Turk J Biol
34 (2010) 211-225

doi:10.3906/biy-0807-7

Diurnal variations of summer phytoplankton and interactions with some physicochemical characteristics under eutrophication in the Dardanelles

Muhammet TÜRKOĞLU, Yasemin ERDOĞAN

Çanakkale Onsekiz Mart University, Fisheries Faculty, Hydrobiology Department, Marine Biology Section, Terzioğlu Campus 17100, Çanakkale - TURKEY

Received: 04.07.2008

Abstract: This study was carried out to determine the diurnal distributions of phytoplankton density, bio-volume, and chlorophyll a in relation to nutrients and CTD measurements in surface waters of the coastal area in the Dardanelles during high density of phytoplankton, especially high diatom production (between 3 July and 4 August 2002). Ninety nine surface samples were collected for nutrient, chlorophyll a, and phytoplankton in 3 different time periods of the day (08:00, 13:00 and 18:00 hours) in the sampling period. Based on the sample analyses, average temperature, salinity, pH, DO, TDS, TSS, NO^-_2+NO^-_3, PO^{-3}_4, SiO_4, chlorophyll a, N:P, and Si:P were calculated as 25 °C, 23.3 ppt, 8.42, 9.26 mg L^{-1}, 23.9 g L^{-1}, 36.1 mg L^{-1}, 1.90 µM, 0.24 µM, 3.61 µM, 1.70 µg L^{-1}, 12.5, and 25, respectively. Total phytoplankton density and bio-volume varied from 2.86×10^5 to 1.5×10^7 cells L^{-1} and from 5.98×10^8 to 8.81×10^{10} μm^3 L^{-1}, respectively. Contribution rate of Bacillariophyceae (66.5%) to total phytoplankton bio-volume was higher than that of Dinophyceae (31.0%). Phytoplankton community structure was observed to be controlled by 6-7 species. Other species can be considered as insignificant species that do not cause important fluctuations in the phytoplankton density and bio-volume. It has been reported that there were 9-11 population growth slopes for different species at different times and densities. Therefore, life cycles of phytoplankton species were completed between 3 and 4 days. Diurnal variations of biological and physicochemical parameters in the time interval between 0800 and 18:00 were generally much higher than daily variations between 3 July and 4 August 2002 due to the 2 counter flows system of the Dardanelles and domestic inputs of Çanakkale city.

Key words: Dardanelles, summer period, phytoplankton, nutrient, chlorophyll a, CTD probe data

Çanakkale Boğazı'nda son yaz döneminde fitoplankton'da oluşan günlük değişimler ve bazı fizikokimyasal değişkenlerle olan karşılıklı ilişkileri

Özet: Bu çalışma, Çanakkale Boğazı'nın kıyısal bir bölgesinin yüzey suyunda yıl içinde aşırı fitoplankton, özellikle aşırı diyatom üreme dönemlerinden biri olan 3 Temmuz ve 4 Ağustos 2002 periyodunda besin tuzları ve diğer bazı fizikokimyasal değişimlerle ilişkili olarak fitoplankton yoğunluğu, biyo-hacim ve klorofil-a düzeylerinin günlük dağılımlarını belirlemek amacıyla planlanmıştır. Bu amaçla, söz konusu örnekleme döneminde günün farklı zaman dilimlerinde (08:00, 13:00 ve 18:00 saatlerinde) besin tuzları, klorofil-a ve fitoplankton için 99 örnekleme yapılmıştır. Örneklerin analizi sonucunda, ortalama tuzluluk, pH, çözünmüş oksijen (ÇO), toplam çözünmüş anyon ve katyonlar (TDS), toplam askıda katı madde (TSS), NO^-_2+NO^-_3, PO^{-3}_4, SiO_4, klorofil-a, N:P ve Si:P düzeyleri sırasıyla 25 °C, 23,3 ppt, 8,42, 9,26 mg L^{-1}, 23,9 g L^{-1}, 36,1 mg L^{-1}, 1,90 µM, 0,24 µM, 3,61 µM, 1,70 µg L^{-1}, 12,5 ve 25 olarak belirlenmiştir. Toplam fitoplankton yoğunluğu ve biyo-hacim sırasıyla 2,86 × 10^5 - 1,5 × 10^7 hücre L^{-1} ve 5,98 × 10^8 – 8,81 × 10^{10} $\mu m^3 L^{-1}$ olarak hesaplanmıştır. Bacillariophyceae taksonomik grubunun toplam fitoplankton biyo-hacmine olan katkısının (% 66,5) Dinophyceae taksonomik grubunun katkısından (% 31,0) daha yüksek olduğu görülmüştür. Çalışma bölgesinin fitoplankton kommunite yapısı 6-7 fitoplankton türü tarafından kontrol edilmekte olduğu gözlenmiştir. Bu türler dışındaki diğer türler fitoplankton yoğunluğu ve biyo-hacminde önemli değişimlere sebep olmayan aksesuar türler olarak düşünülebilir. Bölgede, farklı zaman ve yoğunluklarda farklı türler tarafından oluşturulan 9-11 populasyon gelişim eğrisinin varlığı gösterilmiştir. Bu yüzden, fitoplankton türlerinin hayat döngüsünün 3-4 gün arasında tamamlandığı hesaplanmıştır. Bu çalışma sonucunda, boğazdaki iki tabakalı akıntı sistemi ve Çanakkale şehrinin evsel boşalımları nedeniyle, fizikokimyasal değişkenlerin saat 08:00 ve 18:00 arasında gün içinde oluşan varyasyonları genellikle 3 Temmuz 2002 ve 4 Ağustos 2002 döneminde oluşan günlük varyasyonlarından çok daha yüksek olduğu gösterilmiştir.

Anahtar sözcükler: Çanakkale Boğazı, yaz periyodu, fitoplankton, nutrient, klorofil-a, CTD data

Introduction

The Turkish Straits System, including the Sea of Marmara, the Dardanelles (Çanakkale Strait), and the Bosphorus (İstanbul Strait), connects the Mediterranean and the Black Sea region (1). The Sea of Marmara is a semi-enclosed basin with an 11500 km^2 area and a 3378 km^3 total volume (1). The Dardanelles is located between the Aegean Sea and the Sea of Marmara and has a 50 m mean depth, while the Bosphorus is located between the Sea of Marmara and the Black Sea and has a 35 m mean depth (1,2).

The nutrient dynamics in the system are affected by the distinctly different 2-layer flow regime in the Turkish Straits System. This causes variable seasonal and episodic inorganic nutrient and organic matter fluxes to the adjacent seas (1,2). For example, some of the biogenic organic matter in the Black Sea inflow can be naturally exported by the surface inflow throughout the Sea of Marmara basin and reach the Eastern Mediterranean via the Dardanelles (1,2). Additionally, the polluted Black Sea surface inflow is further contaminated by the waste discharge of the city of İstanbul and released into the Bosphorus before spreading into the Sea of Marmara upper layer (1,3,4). Furthermore, vertical mixing provides nutrient input from the Sea of Marmara lower layer, especially in the Marmara-Bosphorus Junction region (4-6).

As stated in many studies (1,4,5), much of the phosphorus and nitrogen in the Black Sea surface outflow is utilized by micro-organisms and lost before reaching the Dardanelles. On the other hand, the salty, nutrient deficient Mediterranean water becomes enriched by 5-9 folds during its passage through the Sea of Marmara before reaching the Black Sea. With the help of the surface counter flow and vertical mixing, almost 50% of this nutrient-enriched inflow of salty water is returned back to the Aegean basin while the rest reaches the Black Sea (1). In addition to these flow-nutrient interactions, a baseline data set, obtained at the exits of the Bosphorus and Dardanelles from 1980 through 2000, allowed us to understand the seasonal variations in the nutrient properties of the counter flows in the Turkish Straits (2). For example, when entering the Sea of Marmara, brackish outflow from the Black Sea had low levels of inorganic nutrients (PO_4^{-3}-P < 0.1 μmol L^{-1}; NO_3^-+NO_2^--N < 0.1-0.2 μmol L^{-1}) from spring to fall. On the other hand, surprisingly high nutrient concentrations (PO_4^{-3}-P = 0.3-0.4 μmol L^{-1}; NO_3^-+NO_2^--N = 5-7 μmol L^{-1}) were observed in early winter (2). In this system, net primary production is limited by nitrogen and is highest in regions of high nutrient availability, such as the continental shelf and upwelling areas.

