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Seasonal composition and population density of zooplankton in Lake Karaboğaz from the Kızılırmak Delta (Samsun, Turkey)

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Abstract: Zooplankton composition and abundance were investigated seasonally at 6 sites in Lake Karaboğaz in relation to some physicochemical conditions. A total of 63 taxa were identified, among them 51 species of rotifers, 8 cladocerans, and 4 copepods. Rotifera represented the predominant component (79% of the total community), followed by nauplii, cladocerans, and copepods (15%, 5%, and 1%, respectively). The average total zooplankton abundance ranged from 9603 to 22,968 ind/m^3. The maximum and the minimum densities were measured in June and August of 2009, respectively. Of the identified zooplankton, 39 taxa were species with a low frequency in the lake. Among the species with the highest frequency of encounter were *Coronatella rectangula*, *Chydorus sphaericus*, *Colurella adriatica*, *Keratella quadrata*, *Lecane closterocerca*, *L. bulla*, and *Polyarthra vulgaris.* Zooplankton diversity showed a positive correlation with temperature and chlorophyll *a*. However, a significant negative correlation was detected between diversity and salinity.

Key words: Rotifera, Copepoda, Cladocera, species composition, abundance, diversity

1. Introduction

Coastal lagoons are commonly shallow, marine-influenced water bodies, and they are considered ecologically and economically important environments due to their high productivity rates. In spite of their importance and multiple uses, urban development and intense human use of coastal lagoons and their surroundings have often led to water contamination, eutrophication, and habitat destruction (Britton and Crivelli, 1993; Pearce and Crivelli, 1994; Alvarez Cobelas et al., 2005). The Kızılırmak Delta covers an area of 56,000 ha located within the Bafra-Alaçam, Ondokuz Mayıs, and Yakakent regions of Samsun. It is one of the most important Ramsar sites in Turkey in terms of biodiversity, containing a variety of ecosystems such as the sea, river, lake, reeds, marsh, meadow, pasture, forest, dune, and agricultural areas. The delta is a nesting, feeding, and breeding site for the migratory birds that traverse directly over the Black Sea. The delta is a multipurpose wetland ecosystem that makes important contributions to the local economy through mariculture, reed cutting, and grazing activities. In addition, as a wildlife habitat, it is an ideal location for recreational activities, such as bird watching, fishing, and hunting (Özesmi, 2003). A total 6110 ha of the delta is wetland, and the majority of the lagoon lakes (Lake Balık, Lake Uzun, Lake Çernek, Lake Liman, and Lakes Tatlıgöl and Gıcıgöl) are located in the east of the delta, while Lake Karaboğaz, where this study was conducted, is located in the west of the delta.

Despite the fact that the Kızılırmak Delta fulfills the international criteria for the wetland category with its variety of habitats and ecological characteristics of the species it contains, it is under threat due to the Bafra Plain Irrigation Project. Within the scope of this project, the lagoons in the Kızılırmak Delta have been surrounded by drainage channels since 1986. This project resulted in a drastic change in the water regime of the lagoons and the surface area of the lakes decreased. In addition, the discharge of pollutant water from the agricultural lands into the lakes caused eutrophication and serious contamination of the food chain (Demirkalp et al., 2004, 2010). Lake Karaboğaz has been adversely affected by the drainage channels project and is under threat just like the other lakes in the delta.

Hydrological modifications of freshwater inflows and marine inlet channels can cause major changes in lagoon ecosystems and particularly in the plankton (Borja, 2005). Zooplankton communities in coastal lagoons have major importance for the food web structure and ecosystem

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health. Zooplankton plays a significant role as the major link in the local trophic food chain, carrying the energy from bacteria/phytoplankton to other invertebrates and fish (Souza et al., 2011). The structure of plankton communities in any coastal water body is also important for commercial fisheries (Ramdani et al., 2009).

Brackish lakes and lagoons are numerous in many parts of the world, but information on the factors controlling zooplankton taxon richness and trophic structure in such lagoons is scarcer than that for freshwater ecosystems. In addition to this, studies on the zooplankton communities of Lake Karaboğaz are completely unavailable, unlike for the other lagoon lakes of the Kızılırmak Delta. Taking into consideration the importance of Lake Karaboğaz with regard to its being a Ramsar site, it is important to identify the ecosystem components of the lake. The aim of the present investigation is to explain the composition, abundance, and species diversity of the zooplankton community in Lake Karaboğaz.

2. Materials and methods

Karaboğaz is a brackish lagoon lake with a surface area of 1500 ha located at 41′38′N, 35′38′E and 10 km west of the Kızılırmak Delta. Being the closest lake to the Black Sea, Lake Karaboğaz is connected to the sea through a narrow sandy barrier located on the northwest side. Freshwater inflow is provided by small streams and drainage channels connected to the agricultural lands in the south of the lake (Figure 1). The length and the width of the lake are 6 km and about 1 km, respectively. Having a shallow structure like the other lagoons in the delta, the average depth of the lake is 140 cm and the deepest point is 225 cm.

