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Impacts of environmental factors on zooplankton taxonomic diversity in coastal lagoons in Turkey

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Abstract: Lagoons are valuable ecosystems providing various services, such as fishing, recreational activities, and land reclamation, as well as hosting high biodiversity. Although lagoons in Turkey cover a coastal area of more than 36,000 ha, few studies of them have been conducted. Therefore, two lagoons (Dalyan and Arapçiftliği) located on the coast of the Sea of Marmara in the Kocaçay Delta, which is under intense anthropogenic pressure, were investigated between November 2013 and March 2015 to examine the effects of environmental factors on taxonomic diversity. In addition, ongoing high nutrient flow from the Karacabey region triggers eutrophication in the lagoons, thus causing low water transparency. In both lagoons, the zooplankton assemblages were mainly dominated by cosmopolite and eurytopic taxa. Calanoid copepod *Acartia clausi* was the dominant species in both lagoons and showed seasonal variation, while no seasonality appeared in nauplii. The high abundance of rotifer species of the genera *Keratella* and *Brachionus* reflects the harsh conditions in the lagoons, caused by cultural eutrophication, dystrophy, and salinity increase and also by the temperature-enhanced decrease in zooplankton evenness and richness. Flushing rate, precipitation, high temperature, and salinity influence the species composition, which shifted to a greater dominance by hypoxia/salinity-tolerant zooplankters, resulting in lower species diversity in the lagoons.

Key words: Zooplankton, lagoon, species diversity, salinity, Mediterranean

1. Introduction

Coastal lagoons are transitional zones between the landscape and the sea and are often considered as hotspots for biodiversity and usage for transportation, recreation, and food production (aquaculture) (Anthony et al., 2009). Mediterranean coastal lagoons are strongly influenced by natural disturbances such as flooding and summer drought, which result in fluctuations of water temperature, salinity, and trophic state (Cataudella et al., 2015). In addition, the structure and function of these highly resilient and productive systems are further subjected to anthropogenic activities. Land-use change, fluctuations of ground and surface water sources, sedimentation, overfishing, and water pollution have significant impacts on lagoons (EPA, 2007; Khan, 2007; Bilkovic and Roggero, 2008; Hollister et al., 2008).

According to climate change projections, ongoing changes in temperature and precipitation patterns are expected to increase the occurrence of extreme events such as reduction in runoff, particularly in the Mediterranean climate zone (IPCC, 2007, 2014; Giorgi and Lionello, 2008; Pekel et al., 2016). In addition, changes in precipitation patterns can have severe impacts on lagoons due to the modification of freshwater inputs and salinity changes via sea water intrusion as a result of sea-level rise (Schallenberg et al., 2003; Milly et al., 2005). The phenology of aquatic organisms (e.g., becoming active earlier for zooplankton) will also be affected by temperature increases (Edwards and Richardson, 2004). Since zooplankton has a quick response to natural disturbances occurring in lagoons, it may be very useful for the monitoring of environmental changes in these systems. In the food web, zooplankters act not only as consumers of primary producers but also as food for invertebrate organisms (Hoxmeier and Wahl, 2004; Piasecki et al., 2004).

Natural and anthropogenic disturbances (e.g., hydrology, nutrient enrichment, land-use, salinity increase) may strongly influence zooplankton species composition in lagoons (Quintana et al., 1998; Gilabert, 2001; Badosa et al., 2007; Brucet et al., 2010). A cross-comparison of coastal lagoons between cold temperate areas and the Mediterranean climate revealed that salinity

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has a major effect on the zooplankton community (Brucet et al., 2009). Salinity, as an indirect effect of climate change in lagoons, enhances a decrease in species richness (Moss, 1994; Jeppesen et al., 1994, 2007; Boix et al., 2008). Furthermore, the trophic structure of lagoons showed differences compared to freshwater lakes, particularly in Mediterranean region, i.e. zooplankton size structure composed of small-sized individuals reflecting high fish predation (Brucet et al., 2005). Along the salinity gradient fish community composition may change to small planktivorous fish with several cohorts per year, enhancing top-down control of zooplankton (Jensen et al., 2010).

Although Turkey is a coastal country, with a shoreline spanning about 7816 km with 72 lagoons, a relatively small number of studies have been conducted on its lagoon ecosystems (e.g., Demirhindi, 1972; Emir, 1990; Gündüz, 1991a, 1991b; Demirkalp et al., 2010; Özçalkap and Temel, 2011; Ustaoğlu et al., 2012; Yılmaz, 2015; Alp et al., 2016). The most comprehensive review from 35 lagoons in Turkey on the observation of zooplankton taxa reported 125 taxa including 64 from Rotifera, 24 from Cladocera, 32 from Copepoda, and 5 from Ostracoda (Ustaoğlu et al., 2012). However, there are still limited data on the relationship between the trophic state and community structure of the lagoons in Turkey. This study aims to overcome the lack of information and to gain a better understanding of the relationship between environmental variables and zooplankton of the Dalyan and Arapçiftliği lagoons, which are highly influenced by anthropogenic stress such as irrigation, land-use, and nutrient enrichment.