The peaks in the primary productivity of the Black Sea are generally known to occur twice a year (7-13) while the Sea of Marmara normally has a 3-phase sequence (14-16). In the Black Sea, a major diatom bloom occurs in early spring, followed by a secondary bloom, mainly comprising coccolithophores, occurring in late spring. In the Sea of Marmara, diatoms mainly bloom in March while dinoflagellates bloom in April, and coccolithophores bloom in May-July. In addition to early spring diatom blooms, there are some diatom blooms in summer in the Turkish Strait Systems. However, additional summer blooms with a predominance of dinoflagellates and coccolithophores have been increasing in recent years as a result of eutrophication in the Turkish Strait Systems (17-21).

For instance, a study on excessive bloom of coccolithophore *Emiliania huxleyi* (Lohmann) Hay & Mohler, 1967 in June and July 2003 revealed that this species was found to be the dominant species accounting for more than 90% of the phytoplankton assemblage in summer (21). This study (21) also indicated that other important species in summer are *Prorocentrum* spp. and *Ceratium* spp. during the bloom period in the Dardanelles. *Prorocentrum micans* was the second most-abundant species accounting for approximately 5.6% of the total phytoplankton (21). This study indicated advancing of *E.huxleyi* from the Black Sea through the Sea of Marmara and the Dardanelles under favorable conditions. This may be due to the climate changes in addition to the dramatic eutrophication of the system since the 1980s or this occurrence may just be an artifact of the transport of this species by the help of the 2-layer flow regime in the Dardanelles (21).

In this study, we explored the daily and diurnal distributions of inorganic nutrients, chlorophyll a, phytoplankton density, and bio-volume in relation to the other environmental parameters (temperature, salinity, pH, DO, and TDS) of the coastal area in the Dardanelles in the summer period, which has high phytoplankton blooms with a predominance of diatoms, between 3 July and 4 August 2002. We also tried to uncover the connection between eutrophication and existing cell densities among major taxa in the study area. This study can be considered as unique since it contains the first short time series data about the nutrient-phytoplankton interactions with respect to environmental parameters in the summer period in the Dardanelles.

Materials and methods

Definition of study area and sampling period

Sampling station (Figure 1) is located 150 m far from the cost and at 9 m depth. Since the station is located in southeastern part of the Nara cape, it is generally more affected by water characteristics of the southern part than the northern part of the Nara cape (18,19). Although sampling station is also an area near to Çanakkale harbor, it is more affected by flow systems of the Dardanelles than that of the harbor.

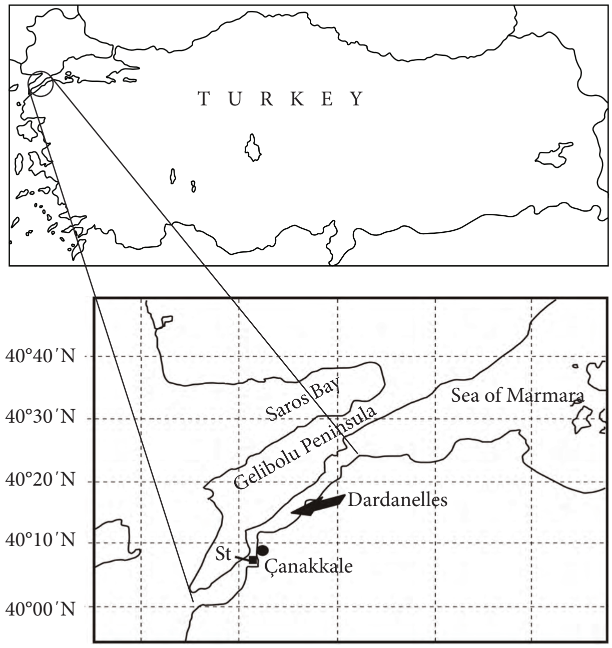

Figure1. Dardanelles and the sampling station (St).

For this study, water quality parameters, phytoplankton, nutrient, and chlorophyll a data were analyzed from 1 station (D) located at 40°09′13″N latitude and 26°24′27″E longitude (Figure 1). The sampling period and frequency were planned as diurnal and daily intervals in the summer period between 3 July 2002 and 4 August 2002. Ninety nine surface (0.5m) samples on 3 different time periods of the day (08:00-09:00, 13:00-14:00, and 18:00-19:00 hours) were collected for nutrient, chlorophyll a, and phytoplankton analyses.

Collection, preservation, and measurement of the samples

Probe (CTD data) measurements

Temperature (T), salinity (S), pH, dissolved oxygen (DO), and total dissolved solids (TDS) were measured in surface water (0.5 m). The water quality parameters were measured in situ using a YSI 556 Model Multiple Water Analysis Probe. Nutrient, chlorophyll a, total suspended solid, and phytoplankton samples were collected from the surface with a Hydro-Bios Universal Series Water Sampler (5 L).

Total suspended solid (TSS) measurements

The water samples were filtered through a pre-weighed GF/F glass fiber filters after the filters were dried for 4 h at 105 °C in an oven. The residues retained on the GF/F glass fiber filters were dried again for 1 h at 105 °C in an oven. Then, the samples were cooled in desiccator to balance the temperature and weighed by a sensitive balance (22). TSS was accepted as an increase in weight of the filter (22).

Nutrient measurements

Nutrient samples were transferred to 100 mL polyethylene bottles and kept frozen until analysis. Nutrient analyses including nitrate (NO^{-}_{3}), nitrite (NO^{-}_{2}), soluble reactive phosphorus (PO^{-3}_{4}), and silicate (SiO_4) were conducted using a Technicon model 2-channel Auto-Analyzer according to Strickland & Parsons (23).

Chlorophyll a measurements

Samples for chlorophyll a determination were obtained immediately after the water sampling. The samples were filtered through GF/F glass fiber filters. Chlorophyll a concentration was analyzed spectrophotometrically after extraction with 90% acetone (23). Filters used for filtration of surface water were wrapped in aluminum foil and kept frozen until analysis.

Phytoplankton cell density and bio-volume measurements

The quantitative phytoplankton samples were preserved with acidic Lugol 2%-4% and kept at 2-4 °C pending microscopic analysis. For enumeration of the phytoplankton species, Uterhmöhl Sedimentation Chambers and Neubauer and Sedgewick-Rafter counting slides were used in combination according to the dimensions of the organisms (24-26). Phytoplanktons were identified under phase-contrast microscopy to the taxonomic level of species (27,28). Depending on the density, sample volumes of 2-8 mL were used. At least 20 random fields of view were counted at 10:00´, 400´, and 200´ magnifications for different cell-size classes of phytoplankton. This resulted in at least 400 individuals counted for each dominant phytoplankton species with a ±10% counting precision within 95% confidence limit (29). Phytoplankton bio-volume was calculated using geometric models improved by Sun & Liu (30) and Biodiversity Pro/BD2.bdp designed and developed by McAleece et al. (31).

Descriptive statistics and correlations of bio-physicochemical data groups were conducted using BioDiversity Pro/BD2.bdp (31,32). The BioDiversity package was devised jointly by P.J.D. Lambshead and G.L.J. Paterson of the Natural History Museum in London and J.D. Gage of the Scottish Association for Marine Science, Oban, Scotland. Growth capacity, growth slope, and growth ratio of phytoplankton were calculated following Venrick (26).

Results

Pearson correlation coefficients of different bio-physicochemical data groups

Pearson correlation coefficients between different biological and physicochemical data groups in the coastal surface waters of the Dardanelles in the sampling period are shown in Table 1.

CTD probe data and total suspended solids (TSS)

Descriptive statistic results of some physicochemical parameters, daily and diurnal distribution of temperature, salinity, pH, dissolved oxygen (DO), total dissolved solids (TDS), and total suspended solids (TSS) in the coastal surface waters of the Dardanelles between 3 July 2002 and 4 August 2002 are shown in Table 2 and Figures 2 and 3.

