Journal of the Marine Biological Association of the United Kingdom

cambridge.org/mbi

Determination of seasonal changes in phytoplankton community of the coastal waters of Burgaz Island (the Sea of Marmara)

Yorgo Kayadelen[1], Neslihan Balkis-Ozdelice[2] and Turgay Durmus[2]

[1]Institute of Science, Istanbul University, 34134 Vezneciler, Istanbul, Türkiye and [2]Faculty of Science, Department of Biology, Section of Hydrobiology, Istanbul University, 34134 Vezneciler, Istanbul, Türkiye

Research Article

Cite this article: Kayadelen Y, Balkis-Ozdelice N, Durmus T (2022). Determination of seasonal changes in phytoplankton community of the coastal waters of Burgaz Island (the Sea of Marmara). *Journal of the Marine Biological Association of the United Kingdom* **102**, 214–226. https://doi.org/10.1017/S0025315422000406

Received: 21 September 2021
Revised: 20 May 2022
Accepted: 30 May 2022
First published online: 6 July 2022

Key words:
Abundance; Burgaz Island; ecological variables; phytoplankton; Sea of Marmara

Author for correspondence:
Neslihan Balkis-Ozdelice,
E-mail: neslbalk@istanbul.edu.tr

Abstract

The aim of this study is to determine the phytoplankton species found on the shores of Burgaz Island and the basic ecological variables that affect their seasonal distribution between May 2013 and February 2014. Water samples were collected from four stations at six different depths and plankton samples were gathered horizontally and vertically. The analysis of phytoplankton community composition revealed 101 phytoplankton taxa belonging to five classes. As a result of the study, two taxa belonging to the Dinophyceae (*Corythodinium frenguellii* and *Gonyaulax scrippsae*) were new records for Turkish coastal waters. Additionally, a taxon belonging to Dinophyceae (*Pronoctiluca pelagica*) and a taxon belonging to Bacillariophyceae (*Nitzschia reversa*) were new records for the Sea of Marmara. *Prorocentrum micans*, was the dominant species throughout all sampling periods. During the study, the highest phytoplankton abundance was observed at 0.5 m depth in May 2013 (138,500 cells l^{-1}) and February 2014 (52,620 cells l^{-1}). Primary ecological variables, such as temperature (9.0–21.5 °C), salinity (15.23–37.22‰) and dissolved oxygen (4.89–15.84 mg l^{-1}), were recorded on each sampling occasion. In addition, nitrite + nitrate–N ($NO_2 + NO_3$–N) (0.01–7.37 µg-at N l^{-1}), phosphate (PO_4–P) (0.05–51.95 µg-at P l^{-1}) and silicate (SiO_4–Si) (0.01–0.20 µg-at Si l^{-1}) concentrations were measured. Chlorophyll *a* and suspended material values ranged between 0.01–3.17 µg l^{-1} and 10.0–61.5 mg l^{-1}, respectively. Spearman's rank correlation was used to determine the relationship between phytoplankton species and ecological variables, and Bray–Curtis analysis and Euclidean distance were applied to bring out the similarity between stations.

Introduction

In order to learn about the ecological status of a region, it is necessary to know the ecological variables that affect the species composition and distribution of phytoplankton, which have the ability to reflect changes in the ecosystem very quickly (Balkis, 2003). For this purpose, although the first research on plankton was related to the determination and systematics of the species, today the number of ecological studies that reveal their relationship with productivity in the sea has increased. In addition, studies on the reproduction of species and cyst distribution in the sediment were carried out in Türkiye (Aydın *et al*., 2015; Balkis *et al*., 2016).

The Sea of Marmara, which is divided into three sub-basins, each deeper than 1000 m in the east-west direction from the topographical direction, is a semi-closed inland sea between the Mediterranean and the Black Sea, with a surface area of 11,500 km^2 and a maximum depth of 1390 m. Connected to the Black Sea by the Bosphorus and to the Aegean Sea by the Dardanelles, the Sea of Marmara is a transition zone from the Mediterranean to the Black Sea. This feature causes both sea traffic to be intense and for it to have two water layers with different salinities. These waters with different salinities reaching the Sea of Marmara form an intermediate salinity layer at a depth of ∼25 m due to their different densities, and dissolved oxygen-rich surface waters are largely prevented from mixing with the lower layer. The upper layer water with low salinity that comes from the Black Sea increases both the amount of organic matter and the pollution in the Sea of Marmara. Bottom layer water with high salinity contains low oxygen as a result of the decomposition of biogenic particles coming from the upper layer. The oceanographic conditions in this sea are controlled by the two straits (Yüce, 1988; Yüce & Türker, 1991; Beşiktepe *et al*., 1994, 2000). In this environment where oxygen intake from the surface is prevented and oxygen consumption increases in the lower layer, the oxygen level is regulated by the Mediterranean water content which has high salinity and rich oxygen level (Beşiktepe *et al*., 2000). In the Sea of Marmara, which has a two-layered water system, vertical mixing is limited. As a result, the dissolved oxygen content of the lower layer water decreases from the Dardanelles to the Bosphorus. Although the surface water in the upper layer is saturated with oxygen, it varies according to the water temperature and season.

As a result of industrial development and the population increase that follows, the discharge of domestic and industrial wastes to the Sea of Marmara, the rapid increase in agricultural activities, industrial activities, tourism, fishing and sea transportation are the elements

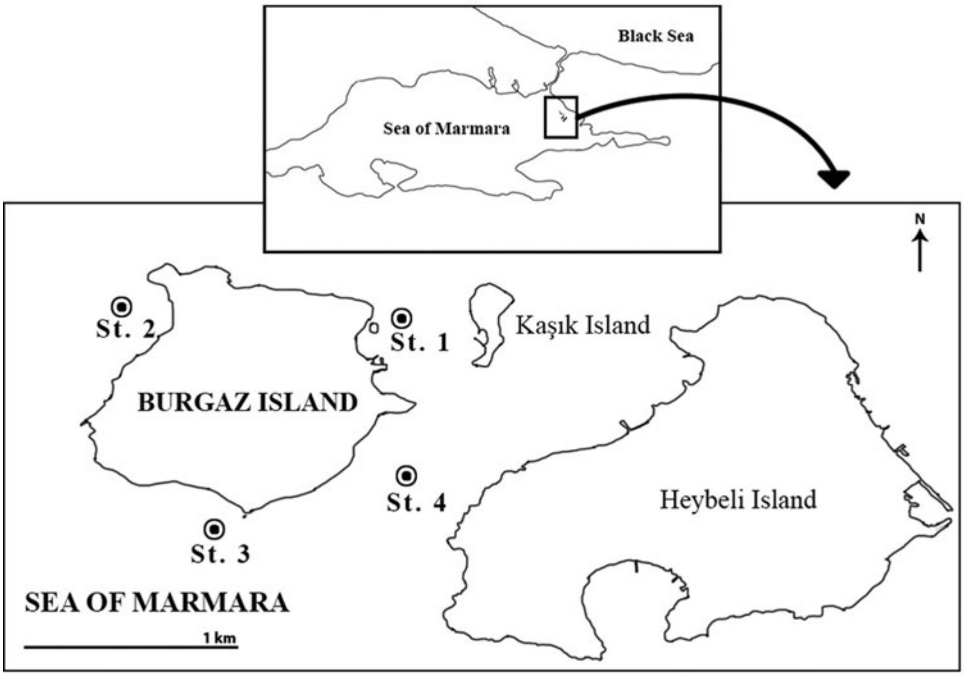

Fig. 1. Study area and sampling stations of Burgaz Island.

that threaten marine life. In developing countries such as Türkiye 90% of household waste and 70% of industrial wastes are discharged into coastal areas without applying any treatment (Creel, 2003; United Nations World Water Assessment Programme, 2018). The pollution load into the Sea of Marmara from Istanbul is also high (Öztürk *et al*., 2021). Marine ecosystems can tolerate wastes with a certain load and eliminate these wastes after a while. In semi-closed seas such as the Sea of Marmara, these wastewater discharges increase the pollutant load and this may cause eutrophication. Suitable environmental conditions with increased nutrients can lead to phytoplankton blooms. Among the species in the phytoplankton community, those that adapt best to the environment can become dominant and multiply enough to change the colour of the seawater and create the phenomenon called red-tide. Continuity of the excessive increase in organic load in the water column may cause the accumulation of organic matter in the sediment, and the decomposition of this organic matter can create an anoxic environment in the bottom waters and negatively affect benthic life.

