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Research Article

Seasonal patterns of the zooplankton community in the shallow, brackish Liman Lake in Kızılırmak Delta, Turkey

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Abstract: The present study reports on the zooplankton community in Liman Lake based on field studies carried out between October 2002 and March 2004. A total of 35 zooplankton taxa, belonging to Rotifera (28), Cladocera (5), and Copepoda (2), were identified. Rotifera was the dominant group in all sampling surveys and accounted for 97% of the zooplankton density in the lake. The average total zooplankton abundance ranged from 993 to 476,912 ind/m3. The maximum and the minimum densities were measured in April and August of 2003, respectively. Seasonal fluctuations of zooplankton found in the current study disagreed with the Plankton Ecology Group (PEG) model. During the study period, only rotifer species were found to be quantitatively dominant in the zooplankton community. Quantitative contributions of Cladocera and Copepoda to the zooplankton community were insignificant. *Keratella quadrata, Keratella cochlearis,* and *Hexarthra oxyuris* were the dominant species and were present during the whole year. Shannon's diversity index ranged from 0.61 to 1.67.

Key words: Lake Liman, brackish lake, zooplankton, seasonal distribution, Turkey

Kızılırmak Deltası'nda bulunan sığ-acısu karakterli Liman Gölü'nün zooplankton kommünitesinin mevsimsel değişimi

Özet: Liman Gölü'nün zooplankton kommunitesi Ekim 2002 ve Mart 2004 tarihleri arasında yapılan arazi çalışmalarında tespit edilmiştir. Rotifera'dan 28, Cladocera'dan, 5 ve Copepoda'dan 2 olmak üzere toplam 35 takson teşhis edilmiştir. Örnekleme yapılan tüm aylarda Rotifera grubu sayısal olarak baskın bulunmuş ve Liman Gölü'nde zooplanktonun % 97'sinin rotiferlerden meydana geldiği belirlenmiştir. Zooplankton birey yoğunluğu minimum 993 birey/m3 ve maksimum 476.912 birey/m3 olarak tespit edilmiş, maksimum yoğunluk nisanda, minimum yoğunluk ise Ağustos aylarında görülmüştür. Zooplanktonda meydana gelen mevsimsel değişimler Plankton Ekoloji Grubu (PEG) modeline uygun olarak gerçekleşmemiştir. Tüm çalışma boyunca Liman Gölü'nde sadece Rotifera grubuna bağlı türler farklı oranlarda sayısal olarak baskın bulunmuştur. Cladocera ve Copepoda grubuna bağlı türlerin zooplantona olan sayısal katkısı çok düşük oranlarda kalmıştır. *Keratella quadrata, Keratella cochlearis, Hexarthra oxyuris* perennial dominant türler olarak belirlenmiş, çeşitlilik indeksi (Shannon) 0,61 ile 1,67 arasında hesaplanmıştır.

Anahtar sözcükler: Liman Gölü, acısu gölü, zooplankton, mevsimsel değişim, Türkiye

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Introduction

The Kızılırmak Delta is located in the central Black Sea region of northern Turkey and covers an area of 50,000 ha, which includes freshwater marshes, swamps, coastal lagoons, and lakes. The delta is one of the most important coastal wetland complexes of the Black Sea, with its rich biodiversity and critical habitat for globally endangered bird species (e.g. *Pelicanus crispus*, *Oxyura leucocephala*, *Branta ruficollis*, *Aythya nyroca*, *Aquila heliaca*) (Hustings and Dijk, 1993). The delta is included in the "Important Bird Areas" (IBA) list of Europe by Bird Life International (Grimmet and Jones, 1989). It is a national biodiversity hotspot with more than 310 bird species, encompassing 75% of all known bird species in Turkey. Because of these characteristics, the delta has recently been declared as a Ramsar Site and a Wetland of International Importance by the Ministry of Environment and Forestry in Turkey (Magnin and Yarar, 1997).

