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The Annual Mesozooplankton Dynamics and Influence of Environmental Parameters in an Urbanized Harbor (Kepez Harbor-Dardanelles Strait, Turkey)

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Abstract

Weekly field samplings were performed at the Kepez Harbor located at the Dardanelles Strait for temperature, salinity, Secchi disk, dissolved oxygen, chlorophyll-*a* and nutrient concentrations, zooplankton abundance, and community structure from 26 April 2005 to 25 April 2006. Zooplankton samples were collected using a plankton net with a mesh size of 180 μm for the mesozooplankton and vertical tows were conducted between 0-5 m, 10-15 m, and 15-20 m. Whole water samples were also collected for microzooplankton. All mesozooplankton groups increased in number starting at the end of May through June. Copepoda dominated the surface and mixed layer during the early spring and *Acartia clausi* was the most abundant species when compared to the others. Cladocera showed a clear seasonal succession pattern in the study site and were mainly composed of *Penilia avirostris*, *Pleopsis polyphemoides*, and *Evadne nordmanni*. *Oikopleura dioica*, the only representative of the appendicularians, reached its maximum abundance during mid summer. The zooplankton species composition in the sampling site was diverse and a unique two layer flow regime of the system allowed us to observe both the Mediterranean and the Black Sea influence on the organisms.

Keywords: Dardanelles, environmental parameters, Kepez Harbor, mesozooplankton, nutrients, species composition.

Şehirleşmenin Etkisindeki Bir Limanda (Kepez Limanı-Çanakkale Boğazı, Türkiye) Yıllık Mezozooplankton Dinamikleri ve Çevresel Parametrelerin Etkisi

Özet

Sıcaklık, tuzluluk, Secchi disk, çözünmüş oksijen, klorofil-*a* ve besin tuzları, zooplankton yoğunluğu ve komünite yapısının belirlenmesi için Kepez Limanı, Çanakkale Boğazı'nda 26 Nisan 2005 ve 25 Nisan 2006 tarihleri arasında haftalık örneklemeler yapılmıştır. Mezozooplankton örneklerinin toplanması için 180 μm göz açıklığında plankton kepçesi ile 0-5 m, 10-15 m ve 15-20 m arasında dikey çekimler gerçekleştirilmiştir. Mikrozooplakton için şişe örneklemesi gerçekleştirilmiştir. Mayıs ayı sonundan başlayarak Haziran boyunca bütün mezozooplankton grupları sayıca artmıştır. İlkbahar başlangıcında, Kopepodlar yüzey ve karışım bölgesinde baskındır ve diğer türlerle karşılaştırıldığında *Acartia clausi*, yoğunluğu en fazla olan tür olmuştur. Kladoserler belirgin bir mevsimsel süksesyon göstermiş ve çoğunlukla *Penilia avirostris*, *Pleopsis polyphemoides*, *Evadne nordmanni* ile temsil edilmiştir. Apendikülerlerin tek temsilcisi *Oikopleura dioica*, yaz ortasında en yüksek yoğunluğa ulaşmıştır. Örnekleme alanında zooplankton tür kompozisyonu çeşitlilik göstermiş ve sistemin özel akış rejimi hem Akdeniz hem de Karadeniz etkisini organizmalar üzerinde görmemizi sağlamıştır.

Anahtar kelimeler: Besin tuzları, Çanakkale Boğazı, çevresel parametreler, Kepez Limanı, mezozooplankton, tür kompozisyonu.

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INTRODUCTION

Zooplankton is known to play a crucial role as the secondary production of dynamic coastal and estuarine waters, significantly influencing the food web structure, plankton succession and outcome of the primary production (Modigh et al. 1996, Lipej et al. 1997, Marazzo and Valentin 2000, 2001). Zooplankton occurrence, distribution and abundance are of extreme importance in aquatic systems since they are sensitive to disturbances including eutrophication due to anthropogenic impacts such as heavy urbanization, domestic and

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industrial pollutants and sewage disposal which can alter ecosystem components (Siokou-Frangou et al. 1998, Kamburska et al. 2003, Shiganova 2005, Vidjak et al. 2006).

