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RESEARCH ARTICLE

Zooplankton abundance in the lower Sakarya River Basin (Turkey): Impact of environmental variables

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Abstract

In the present study the community structure and diversity of zooplankton were investigated seasonally in the polluted water of the lower Sakarya River Basin during February 2008-January 2009. The environmental variables measured were river flow, water temperature, conductivity, dissolved oxygen, pH, suspended particulate matter, chlorophyll *a* and nutrients (NO_2-N, NO_3-N, SiO_2, PO_4-P, TP). Determined environmental parameters were at the suitable intervals for habitat choice of identified zooplankton species. Thirty-two zooplankton taxa were determined , which were mostly indicators of eutrophic water of the study area. Rotifera was the most abundant group (96.4%), followed by Copepoda (2.7%) and Cladocera (1.0%). The dominant taxa were *Brachionus budapestinensis* Daday, *Keratella cochlearis* (Gosse), *Polyarthra vulgaris* (Carlin), *Synchaeta oblonga* Ehrenberg and *Trichocerca ruttneri* Donner from Rotifera, Copepod nauplii from Copepoda and *Bosmina longirostris* (Müller) from Cladocera. Depending on the station, zooplankton abundance and environmental parameters showed seasonal variation. Generally, higher zooplankton abundance and higher temperature resulted in a higher zooplankton diversity index. Statistical analyses indicated that rotifers and total zooplankton were highly associated with environmental parameters, especially water temperature and nutrients. Degree of pollution determines the quality as well as the quantity of plankton in the study area. Consequently, waste waters should be controlled, and pollution must be prevented to conserve biodiversity of zooplankton fauna and in consequence food web of the study area. All zooplankton species identified were the first records for the study area.

Key words: Lower Sakarya River Basin, zooplankton, physicochemical factors, seasonal distribution, Redundancy Analysis (RDA).

Introduction

Studies on zooplankton in running waters, especially relationship between zooplankton and environmental parameters, in Turkey are relatively few. Zooplanktonic organisms are bioindicators of water quality and pollution degree because they are strongly influenced by environmental changes and respond quickly to alternations in locality quality (Gannon and Stemberger 1978). Eutrophication impacts zooplankton composition, replace the dominance from larger species (eg. calanoid copepods) to smaller species (*e.g.* especially rotifers) (Marneffe *et al.* 1996). Zooplankton are an important link in the transformation of energy from producers to consumers (Sharma *et al.* 2010). Zooplankton plays a key role as efficient filter feeders on phytoplankton, and as a food source for other invertebrates, fish larvae and fish (Deksne *et al.* 2011). Consequently studies on zooplankton are quite important. Water flow, showing changes in the river hydromorphology, exerts an important control over lotic communities (Deksne *et al.* 2011).

In the Sakarya River Basin, there appeared water pollution problems, due to the increase in population and industrialization, and it was identified that some branches of river were significantly contaminated by waste discharges of industrial plants. Also the oil pollution level was found in Sakarya River higher than the limit value given by UNESCO (Balcıoğlu and Öztürk 2009).

The aim of this study was to determine the zooplankton fauna and their relationship with environmental parameters and its seasonal composition in the lower Sakarya River Basin for the first time.

Materials and Methods

Study Area and Stations

The Sakarya River is the third largest river in Turkey discharging into the Black Sea. It is 810 km long and 60-150 m wide. Sakarya River is defined hydrologically in three parts: upper, middle and lower Sakarya River Basin (DSI 1992). The dams built on the river, prevent floods and they control the flow regime of lower Sakarya River Basin. Especially Gökçekaya Dam, built on the middle Sakarya River in 1972, changed the flow characteristic of lower Sakarya River, after the dam commencement of operation at full capacity since 1975 (Saltabaş *et al.* 2003). The lower Sakarya River Basin is located between Yenimahalle, where the river flows into the Black Sea, and Doğançay. Samples were collected by boat at the lower river basin in the Karasu Region near the mouth of Sakarya River at four stations. St. 1 is the area influenced by domestic pollution (*e.g.* seawage) by the Çark Stream, St. 2 rural domestic discharges, St. 3 industrial area discharges, and St. 4 both industrial and domestic discharges. The sampling stations are shown in Figure 1.

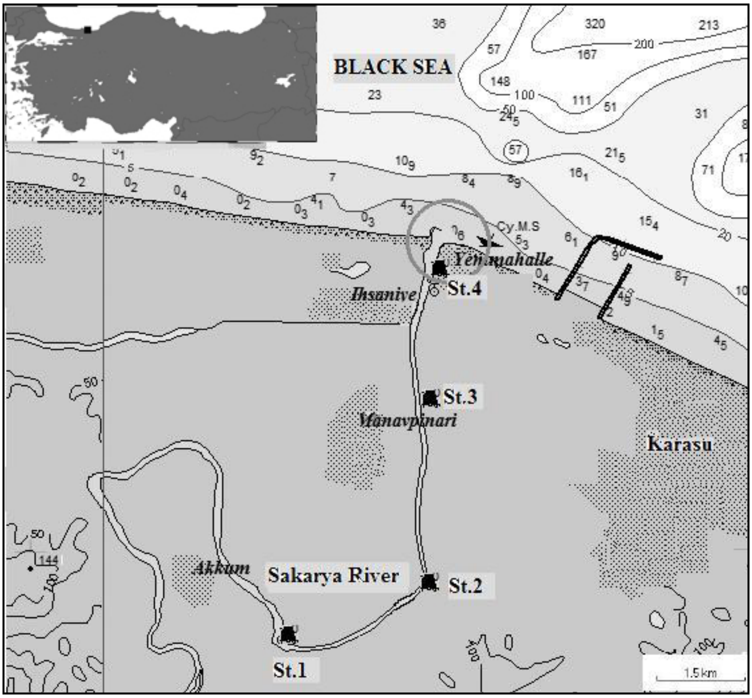

Figure 1. Sampling stations in the lower Sakarya River Basin

Sampling

Some physicochemical and biological variables including chlorophyll-*a* and zooplankton community structure and diversity were investigated seasonally between February 2008 and January 2009.