Liman Lake is located on the northwestern side of the Kızılırmak Delta (between 41°44′N and 35°40′E). It is a brackish lake connected to the Black Sea through a narrow sandy barrier in the north. Liman Lake's water level is mainly controlled by direct freshwater discharge from the drainage channel flowing diffusely from the south (Figure 1). The presence of a freshwater input causes a progressive accumulation of nutrients and organic contents in the lake. The water level of the lake drops by approximately 50-110 cm during the dry period and seawater penetrates into the lake through the surface or underground (Demirkalp et al., 2010). The lake is small (200 ha of surface area), shallow (2.3 m in mean depth), and triangular in shape. It gradually deepens from the south to the north, reaching a maximum of 3.75 m in depth at station 3 (Demirkalp et al., 2010). The south, the southwest, and the southeast of the lake are surrounded by reed beds (*Phragmites australis*). In the south and the middle parts of the lake, the bottom is covered by submerged vegetation (e.g. *Potamogeton perfoliatus*, *Potamogeton pectinatus*, *Potamogeton nodosus*, *Chara vulgaris*). Submerged vegetation has nearly disappeared in the north due to the depth of the lake and the increased salinity of the water (Demirkalp et al., 2010).

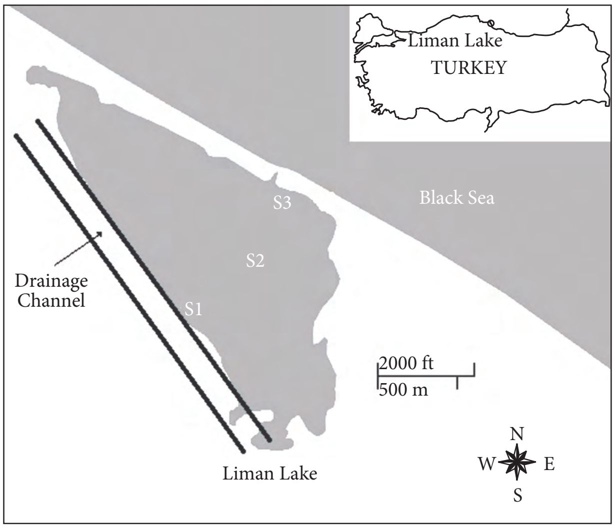

Figure 1. Map of Liman Lake, drainage channel, and sampling stations.

Brackish lakes and lagoons are numerous in many parts of the world (Irvine et al., 1990; Moss, 1994), but information on the factors controlling taxon richness and trophy structure in such lagoons is scarce. Previous studies of Mediterranean coastal wetlands have already demonstrated the strong influence of hydrology on zooplankton communities (Oltra and Miracle, 1992; Quintana et al., 1998). A key structuring factor for invertebrate communities in brackish lagoons is salinity, and decreased species richness has been found with increasing salinity (Schallenberg et al., 2003).

The increasing anthropogenic factors since the 1950s, including urban and agricultural pollution, housing development, and coastal erosion, have seriously threatened the wildlife in the Kızılırmak Delta, causing degradation in the ecosystem. The irrigation channel project managed by the State Water Department (DSI, 1986) caused detrimental effects on the lake's ecosystem and biota due to deep changes in the water regime of the delta and residual irrigation water from regional agricultural areas being brought into the lakes. Liman Lake is one of the water bodies in the delta most affected by regional agricultural activities due to the irrigation channel in the southern part of the lake (Figure 1). In spite of the fluctuating environmental features and the man-made changes introduced into this ecosystem, no specific study has been carried out in Liman Lake prior to the current study. The aim of this paper was to determine the zooplankton community and to establish how the change in the hydrological pattern determines zooplankton dynamics and structure in Liman Lake.

Materials and methods

Based on geographic peculiarities, 3 locations were chosen in the lake as sampling stations. The first (S1) was located in an area covered with macrophytes but heavily affected by irrigation channel discharge, the second (S2) was in the central part of the lake, and the third (S3) was positioned in the connection point to the sea (Figure 1). During the study period, Liman Lake was visited 13 times, between October 2002 and March 2004. Zooplankton was sampled at a depth of 25 to 30 cm using plankton nets with mesh sizes of 30 and 55 µm, and the samples were preserved in 4% formaldehyde. Zooplankton species were identified based on the keys present in the current literature (Kiefer, 1952, 1955, 1978; Dussart, 1967, 1969; Koste, 1978; Pennak, 1978; Negrea, 1983). For quantitative analyses, the number of each species found in a 1-mL aliquot of the field-collected zooplankton concentrate was counted, and then the data were later converted to the actual quantity of water filtered from the lake. For each sample, 3 or 4 aliquots were used. Furthermore, various physical and chemical variables were measured at the time of sampling. The detailed methodologies of the physical and chemical analysis can be found in the work of Demirkalp et al. (2010).