Despite being a small inland sea, the Sea of Marmara has many islands of all sizes. The island community consisting of nine islands and two cliffs, called the Prince Islands, is located in the north-east of the Sea of Marmara, very close to Istanbul. From the upper layer current entering the Sea of Marmara through the Bosphorus, the eastern current extending to the south and the Gulf of Izmit is formed and this flow affects the region that includes the Prince Islands. Due to the large volume of the Sea of Marmara and the long hydraulic residence time of the water in this sea, pollutants can stay in this environment for a long time and pose serious dangers in terms of the ecosystem, especially when considering pollutants with a bioaccumulation character (Taşdemir, 2002).

Burgaz Island, where the study was carried out, is the third largest island of the Prince Islands with a surface area of 1.5 km^2 and a coastline of 5.7 km. Since there is no comprehensive study on current phytoplankton communities and their relationships with ecological variables at Burgaz Island, the main purpose of this study is to define phytoplankton species and their abundance and determine the ecological variables that affect the distribution of these species around the island.

Materials and methods

Samples were collected seasonally at four stations selected around the island's periphery (Figure 1) from six different depths (0.5, 5, 10, 15, 20 and 30 m) between May 2013 and February 2014 by a fishing boat. During the sampling periods, all samples were collected on the same day. A 3-litre Ruttner water sampler with a thermometer was used for water analyses. The salinity of the seawater was determined by the Mohr–Knudsen method (Ivanoff, 1972) and the amount of the dissolved oxygen in the seawater by the Winkler method (Winkler, 1888). For the nutrient samples, samples were collected in polyethylene bottles with a volume of 100 ml and frozen in a deep freezer at −20 °C. Nitrite + nitrate–N ($NO_2 + NO_3$–N) samples were analysed by a Bran + Luebbe AA3 auto analyser (APHA, 1999), phosphate-P (PO_4–P) and silicate-Si (SiO_4–Si) analyses were detected by the methods described by Parsons *et al.* (1984). To determine the chlorophyll *a* concentration in the seawater, samples were taken with polyethylene bottles with a volume of 1-litre and filtered onto membrane filters (pore size: 0.45 μm), then analyses were carried out using the acetone extraction method according to Parsons *et al.* (1984). Suspended solid materials (SSM) of water samples were calculated according to the gravimetric 2540-D standard method (APHA, 1999).

Samples for phytoplankton identification were collected horizontally (the speed of the boat was 1–2 miles per hour for 10 min in each station) and vertically (30 m depth to surface) from the water column by using plankton nets with a mesh size of 40 μm and immediately fixed by the addition of borax-buffered formaldehyde solution (2–4%). In order to determine phytoplankton abundance, seawater samples taken from 0.5, 15 and 30 m depths in 1-litre polyethylene dark bottles were preserved with acidified Lugol's iodine solution (Throndsen, 1978). After sample sedimentation, excess water in the upper part was removed and concentrated to 100 ml, then to 10 ml (Sukhanova, 1978) and 1 ml of the concentrated samples were counted.

https://doi.org/10.1017/S0025315422000406 Published online by Cambridge University Press

Phytoplankton enumeration was carried out in a Sedgewick–Rafter counting chamber of 1000 squares of 1 ml, 20 × 50 mm in size (Semina, 1978) under an 'Olympus CK2' model phase-contrast inverted microscope.

MarBEF data system, World Register of Marine Species (WoRMS) and sources mentioned by Balkis (2003) were used for the identification, systematics and current nomenclature of the detected species. The relation between the species and cell numbers of phytoplankton and the ecological variables were evaluated using Spearman's rank correlation coefficient in SPSS 17.0 software (Siegel, 1956). The similarity between sampling stations in terms of the species abundance was calculated using the Bray–Curtis similarity index in Primer v6 software, based on [log (*x* + 1)] transformation (Clarke & Warwick, 2001). Euclidean distance was used for the similarity between the stations in terms of environmental variables (Clarke & Warwick, 2001). In addition, species diversity was estimated using Shannon–Weaver diversity index (Zar, 1984).

Results

Ecological variables

During sampling periods, water temperature ranged from 9.0 °C (February 2014) to 21.5 °C (August 2013) (Table 1, Figure 2). In the samples of May and August 2013, it was determined that the temperature values of the upper layer water of Black Sea origin were higher than the water temperature values at 20–30 m depths. In November and February sampling, higher temperature values were reached at 30 m depth where Mediterranean-origin waters were dominant. In the study, salinity values varied between 15.2‰ (August 2013) and 37.2‰ (November 2013) and the highest value was measured at 30 m depth where Mediterranean water was dominant (Table 1, Figure 2). Dissolved oxygen values in water began to decrease especially at a depth of 20 m and varied between 4.89 mg l^{-1} (May 2013) and 15.84 mg l^{-1} (August 2013) (Table 1, Figure 2).

Among the nutrients, $NO_2 + NO_3$–N values ranged between 0.01–7.37 µg at N l^{-1}, the amount of PO_4–P between 0.05–51.95 µg at P l^{-1}, the amount of SiO_4–Si between 0.01–0.20 µg at Si l^{-1}. All through the study, the values in the bottom water were higher than the surface layer (Table 1, Figure 2). Especially in May 2013, very high phosphate-P values were obtained at 10 and 15 m depths of station 2. The suspended solid material (SSM) values of the water were between 10.0–61.5 mg l^{-1} in the study, the lowest value was obtained in August 2013 and the highest value was obtained in May 2013 (Table 1, Figure 2). While chlorophyll *a* values were measured between 0.01–3.17 µg l^{-1}, they showed a decreasing trend from the surface to a depth of 30 m throughout the study.

Phytoplankton species diversity and abundance

From the analysis of phytoplankton community composition in the Burgaz Island, 101 taxa of five different algal groups were identified: 49 dinoflagellates (48.5%), 47 diatoms (46.5%), three dictyochophyceans (3%), 1 pyramimonadacean (1%) and 1 (1%) cyanophycean (Table 2). Two dinoflagellate species (*Corythodinium frenguellii* and *Gonyaulax scrippsae*) were new records for the Turkish seas and two species (*Pronoctiluca pelagica* from dinoflagellates and *Nitzschia reversa* from diatoms) for the Sea of Marmara. The highest number of species was obtained in May (64 taxa) and August 2013 (66 taxa) representing the warm period. While 33 of 101 taxa obtained were encountered in all seasons, 31 of them were found only in the single sampling period. Dinoflagellates were the most common group in all sampling periods in terms of number of species.

The cell numbers of phytoplankton species detected in the water column of the stations were determined and are presented in Figure 3. In the May 2013 sampling period, the highest number of cells (138,500 cells l^{-1}) was obtained at 0.5 m depth in station 3 and the lowest cell number (4460 cells l^{-1}) was obtained at 30 m depth in station 4. Dinoflagellates were dominant at all stations and depths, and the most dominant species was *Prorocentrum micans*. During the sampling period of August 2013, the highest cell number (1930 cells l^{-1}) was obtained at 15 m depth at station 1, while the lowest cell number (120 cells l^{-1}) was obtained at 30 m depth at the same station. It is noteworthy that diatoms decreased in terms of species and cell number with the increase in temperature during this period.

