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RESEARCH ARTICLE

The early stage of mucilage formation in the Marmara Sea during spring 2021

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Abstract

In the present study, phytoplankton composition in relation to mucilage and accompanied physicochemical conditions were investigated in the sea water samples collected from four stations in İzmit-Kocaeli, Fatih-İstanbul, Biga-Çanakkale (in the Marmara Sea), and Riva-İstanbul (in the Black Sea). Samplings were carried out before (i.e., during September 2020) and at the beginning stage of the mucilage formations (i.e., during April 2021) which was observed in the Marmara Sea during spring and summer months of 2021. Seawater temperature, salinity, pH, and dissolved oxygen levels were measured *in situ*. Inorganic nitrogen, orthophosphate, and chlorophyll-*a* concentrations were analyzed spectrophotometrically. In total 83 phytoplankton species (44 Bacillariophyceae-BAC, 36 Dinophyceae-DIN, 2 Dictyochophyceae-DIC, and 1 Chlorophyceae-CHL) were identified during the study. BAC species were generally dominant. Among the 83 phytoplankton taxa identified, *Cerataulina pelagica, Cylindrotheca closterium, Pseudo-nitzschia* sp., *Skeletonema costatum, Thalassiosira rotula, Alexandrium tamarense, Dinophysis acuminata, Dinophysis caudata, Dinophysis fortii, Gonyaulax fragilis, Gonyaulax spinifera, Gymnodinium* sp., *Gyrodinium* sp., and *Prorocentrum micans* are known as the species associated with mucilage formation. The highest number of species was determined at the Biga-Çanakkale station (MDG25) with 38 taxa in September 2020.

Skeletonema costatum (11200 cells/L) was the most abundant species at 10 m depth in the İzmit-Kocaeli station (MDG22) in April 2021. The mucilage formations in MDG22, and MDG25 stations were observed at their beginning stage as a tule curtain form in April 2021 while the seawater temperature and salinity levels were below 15°C and around 30‰, respectively. While the taxa dominance of the BAC in the total phytoplankton remained similar from September to April (i.e., 56%), its number of species decreased dramatically from 59 to 28 in the Marmara Sea. Despite the decreasing biodiversity, there was an increase in total abundance in the sampling stations, particularly in MDG22 and MDG25. In both stations, total abundance increased from 12000 to 42000, and 2000 to 50000 cells/L, respectively, compared to September 2020 and April 2021. Despite the decrease in biodiversity, and increase in the number of cells suggests that eutrophication and, as a result, mucilage formation occurred in the Marmara Sea. TRIX values showed that while the eutrophic conditions increased, the ecological quality in the region generally decreased from September 2020 to April 2021, and it was described as Bad for all stations in the Marmara Sea. The data indicated that the limiting factor for phytoplankton was nitrogen during April 2021 simultaneously with the mucilage formation in the Marmara Sea.

Keywords: Mucilage, sea snot, phytoplankton, Marmara Sea, nutrient, *Cylindrotheca closterium, Skeletonema costatum*

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Introduction

The Marmara Sea is an inland sea located between the Black Sea and the Aegean Sea in the borders of Turkey. The sea is known for its layered formation and a sharp density interface separates the two distinct water bodies. The Black-Sea-originated less saline water (i.e., ~18 ‰), entering from the İstanbul Strait, constitutes the upper layer, while the lower layer is formed by the saline waters (i.e., ~38 ‰) originated from the Mediterranean Sea (Besiktepe *et al*. 1994). About five million cubic meters of wastewater, including nitrogen and phosphorus compounds, discharges into the Marmara Sea daily. Wastewater discharges are 204 L/day per capita from more than 25 million people inhabiting around the Marmara Sea (TUIK 2018).

Marine mucilage is a complex organic mass containing its own microbial flora (Turk *et al*. 2010). The process of mucilage formation starts with extracellular secretions of phytoplankton. The majority of these secretions consist of heteropolysaccharides (Svetličić *et al*. 2011). After excreted, hetero-polysaccharide fibrils begin to bond with each other and form nano, later microgels which in time forms macroaggregates, like marine snow (Ricci *et al*. 2014). These macroaggregates stick to detritus, suspended particles, microplastic particles, etc., and form a mass that we call marine mucilage (Chin *et al*. 1998; Turk *et al*. 2010; Svetličić *et al*. 2011; Ricci *et al*. 2014).

Mucilage formations in confined water bodies with restricted water circulation often harm several species and in some cases, sensitive habitats. Several studies

are pointing to mucilage damage in sensitive ecosystems like coral reefs and seagrass beds (i.e., *Posidonia oceanica*) (Giuliani *et al*. 2005; Lorenti *et al*. 2005; Piazzi *et al*. 2018). Shrouding the benthic zone and creating hypoxic conditions also causes an impact on the whole trophic levels (Schiaparelli *et al*. 2007; Özalp 2021). Besides environmental problems, marine mucilage causes economic problems like crippling fishing activities and reducing tourism income and acute health problems in humans like ciguatera poisoning (Zingone *et al*. 2021).

Marine mucilage is a well-documented phenomenon for the Mediterranean Sea. Records of mucilage formation in the Adriatic Sea dates back to 18th century (Bianchi 1746). In the last 50 years, marine mucilage became the subject of many studies (Umani *et al*. 1989; Rinaldi *et al*. 1995; Pistocchi *et al.* 2005; Aktan *et al*. 2008; Tüfekçi *et al.* 2010; Balkis *et al*. 2011, 2013; Taş *et al*. 2016; Ergul *et al.* 2018; Taş *et al.* 2020; Toklu-Alicli *et al*. 2020; Balkis-Ozdelice *et al.* 2021). In the Marmara Sea, marine mucilage was first observed in 1958 (Dr. B. Öztürk pers. comm.). İzmit Bay draws attention as the most prominent region of the Marmara Sea in algal bloom and mucilage events (Ergul *et al*. 2014, 2018), and several of these algal blooms, physicochemical conditions, and mucilage formations were studied extensively in the bay (Ergul *et al*. 2010, 2013, 2014, 2018; Küçük and Ergul 2011; Ergul 2016; Taş *et al*. 2016).

In order to uncover phytoplankton composition and accompanied physicochemical conditions, connected with mucilage formation, four sampling stations located around İzmit-Kocaeli, Fatih-İstanbul, Biga-Çanakkale (in the Marmara Sea), and Riva-İstanbul (in the Black Sea) were selected in the Marmara and Black Seas, in the scope of the project "Water Quality Monitoring of the Marmara Basin", coordinated by the General Directorate of State Hydraulic Works (DSI). The current study aimed 1) to determine the phytoplankton biodiversity and abundances, 2) to determine eutrophication level depending on bio-physicochemical data analysis, 3) to predict phytoplankton species that cause massive mucilage formation, 4) to reveal the relationship of these species which form mucilage with eutrophication, and 5) to expose other reasons leading to massive mucilage formation in the study area.

Materials and Methods

The phytoplankton samplings of the present study were carried out in September 2020 and April 2021, while the physicochemical parameters were measured monthly from June 2020 to May 2021 in the frame of the "Water Quality Monitoring of the Marmara Basin" project coordinated by DSI.

In total four stations were selected 1 mile off the coast in order to compare phytoplankton communities and the effects of accompanying environmental variables on their biodiversity as well as mucilage formation. Three sampling stations were selected in different geographical locations through the Marmara

Sea. These stations were located at the eastern side (around İzmit-Kocaeli, MDG22), at the southwest side (around Biga-Çanakkale, MDG25), and at the İstanbul Strait offshore (around Fatih-İstanbul, MDG31). One station was selected in the Black Sea at the outlet of the İstanbul Strait (around Riva-İstanbul, KDO9). MDG22 was visited on September 19, 2020 and April 17, 2021, MDG25 on September 18, 2020 and April 16, 2021, MDG31 on September 12, 2020 and April 9, 2021, and KDO9 on September 12, 2020 and April 8, 2021 (Figure 1).



Figure 1. The sampling stations in the Marmara and Black Seas (MDG22, İzmit Bay, Kocaeli; MDG25, Biga, Çanakkale; MDG31, Fatih, İstanbul; KDO9, Riva, İstanbul)

Phytoplankton samples were collected by vertical hauling from 10 m depth and horizontal hauling from surface water through 100 m with a plankton net with 25 cm diameter and 20 µm mesh size. Composite water samples were taken from the same depths with a 3L Nansen Bottle. Then the samples were transferred into 1L amber bottles, treated using 2mL of formaldehyde (37% fuming) per 100mL, then labeled. Samples were kept in the dark while being transported to the laboratory and allowed to settle for 3-4 days. The samples were reduced to 100mL and left for the second settling process for 1-2 days, then reduced to 10mL. Afterward, the samples were examined in the Sedgewick Rafter counting chamber using a light microscope (Olympus CX23).

