

Assessment of the zooplankton community structure of the coastal Uzungöl Lagoon (Kızılırmak Delta, Turkey) based on community indices and physicochemical parameters

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Abstract: The objective of this study is to provide information on the zooplankton community and physicochemical properties of Uzungöl Lagoon. Sampling studies were performed at monthly intervals for abiotic factors and community parameters between September 2015 and August 2016. The variations of zooplankton community were estimated using Shannon-Weiner diversity (H'), Pielou evenness (J), species richness (S), frequency, and dominance indices. The relationship between environmental variables and community parameters were analyzed with Pearson's correlation test and redundancy analysis (RDA). During the study, 39 species, most of which belonged to Rotifera, were recorded. The quantitative analysis indicated that most important fraction of zooplankton were small-sized rotifers with low filtration rate. The species belonging to Rotifera reached their most important numerical maximum in February. Dominant organisms in the zooplankton community were found to be *Filinia terminalis*, *Keratella quadrata*, *Brachionus angularis*, and *Polyarthra vulgaris*. The relatively low diversity and evenness values resulted from a clear dominance of few species in the zooplankton community. Temperature had a positive effect on diversity and species richness, but increasing salinity had a negative effect on these indices. RDA biplot indicated that *Anuraeopsis fissa*, *Hexarthra mira*, *Keratella tropica*, and *Polyarthra vulgaris* were positively correlated with temperature. Additionally, *Keratella cochlearis* and *Keratella quadrata* were positively correlated with dissolved oxygen (DO) and negatively correlated with temperature. A negative correlation was found for pH with *Filinia longiseta* and *Keratella quadrata*.

Key words: Uzungöl Lagoon, zooplankton, physicochemical parameters, community indices, species-environment relationship

1. Introduction

Coastal lagoons are transitional zones between marine and terrestrial environment. They are generally recognized by large dynamic changes, high biological activity, and biodiversity. Coastal lagoons have many functions, such as filtering of contaminants, retention and transformation of nutrients, and biogeochemical cycling (Kjerfve, 1994).

Because of their transitional nature, coastal lagoons are regarded as naturally stressful environments that experience frequent ecological fluctuations and disturbances. Coastal lagoons are nowadays deeply influenced by habitat degradation and loss, habitat alteration, and environmental pollution. Moreover, coastal lagoons are among the most vulnerable aquatic ecosystems to current and foreseen climate changes as they are ecotone ecosystems which are open and connected with both freshwater and marine ones (Lloret et al., 2008).

Zooplankton play a multifaceted role in aquatic environments. They influence biological functions such as energy flow and the circulation of matter in trophic networks. Zooplankton occupy a key position in pelagic food webs according to their size range and variety of feeding habits (Lampert, 1997). As in freshwater lakes, in coastal lagoons, zooplankton are strongly affected by many abiotic and biotic factors. These factors influence the community parameters such as abundance, species richness, diversity, frequency, and dominance in zooplankton. One of the most important environmental issues in coastal lagoons is eutrophication process caused by human activities and this process can lead to significant effects on the zooplankton assemblages. Temperate eutrophic and hypertrophic brackish lagoons are often dominated by small planktivorous fish. This situation reveals two significant results, such as high fish predation on zooplankton and low zooplankton grazing

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pressure on phytoplankton. Eutrophic temperate brackish lagoons are therefore often more turbid than comparable temperate freshwater lakes (Jeppesen et al. 1994, 2007). In Mediterranean brackish lagoons, the dominance of small sized zooplankton such as rotifers and nauplii is indicative for high fish predation (Brucet et al. 2005, Badosa et al. 2007). On the other hand, many other disturbances e.g. climate, hydrology, land use, and salinity changes may strongly influence zooplankton community in coastal lagoons (Castro et al., 2005; Paturej, 2006; Paturej and Kruk, 2011; Paturej et al., 2017). Zooplankton species are also considerable indicators of eutrophication, pollution, global warming, and environmental problems since they are sensitive to many environmental and biological alteration originate from these ecosystems (Schallenberg et al., 2003; Brucet et al., 2009).

The Kızılırmak Delta formed by Kızılırmak River is the biggest wetland in the Black Sea region and it is one of the 14 Ramsar sites in Turkey. The delta is an important wetland complex containing various subecosystems, such as coastal lagoons, reeds, marshes, swamp forest, agricultural areas, and rural settlement sites. The delta has a significant contribution to the local economy owing to reed cutting, fishing, farming, and agricultural activities. Additionally, the delta is a wildlife habitat for recreational activities, such as bird watching, fishing, and hunting (Özesmi, 2003). Uzungöl is one of the coastal lagoons and it is located in the eastern part of the delta. A total of 15000 ha of the delta area comprises marshes, swamps, coastal lagoons, but many environmental disturbances have occurred at the coastal lagoons due to agricultural activities arising from rural settlements and Bafra Plain irrigation project (BPI). Drainage canals have been built around the lagoons through BPI project since 1986; this project caused dramatic changes in the hydrology of the lagoons. Environmental contaminants such as pesticides and fertilizers originating from agricultural areas have caused some environmental problems such as eutrophication and nutrient overloading. Consequently, significant degradations and changes have occurred in the food chain of the lagoons (Demirkalp et al., 2004, 2010, 2017; Saygı et al., 2011; Gündüz et al., 2013; Yurtkuran and Saygı, 2013). It is considered that Uzungöl Lagoon is dramatically influenced through the drainage canals project, other activities, and similar environmental problems encountered in other lagoons.

Relatively little research has been undertaken on Uzungöl Lagoon and previous studies have focused basically on biota composition of pelagic zone (Emir, 1990; Gündüz, 1991a, 1991b; Ustaoglu et al., 2012). The aim of this study is to explain the relationship between environmental variables and zooplankton of Uzungöl Lagoon. This article also includes assessment of water

quality and qualitative/quantitative information about zooplankton communities (e.g., composition, abundance, diversity, evenness, richness, frequency, and dominance indices).

2. Material and methods

2.1. Study site

Uzungöl is a typical brackish lagoon lake situated at 41°34' N and 36°05' E in Northern Turkey, covering 219 ha land surface. Uzungöl Lagoon is a part of Kızılırmak Delta and located at the east of it. The lagoon is narrow and shallow with a mean depth that does not exceed 125 cm. The lagoon is isolated from the Black Sea by large sand bars through which there is a swamp forest, agricultural areas, several drainage canals, and main sea connection canal. Freshwater input is provided by small stream and drainage canals connected with the agricultural lands in the south of the lagoon. The east and southeast margins of the lagoon are managed for agriculture, including cattle grazing, and nutrient rich water from this area is discharged into the lagoon through the drainage canals. The littoral margins of the lagoon support abundant growth of emergent macrophytes (*Phragmites australis* and *Juncus acutus*). In summer months submerged macrophytes and filamentous green algae development is evident in most parts of the lagoon (Demirkalp et al., 2017; SKDYP, 2019).