During the November 2013 sampling period, the highest cell number (7060 cells l^{-1}) was determined at 15 m depth at station 3, and the lowest cell number (270 cells l^{-1}) at station 4 at 30 m depth. While *Prorocentrum micans* was determined as the species with the highest number of cells at all stations and depths, an increase was observed in the cell numbers of *Tripos furca* and *Tripos fusus*. In February 2014, the last sampling period of the study, the highest cell number (52,620 cells l^{-1}) was determined at 0.5 m depth in station 4, and the lowest cell number (450 cells l^{-1}) was determined at 30 m depth in station 1. *Prorocentrum micans* was the dominant species with the highest cell number (47,870 cells l^{-1}, Station 4, 0.5 m). It was also observed that *T. fusus* and *T. furca* increased in abundance. As can be seen, the highest abundance in the study was obtained in May 2013 and February 2014 sampling periods and *P. micans* was the most abundant species that played a role in this increase.

Statistical data

In order to reveal the relationship between phytoplankton species and cell numbers obtained from four stations and six different depth points in the coastal waters of Burgaz Island and the ecological variables, Spearman's rank correlation method was used (Table 3). It was observed that $NO_2 + NO_3$–N and SiO_4–Si values of nutrients decreased with increasing temperature and increased with increasing salinity and depth ($P < 0.01$). In the examination it was determined that phytoplankton abundance increased with the increase of PO_4–P in the seawater, while it was found to have a negative relation with SiO_4–Si. It was determined as the depth increased, salinity and SSM amount increased, whereas chl *a* concentration decreased ($P < 0.01$). The concentration of chl *a* decreased with the amount of light and consequently, the total phytoplankton abundance decreased as the depth increased ($P < 0.01$). It is also notable that the concentration of dissolved oxygen increases ($P < 0.01$) with the increase of chl *a* concentration. In addition, the concentration of dissolved oxygen showed a decrease ($P < 0.01$) as the amount of salinity increased with the increase in depth. In the study, it was determined that there was a negative relationship between the amount of SSM, total phytoplankton abundance and chl *a* concentration.

Taking into account ~80% similarity, the Bray–Curtis similarity index which was applied to determine similarities in terms of species number and abundance between stations, it was observed that species especially from dinoflagellates such as *Prorocentrum micans* and *Tripos fusus*, increased similarity at depths and stations with similar abundances in August, November and February, excluding May. In August, station 1/0.5 m and station 3/30 m (77%), station 3/0.5 m and station 3/15 m (81%) in November, station 4/15 m and station 4/30 m (79%) in February were the most similar stations. In May, it was determined that all stations and depths, except 30 m depth, were similar over 80%. Within 30 m depths, station 1/30 m was separated from 30 m depths of other stations due to the lower abundance belonging to the species in August and

Table 1. The minimum and maximum values of ecological variables in Burgaz Island during the sampling periods

Seasons	Depths (m)	Temperature (°C)		Salinity (‰)		Dissolved Oxygen (mg l^{-1})		Nitrate + Nitrite–N (µg–at l^{-1})		Phosphate–P (µg–at l^{-1})		Silicate–Si (µg–at l^{-1})		Chlorophyll *a* (µg l^{-1})		Suspended Solid Matters (mg l^{-1})	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
May 2013	0.5	20.0	21.0	18.4	19.1	8.07	12.15	0.08	1.55	0.53	2.05	0.01	0.02	0.71	2.41	19.1	21.2
	5	20.0	21.0	18.4	19.2	7.66	12.10	0.07	1.61	0.42	1.32	0.01	0.02	0.37	1.17	22.0	23.0
	10	17.0	20.0	19.3	21.2	6.72	11.35	0.08	1.72	0.42	51.95	0.01	0.04	0.59	0.81	18.0	20.0
	15	14.0	19.8	19.5	21.3	8.43	11.92	0.19	0.61	0.42	35.11	0.01	0.03	0.13	0.58	23.4	26.0
	20	11.0	14.0	22.2	22.9	7.82	11.02	0.22	0.80	0.79	10.79	0.01	0.03	0.02	0.47	20.0	28.0
	30	11.0	15.0	21.6	30.8	4.89	9.67	0.81	6.57	0.89	1.58	0.03	0.15	0.01	0.93	37.6	61.5
August 2013	0.5	20.0	21.5	15.2	16.0	10.23	15.84	0.01	1.06	0.16	0.16	0.01	0.02	1.03	1.70	17.0	21.2
	5	19.0	21.5	15.6	16.3	8.95	13.27	0.01	0.21	0.16	0.21	0.01	0.02	0.10	1.03	22.0	24.0
	10	19.0	20.5	16.6	17.5	9.40	14.12	0.01	0.40	0.21	11.53	0.01	0.03	0.46	1.15	10.0	26.0
	15	16.0	17.0	18.9	20.4	9.29	13.95	0.06	0.41	0.11	0.21	0.01	0.18	0.36	1.26	20.6	35.2
	20	14.0	15.0	20.2	23.0	4.99	10.36	0.01	0.50	0.16	10.84	0.04	0.07	0.58	1.02	23.0	29.0
	30	14.0	15.0	22.2	28.6	5.15	9.21	1.15	6.34	0.21	0.89	0.08	0.15	0.12	1.37	35.4	40.6
November 2013	0.5	12.0	14.0	22.2	23.7	8.75	11.34	1.07	2.30	0.05	0.43	0.01	0.04	0.24	0.80	17.6	21.0
	5	12.0	14.0	20.8	24.2	9.90	11.13	1.51	2.31	0.05	0.05	0.01	0.03	0.37	0.80	19.0	23.0
	10	13.0	14.0	23.0	24.9	9.63	10.60	1.40	2.55	0.05	0.16	0.01	0.05	0.46	0.90	17.0	22.0
	15	15.0	15.0	26.1	28.3	8.92	9.90	2.64	4.65	0.05	0.21	0.03	0.20	0.58	0.92	20.6	27.0
	20	15.0	16.0	28.9	30.2	6.68	8.77	0.92	3.28	0.05	0.16	0.04	0.15	0.58	0.92	19.0	24.0
	30	16.0	17.0	34.4	37.2	6.15	7.58	1.96	5.74	0.05	0.21	0.05	0.14	0.02	0.80	29.4	38.8
February 2014	0.5	9.0	9.5	19.5	22.1	8.64	11.91	2.46	3.60	0.11	1.39	0.03	0.08	1.12	3.17	14.2	19.8
	5	9.0	9.5	21.2	23.0	8.27	10.66	2.83	5.71	0.16	1.93	0.04	0.05	1.25	2.72	22.0	23.0
	10	9.5	10.0	22.8	24.1	7.54	10.25	2.26	4.20	0.05	2.68	0.02	0.05	1.58	1.92	19.0	20.0
	15	10.0	10.0	23.6	28.1	9.38	9.70	2.02	6.89	0.05	1.34	0.03	0.09	1.59	1.70	18.6	24.6
	20	10.0	10.5	26.4	28.1	6.86	9.93	1.80	4.81	0.05	1.12	0.03	0.10	1.12	2.48	22.0	29.0
	30	11.0	15.0	29.7	33.4	5.49	9.17	3.77	7.37	0.11	1.98	0.08	0.16	0.46	1.02	23.6	30.6