2. Materials and methods

2.1. Study sites

The Dalyan (40°23′15″N, 28°28′23″E) and Arapçiftliği (40°24′35″N, 28°30′42″E) lagoons are in close proximity to Bursa, which is a densely populated city and an industrial heartland of the basin on the southern part of the Sea of Marmara (Figure 1). The Dalyan and Arapçiftliği lagoons are shallow water bodies having maximum depths of <150 cm and <75 cm, respectively. The surface areas of the Dalyan and Arapçiftliği lagoons are 170 ha and 550 ha, respectively (Ustaoğlu et al., 2012). However, the size of the lagoons varies due to natural processes and anthropogenic activities (Irtem and Sacin, 2012). Sand dunes separate the lagoons from the sea during summer, while during winter the sand barrier is destroyed. The margins of the Arapçiftliği Lagoon are covered with extensive salt marshes. The Dalyan Lagoon is surrounded by reed beds and forested area. Extensive emergent macrophytes in both of the lagoons provide refuge for migrating birds such as the American flamingo (*Phoenicopterus ruber* Linnaeus, 1758).

2.2. Field sampling and laboratory analyses

Zooplankton samples were collected monthly from three different stations of each lagoon between November 2013 and March 2015 (Figure 1; Table 1). Although lagoons are very heterogeneous systems, the sampled lagoons did not show high variations regarding salinity between near-sea and near-river input due to small surface areas and human interference. Thus, samples from 3 different stations were pooled. In order to investigate the species composition,

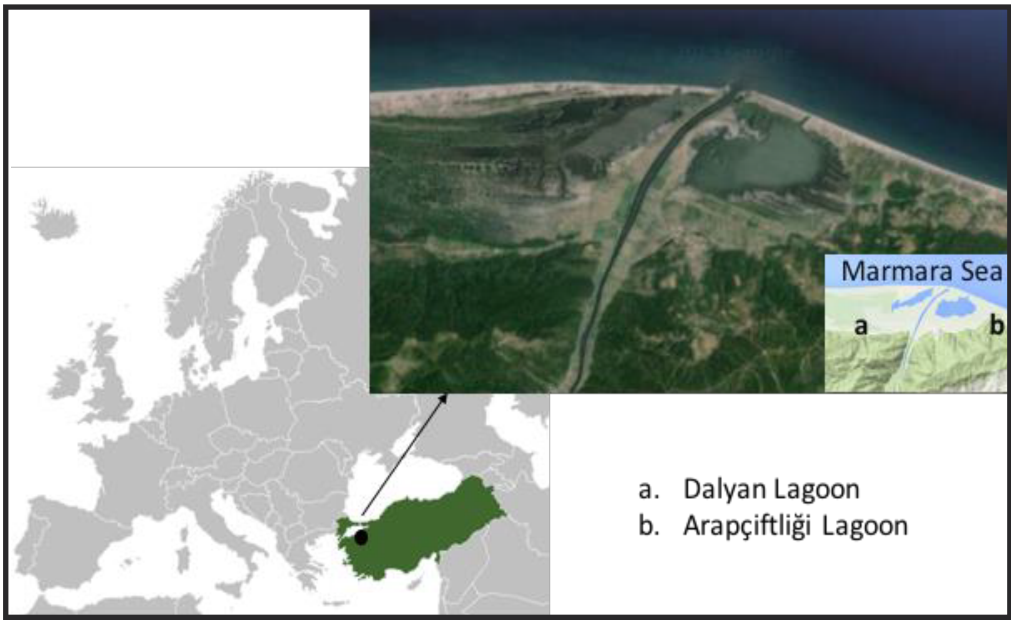

Figure 1. The location of the Dalyan and Arapçiftliği lagoons.

Table 1. General physical and chemical parameters of studied lagoons with standard deviation (±SD) during sampling seasons. Sp: Spring; Su: summer; Au: autumn; Wi: winter.