2.2. Sampling and laboratory analyses

The study was conducted in Uzungöl Lagoon located at the eastern part of Kızılırmak Delta. Zooplankton collected at monthly intervals from September 2015 to August 2016 from the five pelagic sampling stations (Figure 1). Subsurface zooplankton samples were obtained by filtering 100 L of subsurface water through a 30-µm pore-size Hydro-Bios (HYDRO-BIOS, Altenholz, Germany) plankton net. Vertical bottom samples were taken using a Hydro-Bios (Altenholz, Germany) water sampler with 2 L capacity. Zooplankton was concentrated by filtering the samples through a plankton net and preserved in 4% formalin. Two concentrated (1 mL) subsamples at each sampling point were counted in Sedgewick Rafter chamber with a Leica DM light microscope (Leica Microsystems GmbH, Wetzlar, Germany). The data later were converted to the actual quantity of water filtered from the lake. Density of zooplankton samples were expressed as number of individuals per cubic meter. The zooplankton species were examined microscopically and identified according to Koste (1978) and Fontaneto et al. (2006, 2008) for Rotifera; Kiefer (1952, 1955), Dussart and Defaye (2001) for Copepoda, Negrea (1983) for Cladocera.

Environmental parameters were measured simultaneously with plankton sampling and the measurements were made on water column both at surface and bottom due to shallow nature of the lake.

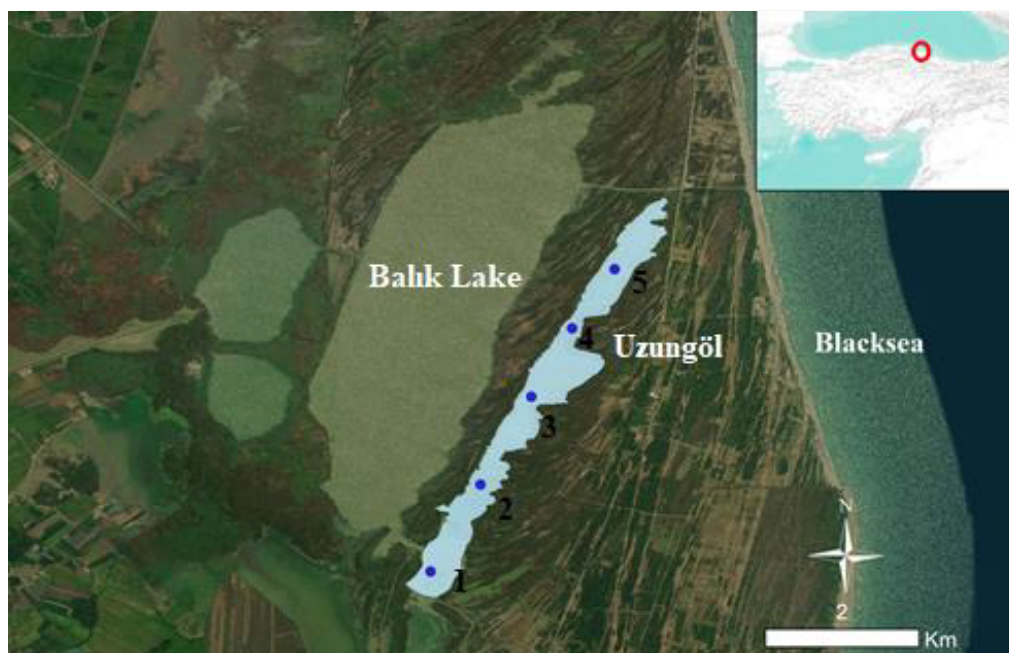


Figure 1. Geographical location of study area, coordinates of sampling points. Station 1: 41°32'33.85"N - 36°04'56.80"E; Station 2: 41°33'36.66"N - 36°05'22.24"E; Station 3: 41°34'11.10"N - 36°05'40.67"E; Station 4: 41°34'44.82"N - 36°06'0.14"E; Station 5: 41°35'7.57"N - 36°06'20.14"E.

Water transparency measurement was carried out with a Secchi disk (maximum depth: 160 cm). The measurements of water temperature, pH, TDS (total dissolved solids), salinity, dissolved oxygen (DO), and electrical conductivity (EC) were conducted in situ with a YSI 556 multiprobe system (MPS). Turbidity was measured by ORION AQ3010 (Thermo Fisher Scientific, Massachusetts, USA) turbidimeter. Chemical analyses to determine total nitrogen (TN) and total phosphorus (TP) were carried out on water samples using standard method 4500 NO₂-B, 4500-Norg-B, 4500P-B, 4500PE. The measurements of Chl-*a* were carried out according to methanol method; samples for the analyses were kept in cool and dark conditions until extraction. The Chl-*a* measurements were carried out with Shimadzu UV 1600 (Shimadzu Corporation, Kyoto, Japan) spectrophotometer.

2.3. Data analyses

The zooplankton community structure was estimated using species richness (S), Shannon-Weiner diversity (H'), Pielou evenness (J), and frequency and dominance indices. To test the seasonal differences in zooplankton community parameters, one-way analysis of variance (ANOVA) with Bonferroni correction applied on the data set. The results were processed with statistical methods using XLSTAT-Ecology and SPSS 22.0 (IBM Corp., Armonk, NY, USA). Before statistical analyses, all the variables were tested for normality (Kolmogorov-Smirnov test) and transformed to $\log_{10}$, $\log_{(x+1)}$ to improve normality (Zar, 2010). A principal

component analysis (PCA) applied on environmental data summarizing the results as an ordination diagram. Environmental variables and community parameters (H' , J , S indices and total abundance) were analyzed with Pearson's correlation test. In order to figure out how the zooplankton related with environmental parameters, RDA (redundancy analysis) ordination analysis was applied to zooplankton species and environmental variables. Infrequent/accessoric-random species were excluded from ordination analysis. Environmental variables with variance inflation factors (VIF) over 20 were deleted from data set to avoid multicollinearity. The significance of RDA axes was assessed by permutation analyses and $P < 0.05$ were considered statistically significant.

3. Results

3.1. Environmental variables

The environmental variables of the water column and Chl-*a* results are presented in Table 1 and these variables showed evident seasonal variations in the lagoon. The mean water temperature was found between 7.6 and 26.2 °C, lowest and highest temperature values were recorded in February and August, respectively. Mean salinity values during the study period varied between 1.05 and 2.08 psu. The average EC values were measured between 1750 and 3558 $\mu\text{S cm}^{-1}$. The average DO concentration ranged between 3.87 and 13.18 mg L^{-1} ; it decreased downward through the water column up to 0.28 mg L^{-1} in September. The mean pH ranged from

Table 1. Physical and chemical parameters of Uzungöl Lagoon between September 2015-August 2016.