Water samples were collected vertically using a 1.5 L Nansen bottle. Dissolved oxygen (DO), conductivity (EC) and pH were measured *in situ* by pIONneer 65 Portable Multi-parameter Instrument. The suspended load concentration (SPM) was determined in the laboratory on a 47-mm cellulose acetate filter with a 0.45 µm pore diam. Samples for nutrient analysis were pre-filtered. Nitrite (NO_2-N), nitrate (NO_3-N), orthophosphat (PO_4-P), total phosphorus (TP) and silica (SiO_2) were detected spectrophotometrically following Parsons *et al.* (1984). For Chlorophyll *a* (Chl *a*) analysis 1000 mL of water was filtered through GF/C membrane filters and deep-frozen. Chl *a* analysis were performed by acetone extraction method (Parsons *et al*. 1984).

Zooplankton Community Structure and Diversity

The plankton samples were collected by filtering 40 Liters of water with a plankton net (pore size 55 µm). All zooplankton samples were immediately preserved in 4% borax-buffered formaldehyde. Zooplankton was enumerated under an inverted microscope and species were identified. In the laboratory, organisms were identified to species level, and counted; densities are presented as number of individuals per cubic meter (ind. m^{-3}). The following references were reviewed to identify the specimens: Dussart (1967, 1969), Koste (1978), Pontin (1978) and Margaritora (1983).

Data Analysis

For each zooplankton sample the Shannon-Wiener diversity index (*H'*) (1949) was calculated according to the following equation;

$$\underset{i=1}{\overset{S}{H'}} = -\sum p_i \ln p_i$$

where *H'* is the Shannon-Wiener diversity index, S is the number of species, p*i* is the relative abundance of each species (p*i*= f*i*/n), f*i* is the abundance of species *i* and n is the total number of all individuals.

Spearman's correlation analysis was used to count the matrix of correlation coefficients between environmental factors completed using the SPSS 16.0 for Windows (Renner 1970). Analysis of variance (ANOVA) was applied to the chemical-physical parameters in order to test differences among samples (temporal patterns) and sampling stations (spatial patterns). In this study, two sets of explanatory variables were built: biotic (zooplankton community) and abiotic (physicochemical factors). The abiotic matrix contained all measured physicochemical variables (including river flow, water temperature, conductivity, dissolved oxygen, pH, nitrate, nitrite, orthophosfate, total phosphorus, silica, suspended particulate matter, chlorophyll-*a*). To determine the relationship between zooplankton and their environmental parameters, the first DCA (detrended correspondence analysis) was performed. The length of the gradient was determined in this analysis. The result (SD<2) showed that the linear method (RDA; redundancy analysis) was appropriate (ter Braak and Šmilauer 2002). In this study, there were 12 measured environmental variables (Table 1) and four samples. To abstain from multicollinearity among the environmental variables, PCA (principal component analysis) was used to reduce the number of environmental variables and the obtained components were used as the new environmental variables in RDA. The biological data and environmental variables in RDA were log (x+1)-transformed. To guard against interpretation of spurious axes, the statistical significance of the first and all the ordination axes was tested by Monte Carlo permutation test (999 unrestricted permutations). DCA and RDA were performed by the computer program Canoco 4.5 for Windows. PCA was completed using the SPSS 16.0 for Windows (Renner 1970).

Results

Environmental Variables

Physicochemical characteristics of water quality over one year (seasonally) study are summarized in Table1. Regarding sampling locations, no significant differences were determined for all physicochemical parameters (ANOVA, $p>0.05$). Significant seasonal differences occured for all environmental variables (ANOVA, $p<0.05$).

Zooplankton

During the study a total of 32 taxa was observed, with 24 species of Rotifera, 3 species of Copepoda and 5 species of Cladocera identified (Table 2). Zooplankton community was characterized by the presence of freshwater species. Seasonal distribution and abundance of zooplankton species (org. m^{-3}) in each station are given in Table 3. Zooplankton fauna of the lower basin of the Sakarya River was composed mainly of Rotifera group (96.4% of the total), with *Trichocerca ruttneri* Donner, 1953 and *Synchaeta oblonga* Ehrenberg 1831 as the most abundant and a high number of species (21.1% of the total). In addition, Copepoda and Cladocera constituted 2.7% and 1.0% of total zooplankton, respectively. *Bosmina longirostris* (Müller 1776) was the most abundant Cladoceran species and Copepoda nauplii was the most representative taxa of Copepoda (0.5% and 2.1% of total zooplankton, respectively). Zooplankton community showed seasonal variations. The maximum zooplankton abundance was recorded during summer (34005 org. m^{-3}), while the lowest number was recorded during spring (11593 org. m^{-3}). Among the total zooplankton, Rotifera was the most abundant (33600 org. m^{-3}, Figure 2) in summer, while Cladocera (376 org. m^{-3}, Figure 2) and Copepoda (1610 org. m^{-3}, Figure 2) were the most abundant in spring and autumn, respectively. The greatest zooplankton abundance was recorded at St. 2, while the lowest was recorded at St. 4 (30923 and 14861 org. m^{-3}, respectively).

