Journal of the Marine Biological Association of the United Kingdom, 2008, 88(3), 433–441. ©2008 Marine Biological Association of the United Kingdom
doi:10.1017/S0025315408000866 Printed in the United Kingdom

Synchronous blooms of the coccolithophore *Emiliania huxleyi* and three dinoflagellates in the Dardanelles (Turkish Straits System)

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This study focuses on the synchronous blooms of the coccolithophore Emiliania huxleyi *and three dinoflagellates* Prorocentrum micans, Ceratium furca *var.* furca *and* Ceratium fusus *var.* seta *observed between 7 June and 11 July 2003 in the Dardanelles. An analysis of the vertical distribution of the* E. huxleyi *population size with respect to various environmental parameters was discussed. Additionally, inorganic nutrients and phytoplankton interactions were investigated in relation to the bloom conditions and hydrography of the Dardanelles. The algal bloom started in nearby Izmit Bay (eastern end of the Sea of Marmara) in early June, then quickly spread through the Sea of Marmara and continued until mid-July. Thermal stratification was observed between different water masses at the time of sampling. During the bloom period, cell density of* E. huxleyi *ranged from 3.58×10^7 to 2.55×10^8 cells l^{-1} in the superficial layer.* Prorocentrum micans *was the second most-abundant species and the cell numbers ranged from 1.0×10^6 cells l^{-1} to 3.3×10^6 cells l^{-1}. Other abundant species in this area included* C. furca *var.* furca *and* C. fusus *var.* seta.

Keywords: Dardanelles; algal blooms; *Emiliania huxleyi*; three dinoflagellates; species interactions

Submitted 27 June 2007; accepted 16 October 2007

INTRODUCTION

The Dardanelles is a very important water passage connecting the Aegean Sea and the Marmara Sea. It has two current systems. One of the currents is derived from the Aegean Sea, where the water density is high. The other comes from the Sea of Marmara, characteristically of low density. Aegean water is typically flowing from the south-west to north-east under the Marmara Sea water. Its north-east–south-west trend is interrupted by a north–south bend between Eceabat and Canakkale. In addition to the bend, there is a second bend 'Nara Cape'. The width of the Strait varies from 1.35 to 7.73 km, the narrowest part located between Canakkale and Kilitbahir. The average depth of the Strait is approximately 60 m; the deepest part reaches more than 100 m (Unsal *et al.*, 2003; Turkoglu *et al.*, 2004a, 2006; Baba *et al.*, 2007).

Emiliania huxleyi (Lohmann) Hay & Mohler is one of the most abundant coccolithophores occurring globally in all oceans, except polar ones. They drift freely and prefer the surface layer of the ocean. This species has received considerable attention since it tends to produce massive blooms under favourable conditions (Balch *et al.*, 1991, 1992; Nanninga & Tyrrell, 1996; Hattori *et al.*, 2004; Smyth *et al.*, 2004). High surface irradiance, shallow stratification with a mixed layer depth of about 10–20 m, anomalies in salinity and temperature, low phosphate and silicate concentrations favour the bloom of this species (Egge & Heimdal, 1994; Nanninga & Tyrrell, 1996; Smyth *et al.*, 2004; Zeichen & Robinson, 2004). During these blooms the numbers of *E. huxleyi* cells usually outnumber those of other species, frequently accounting for 80 or 90% or more of the total number of phytoplankton cells.

One significant problem of high concentrations or 'blooms' of *E. huxleyi*, is to alter ecological conditions of a region by acting as a source of organic sulphur (i.e. dimethyl sulphide) to the atmosphere (Balch *et al.*, 1992; Burkill *et al.*, 2002) and calcium carbonate to the sediments (Balch *et al.*, 1996; Tekiroglu *et al.*, 2001). Additionally, high cell concentrations can cause the water colour to change to a milky white or turquoise due to significant changes in the inherent optical properties of water (Brown & Yoder, 1994; Cokacar *et al.*, 2001, 2004; Smyth *et al.*, 2004). Therefore, documenting the occurrence of blooms in time and space is essential to characterize the biogeochemical environment of a target region.

Thus, the major aim of this study is to explain the bioecological effects of *E. huxleyi* blooms in the Dardanelles. This study focuses on the vertical distribution of the coccolithophore *E. huxleyi* and three dinoflagellates *P. micans*, *C. furca* var. *furca* and *C. fusus* var. *seta* against various environmental parameters. Furthermore, inorganic nutrients and chlorophyll-*a* were investigated in relation to the blooms and hydrography of the Dardanelles. According to previous similar studies, this study can be considered as unique since it contains information on the detailed discussions of the bloom of *E. huxleyi* in the Dardanelles and interactions of this species with other phytoplankton species in response to environmental parameters.

