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Spatio-temporal variation in the distribution and abundance of marine cladocerans in relation to environmental factors in a productive lagoon (Güllük Bay, SW Aegean Sea, Turkey)

by

Nurçin Killi*

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Muğla Sıtkı Koçman University, Faculty of Fisheries, Department of Basic Sciences, 48000 Muğla, Turkey

Abstract

In order to understand the effects of some physical (temperature and salinity) and chemical (dissolved oxygen, nitrate and chlorophyll *a*) factors on the abundance and distribution of cladoceran species, zooplankton samples were seasonally collected between August 2015 and July 2016 from three stations near the entrance to the Boğaziçi Lagoon in Güllük Bay (Aegean Sea, Turkey) using a WP2 plankton net with a mesh size of 200 µm. Four cladoceran species – *Penilia avirostris, Pseudevadne tergestina, Evadne spinifera* and *Pleopis polyphemoides* – were found during all sampling events throughout the study period. They showed high abundance in August (4774 ind. m^{-3}) and October (10 706 ind. m^{-3}) as the dominant zooplankton group. The abundance of *Penilia avirostris* – the dominant cladoceran at all sampling locations – was estimated up to 10 871 ind. m^{-3} in October. *Pseudevadne tergestina* was the second dominant cladoceran. In September, only *Pseudevadne tergestina* and *Pleopis polyphemoides* were found in samples in small numbers. The abundance of cladocerans varied significantly throughout the seasons. Two physicochemical factors, temperature and dissolved oxygen, were the main drivers of changes in the cladoceran composition.

Key words: marine Cladocera, Güllük Bay, Boğaziçi Lagoon, abundance, southwest Turkey

* Corresponding author: nurcinkilli@mu.edu.tr

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Introduction

Marine cladocerans are widely and seasonally distributed in aquatic ecosystems (Egloff et al. 1997). Out of approximately 650 cladoceran species occurring worldwide, only eight are of marine origin (Egloff et al. 1997). Marine cladocerans are primarily surface water species that feed mainly on diatoms and dinoflagellates (Kim et al. 1989) during daylight (Gieskes 1970; 1971), hence they can be transported to ocean waters by surface currents. For instance, *Pseudevadne tergestina* is a widespread species in coastal waters in the north-western Pacific and prefers higher surface temperatures (Kim et al. 1989). Similarly, *Evadne nordmanni*, a cool water species (Gieskes 1970), is found in ocean water (Wiborg 1955).

Energy transfer from primary producers to top predators is done mainly by means of three components, which are phytoplankton, crustaceans (Copepoda and Cladocera) and planktivorous fish. Cladocerans are the preferred food for planktivorous fish because of their slow escape response (Verity & Smetacek 1996). Furthermore, rapid proliferation through parthenogenetic reproduction and high birth rates under optimal conditions (such as temperature and food availability) makes these species preferable in both marine and freshwater ecosystems (Dodson et al. 2010).

All marine Cladocera species identified around the world occur in coastal waters of Turkey and they have been reported in several studies from different locations across the Turkish seas (Table 1). Despite the key role of cladocerans in the zooplankton community of Güllük Bay, especially due to the influence of the open shore of the Aegean Sea (i.e. high nutrient load) and heavy marine traffic resulting from the presence of one of the most important harbors in Turkey (i.e. Güllük Port), the number of studies conducted on cladocerans in the bay are very limited. In fact, this is true for the entire Mediterranean Sea as only a few previous studies focused on understanding the effect of environmental factors on the spatio-temporal distribution and changes in the abundance of mostly freshwater and brackish cladocerans in lagoon systems, although it is expected that even within the Mediterranean region they show some variations based on the environment in which they live (Lesutienė et al. 2005; Polunina 2005; Brugnano et al. 2011; Ferrareze & Nogueira 2011; Yalım et al. 2011).

Therefore, the main objective of the present study was to investigate the monthly abundance and distribution of cladoceran species in relation to environmental factors in an environmentally unpredictable and fertile lagoon (entrance to the Boğaziçi Lagoon in Güllük Bay). The results of the present study are expected to contribute significantly to a better understanding of the distribution pattern of cladocerans in lagoon ecosystems and their role in the food web. Phytoplankton-depleting zooplankton groups are expected to show high abundance. Specifically, cladocerans should be present in the water column throughout the year if the annual water temperature is appropriate.