Located between the Sea of Marmara and the Aegean Sea, the Dardanelles Strait has complex flow dynamics (Beşiktepe et al. 1994, Polat and Tugrul 1996, Polat et al. 1998). This causes variable seasonal and episodic inorganic and organic matter fluxes to and from the adjacent seas such as nutrient rich Black Sea surface inflow is further contaminated by the waste discharge of the city of Istanbul and dispersed from the Sea of Marmara to the Northern Aegean Sea through the Dardanelles Strait. On the other hand, the salty, nutrient deficient Mediterranean water becomes enriched during the passage through the Dardanelles Strait and the Sea of Marmara before reaching the Black Sea (Latif et al., 1991, Oguz and Rozman 1991). The distinctly different two-layer flow regime not only affects the environmental dynamics in the system but the utilization of the sources by organisms (Polat and Tugrul 1996). In addition to the Black Sea originated surface waters, local terrestrial inputs through the Kepez Stream, and domestic pollutants of the city of Canakkale affect the system dynamics in Kepez Harbor. Therefore, these unique dynamics in the system and localization of Kepez Harbor in the Dardanelles Strait provides a significant platform to explore the interactions of the biological and environmental parameters.

Previous studies in this area were mostly focused on the physicochemical parameters as well as nutrient and phytoplankton interactions (Polat and Tugrul 1996, Koçum 2005). This study goes a step further and examines the zooplankton dynamics with respect to chlorophyll-*a*, environmental parameters and nutrient dynamics.

MATERIALS AND METHODS

For this research water samples were collected from one station to gather information on the zooplankton community composition, chlorophyll-*a*, nutrients, and the water quality parameters of the urbanized harbor located at Kepez-Dardanelles, Turkey (40° 09' N, 26° 24' E) (Fig. 1). The maximum depth of the sampling station is 25 m. In order to characterize the two different water masses of the Dardanelles, three sampling layers were selected (surface, mixed layer, bottom layer) representing the upper Black Sea influenced layer, lower Mediterranean influenced layer and a mixed layer. Sampling trips were conducted weekly between 26 April 2005 and 25 April, 2006.

Environmental Parameters and Nutrient Analysis

Environmental conditions were evaluated by measuring an assortment of parameters. Water quality parameters such as temperature, salinity, and dissolved oxygen (DO) were measured in situ using YSI 6600 MPS. Light penetration was estimated by taking the Secchi depth. Water samples for nutrients were collected using a 5 l water sampler and filtered using 47 mm GF/F filters by gentle vacuum then frozen for the laboratory analysis. Analysis for nitrite+nitrate ($NO^{-2}+NO^{-3}$) and ammonia (NH_4) were conducted using an automated continuous flow analyzer (Grasshoff et al. 1983). Spectrophotometric determination of soluble reactive phosphorus (PO_4), total phosphorus (TP), and silicate (SiO_2) was conducted according to Parsons et al. (1984).

Biological Parameters

For the analysis of chlorophyll-*a*, the GF/F filters that were used for the filtration of water samples for the nutrient analysis were wrapped in aluminium foil and kept frozen until analysis. Chlorophyll-*a* concentration was determined spectrophotometrically after extraction by 90% acetone solution (Strickland and Parsons 1972).

Zooplankton samples were collected using a 180 μm mesh size plankton net for large zooplankton and preserved in 4% buffered formalin (v/v). Vertical tows were conducted from the surface (between 0-5 m), from the mixed layer (between 10-15 m), and from the bottom layer (between 15-20 m). For microzooplankton, triplicate whole water samples were collected using a 5 l water sampler. Samples were settled for two weeks and reduced first to 250 ml and then to 10 ml subsamples. 10% or 50% of the samples were counted depending on the plankton abundance. Species identification was performed according to Tregouboff and Rose (1957), Todd et al. (2006) and Young et al. (2006).

Finally, to identify meaningful distributional patterns and relations among numerous data groups within the surface, mixed layer, and bottom layer, a principal component analysis (PCA) and Pearson correlation on subsets of depth-integrated data groups was applied using SPSS 11.5 (SPS, 2003).