		Dalyan				Arapçiftliği			
		Sp	Su	Au	Win	Sp	Su	Au	Win
	WTemp. (°C)	16.9 (±8.1)	27.6 (±0.3)	14.2 (±3.7)	12.6 (±0.5)	19.7 (±9.1)	32.4 (±3.6)	14.8 (±8.6)	13.2 (±8.4)
	DO %	70.5 (±25.1)	78.2 (±1.7)	74.9 (±12.5)	70.5 (±31.1)	79.7 (±21.7)	88.6 (±37.8)	96.9 (±19.8)	87.4 (±20.9)
	DO mg L^{-1}	8.1 (±2.7)	5.8 (±0.0)	7.4 (±1.6)	8.5 (±0.9)	7.0 (±1.8)	5.4 (±2.0)	8.6 (±1.9)	8.24 (±1.8)
	EC (mS cm^{-1})	1242 (±337)	1729 (±12)	1472 (±450)	1429 (±128)	2009 (±1260)	4319 (±1089)	3476 (±664)	2644 (±918)
	Salinity ‰	7.2 (±2.1)	10.1 (±0.1)	8.7 (±2.7)	8.3 (±0.8)	12.1 (±8.5)	27.7 (±7.6)	21.8 (±4.5)	16.4 (±6.3)
	Secchi depth (cm)	50 (±14.4)	40 (±0.0)	25 (±3.8)	50 (±4.2)	<10	<10	<10	<10
	pH	8.7 (±0.7)	8.2 (±0.0)	7.8 (±0.4)	8.3 (±0.5)	8.5 (±0.7)	8.1 (±0.3)	7.8 (±0.4)	8.3 (±0.5)
	Chl-*a* (µg L^{-1})	18.5 (±7.6)	30.6 (±11.2)	23.5 (±6.4)	10.7 (±6.4)	10.2 (±5.8)	10.3 (±7.4)	11.8 (±5.7)	9.4 (±5.2)
Anions	Cl^- (meq L^{-1})	99.5 (±2.7)	185.5 (±1.3)	163.1 (±18.7)	162.6 (±18.4)	227.0 (±150.9)	506.1 (±150.6)	382.3 (±82.4)	316.9
	DIN (meq L^{-1})	0.1 (±0.0)	0.2 (±0.1)	0.2 (±0.1)	0.3 (±0.3)	0.01 (±0.0)	2.5 (±0.3)	0.2 (±0.1)	1.0 (±0.9)
	SO^-_4 (meq L^{-1})	8.7 (±0.5)	16.5 (±0.1)	15.1 (±2.2)	14.6 (±1.6)	19.3 (±12.2)	39.9 (±10.4)	33.1 (±5.9)	25.4
	HCO^-_3 (meq L^{-1})	3.9 (±0.8)	5.6 (±0.1)	5.1 (±0.2)	4.5 (±0.5)	4.4 (±0.8)	5.1 (±0.3)	4.7 (±0.8)	5.2
Cations	Na^+ (meq L^{-1})	81.4 (±2.3)	143.1 (±0.6)	128.8 (±16.3)	126.6 (±16.4)	180.7 (±113.2)	379.9 (±107.7)	308.4 (±57.9)	245.2 (±112.9)
	K^+ (meq L^{-1})	1.8 (±0.0)	2.9 (±0.1)	2.8 (±0.4)	2.7 (±0.2)	3.7 (±1.9)	7.4 (±1.6)	5.9 (±1.1)	5.0 (±1.5)
	Mg^+ (meq L^{-1})	22.7 (±1.1)	35.1 (±0.4)	38.9 (±4.3)	40.6 (±3.5)	52.9 (±33.1)	118.4 (±31.7)	102.7 (±21.2)	95.5 (±25.1)
	Ca^+ (meq L^{-1})	8.7 (±0.8)	9.4 (±0.1)	15.8 (±6.8)	15.9 (±5.2)	15.2 (±6.5)	29.2 (±3.7)	29.4 (±8.0)	31.9 (±7.5)

zooplankton samples were collected using a standard plankton net (mesh diameter: 44 µm) by vertical and horizontal hauls and fixed in formaldehyde solution (4%). In addition, to determine the zooplankton abundance, 10 L of water was collected using a tube sampler and filtered through a 20-µm mesh filter, and samples were fixed in Lugol's solution (4%). Zooplankton species were identified and counted under a binocular microscope (Leica DM5000 B) and were identified according to Emir (1994), Koste (1978), Ruttner-Kolisko (1974), Segers (1995), Nogrady and Pourriot (1995), and De Smet (1996, 1997, 1998) for Rotifera and Kiefer (1978), Reddy Ranga (1994), and Dussart and Defaye (2001) for Copepoda. Moreover, lake water temperature (°C), conductivity (mS cm^{-1}), salinity (‰), dissolved oxygen (mg L^{-1}), and pH were measured in situ using the YSI Pro Plus multiprobe system. Water transparency was measured with a 20-cm diameter Secchi disk. From the mixed water collected with a tube sampler, 1.5 L of water sample was collected for chemical (major anions and cations) and biological (chlorophyll *a* (Chl-*a*)) analyses. All chemical analyses were performed in the Water Chemistry Laboratory of Hacettepe University (www.sukimyasilab.hacettepe.edu.tr). The laboratory followed analysis procedures based on those of the American Public Health Association, American Water Work Association, and Water Pollution Control Federation. Chl-*a* was determined using the ethanol extraction method (Jespersen and Christoffersen, 1987) with three replicates and measured at 663 and 750 nm.

