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Changes in abundance and community structure of the zooplankton population during the 2008 mucilage event in the northeastern Marmara Sea

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Abstract: The composition and abundance of zooplankton and the corresponding environmental conditions were investigated during the 2008 mucilage event (April–December 2008) in the Marmara Sea. As a result, 46 zooplanktonic taxa were identified. Copepods and cladocerans were generally the most abundant groups. *Mnemiopsis leidyi* had a significant seasonality, and abundance was related to fluctuations in temperature and salinity. The most important species were *Acartia clausi* and *Penilia avirostris*, but these species did not reach their usual autumn maximum. As a result, the mucilage event in 2008 caused significant shifts in zooplankton abundance and community structure in the Marmara Sea.

Key words: Zooplankton, mucilage, Marmara Sea

1. Introduction

Mucilage events are characterized by the appearance of gelatinous aggregates suspended in the water column. Massive aggregation is produced by various marine organisms under special seasonal and trophic conditions and meteorological conditions (Innamorati et al., 2001; Mecozzi et al., 2001). Mucilage can heavily affect marine ecosystems by covering large areas; in addition, fisheries and tourism industries can be seriously damaged (Innamorati et al., 2001). The appearance of mucilage formation in the Adriatic Sea has been reported since the 1800s, with major mucus aggregates forming during the 1990s (Totti et al., 2005). Mucilage events have been reported over a wide geographic range, including New Zealand, the Aegean Sea, and the East China Sea (MacKenzie et al., 2002; Nikolaidis et al., 2008; Fukao et al., 2009).

The first appearance of mucilage in the Marmara Sea was recorded in 2007 (Aktan et al., 2008). Similar events had been observed in the past in the western part of the sea, around Erdek Bay, but had never been recorded and studied (Tüfekçi et al., 2010). The Marmara Sea is a transit basin providing water exchange between the Mediterranean Sea and Black Sea. Water masses from these 2 seas form the unique Marmara ecosystem, which includes biological components with different origins. Surface layers of the Marmara Sea are affected by Black Sea water with low salinity (~20‰), while more saline water masses (up to

40‰) from the Mediterranean Sea are located at depths of >20 m. The upper layer of the Marmara Sea largely reflects the seasonal characteristics of Black Sea water, modified in transit through the Bosphorus (Beşiktepe et al., 1994).

Although there have been several studies about the effects of mucilage aggregation on phytoplankton in the Marmara Sea (Aktan et al., 2008; Tüfekçi et al., 2010; Balkıs et al., 2011), there have been no studies targeting its effect on zooplankton. The main aim of this study was to investigate the zooplankton composition and abundance in the Marmara Sea during the mucilage period together with environmental variables.

2. Materials and methods

Sampling was conducted monthly between April and December 2008 at a single station (M10) located in the coastal waters of Heybeliada Island (Figure 1). Zooplankton samples were collected vertically during daytime using a WP2 closing net (200 µm mesh, 0.57 m diameter) from the beginning of the intermediate layer (18–20 m) to the surface for samples of the upper layer, from the end of the upper layer to the beginning of the lower layer for samples from mixed layers, and from the bottom (50 m) to the end of the intermediate layer for samples of the lower layer. The net was rinsed gently, and samples were transferred into plastic containers and fixed by the addition of borax-buffered formaldehyde to a final concentration of

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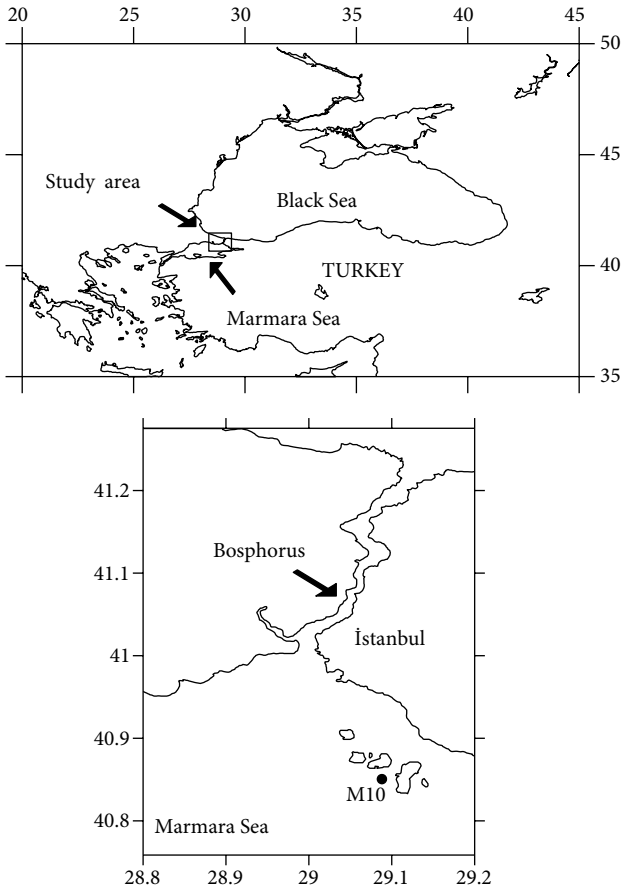


Figure 1. Study area.

4%. Identification of specimens was carried out under a stereomicroscope using a Bogorov-Rass counting chamber. Quantitative analyses of common species were conducted in triplicates from subsamples taken using

a 1-mL Stempel pipette. Rare species were identified from the entire sample. Cladocerans and copepods were identified to species or genus level. All other taxa were identified to the lowest possible taxa. Sampling procedure and species identifications were performed according to Harris et al. (2006), Rose (1933), and Tregouboff and Rose (1957).