Results and discussion

Liman Lake has some different properties of hydrological and ecological process as compared to the other lakes in the Kızılırmak Delta. The exceptional status of the lake is due to its close proximity to the sea, and also due to freshwater entrance and nearby agricultural activities. Liman Lake is the closest wetland to the sea among the lagoons in the eastern region of the Kızılırmak Delta. While the other lagoons in the region may establish connections to each other in the rainy periods, Liman Lake is completely isolated. The drainage channels that transport the irrigation water, including agricultural wastes into the lake, are located south of Liman Lake, as well as around the other lagoons. Liman Lake differs from the other lagoons because it has a direct connection to the Black Sea. There is an entrance for fresh water into the lake in the southern part and an entrance for sea water in the northern part, simultaneously. The situation caused by the flowing fresh water, carrying rich nutrient sources, and by high salinity degrees, reached after the entrance of sea water, results in a negative effect on the food chain.

Data related to the main biological and environmental components of Liman Lake were given by Demirkalp et al. (2010). The presence of freshwater and sea water inputs caused a progressive accumulation of salts, total nutrients, and organic contents in the lake. The salinity of the lake was between 1.96‰ and 4.06‰; thus, it should be classified as mixooligohaline brackish water according to the Venice System (Remane and Schlieper, 1971). The circulation pattern of the lake is polymictic. In Liman Lake, the water inputs from station 1 determined the entry of dissolved inorganic nitrogen into the lagoon (Demirkalp et al., 2010). It was noteworthy that the ammonia concentration was recorded at between 0.018 and 19.15 mg/L, hazardous levels according to the Council of the European Union Directive (EC, 1998). The phytoplankton community structure and dynamics in Liman Lake exhibited a pattern typical to eutrophic water bodies. The chlorophyll a concentration of Liman Lake ranged from 5 to 50 µg/L, with a mean value of 19.7 µg/L (Figure 2). A cyanophyta bloom occurred during summer, and Chlorophyta showed dominance in the autumn and fall (Demirkalp et al., 2010).

The list of zooplankton species found in Liman Lake during the study period is summarized in the Table. The richness of Rotifera, Cladocera, and Copepoda was 28, 5, and 2, respectively. Overall, 74 zooplankton species (43 Rotifera, 23 Cladocera, and 8 Copepoda) were identified in the lagoons of the Kızılırmak Delta (Gündüz, 1989, 1991a, 1991b; Emir, 1990; Demirkalp et al., 2004; Bekleyen and Taş, 2008), approximately 50% of which were recorded in Liman Lake. The zooplankton composition of Liman Lake displayed clear differences compared

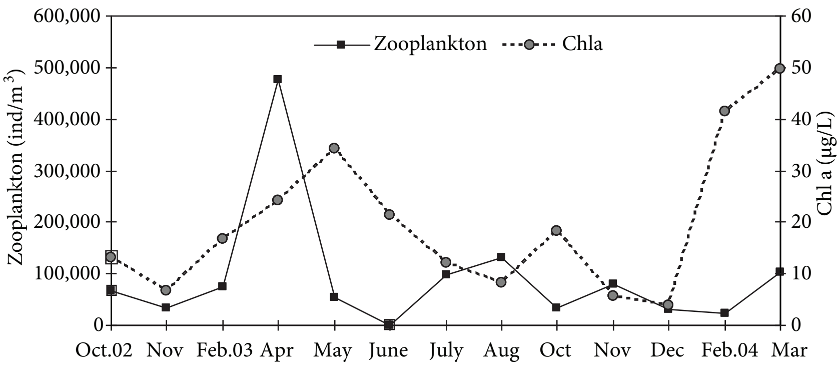

Figure 2. Mean zooplankton abundance and chlorophyll a in Liman Lake, October 2002 to March 2004.

to the other lakes (Table). Only 5 Cladocera and 2 Copepoda species were present in Liman Lake (Table), and the quantitative contribution of these taxa to the zooplankton was very low. This pattern is very different compared to other lakes, in which Cladocera and Copepoda contributed an important amount of richness. Freshwater or sea water input, mixture degree, stratification, and environmental variables such as salinity and temperature can lead to spatial and seasonal zooplankton heterogeneity in lagoons (Joyce et al., 2005). Consequently, the reason for the differences could be attributed to more saline conditions and the lower trophy status of Liman Lake. The Bafra Balık Lakes exhibit similar properties as Çernek Lake based on species composition and seasonal distribution of zooplankton (Demirkalp et al., 2004). This resemblance could also be strongly related to the connection between the Bafra Balık Lakes and Çernek Lake in the rainy seasons, and similar salinity conditions in the lakes. Contrary to the other 2 lakes, Liman Lake is an isolated lake in the Kızılırmak Delta and the sea water effect is stronger. In this respect, it is possible to say that Liman Lake has its own zooplankton community and structure.