Materials and methods

Study area

This study was carried out in the Bay of Güllük located in the south-eastern Aegean Sea (Muğla, SW Turkey). Sampling was conducted near the entrance to the Boğaziçi Lagoon in the bay from August 2015 to July 2016 (Fig. 1). The Bay of Güllük is one of the important fishing areas both in terms of aquaculture and fishing activities (Demirak et al. 2006; Cerim 2017) and a habitat for many species as the bay is a natural harbor with the connection to the open sea (Öztürk et al. 2006). The Bay of Güllük opens to the Aegean Sea in the west and includes the Güllük and Boğaziçi lagoons. The latter lagoon has a surface area of approximately 6.86 km^2 and a depth varying from 0.5 to 3 m. It has a muddy seabed with *Posidonia oceanica* and *Zostera marina* meadows (Cerim 2017).

Figure 1

Sampling locations in Güllük Bay. Sampling sites: 1 – Lagoon entrance 1; 2 – Lagoon entrance 2; 3 – Kıyıkışlacık

Table 1

Studies on marine cladocerans in Turkey

Reference	Study area	Cladocera species
Tarkan 2000	Gökçeada	*Evadne nordmanni*, *Penilia avirostris*, *Evadne spinifera*
Tarkan et al. 2001	Gökçeada	*Evadne nordmanni*, *Penilia avirostris*, *Evadne spinifera*, *Pseudevadne tergestina*, *Podon intermedius*
Toklu-Alıçlı & Sarıhan 2003	İskenderun Bay	*Penilia avirostris*, *Pseudevadne tergestina*, *Evadne spinifera*
Aker & Özel 2006	İzmir Bay	*Evadne nordmanni*, *Pseudevadne tergestina*, *Evadne spinifera*, *Penilia avirostris*, *Pleopis polyphemoides*
Büyükateş & İnanmaz 2007	Kepez Harbor, Dardanelles Strait	*Pleopis polyphemoides*, *Evadne nordmanni*, *Penilia avirostris*
İşinibilir 2008	Güllük Bay	*Pseudevadne tergestina*, *Evadne spinifera*, *Penilia avirostris*, *Podon leuckartii*, *Pleopis polyphemoides*
Büyükateş & İnanmaz 2010	Kepez Harbor, Dardanelles Strait	*Pleopis polyphemoides*, *Evadne nordmanni*, *Penilia avirostris*
Gülşahin & Tarkan 2012	Gökova Bay	*Penilia avirostris*, *Evadne spinifera*, *Pseudevadne tergestina*, *Pleopis polyphemoides*, *Podon intermedius*
Terbıyık Kurt & Polat 2014	İskenderun Bay	*Penilia avirostris*, *Pseudevadne tergestina*, *Evadne spinifera*, *Pleopis polyphemoides*, *Podon intermedius*
Toklu-Alıçlı et al. 2014	Gulf of Erdek, Marmara Sea	*Evadne spinifera*, *Pleopis polyphemoides*, *Penilia avirostris*
Toklu-Alıçlı & Sarıhan 2016	İskenderun Bay	*Evadne spinifera*, *Pseudevadne tergestina*, *Penilia avirostris*, *Podon polyphemoides*
Terbıyık Kurt & Polat 2017	İskenderun Bay	*Evadne spinifera*, *Penilia avirostris*, *Pleopis polyphemoides*, *Podon schmackeri*, *Podon intermedius*, *Pseudevadne tergestina*
Terbıyık Kurt et al. 2018	İskenderun Bay	*Penilia avirostris*, *Evadne spinifera*, *Pseudevadne tergestina*, *Evadne nordmanni*, *Pleopis polyphemoides*, *Podon intermedius*

Sampling and counting

Sampling was performed monthly from August 2015 to July 2016, however, it was not possible to collect samples in January due to adverse weather conditions. Samples were collected horizontally at three locations (Fig. 1) for 10 min during the daytime using a WP2 plankton net (Fraser 1966; UNESCO 1968) with a mesh size of 200 μm and a diameter of 57 cm. Samples were then placed in plastic jars and fixed with 5% formaldehyde solution before being sent to the Marine Biology Laboratory of the Faculty of Fisheries, Muğla Sıtkı Koçman University. Cladocerans were counted in a counting chamber under an Olympus SZX16 stereomicroscope and photographed. Counting was performed on 2 ml subsamples with three replicates. Average counts were recorded and the abundance per cubic meter was calculated according to Niermann & Kıdeyş (1995). Temperature and salinity were measured with a YSI Multiprobe System from the surface water at the sampling sites. Dissolved oxygen, Chl *a*, nitrates, and phosphates were measured in the Environmental Problems Research and Application Center of Muğla Sıtkı Koçman University.

