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Research Article

Seasonal Zooplankton Distribution and Species Composition in the Eastern Sea of Marmara

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ABSTRACT

Seasonal changes in the composition and abundance of zooplankton and their responses to environmental changes were investigated at 30 stations in the upper layer and 13 stations in the lower layer (in February, May, July, and December) of the Eastern Marmara Sea in 2016. A total of 44 species/groups (including jellyfish species) were documented in the study area, with 39 identified in the upper layer water and 31 in the lower layer water. The abundances of zooplankton ranged from 29 to 2822 ind.m^{-3} in the upper layer and from 6 to 2283 ind.m^{-3} in the lower layer. *Acartia clausi, Paracalanus parvus, Penilia avirostris,* and *Oithona similis* were the dominant species in summer and autumn, whereas *Calanus euxinus, Pseudocalanus elongates, Oithona nana, Oithona davisae* and *Pleopis polyphemoides* were the dominant species in winter and spring. *Aetideus* spp., *Clausocalanus* spp., *Ctenocalanus vanus*, *Oncaea minuta, Isopoda*, and *Siphonophora* were observed only in bottom-layer waters. *M. lucens* and *O. davisae* were recorded only in the upper layer in December. In conclusion, our results suggest that zooplankton communities and some species are favorable indicators of the marine environment of the Sea of Marmara.

Keywords: Zooplankton, abundance, species diversity, Sea of Marmara

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INTRODUCTION

Marine coastal areas feature greater levels of plankton biodiversity and production, which play an important role in biogeochemical processes. However, climate change and anthropogenic pressures that degrade ecosystems threaten biodiversity and ecological functions. Increasing anthropogenic activities accelerate eutrophication, often leading to irreversible degradation (Tüfekçi et al., 2010; Kemp and Boynton, 2012; Griffith and Gobler, 2020).

Zooplanktons are highly sensitive to physico–chemical parameters and biological factors in marine systems (Isinibilir et al., 2008; Shi et al., 2015). The composition and abundance of zooplankton largely depend on environmental conditions and respond rapidly to environmental changes (Isinibilir et al., 2011). As a result, zooplankton is considered a biological indicator of environmental water quality. Zooplankton orchestrate marine ecosystems by not only transferring energy from primary producers to higher trophic levels but also regulating phytoplankton production and shaping the pelagic ecosystem (Rissik et al., 2009).

The Marmara Sea is an important transitional basin between the Black Sea and the Mediterranean, connected to the Black Sea via the Bosphorus and to the Aegean Sea via the Dardanelles. The upper layer of the Marmara Sea is influenced by low salinity Black Sea water (18%), while more saline water from the Mediterranean (up to 40%) is found at depths exceeding 20 m (Beşiktepe et al., 1994). Over the last few decades, many factors including excessive nutrients and pollutants, overfishing, the introduction of new species, and climate change have significantly disrupted the Marmara Sea fauna temporally and spatially. These changes have resulted in red tide and mucilage aggregation, the disappearance or sharp decline in population of some species, and a rise in the number of nonindigenous species (Aktan., 2008; Isinibilir et al., 2010; Isinibilir Okyar et al., 2015; Doğan & Isinibilir, 2016; Isinibilir & Yılmaz, 2017, Turkoğlu, 2013). Zooplanktons, the most important link in energy transfer in the seas, were the first to react to these changes (Isinibilir et al., in press).

The main aim of this study is to explore the abundance and fluctuations in species composition of coastal zooplankton communities in the eastern region of the Sea of Marmara. Furthermore, the study seeks to quantify the zooplankton composition in the research area to determine the indicator species composition across environmental conditions as well as to improve existing data by measuring the relationships of indicator species in the research area with environmental parameters.

MATERIALS AND METHODS

Sampling design and analysis of samples

Upper layer samples exposed to both the Black Sea and local pollution were collected from 30 stations on the Marmara Sea in February, May, July, and December in 2016. Stations İZ9, M11, İZ4, and MD102 were located offshore where there is less anthropogenic stress, representing the open-sea ecosystem of the Sea of Marmara, although they were still impacted by the top layer flow from the İzmit Bay and the Istanbul Strait. Stations MD3, MD4, İZ8, and MD8 were considered less polluted and represented a transitional zone from the neritic to open-sea environment. G2, KÇ, M12, M13, M14, MD1, MD2, MD3, MD4, MD5, MD6, MD7, MD9, MD10, MD75, MY5 YK1, İZ7, İZ6, İZ5, İZ3, İZ2, and İZ1 were in the coastal waters of the Sea of Marmara where anthropogenic stress is greatest. Samples were collected from the Mediterranean-originated lower layer at 13 stations (MD1, MD3, MD4, MD5, MD6, MD7, MD8, MD75, MD102, M11, İZ9, İZ8, and İZ4) during periods characterized by both thermal stratification and haline stratification.

Zooplankton samples (including jellyfish species) were gathered vertically using a WP2 closing net with a 0.5 m diameter and a 157-mm mesh. Samples were collected from the bottom to the start of the mixing layer and from the interface (18–20 m) to the surface. The salinity, temperature, and dissolved oxygen of the whole water column were measured with an SBE-19 SEACAT CTD (conductivity, temperature, and pressure recorder) system. Chlorophyll-a analyses were conducted at all stations in the upper water layer using the methodology outlined in APHA (2000). The zooplankton samples were preserved on board using a 4% formalin seawater solution. Three 1-ml aliquots were obtained from the sampling bottle with a Stempel pipette; counting and diagnostics were performed in the zooplankton counting chamber and stereobinocular microscope.