In Liman Lake, 8 rotifer species (e.g. *Keratella quadrata*, *K. cochlearis*, *Polyarthra vulgaris*, *Brachionus calyciflorus*, *B. quadridentatus*, *B. urceolaris*, *B. angularis*, *Filinia longiseta*), which might be indicators of eutrophic conditions (Gannon and Stemberger, 1978), were identified. The ratio of *Brachionus* to *Trichocerca* ($Q_{B/T}$) was 2.5 in Liman Lake, and this value corresponds to eutrophic conditions (Sládecek, 1983). Perennial species such as *Keratella quadrata* and *Keratella cochlearis*, which are euryhaline and adapted to high salinity fluctuations (Ramdani et al., 2001), were dominant in this lake. Another perennial species, *Hexarthra oxyuris*, an organism typically found in brackish waters, was found among the dominant species in Liman Lake. Although *Brachionus angularis*, *Trichocerca stylata*, *Polyarthra vulgaris*, and *Synchaeta pectinata* are widely distributed in freshwater biotopes (May and O'Hare 2005; Bjørklund, 2009), these species have successfully adapted to the brackish water of Liman Lake.

Rotifera was the dominant group during the entire study period and accounted for 96.7% of the zooplankton density in the lake. Cladocera and Copepoda were the least abundant groups in terms of density. The sampling in Liman Lake revealed large seasonal variations in zooplankton abundance (Figure 2). The mean total zooplankton abundance ranged from 993 to 476,912 ind/m^3, which peaked in April and dropped in August (Figure 2). Despite the favorable phytoplankton biomass, a distinct zooplankton increase was not recorded in May-June 2003 or March 2004, which could be a result of the high salinity of the lake (above 4‰). Therefore, it is possible to state that the seasonal distribution of zooplankton was mainly controlled by temperature and/or salinity in the lake. In the temperate zone, seasonal variations of zooplankton communities are usually explained with a Plankton Ecology Group (PEG) model (Sommer et al., 1986). According to

Table. List of zooplankton species found in Liman Lake during the present study and a list of species recorded in previous studies in some lagoons from the Kızılırmak Delta.

