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Phytoplankton composition and environmental conditions of a mucilage event in the Sea of Marmara

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Abstract: The composition and abundance of phytoplankton and the corresponding environmental conditions were investigated during a mucilage event (October 2007-February 2008) in the Sea of Marmara. The mucilage producers *Gonyaulax fragilis, Skeletonema costatum*, and *Cylindrotheca closterium* were identified as abundant species. *Thallassiosira rotula* was also identified in large numbers. The maximum number of *G. fragilis* was observed at 83,600 cells L^{-1} in November 2007 during the first sampling occasion on the surface layer of İzmit Bay, and *T. rotula* was the most abundant diatom species, with 131,040 cells L^{-1} in the same period. *G. fragilis* was recorded at 96,250 cells L^{-1} in the dense mucilage-containing water samples collected from Değirmendere (İzmit Bay) in January 2008, and *C. closterium* was the dominant (161,250 cells L^{-1}) diatom species in the same sample. Species diversity values (H'_{log2}) increased from November to February, displaying maximum values of 2.5-3.5 in February at almost all stations (depths of 0.5 and 10 m), caused by the balanced increase of diatom species and their individual numbers in the total phytoplankton abundance. The surface layer waters of İzmit Bay exhibited severely low nitrogen to phosphorus ratio (N:P) values (0.1-14.4) compared to the Redfield ratio (16), which could be supported by the fact that the limiting nutrient for the Sea of Marmara is nitrogen. Even though there is a lack of data from before the mucilage period, the data obtained during the lifespan of the event indicated that a mixture of several phytoplankton species might have played a key role in the mucilage formation. The high organic carbon content of the mucilage (24% org-C) and the surrounding waters support the possibility that the event could have been related to organically rich cellular exudates of phytoplankton.

Key words: Phytoplankton, mucilage, organic carbon, Sea of Marmara

Marmara Denizi'nde meydana gelen musilaj olayının çevresel koşulları ve fitoplankton komposizyonu

Özet: Bu çalışmada, Marmara Denizi'nde (Ekim 2007-Şubat 2008) müsilaj oluşumu süresince fitoplankton bolluğu ve çevresel şartlar incelendi. Musilaja sebep olduğu bilinen türlerden olan *Gonyaulax fragilis, Skeletonema costatum* ve *Cylindrotheca closterium* çalışmada baskın türler olarak tespit edildi. Aynı zamanda, *Thallassiosira rotula* türü de yüksek sayıda bulundu. *G. fragilis*'in maksimum sayısı, Kasım 2007'de yapılan ilk örnekleme çalışmasında (İzmit Körfezi yüzey suyunda) 83,600 hücre/L olarak belirlenmiştir. Aynı dönemde baskın diatom türü *T. rotula* (131,040 hücre/L)'dır. Müsilajın yoğun olarak bulunduğu Ocak-2008 Değirmendere (İzmit Körfezi) örneklerinde, *G. fragilis*'in hücre sayısı 96,250 hücre/L olarak saptandı ve aynı örneklerde en çok bulunan diatom türü *C. closterium* (161,250 hücre/L) olarak belirlendi. Tür çeşitliliği indeksi (H'_{log2}) Kasım ayından Şubat'a kadar düzenli bir artış sergileyerek, Şubat ayında seçilen istasyonların (0,5 ve 10 m) neredeyse tümünde 2,5-3,5 arasında değişim göstermiştir. Bu ayda diatomların tür ve birey sayılarındaki artışın toplam fitoplankton baskınlığına katkısı bu sonucu doğurmuştur. İzmit Körfezi'nin yüzey suları

Redfield oranı (16) ile karşılaştırıldığında ciddi oranda düşük N:P (0,1-14,4) değerleri sergilemiştir. Bu durum Marmara Denizi'nin bilinen azot sınırlayıcı birincil üretimi ile desteklenebilir. Olayın hemen öncesinde veri olmamasına karşın, olay süresince elde edilen bu bulgular müsilaj oluşumunda birkaç fitoplankton türünün rol oynadığını düşündürdü. Ayrıca, musilaj çevresindeki suda ölçülen ve musilajın kurutulmuş fazında elde edilen yüksek organic karbon içeriği (% 24 org-C), yapının fitoplankton orijinli olduğu düşüncesini desteklemektedir.

Anahtar sözcükler: Fitoplankton, musilaj, organik karbon, Marmara Denizi

Introduction

Even though the mucilage phenomenon has been well known and recorded since the 18th and 19th centuries in the Mediterranean Sea (and particularly for the Adriatic Sea, see Pompei et al. (1)) and other seas in the world (2,3), these events have occurred more frequently since the 1980s and are being better recorded in other parts of the Mediterranean (4,5). Similar events have also been observed from time to time in the Sea of Marmara since the 1990s, which were mostly noticed by fishermen and have never been experimented on or monitored. In the past, the most massive event was observed in 1992 in the western part of the sea, around Erdek Bay, and was recorded only by sportsmen with underwater video cameras.

The diatom species that cause mucilage have been well studied since early times (6-10), whereas the contribution of dinoflagellates has been less well documented. *Skeletonema costatum* and *Cylindrotheca closterium* are the well-known diatom species that cause mucilage (2,6,9,10). *Gonyaulax hyalina* and *G. fragilis*, from the latter group, have been reported as mucilage producers in different seas, including a number of relevant and recent studies in the Tasman Bay, the Catalonian waters, the Adriatic Sea, and, finally, the North Aegean Sea (1,3,5,11). *Prorocentrum micans* is another mucilage producer from the same group (1). In almost all of the above-mentioned studies, the high organic carbon content of the cellular exudates (basically in the form of carbohydrates) has been said to be the main cause of different types of mucilage formations.