Temperature and salinity varied between 22.5 and 26.5 °C (mean 25.04 °C) and 22.72 and 23.71 ppt (mean 23.26 ppt), respectively (Table 2). Based on the seasonal temperature, water temperature increased during the sampling period except the values between 23 and 29 July due to vertical mixing between 2-layer flows in the Dardanelles. There was a decrease in temporal cycle of salinity during the sampling period similar to the temporal cycle of TDS (Figure 2). Temporal cycle of pH showed some fluctuations throughout the sampling period (8.31-8.49; mean 8.42) (Table 1). Temporal cycle of pH was more similar to temporal cycle of DO ($r = 0.175$) than the other temporal cycles. pH values in periods of 10-20 July and 25-31 July were significantly higher than those of the other periods (Figure 2).

Table 1. Pearson correlation coefficients between different bio-physicochemical data groups in surface waters of Çanakkale harbor in the Dardanelles in the summer period (N: 99; Sig. 2-tailed).

	Temp	Salin	PH	DO	TSS	TDS	NO^-_2+ NO^-_3	PO^{-3}_4	SiO_4	Chl-a	Dinop	Bacil.	Other Groups	Tot. Phyto
Temp	1													
	.													
Salin	-0.579**	1												
	0.000	.												
pH	0.003	-0.035	1											
	0.975	0.734	.											
DO	0.073	0.090	-0.012	1										
	0.473	0.377	0.906	.										
TSS	-0.003	0.133	0.090	0.024	1									
	0.973	0.190	0.377	0.812	.									
TDS	-0.594**	0.989**	-0.042	0.074	0.098	1								
	0.000	0.000	0.681	0.465	0.336	.								
NO^-_2+NO^-_3	0.001	0.094	-0.270**	0.069	-0.273**	0.089	1							
	0.995	0.356	0.007	0.497	0.006	0.381	.							
PO^{-3}_4	-0.097	0.333**	-0.019	0.189	-0.004	0.306**	0.576**	1						
	0.340	0.001	0.854	0.061	0.973	0.002	0.000	.						
SiO_4	-0.640**	0.504**	-0.056	-0.263**	-0.140	0.527**	0.216*	0.279**	1					
	.000	.000	0.584	0.009	0.167	0.000	0.032	0.005	.					
Chl-a	-.074	-.007	0.208*	-0.049	0.043	0.027	-0.176	-0.095	-0.166	1				
	.465	.946	0.039	0.630	0.672	0.790	0.082	0.347	0.100	.				
Dinophy	-.284**	.313**	0.071	0.019	0.279**	0.304**	-0.171	0.248*	0.141	0.176	1			
	.004	.002	0.484	0.853	0.005	0.002	0.091	0.013	0.164	0.081	.			
Bacilari	0.050	-0.021	0.090	0.129	0.159	-0.023	-0.144	0.090	-0.134	0.570**	0.374**	1		
	0.623	0.836	0.377	0.205	0.115	0.821	0.156	0.377	0.186	0.000	0.000	.		
Others	-0.150	0.316**	0.056	0.404**	0.202*	0.294**	0.101	0.486**	0.102	-0.145	0.392**	0.059	1	
	0.139	0.001	0.580	0.000	0.045	0.003	0.319	0.000	0.313	0.152	0.000	0.560	.	
Tot.Phyto	-0.030	0.060	0.093	0.130	0.215*	0.055	-0.163	0.153	-0.078	0.536**	0.580**	0.971**	0.177	1
	0.770	0.555	0.361	0.198	0.032	0.589	0.107	0.130	0.441	0.000	0.000	0.000	0.079	.

* Correlations are significant at 0.05 level (2-tailed).

** Correlations are significant at 0.01 level (2-tailed).

Table 2. Descriptive statistic results of some physicochemical parameters in the surface waters of the Dardanelles in the summer period.

	Descriptive Statistics				
	N	Min.	Max.	Mean	Std. Dev.
Temperature (°C)	99	22.50	26.50	25.0444	0.97009
Salinity (ppt)	99	22.72	23.71	23.2608	0.23080
pH	99	8.31	8.49	8.4161	0.03747
DO (mg L^{-1})	99	8.46	10.09	9.2621	0.47957
TDS (g L^{-1})	99	23.41	24.32	23.9047	0.21053
TSS (mg L^{-1})	99	16.80	76.00	36.1444	10.68483

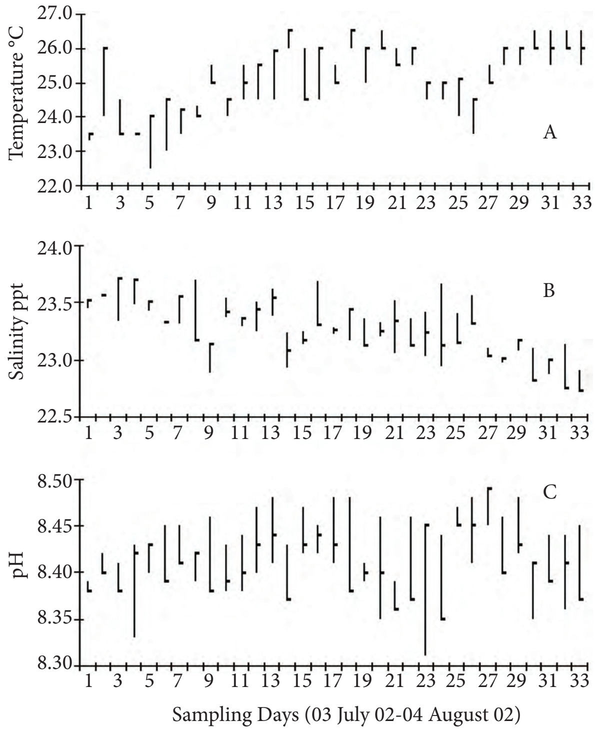

Figure 2. Diurnal distribution of temperature (A), salinity (B), and pH (C) in the Dardanelles in the summer period.

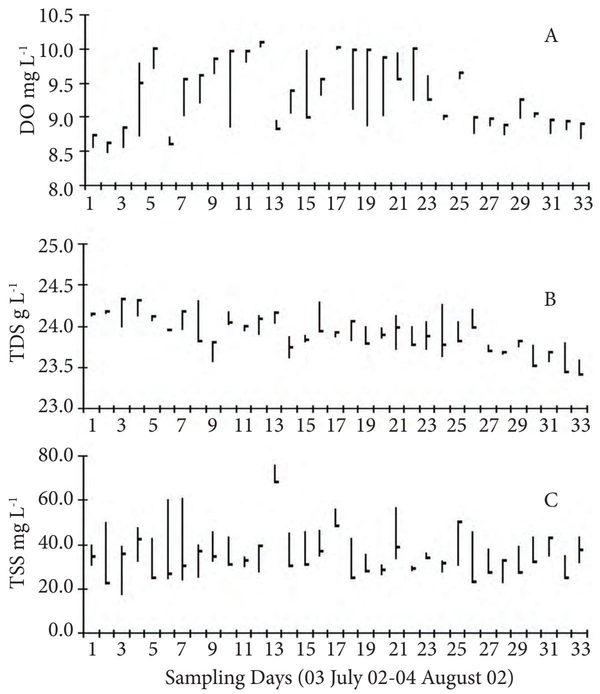

Figure 3. Diurnal distribution of dissolved oxygen (A), total dissolved solids (B), and total suspended solids (C) in the Dardanelles in the summer period.

DO concentrations varied from 8.46 to 10.09 mg L^{-1} (mean 9.26 mg L^{-1}) during the sampling period (Table 2), being lower in early July and early August compared to other sampling dates (Figure 3). However, there was super saturation and high fluctuation level of DO except early and mid-July and early August (Figure 3).

TDS varied from 23.41 to 24.32 mg L^{-1} (mean 23.9 mg L^{-1}) (Table 2) and temporal cycle of TDS were very similar to temporal cycle of salinity (Figure 2). Similar to the temporal cycle of salinity, the cycle of TDS showed that there was a slow decrease from early July to early August (Figure 3).

Due to the fact that Dardanelles have Black Sea surface waters and take in high terrestrial and domestic inputs from Çanakkale city, TSS values varied between 16.8 and 76.0 mg L^{-1} (mean 36.1 mg L^{-1}) during the sampling period (Table 2). The large difference between minimum (16.8 mg L^{-1}) and maximum TSS values (76.0 mg L^{-1}) was based on diurnal fluctuations in time interval between 08:00 and 19:00 hours than daily fluctuations between 3 July and 4 August except TSS values on 15 July (68.0-76.0 mg L^{-1}) (Figure 3).