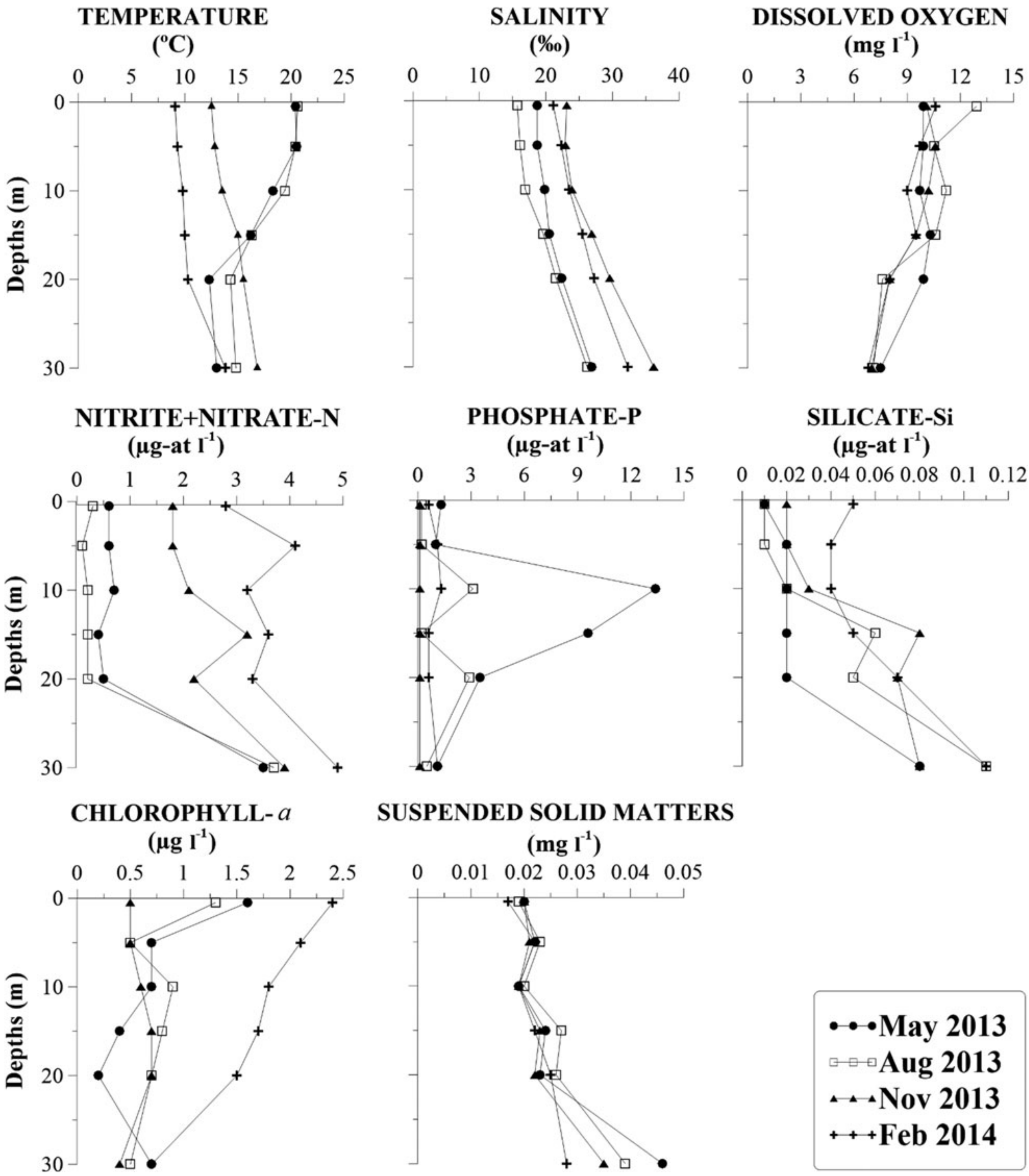

Fig. 2. Seasonal variations of ecological variables along the water column. Data are reported as averages of the sampling stations.

February (Figure 4). The Euclidean distance based on environmental variables and seasons stated that the same depths of the stations are located close to each other (Figure 5).

During the sampling periods, Shannon–Weaver diversity index (H') was used to determine the species diversity and the highest species diversity (H') was found in station 3 of August 2013 ($H' = 2.57$) sampling period, the lowest (H') was observed in station 2 of May 2013 ($H' = 0.18$).

Discussion

In the Sea of Marmara, phytoplankton studies have increased especially after the 2000s; in addition to determining the species, their abundance conditions, ecology and their relationships with ecological variables have been widely studied. Most of the studies are regional studies including bays and gulfs, and generally consist of data for seasonal sampling periods. The first checklist study in the region was made in 2004 (Balkis, 2004) and 168 phytoplankton taxa were reported. In the second comprehensive checklist study (Balkis & Tas, 2016), increased phytoplankton studies in the Sea of Marmara including the straits were evaluated and 333 phytoplankton taxa, 40 of which were genus level, were reported until 2016. In a study conducted in the Golden Horn Estuary, 127 phytoplankton taxa were identified (Tas, 2020). After 2016 new records of *Chaetoceros aequatorialis*, *C. contortus*, *C. lorenzianus* f. *forceps* (Tas & Hernández-Becerril, 2017) from

https://doi.org/10.1017/S0025315422000406 Published online by Cambridge University Press

Table 2. List of phytoplanktonic taxa of the coastal waters of Burgaz Island

Taxa DINOPHYCEAE	May 13	Aug. 13	Nov. 13	Feb. 14
Alexandrium minutum (Lebour, 1925) Balech, 1995	+			+
**Corythodinium frenguellii* (Rampi) F.J.R.Taylor, 1976				+
Dinophysis acuminata Claparède & Lachmann, 1859	+	+	+	+
Dinophysis acuta Ehrenberg, 1839	+	+	+	+
Dinophysis caudata Saville-Kent, 1881		+	+	+
Dinophysis fortii Pavillard, 1923	+	+	+	+
Dinophysis ovum (Schütt) Abé	+		+	
Dinophysis rudgei Murray & Whitting, 1899	+		+	
Dinophysis sacculus Stein, 1883	+	+		+
Diplopsalis lenticula Bergh, 1881			+	
**Gonyaulax scrippsae* Kofoid, 1911	+	+		+
Gonyaulax verior (Claparède & Lachmann) Diesing, 1866	+			
Gyrodinium spirale (Bergh) Kofoid & Swezy, 1921	+	+	+	+
Kofoidinium velleloides Pavillard, 1929	+		+	+
Noctiluca scintillans (Macartney) Kofoid & Swezy, 1921	+	+	+	+
Oxytoxum scolopax Stein, 1883	+	+	+	+
Phalacroma rotundatum (Claparéde & Lachmann) Kofoid & Michener, 1911	+	+	+	+
Podolampas palmipes Stein, 1883	+	+	+	+
***Pronoctiluca pelagica* Fabre-Domergue, 1889	+	+		
Prorocentrum compressum (Bailey) Abé ex Dodge, 1975	+	+	+	+
Prorocentrum micans Ehrenberg, 1834	+	+	+	+
Prorocentrum scutellum Schröder, 1900	+	+	+	+
Prorocentrum gracile Schütt, 1895	+	+	+	+
Protoceratium reticulatum (Claparède & Lachmann) Bütschli, 1885 = *Gonyaulax grindleyi*			+	+
Protoperidinium claudicans (Paulsen) Balech, 1974	+	+	+	+
Protoperidinium conicum (Gran) Balech 1974	+	+	+	+
Protoperidinium depressum (Bailey) Balech, 1974	+	+	+	+
Protoperidinium divergens (Ehrenberg) Balech, 1974	+	+	+	+
Protoperidinium elegans (Cleve) Balech, 1974			+	
Protoperidinium grande (Kofoid) Balech, 1974	+	+		
Protoperidinium leonis (Pavillard) Balech, 1974	+	+	+	+
Protoperidinium oblongum (Aurivillius) Parke & Dodge, 1976	+			
Protoperidinium pyriforme (Paulsen) Balech, 1974	+	+	+	+
Protoperidinium steinii (Jørgensen) Balech, 1974	+	+	+	+
Protoperidinium pellucidum Bergh, 1881	+	+	+	+
Protoperidinium quinquecorne (Abé) Balech, 1974	+			
Protoperidinium sp. 1				+
Protoperidinium sp. 2	+			
Protoperidinium sp. 3	+		+	
Protoperidinium sp. 4	+			+
Pyrophacus steinii (Schiller) Wall & Dale, 1971		+		
Scrippsiella trochoidea (Stein) Loeblich III, 1976	+	+	+	+
Tripos candelabrus (Ehrenberg) F.Gómez, 2013			+	
Tripos furca (Ehrenberg) Gómez, 2013	+	+	+	+
Tripos fusus (Ehrenberg) Gómez, 2013	+	+	+	+