An important work on phytoplanktonic species in the Sea of Marmara was done by Balkıs (12), in which a total of 73 dinoflagellate and 76 diatom species were reported in the area. Diatoms represented the majority of the population (45.2%), followed by dinoflagellates (43.5%). *G. fragilis* was reported as present in different sub-basins of the Mediterranean Sea, including the Black Sea (5,13,14), and it was observed in the Sea of Marmara together with the mucilage event. It was also reported that *S. costatum* and *C. closterium* both caused blooms in the Sea of Marmara in early spring (15).

The main aim of this study was to investigate the environmental variables and the phytoplankton composition and abundance in the Sea of Marmara during and after the mucilage event that began in October 2007 and lasted until February 2008.

Materials and methods

Area description: The Sea of Marmara is located between the Black and the Aegean Seas, where the saline lower layer originating from the Mediterranean is overlaid with brackish waters from the northwestern Black Sea. Therefore, together with the Straits (İstanbul and Çanakkale) and the coastal embayments, the system is permanently stratified, having productive surface and suboxic subsurface layers. The system changes from meso- to eutrophic conditions depending on the location and the season, being under pressure not only from the Black Sea's nutrient rich waters, but also inputs from domestic wastes (insufficiently treated and discharged by underwater disposal units) and industrial and agricultural inputs.

İzmit Bay, with a length of 50 km, is located at the northeastern edge of the Sea of Marmara. The bay is divided into 3 regions: western, central, and eastern. The smallest and most shallow region is the eastern part (15 km in length, with a maximum depth of 35 m) and the largest region is the central part (20 km, with a maximum depth of 170 m); anoxic sub-surface waters are detected in both basins (16,17). During the

last 35 years, industrial development and, hence, an intense urbanization have occurred around İzmit Bay. Consequently, extensive water, air, and soil pollution have been observed. Ten major sources of pollution are located around the coast, carrying untreated or insufficiently treated domestic waste together with effluents from industrial plants such as oil refineries, pulp and paper manufacturers, and metal, pesticides, detergents, dye, varnish, and fertilizer factories. In addition, the bay is also under pressure from heavy shipping activities.

Sampling and analysis: Five stations were monitored within İzmit Bay at fixed coordinates (Figure 1), independent from the mucilage aggregate formations, at 3-4 week intervals between November 2007 and February 2008 and again later, in May 2008. The physical parameters of the water column (temperature and conductivity) were measured in situ using a CTD probe. Secchi disk (SD) depths were measured with a 30 cm diameter white disk. Sea water samples were collected with the aid of Niskin bottles. Nutrient analysis (nitrate+nitrite, phosphate, and silicate) was carried out with a Skalar (2-channel) Autoanalyzer according to colorimetric methods adapted to those described by Hansen et al. (18). The total nitrogen (TN) content of the samples was analyzed with the autoanalyzer after persulfate digestion, as described by APHA, AWWA, and WEF (19). Total phosphorus (TP) samples were digested with potassium persulfate to a reactive form in an autoclave and analyzed in the autoanalyzer according to the methods of Hansen et al. (18). The total organic carbon content (TOC) of the samples was analyzed with a liquiTOC analyzer (combustion at high temperature). In order to analyze the dissolved organic carbon (DOC) of dense mucilage-containing waters, first the water surrounding the aggregates was separated by a glass pipette without disturbing the aggregates, and then the separated water was filtered through pre-combusted GF/C filters at low vacuum pressure and analyzed for TOC. Acid-washed or ignited glassware was used in all DOC analyses. The POC and PON of the freeze-dried mucilage material were measured with a Thermo Finnigan organic elemental analyzer. The chlorophyll a concentrations were measured with the acetone extraction method (19). Phytoplankton samples (1 L of sea water) were collected with the aid of Niskin bottles from the sub-surface and from 10 m depths at stations 1, 3, and 5, representing the 3 different basins of İzmit Bay. Samples were collected in 1 L dark glass bottles, preserved with Lugol's iodine solution, and allowed to settle for 24-48 h; then neutral formaldehyde (4%) was added to preserve the cells (20). The sedimentation method was used for microscopic analyses (20). Cell counting was carried out using an Olympus CK2 inverted phase-contrast microscope equipped with a microphotosystem at a magnification of 400× in a Sedgwick-Rafter cell (21,22).

Spearman's rank correlation coefficient (23) was used to correlate biotic and abiotic parameters at stations 1, 3, and 5. In addition, the Bray-Curtis similarity index in Primer v6 software, based on a log(x+1) transformation, was calculated to detect the similarity between sampling stations (24). Species diversity was also estimated by using the Shannon-Weaver diversity index ($H'_{\log 2}$) (24,25).

Results and discussion

Starting from October 2007, İzmit Bay, as well as Erdek Bay, seriously suffered from intense mucous formation (slippery aggregates) with white and yellowish colors (Figure 1). According to the reports of local inhabitants, fishermen, and NGOs, this was widely observed all over the Sea of Marmara. The event lasted for several months as the aggregates moved up and down through the water column, depending on the wind and mixing regimes. In January 2008, a second new whitish, creamy formation was observed more locally in İzmit bay and a more ribbon-like & cobwebbed structure was observed in Erdek bay as a more ribbon-like and cobwebbed structure. All these structures had been pictorially identified before by other investigators (26). Fishing activities were considerably affected and the fishing associations were highly sensitive to this matter, since the Sea of Marmara is an important fishing ground in Turkey.

Following the first mucous formation in October 2007 in İzmit Bay, a study to monitor phytoplankton composition and abundance and a set of environmental variables was conducted.