ROTIFERA	**1**	**2**	**3**	**CLADOCERA**	**1**	**2**	**3**
Asplanchna girodi de Guerne, 1888	–	+	–	*Alona rectangula* Sars, 1862	+	+	+
Asplanchna priodonta Gosse, 1850	+	–	–	*Alonella excisa* (Fischer, 1854)	+	–	+
Asplanchna sieboldii (Leydig, 1854)	+	+	–	*Bosmina longirostris* (O.F.Müller, 1775)	+	+	–
Asplanchnopus dahlgreni Myers, 1934	+	–	–	*Ceriodaphnia dubia* Richard, 1894	+	+	–
Brachionus angularis Gosse, 1851	+	+	+	*Chydorus latus* Sars, 1862	+	–	–
Brachionus calyciflorus Pallas, 1766	+	+	+	*Chydorus sphaericus* (O.F.Müller, 1776)	–	+	+
Brachionus plicatilis Müller, 1786	–	+	+	*Daphnia curvirostris* Eylmann, 1887	–	+	–
Brachionus quadridentatus Hermann, 1783	+	–	+	*Daphnia galeata* Sars, 1864	+	+	–
Brachionus rubens Ehrenberg, 1838	+	–	–	*Daphnia longispina* O.F.Müller, 1785	+	+	–
Brachionus urceolaris Müller, 1773	+	–	+	*Daphnia magna* Straus, 1820	+	+	–
Cephalodella gibba (Ehrenberg, 1830)	+	–	–	*Daphnia ulomskyi* Behning, 1941	–	+	–
Colurella adriatica Ehrenberg, 1831	–	–	+	*Diaphanosoma brachyurum* (Liévin, 1848)	+	–	–
Colurella colurus (Ehrenberg, 1830)	–	–	+	*Diaphanosoma lacustris* Kořínek, 1981	–	+	–
Euchlanis dilatata Ehrenberg, 1832	–	–	+	*Ilyocryptus samsuni* Gündüz, 1990	+	–	–
Filinia longiseta (Ehrenberg, 1834)	+	+	+	*Leydigia acanthocercoides* (Fischer, 1854)	+	–	–
Filinia terminalis (Plate, 1886)	+	–	+	*Leydigia leydigi* (Schoedler, 1863)	+	+	–
Hexarthra fennica (Levander, 1892)	–	+	–	*Macrothrix laticornis* (Fisher, 1848)	+	–	–
Hexarthra intermedia (Wiszniewski, 1929)	+	–	–	*Moina micrura* Kurz, 1874	+	+	–
Hexarthra mira (Hudson, 1871)	+	–	–	*Oxyurella tenuicaudis* (Sars, 1862)	+	–	–
Hexarthra oxyuris (Sernov, 1903)	–	–	+	*Pleopis* sp.	–	–	+
Keratella cochlearis (Gosse, 1851)	+	+	+	*Pleuroxus aduncus* (Jurine, 1820)	+	+	–
Keratella quadrata (Müller, 1786)	+	+	+	*Pleuroxus trigonellus* (O.F. Müller, 1785)	–	–	+
Keratella tropica (Apstein, 1907)	+	+	+	*Simocephalus vetulus* (O.F. Müller, 1776)	+	+	–
Lecane bulla (Gosse, 1851)	–	+	+	**COPEPODA**			
Lecane closterocerca (Schmarda, 1859)	–	–	+	*Acanthocyclops robustus* (G.O.Sars, 1863)	+	+	–
Lecane imbricata Carlin, 1939	+	–	–	*Calanipeda aquaedulcis* Kritschagin, 1873	+	–	+
Lecane luna (Müller, 1776)	+	–	+	*Cyclops strenuus divergens* (Lindberg, 1956)	+	–	–
Lepadella ovalis (Müller, 1786)	+	–	–	*Cyclops vicinus* Uljanin, 1875	+	+	–
Lepadella patella (Müller, 1773)	–	–	+	*Diacyclops bicuspidatus* (Claus, 1857)	+	–	–
Mytilina mucronata (Müller, 1773)	–	+	–	*Eudiaptomus arnoldi* (Siewerth, 1928)	+	–	–
Notholca acuminata (Ehrenberg, 1832)	+	+	+	*Eurytemora velox* (Lilljeborg, 1853)	+	+	–
Notholca squamula (Müller, 1786)	–	–	+	*Mesochra aestuarii* Gurney,1921	+	–	+
Philodina megalotrocha Ehrenberg, 1832	–	–	+				
Polyarthra dolichoptera Idelson, 1925	+	–	+				
Polyarthra vulgaris Carlin, 1943	+	+	+				
Rotaria neptunia (Ehrenberg, 1830)	+	–	–				
Synchaeta pectinata Ehrenberg, 1832	–	+	+				
Synchaeta sp.	–	–	+				
Testudinella patina (Hermann, 1783)	–	+	–				
Trichocerca elongata (Gosse, 1886)	–	+	–				
Trichocerca longiseta (Schrank, 1802)	–	–	+				
Trichocerca stylata (Gosse, 1851)	–	+	+				
Trichotria pocillum (Müller, 1776)	+	–	+				
Trichotria tetractis (Ehrenberg, 1830)	+	–	–				

1: Bafra Balık Lakes (Emir, 1990; Gündüz, 1991a, 1991b), 2: Çernek Lake (Demirkalp et al., 2004; Bekleyen and Taş, 2006), and 3: Liman Lake (Demirkalp et al., 2010).