In situ chemical analysis and measurements were performed simultaneously with phytoplankton sampling. Water transparency was measured with a Secchi disc. *In situ* salinity, pH, water temperature, and dissolved oxygen measurements were carried out in the samples at the surface, 10 m depth, and near the bottom (if available), using the Hach-Lange HQ 40D digital 2-channel multimeter. Orthophosphate (o-PO_4^{3-}), nitrate-nitrogen (NO_3^--N), nitrite-nitrogen (NO_2^--N), ammonia-nitrogen (NH_3-N), and Chlorophyll-*a* chemical variables were analyzed spectrophotometrically (Bendschneider and Robinson 1952; Mullin and Riley 1955; Murphy and Riley 1962). Graphics were plotted by using MS Excel. The trophic status of the stations was determined using the TRIX index (Vollenweider *et al*. 1998).

Results

Phytoplankton composition and biodiversity

In total 83 phytoplankton species (44 Bacillariophyceae-BAC, 36 Dinophyceae-DIN, 2 Dictyochophyceae-DIC, and 1 Chlorophyceae-CHL) were determined in all stations. The total number of identified phytoplankton taxa were 64 and 39 in September 2020 and April 2021, respectively (Table 1). In the Marmara Sea stations total of 76 taxa (40 BAC, 34 DIN, 1 DIC, and 1 CHL) were identified, whereas in the Black Sea station total of 40 taxa (29 BAC, 9 DIN, and 1 DIC) were present throughout the study (Table 2a, b).

In September 2020, 36 BAC, 27 DIN, and 1 CHL taxa were identified in all stations (Tables 1 and 2a). In the Marmara Sea, while a total of 61 taxa (34 BAC, 26 DIN, and 1 CHL) were determined, in the Black Sea total of 26 taxa (21 BAC and 5 DIN) were identified (Table 2b). Bacillariophyceae was the dominant phytoplankton group in both seas. The number of species found only in the Marmara Sea but not in the Black Sea was 38 (15 BAC, 22 DIN, and 1 CHL). On the contrary, the number of species found in the Black Sea but not in the Marmara Sea were only 3 (2 BAC, and 1 DIN). The number of species found in both seas was 23 (19 BAC, and 4 DIN) (Table 2b). Among the identified species, *Bacteriastrum hyalinum* Lauder, 1864, *Chaetoceros decipiens* Cleve, 1873, *Hemiaulus membranaceus* Cleve, 1873, *Hemiaulus sinensis* Greville, 1865, *Navicula* sp., *Proboscia alata* (Brightwell) Sundström, 1986, *Pseudosolenia calcar-avis* (Schultze) Sundström, 1986, and *Thalassiosira eccentrica* (Ehrenberg) Cleve, 1904 belonging to the BAC, and *Prorocentrum scutellum* Schröder, 1900, *Protoperidinium steinii* (Jørgensen) Balech, 1974, *Tripos furca* (Ehrenberg) Gómez, 2013, *Tripos fusus* (Ehrenberg) Gómez, 2013, and *Tripos trichoceros* (Ehrenberg) Gómez, 2013 belonging to the DIN were found in all three stations in the Marmara Sea. Among the stations in the Marmara Sea, the highest phytoplankton abundance was determined at the MDG31 (i.e., 19200 cells/L). *P. scutellum* was the most abundant species. However, the highest number of species was determined at the MDG25 with 38 taxa in September 2020 (Table 2b).

In April 2021, 22 BAC, 16 DIN, and 1 DIC taxa were present in all stations (Tables 1, 2b). A total of 32 taxa (16 BAC, 15 DIN, and 1 DIC) was determined in the Marmara Sea, whereas a total of 19 taxa (13 BAC, 5 DIN, and 1 DIC) was identified in the Black Sea (Table 2b). Although the taxa number decreased, BAC was the dominant phytoplankton group in both seas in this season, same as September 2020. The number of species found in the Marmara Sea but not in the Black Sea was 20 (9 BAC, and 11 DIN), while the number of species found in the Black Sea but not in the Marmara Sea was 7 (6 BAC, and 1 DIN). The number of species common in both seas was determined as 12 (7 BAC, 4 DIN, and 1 DIC) (Table 2b). Among the identified species, *Cylindrotheca closterium* (Ehrenberg) Reimann & Lewin, 1964, and *Guinardia flaccida* (Castracane) Peragallo, 1892

belonging to the BAC, and *Gonyaulax fragilis* (Schütt) Kofoid, 1911, and *Gymnodinium* sp., belonging to the DIN were found in all three stations in the Marmara Sea. Among the stations in the Marmara Sea, the highest phytoplankton abundance was determined at the MDG25. *Thalassiosira* sp. (i.e., 8800 cells/L) was the most abundant species in the surface waters of this station. On the other hand, the highest number of species was determined at the MDG31 with 21 taxa in April 2021. It should be noted that the most abundant species of this sampling season was *Skeletonema costatum* (Greville) Cleve, 1873 (i.e., 11200 cells/L) in the 10 m depth of MDG22, and at the same time, the mucilage formation was visible with the naked eye as a tulle curtain form in this station (Table 2a).

Table 1. Taxonomic composition and frequency (f) of phytoplankton species during the sampling period

Taxonomic Groups	**Genus**	**Species**	**Variety**	**Forma**	**Taxa**	**f (%)**
			September 2020			
Cyanophyceae	0	0	0	0	0	0
Dinophyceae	14	27	0	0	27	42.19
Chlorophyceae	1	1	0	0	1	1.56
Dictyochophyceae	0	0	0	0	0	0
Bacillariophyceae	27	36	0	0	36	56.25
Euglenophyceae	0	0	0	0	0	0
Total phytoplankton	**42**	**64**	**0**	**0**	**64**	**100**
			April 2021			
Cyanophyceae	0	0	0	0	0	0
Dinophyceae	10	16	0	0	16	41.03
Chlorophyceae	0	0	0	0	0	0
Dictyochophyceae	1	1	0	0	1	2.56
Bacillariophyceae	17	22	0	0	22	56.43
Euglenophyceae	0	0	0	0	0	0
Total phytoplankton	**28**	**39**	**0**	**0**	**39**	**100**
			All Sampling Periods			
Cyanophyceae	0	0	0	0	0	0
Dinophyceae	18	36	0	0	36	43. 37
Chlorophyceae	1	1	0	0	1	1.20
Dictyochophyceae	1	2	0	0	2	2.40
Bacillariophyceae	29	44	0	0	44	53.01
Euglenophyceae	0	0	0	0	0	0
Total phytoplankton	**49**	**83**	**0**	**0**	**83**	**100.0**

Table 2a. Phytoplankton biodiversity, and abundances (cells/L) in the sea water samples carried out from the sampling stations in the Marmara and the Black Seas during September 2020 and April 2021

+: The taxon is present at the station; **-:** The taxon is not present at the station; **s:** Surface (0.5 m); **-10m:** Tenth meter of the water column

Species	MDG22-İzmit						MDG25-Biga						MDG31-Fatih						KDO9-Riva			
	Sep 2020			Apr 2021			Sep 2020			Apr 2021			Sep 2020			Apr 2021			Sep 2020		Apr 2021	
	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	+/-	s
BACILLARIOPHYCEAE (BAC)																						
Amphora sp.	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Asterionella glacialis Castracane, 1886	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Bacillaria paxillifera (O.F. Müller) T. Marsson 1901	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Bacteriastrum delicatulum Cleve, 1897	+	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bacteriastrum hyalinum Lauder, 1864	+	-	-	-	-	-	+	-	-	-	-	-	+	300	-	-	-	-	-	-	-	-
Cerataulina pelagica (Cleve) Hendey, 1937	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chaetoceros affinis Lauder, 1864	-	-	-	-	-	-	+	-	80	-	-	-	+	280	-	-	-	-	-	-	-	-
Chaetoceros danicus Cleve, 1889	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chaetoceros decipiens Cleve, 1873	+	100	40	-	-	-	+	-	-	-	-	-	+	40	-	-	-	-	+	-	+	-
Chaetoceros didymus Ehrenberg, 1945	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chaetoceros sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Chaetoceros socialis Lauder, 1864	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	200	-	-	-	-	-
Cocconeis sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-