MATERIALS AND METHODS

The Dardanelles is located between the Aegean Sea and the Sea of Marmara, Canakkale, Turkey. The location of the sampling station (St; 40°09′ N 26°24′ E) is given in Figure 1. Water

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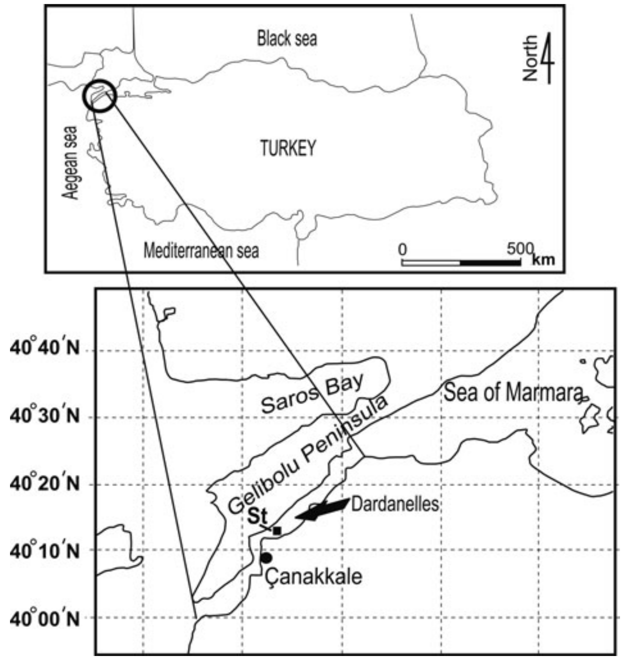

Fig. 1. Map of the Dardanelles and the location of the sampling station (St; 40°09′ N 26°24′ E).

samples were collected using a Nansen sampling bottle for the analysis of nutrients, phytoplankton enumeration and chlorophyll-*a* from the following depths: 0.1, 0.5, 1.0, 2.5, 5.0, 7.5, 10, 25 and 50 m. Weekly samplings were conducted between 5 June and 11 July, 2003.

Water quality parameters such as temperature, salinity, pH and dissolved oxygen (DO) were measured *in situ* using an YSI 6600 Model Multiple Water Analysis Probe during the time of each sampling.

Water for nutrient samples was kept frozen until analysis. Analyses for nitrite (NO_2^-), nitrate (NO_3^-), inorganic phosphate (PO_4^{-3}) and silicate (SiO_4) were conducted using a Technicon model auto-analyser according to the method of Strickland & Parsons (1972).

Chlorophyll-*a* samples were filtered through GF/F glass fibre filters. The filters were folded into aluminium foil and immediately frozen for the laboratory analysis. Chlorophyll-*a* was determined spectrophotometrically after extraction by 90% acetone (Strickland & Parsons, 1972).

For quantitative analysis of phytoplankton, two litres of water samples collected with a Nansen bottle were preserved with 2% buffered formalin (v/v) and microscopic analysis was conducted within a week of the collection. Utermöhl sedimentation chambers and Neubauer and Sedgwick-Rafter counting slides were used in combination for enumeration of the phytoplankton species depending on the dimensions and concentrations of the organisms (Guillard, 1978; Hasle, 1978; Venrick, 1978). Finally, Pearson correlation analysis among data groups within the surface, interface and deep layers was conducted separately using the Statistical Package for the Social Sciences 11.5 (SPSS, 2003). In some cases linear regression relationships were also obtained. All variables except pH were previously $\log_{10}$ transformed to improve linearity, as well as the normality and homogeneity of variances (Quinn & Keough, 2002).

The time-sequence of SeaWiFS true colour images of the Sea of Marmara and the Dardanelles showing the initiation, development and the decay of the *E. huxleyi* bloom in early summer 2003 were provided by Norman Kuring of the NASA SeaWiFS Project and the Goddard Earth Sciences Distributed Active Archive Center.

RESULTS

Vertical profiles of temperature and salinity suggest two different water masses during the *E. huxleyi* bloom (Figure 2A & B). A thin upper layer (0–15 m) had salinity values of 22.3–25.4 ppt while a much thicker lower layer (25–60 m) had salinity values of 36.5–38.5 ppt. However, temperature variations in both the upper layer (19.1–26.4°C) and lower layer (13.8–18.9°C) were more variable than salinity variations. Both seasonal thermocline and halocline interfaces were clear and formed between 15 and 25 m during the algal blooms (Figure 2A & B).