this model, such a succession from small to large zooplankton occurs from spring to early summer. However, it was difficult to explain seasonal variations in the zooplankton community according to this model in Liman Lake. During the study period, only rotifer species were found to be quantitatively dominant in the zooplankton community. The annual composition/abundance of rotifers (Figure 3) is known to be influenced by temperature, favorable food, and environmental conditions (Edmondson, 1965; Dumont, 1977; Herzig, 1987). Therefore, a rapid increase in *Keratella quadrata* in April (399,712-561,811 ind/m^3) could be related to sufficient food conditions and rising temperature in the current study. Afterwards, the Rotifera population suddenly decreased in May and June, in spite of favorable temperatures and food supply. The declining period of rotifers coincided with the maxima of *Calanipeda aquaedulcis* (1362-2831 ind/m^3) and copepodite (334-1328 ind/m^3) populations (Figure 4). It is known that calanoid copepods are potential predators of Rotifera (Williamson and Butler, 1986), and most freshwater fish also feed on zooplankton at some stage of their lives (Herzig, 1987). Therefore, declining Rotifera in this period may be related to Copepoda predation. *Cyprinus*

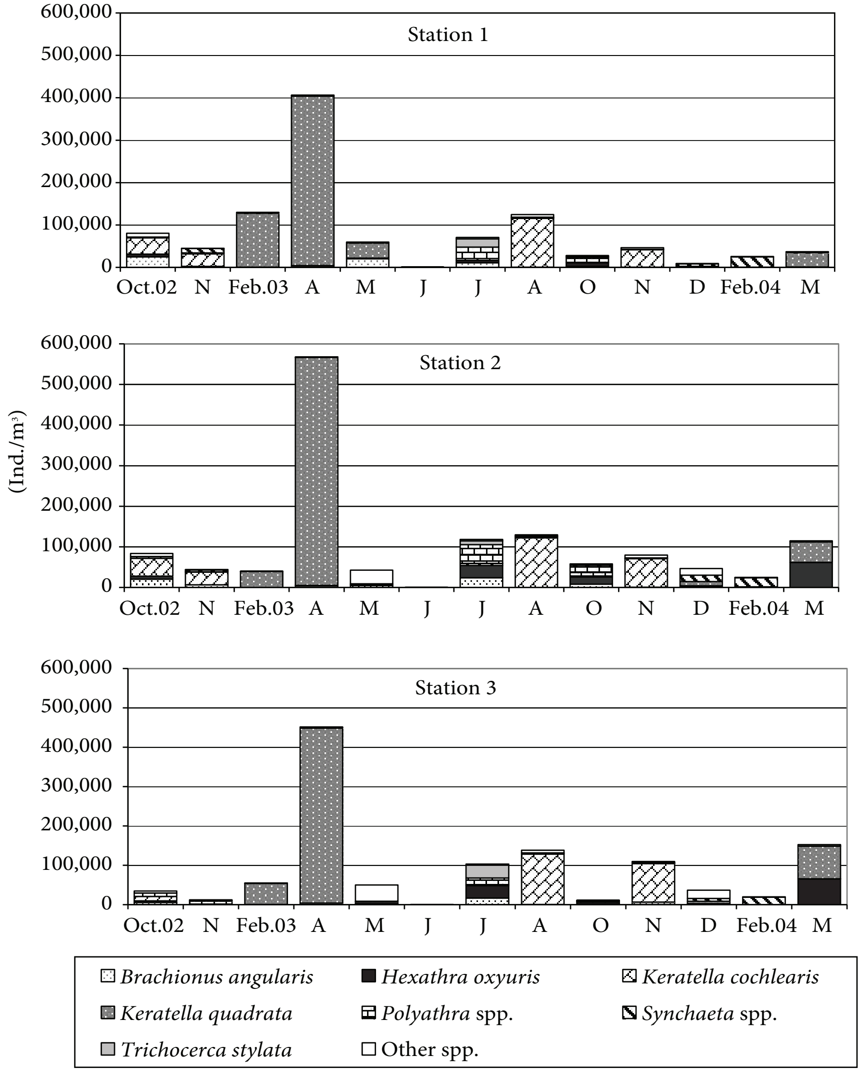

Figure 3. Seasonal distribution of dominant Rotifera species during the study period at the 3 stations in Liman Lake.