There are rural areas and agricultural lands around the lake. Rural residential areas are of greatest density on the narrow sandbank at the north and northwestern parts of the lake. There are extensive farmlands around the southern, southwestern, and southeastern parts of the lake, where agricultural activities are carried out year-round. Except for the northwestern area where the lake connects to the sea, the surroundings of the lake are covered with reed and *Phragmites australis* is widely found. However, this reed field, which is a barrier between the lake and the farmlands, is quite narrow. Residential areas and agricultural lands are located very close to Lake Karaboğaz compared to the other lagoons in the Kızılırmak Delta. In this way, Lake Karaboğaz differs greatly from the other lakes located in the delta. Pesticide-loaded water from agricultural lands is discharged into the lake through the channels (Yurtkuran, 2012). Lake Karaboğaz is of great importance as a wintering and breeding site for birds. Most of the bird species found in Bafra Balık Lake and in its vicinity are also encountered in and around this lake.

Zooplankton sampling was performed monthly (except January 2009) from October 2008 to September 2009 at 6 distinct sampling points along Lake Karaboğaz (Figure 1). Samples were collected by using a Hydrobios plankton net

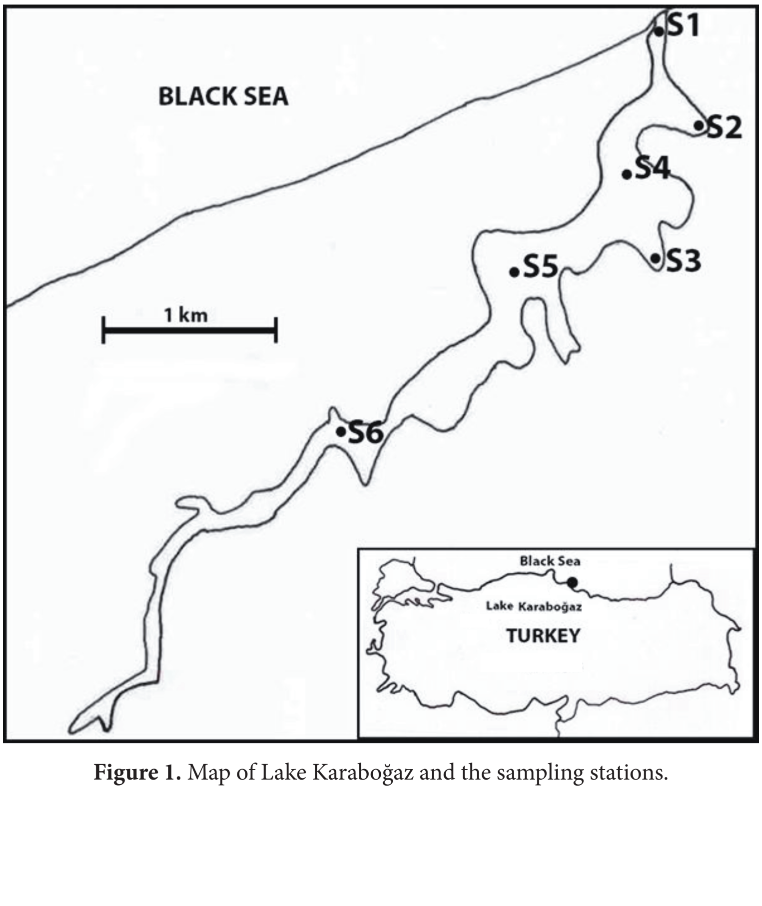

Figure 1. Map of Lake Karaboğaz and the sampling stations.

with a 30-µm mesh size. Samples were immediately fixed with 4% buffered formalin. Qualitative and quantitative analyses were conducted using a Nikon Labophot 2 microscope. Sedgwick–Rafter chambers with a volume of 1 mL were used for counting and 4 aliquots were removed from a well-mixed sample using a Hensen–Stempel pipette. Organisms were separated by species or taxonomic groups. Zooplankton identification was based on specific literature (Kiefer, 1952, 1955, 1978; Koste, 1978; Pennak, 1978; Negrea, 1983). Species richness was measured as the total number of species of zooplankton in the lake (Brucet et al., 2009) and species diversity was determined using the Shannon–Weaver diversity index.

At each sampling point, water depth was measured using a Secchi disk and profiles of water temperature, pH, salinity, dissolved oxygen, and electrical conductivity were determined using a WTW OXI 96 STB/B oxygen meter, WTW LF 90 conductivity meter, and Orion 230 pH meter. Filtering of appropriate water samples through Whatman GF/C glass microfiber filters was carried out to determine chlorophyll *a* values. The pigment extraction was performed using the boiling methanol method (Marker, 1994).