RESULTS

Environmental Variables and Nutrient Concentrations

Water quality parameters such as salinity, temperature, and DO showed temporal fluctuations during the sampling period (Figure 2). Secchi depth, an estimation of light penetration, varied between 2.5 and 13 m depending on the suspended material and/or primary production (Figure 3a). The lowest value observed in the Secchi depth on 14 March 2006 was due to land runoff after a heavy rain event in the area rather than high primary production. Inorganic nutrient concentrations were low to moderate throughout most of the sampling period (Figures 4, 5, 6). Silicate concentration ranged between 0.48-21.72 μg L^{-1} at different sampling depths. These values were well below 30-40 μg L^{-1}, which is considered as the optimum value for diatom growth. Other than the occasional nutrient input through rain and wind induced mixing events, the analysis of the nutrients between the sampling depths over time showed that the dissolved inorganic nitrogen to phosphorus ratios (DIN/PO_4) were lower than the common Redfield Ratio, suggesting that primary production may become limited because of nitrogen (Figure 7).

Biological Components: Chlorophyll-*a* Concentration and Zooplankton Composition

Chlorophyll-*a* concentration, an indication of primary production, ranged between 0.32-6.67 μg l^{-1} (mean=1.49 μg l^{-1}), 0.04-6.91 μg l^{-1} (mean= 1.75 μg l^{-1}) and 0.01-5.23 μg l^{-1} (mean= 1.05 μg l^{-1}) at the surface, mixed, and bottom layers, respectively (Figure 3b). NO_2+NO_3 and PO_4 were well correlated with chlorophyll-*a*, while NH_4 was negatively related (Table 1). Chlorophyll-*a* and Secchi depth measurements were inversely related through the sampling period (Table 1).

The natural zooplankton community structure in the Kepez Harbor was diverse and the community structure changed depending on the changes in the environmental fractions in addition to the biological parameters. Species of Copepoda, Cladocera, Chaetognatha, Appendicularia, and Polychaeta as well as eggs and larvae of some meroplanktonic species were identified in the study area.

Results showed that all zooplankton groups increased in number starting from the end of May through June (Figure 8). There were 17 copepod species recorded during this period in which *Acartia clausi* Giesbrecht, 1889 and *Oithona similis* Claus, 1866 dominated the sampling site (Figure 9).

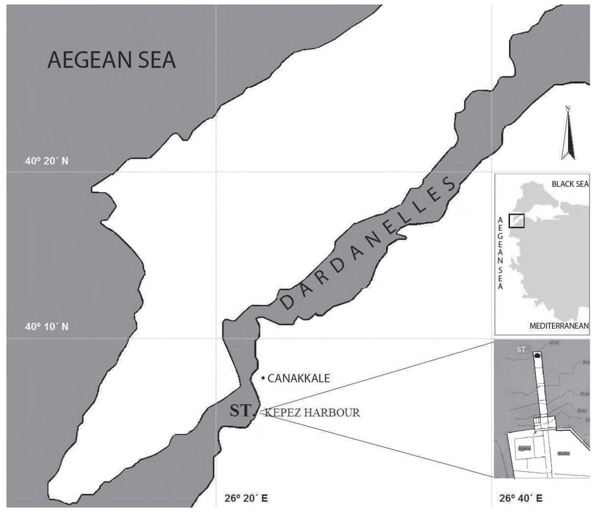

Fig. 1. Location of the study area with the sampling station. Figure is redrawn from Buyukates and İnanmaz (2009, published in Crustaceana).