Shannon–Wiener diversity index of the *log*-transformed means of zooplankton species density for the separate reaches of the study area showed similar values (3.1-3.3) during the study period for all stations. Zooplankton diversity index varied seasonally between 1.7-3.3. Generally, seasonal higher reaches and higher temperatures showed a higher zooplankton diversity index (Figures 3 and 4).

Relationships between Zooplankton and Their Environment

In PCA, varimax was selected to apply a rotation. It could reduce the number of factors with maximum loadings and consequently make it easier to clarify each of the potential components. As a result of the analysis, three components were extracted and they represented 83.717% of the cumulative variance (Table 4). According to the factor loadings shown in Table 5, component 1 was influenced primarily by EC, TP, PO_4 and SPM, component 2 by NO_2, SiO_2, Chl *a*, NO_3 and DO, and component 3 by pH, river flow and water temperature.

With presentation of the first four synthetic gradients to RDA, the first two eigenvalues illustrated 41.9% of the cumulative variance of species data. The species-environmental correlations of axis 1 (0.935) and axis 2 (0.960) were high. The first four environmental variables explained 58.1% of the total variance in species data. The Monte Carlo permutation test was significant on the first axis (*F*-ratio= 4.137, *P*-value=0.001) and all axes (*F*-ratio= 3.457, *P*-value=0.001) (Table 6).

In Figure 5, the upper quadrant was commonly confined to the distribution of zooplanktonic crustaceans (Cladocera and Copepoda) and the lower one mainly to the distribution of Rotifera and the upper quadrant was to the distribution of samples taken St.1, while the lower completely to the distribution samples taken other three stations. Samples taken St. 2, St. 3, and St. 4 were characterized by more rotifers, while samples taken St.1 were characterized by more zooplanktonic crustaceans. According to the centroid principle and distance rule indicated in RDA, in Figure 5 Factor-1, Factor-2 and Factor-3 were associated mainly with rotifers, while zooplanktonic crustaceans were negatively associated with these factors.

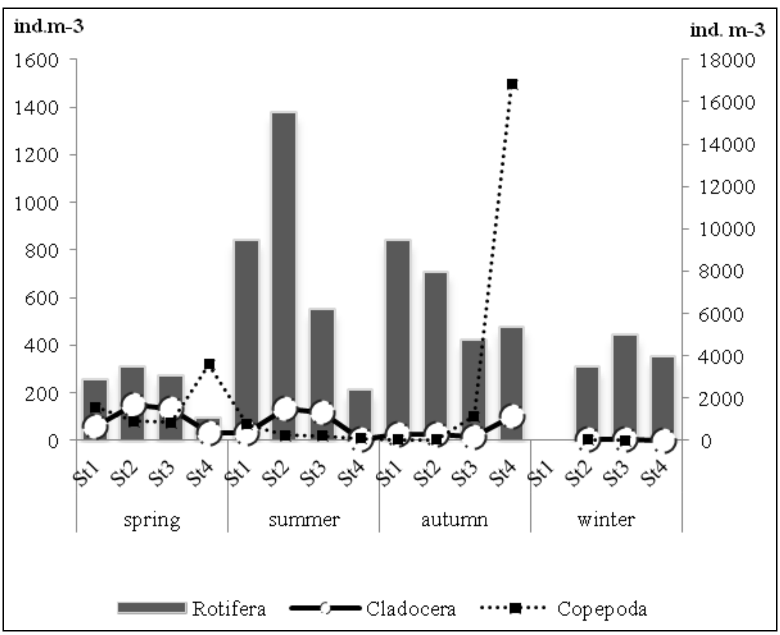

Figure 2. Seasonal distribution of zooplankton groups (total rotifera, total copepoda, total cladocera) (ind. m^{-3}) in the lower Sakarya River Basin during Feb 2008-Jan 2009

Table 1. Physicochemical characteristics of water quality in Lower Sakaya River Basin

Month	**Spring 2008**				**Summer 2008**				**Autumn 2008**				**Winter 2009**			
Station	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1***	**2**	**3**	**4**
River Flow (m^3/sn)	125	125	175	175	67.3	67.3	84.8	84.8	100	100	125	125		150	200	200
Water Temp. (°C)	16.9	17.6	16.6	16.0	23.1	25	25.1	25.2	13.0	13.3	13.0	12.9		7.6	7.6	7.5
EC (μmhos / cm)	446	322	363	352	549	425	466	455	363	310	347	415		413	450	518
DO (mg/L)	4.76	5.31	6.03	6.80	7.6	9.6	8.6	8.9	6.00	6.40	8.50	7.40		10.2	10	9.2
pH	8.0	8.1	8.3	8.5	8.4	8.3	8.5	8.5	8.3	8.4	8.5	8.3		8.0	8.0	8.0
NO_2 (μg/L)	0.57	0.54	0.55	0.49	5.96	3.13	6.19	3.02	1.66	12.63	10.14	7.36		10.88	6.21	5.63
NO_3 (μg/L)	2.40	4.21	1.45	1.37	10.51	56.47	55.82	38.13	2.32	2.55	3.68	2.89		4.09	3.07	5.27
SPM (g/L)	6.25	5.59	5.67	6.47	3.09	3.30	2.25	2.38	3.90	6.70	6.95	2.55		3.45	4.65	4.50
SiO_2 (mg/L)	3.00	8.00	9.00	7.00	3.30	3.62	5.60	4.02	13.93	17.18	29.32	13.84		22.33	21.06	17.24
Chl *a*(mg/L)	1.51	1.55	3.82	1.90	6.17	5.29	5.53	4.57	13.74	17.97	15.20	16.14		26.21	32.83	26.14
TP (μg/L)	1.39	1.04	1.02	1.04	19.35	22.72	19.74	19.07	7.09	3.11	2.13	1.01		8.82	4.73	4.59
PO_4 (μg/L)	0.87	0.65	0.63	0.65	18.93	22.30	19.32	18.65	6.67	2.69	1.71	0.59		8.40	4.31	4.17

*Sample could not be retrieved.