Table 2a. Continued

Species	MDG22-İzmit						MDG25-Biga						MDG31-Fatih						KDO9-Riva			
	Sep 2020			Apr 2021			Sep 2020			Apr 2021			Sep 2020			Apr 2021			Sep 2020		Apr 2021	
	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	+/-	s
Coscinodiscus perforatus Ehrenberg, 1844	-	-	-	-	-	-	-	-	-	+	1200	1600	-	-	-	+	70	-	-	-	+	400
Coscinodiscus oculus-iridis (Ehrenberg) Ehrenberg, 1840	+	100	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Coscinodiscus radiatus Ehrenberg, 1840	+	-	-	-	-	-	+	40	100	-	-	-	-	-	-	-	-	-	-	-	-	-
Cylindrotheca closterium (Ehrenberg) Reimann&Lewin, 1964	+	-	-	+	2200	6400	+	-	80	+	800	-	-	-	-	+	-	-	+	40	+	-
Cylindrotheca sp.	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cymbella sp.	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Ditylum brightwellii (West) Grunow 1885	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Entomoneis alata (Ehrenberg) Ehrenberg, 1845	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Fragilaria sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Grammatophora sp.	-	-	-	-	-	-	-	-	-	-	-	-	+	1100	-	-	-	-	+	-	-	-
Guinardia flaccida (Castracane) Peragallo, 1892	-	-	-	+	-	2600	-	-	-	+	1200	800	-	-	-	+	40	-	-	-	-	-
Gyrosigma reversum (Gregory) Hendey, 1986	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Hemiaulus hauckii Grunow ex Van Heurck, 1882	+	-	-	-	-	-	-	-	-	-	-	-	+	1400	-	-	-	-	+	-	-	-
Hemiaulus membranaceus Cleve, 1873	+	-	100	-	-	-	+	-	120	-	-	-	+	180	-	-	-	-	+	-	-	-

Table 2a. Continued

Species	MDG22-İzmit						MDG25-Biga						MDG31-Fatih						KDO9-Riva			
	Sep 2020			Apr 2021			Sep 2020			Apr 2021			Sep 2020			Apr 2021			Sep 2020		Apr 2021	
	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	+/-	s
Hemiaulus sinensis Greville, 1865	+	-	240	-	-	-	+	-	160	-	-	-	+	2100	-	-	-	-	+	-	-	-
Leptocylindrus danicus Cleve, 1889	-	-	-	+	2400	-	+	-	-	+	1200	2400	-	-	-	-	-	-	-	-	+	400
Licmophora sp.	+	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	+	40	+	-
Navicula sp.	+	-	-	-	-	-	+	-	-	-	-	-	+	-	-	-	-	-	+	-	+	-
Neocalyptrella robusta (Norman ex Ralfs) Hernández-Becerril&Meave del Castillo, 1997	+	300	-	-	-	-	+	-	60	-	-	-	-	-	-	-	-	-	+	-	-	-
Pleurosigma sp.	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Proboscia alata (Brightwell) Sundström, 1986	+	-	-	-	-	-	+	-	-	+	-	800	+	140	-	-	-	-	+	220	-	-
Pseudo-nitzschia pungens (Grunow ex Cleve) Hasle, 1993	+	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pseudo-nitzschia sp.	+	-	-	-	-	-	+	-	-	+	1600	1200	-	-	-	-	-	-	+	-	-	-
Pseudosolenia calcar-avis (Schultze) Sundström, 1986	+	-	140	+	1800	1200	+	-	40	-	-	-	+	550	160	+	130	-	+	-	+	-
Rhizosolenia setigera Brightwell, 1858	+	750	100	-	-	-	+	-	-	+	-	800	-	-	-	+	40	-	+	100	-	-
Skeletonema costatum (Greville) Cleve, 1873	-	-	-	+	1000	11200	+	-	-	-	-	-	-	-	-	+	990	-	-	-	+	800
Striatella unipunctata (Lyngbye) Agardh, 1832	-	-	-	+	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	+	-

Table 2a. Continued

Species	MDG22-İzmit						MDG25-Biga						MDG31-Fatih						KDO9-Riva			
	Sep 2020			Apr 2021			Sep 2020			Apr 2021			Sep 2020			Apr 2021			Sep 2020		Apr 2021	
	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	+/-	s
Thalassionema nitzschioides (Grunow) Mereschkowsky, 1902	-	-	-	-	-	-	-	-	-	-	-	-	+	390	-	+	-	-	+	-	-	-
Thalassiosira eccentrica (Ehrenberg) Cleve, 1904	+	-	-	+	1800	2200	+	-	-	+	3000	-	+	110	-	-	-	-	-	-	-	-
Thalassiosira gravida Cleve, 1896	-	-	-	-	-	-	-	-	-	+	600	-	-	-	-	-	-	-	-	-	-	-
Thalassiosira sp.	+	-	-	-	-	-	-	-	-	+	8800	-	-	-	-	+	210	-	-	-	+	-
DINOPHYCEAE (DIN)																						
Alexandrium tamarense (Lebour) Balech, 1995	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	130	-	-	-	-	-
Corythodinium tesselatum (Stein) Loeblich Jr.&Loeblich III, 1966	+	400	160	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dinophysis acuminata Claparede and Lachmann, 1859	+	300	-	-	-	-	+	-	-	+	400	-	-	-	-	-	-	-	-	-	+	-
Dinophysis caudata Kent, 1881	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-
Dinophysis fortii Pavillard, 1924	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	30	-	-	-	-	-
Diplopsalis lenticula Bergh	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Gonyaulax fragilis (Schütt) Kofoid, 1911	-	-	-	+	-	-	-	-	-	+	1200	4800	-	-	-	+	850	-	-	-	-	-

Table 2a. Continued

Species	MDG22-İzmit						MDG25-Biga						MDG31-Fatih						KDO9-Riva			
	Sep 2020			Apr 2021			Sep 2020			Apr 2021			Sep 2020			Apr 2021			Sep 2020		Apr 2021	
	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	+/-	s
Gonyaulax spinifera (Claparède&Lachmann) Diesing, 1866	-	-	-	-	-	-	+	-	60	-	-	-	+	3600	-	-	-	-	-	-	-	-
Gonyaulax sp.	-	-	-	-	-	-	-	-	-	-	-	-	+	330	-	-	-	-	-	-	-	-
Gymnodinium sp.	-	-	-	+	-	1400	-	-	-	+	1200	1600	-	-	-	+	160	-	-	-	-	-
Gyrodinium sp. 1	-	-	-	+	-	4000	-	-	-	+	7000	4000	-	-	-	-	-	-	-	-	-	-
Gyrodinium sp. 2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-	-	-	-
Oxytoxum scolopax Stein,1883	+	400	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phalacroma oxytoxoides (Kofoid) Gomez, Lopez-Garcia&Moreira, 2011	+	150	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phalacroma rotundatum (Claparéde&Lachmann) Kofoid & Michener, 1911	-	-	-	-	-	-	-	-	-	-	-	-	+	440	-	-	-	-	-	-	-	-
Phalacroma sp.	-	-	-	+	-	-	-	-	-	+	400	-	-	-	-	-	-	-	-	-	-	-
Podolampas palmipes Stein, 1883	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Prorocentrum compressum (Bailey) Abé ex Dodge, 1975	-	-	-	-	-	-	-	-	-	-	-	-	+	610	-	-	-	-	-	-	-	-
Prorocentrum gracile Schütt, 1895	+	150	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Prorocentrum micans Ehrenberg, 1834	+	1500	420	-	-	-	+	-	220	+	800	800	-	-	-	+	20	-	-	-	-	-
Prorocentrum scutellum Schröder, 1900	+	500	200	-	-	-	+	100	400	+	600	800	+	3650	-	-	-	-	+	-	-	-