2.3. Statistical analyses

Prior to the analyses, log transformation (log10, log10+1) was used to adjust for normality as determined by the Kolmogorov–Smirnov test. To test the differences in zooplankton assemblage structure (i.e. richness, diversity, abundance) due to two factors, 'seasons' (spring, summer, autumn, winter) and 'sites' (Dalyan, Arapçiftliği), we used two-way analysis of variance (two-way ANOVA). The post hoc method for pairwise comparisons was performed since significant effects were found.

In order to investigate the variation in zooplankton species and environmental variables, ordination analysis was used. Species data were transformed using the Hellinger transformation for the ordination analysis (Legendre and Gallagher, 2001). During the ordination analysis species with low abundance (below 5%) were excluded. As the first step, detrended correspondence analysis was conducted and indicated that linear response models were suitable for the current dataset (length of the gradient of the first axis: <3 SD) (ter Braak, 1995). Therefore, as the subsequent step, redundancy analysis (RDA) was employed. Environmental variables explaining maximum variation in the species data were chosen by removing highly collinear and insignificant variables. Highly collinear variables were determined based on the variance inflation factors (VIFs), where variables having a VIF value of more than 20 were removed from the environmental dataset. Subsequently, Monte Carlo permutation tests were applied for testing the significance of each environmental variable and variables that did not explain a significant portion of species variance ($P < 0.05$; 999 random permutations) were also removed from the ordination analyses. Monte Carlo permutation tests were applied in order to test the significance of each environmental variable used in the ordination analyses. All analyses were done in R version 2.12.2 (R Core Development Team, 2011) using the vegan package (http://vegan.r-forge.r-project.org).

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

3. Results

3.1. Abiotic data

Environmental variables showed a markedly seasonal variation in lagoons (Table 1). In the Dalyan Lagoon, surface water temperature varied from 12.6 °C in winter to 27.6 °C in summer. Dissolved oxygen concentrations were between 70.5% and 78.2%, reflecting mesotrophic status according to the Development Bank of Turkey (TKB, 2004). Salinity in summer was high at 10.1‰, while in spring it dropped to 7.2‰. Secchi depth, which was used as an indication of water transparency, was very low (~40 cm) throughout the whole period. The mean pH varied in a range of 7.8–8.7, representing alkaline conditions. Dissolved inorganic nitrogen (DIN) was low throughout the sampling period. Chl-*a* concentration was highest during summer, reflecting eutrophic conditions according to the Carlson trophic index. During summer, other major anions (Cl^- and HCO^-_3) were high (Table 1). The cations showed variation among seasons and Na^+, K^+, and Ca^+ were particularly high during summer, while Mg^+ was higher during winter.

In the Arapçiftliği Lagoon, water temperature varied from 13.2 °C in winter to 32.4 °C in summer. Dissolved oxygen concentrations were between 79.7% and 96.9%. Due to the low water depth of the lagoon, causing high resuspension, the recorded water transparency was about 10 cm through the sampling period. Accordingly, the Chl-*a* concentration was slightly low, representing mesotrophic status according to the Carlson trophic index. Salinity changed from 12.1‰ in spring to 27.7‰ in summer. DIN (2.5 meq L^{-1}) was high in summer. The major anions and cations were also high in the summer period, particularly Na^+ and Cl^- (379.9 meq L^{-1} and 506.1 meq L^{-1}, respectively).

3.2. Zooplankton assemblages

In total, 31 zooplankton taxa were observed in both lagoons and 12 of these species were common. Two taxa, *Keratella cruciformis* and *Notholca bipalium*, are new records for the Turkish inland water fauna (Ustaoğlu et al., 2012; Ustaoğlu, 2015). (Table 2; Figure 2).

No Cladocera species were observed during the sampling period. Although Copepoda was represented by a single species, *Acartia clausi*, in Dalyan, it contributed particularly in the early development stage, except in summer. Rotifera made up the highest contribution (64%) and the bdelloid rotifer contribution was highest during summer. In Arapçiftliği we observed harpacticoid copepods as well as *A. clausi* (Figure 2).