Water temperature, salinity, and dissolved oxygen profiles were measured with an SBE-19 SEACAT CTD (conductivity, temperature, and pressure recorder) system. Secchi disk depths were also measured with a white-black disk of 30 cm in diameter. For chlorophyll *a* analysis, 1 L of seawater was filtered through Whatman GF/C glass fiber filters and kept frozen until analysis. Total chlorophyll *a* concentrations were determined spectrophotometrically after the extraction of the filtered samples by acetone (APHA, 1999).

The zooplankton community was analyzed in terms of species richness (*d*), Shannon index of diversity (H'), dominance (*D*), and number of species (*S*) (Shannon and Weaver, 1949; Simpson, 1949; Margalef, 1958). Spearman's rank-correlation coefficient was used to detect any correlation among biotic and abiotic variables (Siegel, 1956). In addition, multidimensional scaling (MDS) analyses of similarity between sampling months were computed on the basis of the Bray-Curtis similarity index using log (*x* + 1)-transformed abundance data and Primer v. 6 software (Clarke and Warwick, 1994).

3. Results

3.1. Environmental variables

The 2-layered structure is evident from the temperature, salinity, and dissolved oxygen profiles (Figure 2). During the sampling period, temperature values ranged between

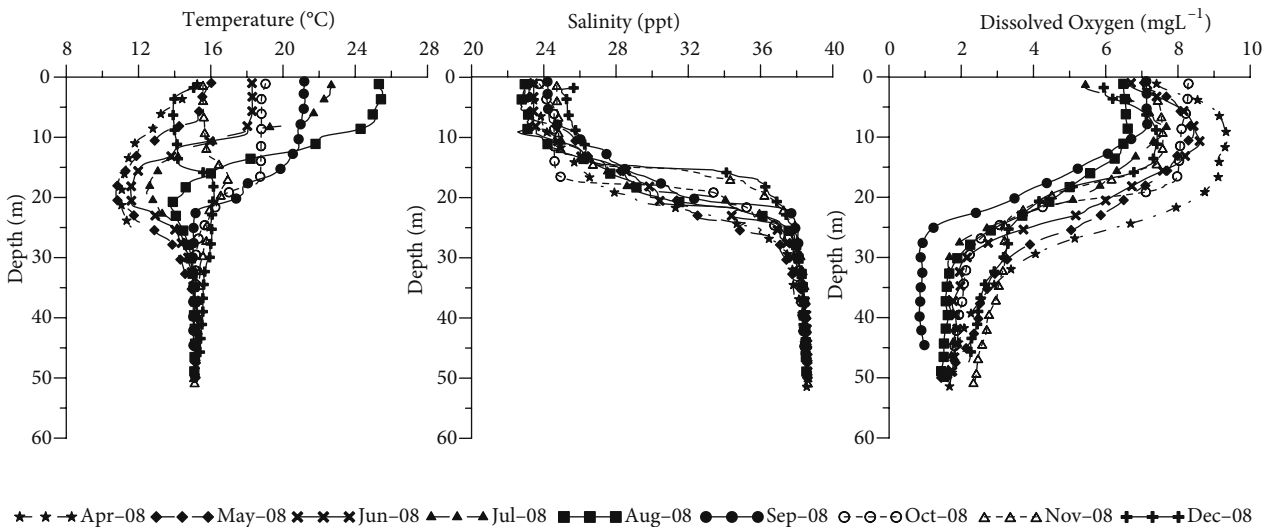


Figure 2. Temperature, salinity, and dissolved oxygen profiles.

9.5 and 25.5 °C. The highest value was observed in August (25.5 °C, 2.5 m) and the lowest in April (9.5 °C, 19 m). The upper-layer waters with 22–29 ppt were separated by a permanent pycnocline from the lower layer, which possessed a salinity of about 38 ppt. Dissolved oxygen values ranged from 9.37 mg L⁻¹ (in April) to 5.41 mg L⁻¹ (in July) in the upper-layer waters. A decreasing pattern was observed in oxygen values from the surface to the bottom along the water column. The lowest dissolved oxygen value was observed in September (0.84 mg L⁻¹). Chlorophyll *a* concentration, an indication of primary production, ranged between 1.14 and 14.51 µg L⁻¹, 1.54 and 18.54 µg L⁻¹, and 1.21 and 130.25 µg L⁻¹ in the upper-layer waters, mixed-layer waters, and lower-layer waters, respectively (Figure 3). The minimum Secchi disk depths occurred in July and October 2008 (Figure 3).

3.2. Zooplankton composition, succession, and abundance

Analysis revealed a total of 46 taxa (excluding *Noctiluca scintillans*) (Table 1), of which 35 derived from Black Sea-originated upper-layer waters, 34 from mixed-layer waters, and 37 from Mediterranean Sea-originated lower-layer waters.