Statistical analyses

Temporal and spatial differences in the abundance of cladocerans were examined by permutational univariate analysis of variance (PERANOVA) using PERMANOVA+ v1.0.1 for PRIMER version 6.1.11 (PRIMER-E Ltd, Plymouth, UK) (Anderson et al. 2008). This was based on a two-way (fully crossed) design, which included the fixed factors: Season and Location. The analysis was carried out on the Euclidean distance following data normalization. The data were used to obtain a distance matrix, which was subjected to 9999 permutations of the raw data and tested for significance, including posteriori pairwise comparisons evaluated at $\alpha = 0.05$.

The relationships between physicochemical factors and the community assemblage were assessed using the distance-based multivariate analysis for a linear model (DISTLM; Legendre & Anderson 1999; Mcardle & Anderson 2001), which examines the relationship between a multivariate data cloud for one or more predictor variables (Anderson et al. 2008). First, forward selection and sequential conditional distance-based redundancy analysis (dbRDA; Legendre & Anderson 1999; Mcardle & Anderson 2001) with 9999 permutations under a reduced model (Freedman & Lane 1983; Anderson & Ter Braak 2003) were used to explain the variation in the zero-adjusted Bray–Curtis dissimilarity matrix of the square-root-transformed data on the cladoceran assemblage. Next, stepwise selection with sequential conditional tests was employed using DISTLM to identify the number of variables (n) that could reasonably be included in a parsimonious model. Finally, the best *n*-variable model was identified on the basis of the direct multivariate analogue to the small-sample-corrected Akaike information criterion (AICc; Anderson et al. 2008; Burnham & Anderson 2002) in order to obtain an overall parsimonious model. Then, the dbRDA was used to visually interpret the resulting model in the multidimensional space. The direction and length of vectors indicate the strength of the relationship between a given variable and the dbRDA axes.

Results

Physicochemical variables

The average temperature for all sampling sites was 22.17°C, ranging from 16.3°C in February to 28.7°C in June. The average salinity in the study area was 38.28 PSU, with high salinity observed in July and August due to evaporation. It decreased to 36.38 and 37.34 PSU in winter and spring, respectively, due to rainfall (Fig. 2). The mean DO value was 7.22 mg l^{-1} and never dropped below 6 mg l^{-1}. The maximum DO values were recorded in October and December. The Chl *a* content in the bay was between 0.53 and 3.77 mg m^{-3}, with its first and second peaks observed in April (mean 3.47 mg m^{-3}) and October (mean 3.42 mg m^{-3}), respectively. The minimum content of Chl *a* was observed in February and March (Fig. 3). Nitrates ranged from 0.144 to 0.267 mg l^{-1} and their two peaks were observed in April and November (Fig. 4). Phosphate values were below the limits, therefore they were not considered here.

Cladoceran assemblages

Four cladoceran species were identified during the sampling process: *Penilia avirostris* Dana, 1849, *Pseudevadne tergestina* Claus, 1877, *Evadne spinifera* P.E. Müller, 1867 and *Pleopis polyphemoides* (Leuckart, 1859). *P. avirostris* and *P. tergestina* were found in all sampling months except for September and February, respectively. *E. spinifera* was absent in the samples collected in September and March. *P. polyphemoides* was not found in August, October, February, June and July. The mean abundance of *P. avirostris* was 1464 ind. m^{-3} with two peaks observed in June (1880 ind. m^{-3}) and October (9649 ind. m^{-3}). The minimum and maximum abundance of *P. avirostris* was determined in July as 15 ind. m^{-3} at site 1 and in October as 10.871 ind. m^{-3} at site 3, which indicates fluctuations in the abundance and its high values in