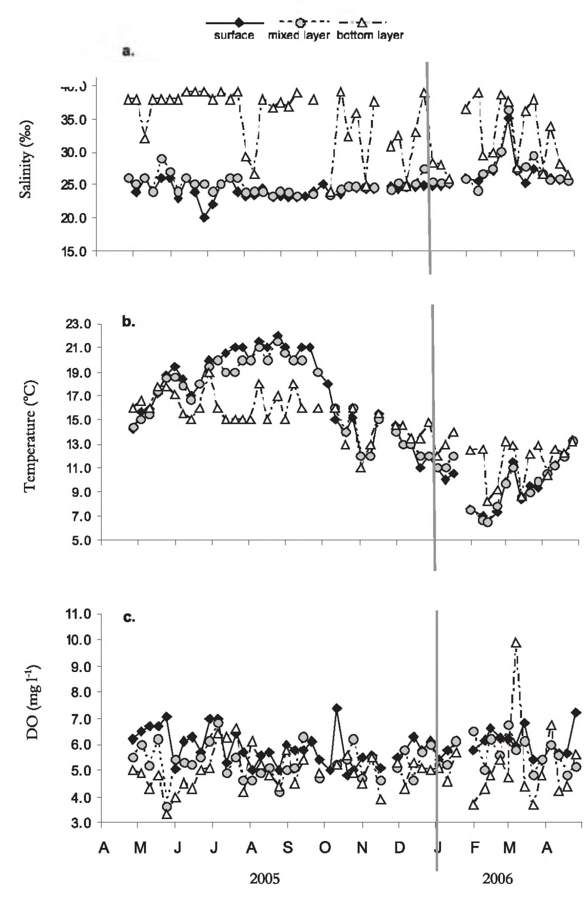

Fig. 2. The water column physical parameters, a. Salinity (‰), b. Temperature (°C), and c. Dissolved oxygen (mg l^{-1}).

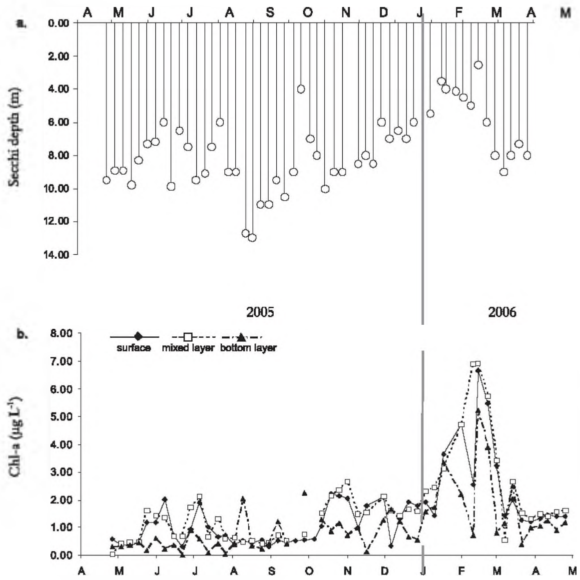

Fig. 3. The temporal variations of a. Secchi depth measurements and b. chlorophyll-*a* concentration in the Kepez Harbor during the sampling period.

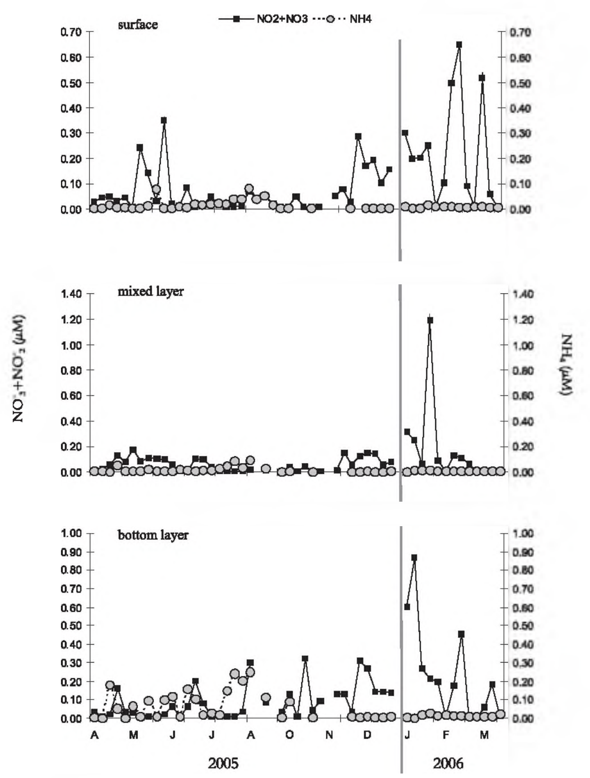

Fig. 4. The temporal variations and vertical distribution of NO^2+NO^3 (mM) and NH_4 (mM) in the Kepez Harbor during the sampling period.