3. Results and discussion

3.1. Environmental parameters

Table 1 shows the average, maximum, and minimum values of some physicochemical parameters measured at the stations. In this study, the depth of the lake varied from 50 to 225 cm. Given its shallowness, it was found to be similar to the other lagoons in the Kızılırmak Delta (Demirkalp et al., 2004; 2010). Stations S1 and S2 represent the deepest and the shallowest points of the lake, respectively. In this study, the average oxygen values measured in the lake water (6.29–8.03 mg/L) exceeded the limit set for surface waters within the EU Water Framework Directive (5 mg/L). However, oxygen deficiency in the water column manifested itself in the summer. During this period, oxygen levels in the deep layers were within the limits of highly contaminated surface waters (EC, 1998). Conductivity values ranging from 470 to 22,000 µS/cm were found to fall between the limit values measured in brackish waters (Suzuki et al., 1998; Lucena et al., 2002). The salinity of the lake was measured to be between 0.24‰ and 13.19‰; therefore, the lake was classified as mixooligohaline, except for at station S1, which connects it to the sea (Remane and Schlieper, 1971). The most important environmental variable that distinguishes Lake Karaboğaz from the other lagoons in the delta is the salinity. Permanent salinity stratification was observed at station S1. The results of the cluster analysis based on lake salinity and conductivity variables indicated that S1 and S4, and S5 and S6, are the most similar stations in terms of these variables (Figure 2). According to the average chlorophyll *a* levels (12.64–38.93 µg/L), the trophic level of the lake was found to be eutrophic (Wetzel, 2001).

3.2. Species richness, composition, abundance, and diversity

A total of 63 taxa belonging to Cladocera, Copepoda, and Rotifera were detected in Lake Karaboğaz (Table 2). However, in previous studies conducted in the other lagoon lakes in the Kızılırmak Delta, 101 species were identified (58 Rotifera, 30 Cladocera, and 13 Copepoda) (Emir, 1990; Gündüz, 1991a, 1991b; Demirkalp et al., 2004; Bekleyen and Taş, 2008; Saygı et al., 2011; Ustaoğlu et al., 2012). All species of the Cladocera group, all species of the Copepoda group except *Paracyclops fimbriatus*, and 29 of the species classified in the phylum Rotifera in Lake Karaboğaz were also reported in the other lagoons in the delta. From Lake Karaboğaz, 22 species categorized in the phylum Rotifera are considered to be new records.

In previous studies, the richness of zooplankton was reported for lagoon lakes in the Kızılırmak Delta (Emir,

Table 1. Average values of some physicochemical parameters and chlorophyll *a* in Lake Karaboğaz during the study period.

	S1	S2	S3	S4	S5	S6
Temp. (°C)	17.6 (5–26.6)	16.8 (5–25.5)	17.9 (5–27.2)	17.6 (6–26.7)	19.9 (5–25.6)	19.7 (5–25.7)
Oxygen (mg/L)	7.67 (0.45–15.4)	6.94 (0.55–14.80)	6.29 (0.50–14)	8.03 (1–14.8)	7.43 (1.11–12.9)	6.72 (0.30–14.5)
EC (µS/cm)	8655 (773–22,000)	3279 (700–14,000)	3083 (621–9370)	4221 (1225–17,490)	3381 (630–6640)	1470 (470–6980)
Salinity (‰)	5.11 (0.40–13.19)	1.79 (0.36–8.09)	1.68 (0.32–4.92)	2.57 (0.65–10.28)	1.84 (0.33–3.68)	1.79 (0.24–3.45)
Depth (cm)	209 (180–225)	74 (50–110)	101 (80–130)	144 (130–185)	151 (120–175)	162 153–180)
Chl_a (µg/L)	17.60 (7.27–37)	19.83 (9–92.4)	38.93 (8–119)	18.45 (4–52)	12.64 (2–30)	16.06 (7–46)

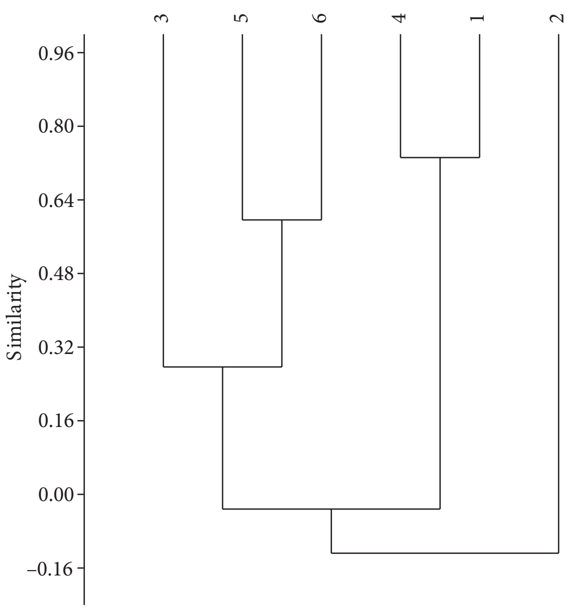

Figure 2. Cluster diagram based on salinity and electrical conductivity recorded at each station.