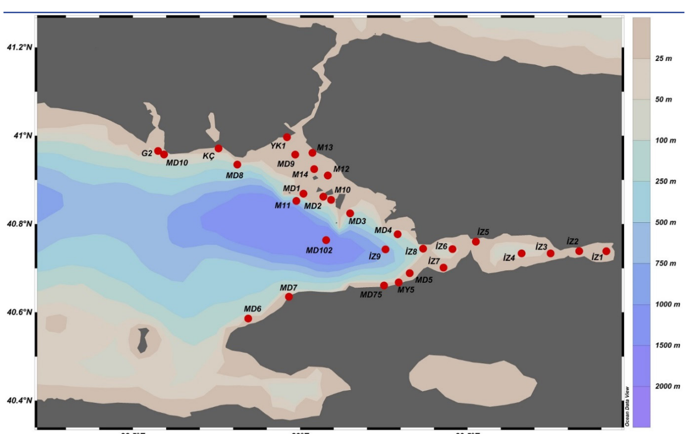

Figure 1. Locations of the sampling stations in the Sea of Marmara.

Statistical analysis

The zooplankton community was assessed according to the Shannon index of diversity (H′) and the number of species (S) as described by Shannon and Weaver (1949). Furthermore, using log (x + 1)-transformed abundance data and Primer v. 6 software, multidimensional scaling (MDS) studies of similarity between sampling months were performed based on the Bray–Curtis similarity index (Clarke & Warwick, 1994). Using SPSS v22 software, Spearman's rank-correlation coefficient was calculated to find associations between biotic and abiotic factors.

RESULTS AND DISCUSSION

The two-layered structure is discernible from the profiles of salinity, temperature, and dissolved oxygen (Figure 2). The highest sea surface temperature and chlorophyll-a values were observed in July (25.3⁰C and 7.7 μg.L^{-1}), whereas the highest salinity (30.4 ppm) and dissolved oxygen (8.8 mg.L^{-1}) values were measured in February (Figure 3). Oxygen values decreased from the surface to the bottom throughout the water column, and values below 2 mg.L^{-1} were detected deeper than 50 m.

The minimum dissolved oxygen value was recorded in May (4.57 mg.L^{-1}). Despite its considerable variability, the distribution of chlorophyll-a exhibited notable spatio-seasonal patterns and a strong correlation with temperature ($r = 0.526$, $p < 0.01$).

Seasonal variations were observed in the abundance and biomass of zooplankton (excluding the dinoflagellate *Noctiluca scintillans*) in the eastern Sea of Marmara (Figure 3). The maximum quantity of zooplankton was observed at station MD6 in December (2822 ind.m^{-3}) due to high abundance of *Paracalanus parvus* and *Penilia avirostris* (1210 ind.m^{-3} and 468 ind.m^{-3}, respectively). In contrast, the zooplankton biomass peaked at station M11 in May due to *Aurelia aurita* (Figure 3).

A total of 44 species/groups were documented in the study area, with 39 identified in the upper layer water and 31 in the lower layer water (Table 1). The most abundant zooplankton groups across all stations were copepods, cladocerans, meroplankton, appendicularians and jellyfishes. *Aetideus spp., Clausocalanus spp. Ctenocalanus vanus, Goniopsyllus rostratus, Oncaea minuta*, Isopoda, and Siphonophora were observed only in bottom-layer waters; *M. lucens* and *O. davisae* were observed only in the upper layer in December.

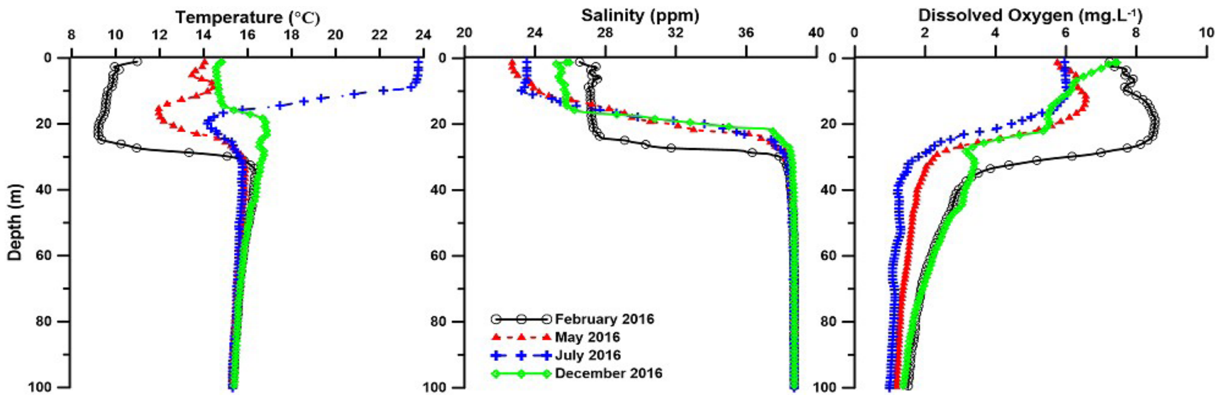

Figure 2. Temperature, salinity and dissolved oxygen profiles in station M11.