Two-way ANOVA results confirmed that the total abundance of copepods did not show any significant difference neither among seasons nor among lagoons throughout the study period. On the other hand, nauplii, the first development stage of copepods, showed differences among seasons (two-way ANOVA, $F = 3.98$; $P < 0.05$). Pairwise comparisons for the factor 'season' revealed a significant difference between summer and winter seasons ($t = 3.404$; $P < 0.01$). Moreover, rotifer biomass showed significant differences in both factors 'season' and 'lagoon' (two-way ANOVA, $F = 4.965$; $P < 0.01$ and $F = 7.74$; $P < 0.01$, respectively).

For Shannon diversity, a similar pattern occurred among seasons in the studied lagoons (two-way ANOVA, $F = 5.32$; $P < 0.05$) (Figure 3). According to pairwise multiple comparisons, seasonal variation was observed in species diversity between spring and summer ($P < 0.05$) as well as between spring and winter ($P < 0.05$) in both lagoons. During spring, the species diversity was significantly higher than in other seasons (Figure 3). Minimum richness was observed during summer in Arapçiftliği, while in Dalyan summer and autumn were the lowest seasons (Figure 3). Significant differences appeared in pairwise comparisons among winter and the other seasons ($P < 0.05$). Furthermore, richness was observed to be different between autumn and spring ($P < 0.001$) (Figure 3). Pielou's evenness also showed a significant difference between seasons (two-way ANOVA, $F = 3.30$; $P < 0.05$). However, no significant difference was revealed for the biomass of groups, neither among lagoons nor between seasons ($P > 0.05$).

Table 2. Observed taxa in the lagoons.

	Dalyan	Arapçiftliği
Copepoda		
Acartia clausi Giesbrecht, 1889	+	+
Calanoid copepodite	+	+
Cyclopoid copepodite	+	+
Harpacticoid copepodite		+
Nauplii	+	+
Rotifera		
Anuraeopsis fissa Gosse, 1851	+	+
Asplanchna priodonta Gosse, 1850	+	+
Ascomorpha sp.	+	
Ascomorpha saltans Bartsch, 1870		+
Brachionus calyciflorus Pallas, 1776	+	+
Brachionus quadridentatus Hermann, 1783	+	
Brachionus urceolaris Müller, 1773	+	+
Brachionus plicatilis Müller, 1786		+
Bdelloid rotifer	+	+
Cephalodella gibba (Ehrenberg, 1830)		+
Colurella adriatica Ehrenberg, 1831		+
Colurella colurus (Ehrenberg, 1830)	+	+
Colurella obtusa (Gosse, 1886)	+	+
Filinia longiseta (Ehrenberg, 1834)		+
Lecane luna (Müller, 1776)	+	
Lecane lunaris (Ehrenberg, 1832)		+
Lepadella sp.	+	
Lophocharis sp.	+	
**Keratella cruciformis* (Thomson, 1892)		+
Keratella quadrata (Müller, 1786)	+	
Keratella cochlearis (Gosse, 1851)		+
Notholca acuminata (Ehrenberg, 1832)	+	
**Notholca bipalium* (Müller, 1786)		+
Notholca squamula (Müller, 1786)		+
Polyarthra dolichoptera Idelson, 1925	+	+
Platyias quadricornis (Ehrenberg, 1832)	+	
Synchaeta pectinata Ehrenberg, 1832	+	+
Synchaeta oblonga Ehrenberg, 1832		+
Testudinella eliptica (Ehrenberg, 1834)		+
Trichocerca cylindrica (Imhof, 1891)	+	+

*New record for the Turkish fauna.

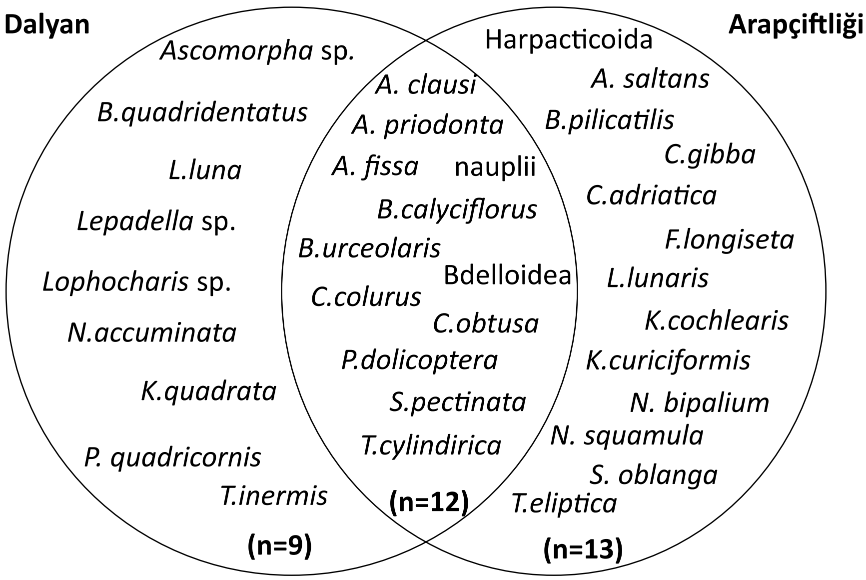

Figure 2. Venn diagram showing identified zooplankton taxa distribution and number of taxa (in parentheses) in the lagoons.