Table 2a. Continued

Species	MDG22-İzmit						MDG25-Biga						MDG31-Fatih						KDO9-Riva			
	Sep 2020			Apr 2021			Sep 2020			Apr 2021			Sep 2020			Apr 2021			Sep 2020		Apr 2021	
	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	+/-	s
Protoperidinium depressum (Bailey) Balech, 1974	-	-	-	-	-	-	+	-	-	-	-	-	+	700	-	+	190	-	-	-	+	-
Protoperidinium divergens (Ehrenberg) Balech, 1974	-	-	-	-	-	-	-	-	-	-	-	-	+	570	-	-	-	-	-	-	-	-
Protoperidinium obtusum (Karsten) Parke&Dodge, 1976	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-
Protoperidinium leonis (Pavillard) Balech, 1974	-	-	-	-	-	-	-	-	-	-	-	-	+	880	-	-	-	-	-	-	-	-
Protoperidinium pellucidum Bergh 1881	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	70	-	-	-	+	-
Protoperidinium pyriforme (Paulsen) Balech, 1974	-	-	-	-	-	-	+	-	40	-	-	-	-	-	-	-	-	-	-	-	-	-
Protoperidinium steinii (Jørgensen) Balech, 1974	+	100	-	-	-	-	+	-	-	-	-	-	+	80	480	-	-	-	-	-	-	-
Pyrocystis fusiformis Thomson, 1876	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-	-
Pyrophacus horologium Stein, 1883	+	50	40	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Scrippsiella acuminata (Ehrenberg)	+	350	-	-	-	-	+	-	-	+	-	-	-	-	-	+	-	-	-	-	-	-
Tripos furca (Ehrenberg) Gómez, 2013	+	3250	320	-	-	-	+	40	140	-	-	-	+	330	-	+	180	-	+	-	+	-
Tripos fusus (Ehrenberg) Gómez, 2013	+	1250	280	-	-	-	+	-	100	-	-	-	+	210	640	+	50	-	+	-	-	-
Tripos lineatus (Ehrenberg) Gómez, 2013	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tripos muelleri Bory, 1826	-	-	-	-	-	-	-	-	-	-	-	-	+	90	-	-	-	-	-	-	-	-

Table 2a. Continued

Species	MDG22-İzmit						MDG25-Biga						MDG31-Fatih						KDO9-Riva			
	Sep 2020			Apr 2021			Sep 2020			Apr 2021			Sep 2020			Apr 2021			Sep 2020		Apr 2021	
	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	-10m	+/-	s	+/-	s
Tripos trichoceros (Ehrenberg) Gómez, 2013	+	150	60	-	-	-	+	-	160	-	-	-	+	1120	1760	-	-	-	+	-	-	-
DICTYOCHOPHYCEAE (DIC)																						
Dictyocha speculum Ehrenberg, 1839	-	-	-	+	1000	2800	-	-	-	-	-	-	-	-	-	+	90	-	-	-	+	400
CHLOROPHYCEAE (CHL)																						
Scenedesmus quadricauda (Turpin) Bribisson, 1835	-	-	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2b. Phytoplankton biodiversity, total number of the taxa and abundances (cells/L) in the sea water samples carried out from the sampling stations in the Marmara and the Black Seas during September 2020 and April 2021

+: Number of taxa/cells present at the station; **s:** Surface (0.5 m); **-10m:** Tenth meter of the water column

TOTAL	MDG22-İzmit						MDG25-Biga						MDG31-Fatih						KDO9-Riva			
	Sep 2020			Apr 2021			Sep 2020			Apr 2021			Sep 2020			Apr 2021			Sep 2020		Apr 2021	
	+	s	-10m	+	s	-10m	+	s	-10m	+	s	-10m	+	s	-10m	+	s	-10m	+	s	+	s
BAC Taxa	24	4	6	8	5	5	23	1	7	11	8	6	12	11	1	9	7	0	21	4	13	3
DIN Taxa	13	13	7	4	5	5	14	2	7	8	7	5	14	13	3	11	9	0	5	0	5	0
DIC Taxa	0	0	0	1	5	5	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	1
CHL Taxa	0	0	0	0	5	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Taxa number	**37**	**17**	**13**	**13**	**6**	**8**	**38**	**3**	**14**	**19**	**15**	**11**	**26**	**24**	**4**	**21**	**17**	**0**	**26**	**4**	**19**	**4**
BAC Abundance	1910	1250	660	32800	9200	23600	680	40	640	26000	18400	7600	6750	6590	160	1680	1680	0	400	400	1600	1600
DIN Abundance	10030	8550	1480	5400	0	5400	1260	140	1120	23600	11600	12000	15490	12610	2880	1680	1680	0	0	0	0	0
DIC Abundance	0	0	0	3800	1000	2800	0	0	0	0	0	0	0	0	0	90	90	0	0	0	400	400
CHL Abundance	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Abundance	**11940**	**9800**	**2140**	**42000**	**10200**	**31800**	**1940**	**180**	**1760**	**49600**	**30000**	**19600**	**19200**	**19200**	**3040**	**3450**	**3450**	**0**	**400**	**400**	**2000**	**2000**

Contribution rates (%) of major taxonomic groups to the total phytoplankton
Looking at the contribution rates (%) of major taxonomic groups to the total taxa number, both in September 2020 and April 2021, during the study, Bacillariophyceae was the dominant phytoplankton group, the following group was Dinophyceae. In all stations, while the contribution of Dinophyceae to total phytoplankton was 42.0%, and 41.0% in September 2020 and April 2021, respectively, the contribution of Bacillariophyceae was 56.0% in both seasons. On the other hand, Dinophyceae rates in April 2021 was higher (47.0%) than its rates in September 2020 (42.0%) in the Marmara Sea. Similarly, the Dinophyceae rate in the Black Sea increased in April 2021 (26%) compared to September 2020 (19%) (Figures 2 and 3).

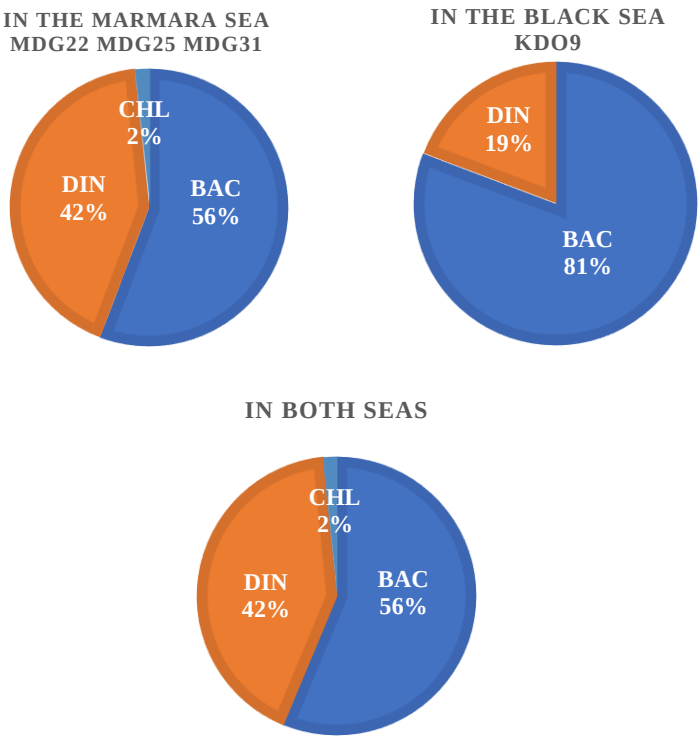

Figure 2. Rational (%) contribution of major taxonomic groups to the total phytoplankton abundance in September 2020

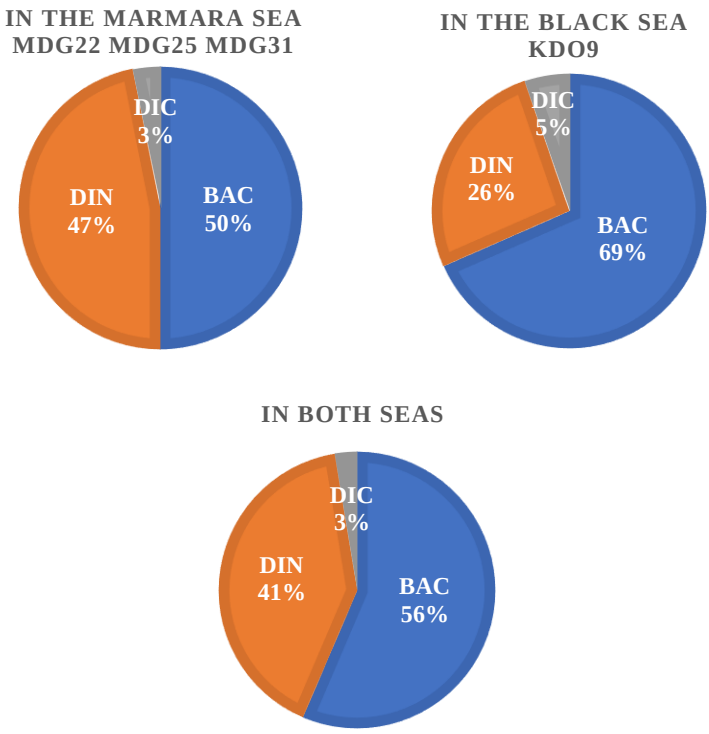

Figure 3. Rational (%) contribution of major taxonomic groups to the total phytoplankton abundance in April 2021

Trophic status of the stations

TRIX values, calculated by using dissolved inorganic nitrogen (DIN), orthophosphate, and oxygen saturation data, indicated that BAD ecological conditions were present in all the Marmara Sea stations in April 2021, whereas the value was MODERATE at the KDO9 station located in the Black Sea in both seasons. Ratios between dissolved inorganic nitrogen (DIN) and o-PO_4^{3-} concentrations represent those phosphorus concentrations relatively increased in April 2021 (Table 3).

