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SUMMER PHYTOPLANKTON COMPOSITION IN THE NERITIC WATERS OF THE SEA OF MARMARA

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Abstract

Summer phytoplankton species were investigated in the Sea of Marmara between 1993-1995. The samples were collected in the months of June-August from the subsurface (0.5 m) with a 55 µm net at 52 stations. A total of 102 phytoplankton species were identified. Of these, 19 species two of them at the generic level, are new to the region. Diatoms and dinoflagellates were present throughout the sampling period and diatoms represented the majority of the population (46.08%), followed by dinoflagellates (44.12%). The others formed only 9.8% of the whole population. The genera *Protoperidinium, Ceratium* and *Chaetoceros* were dominant in terms of diversity. Primary hydrographical observations like salinity, temperature and dissolved oxygen were recorded on each sampling occasion. The species number of phytoplankton was negatively correlated to salinity ($r = -0.33$, $p<0.05$). The other parameters did not appear to play any role with the species number. Salinity was positively correlated to temperature ($r = 0.64$, $p<0.05$) and negatively to dissolved oxygen ($r = -0.42$, $p<0.05$). Furthermore, dissolved oxygen was negatively correlated to temperature ($r = -0.30$, $p<0.05$).

Introduction

The Sea of Marmara is a relatively small inter-continental basin with a surface area of 11 500 km^2 and a volume of 3378 km^3. It is connected to the Black Sea and the Aegean Sea through the straits of Bosphorus and the Dardanelles, respectively (Ünlüata *et al*., 1990).

The chemical oceanography of the Sea of Marmara is significantly influenced by the biochemistry of the Black Sea and the Aegean Sea. Especially, at the depths between 0.5-20 m, affected by the brackish water coming from the Black Sea via the Bosphorus (Yüce & Türker, 1991). In the upper euphotic zone, concentrations of nutrients are relatively low and show fluctuations that reflect the photosynthetic activity (Baştürk *et al*., 1986). Since primary production is always limited to the less saline upper layer (15-20 m) of the Sea of Marmara, the subhalocline waters of Mediterranean origin are always rich in nutrients (Polat *et al*., 1998) and it is oligotrophic in nature (Balkıs, 2003).

There are only few report on the phytoplankton and their ecological features in the Sea of Marmara (Aubert *et al*., 1990; Uysal, 1996; Uysal & Ünsal, 1996; Balkıs, 2000, 2003). This is the first report covering the whole Sea of Marmara. The study was therefore designed to determine the composition of the summer phytoplankton species in this area and to report, if any, species that would be new for this region.

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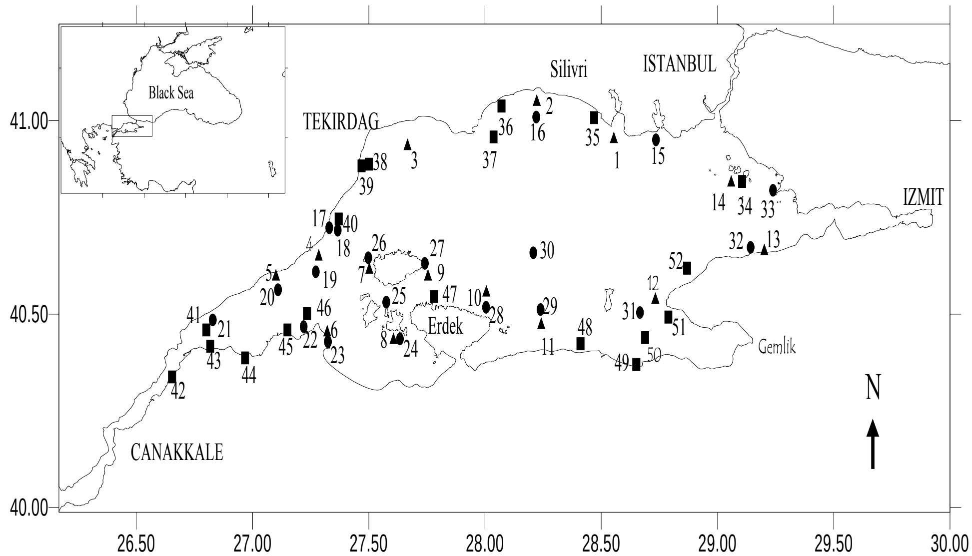