The forward selection (Monte Carlo permutation tests) conducted for the RDA showed that in the Dalyan Lagoon temperature, sulfate (SO_4), and DIN were the significant variables explaining the variation of species ($P < 0.05$), while in the Arapçiftliği Lagoon temperature, calcium (Ca^+), and conductivity were the significant ones ($P < 0.05$) (Figure 4). These environmental variables explained a similar percentage of variance for the Dalyan (54%) and Arapçiftliği (51%) lagoons. For both RDAs temperature was the most significant variable (Figure 4). In the Dalyan Lagoon, *Brachionus urceolaris* was positively associated with temperature; in contrast, *A. clausi*, the early development stages of copepods, and *S. pectinata* were negatively associated with temperature (Figure 4). Furthermore, copepods including the developmental stages were positively associated with DIN (Figure 4). In the Arapçiftliği Lagoon, where conductivity was also highly significant, salinity-tolerant species such as *Brachionus urceolaris* and *Brachionus calyciflorus* were found to be associated with conductivity (Figure 4).

4. Discussion

One year of monitoring data from two lagoons, namely Dalyan and Arapçiftliği, showed strong seasonality in zooplankton composition and taxonomic diversity, indicating water temperature to be the most prominent environmental factor shaping the zooplankton communities in the lagoons.

In general, few species are permanently resident in coastal lagoons, hence dominating the biotic community (Colombo, 1977). Our findings for both of the lagoons point to the dominance of the calanoid copepod species *A. clausi*, which has a cosmopolite distribution throughout the Mediterranean basin (Siokou-Frangou et al., 2004), compatible with the characteristics of Mediterranean coastal lagoons, having a high abundance of calanoid copepods. Accordingly, in the current study, for all monitored seasons, the zooplankton community had low species evenness with only one or a few species having high relative abundance. In addition, different life stages of copepods showed variations among seasons and nauplii was prevalent in the system throughout the whole year, indicating that the variation of the temperature and salinity may affect the development of copepods as confirmed by previous studies (Milione and Zeng, 2008; Pan et al., 2016). Brucet et al. (2009) suggested that indirect effects of climate warming, such as changes in salinity and hydrology, will have larger impacts on these ecosystems than the temperature increase.

In the present study, being indicators for the lagoons, cosmopolite and salinity-tolerant species of the genus *Brachionus* and the genus *Keratella* (e.g., *B. plicatilis* and *K. quadrata*) were high in prevalence. Rotifers appeared to be dominant in some lagoons (e.g., Saygı et al., 2011; Ustaoğlu et al., 2012). However, no efficient filter-feeding cladoceran species were observed in the lagoons, possibly causing a weakening in the grazing pressure on phytoplankton and creating more eutrophic conditions. Several works in the literature confirmed that cladocerans are restricted to salinities below 3.5‰ (Frey, 1993; Viayeh and Špoljar et al., 2012). Furthermore, increase in salinity causes a decrease in their taxonomic diversity (Jensen et al., 2010), which