		Sept	Oct	Nov	Dec	Feb	Mar	Apr	May	June	July	Aug
	Min	22.24	19.00	13.35	7.88	7.15	13.89	16.86	20.25	23.20	24.14	25.45
Temp.	Max	25.97	19.95	14.26	8.46	7.87	14.26	18.50	23.51	28.80	27.95	26.84
(°C)	Mean	24.6 ± 1.2	19.6 ± 0.4	13.9 ± 0.3	8.2 ± 0.2	7.5 ± 0.3	14.0 ± 0.1	17.5 ± 0.6	21.8 ± 1.2	25.6 ± 2.1	25.6 ± 1.4	26.2 ± 0.5
	Min	1405	2175	1045	735	1618	1912	1326	1501	1010	1192	1332
EC	Max	4610	4725	3500	2927	2827	3052	2067	2380	2824	3102	3910
($\mu\text{S cm}^{-1}$)	Mean	2879 ± 1271	3558 ± 1181	2707 ± 927	1763 ± 907	2151 ± 480	2601 ± 440	1750 ± 259	1994 ± 327	2093 ± 686	2224 ± 739	2491 ± 1104
	Min	0.93	1.41	0.88	0.74	1.05	1.24	1.01	1.07	0.65	0.77	1.07
TDS	Max	3.00	3.45	2.87	2.80	1.84	1.98	1.56	1.58	1.87	2.01	2.96
(g L^{-1})	Mean	1.87 ± 0.82	2.54 ± 0.89	2.24 ± 0.71	1.69 ± 0.86	1.40 ± 0.31	1.68 ± 0.28	1.33 ± 0.19	1.38 ± 0.19	1.35 ± 0.45	1.44 ± 0.47	1.88 ± 0.82
	Min	0.70	1.12	0.69	0.41	0.82	0.98	0.78	0.83	0.49	0.59	0.80
Salinity	Max	2.46	2.83	2.36	2.31	1.47	1.60	1.24	1.26	1.49	1.60	2.39
(psu)	Mean	1.50 ± 0.69	2.08 ± 0.76	1.83 ± 0.60	1.35 ± 0.72	1.10 ± 0.25	1.33 ± 0.23	1.05 ± 0.16	1.09 ± 0.15	1.06 ± 0.37	1.14 ± 0.39	1.52 ± 0.69
	Min	0.28	1.18	9.75	4.53	12.32	7.10	4.92	4.80	4.25	0.48	0.85
DO	Max	9.78	7.00	15.33	14.30	14.21	10.86	11.06	12.00	12.60	12.83	8.79
(mg L^{-1})	Mean	4.22 ± 3.41	3.87 ± 2.09	12.78 ± 1.45	11.10 ± 3.08	13.18 ± 0.71	9.14 ± 1.14	7.97 ± 2.46	7.65 ± 1.97	6.71 ± 4.55	5.67 ± 3.72	5.65 ± 2.37
	Min	7.43	8.27	7.45	7.75	8.18	7.71	7.95	8.28	7.90	8.41	7.80
pH	Max	9.52	9.32	9.24	8.65	8.45	8.56	8.71	9.62	9.26	9.87	8.85
	Mean	8.65 ± 0.69	8.88 ± 0.29	8.67 ± 0.49	8.30 ± 0.31	8.29 ± 0.07	8.18 ± 0.33	8.19 ± 0.23	8.74 ± 0.41	8.80 ± 0.54	9.21 ± 0.50	8.28 ± 0.41
	Min	3.37	5.06	2.47	2.55	3.61	2.44	3.90	2.19	2.68	1.67	1.10
Turbidity	Max	17.78	13.67	4.30	22.70	24.10	6.12	13.13	5.08	17.93	7.53	16.09
(ntu)	Mean	12.77 ± 5.63	9.93 ± 3.75	3.60 ± 0.71	12.91 ± 8.78	8.31 ± 8.88	3.51 ± 1.51	6.75 ± 3.83	3.64 ± 1.25	7.50 ± 6.10	4.52 ± 2.73	7.66 ± 5.57
	Min	17.00	20.46	8.64	6.83	15.18	18.66	15.01	9.62	10.08	8.04	10.61
Chl- <i>a</i>	Max	28.36	35.65	22.16	16.78	32.70	25.61	41.91	40.75	37.80	38.95	25.24
($\mu\text{g L}^{-1}$)	Mean	23.4 ± 12.2	28.5 ± 6.2	14.3 ± 9.6	13.7 ± 3.6	23.9 ± 7.55	22.3 ± 3.4	25.8 ± 11.7	23.8 ± 15.1	21.9 ± 12.3	21.6 ± 5.18	18.4 ± 5.21
	Min	0.062	0.017	0.036	0.161	0.047	0.017	0.037	0.017	0.017	0.020	0.017
TP	Max	0.141	0.039	0.065	0.267	0.111	0.054	0.064	0.047	0.071	0.215	0.078
(mg L^{-1})	Mean	0.09 ± 0.03	0.03 ± 0.01	0.05 ± 0.01	0.22 ± 0.04	0.07 ± 0.02	0.02 ± 0.01	0.04 ± 0.02	0.03 ± 0.01	0.04 ± 0.02	0.07 ± 0.08	0.04 ± 0.02
	Min	0.470	1.330	1.760	0.960	1.390	1.710	0.760	1.420	1.420	1.490	2.110
TN	Max	1.230	6.010	2.610	4.690	2.490	4.050	1.860	6.110	7.200	5.850	3.120
(mg L^{-1})	Mean	0.92 ± 0.29	3.74 ± 1.88	2.18 ± 0.36	2.90 ± 1.61	1.82 ± 0.47	2.54 ± 0.95	1.35 ± 0.46	3.20 ± 1.97	4.67 ± 2.35	3.79 ± 1.61	2.67 ± 0.41
	Min	30.00	50.00	80.00	45.00	45.00	65.00	55.00	55.00	50.00	40.00	23.00
Secchi	Max	90.00	85.00	110.00	125.00	112.00	105.00	110.00	100.00	130.00	100.00	100.00
(cm)	Mean	63.0 ± 21.7	68.2 ± 13.7	95.0 ± 12.7	95.0 ± 37.4	79.0 ± 26.4	85.0 ± 17.7	92.0 ± 2.8	87.0 ± 19.9	95.4 ± 29.9	80.0 ± 28.3	69.0 ± 34.2

8.18 to 9.21 and the water was generally alkaline; the pH value approached to neutral values at the bottom in some months. The mean turbidity was observed between 3.51 and 12.91 ntu, the highest values were measured in December when the submerged macrophytes development was minimum in the lagoon. The average TDS increased after August, minimum (1.33 g L^{-1}) and maximum (2.54 g L^{-1}) values were recorded in April and October, respectively. The average TP ranged between 0.020 and 0.220 mg L^{-1} ; it obviously decreased from February and its highest value was detected in December. The mean total nitrogen (TN) was found between 0.92 and 4.67 mg L^{-1} with the highest values recorded in the summer months. The mean Chl-*a* concentration was found between 13.74 and $28.50 \mu\text{g L}^{-1}$ (Table 1).