Fig. 1. The sampling stations in the Sea of Marmara (▲ June, • July, ▪ August)

Materials and Methods

Water samples for species identification were collected from the Sea of Marmara with horizontal tows from the subsurface (0.5 m) with a 55 μm plankton net at 52 stations (Fig. 1), in the months of June-August from 1993 to 1995 and fixed in 4% neutral formaldehyde solution. The 55 μm net possibly underestimates the abundance of smaller species due to reduced retention. The species composition sampled with the plankton net should consequently be viewed as size biased. Identification of smaller species was carried out by using 3 l water sampler with a thermometer. These samples were preserved with Lugol's iodine solution. Then, neutral formaldehyde was added until a concentration of 4% was reached. Samples were settled and the upper layer was removed by siphoning. Observations of species were made through the use of inverted phase contrast microscope equipped with a microphotosystem at X400 magnification. Small forms of doubtful taxonomic classification were not added to the list (Table 2).

Species were identified after reference to literature (Lebour, 1930; Cupp, 1943; Trégouboff & Rose, 1957; Hendey, 1964; Sournia, 1968, 1986; Steidinger & Williams, 1970; Drebes, 1974; Taylor, 1976; Rampi & Bernhard, 1978, 1980; Dodge, 1982; Ricard, 1987; Balech, 1988; Delgado & Fortuno, 1991; Hasle & Syvertsen, 1997; Steidinger & Tangen, 1997; Throndsen, 1997).

At each sampling date measurements of salinity (p.s.u.), temperature (ºC) and dissolved oxygen (mg l^{-1}) were performed (Table 1). The Mohr-Knudsen method (Ivanoff, 1972) was made use of in measuring salinity values, and the Winkler method (Winkler, 1888) in measuring those of dissolved oxygen (DO).

Pearson correlation and simple linear regression were used to correlate the species number of phytoplankton with hydrographical parameters, and among the hydrographical parameters themselves (Makridakis *et al*., 1998) (Table 3; Fig. 3 a-c).

Table 1. Hydrographical parameters of the sampling stations in the Sea of Marmara. Temperature (ºC), salinity (p.s.u.), dissolved oxygen (mg l^{-1}), depth (m).

	Stations																	
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
p.s.u	19.8	20.4	21.9	22.3	22.0	22.2	21.6	22.5	21.3	21.1	20.0	21.4	22.0	21.6	20.0	20.4	22.1	22.4
ºC	23.5	23.8	24.3	24.0	24.4	24.6	24.2	24.7	24.2	24.1	24.2	23.4	23.7	23.1	23.5	24.0	24.2	24.3
mg l^{-1}	9.8	8.9	8.8	8.7	8.3	8.5	8.6	9.0	7.9	8.1	8.0	8.2	7.9	7.7	10.0	8.9	9.2	8.7
m	43	42	56	57	53	45	65	43	63	46	52	53	55	40	60	56	38	63
	Stations																	
	19	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**
p.s.u	22.4	22.2	22.5	22.2	22.3	22.4	22.6	21.6	21.4	21.1	20.0	21.2	21.0	20.8	21.0	20.2	20.4	20.1
ºC	24.6	24.4	24.2	24.6	24.7	24.6	24.4	24.2	24.2	24.1	24.1	24.0	23.6	23.4	23.5	22.2	23.6	23.6
mg l^{-1}	8.8	8.6	9.0	8.5	9.3	8.7	9.7	8.6	8.3	9.3	9.6	9.4	9.5	8.9	8.4	9.2	10.7	9.1
m	58	53	13	55	46	42	17	63	62	46	52	96	43	55	70	37	17	16
	Stations																	
	37	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**		
p.s.u	19.9	21.7	21.8	21.9	22.3	22.4	22.4	22.4	22.1	22.0	20.8	19.8	19.9	20.4	20.3	20.6		
ºC	23.2	23.7	23.7	23.4	23.9	24.2	23.6	24.2	24.1	24.1	23.5	23.4	23.3	23.4	23.3	23.1		
mg l^{-1}	9.1	9.3	9.2	8.9	8.9	8.6	8.7	9.1	9.0	9.8	10.0	10.2	10.0	10.1	10.0	9.6		
m	79	84	17	40	19	36	27	13	52	65	24	22	17	59	42	82		