Seawater temperature, Salinity, pH, Dissolved Oxygen (DO), and Secchi depth was measured in available depths monthly between June 2020 and May 2021 in the water column of the stations if available (Figures 4 and 5). The highest and lowest seawater temperatures were measured as 27.5 °C and 5 °C in the surface waters of MDG25 in August 2020 and January 2021, respectively. The salinity levels fluctuated throughout the study and reached their highest levels on March 2021 in the deep water of MDG31 as 38.9 ‰. Relatively higher levels of salinity were measured during March-May 2021 both in the surface and deep waters in

all stations of the Marmara Sea. Salinity levels were more stable around 20 ‰ at the KDO9 station at the Black Sea. The mucilage formations at MDG22 and MDG25 were observed while the seawater temperatures were below 15°C (Figure 4).

The lowest and the highest pH levels were measured in the surface water of MDG31 in the Marmara Sea in June and December 2020 as 7.96 and 9.01, respectively. In the Black Sea station (KDO9), the pH levels were variated between 8.06 and 8.93. The DO concentrations were higher than 8 mg/L, accordingly the water columns of the stations were oxic both in the Marmara and Black Seas during the study, and the highest DO levels were measured as 12.1 mg/L on January 2021 in 10 m depth at MDG25 (Figure 5). The lowest DO concentration was recorded as 7.10 mg/L at the surface waters of KDO9 in the Black Sea on May 2021. The lowest and the highest Secchi disc depths of the Marmara Sea were measured at MDG22 on June 2020 and November 2020 as 3.50 m and 14.0 m, respectively. In the Black Sea, the lowest Secchi disc depth was measured as 3.00 m in August 2020 and the highest level was 9.00 m measured on June 2021 in KDO9 (Figure 5).

Discussion

It was observed in the Adriatic Sea that phytoplankton can build up extracellular polysaccharides in the photic zone of the water column and under special conditions, these polymers known as mucilage can be excreted at high levels (Svetličić *et al*. 2011). However, the formation and secretion of mucilage from the body of a phytoplankton cell into a marine ecosystem is a very complex issue, and which special environmental conditions affect its formation in a single cell is still not fully understood. Besides, the process of transforming dissolved organic matter into the particulate organic form, accordingly mucilage in the water column, is an important issue that needs to be investigated. In the Marmara Sea a remarkable mucilage event occurred in late 2007 and continued in early 2008. In those events, *Gonyaulax fragilis*, *Skeletonema costatum*, and *Cylindrotheca closterium* which were also determined in the present study were characterized as mucilage producers (Aktan *et al*. 2008; Tüfekçi *et al*. 2010; Balkis *et al.* 2011; Taş *et al*. 2016). In another study, carried out in İzmit Bay, *Prorocentrum micans* which was also identified in the present study (Table 2a) was described as mucilage producer after a red-tide event in 2015 (Ergul *et al*. 2018).

The sampling studies in April 2021 had been carried out before the public awareness of the mucilage phenomenon started in Turkey. In those days there was no news regarding the occurrence of mucilage aggregate in any local or national/international journal or newspaper. In fact, in the frame of the present study, the mucilage formation was first noticed at the Biga station (MDG25) on April 16, and then at the İzmit Bay station (MDG22) on April 17. However, the

formation was not visible in the marine water at the Fatih (MDG31) station located off the İstanbul Strait on April 9 and Riva (KDO9) station on April 8, 2021. Thus, unlike other studies, field researches for physicochemical data and phytoplankton samplings of the present study were begun before mucilage formation, in June 2020 and September 2020, respectively. Spring season samplings were also carried out before mucilage formations or early stage of the occurrence when the mucilage was not visible at the stations in the second week of April 2021 (e.g., MDG31-Fatih on April 9). By the following days of the spring sampling, the mucilage had become noticeable with the naked eye at some stations, e.g., MDG25-Biga on April 16 and MDG22-İzmit on April 17. Therefore, this study contains important results in terms of understanding in which physicochemical conditions were present at the beginning of formation and revealing which phytoplankton species may have played a role in the mucilage occurrence.

Comparison of the data of September 2020 and April 2021 samplings revealed that BAC species were dominant in both seasons during the study in the Marmara Sea and the Black Sea. However, in the Marmara Sea, while the dominance of the BAC in terms of rates in the total phytoplankton, decreased from September 2020 to April 2021 (Figures 2 and 3), the total number of taxa found at three stations decreased dramatically from 59 (i.e., 24, 23, and 12 taxa in MDG22, MDG25, and MDG31, respectively) to 28 (i.e., 8, 11, and 9 taxa in MDG22, MDG25, and MDG31, respectively) (Table 2b). This situation was also similar for the number of taxa of DIN, while its rates increased from 42% to 47% (Figures 2 and 3). Therefore, the total number of phytoplankton remarkably reduced from 101 taxa (i.e., 37, 38, and 26 taxa in MDG22, MDG25, and MDG31, respectively) to 53 taxa (i.e., 13, 19, and 21 taxa in MDG22, MDG25, and MDG31, respectively) for the sum of three stations in the Marmara Sea from September 2020 to April 2021 (Table 2b). Although to a lesser extent, there was a biodiversity decrease in terms of number of taxa in the Black Sea station (Table 2b). However, while BAC dominance decreased 81% to 69%, DIN rates increased 19% to 26% (Figures 2 and 3). Interestingly, despite the decreasing taxa, an increase in total abundance was observed at all stations (Table 1). However, this formation was noticeably larger in the stations MDG22 and MDG25 and total abundance increased from ~12000 to 42000, and ~2000 to 50000 cells/L, respectively, when compared to September 2020 and April 2021 (Table 2b). It should be noted that, unlike the other studies, the mucilage formation was seen by the naked eye for the first time at these stations in the Marmara Sea. Another remarkable point is that the chlorophyll-*a* concentration was higher at 10 m depth in April 2021, which indicates that phytoplankton communities were densely located at this depth and perhaps mucilage formation occurred in the deep waters (~10 m) than the surface (Table 3).

Table 3. Ecological status of the sea waters based on calculated TRIX values (Vollenweider *et al*. 1998), dissolved inorganic nitrogen (DIN), orthophosphate (o-PO_4^{3-}) and Chlorophyll-*a* (Chl-*a*) concentrations in the sampling stations

Station	September 2020						April 2021					
	TRIX	Ecological Quality	DIN	o-PO_4^{3-}	N/P	Chl-*a*	TRIX	Ecological Quality	DIN	o-PO_4^{3-}	N/P	Chl-*a*
			mg/L			µg/L			mg/L			µg/L
MDG22	7.89	BAD	0.012	0.0022	5.45	4.6	6.17	BAD	0.010	0.04	0.25	0.4
MDG22 -10 m	7.03	BAD	0.009	0.0017	5.29	4.1	6.01	BAD	0.012	0.04	0.3	1.4
MDG25	5.32	POOR	0.008	0.0014	5.71	0.8	7.79	BAD	0.006	0.09	0.07	1.5
MDG25 -10 m	4.23	MODERATE	0.006	0.0015	4.00	1.7	7.60	BAD	0.007	0.08	0.09	1.6
MDG31	6.85	BAD	0.018	0.0028	6.43	4.2	6.13	BAD	0.005	0.07	0.07	0.4
MDG31 -10 m	5.71	POOR	0.015	0.0028	5.36	2.3	6.13	BAD	0.006	0.05	0,12	0.5
KDO9	4.64	MODERATE	0.012	0.0010	12.0	1.1	4.55	MODERATE	0.005	0.03	0.17	0.1