1990; Gündüz, 1991a, 1991b; Demirkalp et al., 2004; Bekleyen and Taş, 2008; Saygı et al., 2011; Ustaoğlu et al., 2012). The results revealed that the species richness in Lake Karaboğaz is higher than those of the other lagoons in the delta. Based on the literature data presented by Saygı et al. (2011) and Ustaoğlu et al. (2012), the species richness of the Cladocera and Copepoda groups in Lake Karaboğaz was observed to be lower than in the other lakes in the delta. In contrast to these groups, it was made clear that the species richness of Rotifera is significantly higher than in the other lakes in the delta. This condition is thought to be associated with the salinity and the trophic structure of the lakes. Although the lagoons in the delta are of mixohaline character, their salinity levels and trophic structures are different (Gündüz, 1991a, 1991b; Demirkalp et al., 2004, 2010). Lake Karaboğaz is of a mixooligohaline character like the other lagoons. However, this lake has a higher salinity, which reaches the mixomesohaline level in the region where it connects to the sea (>5‰). The structure of the zooplankton community in brackish water systems is known to change with increasing salinity (Schallenberg et al., 2003). The results of many studies conducted on this subject pointed out that species richness in the zooplankton declined with increasing salinity levels (Green and Menengestou, 1993; Egborge, 1994; Jeppesen et al., 1994). With the exception of Rotifera, all of the findings regarding the zooplankton species richness in Lake Karaboğaz were consistent with those of the other studies. Although an increase in salinity is known to reduce species richness with regard to Rotifera, salinity threshold values are of critical importance. In the study conducted by Egborge (1994) in the Lagos Harbor–Badgary Creek system located on the Atlantic coast of Nigeria, the decrease in the Rotifera richness due to the increase in salinity was presented as a generalized assumption. In addition, this study reported that the number of species also changed at stations with different salinity levels. The number of species was determined as 30 in Badgary Creek with a salinity of 9.7‰ and 34 in the Yewa River with a salinity of 1.9‰, and it was also reported that the number of species dropped to 4 in the Lagos Harbor above a 13‰ salinity. The results of this study demonstrated that a certain amount of increase in salinity did not affect the species richness of Rotifera. However, it also indicated that increases above the threshold significantly reduced species richness. In addition, Kaya et al. (2010) found a positive relationship between species richness and salinity in subsaline waters between 1000 and 6000 µS/cm. Taking the results of these studies into consideration, it is possible to state that this factor does not affect the species richness of Rotifera despite the fact that Lake Karaboğaz is more saline than the other lakes in the delta. This is thought to be associated with the fact that the species recorded in the lake are largely euryhaline (Fontaneto et al., 2006, 2008).

Of the taxa identified in the zooplankton of Lake Karaboğaz, 39 are composed of species that have low frequency in the lake (Table 2). Among the species with the highest frequency of encounter were *Coronatella rectangula*, *Chydorus sphaericus*, *Colurella adriatica*, *Keratella quadrata*, *Lecane closterocerca*, *L. bulla*, and *Polyarthra vulgaris*. Furthermore, *Brachionus calyciflorus*, *B. urceolaris*, *Colurella obtusa*, *Filinia terminalis*, *Lecane luna*, *L. nana*, *L. obtusa*, *Lepadella quadricarinata*, *Notholca* spp., *Polyarthra dolichoptera*, and *Trichocerca rattus* were species observed at relatively high frequencies (Table 2).

The zooplankton density of Lake Karaboğaz was between 9603 and 22,968 ind/m^3 (Figure 3). The zooplankton density of this lake was determined to be significantly lower than that of the other lakes in the delta, which may be related to salinity (Demirkalp et al., 2004, 2010; Saygı et al., 2011). Similarly, a significant decrease in zooplankton density with an increase in salinity was also reported in many brackish water systems in Canada and Denmark (Hammer, 1993; Jeppesen et al., 1994). In addition, in the studies conducted in tropical lagoons, a sudden change in salinity was reported as one of the factors that affect zooplankton communities (Souza et al., 2011). For this reason, sudden changes occurring in Lake Karaboğaz during the periods when it is connected to the sea may have decreased the zooplankton density. The salinity of the lake showed significant changes throughout the year (Figure 4). Aside from this factor, the zooplankton density may have decreased due to the predation pressure of the highly diverse and dense fish communities found in

Table 2. The names, abundance (ind/m^3), and frequency of zooplankton in Lake Karaboğaz between October 2008 and September 2009.