(*Continued*)

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Table 2. (*Continued.*)

Taxa DINOPHYCEAE	May 13	Aug. 13	Nov. 13	Feb. 14
Tripos longipes (Bailey) Gómez, 2013	+	+	+	+
Tripos macroceros (Ehrenberg) Gómez, 2013	+	+	+	+
Tripos muelleri Bory de Saint-Vincent, 1824	+	+	+	+
Tripos trichoceros (Ehrenberg) Gómez, 2013	+		+	
Total Dinoflagellate taxa	41	32	36	35
BACILLARIOPHYCEAE				
Amphora ostrearia Brébisson, 1849	+			
Amphora sp.	+	+		
Bacillaria paxillifera (Müller) Marsson, 1901	+			
Cerataulina pelagica (Cleve) Hendey, 1937		+	+	
Cylindrotheca closterium (Ehrenberg) Reimann & Lewin, 1964	+	+	+	+
Chaetoceros affinis Lauder, 1864		+		
Chaetoceros brevis Schütt, 1895		+		+
Chaetoceros contortus Schütt, 1895		+		+
Chaetoceros cf. *curvisetus* Cleve, 1889				+
Chaetoceros decipiens Cleve, 1873		+		+
Chaetoceros diadema (Ehrenberg) Gran, 1897				+
Chaetoceros lorenzianus f. *forceps* Grunow, 1863			+	
Chaetoceros neogracile VanLandingham, 1968		+		
Chaetoceros peruvianus Brightwell, 1856		+		
Cocconeis scutellum Ehrenberg, 1838				+
Coscinodiscus granii Gough, 1905	+	+	+	
Coscinodiscus perforatus Cleve & Möller, 1878	+	+	+	+
Coscinodiscus radiatus Ehrenberg, 1840	+	+	+	+
Coscinodiscus sp.	+			
Detonula pumila (Castracane) Gran, 1900		+		+
Dactyliosolen fragilissimus (Bergon) Hasle, 1996		+		
Ditylum brightwellii (West) Grunow, 1885			+	+
Grammatophora marina (Lyngbye) Kützing, 1844	+	+		
Guinardia flaccida (Castracane) Peragallo, 1892		+	+	+
Gyrosigma reversum (Gregory) Hendey, 1986		+		
Halamphora acutiuscula (Kützing) Levkov, 2009	+			
Halamphora capitata (R.Hagelstein) Ālvarez-Blanco & S.Blanco, 2014			+	
Hemiaulus hauckii Grunow ex van Heurck, 1882			+	
Licmophora sp.				+
Lyrella lyra (Ehrenberg) Karajeva, 1978 = *Navicula lyra*	+	+	+	
Navicula fuchsii sp. 1		+		
Navicula sp. 2	+	+	+	
Neocalyptrella robusta (Norman ex Ralfs) Hernández-Becerril & Castillo, 1997 = *Rhizosolenia robusta*		+	+	
Nitzschia lorenziana Grunow, 1879	+	+	+	
***Nitzschia reversa* W.Smith 1853	+			
Pleurosigma normanii Ralfs, 1861	+	+	+	
Proboscia alata (Brightwell) Sundström, 1986	+	+		+
Pseudo-nitzschia sp. 1	+	+	+	+
Pseudo-nitzschia sp. 2				+

(*Continued*)

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Table 2. (*Continued.*)

Taxa DINOPHYCEAE	May 13	Aug. 13	Nov. 13	Feb. 14
Pseudosolenia calcar-avis (Schultze) Sundström, 1986	+	+		+
Rhizosolenia hebetata Bailey, 1856	+	+	+	+
Rhizosolenia setigera Brightwell, 1858			+	+
Striatella unipunctata (Lyngbye) Agardh, 1832		+		+
Thalassionema nitzschioides (Grunow) Mereschkowsky, 1902		+	+	+
Thalassiosira anguste-lineata (Schmidt) Fryxell & Hasle, 1977				+
Thalassiosira rotula Meunier, 1910		+	+	+
Trieres mobiliensis (Bailey) Ashworth & Theriot, 2013	+			
Total Diatom taxa	20	30	20	23
DICTYOCHOPHYCEAE				
Dictyocha fibula Ehrenberg, 1839		+	+	+
Dictyocha speculum Ehrenberg, 1839	+	+	+	+
Octactis octonaria (Ehrenberg) Hovasse, 1946			+	+
Total Silicoflagellate taxa	1	2	3	3
PYRAMIMONADACEAE				
Halosphaera viridis Schmitz, 1878	+	+	+	+
Total Pyramimonad taxa	1	1	1	1
CYANOPHYCEAE				
Merismopedia sp.	+	+		
Total Cyanobacteria taxa	1	1	0	0
Total taxa	64	66	60	62

*Indicates new record species in the Turkish seas, **indicates new record for the Sea of Marmara.

the Golden Horn Estuary, *Amphisolenia laticincta*, *Cochlodinium* sp., *Gynogonadinium aequatoriale*, *Heterocapsa rotundata* and *Metaphalacroma* sp. (Balcı & Balkis, 2017) from the Gemlik Gulf, *Gymnodinium dogielii*, *Heterodinium rigdeniae* and *Pseliodinium fusus* (Balkis-Ozdelice *et al.*, 2020) from the Gulf of Erdek have been reported. With the addition of four new records of this study (*Corythodinium frenguellii*, *Gonyaulax scrippsae*, *Pronoctiluca pelagica* and *Nitzschia reversa*) the species number has increased to 348 in the Turkish Straits System.

Comparing with the comprehensive checklist study in the region (Balkis & Tas, 2016), the highest number of species was found in Bacillariophyceae with 162 species (49%) followed by Dinophyceae with 124 species (37%). The finding, which revealed that diatoms were dominant in the region in terms of number of species, is in parallel with the studies conducted in north-west coasts (Velasquez & Cruzado, 1995; 51% diatoms, 36% dinoflagellates) and north-east coasts (Polat & Piner, 2002; 57.4% diatoms and 37.2% dinoflagellates) of the Mediterranean Sea. In addition, in the Aegean Sea, diatoms and dinoflagellate species were reported with the rates of 45.8% and 41.2%, respectively (Koray, 1994). However, in this study carried out in Burgaz Island, Dinophyceae is the dominant group with 49 species (48.5%) and followed by Bacillariophyceae with 47 species (46.5%). Similarly, in a study conducted around Bozcaada in the Aegean Sea (Balkis, 2009), dinoflagellates (50%) were reported as a dominant group over diatoms (47%) in terms of species number. In Villefranche Bay on the north-west coast of the Mediterranean Sea (Gomez & Gorsky, 2003: 52% dinoflagellates, 43% diatoms), in Genoa Bay (Bernhard & Rampi, 1967: 48% dinoflagellates, 31% diatoms) and in the previous studies in the Sea of Marmara (Balkis, 2003: 52% dinoflagellates, 40% diatom; Balcı & Balkis, 2017: 54% dinoflagellates, 42% diatoms; Dursun *et al.*, 2020: 48% dinoflagellates, 42% diatoms; Tas *et al.*, 2020: 48% dinoflagellates, 47% diatoms) it was noted that dinoflagellates showed a greater variety than diatoms. It is known that regional climate changes, increasing temperature, industrialization and anthropogenic pressures can cause regional differences in species diversity (Gomez & Claustre, 2003).