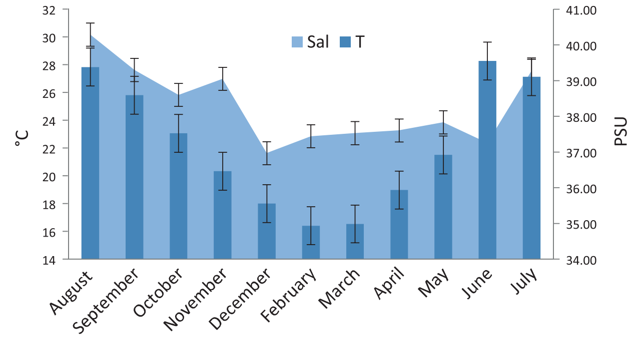

Figure 2

Mean temperature and salinity values in the study area by months

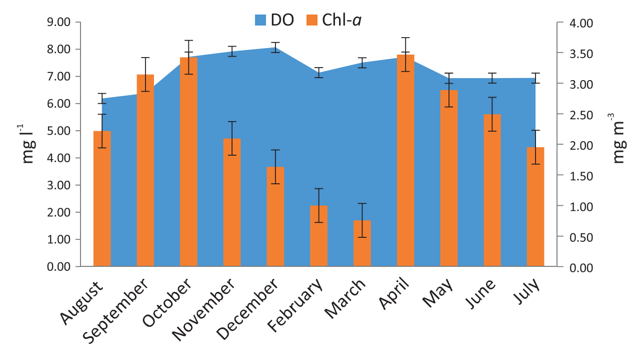

Figure 3

Mean dissolved oxygen (DO) and Chl *a* values in the study area by months

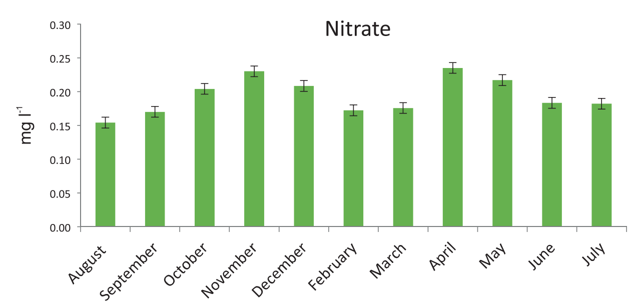

Figure 4

Mean nitrate values in the study area by months some months (e.g. April, May, June, August, October and November). *E. spinifera* was observed in all seasons, however, the maximum abundance was determined in June with a mean annual abundance of 293 ind. m^{-3}. *P. polyphemoides* was not found in the present study during the summer months. The abundance of this species was high in March and April with a mean annual abundance of 50 ind. m^{-3}.

Seasonal distribution of cladoceran species

The main zooplankton groups of the study area were Copepoda, Cladocera, Chaetognatha, Appendicularia, Siphonophora, Thaliacea and meroplankton. Cladocerans constituted 20% of the total zooplankton, while copepods were 73%. Copepods were the dominant group in zooplankton, except for August and October when cladocerans dominated. The highest abundance of copepods was observed in September and June; in September, their abundance at site 2 was recorded as 83 077 ind. m^{-3}. Copepoda and Cladocera species were found in the water column in all sampling months. Meroplankton as the second most abundant group after copepods in November, December and April was an important component of zooplankton in the area. Other zooplankton groups were present in the samples in certain months. Appendicularians showed high abundance in March, April and November. The number of chaetognaths increased in October and November. The total abundance of zooplankton showed three peaks in April (9404 ind. m^{-3}), June (13 472 ind. m^{-3}) and September (61 320 ind. m^{-3}).

There were statistically significant differences in the abundance of cladocerans between the seasons but not between the sampling sites and for the season–sampling site interaction (Table 2). *P. avirostris* showed high abundance in summer (mean 991.11 ind. m^{-3}) and autumn (mean 3635.78 ind. m^{-3}), although the maximum abundance of this species was recorded in October. The abundance of this species decreased in winter, as did other cladocerans (Fig. 5), but began to increase in spring. The abundance of *P. tergestina* also increased in spring (mean 411.67 ind. m^{-3}), whereas the maximum abundance of this species was recorded in summer (mean 1604.89 ind. m^{-3}). *P. tergestina* was found in similar abundance in spring and autumn (Fig. 5). *E. spinifera* showed high abundance only in summer (mean 798.89 ind. m^{-3}), while in other seasons the species was found in small numbers (Fig. 5). *P. polyphemoides* was not found in summer and showed very low abundance in autumn and winter. The maximum abundance of this species was recorded in spring (mean 131.44 ind. m^{-3}; Fig. 5).