	Oct 2008	Nov	Dec	Feb 2009	Mar	Apr	May	Jun	Jul	Aug	Sep	F %
CLADOCERA												
Coronatella rectangula	1849	73	53	435	0	222	52	254	111	24	105	100
Chydorus sphaericus	390	70	432	537	425	1357	191	234	10	14	101	100
Ceriodaphnia reticulata	0	0	376	0	25	0	0	0	0	0	0	18
Daphnia curvirostris	0	0	82	0	0	0	0	0	0	0	0	9
Macrothrix sp.	0	0	0	0	0	0	0	15	0	0	0	9
Pleuroxus aduncus	0	0	316	18	25	0	0	0	0	0	0	27
Pleopsis sp.	83	0	0	0	0	0	0	0	0	0	0	9
Simocephalus vetulus	0	0	0	28	0	41	0	0	0	0	0	18
COPEPODA												
Harpacticoida	7	0	0	0	25	68	0	0	0	0	45	36
Calanipeda aquaedulcis	0	29	0	0	0	0	0	0	0	0	0	9
Cyclops vicinus	0	0	21	0	0	0	0	0	0	0	0	9
Eurytemora velox	0	0	0	35	175	0	0	0	0	0	0	18
Paracyclops fimbriatus	256	0	218	240	82	0	0	0	0	0	0	39
ROTIFERA												
Anuraeopsis fissa	0	0	0	0	0	0	0	0	180	0	0	9
Asplanchna priodonta	0	0	0	0	0	37	0	3	87	0	0	27
Brachionus angularis	0	0	0	0	0	0	11	965	1273	83	0	36
B. calyciflorus	0	0	0	316	236	17	223	1327	80	58	17	72
B. quadridentatus	0	59	0	0	0	0	159	37	57	11	38	36
B. urceolaris	0	0	0	0	0	0	33	185	8	24	0	54
Cephalodella gibba	0	290	0	13	0	0	0	0	0	0	38	27
C. ventripes	0	29	641	87	0	11	80	0	53	0	201	63
Collotheca mutabilis	0	173	0	62	0	0	0	0	0	0	0	18
Colurella adriatica	0	58	99	90	110	149	637	32	159	36	563	91
C. colurus	0	0	0	0	0	57	0	0	10	12	10	36
C. obtusa	0	0	1507	13	30	85	15	0	22	68	153	72
C. uncinata	0	0	329	0	0	0	0	29	0	0	0	18
Euchlanis dilatata	529	0	0	0	0	13	117	0	11	0	90	45
Filinia longiseta	0	0	0	0	0	0	0	0	0	0	73	9
F. limnetica	0	0	0	0	0	24	0	13	0	11	625	36
F. terminalis	0	116	54	33	0	2261	0	0	2306	136	0	54
Hexarthra mira	0	0	0	0	0	39	0	3335	1917	911	0	36
Keratella cochlearis	0	116	54	0	0	0	0	0	0	0	0	18
K. quadrata	92	1375	1317	104	4139	1040	3523	9088	6057	1881	438	100
Lecane bulla	828	0	0	13	0	13	15	16	273	346	1500	81
L. curvicornis	0	403	0	0	0	0	0	0	0	11	0	18
L. closterocerca	510	1207	1792	138	30	108	3429	147	131	760	2399	100
L. hamata	0	0	0	0	0	0	0	0	141	25	306	27

Table 2. (continued).