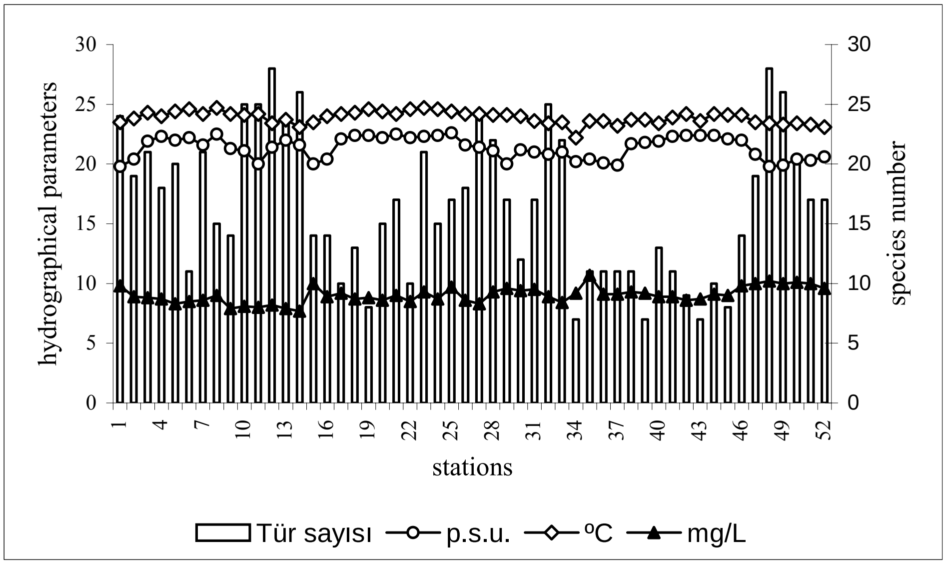


Fig. 2. Hydrographical parameters and species number of phytoplankton in the sampling stations of the Sea of Marmara.

Results

Abiotic parameters: Average surface water temperature in the study area was 23.9±0.51 ºC (from 22.2ºC to 24.7ºC). Salinity showed an average of 21.4±0.92 p.s.u. (from 19.8 p.s.u. to 22.6 p.s.u.), and the average dissolved oxygen was 9.0±0.66 mg l^{-1} (from 7.7 mg l^{-1} to 10.7 mg l^{-1}) (Table 1; Fig. 2).

Phytoplankton composition: A total of 102 microalgae, 45 dinoflagellates, one chrysophycean, one dictyochophycean, 47 diatoms, one euglenophycean, one prasinophycean and six fresh water species were identified (Table 2). Of these, 19 species, two at the generic level, were new to the Sea of Marmara and these species are marked with one asterisk in Table 2.

Bacillariophyceae and Dinophyceae were superior to the other classes in terms of diversity. The most common genera were: *Chaetoceros* Ehrenberg, *Ceratium* Schrank, *Prorocentrum* Ehrenberg and *Protoperidinium* Bergh. *Protoperidinium* was numerically the best represented genus.