Table 2. A list of the zooplankton species living in the lower Sakarya River based on Ustaoğlu (2004)

Copepoda	**Rotifera**
Cyclops vicinus Ulyanin, 1875	*Colurella colurus* (Ehrenberg, 1830)
Macrocyclops albidus (Jurine, 1820)	*C. uncinata* (O. F. Muller, 1773)
Paracyclops fimbriatus (Fischer, 1853)	*Euchlanis dilatata* Ehrenberg, 1832
Cladocera	*Filinia longiseta* (Ehrenberg, 1834)
Alona guttata Sars, 1862	*Keratella cochlearis* (Gosse, 1851)
A. rectangula Sars, 1862	*K. quadrata* (Mùller, 1786)
Bosmina longirostris (O. F. Müller, 1776)	*Lecane closterocerca* (Schmarda, 1859)
Chydorus sphaericus (O.F. Müller, 1785)	*L. signifera* Sudzuki,1991
Daphnia hyalina Leydig, 1860	*Lepadella patella* (Müller, 1773)
Rotifera	*L. ovalis* (Müller, 1786)
Asplanchna priodonta Gosse, 1850	*Notholca squamula* (Müller, 1786)
Brachionus budapestinensis Daday, 1885	*Platyias quadricornis* (Ehrenberg, 1832)
B. calyciflorus Pallas, 1776	*Polyarthra vulgaris* (Carlin, 1943)
B. plicatilis (Müller, 1786)	*Rotaria rotatoria* (Pallas, 1766)
B. quadridentatus Hermann, 1783	*Synchaeta oblonga* Ehrenberg, 1831
B. urceolaris Muller, 1773	*Testudinella mucronata* (Gosse, 1886)
Cephalodella gibba (Ehrenberg, 1830)	*Trichocerca ruttneri* Donner, 1953

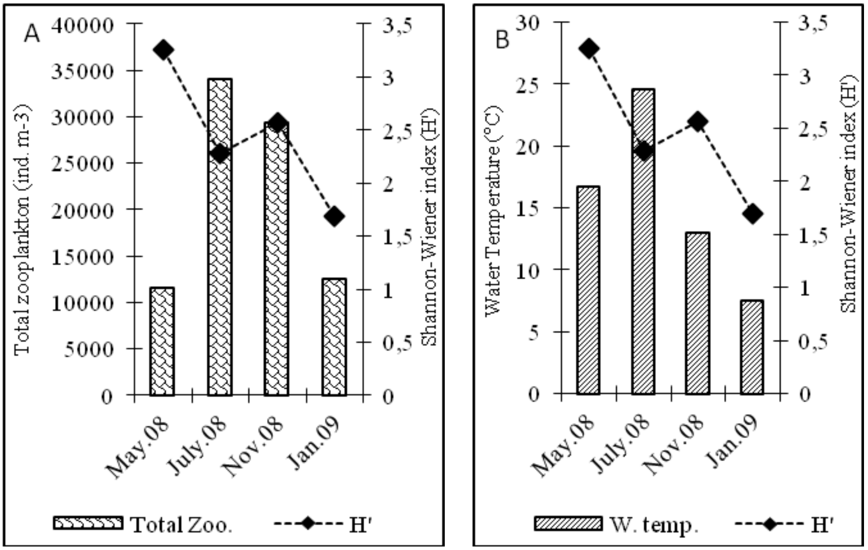

Figure 3. The relationship between Shannon–Wiener diversity indexes for the zooplankton community of the study area and total zooplankton (ind. m^{-3}) and water temperature (ºC) to seasons (A,B)

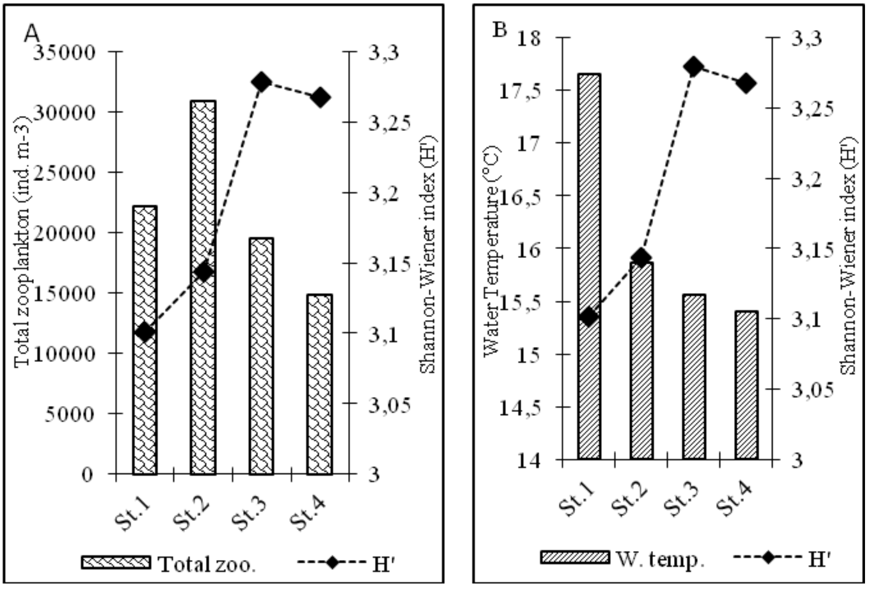

Figure 4. The relationship between Shannon–Wiener diversity indexes for the zooplankton community of the study area and total zooplankton (ind. m^{-3}) and water temperature (ºC) to stations (A, B)