Physicochemical parameters of the five sampling stations were analyzed with principal component analysis

(PCA) to identify the differences between the stations. Before the PCA analysis, the Kaiser-Meyer-Olkin (KMO) and Bartlett's sphericity tests were performed on the parameter correlation matrix in order to examine the validity of the PCA. The KMO result was 0.657, and the significance level determined by Bartlett's sphericity test were less than 0.001, which showed that the PCA was applicable to this data set. The first two principal components described 30.74% and 20.65% of the total variation, respectively. The five sampling stations were mostly differentiated by first and second PCA axis. Environmental variables, such as salinity (0.979), EC (0.961), and TDS (0.980), had a high loading on the first component. On the other hand, Chl-*a* (0.847), turbidity (0.783) and Secchi depth (-0.708) had significant loadings on the second component (Figure 2). Variables associated with axis 1 indicated a salinity gradient, while axis 2

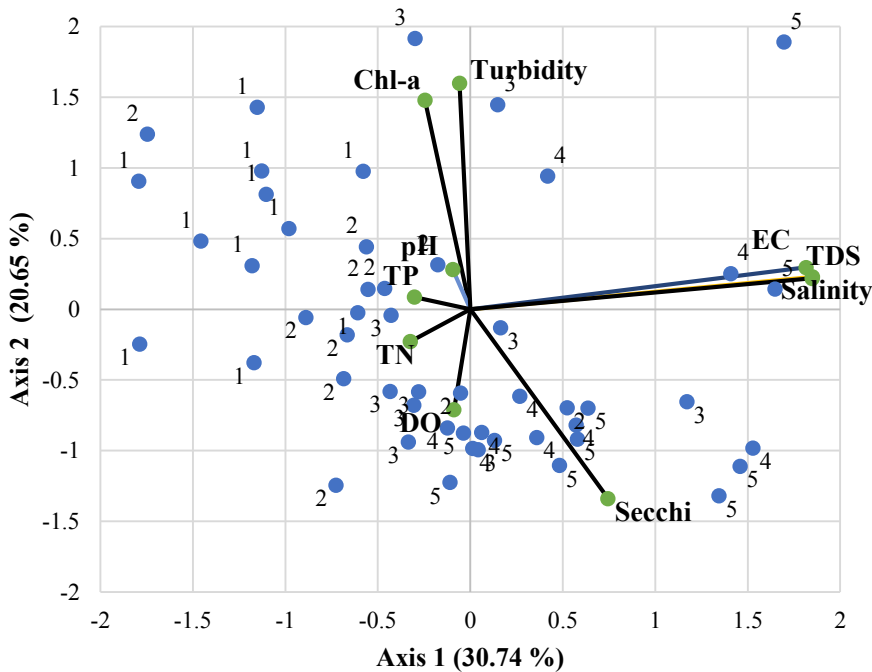


Figure 2. PCA results for environmental variables (number 1-5 represented sampling sites).

was found to be related to eutrophication. According to the Pearson's correlation results, Chl-a showed positive correlation with turbidity ($r = 0.621$, $P < 0.05$) and negative correlation with Secchi depth ($r = -0.473$, $P < 0.05$). Salinity was positively correlated with EC ($r = 0.950$, $P < 0.05$) and TDS ($r = 0.993$, $P < 0.05$).

3.2. Zooplankton assemblages

The zooplankton in Uzungöl Lagoon contained organisms from Rotifera, Cladocera, and Copepoda. They were generally freshwater organisms that were highly tolerant of salinity changes. Additionally, some marine and brackish water taxa found in the samples. In total, 39 species most of which were rotifers (34) were observed. Among these 39 species, only three were cladoceran and two were copepod species. Analyzing the structure of zooplankton in Uzungöl Lagoon, 2 eudominant, 2 dominant, and 6 subdominant species were identified (Table 2). Nauplii larval stages of copepods (9.13%) were also dominant in the zooplankton. The high proportion of rotifers in the total zooplankton was composed of species *Keratella quadrata* (28.78%), *Filinia terminalis* (12.14%), *Brachionus angularis* (9.79%), *Polyarthra vulgaris* (9.55%) as dominant organisms. *Filinia longiseta* (4.98%), *Hexarthra mira* (3.81%), *Anuraeopsis fissa* (3.40%), *Brachionus calyciflorus* (3.25%), *Keratella cochlearis* (2.39%) and *Polyarthra dolicoptera* (2.25%) was found as subdominant species (Table 2). During the study, 9 taxa (*Anuraeopsis fissa*, *Brachionus angularis*, *Filinia terminalis*, *Hexarthra mira*, *Keratella cochlearis*, *Keratella quadrata*, *Lecane luna*, *Polyarthra vulgaris*, *Trichotria*

pocillum) were constantly present in the zooplankton samples of Uzungöl Lagoon (Table 2).

The zooplankton density varied depending on the season and the total density of zooplankton in Uzungöl Lagoon was found between 22978 and 561659 ind. m^{-3} . Rotifers were numerically the most significant part of zooplankton, and 89.9% of all samples was rotifers. Proportional contribution of nauplius larvae to zooplankton was approximately 10%, but Cladocera and adult copepod contribution to zooplankton was insignificant, with the values of 1% (Table 2). Copepoda were mostly represented with organisms in the early development stage, and the highest densities of nauplii larvae and copepodit were 64777 ind. m^{-3} and 13297 ind. m^{-3} , respectively (Figure 3). Within this group, *Mesochra aestuarii* was determined only in June as 632 ind. m^{-3} . The minimum and the maximum densities for *Calanipeda aquaedulcis* was 82 ind. m^{-3} (June) and 5771 ind. m^{-3} (March), respectively (Figure 4). Cladocera species were determined in the samples with low dominance and frequency. The most common Cladocera species *Alona rectangula* was found between 102 and 642 ind. m^{-3} . The density of *Chydorus sphaericus* was between 115 and 452 ind. m^{-3} , while *Graptoleberis testudinaria* was between 61 and 484 ind. m^{-3} (Figure 4). The representatives of Cladocera and Copepoda generally found in spring-early summer months, while rotifer species were found in all samples throughout the year with variable frequency and dominance. *Brachionus angularis*, *Filinia terminalis*, *Keratella quadrata*, *Polyarthra vulgaris* were common

Table 2. The dominance and frequency results of zooplankton in Uzungöl Lagoon.