During the bloom, pH values changed from 8.01 to 8.20 in the upper layer and from 7.72 to 7.96 in the lower layer

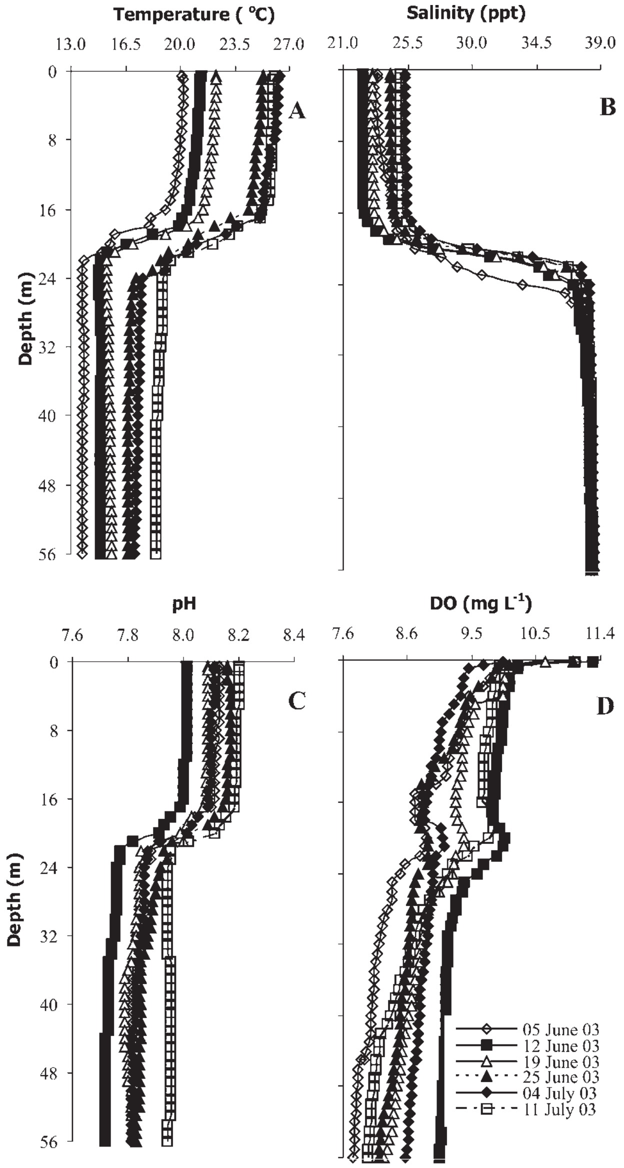

Fig. 2. The vertical profiles of (A) temperature (B) salinity (C) pH and (D) dissolved oxygen during the *Emiliania huxleyi* bloom in the Dardanelles.