Calanoid copepods contributed to the total copepod abundance by 25-75%, while cyclopoids ranged between 5-15% with the highest abundances

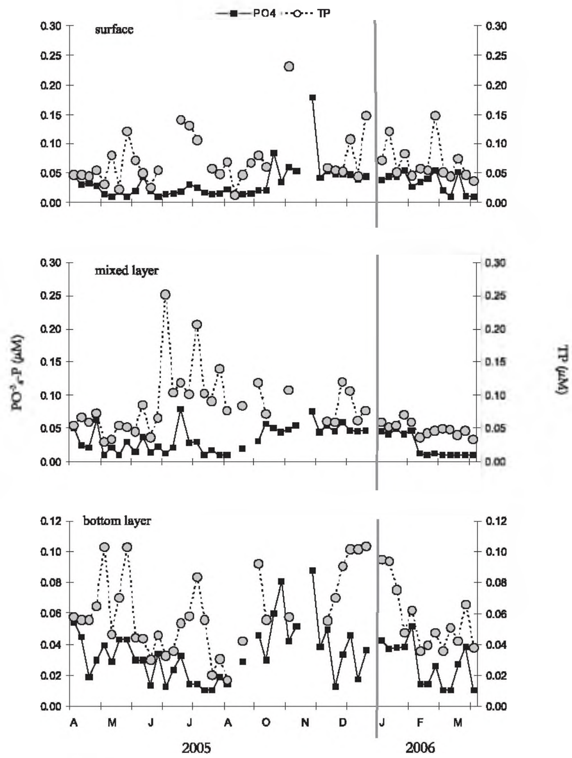

Fig. 5. The temporal variations and vertical distribution of PO_4 (mM) and TP (mM) in the Kepez Harbor during the sampling period.

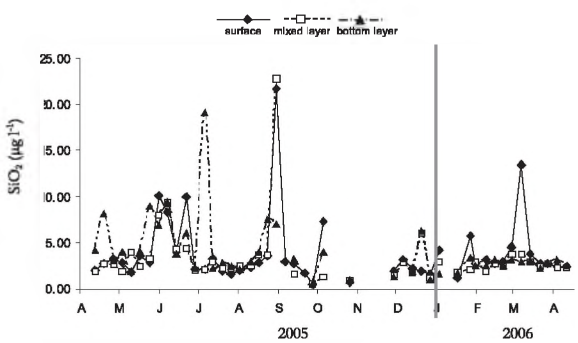

Fig. 6. Temporal variations and vertical distribution of SiO_2 (mg l^{-1}) in Kepez Harbor Dardanelles during the sampling period.

Table 1. Pearson correlations between Chl-*a* and Secchi depth, NO_2+NO_3, NH_4, PO_4, TP, and SiO_2. Variables are depth-integrated in the sampled water column. Significant correlation coefficients are shown (**: $p < 0.01$, *: $p < 0.05$, 2-tailed) and non-significant relationships are indicated (n.s.: $p > 0.05$) (N = 51 for all data groups).

	Secchi	NO_2+NO_3	NH_4	PO_4	TP	SiO_2
Chl-*a*	-0.625**	0.469**	-0.331*	0.319*	n.s.	n.s.

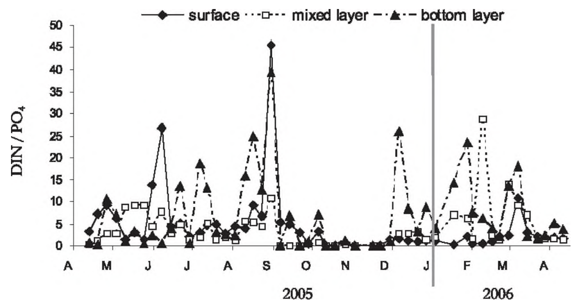

Fig. 7. The temporal variations and vertical distribution of DIN/PO_4 in the Kepez Harbor during the sampling period.