Twenty-nine species were observed in all months during the whole period of this study. Of these, 14 species (*Ceratium furca, C. fusus, C. longirostrum, C. tripos, Noctiluca scintillans, Prorocentrum compressum, P.micans, P. scutellum, P. triestinum, Protoperidinium brochi, P. depressum, P. divergens, P. steinii, Scrippsiella trochoidea*) belonged to dinoflagellates, 14 species (*Cerataulina pelagica, Chaetoceros curvisetus, Climacosphenia* sp., *Coscinodiscus radiatus, Cylindrotheca closterium, Dactyliosolen fragilissimus, Proboscia alata, Pseudo-nitzschia delicatissima, P. pungens, Pseudosolenia calcar-avis, Rhizosolenia hebetata, R. setigera, Skeletonema costatum, Striatella unipunctata*) to diatoms, and 1 species (*Eutreptiella* sp.) to Euglenophyceae.

Table 2. List of phytoplanktonic taxa in summer period of the Sea of Marmara;▲June, •July,▪August.

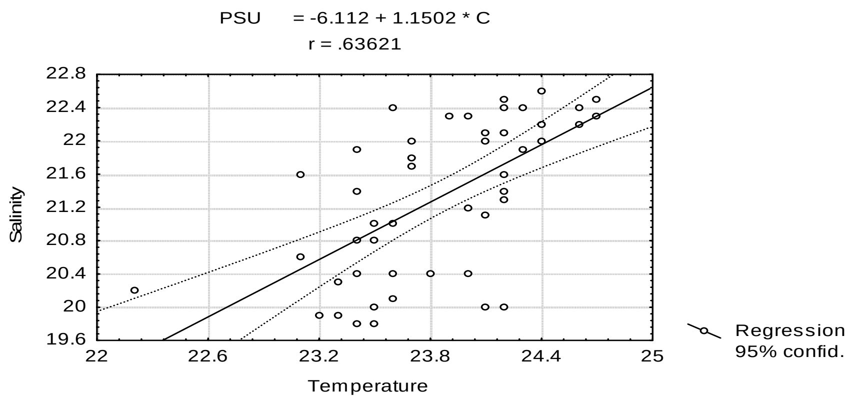
Taxa	1993	1994	1995	Stations
CHROMOPHYTA				
DINOPHYCEAE				
Alexandrium minutum Halim		•		27
Ceratium furca (Ehrenberg) Claparède. & Lachmann	▲•▪	▲•▪	▲•▪	1-18, 20, 21, 23, 24, 26, 27, 29-32,34-52
Ceratium fusus (Ehrenberg) Dujardin	▲•▪	▲•▪	▲•▪	1-16,18,23-29,32-52
**Ceratium gibberum* Gourret			▪	42,44,45,47
**Ceratium inflatum* (Kofoid) J∅rgensen			▪	45
Ceratium longirostrum Gourret	▲•▪	▲•▪	▲•▪	4,5,7-10, 12, 27, 37, 38, 41, 44,45,52
Ceratium macroceros (Ehrenberg) Vanhöffen			▪	40,52
Ceratium minutum Jörgensen		•		26
Ceratium pentagonum Gourret			▪	46
Ceratium trichoceros (Ehrenberg) Kofoid		•		28
Ceratium tripos (O.F.Müller) Nitzsch	▲•▪	▲•▪	▲•▪	1-16,21,23,25,27,29,31-52
Dinophysis caudata Saville-Kent	▲•	▲•		1,2,12,14,30
Dinophysis hastata Stein			▪	50
Diplopsalis lenticula Bergh	▲•	▲•		1,10,24
**Gonyaulax diegensis* Kofoid		•		31
Gonyaulax grindleyi Reinecke		•		33
Gonyaulax sp.		•		20,32
Gymnodinium sanguineum Hirasaka			▪	52
Gyrodinium spirale (Bergh) Kofoid & Swezy		•		31
Heterocapsa triquetra (Ehrenberg) Stein	▲▪		▲▪	1,35,44
Kofoidinium velleloides Pavillard		•		23
Noctiluca scintillans (Macartney) Kofoid & Swezy	▲•▪	▲•▪	▲•▪	8,9,11,14-20,22-43,45-52
Phalacroma rotundatum (Clap. & Lach.) Kof. & Mich	▲			1-5,7,10,14
Prorocentrum compressum (Bailey) Abe *ex* Dodge	▲•▪	▲•▪	▲•▪	1-8,10-14,19-24,26,27,29-33,50
Prorocentrum cordatum (Ostenfeld) Dodge	▲•	▲•		5,10,12,16,17,20,21,23,27,33
Prorocentrum micans Ehrenberg	▲•▪	▲•▪	▲•▪	1-14,19-21,23,24,26,28-33,38,46,48,49
Prorocentrum scutellum Schröder	▲•▪	▲•▪	▲•▪	1-5,7-14, 32, 33, 35, 38, 49,52
Prorocentrum triestinum Schiller	▲•▪	▲•▪	▲•▪	11,13-15,34,40
**Protoperidinium brevipes* Paulsen (Balech)	▲			1,2,7 14
Protoperidinium brochi (Kofoid & Swezy) Balech	▲•▪	▲•▪	▲•▪	3,12,18,40,50
Protoperidinium claudicans (Paulsen) Balech			▪	51
Protoperidinium crassipes (Kofoid) Balech	▲			1,2,7,14
Protoperidinium depressum (Bailey) Balech	▲•▪	▲•▪	▲•▪	1-5,13,16,20,42,47,49-52