L. flexilis	280	0	0	0	0	0	0	0	38	11	0	18
L. lamellata	0	115	0	0	0	0	0	24	77	0	0	27
L. luna	654	334	68	0	0	0	239	295	236	48	115	72
L. nana	0	50	0	0	0	0	0	12	78	21	0	36
L. obtusa	0	29	0	0	0	0	15	126	1097	243	1191	54
L. ludwigii	1299	292	0	0	0	0	15	98	259	12	0	54
Lepadella ovalis	0	58	0	0	0	0	16	12	66	23	149	54
L. patella	0	32	50	16	0	0	21	0	33	0	0	45
L. quadricarinata	436	21	68	13	0	0	0	0	72	14	17	63
Lophocharis salpina	285	32	0	0	0	0	0	0	11	0	0	27
Macrochaetus collinsi	0	0	0	0	0	0	0	0	84	0	0	9
Monommata dentata	0	43	34	0	0	0	0	29	31	0	0	36
Mytilina mucronata	0	0	0	0	0	0	0	0	79	0	0	9
M. ventralis	0	97	0	0	0	0	0	12	0	0	0	18
Notholca acuminata	0	0	279	14,020	1850	2738	52	0	11	0	0	54
N. squamula	0	130	128	488	273	9	0	0	0	0	0	45
Polyarthra dolichoptera	0	4816	373	40	0	166	0	12	53	0	0	54
P. remata	0	723	0	0	0	22	0	0	0	0	0	18
P. vulgaris	0	7845	543	300	678	590	345	4599	2299	2389	226	91
Pompholyx sulcata	0	0	0	0	0	11	0	0	0	0	0	9
Proales similis	0	116	0	0	0	0	0	0	0	0	0	9
Squatinella lamellaris	0	664	34	0	0	0	0	0	0	0	0	18
Synchaeta pectinata	0	0	0	0	0	355	0	0	0	0	0	9
Testudinella patina	0	0	25	0	0	0	0	0	0	0	0	9
Trichocerca pusilla	0	0	0	0	0	0	0	1231	34	24	0	36
T. rattus	145	29	0	0	0	17	0	27	45	200	17	54
Trichotria pocillum	1358	43	0	32	0	0	10	0	0	0	52	45

F = frequency of species.

the lake. Demirkalp et al. (2010) reported 14 fish species in the lake. Supporting our findings, it was reported in many studies that a decrease in the zooplankton density occurred due to the high predation pressure of the fish (Romo et al., 2004; Gyllström et al., 2005; Souza et al., 2011).

During the study, the quantitatively dominant group of zooplankton in Lake Karaboğaz was Rotifera, which constituted 79% of the total zooplankton. In addition, 15% of the zooplankton was found to consist of nauplii (Figure 3). The findings indicated that the quantitatively dominant groups in the lake were small-sized organisms with low filtration rates. The results of the studies conducted by Brucet et al. (2009) and Badosa et al. (2007) in the brackish lagoons of the Mediterranean basin pointed out that small-sized species such as rotifers and nauplii were dominant in the zooplankton. The same situation was noted in a study conducted in Lake Manzala and reported to be associated with eutrophication and aquatic bacteria (Ramdani et al., 2009). Rotifera was also reported to be the most dominant group of the zooplankton in Lake Liman (Saygı et al., 2011). Jeppesen et al. (1994, 1997) pointed out 2 main reasons behind the dominance of small-sized organisms in the zooplankton of the lagoon lakes: 1) the excessive development of vegetation, and 2) predation pressure of fish such as *Gambusia affinis* and *Aphanius* sp. In the spring and summer months, Lake Karaboğaz is covered substantially by submerged vegetation (e.g., *Potamogeton pectinatus* and *Chara vulgaris*). In addition, fish species such as *Gambusia affinis* and *Aphanius* sp. are present in high abundance, especially in the dense vegetation zones. Development of dense vegetation and high fish predation in the lake resulted in the dominance of small-sized organisms in the zooplankton. The quantitatively dominant species of Rotifera in Lake Karaboğaz were

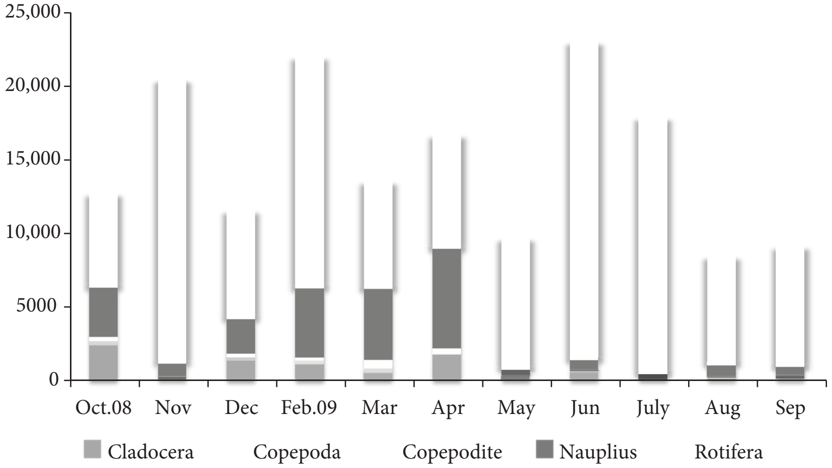

Figure 3. Monthly density variations of the zooplankton groups (ind/m^3).