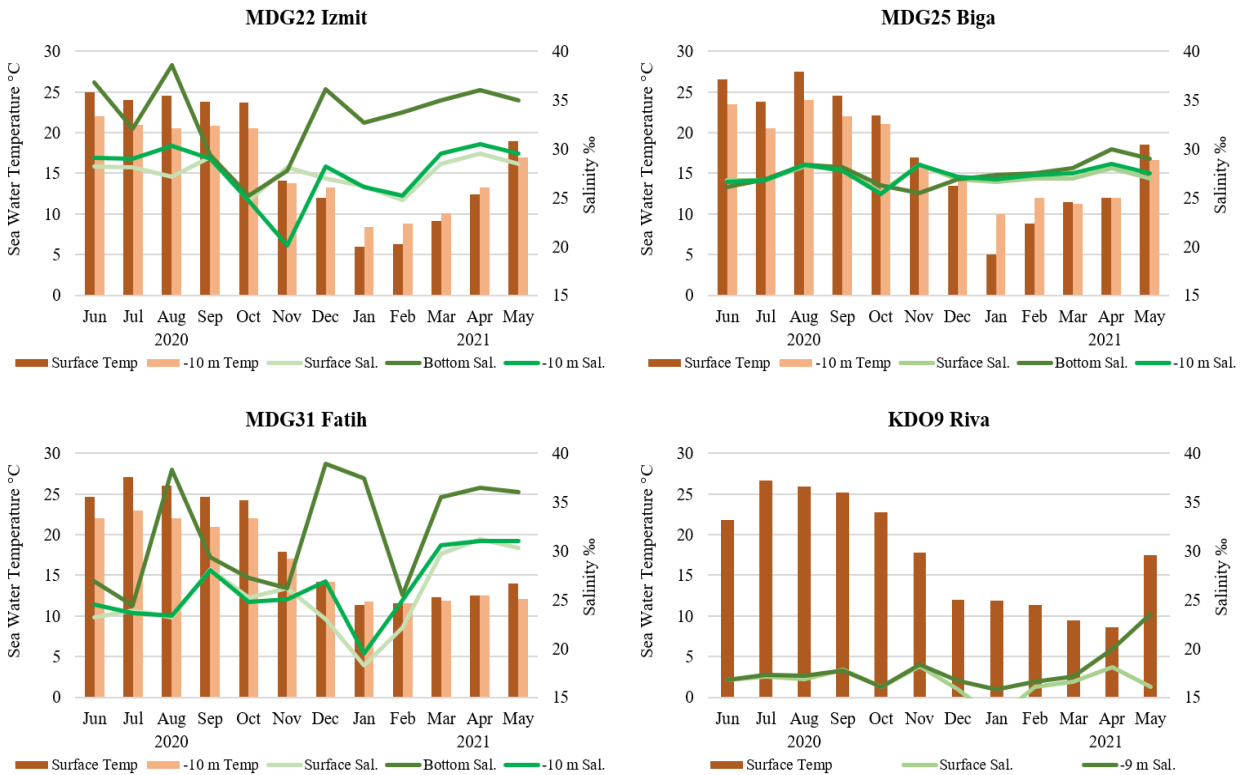

Figure 4. Seawater temperature (°C) and salinity (‰) at the sampling stations in June 2020 and May 2021

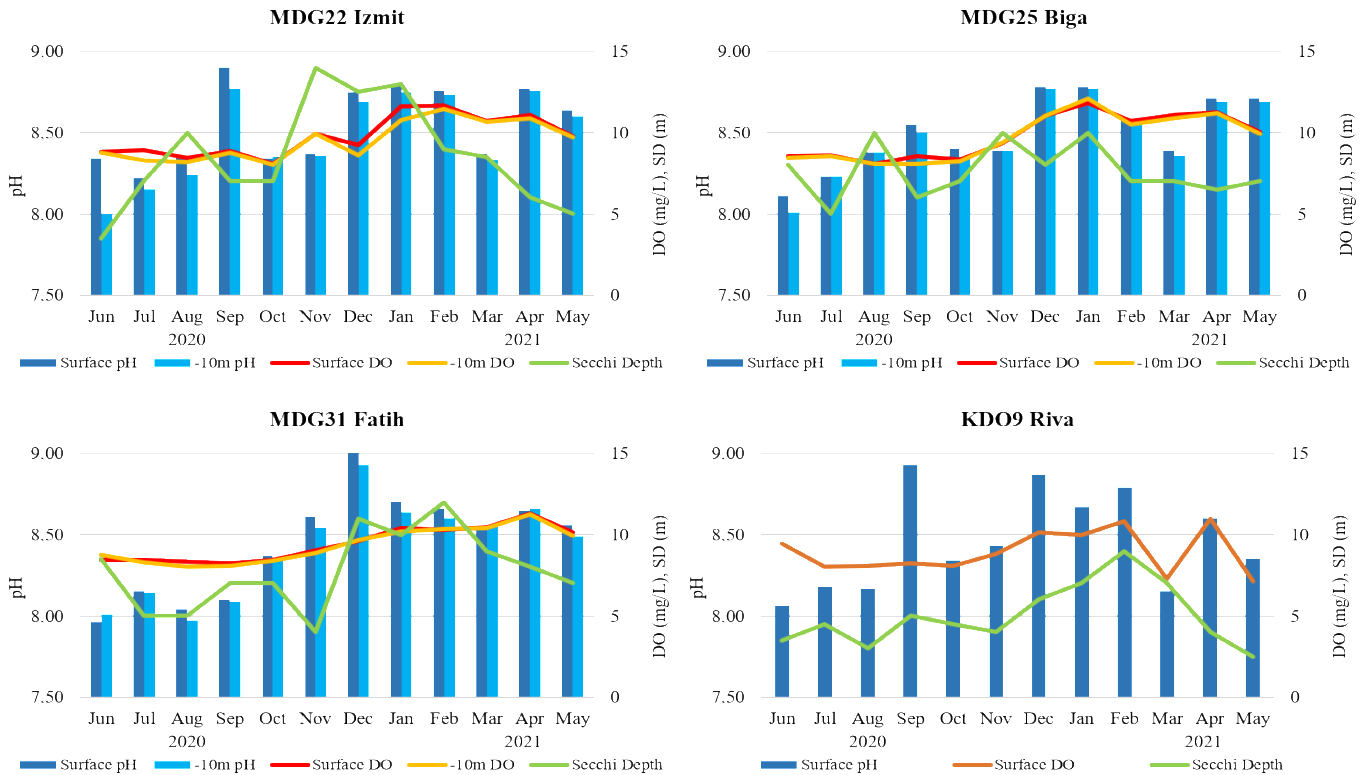

Figure 5. pH and dissolved oxygen (mg/L) levels and Secchi Depth (m) at the sampling stations in June 2020 and May 2021

Consequently, the decreasing in biodiversity, and increasing in the number of cells suggests that mucilage formation occurred in the Marmara Sea as a result of eutrophication. In fact, TRIX values, which is an index used to determine the trophic status of coastal marine ecosystems, were calculated using nitrite, nitrate, ammonia, orthophosphate, chlorophyll-*a*, and dissolved oxygen saturation data measured in the water column of the stations indicated the presence of the eutrophic conditions in the Marmara Sea, particularly in April 2021, while the trophic status remained Moderate in the Black Sea. Besides, the results showed that the ecological quality of the stations generally decreased from September 2020 to April 2021 in the Marmara Sea (Table 3).

Both the TRIX values and N/P ratios (DIN/o-PO_4^{3-}) indicated the presence of the eutrophic conditions due to the increase of the phosphate concentrations relatively in April 2021. Dissolved inorganic nitrogen (DIN= NO^-_2-N+NO^-_3-N +NH_3-N) and orthophosphate (o-PO_4^{3-}) concentrations suggest that the Redfield ratio was very low particularly during the mucilage formation in April 2021 and far from its average values (i.e., N/P=16/1) (Table 3). Therefore, these data indicated that the limiting factor for phytoplankton was nitrogen during the study and the limitation was more pronounced in April 2021 simultaneously with the mucilage formation that occurred in the Marmara Sea (Table 3). As in this case, it was also reported that nitrogen was the limiting nutrient in the mucilage formation that occurred in the Marmara Sea in 2007-2008 (Tüfekçi *et al*. 2010; Balkis *et al*. 2011; Toklu-Alicli *et al*. 2020).