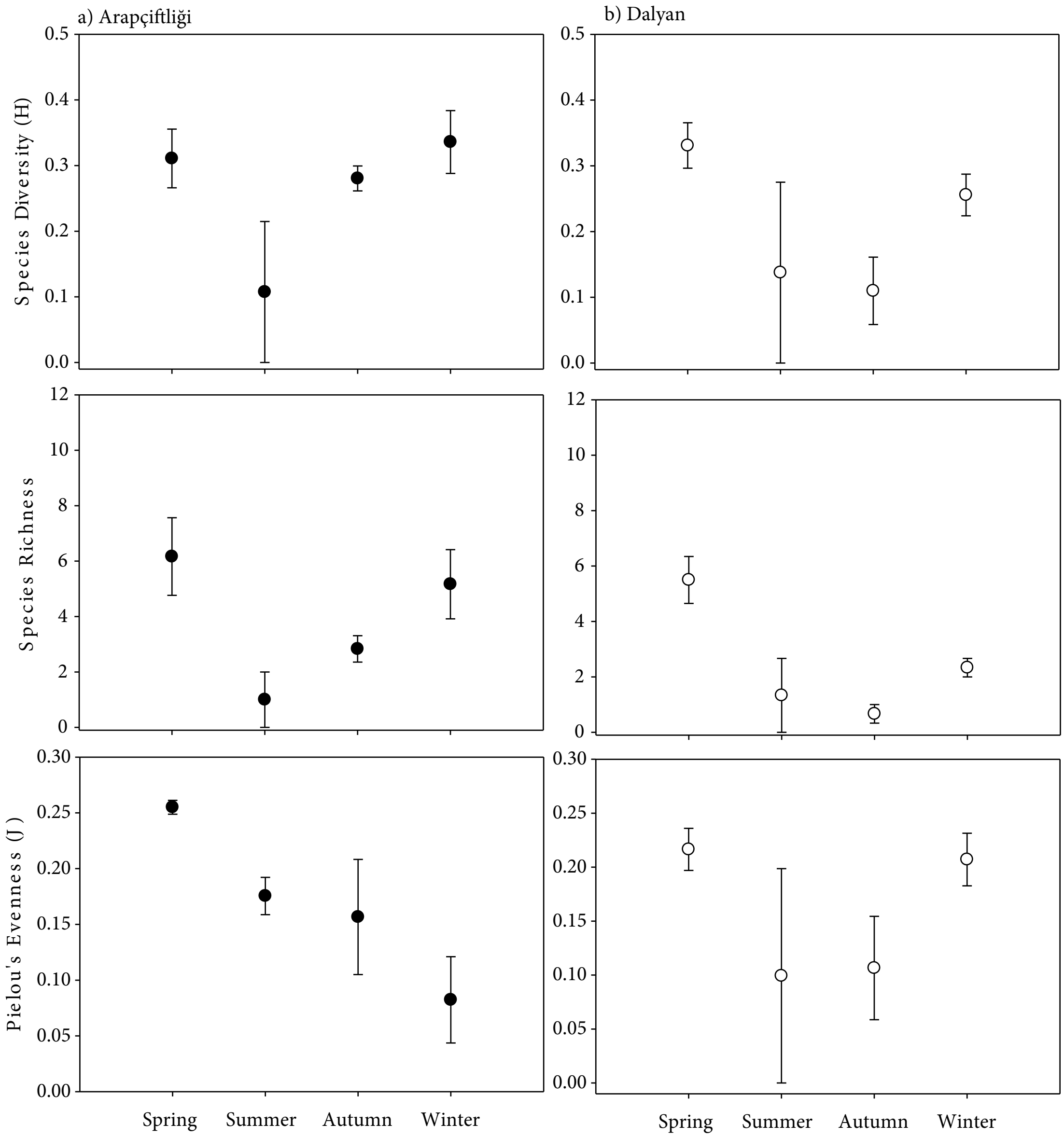

Figure 3. Zooplankton community parameters (Shannon–Wiener diversity, richness, Pielou's evenness) with standard error (±SE) during seasons in each lagoon. White represents Dalyan and black represents Arapçiftliği.

concurs with the present study, where high salinity during summer lowered the species richness in the lagoons. A cross-comparison of coastal brackish lagoons between temperate and Mediterranean regions revealed that salinity was the main factor for low zooplankton richness (Brucet et al., 2009). Moreover, fish communities may also change towards the dominance of small planktivorous fish with increasing salinity levels (Jensen et al., 2010). Hence, intensive top-down control of zooplankton would shape their community composition. The current study did not consider the top-down effect on the zooplankton community; however, crucian carp (*Carassius carassius*) abundances were high during the sampling periods in the Dalyan Lagoon (N Tavşanoğlu, personal observation). In addition, the dominance of copepods, which have high evasive skills, may reflect the strength of the top-down control in the lagoon. However, no fish were observed in the Arapçiftliği Lagoon during the study periods.

Lagoons, in between terrestrial and marine systems, are directly and indirectly influenced by anthropogenic stressors such as chemical pollution, species introduction, physical deterioration (e.g., land reclamation, dikes, artificial bars, channel dredging), and maritime traffic (Chaalali et al., 2013). Moreover, eutrophication, land-