Table 2

PERANOVA results with regard to differences in the abundance of Cladocera species according to season and location. Statistically significant (and ecologically relevant) effects are marked in bold (α = 0.05), including those for posteriori pairwise comparisons (# = permutational value based on 9999 permutations). See also Figure 6

Source of variation	df	MS	F#	$t^{\#}$	$p^{\#}$
Season	3	17.29	5.07		**0.0001**
Spring vs Summer				2.78	**0.0002**
Spring vs Autumn				1.94	**0.0357**
Spring vs Winter				2.23	**0.0436**
Summer vs Autumn				2.26	**0.0014**
Summer vs Winter				2.39	**0.0102**
Autumn vs Winter				1.50	0.1669
Sampling location	2	0.69	0.20		0.9914
Season × sampling location	6	0.51	0.15		1.0000
Residual	21	3.41			

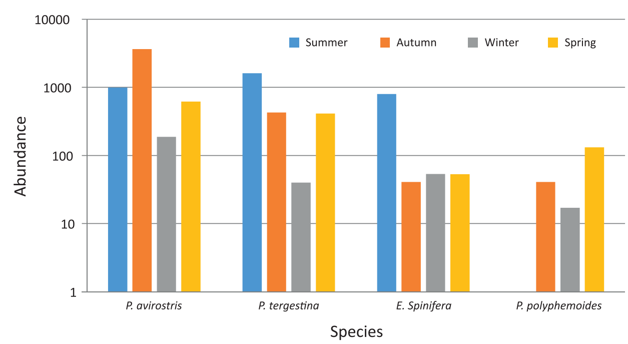

Figure 5

Mean abundance values of Cladocera species according to the seasons

Species–environment relationship

The water temperature, Chl *a* and salinity was significantly correlated with the variation in cladoceran assemblages ($p < 0.05$; Table 3, marginal tests). However, sequential tests with stepwise selection across all potential predictor variables indicated that a parsimonious model explaining the variation in the cladoceran assemblage data based on all potential predictor variables would be achieved using only two variables (Table 3, sequential tests). The best two-variable AICc model included water temperature and dissolved oxygen. The model was visualized with the dbRDA ordination of the fitted values (Fig. 6), whose first two axes explained the total fitted variation, but only 25.96% of the total variation

Table 3

Results of DISTLM analysis on physicochemical variables

variable	Marginal tests			Sequential tests		
	SS (trace)	Pseudo-*F*	*p*	SS (trace)	Pseudo-*F*	*p*
T	10249	6.8112	**0.0002**	10249	6.8112	**0.0001**
DO	3153.3	1.8188	0.1178	4521.3	3.2198	**0.0159**
Chl *a*	7155	4.4590	**0.0027**	2137.3	1.5499	0.1852
NO_3	2797.8	1.6032	0.1747	1041.9	0.7490	0.5612
Salinity	4196.1	2.4682	**0.0440**	499.9	0.3510	0.8494

with an AICc value of 242.84. The dbRDA ordination (Fig. 6) illustrated how the sites were clearly separated by their location along the longitudinal gradient and the principal contributing environmental variables. The first dbRDA axis was strongly correlated with water temperature, while the second axis – with dissolved oxygen.