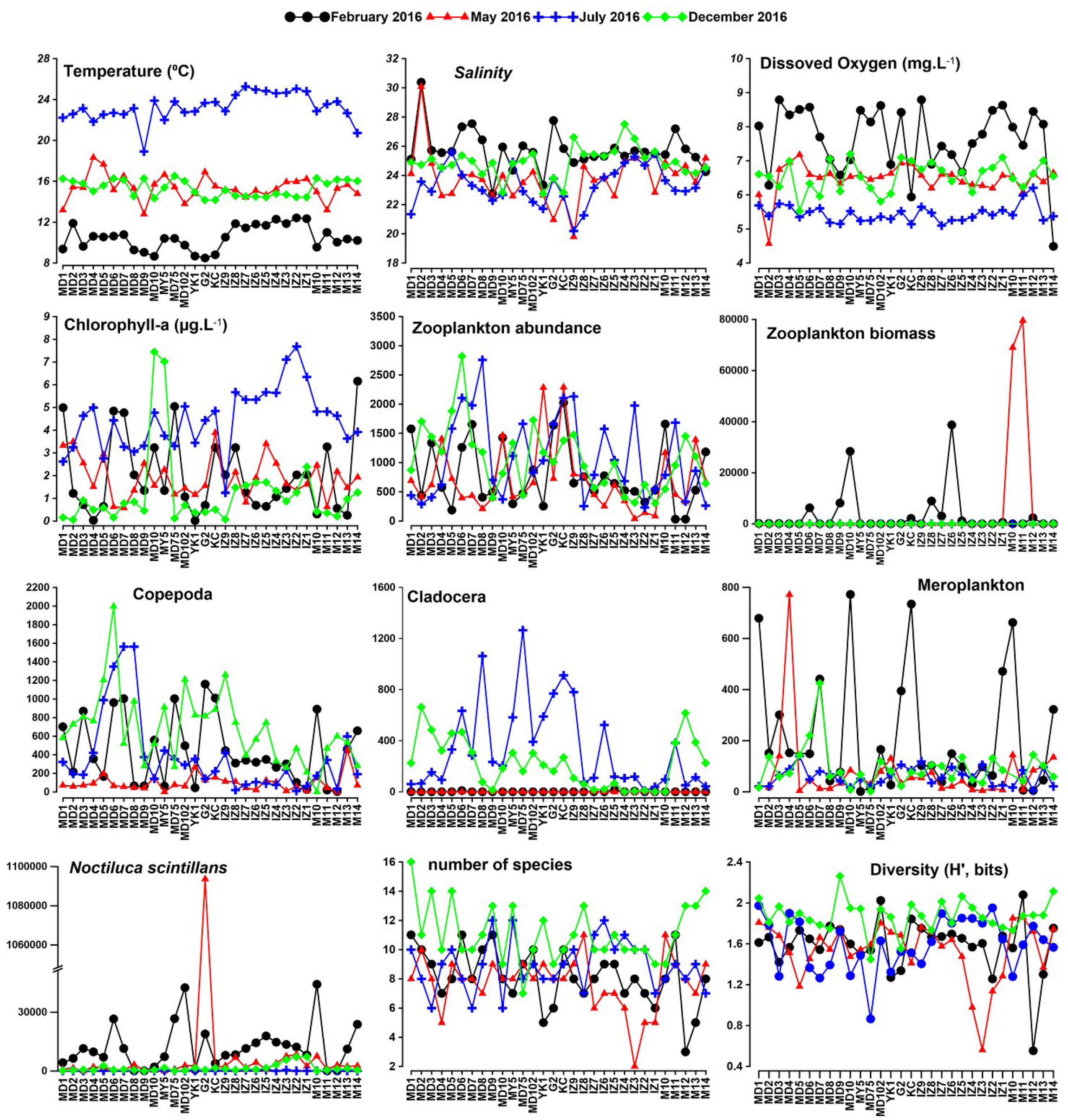

Figure 3. Seasonal fluctuation of temperature, salinity, dissolved oxygen, and chlorophyll-a at the upper layer.

Table 1. The total and seasonal mean abundances (ind.m−3) of zooplankton species/groups and Noctiluca scintillans in the eastern Sea of Marmara.