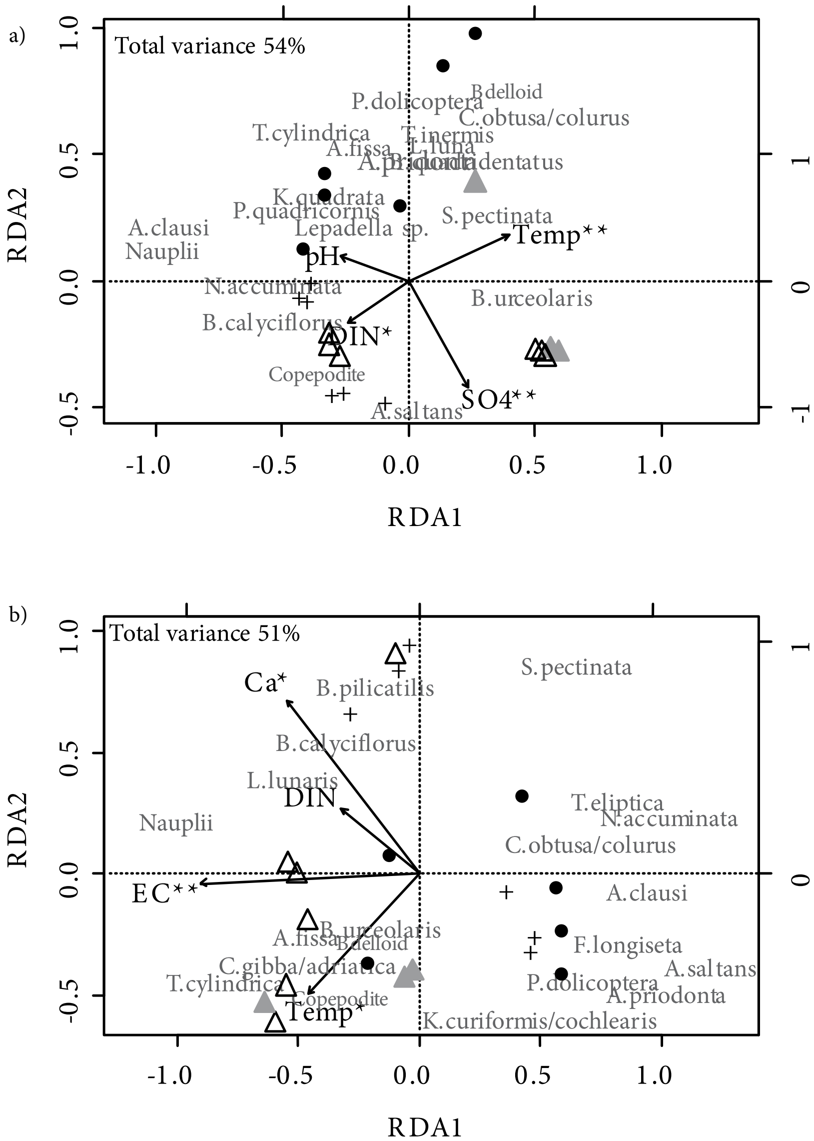

Figure 4. RDA plot of zooplankton taxa and development stage of copepods for the lagoons: a) Dalyan, b) Arapçiftliği. Significance levels are indicated: *0.05 > P > 0.01; **0.01 > P > 0.001; ***P < 0.001. Open triangle: autumn, +: winter, filled circle: spring, filled triangle: summer.

use, and wastewater discharge are among the most important pressures that influence these vital habitats, sheltering many organisms (Kennish and Paerl, 2010). The Karacabey region, where the Kocaçay Delta is located, is an important agricultural area with the cultivation of olive, onion, tomato, etc. Thus, these agricultural activities can trigger natural eutrophication and dystrophic conditions. During the study period a higher dominance of rotifers in lagoons such as *Keratella cochlearis* and *Keratella quadrata*, reflecting eutrophic conditions, was also observed in previous studies (e.g., Saygı et al., 2011; Ustaoğlu et al., 2012).

Temperature increase influences the dissolved oxygen concentration, thereby negatively affecting the organisms (Turner et al., 2003; Anthony et al., 2009). Thus, the high occurrence of rotifers during summer, when the dissolved oxygen concentration is low, pointed to the resilience of these taxa to anoxic conditions. For instance, *B. calyciflorus*, which occurred in both lagoons, was reported to tolerate low dissolved oxygen and pH levels of 7–9 (Güher et al., 2011). In addition, the high sulfate concentration during summer in Arapçiftliği may promote the release of nutrients from the sediment, enhancing internal eutrophication. Furthermore, in the Arapçiftliği Lagoon, the increase in ammonium concentrations during the dry season was a trigger of the remineralization process.

The Sea of the Marmara provides a connection between the Mediterranean and the Black Sea; thus, invasive species can be transported via ballast waters. Although we do not have enough data on the species diversity in the lagoons, environmental conditions related to global warming may influence the establishment of new species with these circumstances and affect the biodiversity from the bottom to the top predators (Anthony et al., 2009). According to an IPCC (2007) report, the Mediterranean region is a hotspot experiencing climate warming. In this context, to improve the environmental state of the coastal lagoons of Turkey, monitoring programs and restoration applications should be accelerated urgently. Furthermore, the microbial loop should also be taken into account for the lagoons, since bacteria can be an alternative carbon source for zooplankton, particularly for rotifers (Agasild and Nõges, 2005). Moreover, high fertilizer usage in the basins, as in the Karacabey region, should be considered by policymakers by formulating strict regulations on nutrient limitations and chemical contaminant input from the basins to the lagoons.

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