recorded for *O. similis* (5639 ind. m^{-3}) towards the end of May. *A. clausi* was present all through the sampling period reaching its maximum abundance with 21700 ind. m^{-3} at the surface on 14 March 2006. Other than *A. clausi*, *Centropages typicus* Krøyer, 1849, *Paracalanus parvus* (Claus 1863), and *Pseudocalanus elongatus* (Boeck 1865) also dominated the calanoids (Figure 9). *P. parvus* had its greatest abundance in July 2005 with 1877 ind. m^{-3} while *P. elongatus* and *C. typicus* reached their maximum abundances with 1889 in ind. m^{-3} and 2796 ind. m^{-3} in February and March 2006, respectively. The only representative of harpacticoids was *Microsetella norvegica* (Boeck 1864). It had the highest abundance with 350 ind. m^{-3} in July sampling. Few calanoid species dominated the surface layer with high abundances while the number of species increased with increasing depth. *M. norvegica* and *Oncaea* species of poecilostomatoids, especially *Oncaea mediterranea* (Claus 1863) and *Oncaea longiseta* (Shmel, 1968), were mostly abundant in the bottom layer. The densities of *Calanus euxinus* (Claus 1863), *Calanus helgolandicus* (Claus 1863), *Clausocalanus* sp. Giesbrecht, 1888, *Calocalanus pavo* (Dana 1849), *Temora stylifera* (Dana 1848), *Temora longicornis* (Müller 1792), *Anomalocera patersoni* (Templeton 1837), *Eucalanus elongatus* (Dana 1849) from the calanoids, and *Oithona nana* (Giesbrecht 1889) from the cyclopoids never exceeded 5% of the total copepod abundance throughout the sampling period at the sampling site. Copepod nauplii showed an increase parallel to an increase in copepod adults in the surface and the mixed layer while numbers were less pronounced at the bottom. Considering cladocerans, *Pleopsis polyphemoides* (Leuckart 1859) was the dominant species (maximum abundance 11550 ind. m^{-3}) by the end of

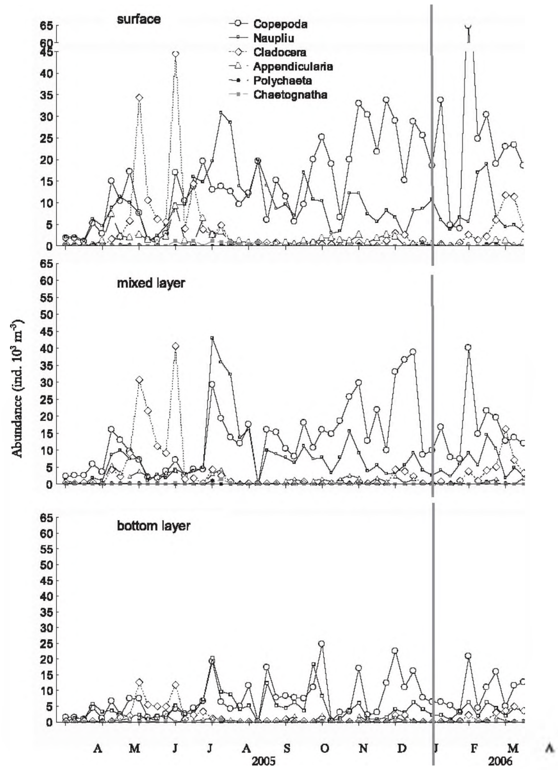

Fig. 8. The zooplankton community structure divided into copepods, copepod nauplii, cladocerans, appendicularians, polychaeta, and chaetognatha in the Kepez Harbor during the sampling period.

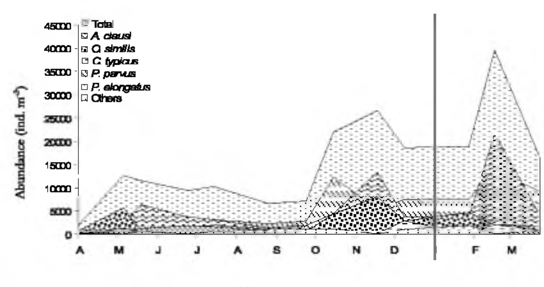

Fig. 9. The copepod species abundance in the Kepez Harbor during the sampling period. Figure shows the abundant species in each month through the sampled water column. "Others" include *C. euxinus*, *C. helgolandicus*, *Clausocalanus* sp., *C. pavo*, *T. stylifera*, *T. longicornis*, *A. patersoni*, *E. elongates*, *O. nana*, *O. mediterranea*, *O. longiseta* and *M. norvegica*.