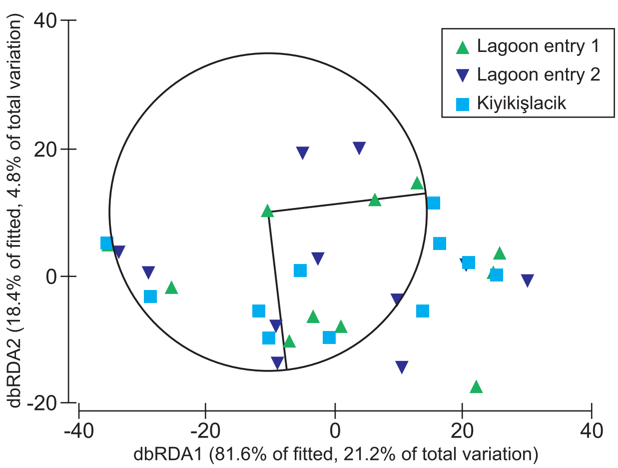

Figure 6

Constrained ordination relating cladoceran data to predictor variables. Distance-based redundancy analysis (dbRDA) of zero-adjusted Bray-Curtis dissimilarities calculated from square-root transformed abundance of four cladocerans vs water temperature and dissolved oxygen, identified as the best two-variable model using the AICc selection criterion. Colors denote the three sampling locations in Güllük Bay

Discussion

The high concentrations of Chl *a* and nitrates found in Güllük Bay in some sampling months during the present study corroborated the results of the previous study on water quality in the bay (Demirak et al. 2006). The salinity and DO values in the present study were similar to those reported by Killi & Sağdıç (2018), who studied the seasonal distribution and abundance of Cladocera species in Güllük Bay, whereas the reported mean temperature of the same sampling months was lower compared to our results. In this study, the temperature values were higher than in some previous studies (Demirak et al. 2006; Yıldırım & Ercan 2017; Killi & Sağdıç 2018) performed in Güllük Bay. This could be attributed to the depth of our sampling area (15–20 m), which was shallower than in other studies. Shallow waters in the Boğaziçi Lagoon (i.e. maximum 1.5 m) clearly increase the temperature in the study area (Cerim 2017). Öztürk et al. (2006) recorded high phytoplankton density but low nutrient levels in Güllük Bay from 11 August to 7 September 2006, which could be related to high nutrient consumption by phytoplankton. The same study reported that zooplankton abundance was also high (mean 6278 ind. m^{-3}) due to the high phytoplankton density (Öztürk et al. 2006). Indeed, zooplankton started to increase as the Chl *a* content increased in the sampling area. Similarly, Ferrareze & Nogueira (2011) observed that the abundance of cladocerans increased with the increase in nutrients and temperature in four marginal lagoons and the Rosana Reservoir (SE Brazil). Furthermore, according to Öztürk et al. (2006), *P. avirostris* and copepods were dominant in Güllük Bay. *P. avirostris* in October and *P. tergestina* in August were the dominant species in zooplankton in the present study and this could be explained by the input of organic matter from the Boğaziçi Lagoon as well as aquaculture activities that affect Güllük Bay in terms of nitrate and phosphate input (Demirak et al. 2006). The nitrate values in our study increased in April and remained high in May, October, November and December. These values were consistent with those reported by Yıldırım & Ercan (2017), who recorded two peaks of nitrates in December and April, and by Akdoğan (2016), who recorded a high nitrate value in December.

Cladocera species reproduce parthenogenetically and increase their abundance under favorable conditions (Gieskes 1971). Parthenogenetic females of *P. avirostris* are observed throughout the summer and to some extent in autumn (Johns et al. 2005). In the present study, the species showed high abundance in summer and autumn, except in July and September. It is believed that the reason for the absence of this species in September is predation pressure from fish larvae and carnivorous copepods (Dodson et el. 2010), which showed excessive increase in that month. Yalım et al. (2011) indicated that fish predation affects seasonal abundance of cladocerans in a lagoon system. *P. avirostris* is a cosmopolitan cladoceran that occurs in tropical and subtropical coastal waters (Marazzo & Valentin 2003a). It is a eurythermal species, but prefers mainly warm waters (Tokioka 1979; Rose et al. 2004). According to Kim & Onbè (1995), *P. avirostris* occurs mostly in the temperature range of 12 to 30°C. The water temperature in Güllük Bay did not drop below 16°C at any time of the year (Fig. 2). Therefore, in this study, the abundance of *P. avirostris* was also high in October, November and December and started to increase from April onwards. On the other hand, *P. avirostris* was not found in the water column of the bay in August 2017 (Killi & Sağdıç 2018). In the present study, although the species did not occur around the lagoon in September, it dominated in terms of abundance during the whole sampling period, with a peak in August 2015 (1040.33 ind. m^{-3}). This difference may be related to differences between Chl *a* concentrations in August 2015 and 2017. Similarly, Terbıyık Kurt & Polat (2014) noted that *P. avirostris* as the dominant species was positively correlated with Chl *a* in the Gulf of Iskenderun (Mediterranean coast in southern Turkey). Further, this species is commonly found in large numbers in estuarine waters (Paranaguá et al. 2005); in the seaward part of the Lesina Lagoon (South Adriatic Sea), it was identified as the dominant cladoceran (Brugnano et al. 2011). Therefore, in the present study, higher abundance of *P. avirostris* is expected compared to that in the northern part of the bay.