	Frequency ¹ (%)	Dominance ² (%)
CLADOCERA		
<i>Alona rectangula</i> Sars, 1862	64	0.10
<i>Chydorus sphaericus</i> (O.F.Müller, 1776)	36	0.10
<i>Graptoleberis testudinaria</i> (Fischer, 1848)	27	0.04
COPEPODA		
<i>Mesochra aestuarii</i> Gurney, 1921	9	0.03
<i>Calanipeda aquaedulcis</i> Krichagin, 1873	45	0.35
Copepodit	100	0.95
Nauplius	91	9.13
ROTIFERA		
<i>Anuraeopsis fissa</i> (Gosse, 1851)	91	3.40
<i>Asplanchna priodonta</i> Gosse, 1850	64	0.27
<i>Brachionus angularis</i> Gosse, 1851	100	9.79
<i>Brachionus calyciflorus</i> Pallas, 1766	55	3.25
<i>Brachionus diversicornis</i> (Daday, 1883)	27	0.35
<i>Brachionus plicatilis</i> Müller, 1786	9	0.01
<i>Brachionus quadridentatus</i> Hermann, 1783	27	0.09
<i>Brachionus urceolaris</i> Müller, 1773	64	0.23
<i>Cephalodella gibba</i> (Ehrenberg, 1830)	64	0.65
<i>Colurella adriatica</i> Ehrenberg, 1831	9	0.01
<i>Colurella colurus</i> (Ehrenberg, 1830)	36	0.72
<i>Filinia longiseta</i> (Ehrenberg, 1834)	55	4.98
<i>Filinia terminalis</i> (Plate, 1886)	82	12.14
<i>Hexarthra intermedia</i> (Wiszniewski, 1929)	27	0.47
<i>Hexarthra mira</i> (Hudson, 1871)	82	3.81
<i>Keratella cochlearis</i> (Gosse, 1851)	82	2.39
<i>Keratella quadrata</i> (Müller, 1786)	82	28.78
<i>Keratella tropica</i> (Apstein, 1907)	73	1.02
<i>Lecane bulla</i> (Gosse, 1851)	45	0.13
<i>Lecane imbricata</i> (Carlin, 1939)	45	0.10
<i>Lecane luna</i> (Müller, 1776)	100	1.74
<i>Lecane obtusa</i> (Murray, 1913)	18	0.11
<i>Lecane sp.</i>	18	0.41
<i>Lepadella sp.</i>	73	0.55
<i>Lepadella ovalis</i> (Müller, 1786)	36	0.59
<i>Notholca acuminata</i> (Ehrenberg, 1832)	55	0.24
<i>Polyarthra dolichoptera</i> Idelson, 1925	73	2.25
<i>Polyarthra vulgaris</i> Carlin, 1943	100	9.55
<i>Synchaeta pectinata</i> Ehrenberg, 1832	36	0.13
<i>Testudinella patina</i> (Hermann, 1783)	45	0.39
<i>Trichocerca marina</i> (Daday, 1890)	64	0.34
<i>Trichocerca stylata</i> (Gosse, 1851)	9	0.09
<i>Trichotria pocillum</i> (Müller, 1776)	82	0.19
<i>Trichotria tetractis</i> (Ehrenberg, 1830)	64	0.13

¹Frequency criterion cited in Paturej et al. (2017): 100% - 76% absolutely constant species, 75% - 51% constant species.

²Species dominance classes cited in Paturej et al. (2017) : > 10.0% eudominant species, 5.1% - 10.0% dominant species, 2.1% - 5.0% subdominant species.

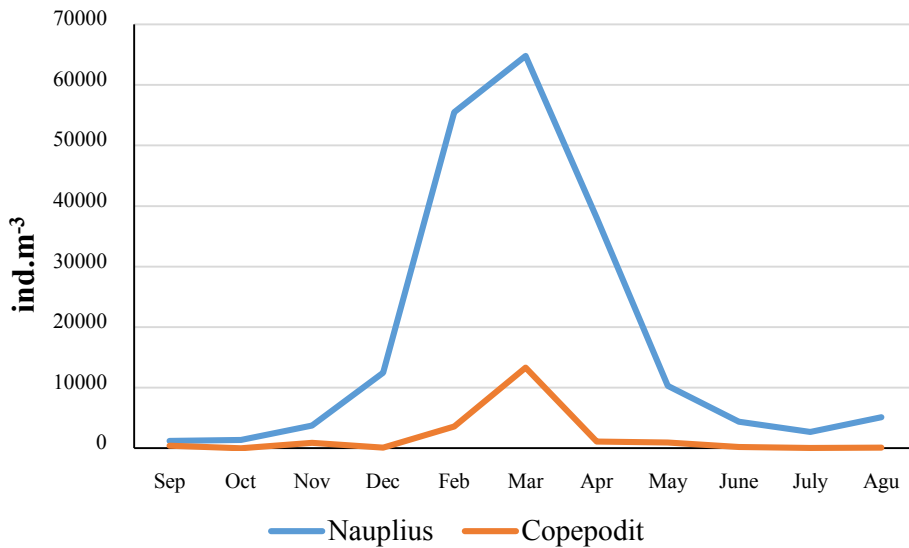


Figure 3. Seasonal density (ind. m⁻³) changes of nauplii larvae and copepodit individuals in Uzungöl Lagoon.

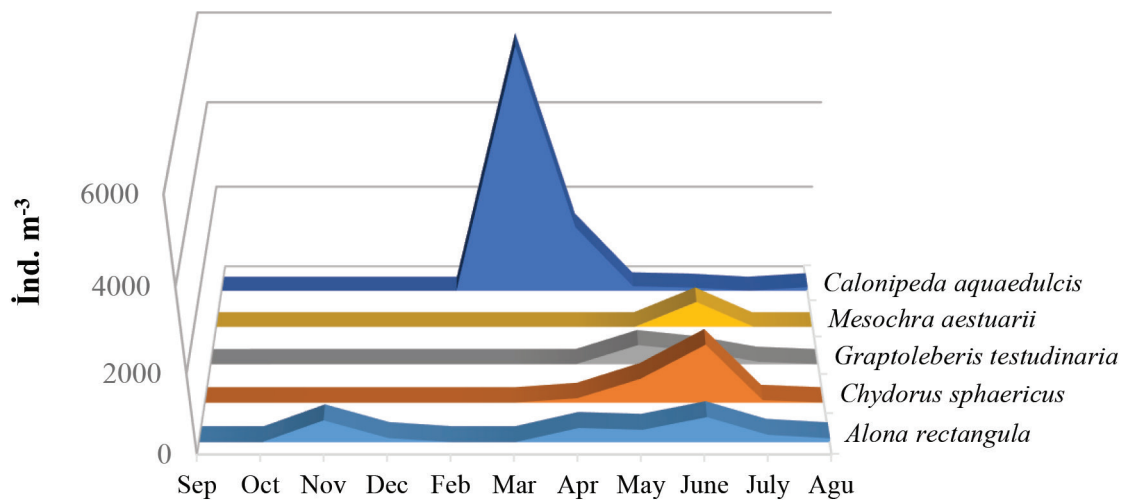


Figure 4. Seasonal density (ind. m⁻³) changes of Copepoda and Cladocera species in Uzungöl Lagoon.

dominant taxa. Among them, the densities were between 586 and 123669 ind. m⁻³ for *Brachionus angularis*, 115 and 169175 ind. m⁻³ for *Filinia terminalis*, 102 and 287720 ind. m⁻³ for *Keratella quadrata*, 2069 and 62586 ind. m⁻³ for *Polyarthra vulgaris* (Figure 5).