Nutrients and chlorophyll a

Descriptive Statistics of nutrients, chlorophyll a and N:P and Si:P ratios are shown in Table 3. Daily and diurnal distributions of nutrients and chlorophyll a in the costal surface waters of the Dardanelles during the study period are shown in Table 3 and Figure 4, respectively.

Due to the increase in phytoplankton abundance during the sampling period, N:P ratio (0.44-142.8; mean 10.54) (Table 3) was lower than the assimilatory optimal of the Redfield ratio (33). Generally, the N:P ratio in this study was higher than the previously reported N:P ratios (2.0-7.0; mean 4.22) in the costal surface waters of the Dardanelles (19,34,35). However, Si:P ratio (3.82-125.0; mean 22.52) was generally similar to other Mediterranean ecosystems, such as Eastern Mediterranean (İskenderun Bay) (36) and northern Aegean Sea (Saros Bay) (19, 37). Naturally, the study area is nitrogen limited and low N:P ratio in this study confirmed previously reported values of Polat et al. (6) and Turkoglu et al. (19).

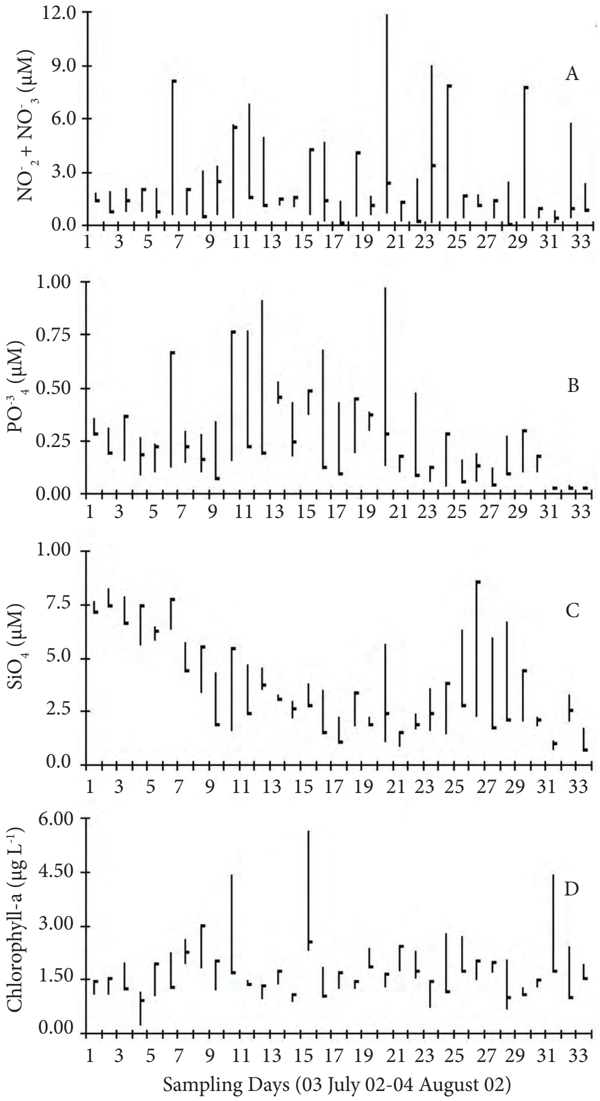

Figure 4. Diurnal distribution of NO^-_2+NO^-_3 (A), PO^{-3}_4 (B), SiO_4 (C), and chlorophyll a (D) in the Dardanelles in the summer period.

Table 3. Descriptive statistics of nutrient, N:P and Si:P ratios, and chlorophyll a in the Dardanelles in the summer period.

	Descriptive Statistics				
	N	Min.	Max.	Mean	Std. Dev.
Nitrite+Nitrate	99	0.04	11.8	1.897	2.150
Phosphate	99	0.02	0.97	0.243	0.198
Silicate	99	0.64	8.50	3.610	2.147
Chlorophyll a	99	0.21	5.62	1.699	0.764
N:P Ratio	99	0.44	142.8	12.50	19.45
Si:P Ratio	99	3.82	125.5	24.97	22.34

NO^-_2+NO^-_3, PO^{-3}_4, and SiO_4 varied from 0.04 to 11.8 (mean 1.897 µM), from 0.02 to 0.97 (mean 0.243 µM), and from 0.64 to 8.50 µM (mean 3.610 µM), respectively, in the coastal surface waters of the Dardanelles (Table 3). There were high fluctuations in nutrient concentrations, especially NO^-_2+NO^-_3 and PO^{-3}_4 concentrations, during the sampling period due to intensive domestic inputs of Çanakkale. Particularly, the level of the diurnal nutrient fluctuations in the time interval of 08:00 and 19:00 hours were higher than the level of the temporal fluctuations in between 3 July and 4 August. The best examples to these fluctuations are minimum and maximum values of NO^-_2+NO^-3 (0.63-11.83 µM) and PO^{-3}_4 (0.13-0.97 µM) in different time periods (08:00-09:00, 13:00-14:00, and 18:00-19:00 hours) of 22 July 2002. However, the temporal fluctuations of the NO^-_2+NO^-_3 and SiO_4 concentrations were more regular than the temporal fluctuation of the PO^{-3}_4 concentrations (Figure 4). Due to some excessive diatom blooms, SiO_4 concentration showed a gradual decrease between 3 and 23 July 2002. Then, SiO_4 increased from 23 July to end of July. Due to other excessive diatom blooms in early August, SiO_4 again reduced to minimal values in first days of August (Figure 4C) similar to the temporal cycle of PO^{-3}_4 (Figure 4B). This similarity between temporal distribution of NO^-_2+NO^-_3 and that of PO^{-3}_4 was supported by the correlation coefficient between NO^-_2+NO^-_3 and PO^{-3}_4 (r = 0.609).

Chlorophyll a concentrations varied from 0.21 to 5.62 µg L^{-1} (mean 1.699 µg L^{-1}) in the coastal surface waters of the Dardanelles during the summer sampling period (Figure 4D). The temporal distribution of chlorophyll a approximately showed a regular undulation (Figure 4D) and the chlorophyll a values were generally similar to the summer results in previous studies (18-20,34,35). Chlorophyll a was more significantly correlated with phytoplankton bio-volume (r = 0.536) than with phytoplankton cell density (r = 0.482).

Phytoplankton cell density and bio-volume

Results of descriptive statistic in density, bio-volume, and rates (%) of different phytoplankton groups are shown in Tables 4 and 5. Daily and diurnal distribution of phytoplankton density and phytoplankton bio-volume in the coastal surface waters of the Dardanelles between 3 July 2002 and 4 August 2002 are also shown in Figures 5 and 6.

Table 4. Results of descriptive statistic in density and bio-volume of different phytoplankton taxonomic groups in the Dardanelles in summer period.

Taxonomic Groups	Samp Time	N	Cell Density (Cell L^{-1})				Bio-volume ($\mu m^3 L^{-1}$)			
			Min	Max	Mean	SD	Min	Max	Mean	SD
Dinophyceae	0800-0900	33	2.20×10^4	8.65×10^5	2.12×10^5	1.71×10^5	9.00×10^7	1.69×10^{10}	4.32×10^9	3.54×10^9
	1300-1400	33	1.47×10^4	8.80×10^5	1.97×10^5	1.60×10^5	3.11×10^8	8.26×10^9	3.53×10^9	2.22×10^9
	1800-1900	33	0.00	4.25×10^5	1.66×10^5	1.13×10^5	0.00	8.42×10^9	3.17×10^9	2.26×10^9
Bacillariophyceae	0800-0900	33	2.42×10^5	1.43×10^7	2.14×10^6	2.66×10^6	1.52×10^9	8.16×10^{10}	1.08×10^{10}	1.42×10^{10}
	1300-1400	33	4.99×10^4	6.93×10^6	1.65×10^6	1.67×10^6	1.36×10^9	3.51×10^{10}	8.07×10^9	6.45×10^9
	1800-1900	33	4.40×10^4	1.07×10^7	1.65×10^6	2.14×10^6	1.53×10^8	3.80×10^{10}	8.32×10^9	8.18×10^9
Other Taxonomic Groups	0800-0900	33	0.00	2.43×10^6	5.82×10^5	6.33×10^5	0.00	1.27×10^9	2.91×10^8	3.34×10^8
	1300-1400	33	0.00	2.93×10^6	6.37×10^5	6.19×10^5	0.00	1.55×10^9	3.01×10^8	3.47×10^8
	1800-1900	33	0.00	2.64×10^6	6.84×10^5	6.57×10^5	0.00	1.38×10^9	2.93×10^8	3.32×10^8
Total Phytoplankton	0800-0900	33	3.08×10^5	1.50×10^7	2.91×10^6	2.66×10^6	2.23×10^9	8.81×10^{10}	1.54×10^{10}	1.60×10^{10}
	1300-1400	33	4.84×10^5	7.41×10^6	2.45×10^6	1.66×10^6	1.94×10^9	3.80×10^{10}	1.18×10^{10}	7.36×10^9
	1800-1900	33	2.86×10^5	1.08×10^7	2.50×10^6	2.11×10^6	5.98×10^9	4.50×10^{10}	1.18×10^{10}	9.50×10^9