	February 2016		May 2016		July 2016		December 2016		Total mean abundance in 2016	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
COPEPODA										
Acartia clausi Giesbrecht. 1889	2624.94	285.84	2133.62	166.81	7112.53	745.82	4147.87	239.37	4000.474	359,46
Aetideus spp.	0	0	0	5.27	0	5.27	0	0	0	2.635
Calanus euxinus Hulsemann. 1991	67.01	30.45	0	0	0	0	12.74	2.62	19.937	8.267
Centropages ponticus Karavaev. 1895	15.71	9.26	0	0	0	0	0	0	3.927	2.315
Centropages typicus Kröyer. 1849	51.97	0	11.89	0	8.49	4.37	33.97	7.42	26.58	2.947
Clausocalanus spp.	0	4.25	0	0.31	0	0.24	0	0.24	0	1.26
Ctenocalanus vanus Giesbrecht. 1888	0	12.74	0	5.27	0	5.27	0	12.74	0	9.005
Euterpina acutifrons (Dana. 1847)	82.31	69.78	17.83	8.49	21.23	5.27	433.12	42.48	138.622	31.505
Euchaeta marina (Prestandrea. 1833)	0	2.62	0	0	0	5.27	0	8.49	0	4.095
Metridia lucens Boeck. 1864	0	0	0	0	0	0	29.72	0	7.430	0
Microcalanus pygmaeus (Sars G.O. 1900)	2.62	8.49	0	0	0	0	2.62	4.37	1.310	3.215
Oithona davisae Ferrari & Orsi. 1984	0	0	0	0	0	0	65.19	0	16.297	0
Oithona nana Giesbrecht. 1893	1616.31	211.67	5696.53	1016.85	2005.66	617.09	2057.70	232.40	2844.050	519.502
Oithona similis Claus. 1866	146.07	37.77	325.27	39.28	430.29	95.66	2466.59	509.71	842.055	170.605
Oithona spp.	0	0	0	0	0	2.62	0	0	0.655	0
Oncaea minuta Giesbrecht. 1893	0	17.83	0	25.48	0	17.83	0	25.48	0	21.655
Oncaea spp.	0	2.62	0	0	0	0	0	5.27	0	1.972
Paracalanus parvus (Claus. 1863)	5945.53	550.47	1926.11	308.59	3841.47	652.69	6904.46	245.27	4654.39	439.255
Pseudocalanus elongatus (Boeck. 1865)	0	0	25.48	0	12.74	0	35.47	0	18.422	0
Temora stylifera (Dana. 1849)	0	0	12.74	0	2.62	0	2.62	0	4.495	0
Copepoda nauplii	89.51	27.55	50.96	15.79	56.62	14.76	83.68	13.25	70.192	17.837
CLADOCERA										
Penilia avirostris Dana. 1852	0	0	0	8.49	8980.89	1530.89	6326.71	258.35	3826.90	449.432
Pleopis polyphemoides (Leuckart. 1859)	901.40	63.09	4206.37	15.41	227.88	3.73	80.18	0	1353.957	20.557
Pseudevadne nordmanni Lovén. 1836	8.49	0.24	0	0	12.74	0	0	0	5.307	0.060
APPENDICULARIA										
Oikopleura dioica Fol. 1872	875.30	175.12	976.93	33.20	635.53	135.29	1129.51	85.28	904.317	107.222
CHAETOGNATHA										
Sagitta setosa (Müller. 1847)	74.73	21.91	0	0	0	99.86	167.27	69.52	60.5	47.822

Table 1. Continue.

	February 2016		May 2016		July 2016		December 2016		Total mean abundance in 2016	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
MEROPLANKTON										
Fish larvae	136.83	8.66	4.25	0	0	0	0	0	35.27	2.165
Fish egg	1524.44	17.66	619.96	13.87	97.86	45.55	31.75	6.55	568.502	20.907
Bivalvia larvae	2505.19	486.75	615.71	82.29	703.47	55.04	1694.80	217.01	1379.792	210.272
Decapoda larvae	2.14	0.20	17.24	6.09	139.79	55.04	7.79	22.21	41.74	20.885
Cirripedia larvae	21.23	0	0	0	0	0	0	0	5.307	0
Polychaeta larvae	230.29	35.41	457.44	28.77	349.61	18.04	256.53	70.22	323.467	38.11
Isopoda larvae	0	0	0	0	0	0	0	0.17	0	0.042
Gastropoda larvae	4.25	0	0	0	0	0	0	0	1.062	0
Reptantia (Brachyura) larvae	2.62	0	0	0	0	0	2.62	0	1.31	0
Pteropoda	0	0	2.62	0	2.62	0	0	0	1.31	0
OTHER GROUPS AND SPECIES										
Aglaura hemistoma Péron & Lesueur. 1810	0	0	0	0.68	0	0	4.76	0.34	1.19	0.255
Aurelia aurita (Linné. 1758)	4.62	3.52	1395.61	2.67	108.85	1.70	991.63	3.40	625.177	2.822
Beroe ovata Chamisso ve Eysenhardt. 1821	14.95	0.59	0.36	4.53	0	0	0.51	0	3.955	1.28
Mnemiopsis leidyi A. Agassiz. 1865	0.25	0	0	0	0	0	0	0	0.062	0
Pleurobrachia pileus (O.F.Müller. 1776)	26.77	7.42	24.29	5.34	0.51	0	0	0	12.892	3.19
Siphonophora (sp.)	0	0.15	0	0	0	0	0	0	0	0.037
Total zooplankton	242339.5	2092.060	51284.98	1793.48	25034.49	4061.96	42510.21	2082.16	89687.463	2978,7395
Noctiluca scintillans (Macartney. Kofoid et Swezy. 1921)	225358.08	0	32763.77	0	283.09	0	15540.40	0	68486.335	0

The abundance of most zooplankton groups displayed distinct seasonal patterns in the eastern Sea of Marmara. In general, copepods and cladocerans were the predominant groups (Table 1), whereas meroplankton became more prominent in coastal regions, eventually dominating the zooplankton community (e.g., stations MD10 and KC in February) (Figure 3). *Acartia clausi* was present year-round, reaching higher densities at station MD7 (913 ind.m^{-3}) and İZ9 (904 ind.m^{-3}) in July, whereas *P. parvus*, *E. acutifrons*, and *C. euxinus* were the primary members of the copepod community during February and December (Table 1, Figure 4). *Oithona nana, Pleopis polyphemoides*, and fine particle filter feeder, *Oikopleura dioica*, dominated the zooplankton community in all seasons, and *Oithona similis* and other fine particle filter feeder *Penilia avirostris* were abundant in July and December. High concentrations of bivalve and polychaeta larvae were measured in February and May, especially in coastal areas, whereas *Parasagitta setosa* was detected in February, July, and December. *Oithona davisae* was observed only in December and mostly at coastal stations (KC, YK1, MD1, MD3, MD5, M12, M13, M14, MY5, 1Z8, IZ7, IZ5, IZ4, IZ3, IZ1).