Table 1 (Cont'd.)

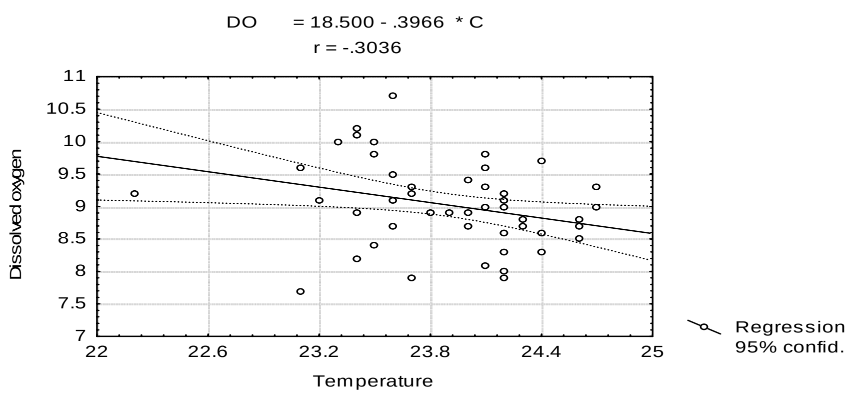
**Protoperidinium diabolus* (Cleve) Balech			■	48,49
Protoperidinium divergens (Ehrenberg) Balech	▲●■	▲●■	▲●■	1-7,10-13, 19, 20, 25, 35, 37,38,43, 46-52
Protoperidinium leonis (Pavillard) Balech	▲			4,11
Protoperidinium oceanicum (Vanhöffen) Balech	▲■		▲■	7,47,51
Protoperidinium paulseni Pavillard		●		20,25,32,33
Protoperidinium pellucidum Bergh		●■	●■	19,27,49,50
Protoperidinium pentagonum (Gran) Balech	▲			12
Protoperidinium steinii (Jörgensen) Balech	▲●■	▲●■	▲●■	1-18,20,21,23-33,35,47,49
Protoperidinium subinerme (Paulsen) Loeblich III		●		28
Protoperidinium sp.	▲■		▲■	13,40,41
Pyrophacus horologium Stein	▲			2-8,11
Scrippsiella trochoidea (Stein) Loeblich III	▲●■	▲●■	▲●■	2,3,10-14, 21, 25, 29, 31, 32, 34-36, 46-49,51
CHRYSOPHYCEAE				
Bicosoeaca mediterranea Pavillard	▲			13
DICTYOCHOPHYCEAE				
Dinobryon sp.			■	48
BACILLARIOPHYCEAE				
**Asterionellopsis glacialis* (Castracane) Round		●		18
**Bacillaria paxillifera* (Müller) Hendey		●		17
**Bacteriastrum delicatulum* Cleve		●		18,28
Cerataulina pelagica (Cleve) Hendey	▲●■	▲●■	▲●■	1,3,5,7-14,16,17,19-26, 28, 29, 31-37,44,47-52
Chaetoceros affinis Lauder		●■	●■	30,31,50
**Chaetoceros brevis* Schütt		●		16,33
Chaetoceros curvisetus Cleve	▲●■	▲●■	▲●■	12,18,24,27,28,30,32,36,37, 47,49-52
Chaetoceros debilis Cleve		●■	●■	26-28,48
Chaetoceros decipiens Cleve	▲●	▲●		10,27-29
Chaetoceros didymus Ehrenberg			■	48,49,52
Chaetoceros laciniosus Schütt	▲			5,10
Chaetoceros lorenzianus Grunow		●		25-27
Chaetoceros peruvianus Brightwell		●		25,26
**Chaetoceros socialis* Lauder		●		25
Chaetoceros sp.	▲●■	▲●■	▲●■	10,14,15,20,22,23,25,29,32,41,44,46, 47,50,51
Climacosphenia sp.	▲●■	▲●■	▲●■	1,33,41,45,46,48,52
Coscinodiscus perforatus Ehrenberg	▲			1,3,4,11,12
Coscinodiscus radiatus Ehrenberg	▲●■	▲●■	▲●■	1-12,14,26,32,36-38,40-42,48,49,52
Coscinodiscus sp.	▲■		▲■	3,4,13,39,50,51
Cylindrotheca closterium (Ehren.) Lewin & Reimann	▲●■	▲●■	▲●■	12,14,15,21,23,39,40
Dactyliosolen fragilissimus (Bergon) Hasle	▲●■	▲●■	▲●■	1,3,7,9-14,22,23,27, 31-33,36,40,43,47,48