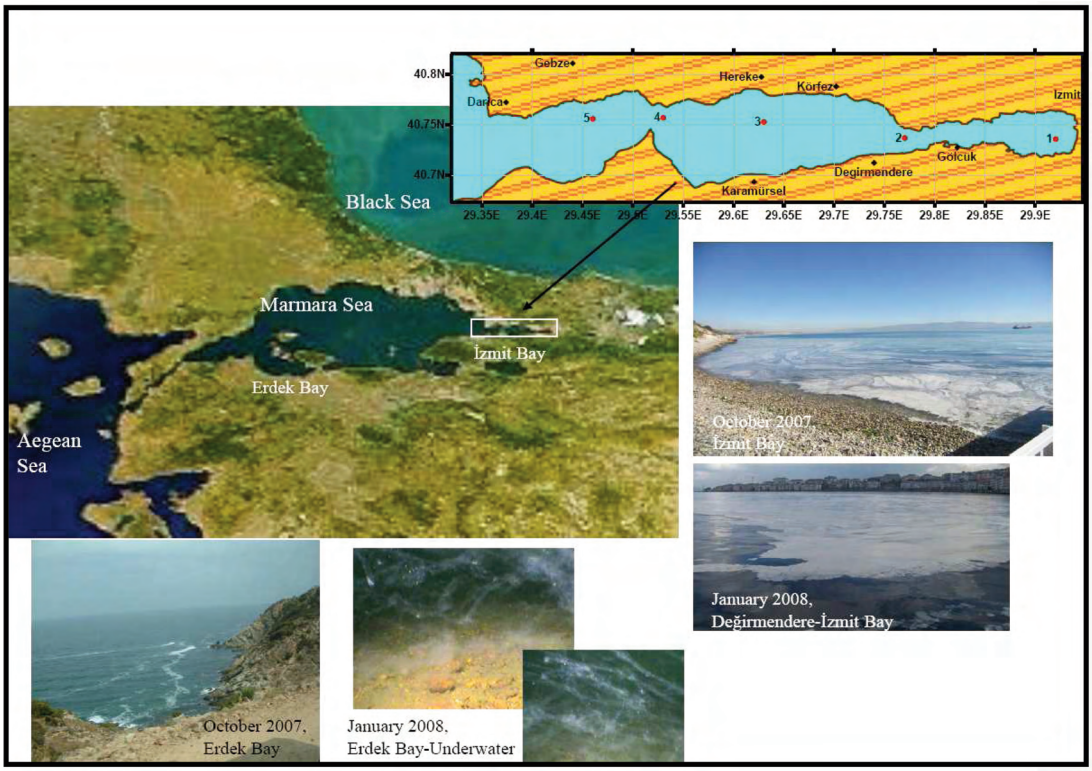

Figure 1. Study area, stations, and visual presentation of mucilage aggregates.

Environmental variables

The ranges of measured environmental variables in the upper layer waters (0.5 to 15 m) are presented in Table 1. Sampling stations were selected from east to west to represent the inner, central, and outer bay with different geographic and environmental features (16), whereas all throughout the bay, the upper layer waters with 23-29 ppt were separated by a permanent

Table 1. Ranges of measured environmental parameters in İzmit Bay during the study period.

Dates	Ranges of measured parameters from stations 1-5 for surface layers (0.5-15 m)					
	02/11/07	21/11/07	18/12/07	10/01/08	07/02/08	13/05/08
Temperature	17.5-18.5	14.1-15.8	10.6-15.3	7.7-10.7	7.4-8.9	11.0-17.8
Salinity	26.2-33.8	22.7-37.2	26.5-37.5	25.7-29.4	25.3-28.2	23.9-29.8
Secchi D. (m)	3.5-7.0	2.5-5.5	2.0-3.5	2.0-5.0	1.5-4.0	2.0-5.0
PO4-P (µM)	0.13-0.43	0.42-1.25	0.32-0.91	0.23-0.61	0.08-0.65	0.23-0.45
NO_3+NO_2-N	0.16-3.20	0.39-6.45	0.05-4.72	0.10-1.47	0.07-0.68	0.18-0.52
N:P (atomic)	1.3-14.4	0.4-13.3	0.1-8.9	0.3-2.5	0.3-4.0	0.4-2.1
TP (µM)	0.20-1.06	1.60-5.79	1.03-3.13	0.27-0.93	0.17-0.98	0.28-0.88
TN (µM)	-	1.7-21.1	7.7-19.2	7.8-23.0	7.4-27.7	12.6-28.7
TOC (µM) (*)	-	301-610	143-301	189-442	220-420	140-484
Chl-a (µg/L)	1.9-6.3	1.0-19.0	1.0-16.7	6.8-22.0	5.1-17.3	1.0-6.7

* There are higher values at lower depths within the pynocline (20-30 m), most probably related to trapped aggregates.

pycnocline from the lower layer, which possessed a salinity of about 38 ppt. The temperature ranged between 7.4 and 18.5 °C in the upper layer waters. The lowest temperature was recorded in the January and February sampling period. The PO_4-P and NO_2+NO_3-N concentrations varied from 0.08 to 1.25 μM and 0.05 to 6.45 μM in the upper layer, respectively. The limiting nutrient in both the Sea of Marmara and İzmit Bay has been reported as nitrogen (27,28), which is confirmed by the low N:P ratios presented in Table 1. TP and TN concentrations varied from 0.17 to 5.79 μM and from 1.7 to 28.7 μM, respectively. TOC concentrations ranged between 140 and 610 μM in the first 15 m, while higher values were also distinctly measured at 20-30 m. Chlorophyll a concentration varied from 1 to 22 μg L^{-1} in a westward to eastward direction along the bay. Secchi depths are almost always lower than 5 m throughout the bay.