It is known that low salinity Black Sea waters affect the surface waters of the Sea of Marmara. According to Türkoğlu (1998), Bacillariophyceae were dominant in the Black Sea in the 1960–1970 period with the populations they formed, however; recent studies have shown that dinoflagellates species have increased in the phytoplankton assemblages. It has been reported that where there is an excess of nutrients in an environment, a decline in the number of phytoplankton species and a proportional variation between the taxonomic groups might be seen as an indication of stress (Türkoğlu, 1999). The increase of dinoflagellate species in terms of diversity compared with diatoms in an environment shows that the Sea of Marmara is particularly affected by the waters of the Black Sea, as it shows the increasing negative change.

Most of the phytoplankton species identified on the shores of Burgaz Island are neritic, temperate and subtropical climate species, but oceanic species were also found. Benthic species adapted to planktonic life such as *Licmophora* sp. and *Pleurosigma normanii*, typical marine species such as *Proboscia alata*, *Thalassionema nitzschioides* and *Tripos fusus*, brackish water species such as

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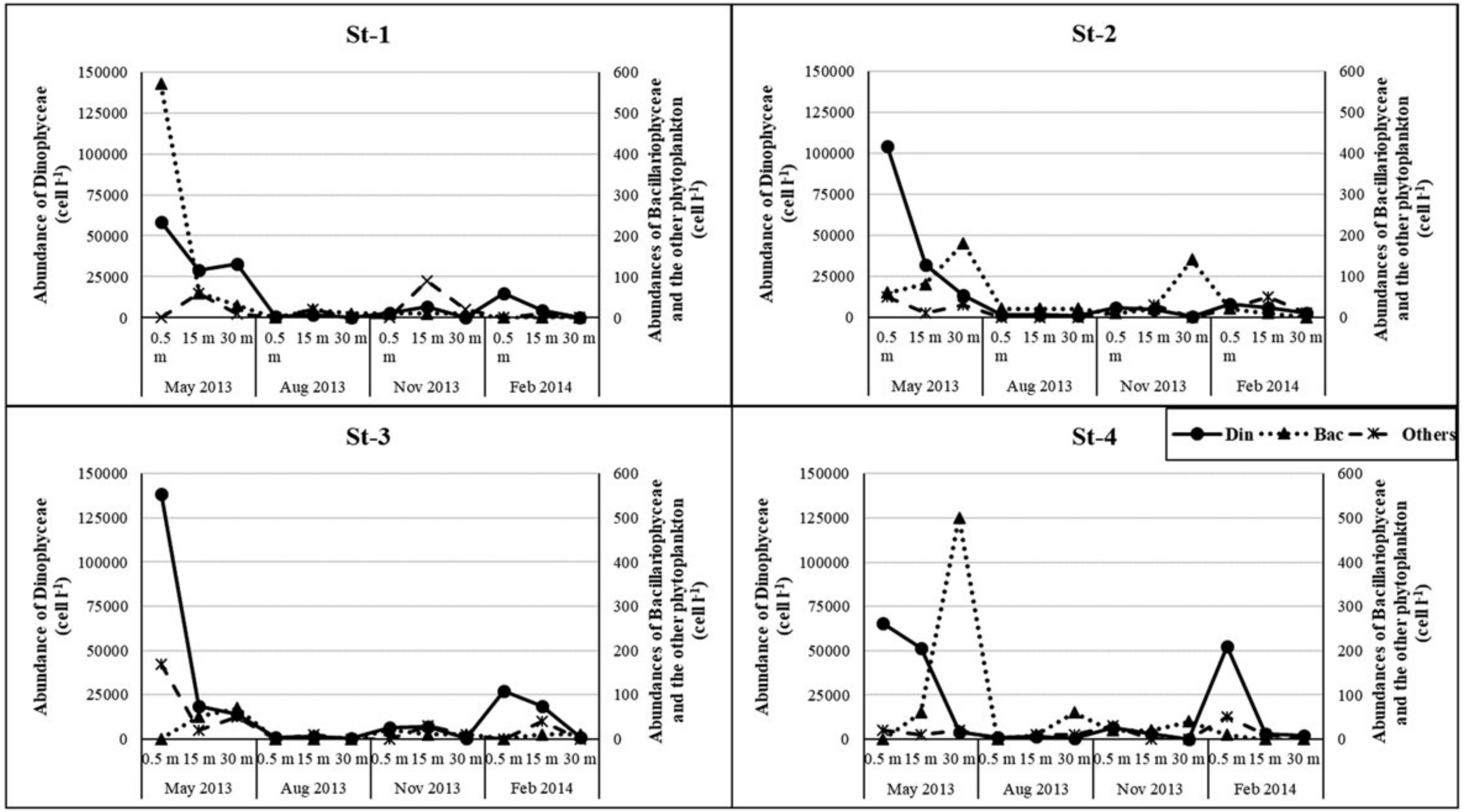

Fig. 3. Seasonal variations in the abundance (cells l^{-1}) of different phytoplankton taxonomic groups at the stations.

Table 3. Spearman's rank correlation coefficient between the environmental factors and phytoplankton communities

	Temp	Sal	DO	$NO_2 + NO_3$-N	PO_4-P	SiO_4-Si	Chl *a*	SSM	Depth	TS	TN	DinS	DinN	BacS
Sal	−0.318*													
DO	0.062	−0.674**												
$NO_2 + NO_3$-N	−0.463**	0.837**	−0.550**											
PO_4-P	0.046	−0.096	−0.116	−0.036										
SiO_4-Si	−0.405**	0.738**	−0.522**	0.758**	0.055									
Chl *a*	−0.161	−0.438**	0.386**	−0.191	−0.015	−0.252								
SSM	0.024	0.540**	−0.686**	0.361*	0.128	0.493**	−0.482**							
Depth	−0.080	0.744**	−0.716**	0.536**	0.156	0.678**	−0.463**	0.879**						
TS	−0.189	−0.225	0.301*	−0.193	0.271	−0.130	−0.025	−0.074	−0.183					
TN	−0.179	−0.372**	0.337*	−0.197	0.408**	−0.370**	0.301*	−0.388**	−0.488**	0.753**				
DinS	−0.153	−0.230	0.317*	−0.171	0.147	−0.141	0.020	−0.243	−0.312*	0.921**	0.735**			
DinN	−0.179	−0.377**	0.344*	−0.204	0.407**	−0.377**	0.302*	−0.393**	−0.492**	0.752**	0.999**	0.735**		
BacS	−0.008	0.135	−0.110	0.036	0.196	0.174	−0.358*	0.419**	0.314*	0.410**	0.144	0.120	0.134	
BacN	0.065	0.037	−0.022	−0.067	0.209	0.056	−0.352*	0.355*	0.209	0.458**	0.223	0.187	0.212	0.933**

Temp, temperature; Sal, salinity; DO, dissolved oxygen; Chl *a*, chlorophyll *a*; SSM, suspended solid material; TS, total number of species; TN, Total abundance; DinS, number of Dinophyceae species; DinN, abundance of Dinophyceae; BacS, number of Bacillariophyceae species; BacN, abundance of Bacillariophyceae. $^*P < 0.05$, $^{**}P < 0.01$, N = 48.