Physicochemical data showed that relatively low temperatures (i.e. ~15°C) and moderate salinity levels (i.e. ~30‰) were measured during the initial stage of mucilage formation during April 2021 (Figure 3). However, at the Marmara Sea stations (i.e. MDG22, MDG25, and MDG31) slight increases in seawater salinity were observed during the spring 2021 months (Figure 4). Although not examined within the scope of the present study, it is possible that the strong winds blowing at the beginning of the spring period may disrupt the layered structure of the Marmara Sea. This increase in the salinity concentration of the upper layer waters may be related to the loss of stratification in the Marmara Sea. This process may cause the transportation of the nutrients to the upper layer, where phytoplankton is densely located, and may trigger excessive proliferation of the phytoplankton or excessive mucilage secretion. In fact, in a study conducted in İzmit Bay in 2015, it was reported that gust winds caused resuspension by removing stratification, and followingly a phytoplankton bloom and mucilage formation was observed resulting in the excessive proliferation of *Prorocentrum micans* (Ergul *et al*. 2018). Although there were occasional fluctuations in pH, Secchi depth, and DO levels, there were not anoxic conditions during the study, and the DO concentrations measured as ~11 mg/L perhaps due to atmospheric mixing caused by winds (Figure 5).

All the data obtained within the present study suggest that mucilage is a macromolecule secreted by certain phytoplankton species under favorable physicochemical and stress-induced conditions such as eutrophication. Among the 83 phytoplankton taxa identified by the present study, *Cerataulina pelagica* (Cleve) Hendey, 1937, *Cylindrotheca closterium* (Ehrenberg) Reimann & Lewin, 1964, *Pseudo-nitzschia* sp., *Skeletonema costatum* (Greville) Cleve, 1873, *Alexandrium tamarense* (Lebour) Balech, 1995, *Dinophysis acuminata* Claparede and Lachmann, 1859, *Dinophysis caudata* Kent, 1881, *Dinophysis fortii* Pavillard, 1924, *Gonyaulax fragilis* (Schütt) Kofoid, 1911, *Gonyaulax spinifera* (Claparède&Lachmann) Diesing, 1866, *Gymnodinium* sp., *Gyrodinium* sp., and *Prorocentrum micans* Ehrenberg, 1834 were distinguished as the species associated with mucilage formation in previous studies (Daniel *et al*. 1980; Ehrhardt and Burns 1993; Pistocchi *et al.* 2005; Urbani *et al.* 2005; Aktan *et al.* 2008; Tüfekçi *et al*. 2010; Balkis *et al.* 2011; Taş *et al*. 2016; Ergul *et al.* 2018). As mentioned above, *Coscinodiscus perforatus*, *Cylindrotheca closterium*, *Skeletonema costatum*, *Gonyaulax fragilis*, *Gymnodinium* sp., *Gyrodinium* sp., and *Dictyocha speculum* were frequently identified in the stations of the Marmara Sea simultaneously with the early stage of the mucilage formation in the present study. Therefore, it is thought that these species in particular may be associated with the mucilage formation in the Marmara Sea and these data may provide basic knowledge for future studies. However, while *Phaeocystis pouchetii* known as a mucilage producer organism was reported in mucilage aggregates formed in the Marmara Sea in May 2021 (Balkis-Ozdelice *et al.* 2021), this species was not observed, in the mid of April 2021, in the present study.

Finally, it is thought that it would be useful to establish permanent monitoring stations to follow changes in the ecosystem in order to take duly and effective measures in unexpected ecological events, such as the intense mucilage formation encountered in the Marmara Sea. Therefore, monitoring stations where certain oceanographic and physicochemical parameters are constantly measured should be established throughout the Marmara Sea.

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Marmara Denizi'nde ilkbahar 2021'de görülen deniz salyası oluşumunun erken aşaması

Öz

Bu çalışmada, Marmara Denizi'nde bulunan İzmit-Kocaeli, Fatih-İstanbul, Biga-Çanakkale ve Karadeniz'de Riva-İstanbul açıklarında bulunan dört istasyondan toplanan

deniz suyu örneklerinde deniz salyası (müsilaj) oluşumu ile ilişkili fitoplankton kompozisyonu ve eşlik eden fizikokimyasal koşullar araştırıldı. Örneklemeler, 2021 yılının ilkbahar ve yaz aylarında Marmara Denizi'nde gözlenen yoğun oluşumlarının öncesinde, Eylül 2020'de ve Nisan 2021'de, müsilaj oluşumunun başlangıç aşamasında yapıldı. Deniz suyu sıcaklığı, tuzluluk, pH ve çözünmüş oksijen seviyeleri sahada ölçüldü. İnorganik azot, ortofosfat ve klorofil-*a* derişimleri spektrofotometrik olarak analiz edildi. Çalışma sırasında toplam 83 fitoplankton türü (44 Bacillariophyceae-BAC, 36 Dinophyceae-DIN, 2 Dictyochophyceae-DIC ve 1 Chlorophyceae-CHL) teşhis edildi. BAC türleri genel olarak baskındı. Tespit edilen 83 fitoplankton taksonu arasında müsilaj oluşumu ile ilişkili türler olarak bilinen, *Cerataulina pelagica, Cylindrotheca closterium, Pseudo-nitzschia* sp., *Skeletonema costatum, Thalassiosira rotula, Alexandrium tamarense, Dinophysis acuminata, Dinophysis caudata, Dinophysis fortii, Gonyaulax fragilis, Gonyaulax spinifera, Gymnodinium* sp., *Gyrodinium* sp., ve *Prorocentrum micans* 'a rastlandı. En fazla tür Eylül 2020'de 38 takson ile Biga-Çanakkale istasyonunda (MDG25) tespit edildi. *Skeletonema costatum* 11200 hücre/L ile Nisan 2021'de İzmit-Kocaeli istasyonunda (MDG22) 10 m derinlikte en çok bulunan tür oldu. Nisan 2021'de MDG22 ve MDG25 istasyonlarındaki müsilaj oluşumları, deniz suyu sıcaklığı 15 °C'nin altında ve tuzluluk 30 civarında iken, başlangıç aşamasında tül perde şeklinde gözlendi. BAC'nin toplam fitoplanktondaki takson hakimiyeti Eylül'de Nisan'da %56 ile aynı oranda kalırken, Marmara Denizi'nde tür sayısı önemli ölçüde azaldı ve 59'dan 28'e düştü. Azalan biyoçeşitliliğe rağmen, özellikle MDG22 ve MDG25'te örnekleme istasyonlarında toplam bolluk arttı. Her iki istasyonda da toplam bolluk Eylül 2020 ve Nisan 2021 ile karşılaştırıldığında sırasıyla yaklaşık 12000'den 42000'e ve 2000'den 50000 hücre/L'ye yükseldi. Biyolojik çeşitlilikteki azalma ve hücre sayısındaki artışla birlikte ötrofikasyon ve bunun sonucunda Marmara Denizi'nde müsilaj oluşumu gözlendi. TRIX değerleri, ötrofik koşulların arttığını, bölgedeki ekolojik kalitenin Eylül 2020'den Nisan 2021'e kadar genel olarak düştüğünü ve Marmara Denizi'ndeki tüm istasyonlar için Kötü olduğuna işaret etti. Çalışma kapsamında elde edilen veriler, Nisan 2021'de Marmara Denizi'ndeki müsilaj oluşumuyla eş zamanlı olarak fitoplankton için sınırlayıcı faktörün azot olduğunu gösterdi.

Anahtar kelimeler: Müsilaj, deniz salyası, fitoplankton, Marmara Denizi, besleyici element, *Cylindrotheca closterium, Skeletonema costatum*

References

Aktan, Y., Dede, A., Ciftci, P.S. (2008) Mucilage event associated with diatoms and dinoflagellates in Sea of Marmara, Turkey. *Harmful Algae News* 36: 1-3.

Balkis, N., Atabay, H., Turetgen, I., Albayrak, S., Balkis, H., Tüfekçi, V. (2011) Role of single-celled organisms in mucilage formation on the shores of Buyukada Island (the Sea of Marmara). *J Mar Biol Assoc UK* 91: 771-781.

Balkis, N., Sivri, N., Fraim, N.L., Balci, M., Durmus, T., Sukatar, A. (2013) Excessive growth of *Cladophora laetevirens* (Dillwyn) Kutzing and enteric bacteria in mats in the Southwestern Istanbul coast, Sea of Marmara. *IUFS J Biol* 72(2): 43-50.