Detailed chemical studies of the mucilage aggregates were also planned and the material was preserved for future elemental and spectral analysis. As preliminary work, the dissolved organic carbon (DOC) content of the filtered water surrounding the mucilage aggregates was investigated at 2 newly formed mucilage aggregates obtained from İzmit Bay (Değirmendere, close to station 2, Figure 1) on 10 January 2008 and Erdek Bay on 16 January 2008. Both materials were found to be surrounded by organically rich water with DOC levels above 1600 and 1000 μM, respectively, for İzmit Bay and Erdek Bay. These values are considerably higher (5-10 times) than the TOC and DOC values reported in Table 1 and the previous studies (29-31). The POC and PON content of the freeze-dried İzmit mucilage was 24 ± 0.8% C and 1.3 ± 0.10% N with a C:N ratio of 18.5, which is considerably higher than the Redfield POC to PON ratio of 7 previously obtained (27) from long-term data for the surface layer of the Sea of Marmara.

Phytoplankton composition, succession, and abundance

Between October 2007 and May 2008 at the 3 sampling stations (stations 1, 3, and 5), analysis of the phytoplankton community composition showed that there were 46 species of 4 different algal groups identified: 21 dinoflagellates (45.7%), 2 dictyochophyceans (4.3%), 22 diatoms (47.8%), and 1 euglenophycean (2.2%) (Table 2). Diatoms and dinoflagellates were identified as the most abundant (dominant) groups in terms of species number observed at the 3 sampling stations. The maximum total phytoplankton abundance was observed in the surface water of station 1 in February 2008 (1,877,200 cells L^{-1}) (Figure 2). The highest diatom abundance was also recorded in this month and at this depth (1,618,800 cells L^{-1}, station 1, 0.5 m depth). The dominant diatom species were *Skeletonema costatum* (1,140,000 cells L^{-1}), *Cylindrotheca closterium* (197,600 cells L^{-1}), *Thalassiosira rotula* (68,400 cells L^{-1}) and *Leptocylindrus danicus* (60,800 cells L^{-1}). In addition, increases of *Eutreptiella* sp. (205,200 cells L^{-1}, 0.5 m depth) and *Gonyaulax fragilis* (78,720 cells L^{-1}, 10 m depth) were detected at this station. The maximum dinoflagellate abundance was recorded at the surface layer of station 3 in May (355,030 cells L^{-1}), with *Prorocentrum micans* being the most dominant species of that month (351,000 cells L^{-1}).

G. fragilis and *T. rotula* were the most abundant species found throughout the sampling periods in İzmit Bay, as the maximum numbers obtained in November 2007 were 131,040 cells L^{-1} (station 5, 10 m depth) for *T. rotula* and 83,600 cells L^{-1} (station 1, 0.5 m depth) for *G. fragilis*. In the same period, *P. micans* was also observed and its maximum abundance was 42,900 cells L^{-1} (station 1, 0.5 m depth). While *G. fragilis* was observed as the most abundant of the dinoflagellates during the October to February sampling period, *P. micans* was the dominate dinoflagellate species during the May sampling period. Phytoplankton species displayed the lowest abundance in December. A decrease in the abundance of *T. rotula* was observed in May 2008. *G. fragilis* was not observed during the May sampling period.

The contribution of dinoflagellates and diatoms to the total phytoplankton abundance at surface layer of the stations is given in Figure 3. Contribution of diatoms to the total surface abundance changed from 35% to 86% during the sampling period, whereas the dinoflagellate contribution to the total abundance varied between 3% and 64%, decreasing from November to February and then increasing again in late spring at station 1 (Figure 3). The diatom and dinoflagellate contribution to the total abundance shifted between 27% and 73% and 19% and 73%,

Table 2. List and frequency distribution of phytoplanktonic taxa observed in the mucilage event in the Sea of Marmara.

Phytoplankton Species	Sampling Time					
	Nov. 2007	Dec. 2007	Jan. 2008	Feb. 2008	May 2008	f
DINOPHYCEAE						
Alexandrium minutum					+	R
Ceratium fusus					+	R
Ceratium tripos				+	+	R
Dinophysis acuta	+				+	R
Dinophysis acuminata					+	R
Gonyaulax sp.					+	R
Gonyaulax fragilis	+	+	+	+		Ab
Gymnodinium sp.		+	+	+	+	R
Gyrodinium spirale					+	R
Noctiluca scintillans					+	R
Oxytoxum scolopax					+	R
Phalacroma rotundatum					+	R
Polykrikos schwartzii					+	R
Prorocentrum micans	+	+		+	+	Ab
Prorocentrum minimum					+	R
Prorocentrum scutellum	+				+	R
Protoperidinium bipes				+	+	R
Protoperidinium depressum					+	R
Protoperidinium steinii					+	R
Protoperidinium sp.					+	R
Scrippsiella trochoidea					+	R
DICTYOCHOPHYCEAE						
Dictyocha speculum					+	R
Octactis octonaria					+	R
BACILLARIOPHYCEAE						
Cerataulina pelagica	+	+	+	+	+	Ab
Chaetoceros sp.				+		R
Chaetoceros lorenziana					+	R
Climacosphenia sp.					+	R
Coscinodiscus sp.	+		+	+	+	R
Coscinodiscus radiatus				+		R
Cylindrotheca closterium		+	+	+	+	Ab
Dactyliosolen fragilissimus				+	+	R
Ditylum brightwellii			+		+	R
Guinardia flaccida		+	+	+	+	C
Leptocylindrus danicus				+		R
Navicula sp.					+	R
Pleurosigma sp.					+	R
Proboscia alata		+	+	+	+	R
Pseudo-nitzschia sp.					+	R
Pseudo-nitzschia pungens		+	+	+	+	C
Pseudosolenia calcar-avis					+	C
Rhizosolenia setigera			+			R
Rhizosolenia styliformis					+	R
Skeletonema costatum		+	+	+	+	Ab
Thalassiosira anguste-lineata			+	+		R
Thalassiosira rotula	+	+	+	+	+	Ab
EUGLENOPHYCEAE						
Eutreptiella sp.				+		R