The highest number of species was observed at MD1 (16 species/groups) in December and the lowest number at İZ3 (3 species/groups) in May and at M12 (3 species/groups) in February. The maximum diversity index was recorded at station MD9 (2.3) in December. The minimum diversity index was 0.6 at station M12 in February and at station İZ3 in May. This decrease in diversity was due to dominance of *P. polyphemoides* and *A. clausi* (Figure 3).

The heterotrophic dinoflagellate *Noctiluca scintillans*, an important component of the net samples in the Sea of Marmara, showed sea-

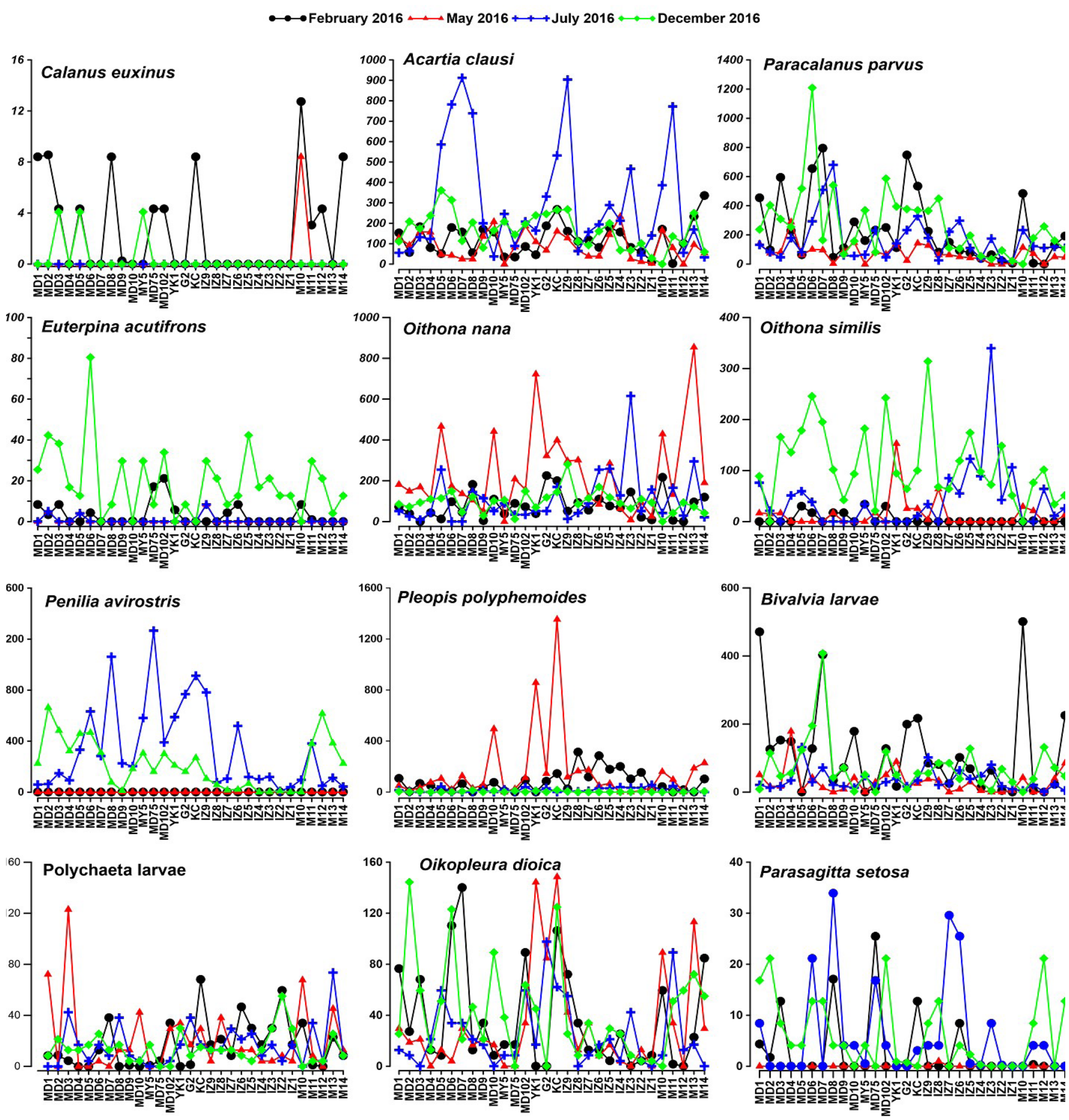

Figure 4. Variations in the abundance (ind.m−3) of primary zooplankton species and groups within the upper layer.

sonal distribution (Figure 2), peaking in February (225358 ind.m^{-3}) and reaching its minimum in July (283 ind.m^{-3}). *N. scintillans* reached its maximum abundance (1093617 ind.m^{-3}) at station G2, located at the entrance of Büyükçekmece Bay. The densities of *N. scintillans* fell to minimum levels in July but increased in December. MDS ordination of combined data across seasons showed that the zooplankton community of the eastern Sea of Marmara had high seasonality (Figure 5). Total zooplankton assemblage exhibited heterogeneity from July to December (Group I) and February to May (Group II). The species predominant from July to December included *Acartia clausi, Paracalanus parvus*, *Penilia avirostris,* and *Oithona similis* (Group I); those predominant from February to May community included *Calanus euxinus, Pseudocalanus elongates, Oithona nana, Oithona davisae, Pleopis polyphemoides*, polychaeta, and bivalve larvae. Moreover, stations M11 and M12 in February and IZ3 in May (Group III) were distinct from other samplings due to the dominance of *Pleopis polyphemoides, Oithona nana*, and *Acartia clausi* as well as low species diversity.