The biological diversity of zooplankton communities in the Uzungöl Lagoon was evaluated based on species richness, Shannon diversity and Pielou's evenness indices. Mean species richness was found between 7 and 16.6, minimum value was detected in November, maximum was detected in June. Mean diversity was estimated between 0.34 and 2.48, minimum was found in December, maximum was detected in June. Mean Pielou's evenness index remained in the 0.16 - 0.79 range, minimum and

maximum values were estimated in December and June, respectively (Figure 6). The statistical analyses demonstrated significant seasonal differences in the course of community parameters (for species richness $F=8.074$, $P=0.001$; for Shannon diversity $F=2.061$, $P=0.037$; for Pielou's evenness $F=1.953$, $P=0.0043$) (Table 3).

In order to see how the zooplankton was associated with environmental parameters, RDA ordination analysis was applied to zooplankton species and environmental variables. RDA was performed for 21 taxa and eight environmental variables. Variables in the RDA ordination analysis explained 66.7% of the total variability. The species-environment correlation of all axes were found significant in the permutation test ($F=1.342$, $P<0.05$).

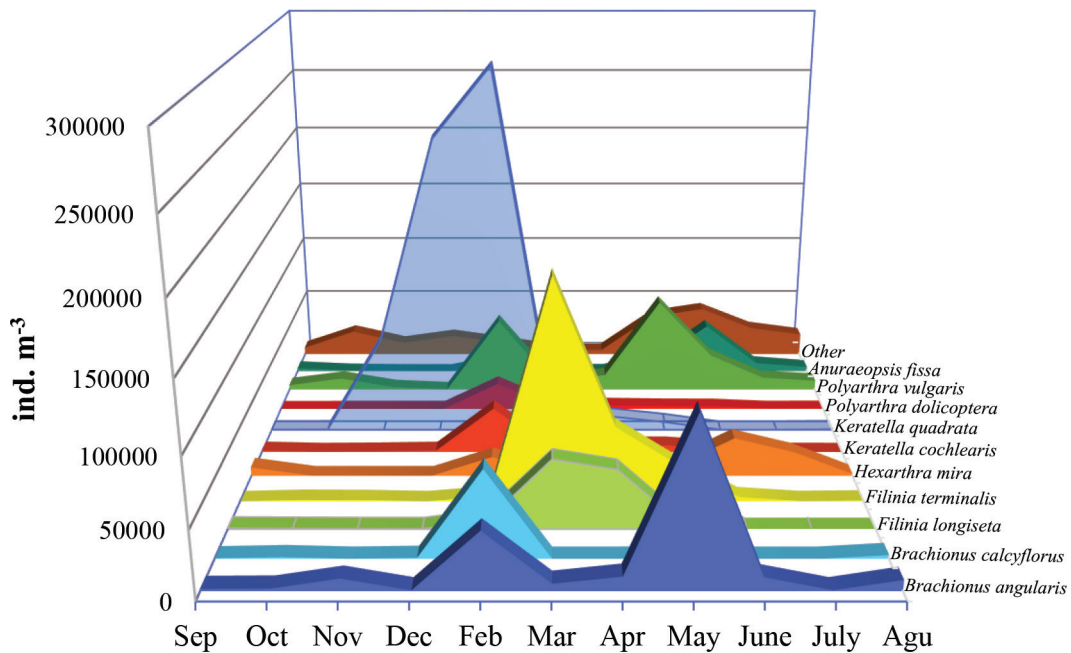


Figure 5. Seasonal density (ind. m⁻³) changes of dominant Rotifera species in Uzungöl Lagoon.

RDA analysis revealed that temperature, EC, TP, DO and pH values related significantly with zooplankton. Along the first RDA axis, significant correlations between environmental parameters and zooplankton species found for pH ($r = -0.56$) and DO ($r = 0.47$), whereas along second axis significant correlations were observed for temperature ($r = -0.58$), TP ($r = 0.51$) and EC ($r = -0.45$). The RDA biplot for species and environmental variables indicated that *Anuraeopsis fissa*, *Hexarthra mira*, *Keratella tropica*, *Polyarthra vulgaris* were positively correlated with temperature. A positive correlation was found among *Brachionus calyciflorus*, *Brachionus urceolaris* and TP. Additionally, *Keratella cochlearis*, *Keratella quadrata* were positively correlated with DO and negatively correlated with temperature. A negative correlation was determined for pH with *Filinia longiseta*, *Keratella quadrata*, for EC with *Lecane luna*, and *Trichotria tetractis* (Figure 7).

4. Discussion

Uzungöl Lagoon is a brackish water body that is formed near coastal area of Black Sea. Uzungöl Lagoon is very shallow, semi-enclosed lagoon and shares some limnological features with other shallow lakes. The water column is usually well mixed with wind-induced turbulence; this caused a high content of suspended detritus in the water column. In Uzungöl Lagoon, especially during the summer stagnation, oxygen is generally below 1 mg L⁻¹ at the bottom. According to Carlson and Simpson (1996), TSI (Chl-*a*) and TSI (TP) values estimated for Uzungöl Lagoon showed that trophic is generally at the eutrophic level, but it

approached the hypertrophic level in the summer period. In terms of salinity, Uzungöl Lagoon is a mixooligohaline brackish water body and is in contact with open sea water at the northern side through a narrow and long canal. In Uzungöl Lagoon, differences in salinity are caused by seawater intrusion or freshwater inflow, which is typical of shallow coastal lagoons. The lowest salinity level was noted in the vicinity of riverine water inflow at southern part of the lagoon, while the highest was observed in the vicinity of canal that link the water body with the sea.

