystem functioning related to changes in environmental variables.

In the present study, we did not take into account the top-down impact on zooplankton community but the high abundance of carp (*Carassius* sp.) was observed during samplings from low-flow fisherman capture areas (N. Tavşanoğlu, personal observation). However, planktivorous fish or benthic bivalves have a significant top-down effect on the abundance and structure of zooplankton in several large rivers (e.g. Jack & Thorp, 2000; Ning *et al*., 2010). Thus, the dominance of microphagous rotifers in the present study may indicate the top-down effect on zooplankton.

The trait-based approach would be useful to indicate complex interactions and to assess the degree of environmental disturbances (Obertegger, Smith, Flaim, & Wallace, 2011). In the present study, microphagous rotifers were used as an indicator for evaluation of trophic state in Kocacay Delta. Further research is needed to confirm the impacts on the functional group of riverine zooplankton. Long-term monitoring would be a best opportunity to assess the ecosystem functioning.

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