While *P. avirostris* was positively affected by temperature increase ($r = 0.510$, $p < 0.01$), it was negatively correlated with salinity ($r = -0.282$, $p < 0.01$) and dissolved oxygen ($r = -0.400$, $p < 0.01$). Bivalvia larvae were positively affected by salinity ($r = 0.247$, $p < 0.01$) and dissolved oxygen ($r = 0.196$, $p < 0.05$) but inversely related to temperature increase ($r = -0.305$, $p < 0.01$). *A. clausi* was positively affected by temperature ($r = 0.381$, $p < 0.05$) and negatively correlated with increased salinity ($r = -0.214$, $p < 0.05$) and dissolved oxygen ($r = -0.284$, $p < 0.01$).

Zooplankton abundance, *P. parvus,* and *P. setosa* positively correlated with temperature ($r = 0.186$, $r = 0.194$, and $r = 0.186$, $p < 0.05$, respectively), whereas polychaeta larvae ($r = -0.295$, $p < 0.05$) and *C. euxinus* ($r = -0.370$, $p < 0.01$) had a negative correlation with it. *E. acutifrons* ($r = 0.134$, $p < 0.05$) and *O. nana* ($r = 0.216$, $p < 0.05$) had a positive correlation with dissolved oxygen, whereas *N. scintillans* ($r = -0.201$, $p < 0.05$) and *P. polyphemoides* ($r = -0.244$, $p < 0.01$) were inversely related to dissolved oxygen increase. Furthermore, jellyfish abundance was weakly correlated with total zooplankton abundance, *O. similis, P. avirostris*, and *P. setosa*, ($r = -0.107$, $r = -0.112$, $r = -0.123$, $r = -0.103$ $p < 0.001$, respectively) but it was positively correlated with *P. parvus* ($r = 0.151$, $p < 0.001$) and *O. dioica* ($r = 0.181$, $p < 0.05$).

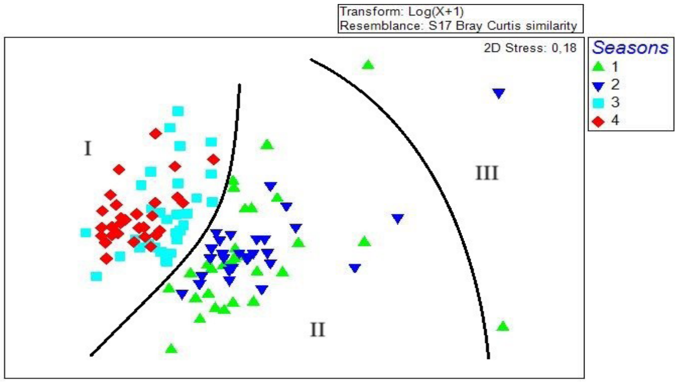

Figure 5. MDS analyses by seasons (1: February. 2: May. 3: July. 4: December)

The upper layer waters generally exhibited a greater zooplankton abundance than the lower layer waters but a lower number of species (Table 1, Figure 6, 7). The maximum average abundance in the upper layer was 2822 – 29 ind. m^{-3}, whereas the corresponding value in the lower layer was 462 – 6 ind. m^{-3}. The number of species and zooplankton abundance significantly differed between groups; zooplankton were more abundant in the upper layer than in the lower layer. The biggest difference between the lower and upper layers was measured in July and December 2016 when Cladocera dominated the upper layer of Marmara. Species such as *Aetideus* spp., *Clausocalanus* spp., *Ctenocalanus vanus, Oncaea minuta, Oithona davisae,* Pteropoda, and Siphonophora contribute to the differences in zooplankton communities between the upper and lower layers. The corresponding MDS analysis revealed significant differences between the lower and upper layers (Figure 8).

This study identified the major zooplankton species and their seasonal availability in the Marmara Sea. The most widely distributed zooplankton species were also the most prevalent and dominant species such as *Paracalanus parvus, Acartia clausi, Oithona nana, Penilia avirostris, Pleopis polyphemoides*, and bivalve larvae. These species are similar to those found in previous studies in the Marmara Sea (Yılmaz et al., 2005; Tarkan et al., 2005; Isinibilir et al., 2011). Notably, *O. davisae,* an invasive species that was first recorded in the Marmara Sea in 2014 (Doğan & Isinibilir, 2016), has expanded its distribution area to the Izmit Bay in the Sea of Marmara. The Sea of Marmara is home to several Mediterranean species, including *Oncaea minuta, Aetideus spp., Ctenocalanus vanus, Clausocalanus spp., Euchaeta marina*, and Siphanophore (Isinibilir et al., 2011).