Balkis-Ozdelice, N., Durmus, T., Balci, M. (2021) A preliminary study on the ıntense pelagic and benthic mucilage phenomenon observed in the Sea of Marmara. *Int Journal of Environment and Geoinformatics* 8(4): 414-422.

Bendschneider, K., Robinson, R.J. (1952) A new spectrophotometric method for the determination of nitrite in sea water. *J Mar Res* 11: 87-96.
Besiktepe, S., Sur, H., Özsoy, E., Latif, M., Oguz, T., Ünlüata, Ü. (1994) The circulation and hydrography of the Marmara Sea. *Prog Oceanogr* 34: 285-334.

Bianchi, G. (1746) Jani Planci Ariminensis De Mola pisce ad Josephum Montium bononiensem. *De Bononiensi Scientiarum Et Artium Instituto Atque Academia Commentarii* 2: 297-303.

Chin, W., Orellana, M.V., Verdugo, P. (1998) Spontaneous assembly of marine dissolved organic matter into polymer gels. *Nature* 391: 568-572.

Daniel, G.F., Chamberlain, A.H.L., Jones, E.B.G. (1980) Ultrastructural observations on the marine fouling diatom *Amphora*. *Helgoländer Meeresunters* 34: 123-149.

Ehrhardt, G.M., Burns, K.A. (1993) Hydrocarbons and related photo-oxidation products in Saudi Arabian Gulf coastal waters and hydrocarbons in underlying sediments and bioindicator bivalves. *Mar Poll Bull* 27: 187-197.

Ergul, H.A. (2016) Evaluation of seasonal physicochemical conditions and chlorophyll-a concentrations in İzmit Bay, Marmara Sea. *Journal of the Black Sea/Medit Environ* 22: 201-217.

Ergul, H.A., Aksan, S., İpşiroğlu, M. (2018) Assessment of the consecutive harmful dinoflagellate blooms during 2015 in the İzmit Bay (the Marmara Sea). *Acta Oceanol Sin* 37: 91-101.

Ergul, H.A., Aksan, S., İpşiroğlu-Koral, M., Baysal, A. (2014) Assessment of consecutive plankton blooms on March and April 2014 in İzmit Bay (The Marmara Sea). *Hydromedit* 1: 127-131.

Ergul, H.A., Çelebi, N.G., İpşiroğlu-Koral, M. (2013) A study on plankton proliferation in İzmit Bay (March 2013). In: 17. Ulusal Su Ürünleri Sempoyumu, İstanbul 1: 74 (in Turkish).

Ergul, H.A., Küçük, A., Terzi, M. (2010) A research on an algae bloom in İzmit Bay. In: Proceedings of the Symposium “the Marmara Sea 2010” (ed., Öztürk, B.), Turkish Marine Research Foundation, Publication no: 32, İstanbul, Turkey, pp. 464-468 (in Turkish).

Giuliani, S., Lamberti, C.V., Sonni, C., Pellegrini, D. (2005) Mucilage impact on gorgonians in the Tyrrhenian Sea. *Sci Total Env* 353: 340-349.

Küçük, A., Ergul, H.A. (2011) Seasonal variations of microplankton composition in İzmit Bay (Sea of Marmara). *J Black Sea/Medit Environ* 17: 216-222.

Lorenti, M., Buia, M.C., Martino, V., Modigh, M. (2005) Occurrence of mucous aggregates and their impact on *Posidonia oceanica* beds. *Sci Total Env* 353: 369-379.

Mullin, J.B., Riley, J.P. (1955) The colorimetric determination of silicate with special reference to sea and natural waters. *Anal Chim Acta* 12: 162-176.

Murphy, J., Riley, J.P. (1962) A modified single solution method for the determination of phosphate in natural-waters. *Anal Chim Acta* 27: 31-36.

Özalp, H.B. (2021) First massive mucilage event observed in deep waters of Çanakkale Strait (Dardanelles), Turkey. *J Black Sea/Medit Environ* 27(1): 49-66.

Piazzi, L., Atzori, F., Cadoni, N., Cinti, M.F., Frau, F., Ceccherelli, G. (2018) Benthic mucilage blooms threaten coralligenous reefs. *Mar Environ Res* 140: 145-151.

Pistocchi, R., Cangini, M., Totti, C., Urbani, R., Guerrini, F., Romagnoli, T., Sist, P., Palamidesi, S., Boni, L., Pompei, M. (2005) Relevance of the dinoflagellate *Gonyaulax fragilis* in mucilage formations of the Adriatic Sea. *Sci Total Env* 353(1-3): 307-316.

Ricci, F., Penna, N., Capellaci, S., Penna, A. (2014) Potential environmental factors influencing mucilage formation in the northern Adriatic Sea. *Chem Ecol* 30(4): 364-375.

Rinaldi, A., Vollenweider, R.A., Montanaria, G., Ferraria, C.R., Ghetti, A. (1995) Mucilages in Italian seas: the Adriatic and Tyrrhenian Seas, 1988-1991. *Sci Total Env* 165: 165-183.

Schiaparelli, S., Castellano, M., Povero, P., Sartoni, G., Vietti, R.C. (2007) A benthic mucilage event in North-Western Mediterranean Sea and its possible relationships with the summer 2003 European heatwave: short term effects on littoral rocky assemblages. *Mar Ecol* 28(3): 341-353.

Svetličić, V., Žutić, V., Radić, T.M., Pletikapić, G., Zimmermann, A.H., Urbani, R. (2011) Polymer networks produced by marine diatoms in the Northern Adriatic Sea. *Marine Drugs* 9: 666-679.

Taş, S., Ergul, H.A., Balkis, N. (2016) Harmful algal blooms (HABs) and mucilage formations in the Sea of Marmara. In: The Sea of Marmara Marine Biodiversity, Fisheries, Conservation and Governance, (eds., Özsoy, E., Çağatay, M.N., Balkis, N., Balkıs, N., Öztürk, B.), Turkish Marine Research Foundation, Publication No: 42, Turkey, pp. 768-786.

Tas, S., Kus, D., Yilmaz, I.N. (2020) Temporal variations in phytoplankton composition in the north-eastern Sea of Marmara: potentially toxic species and mucilage event. *Mediterranean Marine Science* 21: 668-683.

Toklu-Alicli, B., Polat, S., Balkis-Ozdelice, N. (2020) Temporal variations in the abundance of picoplanktonic *Synechococcus* (Cyanobacteria) during a mucilage event in the Gulfs of Bandırma and Erdek. *Estuar Coast Shelf Sci* 233: 1-12.

Tüfekçi, V., Balkis, N., Beken, C.P., Ediger, D., Mantıkçı, M. (2010) Phytoplankton composition and environmental conditions of a mucilage event in the Sea of Marmara. *Turk J Biol* 34: 199-210.

TUIK (2018) Municipality Wastewater Statistics, 2018. Available at: https://biruni.tuik.gov.tr/medas/?kn=120&locale=tr (accessed 14 Aug 2021)

Turk, V., Hagström, A., Kova, N., Faganeli, J. (2010) Composition and function of mucilage macroaggregates in the northern Adriatic. *Aquat Microb Ecol* 61(3): 279-289.

Umani, S.F., Ghirardelli, E., Specchi, M. (1989) Gli episodi di" mare sporco" nell'Adriatico dal 1729 ai giorni nostri. Regione Autonoma Friuli Venezia Giulia. Direzione Regionale dell'Ambiente, 178 pp.

Urbani, R., Magaletti, E., Sist, P., Cicero, A.M. (2005) Extracellular carbohydrates released by the marine diatoms *Cylindrotheca closterium*, *Thalassiosira pseudonana* and *Skeletonema costatum*: Effect of P-depletion and growth status. *Sci Total Env* 353: 300-306

Vollenweider, R.A., Giovanardi, F., Montanari, G., Rinaldi, A. (1998) Characterization of the trophic conditions of marine coastal waters, with special reference to the NW Adriatic Sea: proposal for a trophic scale, turbidity and generalized water quality index. *Environmetrics* 9(3): 329-357.

Zingone, A., Escalera, L., Aligizaki, K., Tejedor, M.F., Ismael, A., Montresor, M., Mozetic, P., Taş, S., Totti, C. (2021) Toxic marine microalgae and noxious blooms in the Mediterranean Sea: A contribution to the Global HAB Status Report. *Harmful Algae* 102(1): 101843.