Table 3. Seasonal distribution and abundance of zooplankton species in each station in the study area (org. m^{-3})

	Spring 2008				Summer 2008				Autumn 2008				Winter 2009			
Rotifera	**St.1**	**St.2**	**St.3**	**St.4**	**St.1**	**St.2**	**St.3**	**St.4**	**St.1**	**St.2**	**St.3**	**St.4**	**St.1**	**St.2**	**St.3**	**St.4**
A. priodonta	100															
B. budapestinensis					800	2500	1000	1133	1000	1247						
B.calyciflorus			100		550	750	700	400								
B. plicatilis	100	100														
B. quadridentatus					50					500		200				
B. urceolaris											300					
C. gibba	200								998	250		100			500	
C. colurus	100	400	200	400	50	250	200	67		500						
C. uncinata										100		293		500		
E. dilatata					50		200									
F. longiseta		100	100	100	150	250	100		465							
K. cochlearis	500	800	700	100	800	1500	700	200		250	100	698			500	1000
K. quadrata		100	100											500		
L. clostrocerca					100	250	200									
L. signifera	100	400	100	200												
L. patella								67								
L. ovalis			200	100												500
N. squamula			100												500	
P. quadricornis										250						
P. vulgaris	500		100	200	1050	250	400	133	250			100				
R. rotatoria	100	200							2750	1905		1100		2500	3500	2500
S. oblonga	1200	1400	1400		350				4000	3000	4200	2902				
T. mucronata					100											
T. ruttneri					5450	9750	2700	400			200					
Total Rotifera	2900	3500	3100	1100	9500	15500	6200	2400	9463	8002	4800	5393		3500	5000	4000

Table 3. Continued

	Spring 2008				Summer 2008				Autumn 2008				Winter 2009			
Cladocera	**St.1**	**St.2**	**St.3**	**St.4**	**St.1**	**St.2**	**St.3**	**St.4**	**St.1**	**St.2**	**St.3**	**St.4**	**St.1**	**St.2**	**St.3**	**St.4**
A. guttata	13	17	11	13	10	10	8	2	2					1		1
A. rectangular	47	32	23	10	20	18	9	1	1		1				1	
C. sphaericus				10		5	3	2							2	
B. longirostris		100	100			100	100		25	25	14			5	3	1
D. hyalina												100				
Total Cladocera	60	149	134	33	30	133	120	5	28	25	15	100		6	6	2
Copepoda																
C. vicinus	54	13	30	62	30	12	12	3		1	1	1			2	1
M. albidus	45	15	32	23	23	8	5	2		2	2	1				1
P. fimbriatus	18	22	15	35	15	1	3	3			1	1			1	
Copepod nauplii	23	30		200								100		1500		
Total Copepoda	140	80	77	320	68	21	20	8		3	4	103		1500	3	2
Total Zooplankton	3100	3729	3311	1453	9598	15654	6340	2413	9494	8031	4918	6993		3509	5008	4002

Table 4. Total variance of PCA

Component	Rotation Sums of Squared Loadings		
	Total	**% of Variance**	**Cumulative (%)**
1	4.009	33.410	33.410
2	3.267	27.222	60.631
3	2.770	23.086	**83.717**

Table 5. Rotated Component Matrix[a] of PCA

Rotated Component Matrix[a]			
Variable	**Factor**		
	1	**2**	**3**
EC	**.877**	.060	-.224
TP	**.859**	-.048	.453
PO_4	**.858**	-.047	.453
SPM	**-.828**	-.114	-.164
NO_2	.117	**.859**	.023
SiO_2	-.426	**.836**	-.230
Chl *a*	.038	**.831**	-.497
NO_3	-.518	**-.650**	-.185
DO	.554	**.620**	-.094
pH	-.068	-.022	**.891**
River flow	-.341	.126	**-.818**
Water temperature	.434	-.544	**.690**

[a] Rotation converged in 5 iterations

Extraction Method: Principal Component Analysis
Rotation Method: Varimax with Kaiser Normalization

Table 6. Summary of the RDA analysis

Axes	**1**	**2**
Eigenvalues	0.273	0.146
Species-environment correlation	0.935	0.960
Cumulative percentage variance		
of species data	27.3%	41.9%
of species-environment relation	56.3%	86.47%
The Monte Carlo permutation test	*F*-ratio	*P*-value
Total variance explained	58.1%	
on the first axis	4.137	0.001
on all axes	3.457	0.001