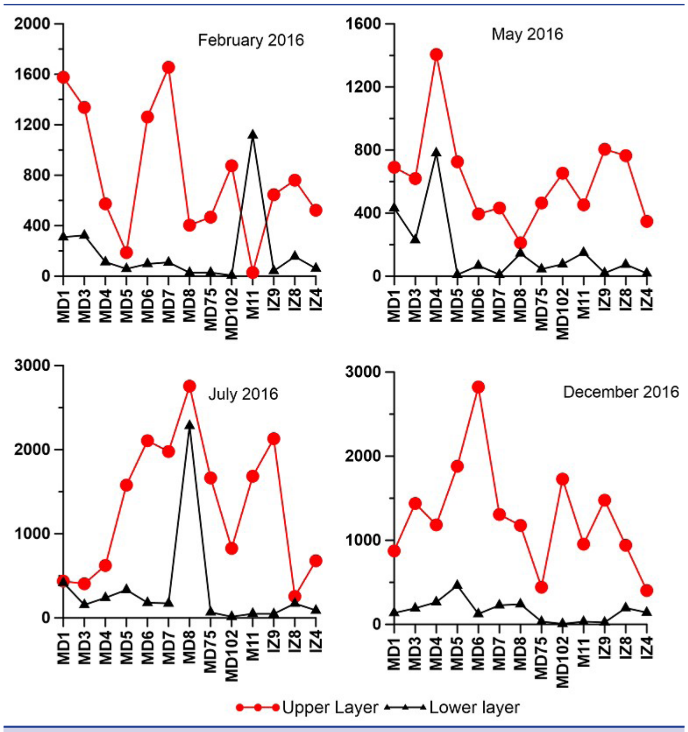

Figure 6. Seasonal distribution of zooplankton abundance (ind.m^{-3}) in the upper and lower layers at various sampling stations.

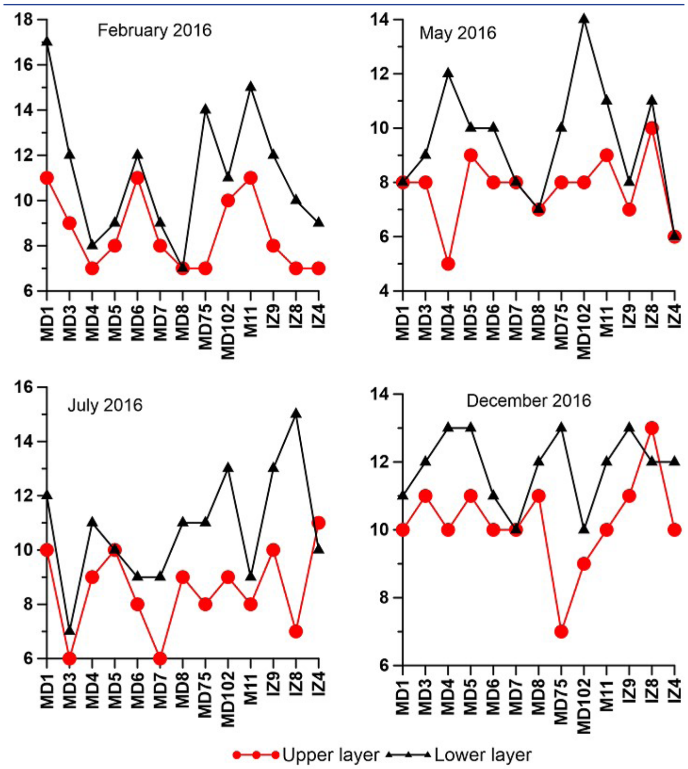

Figure 7. The variation in the number of species in the lower and upper layers at the sampling stations.

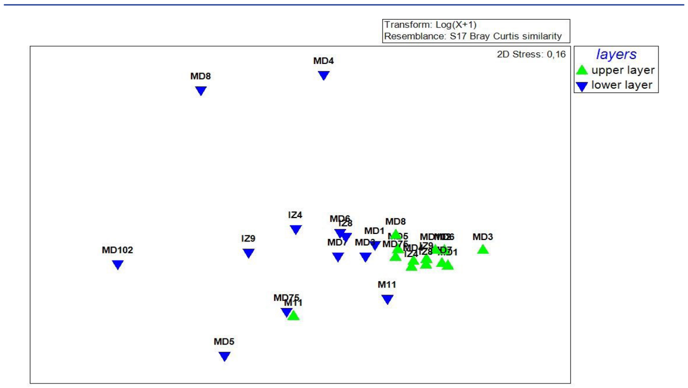

Figure 8. MDS ordination of combined data of upper- and lower layer samples.