P. tergestina is a warm water species found throughout the study period, except for February characterized by the lowest water temperature. The average annual abundance of this species in Güllük Bay was higher than its maximum abundance in the northern part of the bay and the location of the sampling sites close to the Boğaziçi Lagoon was indicated as the most likely cause of this difference (Killi & Sağdıç 2018). The negative correlation between *P. tergestina* and Chl *a* was demonstrated by Terbıyık Kurt & Polat (2014). The maximum abundance of this species in the present study was indeed determined in July and August and the Chl *a* levels were not high in the sampling area in those months, which suggests that the abundance of *P. tergestina* is more related to the water temperature, as supported by the species–environment relationship analysis (Table 3 and Fig. 6).

P. polyphemoides occurs in warm waters of coastal zones (Della Croce & Venugopal 1972). In the present study, the abundance of this species increased in March and April when the water temperature ranged between 16.53°C and 18.97°C, respectively, and the species was not found in the summer months. Onbè (1974) reported that *P. polyphemoides* is a warm water species and its populations thrive mainly in waters with a temperature of 18–22°C, as observed in the Inland Sea of Japan. Lesutiené et al. (2005) noted that *Pleopis sp*. was less abundant than copepods in some locations of the Curonian Lagoon (SE Baltic Sea) in June and July, when the water temperature was not so high as at the lower latitudes. However, Marazzo & Valentin (2003b) recorded that this species is an important food item for fish larvae, also for Polychaeta and Chaetognatha. Therefore, the low density of the *P. polyphemoides* population in the present study may be caused by the predation by meroplankton and chaetognaths. The abundance of chaetognaths was high between September and December as well as in June, when abundances of *P. polyphemoides* were very low or absent.

It was observed that *E. spinifera* was present in large numbers in June and July, followed by a declining trend (i.e. low abundance in autumn and winter), which is consistent with the strong positive correlation between the cladoceran species and temperature (Table 3 and Fig. 6). It could also be explained by the fact that they are commonly consumed by pilchards (Van Der Lingen 1994), which have a long reproductive period, i.e. between September and June in the Aegean Sea (Cihangir 1991). The abundance and distribution characteristics of *E. spinifera* at the entrance to the Boğaziçi Lagoon are similar to those established by Killi & Sağdıç (2018), however, there are only few studies on the ecological role and population density of *E. spinifera*.

The fact that *P. intermedius* could not be found in the present study but was reported from the northern part of Güllük Bay (Killi & Sağdıç 2018) may be related to environmental differences affecting the occurrence of this species. Salinity may be a key factor explaining why *P. intermedius* could not be found in the present study, as the species is known as a stenohaline species that does not tolerate low salinity at the sampling locations in the present study.

The species–environment analyses showed that the temperature and dissolved oxygen were the main explanatory variables for the distribution and abundance of the identified cladoceran species at the entrance to the Boğaziçi Lagoon (Table 3 and Fig. 6). In the present study, the abundance of cladocerans decreased in the months with high oxygen levels and low temperatures. On the other hand, Daborn et al. (1978) observed that the populations of the common cladoceran *Daphnia pulex* increased with high temperature and low oxygen levels in the ponds of Nova Scotia. Yalım et al. (2011) showed that the temperature and salinity were the two main factors affecting cladocerans in the Beymelek Lagoon (Antalya, Turkey). Although conducted in very similar habitats (i.e. lagoons), miscellaneous reports on the ecological interactions of cladocerans suggest certain context dependency. Overall, this study indicates the need for more research that would focus specifically on the ecology of cladocerans in the Aegean Sea and the Eastern Mediterranean.

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