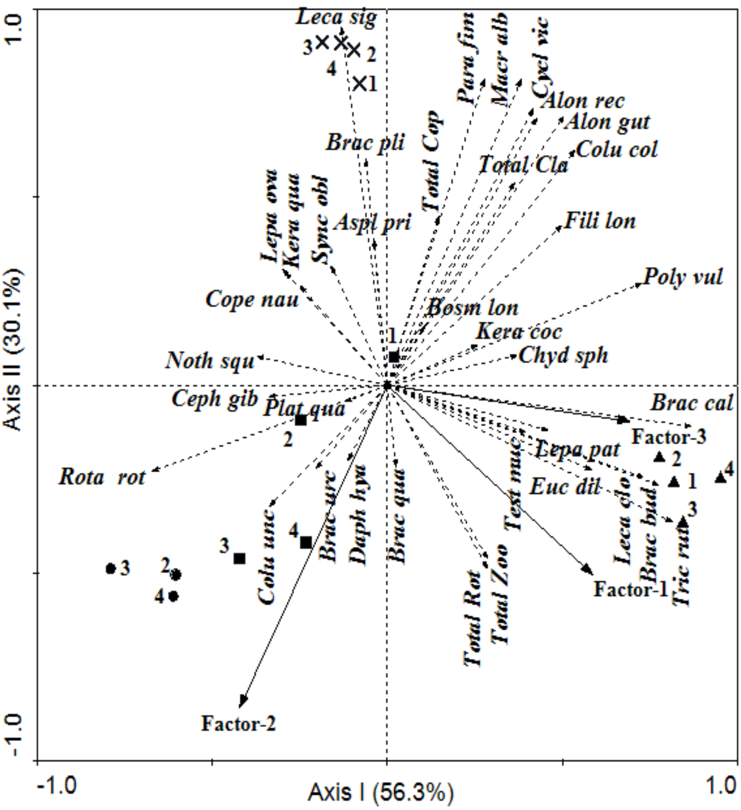

Figure 5. RDA ordination plot for zooplankton taxa, factors (environmental variables), sampling seasons and stations. Sampling stations in RDA plot indicated with St.1: remark, St. 2: filled triangle, St. 3: filled square, St. 4: filled circle; sampling seasons in RDA plot indicated with Spring 2008: 1, Summer 2008:2, Autumn 2008: 3, Winter: 4. Taxa in RDA plot indicated with abbreviation instead of arrows: *Asplanchna priodonta- Aspl pri*; *Brachionus budapestinensis- Brac bud; Brachionus calyciflorus- Brac cal; Brachionus plicatilis-Brac pli; Brachionus quadridentatus- Brac qua; Brachionus urceolaris- Brac urc; Cephalodella gibba- Ceph gib; Colurella colurus- Colu col; Colurella uncinata- Colu unc; Euchlanis dilatata- Euc dil; Filinia longiseta- Fili long; Keratella cochlearis- Kera coc; Keratella quadrata- Kera qua; Lecane clostrocerca- Leca clo; Lecane signifera- Leca sign; Lepadella patella- Lepa pat; Lepadella ovalis- Lepa ova; Notholca squamula- Noth squ; Platyias quadricornis- Plat qua; Polyarthra vulgaris- Poly vul; Rotaria rotatoria- Rota rot; Synchaeta oblonga- Sync obl; Testudinella mucronata- Test muc; Trichocerca ruttneri- Tric rut; Alona guttata- Alon gut; Alona rectangula- Alon rec; Chydorus sphaericus- Chyd sph; Bosmina longirostris- Bosm long; Daphnia hyalina- Daph hya; Cyclops vicinus- Cycl vic; Macrocyclops albidus- Macr alb; Paracyclops fimbriatus- Para fim;* Copepod nauplii- Cope nau; Total Copepoda- Total Cop; Total Cladocera- Total Cla; Total Rotifera- Total Rot; Total Zooplankton- Total Zoo.

Discussion

In this study, zooplankton fauna and their relationship with environmental parameters were determined seasonally at the lower Sakarya River Basin for selected four stations. Study area has identified with diversified pollution loads (*e.g.* seawage, domestic and industrial discharges) in the direction of flow.

The highest pH recorded in summer were the results of decreasing rainfall and increasing phytoplankton production due to increasing temperature. In the present study, when DO concentration increased due to photosynthetic activity in summer, pH values ascended at the same period. Following rains in the basin pH values dropped.

Significant decrease in Chl *a* in spring was noted when high SPM (suspended particulate matter) were measured. This was probably due to the decreasing transparency of the water and phosphorus levels. Aquatic microorganisms uses mostly, soluble orthophosphate form of phosphorus. Due to low orthophosphate levels in spring, phytoplankton was not shown development, and so the values of Chl *a* were found low. There were significant positive correlations between Chl *a* and SiO_2 levels in the study (Spearman's rho, $p<0.01$, $n=15$).

The conductivity did show significant differences seasonally ($p<0.05$). Conductivity values are affected by human-induced pollution. EC values tend to increase with increasing pollution. Due to the increase in population in study area during summer, pollution (*e.g.* nutrients) was increased, and so that has led to the increase in EC values.

Inorganic nitrogen (NO_2-N and NO_3-N) values, phosphate and total phosphorus (TP) concentration increased in summer due to ascended anthropogenic influences in the study area.

River flow changed seasonally and its high values were measured in the rainy seasons.

Changing physicochemical conditions affects the distribution and occurrence of zooplankters directly or indirectly. To understand the factors affecting the distribution of population, all physical, chemical and biological properties should be considered (Sharma *et al.* 2010).

Zooplankton is the secondary producer group of the food chain in an aquatic ecosystem, which convert the vegetable product to the animal protein. Therefore they provide a flow of energy through the food chain. Becasue of zooplankters are strongly affected by environmental alteration and respond faster than the other aquatic organisms to the condition changes, they are good indicators of water quality changes (Berzins and Pejler 1987; Mikshi 1989).