Table 5. Descriptive statistic results (%) of different phytoplankton taxonomic groups in the Dardanelles in summer period.

Taxonomic Groups	Sampling Time	N	Ratios (%) Min	Max	Mean	SD
Dinophyceae	0800-0900	33	2.77	63.86	31.06	16.19
	1300-1400	33	5.56	57.58	31.42	13.65
	1800-1900	33	0.00	88.55	30.53	17.76
Bacillariophyceae	0800-0900	33	27.70	97.23	66.56	17.05
	1300-1400	33	38.00	94.35	65.87	14.64
	1800-1900	33	3.51	100.00	66.98	18.81
Other Taxonomic Groups	0800-0900	33	0.00	12.49	2.38	2.89
	1300-1400	33	0.00	17.90	2.71	3.56
	1800-1900	33	0.00	8.83	2.48	2.39

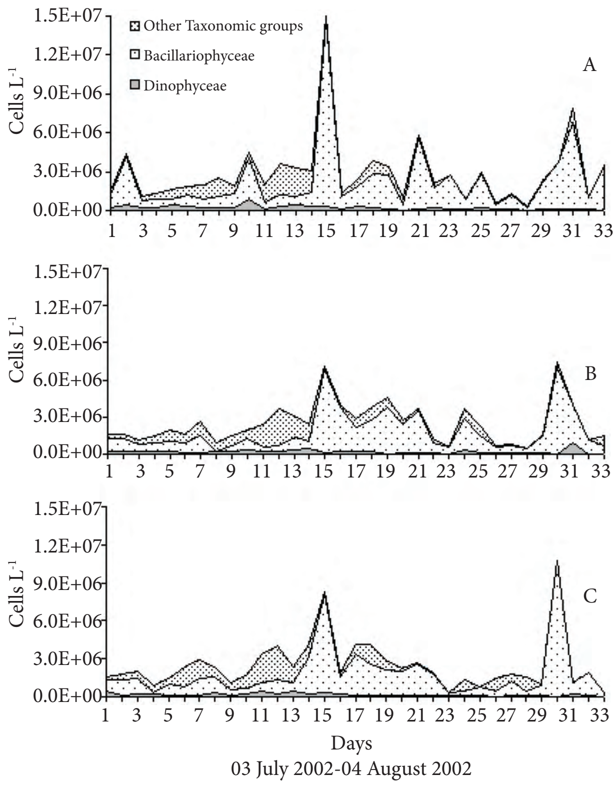

Figure 5. Diurnal fluctuations in the density of different phytoplankton groups in the Dardanelles in the summer period (Sampling times; A: 0800-0900, B: 1300-1400, C: 1800-1900).

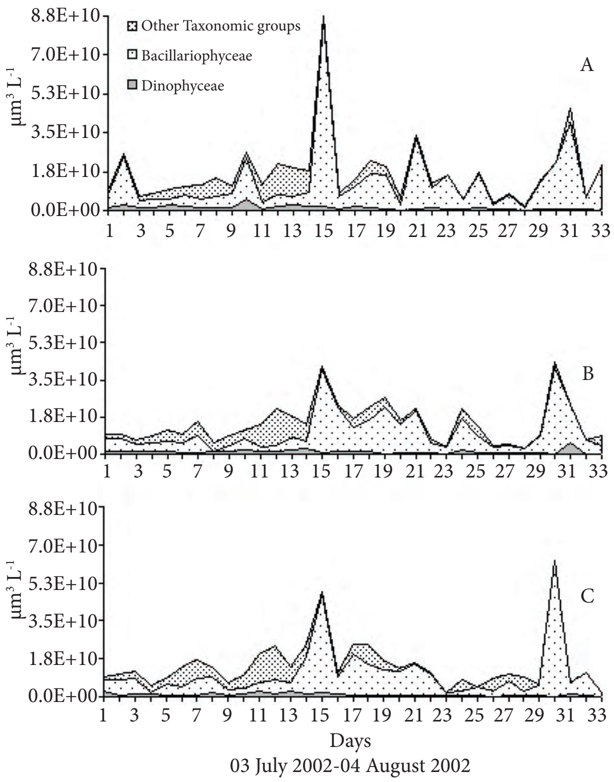

Figure 6. Diurnal fluctuations in bio-volume of different phytoplankton groups in the Dardanelles in the summer period (Sampling times; A: 0800-0900, B: 1300-1400, C: 1800-1900).

While Dinophyceae cell density and bio-volume varied from 0.00 to 8.80×10^5 cells L^{-1} (mean 1.92×10^5 cells L^{-1}) and from 0.00 and 1.69×10^{10} μm^3 L^{-1} (mean 3.67×10^9 μm^3 L^{-1}), Bacillariophyceae cell density and bio-volume varied from 4.40×10^4 to 1.43×10^7 cells L^{-1} (mean 1.81×10^6 cells $L^{-}1$) and from 1.53×10^8 to 8.16×10^{10} μm^3 L^{-1} (mean 9.06×10^9 μm^3 L^{-1}), respectively. Cell density and bio-volume of the other taxonomic groups (Cyanophyceae, Prymnesiophyceae, Dictyochophyceae, and Euglenophyceae) varied from 0.00 and 2.93×10^6 cells L^{-1} (mean 6.34×10^5 cells L^{-1}) and from 0.00 and 1.55×10^9 μm^3 L^{-1} (mean 2.95×10^8 μm^3 L^{-1}). Total phytoplankton cell density and bio-volume also varied from 2.86×10^5 to 1.50×10^7 cells L^{-1} (mean 2.62×10^6 cells L^{-1}) and from 5.98×10^8 to 8.81×10^{10} μm^3 L^{-1} (mean 1.30×10^{10} μm^3 L^{-1}), respectively (Table 4).

Although there were dramatic changes due to various algal blooms during the summer period, phytoplankton growth capacity in the period between 16 July and 4 August 2002 was much higher than the period between 3 July and 16 July 2002 in view of cell density (Figure 5). Although the largest contribution to the total phytoplankton growth was by diatoms (Bacillariophyceae) in the period of high phytoplankton growth capacity, contribution of diatoms was decreased in the period of lower phytoplankton growth capacity in terms of cell density. In the period of lower phytoplankton growth capacity, contribution of other taxonomic groups (Cyanophyceae, Prymnesiophyceae, Dictyochophyceae, and Euglenophyceae) to the total phytoplankton was much higher than contributions of Dinophyceae and Bacillariophyceae in terms of cell density (Figure 5). On the other hand, phytoplankton growth capacity, especially Bacillariophyceae, early in the day (08:00-09:00) was much higher compared to mid-day (13:00-14:00) and later in the day (18:00-19:00) (Table 4 and Figures 5 and 6).