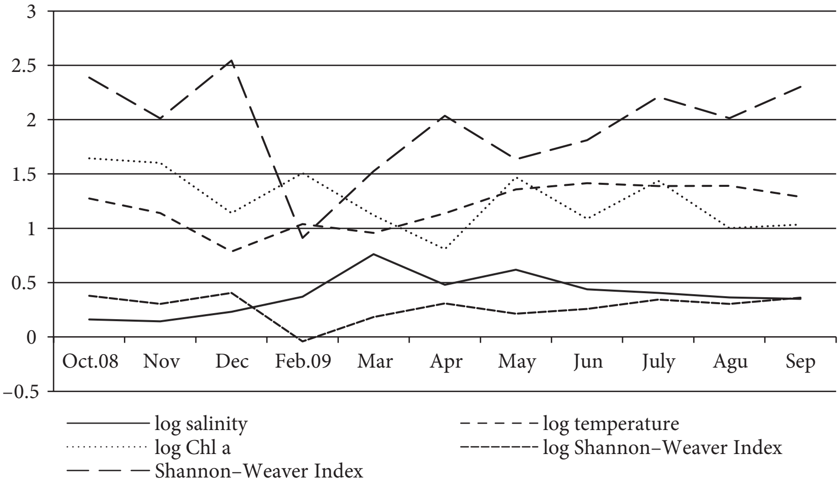

Figure 4. Seasonal distribution of the diversity in zooplankton; relationship between diversity, temperature, chlorophyll *a*, and salinity.

found to be *Keratella quadrata* (92–9088 ind/m^3), *Lecane closterocerca* (30–3429 ind/m^3), *Notholca acuminata* (11–14,020 ind/m^3), and *Polyarthra vulgaris* (226–7845 ind/m^3) (Table 2). With all of these species being euryhaline, *Notholca acuminata* shows good development in aquatic habitats with dense vegetation as well as in Lake Karaboğaz (Sládecek, 1983; Fontaneto et al., 2006, 2008). Out of the species classified in the Rotifera group, *Keratella quadrata*, *K. cochlearis*, *Polyarthra vulgaris*, *Brachionus calyciflorus*, *B. quadridentatus*, *B. urceolaris*, *B. angularis*, and *Filinia longiseta* are indicator species of eutrophic conditions (Ganon and Stemberger, 1978). The *Brachionus*/*Trichocerca* ($Q_{B/T}$) ratio was calculated to be 2.0 and this result confirmed that the lake is at a eutrophic level (Sládecek, 1983).

Eight species of Cladocera were recorded in Lake Karaboğaz; however, out of these species only *Chydorus sphaericus* and *Coronatella rectangula* were constantly present in the zooplankton (Table 2). The cladoceran group quantitatively comprises 5% of the zooplankton in the lake. Within this group, the lowest abundance of *Chydorus sphaericus* was recorded in July as 10 ind/m^3 and the highest abundance was recorded in April as 1357 ind/m^3. The lowest and the highest densities recorded for *Coronatella rectangula* were in August (24 ind/m^3) and October (1849 ind/m^3), respectively. Other Cladocera species were encountered in low density and all of them were recorded as having a low or rare frequency of occurrence. Of these species, the densities of *Simocephalus vetulus*, *Pleuroxus aduncus*, and *Ceriodaphnia reticulata* ranged from 28 to 41 ind/m^3, from 18 to 316 ind/m^3, and from 25 to 376 ind/m^3, respectively, while *Pleopsis* sp. and *Daphnia curvirostris* were only detected at a single sampling period. All the species found in the Cladocera

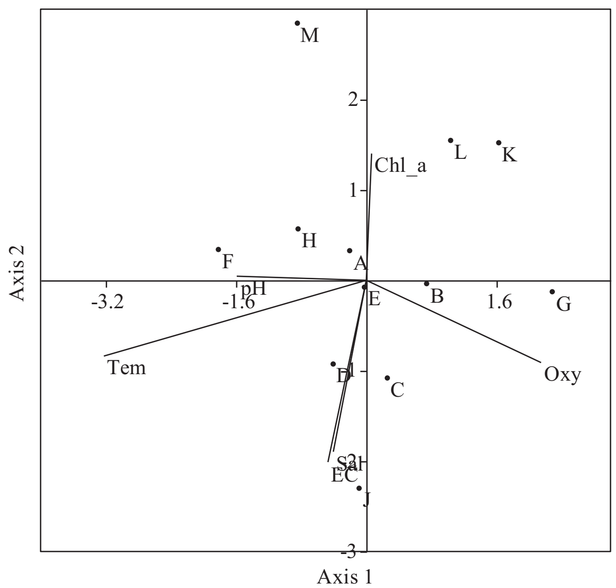

Figure 5. Canonical correspondence ordination of the zooplankton samples collected at 6 different stations and associated environmental parameters. Biplots of the species (occurrence frequency of >63%) and the environmental parameters. A = *Coronatella rectangula*, B = *Chydorus sphaericus*, C = *Colurella adriatica*, D = *Keratella quadrata*, E = *Lecane closterocerca*, F = *Lecane luna*, G = *Notholca acuminata,* H = *Polyarthra vulgaris,* J = *Brachionus calyciflorus*, K = *Colurella obtusa*, L = *Cephalodella ventripes*, and M = *Lepadella quadricarinata.*