There are some minor differences in the zooplankton assemblages of the upper and lower layers, e.g., the occurrence of *Aglaura hemistoma* and *Euchaeta marina* (Table 1). MDS ordination of the combined data of the upper and lower layers showed that samples were clearly discriminated according to their strata (Figure 4); the upper layer in October was characterized by the dominance of *Acartia clausi* and low species richness, which was completely different from other months and

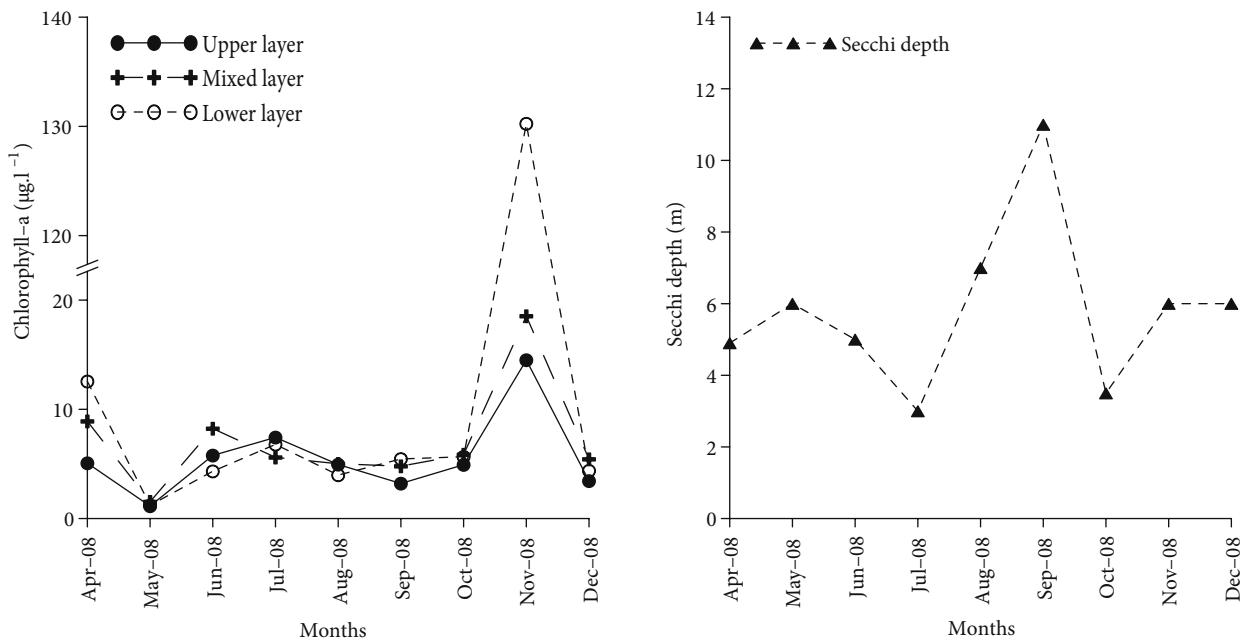


Figure 3. Fluctuation of chlorophyll *a* and Secchi disk depth at the sampling station in the Marmara Sea.

Table 1. List and relative abundance of zooplanktonic taxa in the northeastern Marmara Sea (U: upper water, M: mixed water, L: lower water; Apr-08: April 2008, May-08: May 2008, Jun-08: June 2008, Jul-08: July 2008, Sep-08: September 2008, Oct-08: October 2008, Nov-08: November 2008, Dec-08: December 2008).

	Apr-08	May-08	Jun-08	Jul-08	Aug-08	Sep-08	Oct-08	Nov-08	Dec-08	Mean F%
Copepoda										
<i>Acartia clausi</i>	U, M, L	U, M, L	U, M, L	U, M, L	U, M	U, M, L	U, M, L	U, M, L	U, M, L	30.71
<i>Acartia</i> spp.					U					0.01
<i>Acartia tonsa</i>					U, L					0.12
<i>Aetideus armatus</i>	M	U	U	M, L						0.04
<i>Calanus euxinus</i>	U, M	U	U, M, L	M		M		U, L	M, L	0.14
<i>Centropages ponticus</i>		U	M			U, M	U, M, L	U		0.05
<i>Clytemnestra rostrata</i>				L						0.00

Table 1. (Continued).

<i>Corycaeus limbatus</i>		U								0.00
<i>Ctenocalanus vanus</i>	L	U, M	U, M, L	U, M, L	M, L	L			L	0.41
<i>Euchaeta marina</i>			L	L						0.01
<i>Euterpina acutifrons</i>		M					L	M, L	L	0.12
<i>Lucicutia clausi</i>		U								0.00
<i>Metridia lucens</i>	M	U	U, M, L	U, M, L	M, L	L	L	M, L	L	0.73
<i>Microcalanus pusillus</i>	M, L			L	L					0.13
<i>Microsetella rosea</i>									M	0.00
<i>Oithona nana</i>	U, M	U		U	M		U		U, M	0.35
<i>Oithona setigera</i>			L	L	L				L	0.13
<i>Oithona similis</i>	U	U, M, L	U, M, L	U, M, L	U, M, L		M, L	M	U, M	0.66
<i>Oncaea media</i>	U	U, M		U, M, L		L	U	U, M, L	L	0.74
<i>Oncaea minuta</i>	M, L	U, L	U, M, L	M, L	M, L		L	M, L	U, M, L	3.26
<i>Oncaea subtilis</i>	M	U, M, L	L	U, M, L	L			M, L	L	0.37
<i>Paracalanus parvus</i>	U, M, L	U, M, L	U	U, L	M, L	U, M	U	U, M, L	M, L	2.85
<i>Pseudocalanus elongatus</i>	U, M, L	U	U, M, L	U, M, L	M, L	L			U, M	3.16
<i>Scolecithricella abyssalis</i>		U								
Cladocera										
<i>Evadne nordmanni</i>	U	U, M, L	U, M, L		M					1.30
<i>Evadne tergestina</i>		U			U	U		U, L	L	0.10
<i>Penilia avirostris</i>	L		U, M	U, M	U, M, L	U, M	M, L	U, M	L	12.70
<i>Pleopis polyphemoides</i>	U, M, L	U, M, L	U, M, L	U	U	U, L		U	U, M, L	2.85
Ctenophora										
<i>Mnemiopsis leidyi</i>				U	U, M	U				0.05
<i>Pleurobrachia pileus</i>		U	M, L	M, L		U, M		M		0.03
Cnidaria										
<i>Aglaura hemistoma</i>				L	L	L	L			0.01
<i>Aurelia aurita</i>		U	U	U						0.00
<i>Medusa planula</i>			M							0.00
Siphonophora			M, L	M, L	M, L					0.01
Meroplankton										
Actinotroch larvae		U	U	U, M	M	L		M, L		0.03
Bivalvia larvae	U, M	U, M, L	U, M, L	U, M, L	U, M, L	U, M, L		M	L	1.46
Cirripedia nauplii	U, M	U, M	U, M, L	U, M, L	U, M	U			M, L	0.30
Decapoda larvae	U, M	U	U, M, L	U, M, L	U, M, L	U, M			M, L	0.08
Echinodermata larvae	M	U, M, L	U, M, L	U, L	M, L	U, L	M, L	U, M, L		1.40
Gastropod larvae	L	U, L	U, M, L	U, M	U, M	U, M, L			U, M, L	0.24
Pisces eggs and larvae	U, M	U	U, M, L	U, M, L	U, M, L	U		U	L	0.04
<i>Pisidia longimana</i>						M				0.00
Polychaeta larvae	M	U	U, M	U, M, L	U, M, L	U, L		U, M, L	U, L	0.23
Appendicularia										
<i>Fritillaria</i> sp.					L					0.00
<i>Oikopleura dioica</i>	M	U, M, L	U, M, L	U, M	U, M, L	U, M		M	U	0.69
Chaetognatha										
<i>Sagitta setosa</i>			L			U, M	U, M, L	U, L		0.81