Zooplankton community in the study area was chracterized by presence of freshwater zooplankton. Life cycles of zooplankters are related to the environmental factors (*e.g.* water temperature, conductivity, pH, dissolved oxygen). Water temperature and dissolved oxygen values are the most important factors affecting the abundance of zooplankton (Park and Marshall 2000). Water temperature is one of the most important parameter, which manages chemical and biological activity of organisms in aquatic life. Increase in temperature has been associated with higher abundance and species diversity of zooplankton in aquatic ecosystems (Castro *et al.* 2005; Buyurgan *et al.* 2010). Dissolved oxygen concentration reflects the dominating biological and physical processes in aquatic environments, and it is one of the most important parameter to determine the water quality. Despite the fact that cladocerans were reported to tolerate dissolved oxygen concentrations below 1 mg/L (*e.g.* Murtaugh 1985), their feeding is considerably reduced at oxygen levels below 3 mg/L (Heisey and Porter 1977). Physiology of zooplankters is under the influence of temperature, and especially the development of rotifer population is limited by the combined effect of DO concentration and temperature (Mikshi 1989). The conductivity variation can be an important regulator of the structure of zooplankton assemblages, especially species diversity and number of species (Williams 1998). Most of the biological processes and biochemical reactions depend on pH, therefore it affects distribution of zooplankton, and in terms of pH, alkaline limit was reported 8.5 (Berzins and Pejler 1987). Bozkurt and Sagat (2008) was reported the acceptable value for aquatic organisms between 250-500 µmhos/cm (max. 2000 µmhos/cm). The conductivity variation can be an important regulator of the structure of zooplankton assemblages, especially for species diversity and richness (Williams 1998).

In the present study, water temperature showed seasonal changes between 7.5 ºC in winter and 25.2 ºC in summer. Depending on the water temperature maximum abundance of zooplankton was found at the same time. DO values were determined between 4.76 mg/L (in spring) and 10.2 mg/L (in winter). pH values were determined on the alkaline side (8.0-8.5). Conductivity values varied between 310-549 µmhos/cm. According to the results of the present study, the mainly physicochemical conditions (water temperature, DO, pH, EC) of study area were found to be suitable for life cycle of identified zooplankton population.

Rotifers are more sensitive to environmental changes compared to other zooplankton groups and are used as indicators of water quality (Gannon and Stremberger 1978). They are frequently abundant in eutrophic freshwater ecosystems and are more abundant than other zooplankton groups, because of their short generation time and high reproductive rate (Herzig 1987). Furthermore, Cladocerans and Cyclopoid Copepods are well adapted to eutrophic conditions (Gannon and Stremberger 1978).

Most of the defined taxa are cosmopolitan. Some species belonging to the genera *Keratella*, *Brachionus* and *Trichocerca* are usually reported as dominant zooplankton taxa of lotic areas (Altındağ and Özkurt 1998; Bekleyen 2001; Altındağ and Yiğit 2002; Tellioğlu and Şen 2002; Güher 2003). Among the zooplanktonic species identified in the study area: *Brachionus* spp., *E. dilatata,* *F. longiseta*, *K. cochlearis*, *K. quadrata*, *P. quadricornis*, *B. longirostris*, *C. sphaericus* and *C. Vicinus* are typical in eutrophic waters (Kolisko 1974; Sláděcek 1983; Apaydın Yağcı and Ustaoğlu 2012).

Because zooplankton taxa are key components of aquatic ecosystems, their composition pattern may reflect the ability of larger Cladocera to competitively exclude smaller species when nutrients are limited, as larger cladocerans have lower limiting thresholds for nutrients than smaller species (Brooks and Dodson 1965). When nutrient levels are higher, competition decreases and smaller individuals can proliferate. This situation could explain the relationship between nitrate and nitrite with cladocerans. In the present study, the abundance of Cladocera determined in high values in summer when nutrients were increased. Copepoda were affected indirectly by NO_2-N and NO_3-N. The presence of phytoplankton is controlled by utilizable nitrogen and phytoplankton is important diet for Copepoda (Lawrence *et al.* 2004). The high abundande of Copepoda noted in autumn with the increased Chl *a* concentration.

The relation between zooplankton taxa, water temperature and high concentrations of nutrients has been detected by many studies (*e.g.* Park and Marshall 2000). It is a consensus that an increase in the concentration of nutrients influences the top levels of a food web through a cascade of interactions (Anderson *et al.* 2002). Seasonal variation in the study area showed similarities with other rivers where the zooplankton population is higher in summer than in winter (Özbay and Altındağ 2009).

Inorganic nitrogen such NO_2-N and NO_3-N can help the increase of rotifer density. In the present study, nutrients were increased in summer owing to increasing amount of waste discharges into the river from rural, urban and industrial sites located alongside it, and consequently water quality degradation was observed. Due to this deterioration in the water quality in summer, the abundance of indicator species of eutrophication (*e.g.* *Keratella* spp., *Trichocerca* spp., *Brachionus* spp. and *E. dilatata*) were increased simultaneously with the help of the rise of temperature. The abundance of total rotifer was determined in high value up to 33600 ind. m^{-3} during summer, while the abundance of crustacea was 405 ind. m^{-3}.

In the present study rotifers were positively related to nutrient levels, while the zooplanktonic crustaceans were negatively related. This can be illustrated by the RDA analysis in the context, which displayed a distinct relationship between zooplankton taxa composition and their environment. The first four synthetic environmental variables explained 58.1% of the taxonomic structure. The zooplankton community structure responded rapidly to the environmental changes.