Cylindrotheca closterium and *Prorocentrum micans* were observed during the sampling periods. Species such as *Skeletonema costatum* and *Lingulodinium polyedra*, which are typical species of eutrophic areas, were not encountered in this study. However, these two species are known from previous studies conducted in the Sea of Marmara and it has been reported that especially *S. costatum* shows an excessive increase in certain periods (Balkis, 2003). The dominance of *P. micans*, one of the brackish water species, in terms of abundance compared with other species in this study is another indication that the low salinity Black Sea waters are affecting the surface waters of the Sea of Marmara. In addition, *Pseudosolenia calcar-avis* and *Hemiaulus hauckii*, which are characteristic species of oligotrophic waters (Kimor, 1985), were also observed, but *H. hauckii* was detected only in November 2013.

Phytoplanktonic organisms form two seasonal peaks, a characteristic feature seen in temperate regions (Barnes & Mann, 1980). According to Sorokin (1983), for algal growth in the Black Sea, the larger of these peaks occurs at the end of winter (February) and early spring (March and April), then a second and smaller peak at the end of summer (August) and early autumn (September). In this study, when the species were evaluated in terms of abundance, dinoflagellates were the group with an increase, two peaks were observed in the sampling periods; one peak in May representing spring and one in February representing the winter period. In terms of abundance, especially *P. micans* was the most abundant species in this increase. As is well known, *P. micans* is a red-tide species that can cause harmful effects (palytoxin, ovatoxin-a; Khokhar *et al.*, 2018) during its dense blooms (Tas *et al.*, 2016).

However, in this study, the highest cell number of *P. micans* was observed in the sampling period of May 2013 (135,540 cells l^{-1}) and this cell number was not enough to form a water discolouration. In a study in the Black Sea, Bodeanu *et al.* (1998) observed that phytoplanktonic organisms larger than 50 µm may cause harmful effects when they reach 10^5 cells l^{-1}. It was reported that *P. micans* increased to their abundance in the Sea of Marmara in May (Balkis, 2003). It has been stated that red-tide is observed especially in the Gulf of Izmit (Öktem, 1997), which, compared with Burgaz Island, is a semi-closed, stable water environment with high nutrient values from the wastewater inputs and agricultural fertilizers.

Even though it has low cell densities ($<10^3$ cells l^{-1}), *Dinophysis*, which is known to cause diarrhetic shellfish poisoning (DSP) with the okadaic acid and dinophysistoxins (DsT) it produces (Reguera *et al.*, 2014), is represented by seven species in Burgaz Island (Table 2). Among the species obtained in the study, *Dinophysis acuminata*, *D. acuta*, *D. caudata*, *D. fortii*, *D. ovum* and *D. sacculus* are known to produce DsT (Reguera *et al.*, 2014). *Dinophysis* species reached their highest abundance in May 2013 (station 4, 15 m depth: 250 cells l^{-1}) in Burgaz Island, and *D. acuta* played an important role in this increase (190 cells l^{-1}). *Dinophysis acuminata*, *D. acuta* and *D. fortii* were encountered in all sampling periods. DSP cases were generally reported from regions where aquaculture studies are conducted (Economou *et al.*, 2007; Farrell *et al.*, 2018). There are no aquaculture studies around Burgaz Island, but it has been observed that people living in the region collect mussels from the sea and consume them. However, there has been no case of DSP reported from around the Sea of Marmara to date (Balkis, 2003; Tas & Yilmaz, 2015; Balcı & Balkis, 2017). These species, which cause harmful effects even under 10^3 cells l^{-1}, need to be monitored in the Sea of Marmara.

In the samples of May and August 2013, it was determined that the upper layer water temperature values were higher than the lower layer. This is because the surface water temperature is affected by the atmosphere. Delcroix (1993) reported that the

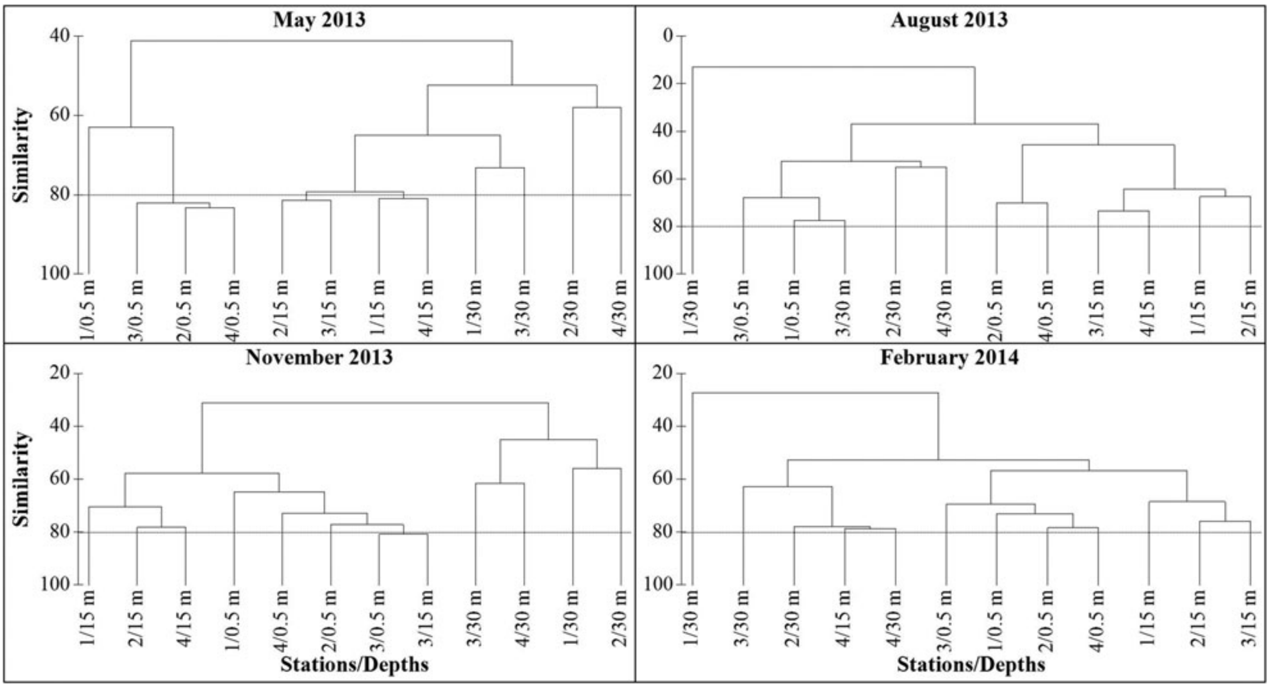

Fig. 4. Bray–Curtis similarity dendrogram of the sampling stations and periods.

most important event affecting changes in surface water temperature is weather conditions. After 20 m depth in the samples of November 2013 and February 2014, temperature values were measured higher than the upper layer. The reason for this is that the Mediterranean Sea is dominant in the bottom layer. Similarly, the high salinity values at 30 m depth show the effect of the Mediterranean Sea. The lowest salinity values were found in the surface in all sampling periods and it was observed that salinity increased in parallel with the increase in depth. Low salinity waters coming from the Black Sea via the Bosphorus are influential in the depths of the Sea of Marmara between 0–20 m (Yüce & Türker, 1991). In this study, it was noted that salinity values between 0–20 m were lower than those at 30 m depth in all sampling periods. In terms of dissolved oxygen, surface waters in contact with the atmosphere have higher dissolved oxygen values. Spearman's rank correlation has also shown that dissolved oxygen was negatively correlated with increasing depth and salinity ($P < 0.01$). Moreover, DO values were positively correlated with chl *a* ($P < 0.01$) and the total phytoplankton abundance ($P < 0.05$). Photosynthetic organisms enable surface waters to be enriched with oxygen as a result of photosynthesis (Geldiay & Kocataş, 1998). Higher chl *a* values were determined in the