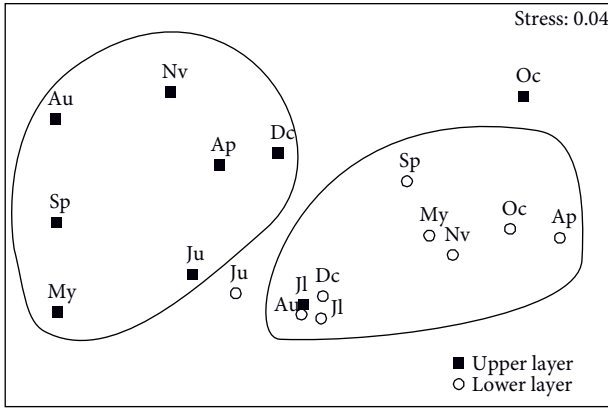


Figure 4. MDS ordination of combined data of upper- and lower-layer samples (Ap: April; My: May; Ju: June; Jl: July; Sp: September; Oc: October; Nv: November; Dc: December).

layers. The most important differences in total zooplankton abundance were observed in October, when abundance of some significant species deteriorated from 2001 to 2008 (Table 2). The most severe decrease was observed in *Penilia avirostris*, the dominant species in the summer–autumn periods in the Marmara Sea.

The heterotrophic dinoflagellate *Noctiluca scintillans* was characterized by 2 peaks, in June and September 2008 (Figure 5); maximum and minimum values were recorded in the mixed layer (54,181 ind. m⁻³) and in the lower layer (801 ind. m⁻³). The abundance of *N. scintillans* dropped sharply to minimum levels following October–November 2008, when mucilaginous aggregates were observed.

A total of 6 jellyfish taxa were recorded throughout the study period (Table 1). *Mnemiopsis leidyi* and *Aurelia aurita* were found in the upper layer, while *Aglaura hemistoma* and Siphonophora were observed in the lower layer. Maximum jellyfish abundance (Cnidaria and Ctenophora) observed in the upper layer in August 2008 (36 ind. m⁻³) was due to *Mnemiopsis leidyi*, but in the mixed layer (32 ind. m⁻³) and in the lower layer (18 ind. m⁻³), the maximum jellyfish abundance (in July 2008) was due to *Pleurobrachia pileus* (Figure 5).

Mesozooplankton abundance in the upper water layer was characterized by the first maximum in May (18,048 ind. m⁻³), particularly due to high *Acartia clausi* abundance (12,638 ind. m⁻³), and the second in September (14,210 ind. m⁻³), due to *Penilia avirostris* (9998 ind. m⁻³) (Figure 5). Samplings performed in the mixed and lower layers showed that the upper layer generally had higher zooplankton abundance than the other layers (Figure 5). However, mesozooplankton abundance in all of the layers sharply decreased in the summer (June–July) and in October 2008.

Copepods and cladocerans were generally the most abundant groups, while the contribution of meroplankton increased in mixed- and lower-layer waters (Figure 6). A total of 24 copepod species were recorded during the sampling period (Table 1). Minimum and maximum values of copepods were recorded in October (85 ind. m⁻³) and in May (13,631 ind. m⁻³) in the upper layer, in October (55 ind. m⁻³) and in June (1167 ind. m⁻³) in the mixed layer, and in April (42 ind. m⁻³) and in June (711 ind. m⁻³) in the lower layer, respectively. Seasonal fluctuations of

Table 2. Abundance (ind. m⁻³) of important zooplankton species in October for the northeastern Marmara Sea.