According to the RDA results, all Factors associated with rotifers and total zooplankton tightly and zooplanktonic crustaceans (total cladocera and total copepoda) associated negatively with all factors. It can be concluded that rotifers were much related to nutrients. This is consistent with the other studies, that rotifers respond faster to the changes in nutrients than crustaceans (Gannon and Stemberger 1978). Rotifers and cladocerans are less able to maintain their positions in flowing water than copepods (Richardson 1992). Therefore, copepods and rotifers differ in their tolerance to flow (van Dijk and van Zanten 1995), which may cause changes in zooplankton community structure. As follows, members of zooplankton, especially rotifers, have a short generation time (Gillooly 2000). According to the results, St.2 had the highest nutrient values and abundance of zooplankton, than the other three stations. Because of, determined highest nutrient values, reproduction and behavioural characteristics of zooplankton, abundance of all zooplankton groups were determined higher at St. 2.

Conclusions

In large rivers, true plankters often predominate and fast growing rotifers are often dominant (Marneffe *et al*. 1996). This may be a simple trophic effect or it may be that similar conditions favour both types of organism (Hynes 1970). Water discharge is considered to be one of the main factors affecting zooplankton seasonal variations in rivers (Saunders and Lewis 1988 a,b; Brown *et al*. 1989; Pace *et al*. 1991; van Dijk and van Zanten 1995; Vranovsky 1995). In the lower Sakarya River basin, a few ubiquitous rotifer species dominate the zooplankton fauna: *Brachionus budapestinensis*, *Keratella cochlearis*, *Polyarthra vulgaris* and *Synchaeta oblonga*. Most of the species found on the studied area of the Sakarya River were indicator species of eutrophication (classified by Kolisko 1974; Sláděcek 1983; Berzins and Bertilson 1989; and Apaydın Yağcı and Ustaoğlu 2012), which is an adequate amount to consider the river pollution level according to zooplankton. Changes in plankton biomass and composition affected both by physicochemical factors and biotic factors such as growth rates and grazing. In the present study, physicochemical variables (oxygen, utilizable nitrogen and phosphate) and abundance of zooplankton showed significant changes seasonally. Plankton biomass is affected by local conditions (*e.g.* physicochemical variables) caused by domestic and industrial wastes. The results of the present study should be important data for future monitoring studies, because changes in composition of the zooplankton as anthropogenic influence may increase through time. It is possible that the zooplankton might have a significant impact on the ecological functioning of the river downstream. Degree of nutrients determines the quality as well as the quantity of plankton along the study area. In last decades, as the environmental pollution is increased, the importance of biodiversity rises in the various areas, as in the study area. Gökçekaya Dam on the middle Sakarya River manage well the flow regime of lower Sakarya River basin, as previously described (Saltabaş *et al*. 2003). Therefore, the most important pollution source of the lower Sakarya River Basin seems as Çarksuyu Stream. Hence, Çarksuyu

Stream should be controlled, and pollution must be prevented for the health of the lower Sakarya River Basin.

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Alt Sakarya Nehri Havzası (Türkiye)'nda zooplankton bolluğu: Çevresel değişkenlerin etkisi

Özet

Bu çalışmada Şubat 2008-Ocak 2009 tarihleri arasında mevsimsel olarak kirlenmiş aşağı Sakarya Nehri Havzası'nda zooplankton kommunite yapısı ve çeşitliliği incelenmiştir. Ölçülen çevresel değişkenler nehir akışı, su sıcaklığı, elektriksel iletkenlik, çözünmüş oksijen, pH, askıda katı madde, klorofil *a* ve besin tuzları (NO_2-N, NO_3-N, SiO_2, PO_4-P,TP)'dır. Çevresel değişkenler ve zooplankton arasındaki ilişki istatiksel olarak test edildi. Belirlenen çevresel parametreler tespit edilen türlerin yaşam alanı seçimi için uygun aralıklarda bulunmuştur. Çalışma alanında suyun fizikokimyasal özellikleri açısından onaylanacak şekilde çoğunluğu ötrofik suların göstergesi olan otuziki zooplankton taksası belirlenmiştir. Rotiferler en bol bulunan grup olmuştur (%96.4), bunu kopepodlar (%2.7) ve kladoserler (%1.0) takip etmiştir. Baskın taksalar rotiferlerden *Brachionus budapestinensis* Daday, *Keratella cochlearis* (Gosse), *Polyarthra vulgaris* (Carlin), *Synchaeta oblonga* Ehrenberg and *Trichocerca ruttneri* Donner; kopepodlardan kopepod nauplii ve kladoserlerden *Bosmina longirostris* (Müller) olmuştur. İstasyonlara göre, zooplankton bolluğu ve çevresel parametreler mevsimsel değişim göstermiştir. Genel olarak, yüksek zooplankton bolluğu ve yüksek sıcaklıklarda daha yüksek bir zooplankton çeşitlilik indeksi ile sonuçlanmıştır. İstatiksel analizler, çalışma alanında rotiferlerin ve toplam zooplanktonun çevresel parametrelerle, özellikle de su sıcaklığı ve besin tuzları ile kuvvetli ilişkide olduğunu göstermiştir. Kirliliğin derecesi çalışma alanı boyunca planktonun nitelik ve niceliğini belirler. Bu nedenle, çalışma alanının zooplankton faunasının ve dolayısıyla besin ağının biyoçeşitliliğini korumak için atık sular kontrol edilmeli ve kirlilik önlenmelidir. Belirlenen tüm zooplankton türleri çalışma alanı için ilk kayıttır.

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