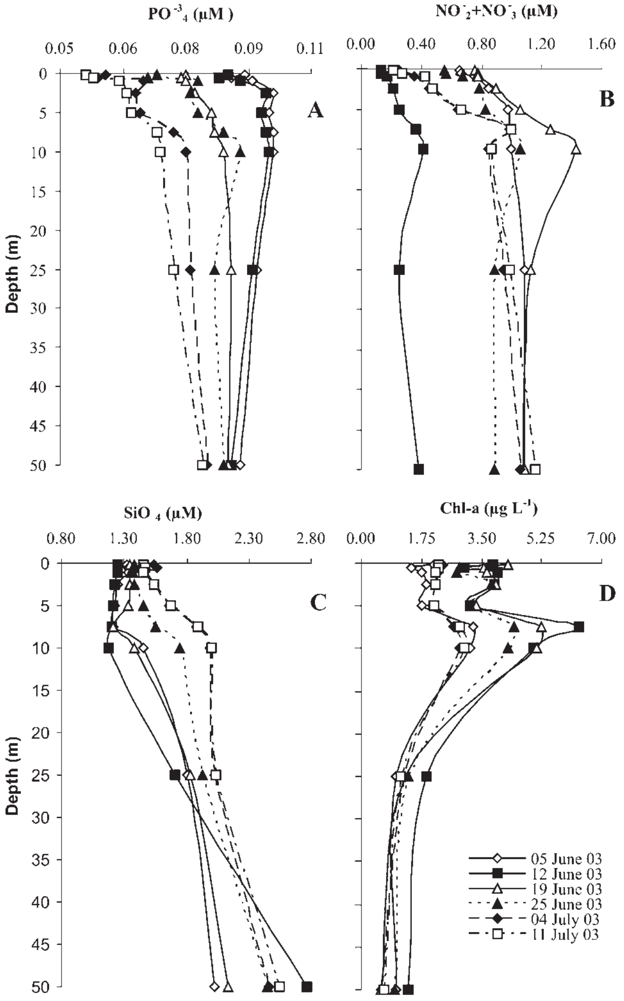

Fig. 3. The vertical profiles of (A) PO_4^{-3}, (B) $NO_2^- + NO_3^-$, (C) SiO_4 and (D) chlorophyll-*a* during the *Emiliania huxleyi* bloom in the Dardanelles.

(Figure 2C). However, DO values changed from 8.67 to 11.3 mg l^{-1} in the upper layer and from 7.75 to 9.01 mg l^{-1} in the lower layer. DO values in both upper and lower layer of the Dardanelles revealed high saturation (Figure 2D). According to the temperature and salinity values, it was calculated that DO values above 8.0 mg l^{-1} are high saturation values in both the upper layer and in the lower layer during the bloom. High saturated DO concentrations gradually decreased from the upper to the lower layer during the bloom.

Vertical profiles of inorganic nutrients showed that the concentrations in the upper layer were lower than the concentrations in the lower layer during bloom conditions (Figure 3A, B & C). Nutrient concentrations increased from the surface to 10 m. $NO_2^- + NO_3^-$ had a peak value (1.5 μM) at 10 m. Below 10 m, all nutrients but silicate gradually decreased with depth. Silicate concentrations increased rather dramatically with depth (Figure 3C). N:P, Si:P and Si:N ratios are displayed in Figure 4A, B & C, respectively. N:P ratios were significantly lower than the assimilatory optimal of the Redfield ratio (Figure 4A). On the other hand, it is observed that the mean Si:P ratios were higher in the lower layer than in the upper layer (Figure 4B). N:P ratios ranged from 1.58 to 16.96 (mean 9.11 ± 3.95) while Si:P ratios ranged from 12.32 to 28.98 (20.91 ± 5.97) in the upper layer during the bloom conditions. However, Si:N ratios varied between 1.23 and 9.34 (mean 3.07 ± 2.16) in the upper layer and between 1.62 and 7.19 (mean 2.89 ± 1.93) in the lower layer during the bloom in the Dardanelles (Figure 4C).

Chlorophyll-*a* concentrations ranged from 1.5 to 6.5 μg l^{-1} in the upper layer (Figure 3F). The chlorophyll-*a* maximum was observed at about 7.5–10 m, the same depth as the $NO_2^- + NO_3^-$ peak (Figure 3D).

The time-sequence of SeaWiFS images in Figure 5 shows the development of the *E. huxleyi* bloom in the Sea of Marmara in early summer 2003. The turquoise colour indicates the regions with the highest coccolith accumulations. The algal bloom