	2001 ^a	2005 ^b	2008
<i>Acartia clausi</i>	366.9	115	50.0
<i>Paracalanus parvus</i>	407.6	345	5.3
<i>Euterpina acutifrons</i>	407.6	0	1.3
<i>Oithona</i> spp.	346.5	80	5.7
<i>Penilia avirostris</i>	2038.2	370	10.3
<i>Pleopis polyphemoides</i>	244.6	145	5.3
<i>Pseudoevadne tergestina</i>	203.8	120	0.0
<i>Sagitta setosa</i>	224.2	65	9.0
<i>Oikopleura dioica</i>	203.8	630	0.0
Bivalvia	163.1	20	0.0

^a İşinibilir, unpublished data.

^b Svetlichny et al., 2006.

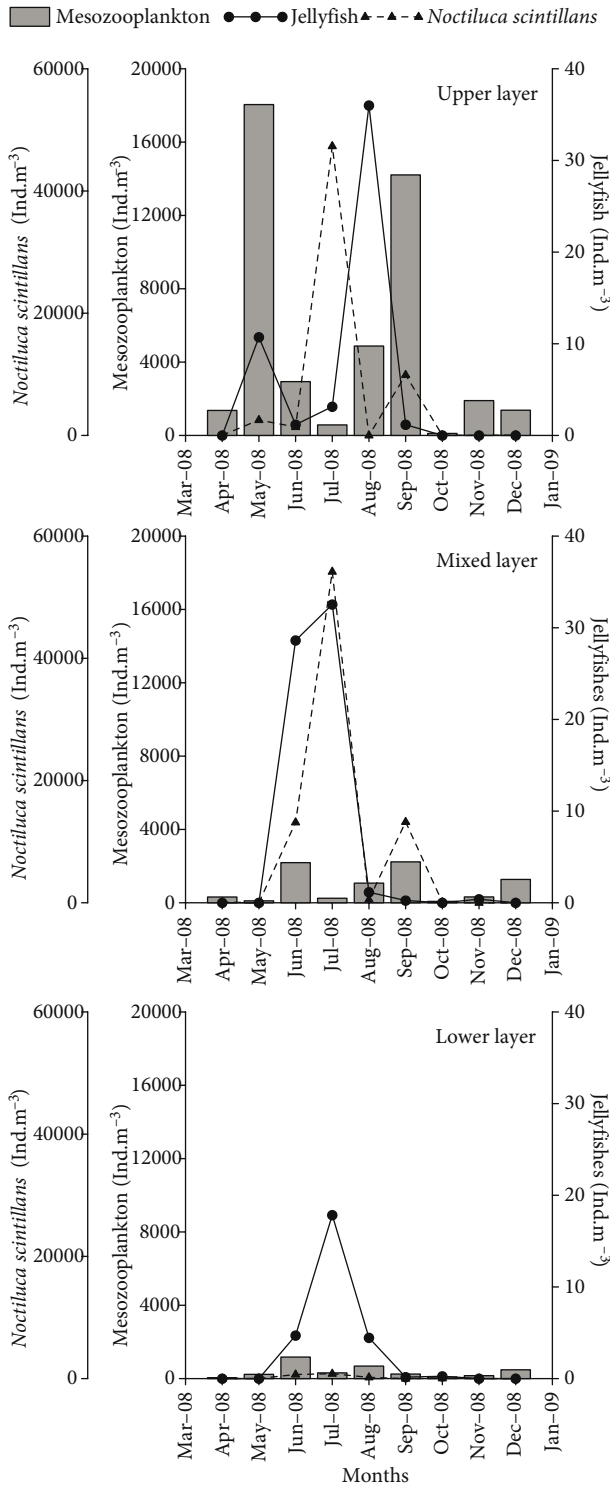


Figure 5. Fluctuations in total abundance of mesozooplankton *Noctiluca scintillans* and jellyfish in the upper, mixed, and lower layers.

total copepod abundance were significantly dependent on the changing abundance of *Acartia clausi*. *A. clausi* was present in all sampling months and layers, reaching

maximum abundance in May (12,638 ind. m⁻³, 70% in upper layer), while the lowest abundance was observed in the lower-layer waters in April (1%) (Figure 7). *Paracalanus parvus*, *Pseudocalanus elongatus*, and *Oncaea minuta* were other important copepod species (Table 1). Cladocerans occupied a higher percentage of mesozooplankton in the upper layer, with a maximum abundance of 10,753 ind. m⁻³ in September 2008. A gradual decrease in the relative abundance of cladocerans with depth was observed; only in August 2008 was the percentage value noteworthy in the lower layer. *Penilia avirostris* prevailed during the warmer period from July to September, but it was present during all sampling periods, the highest abundance being observed in September (9998 ind. m⁻³, 70% in upper layer). *Pleopis polyphemoides* had the highest abundance in April (879 ind. m⁻³) in upper-layer water. Meroplankton species were relatively abundant in the lower-layer waters (average 17%) and mixed-layer waters (average 14%). They were well represented down to the lower-layer waters, but the highest abundance was recorded in the upper-layer waters in May due to high abundance of *Bivalvia* larvae (863 ind. m⁻³). The abundance of chaetognaths showed an increase in autumn, with highest abundance (235 ind. m⁻³) in upper waters in September, whereas Appendicularia was recorded in May, with high abundance in the upper layer.

Species number (S), species richness (d), and diversity (H') varied significantly during the sampling period and dropped to lower values in the late summer and autumn, when dominance in the mesozooplankton community (D) attained the highest values (Figure 8). The lowest species diversity (H') was found in August in the upper-layer waters (0.23) due to the numerical dominance of *Penilia avirostris* (96%). The decrease in species richness and diversity in October was due to mucilage aggregates.