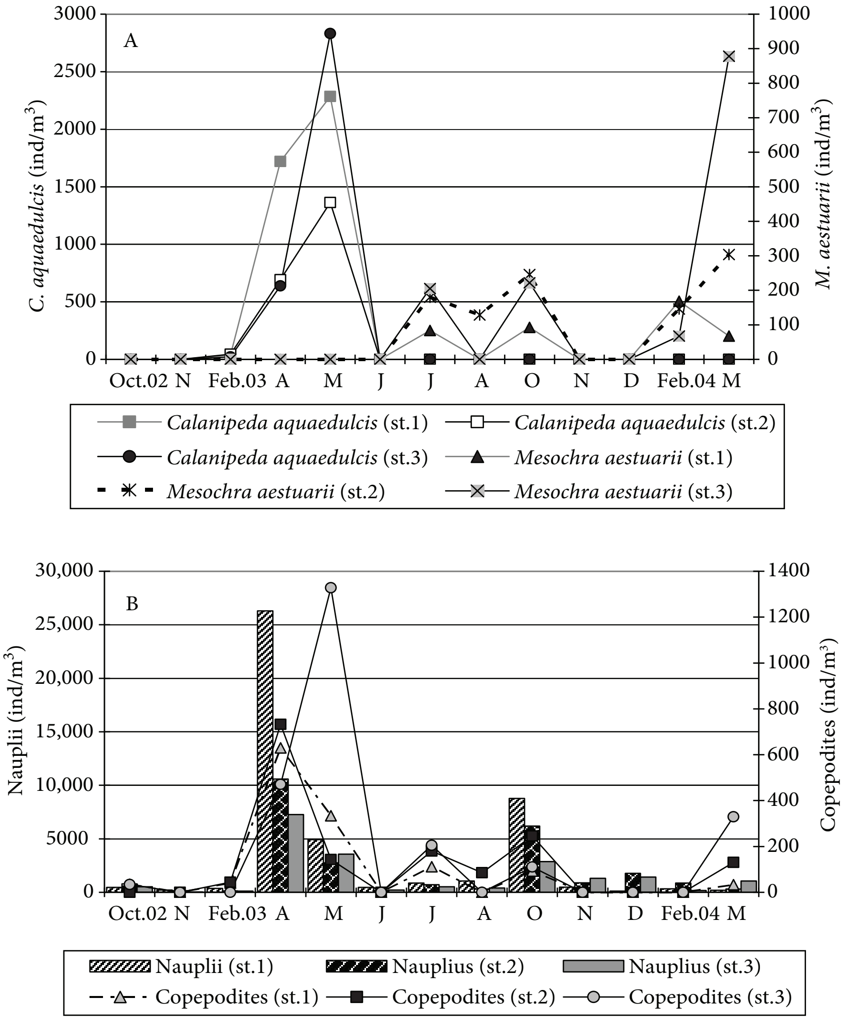

Figure 4. Seasonal distribution of main copepod species at the 3 sampling stations: A) adults and B) nauplii and copepodites.

carpio, *Mugil cephalus*, *Carassius carassius*, *Sander lucioperca*, and *Scardinius erythrophthalmus* were the most abundant species in Liman Lake (Demirkalp et al., 2006). Such a decline may also be the result of predation by these species, which are often active during the late spring and early summer (Brooks and Dodson, 1965; Hall et al., 1976). During the summer period, except for June, the phytoplankton community was mainly composed of Cyanophyta, especially *Chroococcus minutus*, *Phormidium* sp., *Phormidium tenue*, and *Spirulina major* (Demirkalp et al., 2006). Mayer et al. (1997) stated that rotifers played an important role as herbivorous components when the phytoplankton was composed of smaller forms. Indeed, the Rotifera increase was parallel to the development of small Cyanophyta forms during the summer period in Liman Lake. A heterogeneous species composition appeared in July and the main Rotifera species in the community were *Hexarthra oxyuris*, *Polyarthra* spp., *Trichocerca stylata*, and *Brachionus angularis*. In July, rotifer abundance and species composition also indicated a significant variation between sampling stations. The salinity pattern was very variable among the stations, and station 1 was found to be significantly different in this respect between July and November. While salinity measured between 1.5‰ and 1.9‰ at station 1, this value was between 2‰ and 3.6‰ at stations 2 and 3 at the stated periods (Demirkalp et al., 2006). Probably related to the higher salinity conditions, *Hexarthra oxyuris* was found in large amounts at stations 2 and 3. Subsequently, in August, the *Keratella cochlearis* abundance increased. The decrease in Rotifera density in October was observed simultaneously with the development of *Mesochra aestuarii* and copepodite populations. *Filinia terminalis* showed a single peak in April and *Synchaeta* spp. was recorded in the winter months (Figures 3 and 4).