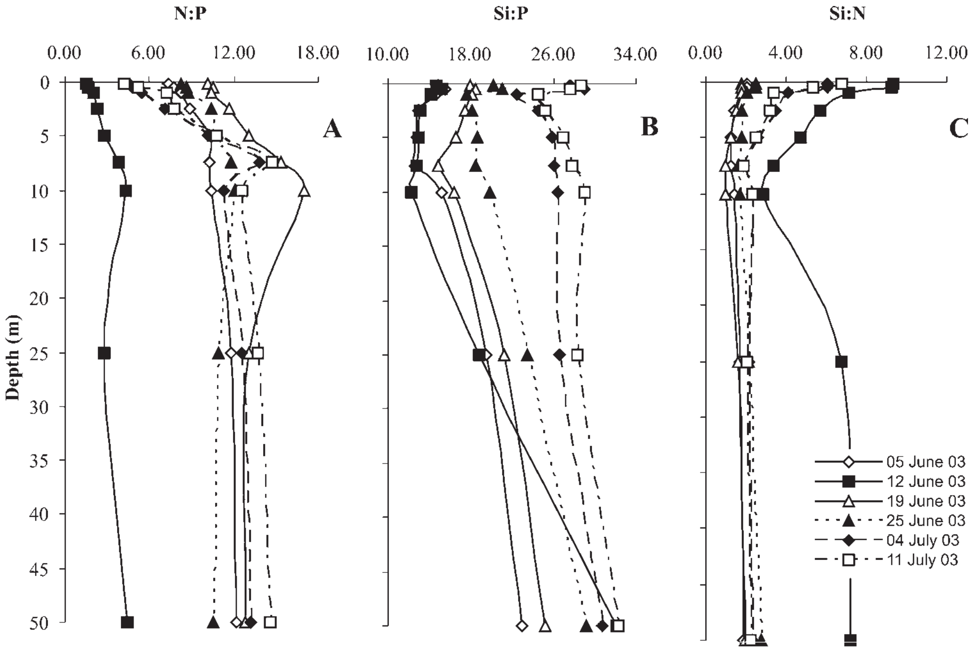

Fig. 4. The vertical profiles of (A) N:P, (B) Si:P and (C) Si:N during the bloom in the Dardanelles.

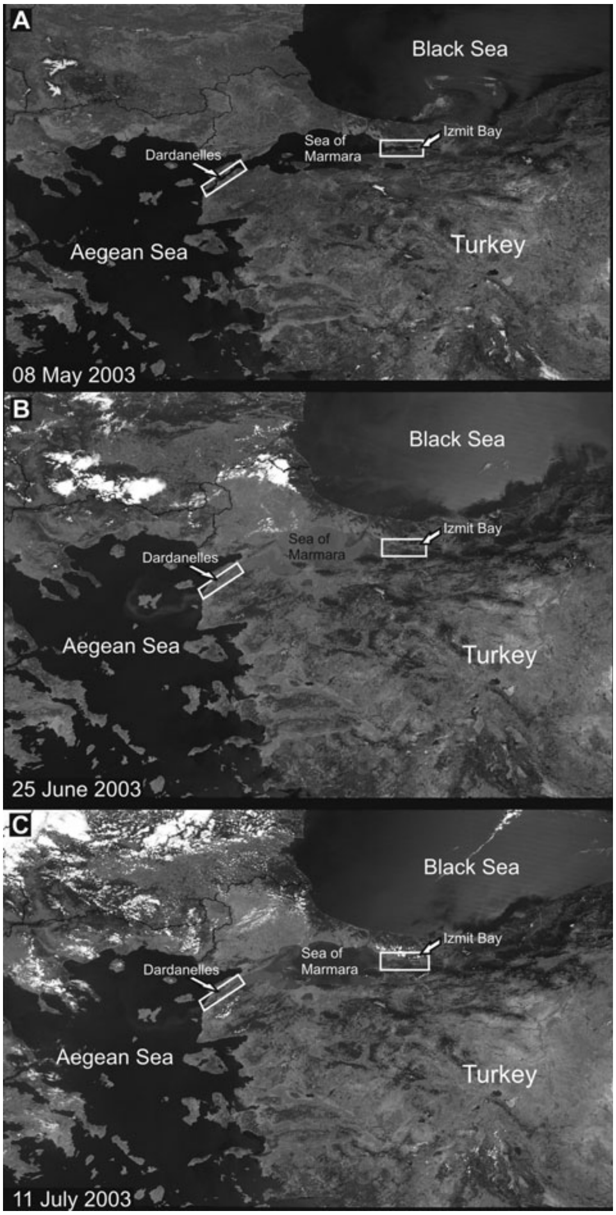

Fig. 5. SeaWiFS true colour images of the Sea of Marmara and the Dardanelles showing the (A) initiation, (B) development and (C) decay of the *Emiliania huxleyi* bloom in early summer 2003. The images are provided by Norman Kuring of the NASA Project/Goddard Earth Sciences. Turquoise colour marks the coccoliths in images (B) and (C).

started in Izmit Bay in early June then quickly spread through the Sea of Marmara and lasted until mid-July (Figure 5).

Vertical profiles of *E. huxleyi*, *Ceratium furca* var. *furca* (Ehrenberg) Sournia, *Ceratium fusus* var. *seta* (Ehrenberg) Schiller and *Prorocentrum micans* Ehrenberg are shown in Figure 6. During the bloom period, cell density of *E. huxleyi* increased from 3.58×10^7 to 2.55×10^8 cells l^{-1} in the superficial layer. Between 12–25 June, *E. huxleyi* exceeded 2.0×10^8 cells l^{-1} in the superficial layer. In general, the density dramatically decreased with depth (Figure 5A). Cell density of *P. micans* exceeded 1.0×10^6 cells l^{-1} in the surface layer, reaching its peak on 12 June with a value of 3.3×10^6 cells l^{-1} (Figure 6B). After this major peak, density of this species gradually decreased with depth. Other abundant species in this area included *C. furca* var. *furca* and *C. fusus* var. *seta*. *Ceratium* spp. in Figure 6C combines these two species for simplicity. Although cell density of these combined species was less (minimum–maximum: $3.90 \times 10^4 - 1.05 \times 10^6$ cells l^{-1}; mean: $2.44 \times 10^5 \pm 2.30 \times 10^5$ cell l^{-1}) than cell density of *P. micans* (minimum–maximum: $4.4 \times 10^4 - 3.30 \times 10^6$ cells l^{-1}; mean: $7.82 \times 10^5 \pm 8.96 \times 10^5$ cell l^{-1}), the vertical profile was similar to *P. micans* in the surface layer during the algal bloom (Figure 6B & C).