(Abbreviations used: f: frequency; Ab: Abundant; C: Common; R: Rare)

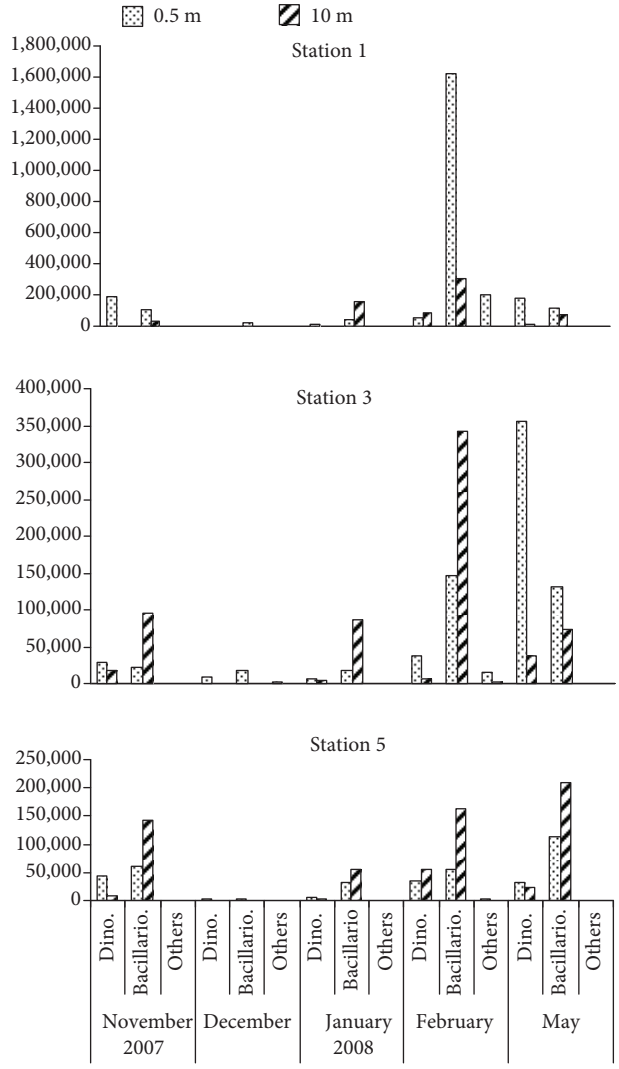

Figure 2. Variations in the abundance (cell L^{-1}) of different phytoplankton groups at the sampling stations.

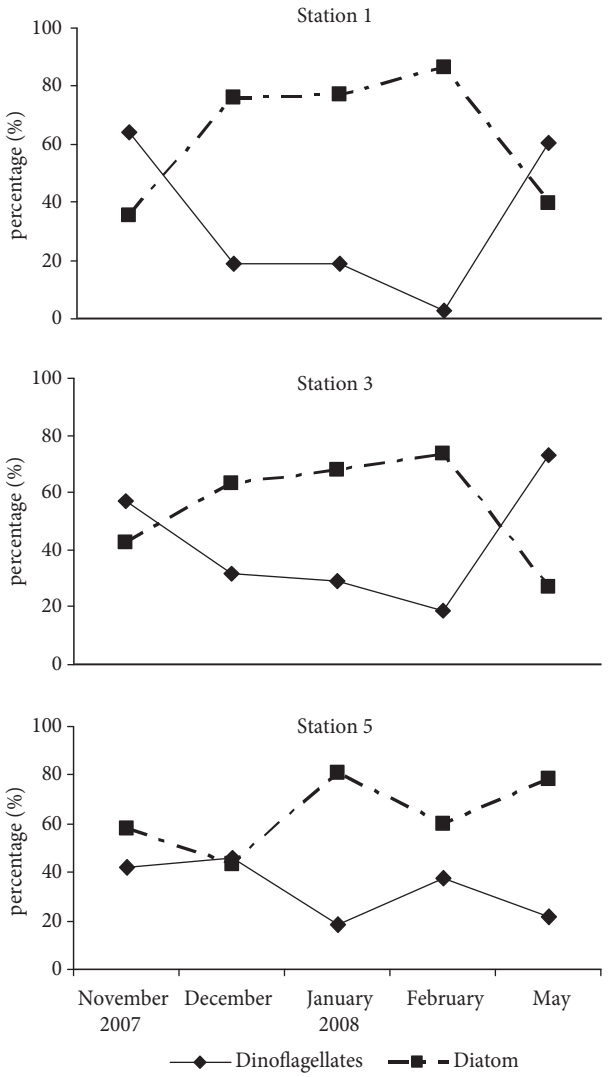

Figure 3. Percentage contribution of diatoms and dinoflagellates in terms of abundance in the surface layer of the sampling stations.

respectively, in the surface layer of station 3. The contribution of diatom and dinoflagellate abundance to the total was, respectively, between 43% and 81% and 18% and 46% in the surface layer of station 5. The contribution of diatoms and dinoflagellates to the total abundance showed seasonal variation, but, unfortunately, could not be sampled during the period from July to October, before the mucilage aggregates were observed and just as they started, because of the lack of a continuous monitoring program in the Sea of Marmara. *G. fragilis* and *P. micans* among the dinoflagellates and *S. costatum* and *T. rotula* among the diatoms were identified as the most abundant species. Their contribution to total group abundance is presented in Table 3, in which their seasonal variations are obvious. While *G. fragilis* showed a maximum contribution to total dinoflagellate abundance in November, December, and January (70%-95%), *P. micans* showed a maximum contribution in May (98%). The highest *T. rotula* contribution to the total diatom abundance was observed in November (93%). The percentage of *S. costatum* among diatoms was between 1% and 43%, with its maximum contribution recorded in February.