In the Eastern Marmara Sea, zooplankton are more abundant in the upper layer than in the lower, which agrees with previous studies (Tarkan et al., 2005; Isinibilir et al., 2008, 2011). Strong stratification in the basin, depending on temperature and salinity, limits the daily vertical migration pattern of zooplankton (Isinibilir et al., 2011). Accordingly, species compositions differ between layers, and the main zooplankton biomass is concentrated in the upper layer (Mutlu, 2005; Isinibilir Okyar, et al., 2015). Thus, this study further corroborates that the top layer has larger values in terms of biomass and abundance than the lower layer. Oithona is a widespread genus in eutrophic and degraded unstable environments due to its resilience (Richard & Jamet, 2001; Castellani et al., 2005; Isinibilir et al., 2016; Svetlichny et al., 2018). In particular, *O. davisae* and *O. nana* are classified as polluted area species (Drira et al., 2017; Isinibilir et al., 2008, 2016). *O. davisae*, a cyclopoid copepod originating from the western Pacific Ocean (Hirakawa, 1988), was first recorded in the Black Sea in the Sevastopol Bay in December 2001 (Zagorodnyaya 2002). Over the last decades, this species gradually spread to the entire eastern and western coasts of the Black Sea (Altukhov et al., 2014; Gubanova & Altukhov, 2007; Mihneva & Stefanova, 2013), the Sea of Marmara (Doğan & Isinibilir, 2016; Isinibilir et al., 2016) and the Aegean Sea (Terbıyık-Kurt & Beşiktepe, 2019). Due to its thermophilic nature (Svetlichny et al., 2016), this species is most abundant during the warm seasons and least abundant during winter and early spring (Altukhov et al., 2014; Mihneva & Stefanova, 2013; Uye & Sano, 1998; Zagami et al., 2018). However, variations in the population density of *O. davisae* showed differences across regions (Ambler et al., 1985; Uye and Sano, 1995; Svetlichny et al., 2018). In this study, *O. davisae* was distributed in eutrophic coastal areas and less abundant only in December. As *O. nana* is a tolerant, opportunistic, and widely adapted species, this species can be found in sea ports and near urban wastes and/or brackish waters with varying degrees of pollution (Richard and Jamet, 2001; Beşiktepe et al., 2023). As in previous studies on the Sea of Marmara (Isinibilir et al., 2008, 2016; Isinibilir Okyar et al., 2015), this work showed that *O. nana* is the predominant zooplankton species year-round, especially in severely perturbed coastal areas.

A. clausi, widely distributed in temperate waters and dominates zooplankton in polluted areas, is also the most prevalent species in the Sea of Marmara year-round (Gubanova et al., 2001; Isinibilir et al., 2008; 2011; Svetlichny et al., 2022, Beşiktepe et al., 2023). This study supports previous findings that *A. clausi* predominates in coastal areas, reflecting the eutrophic characteristics of this sea. On the other hand, *O. similis* and *P. parvus*, the other dominant copepod species in the Marmara Sea (Isinibilir et al., 2008; Isinibilir, 2009; 2010), are nonsensitive species that can live in both polluted and unpolluted marine environments (Drira et al., 2017).

Environmental factors such as temperature, salinity, predation, food availability, and water transparency can affect the Cladocera population (Calbet et al., 2001; Marques et al., 2006; Atienza et al., 2008; Isinibilir et al., 2011). At different spatiotemporal scales, the dynamics of small-sized cladoceran abundance are influenced by predatory forces from planktivorous fish and invertebrates (Onbe & Ikeda 1995, Egloff et al., 1997; Camatti et al, 2008). In this study, the increase in *P. avirostris* abundance was triggered by water temperature, whereas salinity caused the reverse effect. In addition to being an important food source for marine pelagic fish, *P. avirostris* plays an important role in the zooplankton community due to its high abundance in tropical and temperate waters, especially during the summer (Calbet et al., 2001; Marazzo & Valentin, 2003; Rose et al., 2004). As the body length of *P. avirostris* varies between 0.70 and 1.09 mm (Zhou et al., 2022), this species may be important for fisheries by attracting many larvae and adult pelagic fish such as mackerel, sardine, horse mackerel, and anchovy (Wu et al., 2023). *Penilia avirostris* exhibits a broad dietary spectrum, encompassing small diatoms and bacterivorous microflagellates (Turner et al., 1988) as well as prymnesiophyceans (Paffenhofer & Orcutt, 1986) and bacteria (Lipej et al., 1997). The contributions of predation to the formation of marine zooplankton ecosystems have previously been disregarded (Verity & Smetacek, 1996). However, fish larvae, chaetognaths, and ctenophores are among the predators that might wipe out marine cladoceran populations (Duró & Saiz, 2000; Barz &Hirche, 2005). Nevertheless, how predation affects *P. avirostris* population dynamics in the Sea of Marmara is unclear. Other important cladoceran species like *Pleopis polyphemoides*, the most euryhaline species (Viñas et al., 2007), transpired throughout the winter months after going dormant during the warmer ones, as in previous studies (Isinibilir et al., 2008; Isinibilir, 2009; Isinibilir Okyar et al., 2015).

In the Sea of Marmara, *N. scintillans* exhibits a year-round distribution, with the greatest abundance in the spring and a secondary increase in the autumn (November) (Isinibilir et al., 2008; Isinibilir 2009). This species competes with zooplankton for food, and its high tolerance for temperature and salinity, coupled with its feeding on zooplankton eggs, promote its ecological success (Schaumann et al., 1988; Kirchner et al., 1996; Elbrachter & Qi, 1998; Quevedo et al., 1999). Thus, it is crucial to monitor the distribution and abundance of this species in the Sea of Marmara.

CONCLUSION

In conclusion, the zooplankton communities in the Marmara Sea exhibited notable seasonal fluctuations in abundance and species diversity. Given the correlations between seasonal changes in dominant species and environmental factors such as temperature, salinity, and chlorophyll-a, zooplankton can serve as a significant indicator of changes in this marine environment. The Sea of Marmara has undergone significant changes recently due to rising temperatures and increased industrial pollution, which negatively influence zooplankton ecosystems. Extensive research conducted at the basin level is still required to elucidate the evolution and changes of this ecosystem that is vulnerable to human impacts and climate change.

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