In contrast to cell density, phytoplankton bio-volume levels in the first half period of the sampling period (3-21 July 2002) was much higher compared to the second half of the sampling period (17 July-4 August 2002) due to combinations in dimensions of the organisms (Figure 6). While there were large sized phytoplankton species, such as dinoflagellates *Prorocentrum* spp. (especially *Prorocentrum compressum* (Bailey, 1850) Abé ex Dodge, 1975, *Prorocentrum micans* Ehrenberg, 1834, *Prorocentrum scutellum* Schröder, 19:00 and diatoms *Pseudosolenia calcar-avis* (Schultze) Sundström, 1986, *Pseudo-nitzschia pungens* (Grunow ex P.T. Cleve) Hasle, 1993, in the first half of the study period, there were small sized species, such as diatoms *Chaetoceros* spp. Ehrenberg, 1844, *Cylindrotheca closterium* (Ehrenberg) Reiman and Lewin, 1964, *Leptocylindrus danicus* P.T. Cleve, 1889, *Dactyliosolen fragilissimus* (Bergon) G. R. Hasle, 1991, in the second half of the study period. Due to decrease in *Prorocentrum* spp., there was a fall in the number of dinoflagellates in the second period in terms of both cell density (Figure 5) and bio-volume (Figure 6). In terms of both cell density and bio-volume, although diatoms (Bacillariophyceae) showed some bloom patterns in the summer period (Figures 5 and 6), dinoflagellates (Dinophyceae) showed more regular and stabile fluctuations in the sampling period especially in temporal distribution of bio-volume (Figure 6).

Contributions of Dinophyceae, Bacillariophyceae, and other taxonomic groups (Cyanophyceae, Prymnesiophyceae, Dictyochophyceae, and Euglenophyceae) to the total phytoplankton varied from 0.00% to 88.6% (mean 31.0%), from 3.51% to 100.0% (mean 66.5%), and from 0.0% to 17.9% (mean 2.52%), respectively (Table 5). The major contributions to the total phytoplankton population came from dinoflagellates *P. compressum*, *P. micans, P. scutellum,* and diatoms *Chaetoceros* spp., *C. closterium*, *L. danicus*, *P. pungens*, *P. calcar-avis, D. fragilissimus, E. huxleyi* in the coastal surface waters of the Dardanelles. These species were also responsible for blooms in different times during the sampling period. For instance, diatoms *D. fragilissimus, P. pungens,* and *L. danicus* were responsible for the peak on 17 July 2002.

Although dinoflagellate *P. compressum* was the species responsible for the peak in the temporal distribution of dinoflagellate on 12 July (day 10), diatoms *P. calcar-avis* and *P. pungens* were responsible for the peak in the distribution of diatom on 17 July (day 15) similar to the peak in the distribution of diatom on 12 July (Figures 5 and 6). On the other hand, *D. fragilissimus* contributed to the peak of 17 July in addition to above 2 diatoms. Contribution of the 3 species to diatom peak was above 90% on 17 July. Otherwise, contribution of *P. compressum* to Dinophyceae was above 50% in the peak of 12 July (day 10). Contributions of the 4 species to the total phytoplankton population were between 50% and 75% during the sampling period.

Discussion

The study was carried out to explore not only the daily distributions of inorganic nutrients (NO^-_2+NO^-_3, PO^{-3}_4, and SiO_4), chlorophyll a, phytoplankton density, and bio-volume in the summer period (3 July 2002 and 4 August 2002), but also diurnal distributions of those in very short time intervals (09:00, 14:00 and 18:00 hours) in relation to the other environmental parameters (CTD probe data) in the costal surface waters of the Dardanelles during the sampling period. This study is unique since it contains the first very short time series data about the nutrient, phytoplankton interactions with respect to environmental parameters in the costal surface waters of the Dardanelles.

Due to vertical mixing between 2-layer flows in the Dardanelles, temporal cycle of temperature and salinity were variable like in the other temporal distributions, such as pH, DO, and TDS not only during the full sampling period (3 July and 4 August 2002), but also during the diurnal period (08:00-18:00) (Figures 2 and 3). Temperature distribution showed that there was an unseasonal decrease in temperature between 25 and 29 July 2002 due to intense vertical mixing of the counter-flows in the Dardanelles (Figure 2). In a previous study by Turkoglu et al. (38), temperature and salinity measurements showed high variability in the southern part of the Nara cape in the Dardanelles. The narrowing of the Dardanelles leads to different surface temperature and salinity values in the northeast and southwest of the Nara Cape. The surface waters in the southern part of the Dardanelles were also more saline especially in spring and winter compared to other seasons (18,19,38). Additionally, salinity variations affect other biological and physicochemical variations due to different characters of the lower layer waters. For instance, correlations between salinity and other physicochemical parameters indicated that TDS (r = 0.999) and temperature (r = -0.613) were strongly affected by salinity variations. Especially, the negative correlation between salinity and temperature had arisen from lower temperature values in the lower layer compared to the surface layer temperature in the summer period. At the same time, there were super saturation levels of DO (8.46 to 10.09 mg L^{-1}) in early July and early August due to vertical mixing and phytoplankton blooms. However, there were high fluctuation levels of DO in the sampling period.

Due to inputs from coastal area and Black Sea surface waters, TSS values were found in high levels (16.80 and 76.0 mg L^{-1}; mean 36.14 mg L^{-1}) in the costal surface waters of the Dardanelles during the summer period. However, these high TSS values were not related with phytoplankton and it was supported by low correlation coefficients between TSS and phytoplankton (r = 0.215) (Table 1). However, the correlation between Dinophyceae and TSS (r = 0.279) and between other taxonomic groups and TSS (r = 0.202) were higher than the correlation between Bacillariophyceae and TSS (r = 0.159). This relationship showed that Dinophyceae growth will able to be much higher than Bacillariophyceae growth in coastal marine systems having high TSS levels. However, it is known that TSS is not only dependent on quantity of non-living suspended inorganic particulate material in waters, but on the quantity of suspended organic particulate material, such as phytoplankton, as well. It is also known that the effect of phytoplankton, especially Bacillariophyceae, on TSS in offshore ocean waters was higher compared to coastal waters (39).

Daily and diurnal distributions of NO^-_2+NO^-_3 (0.04-11.8; mean 1.897 µM), PO^{-3}_4 (0.02-0.97; mean 0.243 µM), and SiO_4 (0.64-8.50; 3.610 µM) have showed periodic fluctuations similar to the temporal cycle of the phytoplankton cell density and bio-volume in the coastal surface waters of the Dardanelles. Besides the temporal variations in the nutrient concentrations, the southern part of the Dardanelles receives notable nutrient inputs due to domestic wastes from Çanakkale (34,35) and from the rivers such as Sarıçay and Kalabaklı (1,6,38). Therefore, in some periods (especially 8, 12-13, 17-18, 22, 25-26, and 31 July 2002) of this study, extra accumulation of inorganic nutrients, especially NO^-_2+NO^-_3 and PO^{-3}_4 were highly pronounced as connected with flow direction and speed. Additionally, the observed maximum values in different periods were principally due to entrainment of the inorganic nutrient-enriched salty Mediterranean waters from the lower layer by intense vertical mixing with the western basin surface layer. Therefore, the differences between diurnal temporal (08:00-19:00 hours) levels of NO^-_2+NO^-_3 and PO^{-3}_4 were higher than the differences between daily temporal (3 July-4 August 2002) levels of NO^-_2+NO^-_3 and PO^{-3}_4 in some periods of the study period. However, the temporal fluctuation of the PO^{-3}_4 was more regular than temporal fluctuation of the NO^-_2+NO^-_3. As a result of the high diurnal fluctuations, differences between minimum and maximum levels of NO^-_2+NO^-_3 and PO^{-3}_4 showed that the difference in NO^-_2+NO^-_3 (0.04-11.76) was much higher than the difference in PO^{-3}_4 (0.02-0.97) in the summer period. In fact, it has been shown that nutrient concentrations encountered in the Mediterranean waters are controlled by the exchanges at the straits (39).

On the other hand, during its passage through the Dardanelles, the Black Sea surface water outflow loses much of its phosphorus and nitrogen through utilization and vertical loss (1). Additionally, the salty Mediterranean inflow to the Marmara deep basin through the Dardanelles contains low nutrient concentrations (1). However, levels of NO^-_2+NO^-_3 (0.04-11.76; mean 1.90 µM) and PO^{-3}_4 (0.02-0.97; mean 0.24 µM) in this study were much higher than summer levels between 1995 and 1999 and in July 2001 in the same study area (34,35,40). It is known that there was an increase in nutrient concentrations in the summer period (especially in July) in addition to peaks in spring, winter, and autumn periods in the costal surface waters of the Dardanelles (19, 34, 35, 40).