Emiliania huxleyi was found to be the dominant species accounting for more than 90.0% of the phytoplankton assemblage (Table 1). Three dinoflagellates, *C. furca* var. *furca*, *C. fusus* var. *seta* and *P. micans* were other important species at the time of the *E. huxleyi* bloom. *Prorocentrum micans* was the second most-abundant species accounting for approximately 5.6% of the total phytoplankton (Table 1).

Analysis showed strong positive correlations between *E. huxleyi* and chlorophyll-*a* in the surface and interface layers (Table 2). There was not a significant relation between *E. huxleyi* and the other parameters (Figure 7). *Prorocentrum micans*, *Ceratium* spp. and other dinoflagellates showed strong negative correlations with SiO_4 in the surface layer (Table 2). Additionally, strong positive relations were observed between *P. micans*, dinoflagellates and PO_4^{-3} in the surface layer. Diatoms were strongly related with temperature, pH, PO_4^{-3} and SiO_4 in the interface layer (Table 2). *Prorocentrum micans* showed strong negative relations with temperature, pH and SiO_4 while there was a strong positive correlation between PO_4^{-3} in the interface layer. Dinoflagellates showed a relatively strong positive relation with PO_4^{-3} and negative correlation with temperature in the deep layer (Table 2).

While cell densities of the diatoms and dinoflagellates in the superficial layer varied between $5.0 \times 10^5 - 4.5 \times 10^6$ cells l^{-1} and $4.0 \times 10^4 - 1.1 \times 10^6$ cells l^{-1} respectively, their densities in the sub-surface layer varied between $7.8 \times 10^5 - 2.4 \times 10^7$ cells l^{-1} and $5.6 \times 10^4 - 2.1 \times 10^6$ cells l^{-1} respectively. Except the 5 June 2003 sampling date, although cell density of diatoms was under 1.0×10^6 cells l^{-1} in the superficial layer (0–5 m) due to the rather high *E. huxleyi* bloom, it was above 1.0×10^7 cells l^{-1} in the sub-surface layer (10–25 m) in the second half period of the bloom (25 June–11 July 2003) (Figure 6E) due to the more dramatic decrease of the bloom (Figure 6A). On the other hand, while production of *E. huxleyi* was more important in the superficial layer than in the sub-surface layer, production of diatoms was more important in the sub-surface layer than in the superficial layer (Figure 4E). This low diatom production in the superficial layer was clear in the bloom period due to the significant decrease of phosphate (Figure 3A) and also the deficiency of silicate (<2.0 μM) essential for diatom production in the superficial layer in spite of the partial decay of the bloom (Figure 3C). However, high diatom production was clear in the sub-surface layer due to the sufficient amounts of nutrients, especially silicate and the dramatic decrease of the *E. huxleyi* bloom. This tendency of diatoms in the vertical profile was roughly similar to the vertical profile of the dinoflagellates except for *P. micans* and *Ceratium* spp. (Figure 6D). Contrary to other dinoflagellate species, *P. micans* and *Ceratium* spp. in the upper layer were higher than in the sub-surface layer.

DISCUSSION

Recently depleted inorganic nutrients, high irradiance and a stable water column in terms of vertical mixing following