Table 3. Percentage contribution of main species in the surface layer of the studied area.

	G. fragilis % in dinof.	*P. micans* % in dinof.	*S. costatum* % in diatoms	*T. rotula* % in diatoms	*C. closterium* % in diatoms	Average phytoplankton abundance in surface water (cells/L)
Nov. 07	70	9	1	93	2	148,500
Dec. 07	95	5	1	63	4	18,210
Jan. 08	84	8	9	45	12	57,960
Feb. 08	54	10	43	8	23	722,374
May. 08	-	98	30	1	9	295,163

In addition, the phytoplankton composition in dense mucilage-containing water samples from Değirmendere (İzmit Bay) and Erdek Bay in January 2008 was also examined and is presented in Table 4. The dominant species found were *C. closterium* (161,250 cells L^{-1}), *T. rotula* (82,500 cells L^{-1}), and *G. fragilis* (96,250 cells L^{-1}) in the Değirmendere samples, whereas *S. costatum* (118,300 cells L^{-1}), *C. closterium* (91,000 cells L^{-1}), and *G. fragilis* (57,400 cells L^{-1}) were most abundant in the samples from Erdek Bay. The results show that the cell numbers of these species in the surface layer were less than in the mucilage-containing water samples.

Previous phytoplankton studies in İzmit Bay were limited to sporadic sampling periods in the past and were presented by Uysal (32), Tüfekçi et al. (28), and Aktan et al. (33). These studies revealed a shift from diatom dominance to dinoflagellate dominance and a loss of diversity over the last decade, especially in the northeastern Marmara Sea and İzmit Bay. This might be an expected consequence of both the intense human activities around İzmit Bay and the Sea of Marmara and the permanent 2-layered water structure in which the upper layer waters (coinciding with the euphotic zone) are continuously fed with productive brackish waters of the northwestern Black Sea.

Statistical analysis of the results

As shown in the Bray-Curtis similarity index (Figure 4), similarity among the monitoring stations selected for phytoplankton investigation (stations 1, 3, and 5) was high and no pronounced difference in physical and chemical variables was observed. The lowest similarity was between station 1 (0.5 m) and station 3 (10 m), 88%. High similarity was observed between the same depths according to the environmental variability.

The highest species diversity (H') was found in February (3.45, station 5, 0.5 m depth), according to the Shannon-Weaver index values (Figure 5). The lowest species diversity was observed in May (0.83,

Table 4. Cell counts (cells L^{-1}) of dominant phytoplankton species in 2 newly formed mucilage aggregates in İzmit and Erdek Bays, January 2008.

	C. closterium		*T. rotula*		*S. costatum*		*G. fragilis*	
	Mucilage-rich	Surface Water	Mucilage-rich	Surface Water	Mucilage-rich	Surface Water	Mucilage-rich	Surface Water
Değirmendere (İzmit Bay)	161,250	9600	82,500	41,400	25,000	8800	96,250	22,040
Erdek Bay	91,000	1890	21,000	210	118,300	Not observed*	57,400	2310

* It was only obtained from horizontal tows, not observed quantitatively.

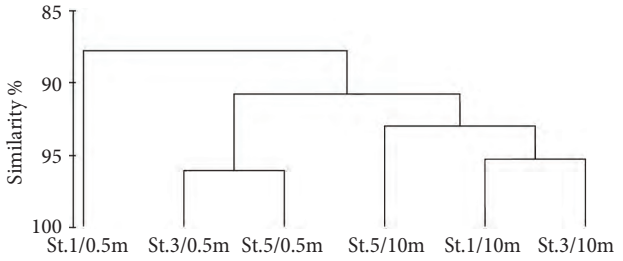

Figure 4. Bray-Curtis similarity dendrogram of the sampling stations.

station 3, 10 m depth) and November (0.99, station 5, 10 m depth) due to an extreme increase of *C. closterium* (68,200 cells L^{-1}) and *T. rotula* (131,040 cells L^{-1}), respectively. It is known that species diversity decreases to a minimum level in the event of sudden increases in phytoplankton (34).

According to the Spearman rank order correlation (Table 5) of phytoplankton assemblage and environmental variables at stations 1, 3, and 5 (0.5 m and 10 m), temperature was negatively correlated with dissolved oxygen, chlorophyll a, and the Shannon index ($P < 0.01$) and with TN and diatom abundance ($P < 0.05$), whereas it was positively correlated with NO_3+NO_2-N, the N:P ratio ($P < 0.01$), and with PO_4-P and TP ($P < 0.05$). There was no significant relationship between salinity and NO_3+NO_2-N, PO_4-P, silica, dissolved oxygen, total phosphorus, or chlorophyll a; however, there was a significant inverse relationship ($P < 0.01$) between salinity and total nitrogen, total organic carbon, total phytoplankton, and the total abundance of dinoflagellates and diatoms. Dissolved oxygen was negatively correlated with depth ($P < 0.01$) and nitrogen, phosphorus, and the N:P ratio, whereas there was only a significant positive relationship between dissolved oxygen and chlorophyll a and the Shannon index. Nitrogen and phosphorus were negatively correlated with total phytoplankton abundance and the abundance of dinoflagellates and diatoms, and this relation is a result of the consumption of nutrients by phytoplankton. All nutrients were positively correlated with each other ($P < 0.01$). TOC was positively related to total phytoplankton abundance as well as to the abundance of dinoflagellates and diatoms. There was an expected positive relation between salinity and depth ($P < 0.01$), whereas there was no significant relation between depth and temperature, meaning that the stratification was only dependent on salinity during the study period and the temperature was dependent on seasonal variability.