There was a high correlation between temperature and abundance of chaetognaths, *Penilia avirostris*, and *Pseudocalanus elongatus* (Table 3). Salinity was significantly negatively correlated with the abundance of mesozooplankton, Cladocera, Appendicularia, and *A. clausi* and positively correlated with *Oncaea minuta*, *Metridia lucens*, and the Shannon–Weaver diversity index. Dissolved oxygen was significantly correlated with *Penilia avirostris*. Chlorophyll *a* was not correlated with any zooplankton except Appendicularia.

4. Discussion

Mucilage aggregates were first observed in the Marmara Sea in October 2007 (Aktan et al., 2008). According to fishermen and local inhabitants, this was widely observed all over the Marmara Sea. The event lasted for several months, and the aggregates were observed throughout the water column. In January 2008, a second formation was observed in the Marmara Sea (especially at İzmit and in

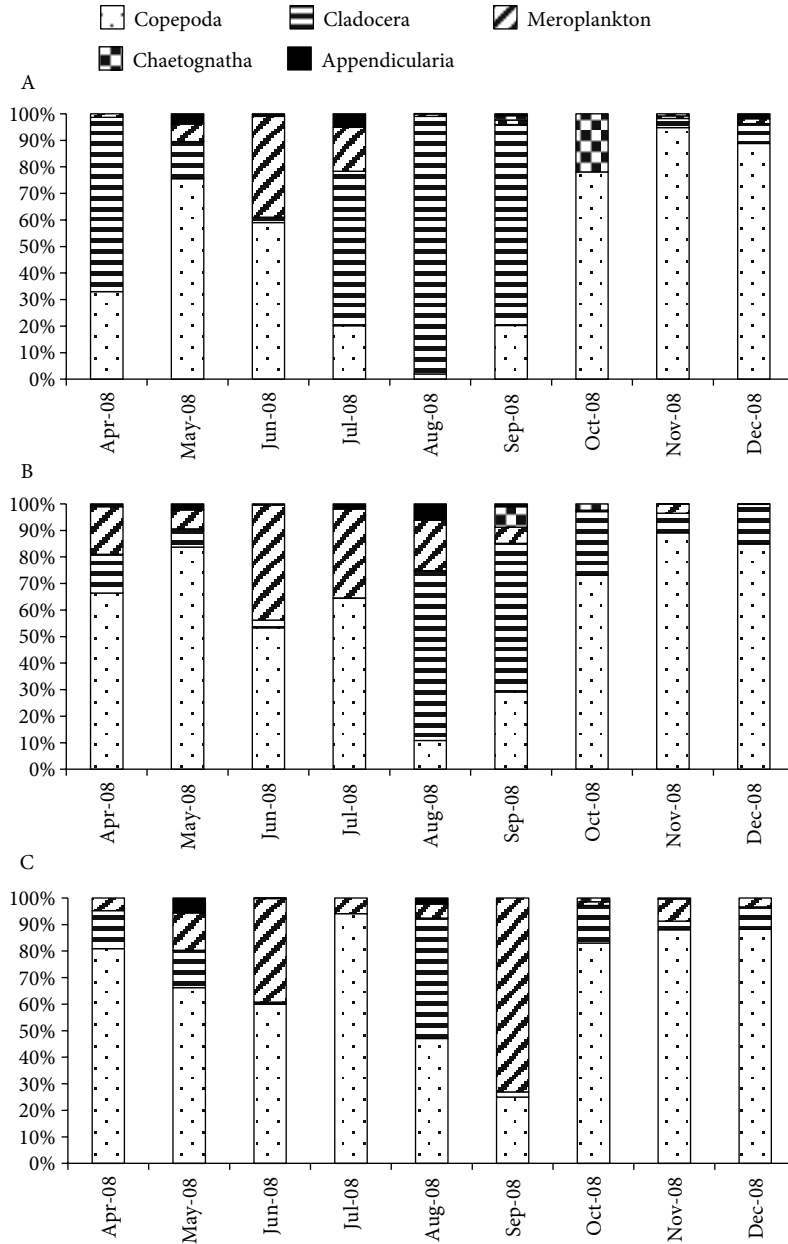


Figure 6. Relative abundance of zooplankton groups among sampling months (A: upper layer; B: mixed layer; C: lower layer).

Erdek Bay). In October–November 2008, a third mucilage aggregation was observed in the Marmara Sea. Fishing activities were considerably affected and the fishermen were highly sensitive to this matter, since the Sea of Marmara is an important fishing ground in Turkey.

High sea temperatures have often been considered as a factor favoring mucilage events (Degobbis et al., 1999). Our data indicate that the temperature values in 2008 were warmer when compared to 2001–2002 values (İsinibilir et al., 2008), with average temperatures up to 2 °C above the

previous temperatures. The increase of temperature in the Marmara Sea alone could not have created the mucilage event because several other factors may promote mucilage events, including the hydrodynamic regime, oxygen availability, and meteorological factors.