Table 1 (Cont'd.)

Ditylum brightwellii (T.West) Grunow *in* V.Heurck		●■	●■	23,40,41,46,48-52
Guinardia flaccida (Castracane) Peragallo	▲			1,3,5,7,9-14
Gyrosigma sp.			■	49
Leptocylindrus danicus Cleve	▲●	▲●		8,10-14, 18, 21, 23, 24, 27, 28,31-33
Leptocylindrus minimus Gran	▲			12
Licmophora abbreviata Agardh			■	41,44,47
**Licmophora flabellata* Agardh			■	42
Melosira moniliformis (Müller) Agardh		●		28
Navicula sp.		●■	●■	26,46,48,49
Nitzschia longissima (Brébisson) Ralfs *in* Pritchard		●		33
Pleurosigma normanii Ralf *in* Pritchard			■	38
Pleurosigma sp.			■	46
Proboscia alata (Brightwell) Sundstrom	▲●■	▲●■	▲●■	12,16,18,21,23-25,27-29, 32, 33,37
Pseudo-nitzschia delicatissima (Cleve) Heiden *in* Heiden & Kolbe	▲●■	▲●■	▲●■	5,30,32,47
**Pseudo-nitzschia fraudulenta* (Cleve) Hasle		●		15
Pseudo-nitzschia pseudodelicatissima (Hasle) Hasle	▲●	▲●		1-3,7,8,10-15,18,26,28
Pseudo-nitzschia pungens (Grunow *ex* Cleve) Hasle	▲●■	▲●■	▲●■	1,5,9,11-13,23,27-33,40
Pseudo-nitzschia sp.	▲●■	▲●■	▲●■	4,10,15-18,21,25-28, 35, 36, 38,48-51
Pseudosolenia calcar- avis (Schultze) Sundsrôm	▲●■	▲●■	▲●■	1-17,20-33,36,37,47-52
Rhizosolenia hebetata (Bailey) Gran	▲●■	▲●■	▲●■	6,11,22,27-29,50
Rhizosolenia setigera Brightwell	▲●■	▲●■	▲●■	2,13-17,19-33,47,49-51
Rhizosolenia styliformis Brightwell		●		23,24
Skeletonema costatum (Greville) Cleve	▲●■	▲●■	▲●■	7,10,11,13-29,31-33,49
**Stephanopyxis turris* (Greville) Ralfs *in* Pritchard		●		21,22,27
Striatella unipunctata (Lyngbye) Agardh	▲●■	▲●■	▲●■	14,32,39,49
Thalassionema nitzschioides (Grunow) Meresch.		●■	●■	28,32,42,48,49
CHLOROPHYTA				
EUGLENOPHYCEAE				
Eutreptiella sp.	▲●■	▲●■	▲●■	11-13,21,33,43,44,46-49
PRASINOPHYCEAE				
Halosphaera viridis Schmitz			■	48
Fresh water species				
**Anabaena* sp.			■	48
**Euglena viridis* Ehrenberg			■	48
**Mereraphidium* sp.			■	48
**Pediastrum boryanum* (Turpin) Meneghini			■	48
**Pediastrum simplex* (Schröder) Lemmerman			■	48
**Scenedesmus quadricauda* (Turpin) Breb.			■	48