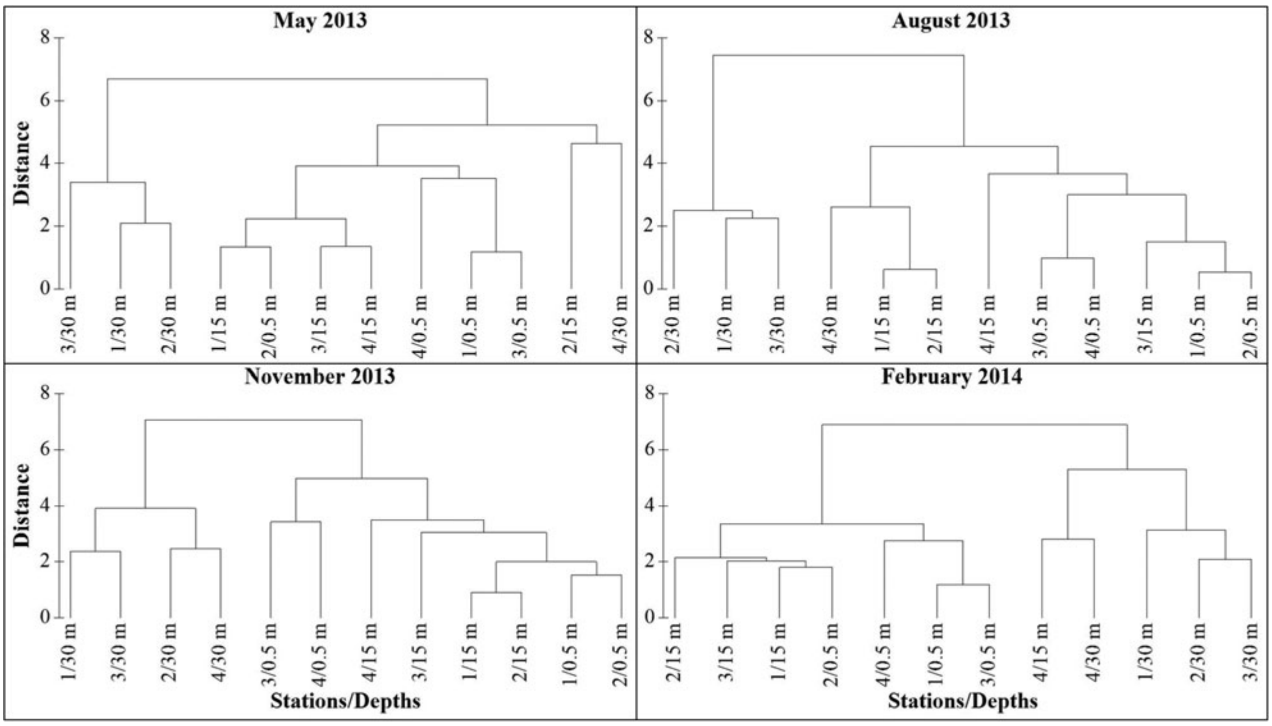

Fig. 5. Dendrogram of the Euclidean distance dendrogram of the sampling stations and periods.

surface layer where the light was effective, and the highest total phytoplankton abundance was obtained at 0.5 m depth at the stations. The total abundance and chl *a* values decreased as the depth increased ($P < 0.01$). Specifically, the total phytoplankton abundance reached its highest value with the increase of dinoflagellates in May, while chl *a* reached its highest value in February 2014, when the second peak was observed. However, Travers (1971) also stated that there is not always connection between chl *a* amounts and phytoplankton abundance. It has been reported that chl *a* values change depending on hydrochemical conditions such as nutrients, temperature, light and water mixtures (Lakkis *et al*., 2003). In the study, it was determined that salinity, which is one of the basic ecological variables, is correlated with a decrease in chl *a* values with increasing salinity ($P < 0.01$). This is also associated with a decrease in phytoplankton biomass and chl *a* values as a result of decreasing light with depth.

In a classification made in the Aegean Sea according to chl *a* values, <0.5 $\mu g\,l^{-1}$ was evaluated as oligotrophic, 0.5–1.0 $\mu g\,l^{-1}$ as mesotrophic and > 1.0 $\mu g\,l^{-1}$ as eutrophic (Ignatiades, 2005). In this study, considering the chl *a* values (0.01–3.17 $\mu g\,l^{-1}$), it was determined that the environment, especially the intermediate layer waters, reflected mesotrophic/oligotrophic conditions, while eutrophic conditions prevailed especially in surface waters during the sampling periods of May 2013 and February 2014. According to Simboura *et al.* (2005), moderate water quality (chl *a*: 0.4–0.6 $\mu g\,l^{-1}$), low water quality and high mesotrophic (chl *a*: 0.6–2.21 $\mu g\,l^{-1}$) conditions prevail in the study. Considering that *S. costatum*, which is one of the dominant species of eutrophic areas, was not observed during the sampling periods, and taking into account the intermediate layer chl *a* values and nutrient ratios, it can be said that the island shores are generally oligotrophic. It has also been stated that there was a decrease in the abundance of species such as *Leptocylindrus danicus*, *D. brightwellii* and *P. calcar-avis*, and an increase in the abundance of dinoflagellates such as *Prorocentrum balticum*, *P. cordatum* and *P. micans* before eutrophication (Zaitsev & Mamaev, 1997). In this study carried out in Burgaz Island, it was determined that *P. micans* species increased in surface layer waters reflecting potentially eutrophic conditions.

In the study area, nutrient values also increased in parallel with the increase in depth. Higher values were obtained especially in the bottom layer where the Mediterranean Sea is effective. The reason for this is that Mediterranean Sea waters, poor in nutrients at the entrance of Dardanelles, become enriched in nitrate and ortho-phosphate due to particulate organic matter in the bottom water by the time they reach to the Bosphorus (Polat & Tuğrul, 1995). According to Spearman's rank correlation, it was observed that especially Nitrite + Nitrate–N and Silicate–Si values were positively correlated with the depth increase ($P < 0.01$), and it was revealed that the total phytoplankton abundance increases with the increase of Phosphate–P ($P < 0.01$) and decreases with the increase of Silicate-Si ($P < 0.01$). The reason that the total phytoplankton abundance is inversely related to Silicate-Si is that dinoflagellates are dominant in abundance during the entire study period, whereas diatoms, that require silica, have lower abundance. The fact that there are low nutrient amounts in surface and near-surface waters compared with the lower layer is due to the rapid consumption of rich nutrient surface waters, which originate from the Black Sea, in primary production.

The main purpose of determining the diversity indices in a region is to examine the changes in the community structure in the region and to find a relationship between the degree of pollution and the structural changes of living communities if there is any pollution (Koray, 1987). The same researcher stated that if the selected organism group is phytoplankton, it might be erroneous to use the diversity index results as a degree of contamination process, but it would be more appropriate to use it in comparisons based on time or regions. The reason that the Shannon–Weaver diversity index is low during the May 2013 sampling period when the phytoplankton abundance increased is that *Prorocentrum micans* is dominant to other species in terms of the abundance. In addition, considering both the abundance of species and ecological variables throughout the study, it has been revealed that the depths of the stations show close similarity by grouping them within themselves.

In conclusion, this study carried out on the shores of Burgaz Island aimed to reveal the phytoplankton species and their abundance in the region. It was determined that dinoflagellates were dominant in terms of species number and number of cells and with the addition of newly recorded species, it has contributed to the checklist of the plankton species of the Sea of Marmara and the relationship between species and ecological variables has been investigated.

Data. The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author contributions. Kayadelen, Y., and Balkis-Ozdelice, N., collected and identified the phytoplankton samples and evaluated the psycho-chemical data. Also, Durmus, T. helped to collect the samples. Statistical evaluation of the data was made by all authors, and they read and approved the final manuscript.

Financial support. This study was supported by the Research Fund of Istanbul University, Project number 34159.

Conflict of interest. The authors declare no conflicts of interest.

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