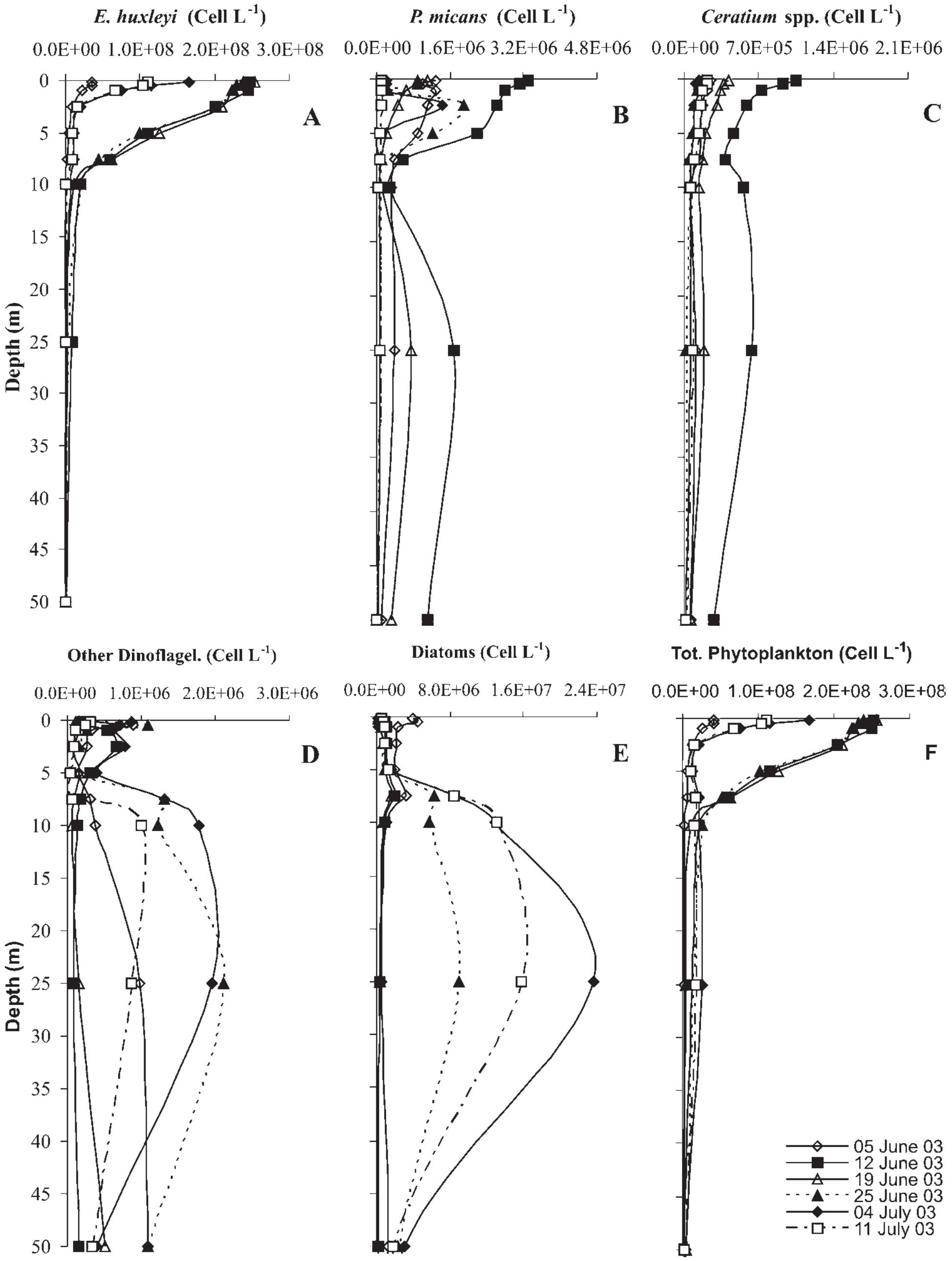

Fig. 6. The vertical profiles of (A) coccolithophore *Emiliania huxleyi*, (B) dinoflagellates *Prorocentrum micans* and (C) *Ceratium* spp., (D) other dinoflagellates, (E) diatoms and (F) total phytoplankton during the bloom. Numbers are in cells l^{-1}. Note that scales are different for different phytoplankton groups.

the establishment of the seasonal thermocline were the characteristics of the *E. huxleyi* bloom and the others in the Dardanelles confirmed previous studies on *E. huxleyi* blooms in the North Sea and north-eastern Atlantic (Nanninga & Tyrrell, 1996; Smyth *et al.*, 2004; Zeichen & Robinson, 2004). In general, it has been suggested that *E. huxleyi* blooms follow those of diatoms (Holligan *et al.*, 1993; Uysal, 1995; Turkoglu & Koray 2002, 2004; Broerse *et al.*, 2003; Turkoglu *et al.*, 2004b; Turkoglu, 2005) and the summer 2003 event in the Sea of Marmara and the Dardanelles was no exception.