Concluding remarks

The intense mucous formations both in the surface and subsurface (the permanent pycnocline, at depths of about 10-20 m) waters of the Sea of Marmara are here reported as mucilage aggregates caused by direct, coagulated cellular exudates of phytoplankton. This hypothesis is firstly based on the presence of mucous producing species, especially of *G. fragilis*, throughout the mucilage period in all observations with a high number of cell counts. Secondly, the presence of high DOC content in the waters surrounding the aggregate

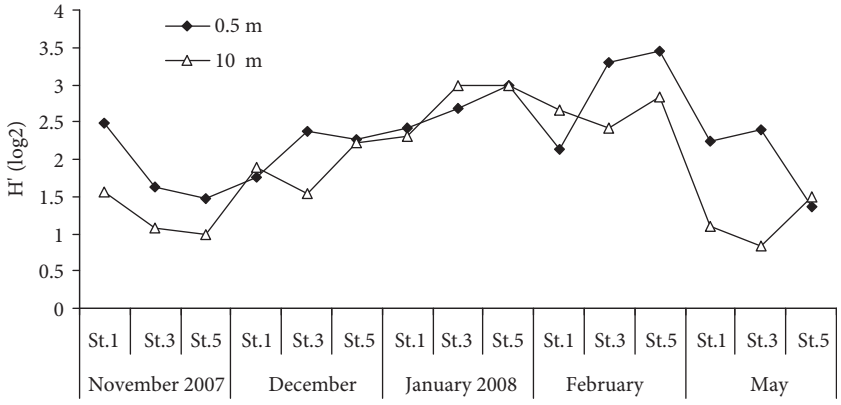

Figure 5. Variations of the Shannon-Weaver index (H'_{log2}) of the sampling stations.

Table 5. Spearman's rank-correlation matrix (r_s) to correlate phytoplankton assemblages and environmental variables in the study area.

	Temperature	Salinity	Dissolved oxygen	Depth	NO_3+NO_2	PO_4-P	Silica	N/P	TP	TN	TOC	Chl a
Temperature	1.000											
Salinity	ns	1.000										
Dissolved oxygen	- 0.849**	ns	1.000									
Depth	ns	0.528**	- 0.435**	1.000								
NO_3+NO_2-N	0.571**	ns	- 0.568**	ns	1.000							
PO_4-P	0.412*	ns	- 0.385*	ns	0. 855**	1.000						
Silica	ns	ns	ns	ns	0.476**	0.553**	1.000					
N/P	0.566**	ns	- 0.555**	ns	0.885**	0.579**	0.316*	1.000				
TP	0.341*	ns	- 0.342*	ns	0.660**	0.820**	0.331*	0.405*	1.000			
TN	- 0.319*	- 0.474**	ns	ns	ns	ns	ns	ns	ns	1.000		
TOC	ns	- 0.603**	ns	- 0.374*	ns	ns	ns	ns	0.350*	0.319*	1.000	
Chl a	- 0.649**	ns	0.776**	-0.481**	ns	ns	0.422*	ns	ns	ns		1.000
Shannon index	- 0.679**	ns	0,738**	ns	- 0.537**	- 0.449*	ns	- 0.473**	- 0.471**	ns	ns	0.560
Total phytoplankton	ns	- 0.518**	ns	ns	- 0.318*	- 0.354*	ns	ns	ns	ns	0.482**	ns
Dinoflagellate abundance	ns	- 0.714**	ns	- 0.389*	ns	- 0.329*	ns	ns	ns	ns	0.669**	ns
Diatom abundance	- 0.345*	- 0.345*	ns	ns	- 0.363*	- 0.369*	ns	- 0.346*	ns	ns	0.351*	ns

(** $P < 0.01$, * $P < 0.05$, ns = not significant, n = 30).

indicated that the vicinity of the material produced was 5-10 times richer in organic material than the usual organic carbon content of the sea. This was strongly supported by the high Org-C content of the freeze-dried mucilage, which was at the level of 24% (C/N~18.5).