(a)



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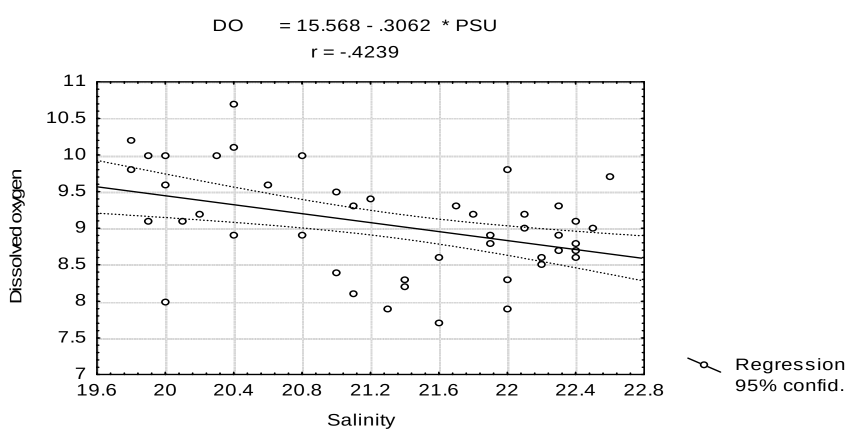

(c)

Fig. 3 (a-c). The relationships between primary hydrographical conditions during sampling cruise.

Table 3. The results of statistical analyses between the species number of phytoplankton and hydrographical parameters, and among the hydrographical parameters themselves.

x	y	r	r²	Slope	İntercept	F	p-level
Salinity	Species number	- 0.330	0.109	- 2.172	62.920	6.125	0.017
Temperature	Species number	- 0.122	0.015	- 1.453	51.229	0.759	0.388
Dissolved oxygen	Species number	- 0.128	0.016	- 1.166	27.045	0.835	0.365
Salinity	Dissolved oxygen	- 0.424	0.180	- 0.306	15.568	10.951	0.002
Temperature	Salinity	0.636	0.405	1.150	- 6.112	34.000	0.000
Temperature	Dissolved oxygen	- 0.304	0.092	- 0.396	18.500	5.078	0.029

A total of 52 species were observed in 1993. Dinoflagellates represented the majority of the population (50%), followed by diatoms (46.2%). The others formed only 3.8% of the whole population. In 1994, the largest components in the population were diatoms (55.4%) and dinoflagellates (43.1%). The others formed 1.5% of the whole community. The highest diversity was detected in this year (65 species). A total of 63 species were identified in 1995. Diatoms were still an important component of the population (44.4%), followed by dinoflagellates (41.3%). The rest of the population (14.3%) was made up of remaining species.