May through early June. However, after 21 June 2005 *Penilia avirostris* (Dana 1849) was the common species in all sampling layers reaching its maximum density of 43560 ind. m^{-3} in July. *Oikopleura dioica* (Fol 1872) was the abundant species in the appendicularians during the sampling period having the highest abundance with 7407 ind. m^{-3} at the surface.

The PCA results of the bottom layer revealed significant positive relations between the cladocerans, appendicularians and salinity along the first component (~24% of the total variability) (Tables 2, 3). Peaks in the inorganic nutrient concentrations mostly coincided with the throughs in the zooplankton groups' abundance (Figures 4, 5, 6, 8). This relationship was also supported in PCA (Tables 2, 3), where different groups of zooplankton were either positively or negatively related to different inorganic nutrients in the first three components at the surface and the first component at the mixed layer. Results of the principal component analysis of the data showed a positive correlation between copepods and chlorophyll-*a* along the first principal component (~27% of the total variability) at the surface (Tables 2, 3). The PCA indicated a strong relationship between the copepods and nauplii along the second component at the surface and mixed layer, which explained ~17% of the total variability.

Table 2. The variance accounted for by each component to the total variance in all of the variables at the location of each sampling event in the PCA and the first five principal components form the extracted solution. The extracted components explained 74%, 74%, and ~82% of the total variability at the surface, mixed, and bottom layers, respectively.

Surface

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.508	26.983	26.983	3.508	26.983	26.983
2	2.195	16.886	43.869	2.195	16.886	43.869
3	1.562	12.012	55.880	1.562	12.012	55.880
4	1.353	10.410	66.290	1.353	10.410	66.290
5	1.010	7.772	74.063	1.010	7.772	74.063

Mixed Layer

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.450	26.540	26.540	3.450	26.540	26.540
2	2.248	17.294	43.835	2.248	17.294	43.835
3	1.624	12.494	56.328	1.624	12.494	56.328
4	1.253	9.640	65.969	1.253	9.640	65.969
5	1.085	8.344	74.313	1.085	8.344	74.313

Bottom Layer

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.135	24.114	24.114	3.135	24.114	24.114
2	2.540	19.536	43.650	2.540	19.536	43.650
3	2.099	16.144	59.794	2.099	16.144	59.794
4	1.514	11.644	71.439	1.514	11.644	71.439
5	1.339	10.302	81.741	1.339	10.302	81.741

DISCUSSION

Water quality parameters fluctuated considerably among the sampling depths throughout the sampling period. Other than, sporadic wind induced mixing events, temperature and salinity values clearly indicated the characteristics of the two different water masses in the Dardanelles Strait in the study area. It is known that the system is naturally nitrogen limited (Polat et al. 1998) and in this study chlorophyll-*a* responded well to the changes in nitrogen concentrations indicating a nitrogen limitation.

During the study period two peaks were observed in zooplankton abundance, one in early spring and the other in mid-summer. Although Tarkan et al. (2005) observed the highest zooplankton abundance in the Bosphorus Strait during spring and fall, the timing of the peaks and abundances in the present study were coincided with the ones observed in the studies conducted by İnanmaz (2001), Kovalev et al. (2003) and Siokou-Frangou et al. (2004) in the Mediterranean, Aegean Sea, Sea of Marmara, and the Black Sea.

As in many marine systems, copepods were the significant contributors of the zooplankton community in terms of abundance at the study site. Results showed that, Copepoda dominated the surface and the mixed layer during early spring and *A. clausi* was the most abundant species when compared to others. İnanmaz (2001), Siokou-Frangou et al. (2004) and Tarkan et al. (2005) reported *A. clausi* as the most common copepod species in the Aegean Sea, Sea of Marmara, and the Black Sea having the highest abundance in early spring similar to this study. All dominant copepod species were present all through the sampling period without showing a clear succession pattern. Characteristic peaks were observed in the species abundances depending on temporal variations. For example, being a cold water species *P. elongatus* has its greatest abundance during the colder months such as January and February of 2006 while the eurythermic species *P. parvus* appeared in the plankton all through the year (Shiganova 2005). Although known as a neritic species (Vidjak et al. 2006), *C. typicus* contributed to the copepod abundance, up to 15%, during the sampling period most probably because of the flow regime of the system. *O. similis* was found in the sampling site all

Table 3. The component matrix of extracted components at the location of each sampling event in the PCA. The first three components contributed the most to the solution for each depth layer are shown in the table.