Seasonal distribution of the Copepoda species, including nauplii and copepodites, is presented in Figure 4. Nauplii were found in all samples, whereas adult calanoid *Calanipeda aquaedulcis* were recorded in only 3 of the samplings (22-2831 ind/m^3) between February and May of 2003. Nauplii reached a maximum in April (7264-26,306 ind/m^3) and in October (2282-8781 ind/m^3). Boix et al. (2005) reported that *Calanipeda aquaedulcis* was positively correlated to the oligotrophic conditions. On the contrary, we recorded *C. aquaedulcis* when chlorophyll a levels was over 20 µg/L (Figures 2 and 4). The other copepod species, *Mesochra aestuarii*, was recorded more frequently, but in low densities (84-878 ind/m^3). Although *Calanipeda aquaedulcis* and *Mesochra aestuarii* are characterized as euryhaline species (Remane and Schlieper, 1971), the low density of these organisms was presumably due to size-selective predation by planktivorous fish on larger zooplankton in the current study (Brooks and Dodson, 1965; Hall et al., 1976).

A total of 5 species of Cladocera (*Alona rectangula*, *Alonella excisa*, *Chydorus sphaericus*, *Pleuroxus trigonellus*, and *Pleopis* sp.) were identified in this brackish water system. A perennial species, *C. sphaericus*, occurred at concentrations of 35-2017 ind/m^3. *C. sphaericus* reached a maximum during the summer (Figure 5). With the exception of *C. sphaericus*, the other Cladocera species were recorded in very low abundances. Large-bodied Cladocera species were not found during the study period, which might be due to the salinity (Brucet et al., 2009), selective predation by planktivorous fish on larger zooplankton, and insufficient food availability during mid-late summer (Brooks and Dodson, 1965; Hall et al., 1976; Murtaugh, 1989).

Diversity in Liman Lake ranged from 0.61 to 1.67; it was generally lower during cold months and higher during warm months. Hofmann (1975) also stated positive relationships between diversity and

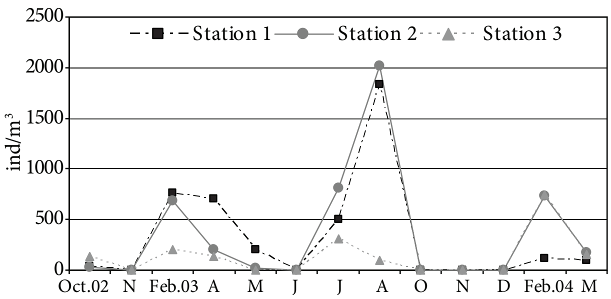

Figure 5. Seasonal distribution of *Chydorus sphaericus* at the 3 sampling stations during the study period at Liman Lake.

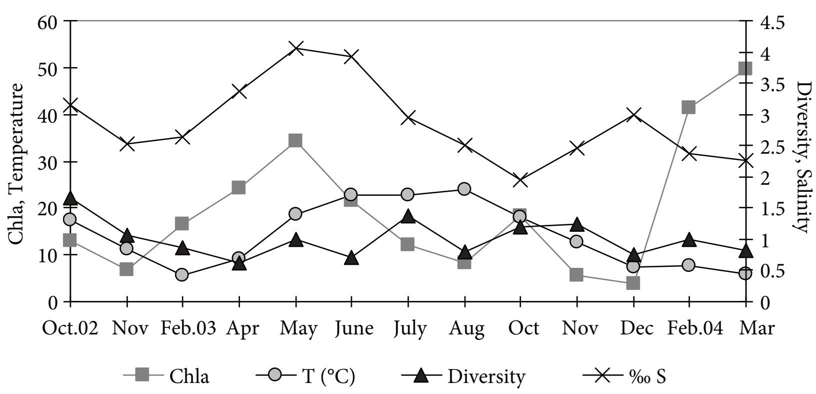

Figure 6. Seasonal distribution of the diversity in zooplankton, relationship between diversity, temperature (°C), chlorophyll a (Chl a, µg/L), and salinity (‰).

temperature. Nevertheless, temperature does not seem to be the only factor affecting zooplankton diversity in Liman Lake. Despite high temperatures, the diversity in some months was found to be low, probably depending on changing salinity and food concentrations (Figure 6).

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