According to the values of correlation between salinity and other nutrients (Table 1), higher positive correlation between SiO_4 and salinity (r = 0.504) revealed that SiO_4 was more affected from salty deep waters of the Dardanelles than the domestic waste waters of Çanakkale. On the other hand, high nutrient concentration levels in early hours (09:00-10:00) of the day caused high phytoplankton growth capacity in the same periods of the day during the sampling period (Figures 5 and 6). In contrast to other variations, although phytoplankton growth capacity in early hours of the day was much higher than other time periods of the day, daily variations of phytoplankton between 3 July and 4 August were generally much higher than diurnal variations between 08:00 and 18:00 hours due to algal blooms in different times during the sampling period.

While there was gradually decreased in SiO_4 concentration in the period of the high diatoms growth (between 3 and 23 July 2002), there was an increase in the period of the low diatom growth (between 23 and 30 July 2002). This similarity between temporal distribution of SiO_4 and diatoms was supported by significant negative correlation coefficient between them at the 0.01 level (r = -0.295). On the other hand, the negative correlation between SiO_4 and diatom cell density (r = -0.295) was more significant than between SiO_4 and diatom bio-volume (r = -0.134) (Table 1). These correlations showed that utilization of SiO_4 by diatoms was more connected with diatom cell density than with diatom cell volume.

The chlorophyll a concentrations ranged from 0.21 to 5.62 µg L^{-1} (1.70 µg L^{-1}) in the summer periods. The observed mid-July (12 July and 17 July 2002) and early August (2 August 2002) maxima were principally due to diatom (*P. pungens*, *P. calcar-avis*, and *D. fragilissimus*) and dinoflagellate (*P. compressum*) blooms in the study area. Despite maximum values of chlorophyll a on 12 July, 2 August 2002 (4.42 µg L^{-1}) and 17 July 2002 (5.62 µg L^{-1}), average chlorophyll a concentration (1.70 µg L^{-1}) was under the 2 µg L^{-1} during the study period. High chlorophyll a values and phytoplankton production capacity showed that costal surface waters of the Dardanelles has high eutrophication structure in summer period. Average chlorophyll a value (1.70 µg L^{-1}) in this study was lower than July 2001 (3.34 µg L^{-1}), July 2002 (3.17 µg L^{-1}), and July 2003 chlorophyll a values (2.94 µg L^{-1}) in the southern area of the Dardanelles (19). However, the average value in this study was higher than in the Aegean Sea (37,41) and in other parts of the Mediterranean Sea (Salihoğlu et al., 1990). This study showed that the relationship between chlorophyll a and phytoplankton (r = 0.536) was significant at 0.01 level. This situation validates dramatic undulation in diurnal variations of chlorophyll a, especially on 12 (day 10), 17 July (day 15) and 2 August 2002 (day 31).

However, this dramatic undulation is more affected by diatoms (r = 0.570) than dinoflagellates (r = 0.176).

High nutrient concentrations and high phytoplankton densities in the study period showed that surface waters of Dardanelles can be eutrophicated from time to time, comparable to their levels in the Black Sea (9,10,12,13,42) and in the Sea of Marmara (1,4). Phytoplankton community structure was observed to be controlled by 1-2 dinoflagellates (*P. compressum* and *P. micans*), 3-4 diatoms (*P. pungens*, *P. calcar-avis*, *D. fragilissimus,* and *Chaetoceros* spp.) and a globally significant coccolithophore (*E. huxleyi*) in the early summer period in the costal surface waters of the Dardanelles as shown in eutrophicated ecosystems, such as the Sinop Bay in the Black Sea (10,12,13,42) and İskenderun Bay in the eastern Mediterranean (43). Other species can be considered as insignificant species not causing important fluctuations in the phytoplankton density and bio-volume as shown by many researchers (9,10,12,13,44,45). This study showed that the relationship between chlorophyll a and Bacillariophyceae (r = 0.570) was more important than the relationship between chlorophyll a and Dinophyceae (r = 0.176) and between chlorophyll a and other taxonomic groups (r = -0.145). These relationships between chlorophyll a and the major taxonomic groups of phytoplankton showed that chlorophyll a was highly controlled by species of Bacillariophyceae than those of Dinophyceae and other taxonomic groups. In fact, the very important relationship between Bacillariophyceae and total phytoplankton (r = 0.702) also support the important contribution of Bacillariophyceae to the total phytoplankton population.

It has been showed that there are 9-11 population growth slopes for different species, such as dinoflagellates *P. compressum* and *P. micans* and diatoms *P. pungens*, *P. calcar-avis*, *D. fragilissimus* at different times and different densities in the costal surface waters of the Dardanelles during the summer period (Figures 6 and 7). Therefore, it can be said that life cycles of phytoplankton species are completed between 3-4 days. It was shown in a similar study carried out in Mersin harbor between 1995 and 1997 that growth rate of *P. micans* was ~3.37 day L^{-1} (46). Due to the fact that dinoflagellates *Prorocentrum* spp., such as *P. compressum* and *P. micans,* were chiefly dominant phytoplankton species together with diatom species, such as *P. pungens* and *P. calcar-avis,* in the study area, population growth rate of phytoplankton was similar to the one observed in Mersin harbor (46).

Conclusion

As a result, diurnal variations of biological and physicochemical parameters between 08:00 and 18:00 hours were generally much higher than daily variations between 3 July and 4 August due to 2 counter-flow systems of the Dardanelles and domestic inputs of Çanakkale.

We also revealed that the process of eutrophication is accompanied by a shift in the existing cell density relations among major taxa due to high nutrient concentrations. Although coastal surface waters of the Dardanelles are originated from the Black Sea surface waters polluted by various terrestrial sources, contribution of dinoflagellates (30.5%-31.4%) were much lower than contribution of diatoms (65.9%-67.0%) to the total phytoplankton population in the costal surface waters of the Dardanelles. On the other hand, contributions of Dinophyceae species (52.0%-59.1%) to the total phytoplankton population were much higher than contributions of Bacillariophyceae species (39.8%-42.7%) to the total phytoplankton population in the Black Sea (Sinop Bay) (9,12,13). While contributions of Bacillariophyceae to the total phytoplankton population were gradually decreasing, contributions of Dinophyceae and other mixotrophic taxonomic groups to the total phytoplankton population were gradually increasing in marine systems polluted by terrestrial inputs. In fact, a previous study in the Black Sea (Sinop Bay) during 1995 and 1996 showed that contributions of dinoflagellates (52.0%-59.1%) were much higher than the contributions of diatoms (39.8%-42.7%) to the total phytoplankton population in the summer period (8,9,12,42). Although surface waters of the Dardanelles are the origin of the Black Sea surface waters, it can be said that surface waters of the Dardanelles was less polluted than the Black Sea according to contributions of different taxonomic groups to total phytoplankton. As stated in many studies (1,4,5), since much of the nutrients in the Black Sea surface outflow is utilized by phytoplankton and lost before reaching the Dardanelles due to vertical sinking, nutrient concentrations of the Dardanelles remain generally lower than the values of the Black Sea (12,13).

Acknowledgments

This study was funded by COMU- BAP Project # 2002/02. The material in this manuscript was derived in part from the master's thesis of Yasemin Erdoğan.