Surface	Component			Mixed Layer	Component			Bottom Layer	Component		
	1	2	3		1	2	3		1	2	3
Copepod	.615	.591	.100	Copepod	-.236	.683	.474	Copepod	-.672	.235	.083
Naupliu	-.233	.615	-.155	Naupliu	.591	.583	.162	Naupliu	-.612	-.194	-.095
Cladocer	-.326	.133	.570	Cladocer	.322	-.484	.654	Cladocer	.591	.494	-.316
Appendic	-.119	.543	-.113	Appendic	.453	-.014	.658	Appendic	.646	.474	-.242
Salinity	.544	.172	-.206	Salinity	-.498	-.496	.018	Salinity	.607	-.577	.070
Temp	-.906	.020	-.139	Temp	.877	-.178	-.135	Temp	.075	-.630	.342
Chla	.690	-.143	.228	Chla	-.740	.342	.397	Chla	-.529	.544	.148
No_2+No_3	.529	-.126	.566	No_2+No_3	-.610	.170	.185	No_2+No_3	.486	.543	-.193
Nh_4	-.663	.231	.511	Nh4	.529	.410	-.234	Nh_4	-.065	-.679	-.431
Po_4	.674	.055	.286	Po_4	-.311	.438	-.159	Po_4	.460	.168	.788
Tp	.161	.675	.046	Tp	.518	.338	.281	Tp	-.234	.246	.838
Sio_2	-.398	-.071	.639	Sio_2	.151	-.524	.315	Sio_2	.476	-.277	.138
Do	.056	-.756	-.059	Do	-.361	-.185	.212	Do	-.396	.172	-.464

through the year reaching its maximum abundances during spring.

The characteristic cladoceran species of the Black Sea, Sea of Marmara and the northern Aegean Sea were observed in this study as well (Moraïtou-Apostolopoulou and Kiortsis 1973, Shiganova 2005, Buyukates and İnanmaz 2007). The fact that, the cladoceran species abundance, timing of occurrence and maximum densities were considerably different during the sampling period when compared with the other studies was previously recorded by Buyukateş and İnanmaz (2007).

Oikopleura dioica which is a common and significant appendicularian in the pelagic food web was also observed in the plankton all through the sampling period. Being a eurythermic species, it has been recorded in the Aegean and Black Sea year around (Siokou-Frangou et al. 2004, Shiganova 2005) and this study was no exception. *O. dioica* reached its maximum abundance during mid summer confirming a previous study conducted in the Black Sea (Shiganova 2005). As being effective filter feeders appendicularians and cladocerans share a similar feeding behavior even feeding on particles smaller than <2 μm (Turner et al. 1988, Sommer and Stibor 2002, Katechakis et al. 2004) and this relation was supported particularly along the first component of the PCA at the bottom layer.

Although grazer driven nutrient cycling is beyond the scope of this study, upon examination of the zooplankton groups with respect to nutrients, there appeared to be significant relations between the inorganic nutrients and the zooplankton groups which can be considered as evidence of grazer contribution to nutrient cycling. Especially, positive correlations of copepods, nauplii, calodocerans and appendicularians with NO_2+NO_3, NH_4, PO_4 and SiO_2 along the first three components and the first component of the surface and the mixed layer respectively, may suggest grazing activities and fertilization of zooplankton groups such as sloppy feeding, excretion, and egestion (Sterner 1986, Ingrid et al. 1996, Tang and Dam 1999, Roelke 2000). Therefore, zooplankton grazing activity and nutrient interactions as well as the effects of the prey item quality to the zooplankton groups in the study area can be considered for future research.

Closed coastal systems such as harbors are excellent test areas to observe the effects of anthropogenic stress on the water quality and the lower food web, particularly the zooplankton dynamics as the supporting secondary production to higher trophic levels. It is important to continually monitor these kinds of systems to detect any significant changes due to human induced activities. To better understand the importance of zooplankton both as a food source and a driving mechanism of the lower food web dynamics in such systems, detailed experimental research such as nutrient bioassays and competition experiments should be conducted.

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