were recorded in the other lagoons in the Kızılırmak Delta during previous studies (Gündüz, 1991a, 1991b; Demirkalp et al., 2004; Bekleyen and Taş, 2008; Saygı et al., 2011; Ustaoğlu et al., 2012). In terms of the quantitative and species composition of the Cladocera group in Lake Karaboğaz, it is thought to be more similar to that of Lake Liman in the delta. In previous studies, *C. sphaericus* was the permanent and dominant species (35–2017 ind/m^3) within the cladoceran group found in low densities in Lake Liman (Saygı et al., 2011). The studies conducted in brackish lakes showed that the dominant species in the cladoceran group were small organisms such as *Bosmina* and *Chydorus* (Jeppesen et al., 1994; Brucet et al., 2009). In addition, it was reported that the *Daphnia* species were not present at salinities of >2‰, with the exception of *Daphnia manga* (Jeppesen et al., 1994). In the lagoons located in the Mediterranean Catalonia region, *Simocephalus vetulus* appeared at salinities of >5‰. Moreover, in lagoons dominated by planktivorous fish, higher fish predation results in the dominance of small-sized Cladocera species in the zooplankton. In accordance with the findings of these studies, the record of only small-sized species of the cladoceran group in Lake Karaboğaz is thought to be associated with salinity (Brucet et al., 2009) and predation pressure of planktivorous fish species (Brooks and Dodson, 1965; Murtaugh, 1989).

The copepods in Lake Karaboğaz quantitatively comprise only 1% of the zooplankton. *Calanipeda aquaedulcis*, *Cyclops vicinus*, and *Eurytemora velox* detected in Copepoda are euryhaline species that have been identified before in the Kızılırmak Delta (Remane and Schlieper, 1971; Gündüz 1991a, 1991b; Demirkalp et al., 2004; Bekleyen and Taş, 2008; Saygı et al., 2011). However, *Paracyclops fimbriatus* is a new record for this lake. Despite *Paracyclops fimbriatus* (82–256 ind/m^3) and *Eurytemora velox* (35–175 ind/m^3) being the dominant species in the copepods, their individual densities are at a very low level (Table 2). Although nauplius and copepodite stages of the organisms were detected in almost all samples, the quantitative contribution of the adult copepod to the zooplankton is very low, and this phenomenon was also observed in Lake Liman (Saygı et al., 2011). The results of the studies conducted in the Mediterranean Catalonia lagoons show that *Calanipeda aquaedulcis* and *Eurytemora velox* are prevalent at salinities of >20‰ (Brucet et al., 2009). The low number of individuals of these 2 euryhaline species encountered in Lake Karaboğaz can be explained by the fact that the salinity of the lake is too low for these 2 species. In addition, the scarcity of copepods is attributed to limited food resources and to fish predation, following the model observed at the Massa lagoon located along the southeast coast of Morocco and dominated by the rotifer zooplankton group (Badsi et al., 2010). Therefore, these 2 factors might have led to the low density of copepods in Lake Karaboğaz.

Seasonal changes in the species-individual distributions were evaluated using the Shannon–Weaver diversity index. The relationship between salinity, temperature, and chlorophyll *a* values were examined using correlation analysis. The lowest diversity of 0.91 was found in February and the highest value of 2.54 was detected in December (Figure 4). The results of the correlation analysis showed that there was a strong negative correlation between salinity and diversity ($r = -0.67$). In the analysis, a positive correlation was detected between diversity and the variables of chlorophyll *a* and temperature ($r = 0.323$ for temperature and $r = 0.280$ for chlorophyll *a*).

A canonical correspondence analysis (CCA) was applied to explore the distribution of the zooplankton communities in relation to the environmental parameters. Species whose occurrence frequency was less than 63% were excluded from the CCA. All continuous environmental variables were log-(1 + x) transformed. The statistical significance of the CCA was determined using Monte Carlo permutations, and the level of significance was set at $P < 0.05$. The biplot of the first 2 CCA axes is shown in Figure 5. For clarity, only species whose occurrence frequency was more than 63% are displayed in the plot. The first 2 axes explain 68.5% of the variance in the species–environment relationships. Among the variables included in the CCA, salinity (Sal), electrical conductivity (EC), and water temperature were significant ($P < 0.05$), and the eigenvalue of axis 1 was 0.119, which accounts for 49.1% of the total variance. Figure 5 shows that zooplankton species distribution was strongly related to water salinity and temperature. Based on the first 2 axes, the species distribution is mainly ordered according to the gradients of salinity and temperature.

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