Cylindrotheca closterium, *Skeletonema costatum*, *Thalassiosira* spp., and *Gonyaulax fragilis* were reported as dominant phytoplankton species during the mucilage period in the Marmara Sea (Aktan et al., 2008; Tüfekçi et al., 2010; Balkıs et al., 2011). These species are known to

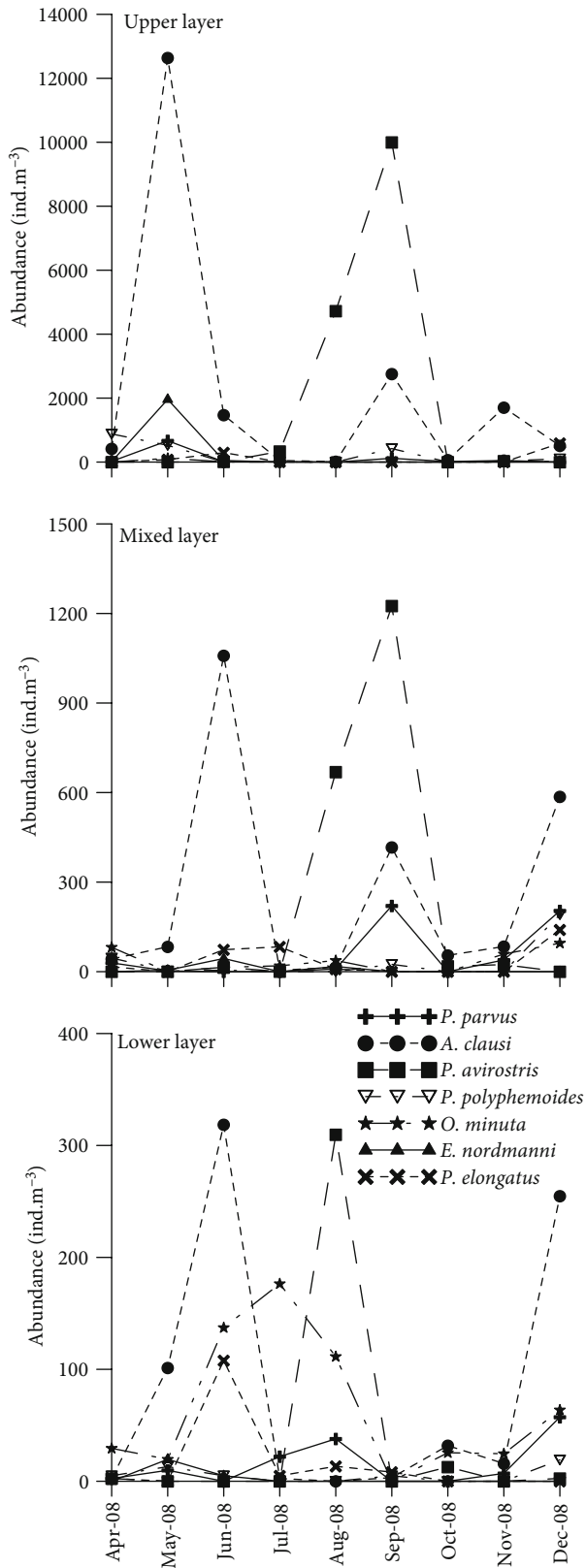


Figure 7. Fluctuations in abundance of major zooplankton species and groups in the upper, mixed, and lower layers.

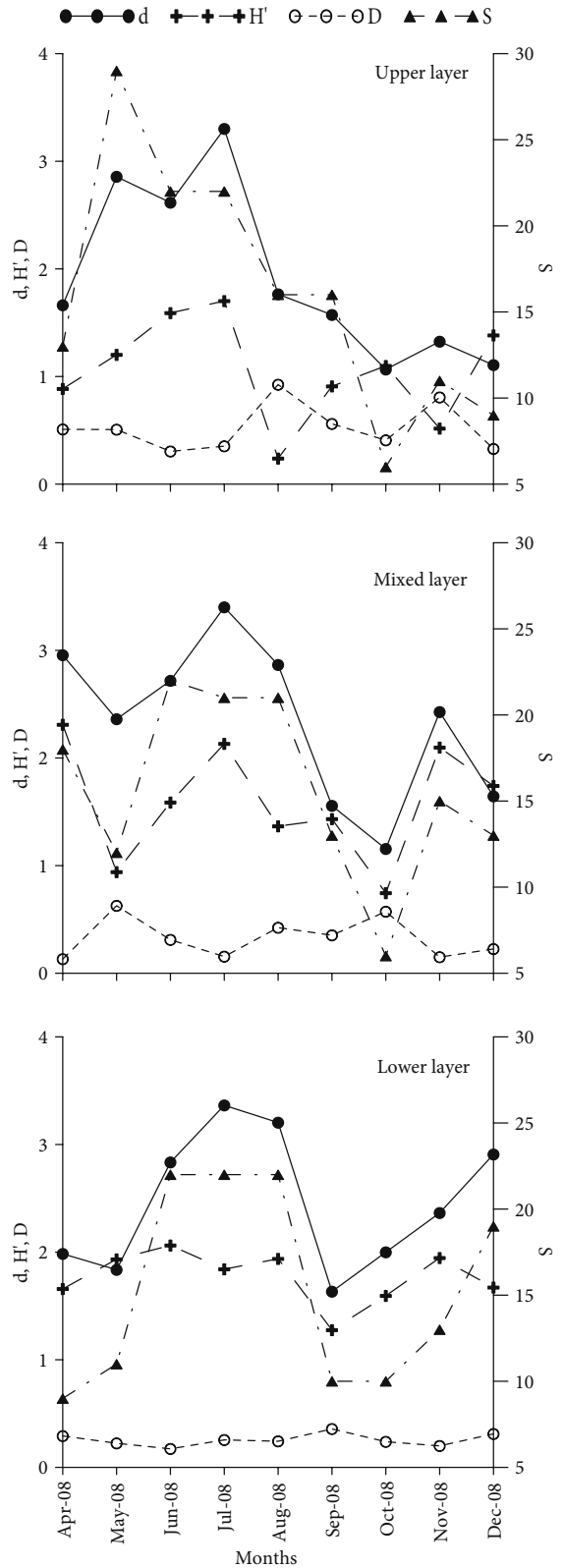


Figure 8. Fluctuations in number of species (S), species richness (d), Shannon index of diversity (H'), and dominance (D) in the upper, mixed, and lower layers.