The results of Pearson correlation and simple linear regression employed to explain the relationships between the species number of phytoplankton and hydrographical parameters, and among the hydrographical parameters themselves are given in (Table 3). The species number of phytoplankton in the Sea of Marmara appears to be negatively correlated to salinity ($r= -0.33$, $p<0.05$). The other parameters did not appear to play any role with the species number. From the values of hydrographical parameters in the Table, the relationship among them is seen to be of significance. Salinity is positively correlated to temperature ($r= 0.64$, $p<0.05$) and negatively to dissolved oxygen ($r= -0.42$, $p<0.05$). Furthermore, dissolved oxygen is negatively correlated to temperature ($r_s= -0.30$, $p<0.05$) (Fig. 3 a-c).

Discussion

The present study has made it possible to determine a number of phytoplanktonic members of algae belonging to 6 classes, viz., Dinophyceae, Chrysophyceae, Dictyochophyceae, Bacillariophyceae, Euglenophyceae and Prasinophyceae in addition to six fresh water species. As a result of this study, a total number of 102 microalgae were determined. Thirteen of the 102 taxa could not be identified and were thus classified to genus. Twenty-nine of these species were new records for the Sea of Marmara. If the sampling had been carried out by using a smaller mesh size, more phytoplankton species may have been detected.

Koray (2001) reported the total of 7 procaryotes and 485 eucaryotes taxa from Turkish Seas. So far, a total of approximately 147 species have been identified from the

Sea of Marmara (Aubert *et al*., 1990; Uysal, 1996; Uysal & Ünsal, 1996; Balkıs, 2000, 2003).

Most of the species identified in the region were neritic, temperate and subtropical in nature. Along with some benthic species belonging to such genera as *Gyrosigma, Licmophora, Navicula, Pleurosigma* and *Striatella,* which have adapted to plankton life, marine species (*Proboscia alata, Thalassionema nitzschioides, Ceratium fusus*), brackish species (*Prorocentrum micans, Cylindrotheca closterium*) and typical species (*Skeletonema costatum*) pertaining to the eutrophic areas have also been found in this region. Moreover, six fresh water species were detected. These species were obtained in station 48 where Kocasu river flows to the sea.

In addition, the presence of certain dinoflagellate species viz., *Alexandrium minutum, Heterocapsa triquetra, Noctiluca scintillans, Phalacroma rotundatum, Prorocentrum micans, Prorocentrum triestinum, Scrippsiella trochoidea* that are known to be responsible for red tides and other noxious algal blooms in other geographical areas was detected. Any statement could not be made about their abundance since individual numbers of species were not counted. However, red tides were not recorded in this region since 1998 according to last study (Balkıs, 2003) carried out in Büyükçekmece Bay of the Sea of Marmara.

The highest numbers of phytoplankton species were found at stations 12 and 48 (28 species) and the lowest number at stations 34, 39 and 43 (7 species). Throughout the summer season, the phytoplankton species were found in the range of 22.2-24.7ºC, 19.8-22.6 p.s.u. and 7.7-10.7 mg l^{-1}. These values are characteristic for this area (Ünlüata *et al*., 1990; Beşiktepe *et al*., 1995) and the chemical oceanography of the Sea of Marmara is significantly influenced by the biochemistry of the Black Sea and the Aegean Sea. Because of the large volume of water inflow from the adjacent Black Sea (about 600 km^3) into the relatively small upper layer volume (about 225 km^3) of the Sea of Marmara, the upper layer ecosystem has been affected by the brackish water coming from the Black Sea via the Bosphorus (Ünlüata *et al*., 1990; Yüce & Türker, 1991; Tuğrul & Polat, 1995).

In conclusion, this study covering the whole Sea of Marmara contributes to the recognition of biological diversity of this region with the addition of new recorded species and the study has further attempted to find out the relationship between these species and hydrographical parameters.

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