Zooplankton researches on Uzungöl Lagoon began in the 1989s. Previous studies have only focused on species composition of zooplankton assemblages (Emir, 1989; Gündüz, 1991a, 1991b; Ustaoglu et al., 2012). Since the beginning of the zooplankton researches, taxon number of rotifers had highest in the zooplankton community. During the previous studies, of 49 identified species, 25 belonged to Rotifera; additionally 17 Cladocera and 7 Copepoda species were reported. Partially an analogous results was observed in the present study; of 39 identified species, 34 belonged to Rotifera, however only 3 Cladocera and 2 Copepoda species was identified. The results of our study revealed that the composition of the species in zooplankton varied considerably temporally, there was an significant increase in the number of species in the Rotifera and the species substantially disappeared in the Cladocera and Copepoda groups. Various studies in lagoons in coastal regions revealed that rotifer species richness increases in zooplankton in relation with eutrophication (Park and Marshall, 2000;

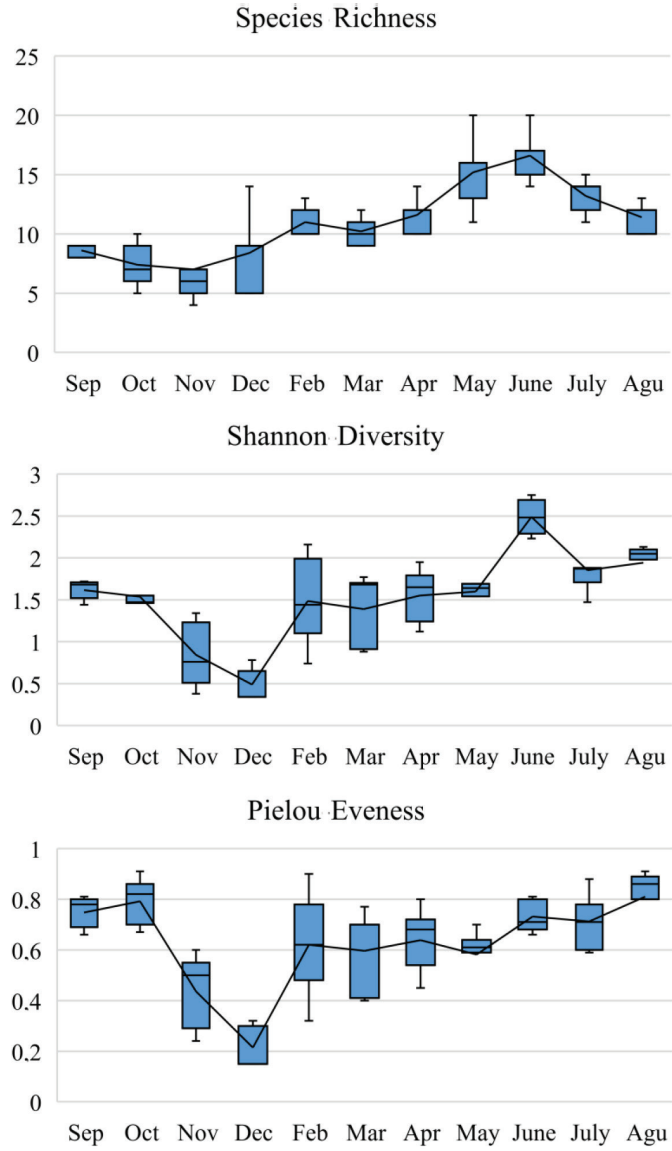


Figure 6. Zooplankton community indices (Shannon Diversity, Pielou evenness and Species richness) during the study period.

Table 3. One-way ANOVA results for zooplankton community parameters between sampling periods

	Min	Max	Mean	Std. Dev.	F	P
Shannon-Diversity	0.34	2.75	1.54	0.57	2.061	0.037
Pielou-Evenness	0.15	0.91	0.65	0.21	1.989	0.043
Species Richness	4	20	10.89	3.8	8.074	0.001
Density	5885	605301	178361	185512	9.670	0.000

Demirkalp et al., 2004; Saygı et al., 2011; Gündüz et al., 2013; Gutkowska et al., 2018). Therefore, it is thought that the change in the composition of the species in the zooplankton community in Uzungöl Lagoon may be

related primarily to changes in the trophic level of the lake. The zooplankton community in Uzungöl Lagoon is quite characteristic for eutrophic brackish water bodies and has similarities with other eutrophic lagoons in

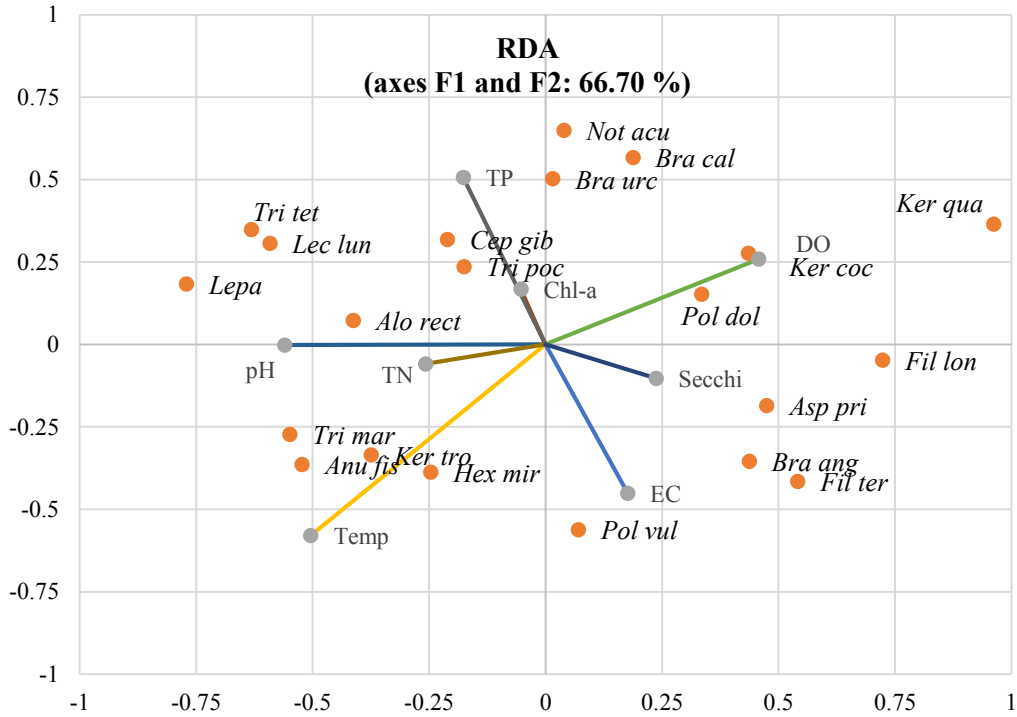


Figure 7. RDA ordination plot for zooplankton taxa and some environmental variables. Taxa in RDA plot indicated with abbreviation: *Alona rectangular* - *Alo rect*; *Anuraeopsis fissa* - *Anu fis*; *Asplanchna priodonta* - *Asp pri*; *Brachionus angularis* - *Bra ang*; *Brachionus calyciflorus* - *Bra cal*; *Brachionus urceolaris* - *Bra urc*; *Cephalodella gibba* - *Cep gib*; *Filinia longiseta* - *Fil lon*; *Filinia terminalis* - *Fil ter*; *Hexarthra mira* - *Hex mir*; *Keratella cochlearis* - *Ker coc*; *Keratella quadrata* - *Ker qua*; *Keratella tropica* - *Ker tro*; *Lecane luna* - *Lec lun*; *Lepadella* - *Lepa*; *Notholca acuminata* - *Not acu*; *Polyarthra dolichoptera* - *Pol dol*; *Polyarthra vulgaris* - *Pol vul*; *Trichotria pocillum* - *Tri poc*; *Trichocerca marina* - *Tri mar*; *Trichotria tetractis* - *Tri tet*.