Table 3. Spearman's rank-correlation matrix (r_s) to correlate zooplankton assemblages and environmental variables in the study area (**: $P < 0.01$; *: $P < 0.05$; $N = 27$).

	Temperature (°C)	Salinity (‰)	Dissolved oxygen (mg L ⁻¹)	Chlorophyll <i>a</i> (µg L ⁻¹)
Mesozooplankton	0.176	-0.488**	0.400*	-0.282
Cladocera	0.231	-0.569**	0.440*	-0.325
Chaetognatha	0.443*	-0.043	0.020	0.014
Appendicularia	0.052	-0.429*	0.279	-0.443*
<i>Acartia clausi</i>	0.077	-0.404*	0.592**	-0.267
<i>Penilia avirostris</i>	0.612**	-0.333	0.037	0.117
<i>Pseudocalanus elongatus</i>	-0.395*	-0.059	0.086	-0.068
<i>Oncaea minuta</i>	-0.290	0.565**	-0.372	-0.023
<i>Metridia lucens</i>	-0.163	0.498**	-0.512**	0.284
<i>Noctiluca scintillans</i>	0.011	-0.247	0.138	-0.116
<i>Mnemiopsis leidyi</i>	0.553**	-0.505**	0.199	-0.092
Shannon diversity index	-0.222	0.549**	-0.449*	0.256

cause mucilage aggregates. Although the diet of *Acartia clausi* and *Penilia avirostris*, the dominant zooplankton during the massive mucilage event, includes diatoms (*Skeletonema costatum*, *Thalassiosira* spp.), dinoflagellates, and microzooplankton (Fonda Umani et al., 2005), a major part of zooplankton is not able to feed on phytoplankton when it is embedded in mucus (Bochdanský and Herndl, 1992). In addition, the reproductive rates of mesozooplankton were decreased when embedded in mucilage aggregates (Bochdanský and Herndl, 1992). All these factors might have contributed to the observed low abundance of zooplankton in October 2008.

In this study, extensive mucilage aggregation was observed in October 2008. Considering the seasonal zooplankton abundance in the Marmara Sea, zooplankton decreases happened 3 times (in the spring, summer, and autumn periods). The first reduction of zooplankton in the beginning of the study period (with an average abundance in the upper layers of 1363 ind. m⁻³ in April 2008) reflected the remnants of the mucilage phenomenon in the winter period of 2007 and 2008. A surprising second drop occurred in July 2008, characterized mainly by *N. scintillans* and jellyfish bloom, and also high chlorophyll *a* values, depending on phytoplankton activity. In this study, zooplankton community structure and abundance in the Marmara Sea, and in particular Copepoda, were affected in the summer months by predation pressure of jellyfish and competitive pressure of *N. scintillans*, as demonstrated in previous studies (Yılmaz et al., 2005; Isinibilir et al., 2008;

Isinibilir et al., 2011; Isinibilir, 2012). The third decrease, with intensive mucilage formation in surface waters of the Marmara Sea, was observed in October 2008, and the total abundance of zooplankton in the upper water layer sharply decreased (109 ind. m⁻³). Diatoms and dinoflagellates were the most dominant groups in the Marmara Sea during the 2007–2008 mucilage periods (Balkıs et al., 2011); they are the main producers of mucilage (Rinaldi et al., 1995; MacKenzie et al., 2002). It has been well documented that some phytoplankton species have been shown to produce compounds that deter copepod feeding (Huntley et al., 1986; Uye and Takamatsu, 1990; Malej and Harris, 1993). These authors also suggested that reduced grazing pressure of copepods was an important factor in development of algal blooms. The presence of insufficient copepod stock in the Marmara Sea during the growing algal blooms in July 2008 may have allowed diatom and dinoflagellate stocks to persist and continue producing mucus. Finally, mucilage aggregation may also occur as a result of mucus production as well as appropriate physicochemical conditions.

Once formed in autumn 2007 and 2008, large aggregates dramatically impacted the whole plankton community (Aktan et al., 2008; Tüfekçi et al., 2010; Balkıs et al., 2011). As already stated, they can influence mesozooplankton temporal and spatial variability directly by decreasing naupliar copepod populations (Kršinić, 1995) and altering feeding capability (Bochdanský and Herndl, 1992; Malej and Harris, 1993), or indirectly by altering food web

structure and functioning (Cataletto et al., 1996). Our findings are in agreement with previous results. Impact on mesozooplankton was especially evident since mucilage particularly affected the abundant copepods and cladocerans, especially the dominant autumn species *Penilia avirostris* (Svetlichny et al., 2006; Isinibilir et al., 2008; Isinibilir, 2009), which in October–November 2008 did not reach its usual autumn maximum. The negative effects of mucilage on zooplankton in the Marmara Sea were particularly evident in October 2008, when mucilage aggregates were denser.

In conclusion, the Marmara Sea in recent years has been undergoing profound changes, mostly due to excessive fishing, increasing eutrophication, and the introduction and bloom of jellyfish species that strongly impact the zooplankton communities (Zengin and Mutlu, 2000;

Morkoç et al., 2001; Yılmaz, 2008; Isinibilir et al., 2010). Furthermore, the massive mucilage event that occurred in 2007–2008 has caused significant shifts in zooplankton abundance and community structure. Finally, long-term studies of the Marmara Sea are still needed to continuously monitor the evolution of this delicate ecosystem.

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