Corresponding Author:

Muhammet TÜRKOĞLU

Çanakkale Onsekiz Mart University,

Fisheries Faculty,

Hydrobiology Department,

Marine Biology Section,

Terzioğlu Campus,

17100 Çanakkale - Turkey

E-mail: mturkoglu@comu.edu.tr

References

1. Polat SC, Tugrul S. Chemical exchange between the Mediterranean and Black Sea via the Turkish strait. Bull. Inst. Oceanography 17: 167-186, 1996.
2. Tugrul S, Polat C, Basturk O et al. Chemical properties of the two-layer flow regimes in the Turkish Straits. Turk J Mar Sci 2/3: 81-94, 1995.
3. Orhon D, Uslu O, Meric S et al. Wastewater management for Istanbul: Basis for treatment and disposal. Environ Pollut 84: 167-178, 1994.
4. Polat SC, Tugrul S. Nutrient and organic carbon exchanges between the Black and Marmara seas through the Bosphorus. Cont Shelf Res 15: 1115-1132, 1995.
5. Basturk O, Tugrul S, Yilmaz A et al. Health of the Turkish Straits: Chemical an environmental aspects of the Sea of Marmara. METU Institute of Marine Science Technical Report, 1990.
6. Polat SC, Tugrul S, Coban Y et al. Elemental composition of seston and nutrient dynamics in the Sea of Marmara. Hydrobiologia 363: 157-167, 1998.
7. Feyzioğlu M. Seasonal variations in phytoplankton dinamic of coastal ecosystem in the easthern Black Sea. Ph.D Thesis, Karadeniz Tecnic University, Natural And Applied Sciences Institute, 1996.
8. Turkoglu M. Phytoplankton Composition and effects of Bio-Ecologic factors of Middle Black Sea Area (Coasts of Sinop Peninsula). Ph.D Thesis, Ege University, Natural And Applied Sciences Institute, 1998 (in Turkish).
9. Turkoglu M. Some fluctuations in phytoplankton community structures of the Black Sea. E.U. Journal of Fisheries and Aquatic Science 16 (1-2): 201-217, 1999 (in Turkish).
10. Turkoglu M. Succession of picoplankton (coccoid cyanobacteria) in the Southern Black Sea (Sinop Bay, Turkey). Pak J Bio Sci 8 (9): 1318-1326, 2005.
11. Tufekçi V. İstanbul Boğazı İle Boğazın Marmara Denizi ve Karadeniz Girişindeki Fitoplankton Dağılımı, Doktora Tezi, İstanbul Üniversitesi Deniz Bilimleri ve İşletmeciliği Enstitüsü, 2000.
12. Turkoglu M, Koray T. Phytoplankton species succession and nutrients in Southern Black Sea (Bay of Sinop). Turk J Bot 26: 235-252, 2002.
13. Turkoglu M, Koray T. Algal Blooms in Surface Waters of the Sinop Bay in the Black Sea, Turkey. Pak. J. Bio Sci 7 (9): 1577-1585, 2004.
14. Sorokin YUI. The Black Sea. In: Ketchum PH. ed. Ecosystems of the world: Estuaries and enclosed seas. Elsevier; 1983: pp. 253-291.
15. Hay BJ, Honjo S, Kepme S et al. Interannual variability in particle flux in the south-western Black Sea. Deep-sea Research 37 (6): 911-928, 1990.
16. Uysal Z, Sur HI. Net phytoplankton discriminating patches in winter in Southern Black Sea. Oceanologica Acta 18 (6): 639-647, 1995.
17. Uysal Z. A net plankton study in the Bosphorus junction of the Sea of Marmara. Turk J Bot 20: 321-327, 1995.
18. Unsal M, Turkoglu M, Yenici E. Biological and physicochemical researches in the Dardanelles (Canakkale Strait), TUBITAK-YDABAG Technical Final Report, No: 101Y075, 2003 (unpublished).
19. Turkoglu M, Unsal M, Ismen A et al. Dinamics of lower and high food chain of the Dardanelles and Saros Bay (North Aegean Sea). TUBITAK-YDABAG Technical Final Report, No: 101Y081, 2004a (in Turkish).
20. Turkoglu M, Buyukates Y, Kaya S. Excessive Blooms of Coccolithophore *Emiliania huxleyi* and some dinoflagellates in the Dardanelles. Turkish Journal of aquatic Science 2 (3): 423-423, 2004b (in Turkish).

21. Turkoglu M. Synchronous blooms of the coccolithophore Emiliania huxleyi (Lohmann) Hay & Mohler and three dinoflagellates in the Dardanelles (Turkish Straits System). Journal of the Marine and Biological Association of the United Kingdom 88 (3): 433-441, 2008.

22. APHA. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington DC; 1998.

23. Strickland JDH, Parsons TR. A practical handbook of seawater analysis. Bulletin Fisheries Research Board. Canada; 1972.

24. Guillard RRL. Counting slides. In: Sournia A. ed. Phytoplankton Manual. Unesco; 1978: pp. 182-189.

25. Hasle GR. Using the inverted microscope. In: Sournia A. ed. Phytoplankton Manual. Unesco; 1978: pp. 191-196.

26. Venrick EL. How many cells to count? In: Sournia A. ed. Phytoplankton Manual. Unesco; 1978: pp. 167-180.

27. Tregouboff G, Rose M. Manuel de Planctonologie Mediterraneenne: Texte et Illustrationes. Centre National De la Resherche Scientifique, Paris; 1957.

28. Cupp EE. Marine Plankton Diatoms of the West Coast of North America. University of California Press. Berkeley and Los Angeles; 1977.

29. Lund JWG, Kipling C, LeCren ED. The inverted microscope method of estimating algal numbers and the statistical basis of estimations by counting. Hydrobiologia 11: 143-170, 1958.

30. Sun J, Liu D. Geometric models for calculating cell biovolume and surface area for phytoplankton. Journal of Plankton Research 25: 1331-1346, 2003.

31. McAleece N, Lambshead PJD, Paterson GLJ et al. Biodiversity Pro. A program research for ecological data. http://www.nrmc.demonco.uk, 1999.

32. SPSS. Advanced statistics™ 6.1., SPS Inc. Chicago; 1994.

33. Redfield AC, Ketchum BH, Richards FA. The influence of organisms on the composition of seawater. In: Hill MN. Ed. The sea, ideas and observations on progress in the study of the seas. New York; 1963: pp. 26-77.

34. Turkoglu M, Yenici E, Ismen A et al. Variations of Nutrient and Chlorophyll a in the Canakkale Strait (Dardanelles). E.U. Journal of Fisheries and Aquatic Science 21 (1-2): 93-98, 2004c (in Turkish).

35. Turkoglu M, Buyukates Y, Kaya S. Temporal Distribution of Phytoplankton and Nutrients in the Dardanelles. Turkish Journal of aquatic Science 2 (3): 201-201, 2004d (in Turkish).

36. Yılmaz A, Basturk O, Saydam C et al. Eutrophication in Iskenderun Bay, North-eastern Mediterranean. In: Vollenweider RA, Marchetti R, Viviani R. ed. Marine Coastal Eutrophication Science Total Environment Supply (Species Issue). Elsevier, Amsterdam; 1992: pp. 705-717.

37. Kucuksezgin F, Balci A, Kontas A et al. Distribution of nutrients and chlorophyll a in the Aegean Sea. Oceanologica Acta 18: 343-352, 1995.

38. Turkoglu M., Baba A, Ozcan H. Determination and Evaluation of Some Physicochemical Parameters in the Dardanelles (Canakkale Strait-Turkey) Using Multiple Probe System and Geographic Information System. Nordic Hydrology 37 (3): 293-301, 2006.

39. Besiktepe S, Sur HI, Ozsoy E et al. The circulation and hydrography of the Marmara Sea. Prog. Oceanography 34: 285-334, 1994.

40. Turkoglu M, Kaya S, Yenici E. Dinamic and time series of phytoplankton in the Dardanelles. Canakkale Onsekiz Mart Univ., Scientific Research Project (BAP), No: 2000/22, 2003 (in Turkish).

41. Koray T. Phytoplankton species succession, diversity and nutrients in neritic waters of the Aegean Sea (Bay of İzmir). Turk J Bot 19: 531-544, 1995.

42. Turkoglu M, Koray T. Ecological and geographical distributions of the planktonic protista in the southern part of the Black sea (neritic waters of Sinop peninsula, Turkey). E.U. Journal of Fisheries and Aquatic Science 17 (1-2): 161-178, 2000.

43. Polat S, Sarihan E, Koray T. Seasonal Changes in the Phytoplankton of the Northeastern Mediterranean (Bay of Iskenderun). Turk J Bot 24: 1–12, 2000.

44. Pielou EC. Ecological Diversity. Printed in the USA. Dalhousie University, Halifax, Nova Scotia, 1975.

45. Lukatelich RJ, McComb AJ. Nutrient levels and the development of diatom and blue-green algal blooms in a shallow Australian estuary. Journal of Plankton Research 8: 597-618, 1986.

46. Eker E, Kıdeys AE. Weekly Variations in Phytoplankton Structure of a Harbour in Mersin Bay (north-eastern Mediterranean). Turk J Bot 24:13-24, 2000.