Kızılırmak Delta (e.g., Liman, Karaboğaz Lake) (Saygı et al., 2011; Gündüz et al., 2013).

The rotifers have numerically high importance in the zooplankton community of eutrophic Uzungöl Lagoon. However, the numeric proportional contribution of many rotifer species identified in the zooplankton community in Uzungöl Lagoon remained below 1%. In the present study the eudominant-dominant / absolutely constant organisms in the zooplankton community were found to be *Filinia terminalis*, *Keratella quadrata*, *Brachionus angularis* and *Polyarthra vulgaris*, nauplius larvae of copepods. Additionally, the most common subdominant species was determined as *Anuraeopsis fissa*, *Brachionus calyciflorus*, *Filinia longiseta*, *Hexarthra mira*, *Keratella cochlearis* and *Polyarthra dolichoptera*. It was observed that small-sized organisms with low filtration rate in zooplankton were dominant in Uzungöl Lagoon. All of these species are organisms of freshwater origin with high compatibility with brackish waters. They are also among the species associated with high trophic level as an eutrophication indicator (Gannon and Stemberger, 1978; Fontaneto et al., 2006, 2008). Rotifer abundance is known

to increase with rising trophic and their dominance in the zooplankton community of brackish water bodies is well documented. Studies on shallow coastal brackish lagoons in the Mediterranean region have revealed that small-sized organisms (e.g., nauplius larvae, rotifers) in numerical majority in the zooplankton (Badosa et al., 2007; Brucet et al., 2010). Additionally, Ramdani et al. (2009) reported similar results in Lake Manzala and these results have been related with eutrophication and aquatic bacteria. In the studies conducted in the Karaboğaz and Liman lagoons in Kızılırmak Delta, it has been reported that Rotifera was the most dominant group of zooplankton and this was related to eutrophication (Saygı et al., 2011; Gündüz et al., 2013). In the Baltic Lagoons, the zooplankton community of the coastal brackish waters have dominated mainly small eutrophic organisms belonging to Rotifera (Gutkowska et al., 2018).

In general, with the increase of temperature, first microzooplanktonic organisms such as rotifer species, and then macrozooplanktonic organisms increase in a successional way in zooplankton communities (Sommer et al., 1986). The most important factors affecting the species

composition and density of the Rotifers in the annual cycle are temperature and nutrients (Edmondson, 1965; Dumont, 1977; Herzig, 1987). In Uzungöl Lagoon, zooplankton community showed very significant quantitative seasonal changes. The density of zooplankton changed among the seasons, exhibiting temporal significant differences ($P < 0.05$) and zooplankton densities were positively correlated with DO, negatively correlated with temperature and pH (Table 3). The species belonging to the Rotifera reached their most important numerical maximum in February. The rotifers decreased numerically in March-April periods. In these months *Calanipeda aquaedulcis* adult individuals, and nauplius /copepodite density had the highest values in Copepoda. In addition, the species belonging to Cladocera started to increase numerically in spring, their highest peak observed in summer period. The highest peak of rotifers in February is not prevalent in freshwater/brackish water systems. However, similar results have been reported in several studies (Castro et al., 2005; Virro et al., 2009). The rotifer species reaching the peak in winter period in Uzungöl Lagoon were determined as *Keratella quadrata*, *Keratella cochlearis*, *Brachionus calyciflorus* and *Polyarthra dolichoptera*. These are generally among eurythermal species and the last one is among thermophobic species (Herzig, 1987; Bērziņš and Pejler, 1989). In the winter months when macrophytes almost completely decomposed and degraded in Uzungöl, these species contributed to the winter community as microfilter-sedimentator organisms (Pourriot, 1977; Karabin, 1985). Thermophilous species peaking in Uzungöl Lagoon in spring and summer were determined as *Brachionus angularis*, *Filinia longiseta*, *Anuraeopsis fissa*, *Polyarthra vulgaris* and *Hexarthra mira*. Although *Filinia terminalis* is a cold stenothermal species (Ruttner-Kolisko, 1977; Herzig, 1987), it reached its maximum in Uzungöl Lagoon in the spring period.

The seasonal differences of zooplankton community structure in Uzungöl Lagoon was estimated based on species richness, Pielou's evenness and the Shannon-Weiner diversity index. In Uzungöl Lagoon, the sampling times significantly impacted the zooplankton community indices, and ANOVA results of community indices also showed significant seasonal differences ($P < 0.05$). The relatively low diversity and evenness values were observed in few species in the zooplankton community with a clear dominance. In Uzungöl Lagoon, environmental variables and community indices were also analyzed with Pearson's correlation test (Table 4). Analyzing the cumulative data, it is concluded that temperature had a positive effect on diversity and species richness, but increasing salinity had a negative effect on these indices; our results presented here were found consistent with previous studies. In the brackish lagoon or lakes, a key structuring factor for

Table 4. Correlation (r) matrix for environmental variables, Chl-*a*, zooplankton density (D) and community indices (H' , J and S) in Uzungöl Lagoon. Significant correlations ($P < 0.05$) are in boldface type.

Pearson's Correlation; n=55				
	D	H'	J	S
Temperature	-0.564	0.458	0.421	0.390
EC	-0.127	-0.415	-0.030	-0.515
Salinity	-0.122	-0.403	-0.165	-0.646
TDS	-0.122	-0.413	-0.175	-0.643
Turbidity	-0.135	0.251	0.315	0.044
DO	0.498	-0.294	-0.322	0.180
pH	-0.325	0.258	0.210	0.239
Chl- <i>a</i>	-0.072	0.261	0.319	0.038
TP	0.093	-0.207	-0.229	-0.260
TN	-0.109	0.211	0.109	0.330
Secchi Depth	0.218	-0.512	-0.559	-0.201

invertebrate communities is salinity; species richness and the diversity of zooplankton generally decrease with increasing salinity (Schallenberg et al., 2003; Brucet et al., 2009; Jensen et al., 2010). Additionally, Uzungöl Lagoon presented much more diversified zooplankton community in the warmer months. This could be mainly due to the higher macrophyte coverage and this situation is probably a consequence of the spatial heterogeneity, which allows a greater diversity of zooplankton. Thus, macrophyte-dominated habitats are usually richer in terms of rotifer taxa (Green, 2003; Castro et al., 2005).

In conclusion, the study has exhibited that the zooplankton community of eutrophic Uzungöl Lagoon has some distinctive features such as high dominance of rotifers and maximum number of zooplankton during winter. In the winter period, zooplankton community has substantially composed of eurythermal and microfilter-sedimentator organisms. Our results reveal that eutrophication has major effects on zooplankton community. Although Uzungöl Lagoon is a mixooligohaline brackish water body, dominant organisms in the zooplankton community is freshwater originated but compatible with brackish waters. Increasing salinity has a negative effect on diversity and species richness.

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