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References

1. Pompei M, Mazziotti C, Guerrini F et al. Correlation between the presence of *Gonyaulax fragilis* (Dinophyceae) and mucilage phenomena of the Emilia-Romagna coast (northern Adriatic Sea). Harmful Algae 2: 301-316, 2003.
2. Mingazzini M, Colombo S, Ferrari GM. Application of spectrofluorimetric techniques to the study of marine mucilages in the Adriatic Sea: preliminary results. Sci Total Environ 165: 133-144, 1995.
3. MacKenzie L, Sims I, Beuzenberg V et al. Mass accumulation of mucilage caused by dinoflagellate polysaccharide exudates in Tasmanian Bay, New Zealand. Harmful Algae 1: 69-83, 2002.
4. Metaxatos A, Panagiotopoulos C, Ignatiades L. Monosaccharide and aminoacid composition of mucilage material produced from a mixture of four phytoplanktonic taxa. Journal of Experimental Marine Biology and Ecology 294: 203-217, 2003.
5. Nikolaidis G, Aligizaki K, Koukaras K et al. Mucilage phenomena in North Aegean Sea, Greece: another harmful effect of dinoflagellates? 12th International Conference on Harmful Algae, Copenhagen, Denmark, 2006.
6. Marchetti R. Algal blooms and gel production in the Adriatic Sea. In Barth H, Fegan L (ed): Eutrophication-related phenomena in the Adriatic Sea and in other Mediterranean Coastal Zones, EUR 12978. Water Pollut Res Rep 16:21-42, 1990.
7. Mingazzini M, Thake B. Summary and conclusions of the workshop on marine mucilages in the Adriatic Sea and elsewhere. Sci Total Environ 165: 9-14, 1995.
8. Degobbis D, Fonda-Umani S, Franco P et al. Changes in the northern Adriatic ecosystem and the hypertrophic appearance of gelatinous aggregates. Sci Total Environ 165: 43-58, 1995.
9. Urbani R, Magaletti E, Sist P et al. Extracellular carbohydrates released by the marine diatoms *Cylindrotheca closterium, Thalassiosira pseudonana* and *Skeletonema costatum*: Effect of P-depletion and growth status. Sci Total Environ 353: 300-306, 2005.
10. Najdek M, Blazina M, Djakovac T. et al. The role of the diatom *Cylindrotheca closterium* in a mucilage event in the northern Adriatic Sea: coupling with high salinity water intrusions. J Plankton Res 27: 851-862, 2005.
11. Pistocchi R, Cangini M, Totti, C et al. Relevance of the dinoflagellate *Gonyaulax fragilis* in mucilage formations of the Adriatic Sea. Sci Total Environ 353: 307-316, 2005.
12. Balkıs N. List of phytoplankton of the Sea of Marmara. J Black Sea/Mediterranean Environment 10:123-141, 2004.
13. Gómez F. Checklist of Mediterranean free-living dinoflagellates. Bot Mar. 46: 215-242, 2003.
14. Gómez F. An annotated checklist of dinoflagellates in the Black Sea. Hydrobiologia 517: 43-59, 2004.
15. Balkıs N. Seasonal variations in the phytoplankton and nutrient dynamics in the neritic water of Büyükçekmece Bay, Sea of Marmara. J Plankton Res 25: 703-717, 2003.
16. Morkoç E, Tugrul S, Okay OS et al. Eutrophication of İzmit Bay, Marmara Sea. Croatica Chemical Acta 70: 347-359, 1997.
17. Balkıs N. The effect of Marmara (Izmit) earthquake on the chemical oceanography of Izmit Bay, Turkey. Mar Poll Bull 46: 865-878, 2003.
18. Hansen HP, Grasshoff K. Automated chemical analysis. In Grasshoff K, Ehrhard M, Kremling K (ed): Methods of seawater analysis. pp 347-379. 2nd. Verlag Chemie. Weinheim; 1983.

19. Eaton AD, Clesceri LS, Rice EW et al. (ed). Standard Methods for the Examination of Water and Wastewater, 21st Edition. Greenberg A.E.United States of America. 4500-N (4-105), 10200-H (10-19). 2005.

20. Throndsen J. Preservation and storage. In Sournia A (ed): Phytoplankton manual. pp. 69-74. UNESCO. UK; 1978.

21. Guillard RRL. Counting slides. In Sournia A (ed): Phytoplankton manual. pp. 182-189. UNESCO. UK; 1981.

22. Semina HJ. Treatment of an aliquot sample. In Sournia A (ed): Phytoplankton manual. pp. 181. UNESCO. Paris; 1978.

23. Siegel S. Non-parametric statistics for the behavioral sciences. McGraw-Hill, New York, 1956.

24. Clarke KR, Warwick RM. Change in marine communities: an approach to statistical analysis and interpretation, second ed., PRIMER-E: Plymouth, 2001.

25. Zar JH. Biostatistical Analysis. 2nd ed. Prentice Hall, Englewood Cliffs, NJ, 1984.

26. Precali R, Giani M, Marini M et al. Mucilaginous aggregates in the northern Adriatic in the period 1999-2002: Typology and distribution. Sci Total Environ 353: 10-23, 2005.

27. Polat, SÇ, Tuğrul S, Çoban Y et al. Elemental composition of seston and nutrient dynamics in the Sea of Marmara. Hydrobiologia 363: 157-167, 1998.

28. Tüfekçi V, Okay OS, Tolun L et al. Chemical oceanographic characteristics of İzmit Bay and determination of limiting nutrient(s). International Conference on Ecotoxicology and Environmental Safety at Antalya, Turkey; 1998.

29. Polat SÇ, Tuğrul S. Nutrient and organic carbon exchanges between the Black and Marmara Seas through the Bosphorus Strait. Cont Shelf Res 15:1115-1132, 1995.

30. Morkoç E, Okay OS, Tolun L et al. Towards a clean Izmit Bay. Environ International 26: 157-161, 2001.

31. Morkoç E, Tarzan L, Okay OS et al. Changes of oceanographic characteristics and the state of pollution in the Izmit Bay following the earthquake of 1999. Environ Geol 53: 103-112, 2007.

32. Uysal Z. A net-plankton study in the Bosphorus junction of the Sea of Marmara. Turk J Bot 20: 321-327, 1996.

33. Aktan Y, Tüfekçi V, Tüfekçi H et al. Distribution patterns, biomass estimates and diversity of phytoplankton in Izmit Bay. Estuarine Coastal and Shelf Science 64: 372-384, 2005.

34. Ignatiades L. Annual cycle, species diversity and succession of phytoplankton in lower Saronicos Bay, Aegean Sea. Mar Biol, 3: 196-200, 1969.