Nutrient dynamics in the Dardanelles differ slightly due to different water masses (Polat & Tugrul, 1995; Unsal *et al.*, 2003; Turkoglu *et al.*, 2004a, c, d; Turkoglu & Erdoğan, 2007a, b; Turkoglu *et al.*, 2007). Our results, however, are contradictory to previous observations, where the brackish Black Sea upper layer has high nutrient values and the salty Mediterranean lower layer has low nutrient values (Polat & Tugrul, 1995; Polat *et al.*, 1998). Lower nutrient concentrations in the upper layer than the lower layer were probably due to the removal of nutrients by the early bloom of diatoms. Therefore, for instance, while diatoms were diminishing in the superficial layer (0–5 m), they were increasing in sub-surface layer (10–25 m) due to the sufficient nutrient concentration. As a result of the sufficient nutrient concentration in the sub-surface layer, there were intensive blooms of some diatoms (5.7 × 10^{6} – 2.4 × 10^{7} cells l^{-1}) such as *Rhizosolenia setigera* Brightwell, *Rhizosolenia fragilissima*

Table 1. Rational contributions (%) of coccolithophore *Emiliania huxleyi*, dinoflagellates *Prorocentrum micans*, *Ceratium* spp., other dinoflagellates and diatoms to phytoplankton community composition placed into different groups in the different water layers of the Dardanelles in the *E. huxleyi* bloom period of 5 June–11 July 2003.

Layer	**Rational contribution (%) of *E. huxleyi* to total phytoplankton**					
	5 June	**12 June**	**19 June**	**25 June**	**4 July**	**11 July**
Superficial (0.1 m)	60.73	96.15	97.58	93.19	79.10	76.02
Interface (25 m)	4.12	78.60	62.74	14.62	0.42	0.89
Deep (50 m)	1.72	13.91	9.56	2.51	1.64	0.52
Rational contribution (%) of *P. micans* to total phytoplankton						
Superficial (0.1 m)	7.50	1.31	0.37	0.49	0.40	0.37
Interface (25 m)	19.18	13.18	19.61	0.58	0.34	0.34
Deep (50 m)	4.32	54.66	26.29	0.32	1.25	0.52
Rational contribution (%) of *Ceratium* spp. to total phytoplankton						
Superficial (0.1 m)	1.54	0.72	0.32	0.08	0.31	0.54
Interface (25 m)	5.14	5.00	4.89	0.17	0.27	0.46
Deep (50 m)	2.20	13.66	5.26	0.63	0.62	0.52
Rational contribution (%) of other dinoflagellates to total phytoplankton						
Superficial (0.1 m)	4.60	0.33	0.17	1.15	3.18	1.22
Interface (25 m)	45.84	0.16	4.26	16.17	7.55	5.13
Deep (50 m)	42.62	8.2	40.96	31.64	11.2	15.54
Rational contribution (%) of diatoms to total phytoplankton						
Superficial (0.1 m)	25.63	1.49	1.56	5.09	17.01	21.85
Interface (25 m)	25.72	3.06	8.5	68.46	91.42	93.18
Deep (50 m)	49.14	9.57	17.93	64.9	85.29	82.9

Bergon and *Pseudonitzchia pungens* (Grunow *ex* P.T. Cleve) Hasle between 25 June 2003 and 11 July 2003 in the sub-surface layer due to the high nutrient concentration, especially the high $NO_2^- + NO_3^-$ concentration. It is known that diatoms are favoured when nitrogen is available at higher concentrations (Piehler *et al.*, 2004) and it is also known that large phytoplankton cells such as *R. setigera*, *R. fragilissima* and *P. pungens* are better competitors for nitrate because of their larger specific storage volume (Dauchez *et al.*, 1996; Kormas *et al.*, 2002).

Emiliania huxleyi is known to tolerate low nutrient levels and this ability allows this group to outcompete other species (Balch *et al.*, 1991; Paasche, 2002). It is also known that *E. huxleyi* growth is limited by phosphate (Paasche, 2002). Naturally, the study system is nitrogen limited and low N:P ratios in this study confirmed previously reported values in other studies (Polat *et al.*, 1998; Turkoglu *et al.*, 2004a, c, d; Turkoglu & Erdoğan, 2007a, b; Turkoglu *et al.*, 2007). It is known that Redfield *et al.* (1963) mentioned a ratio (C:N:P = 106:16:1) among the elements of sea water. If N:P ratios in a system are below the normal value of 16:1, the system is a nitrogen limited area (Stefanson & Richards, 1963). However, if Si:N ratios in a system are below the value of 1:1, the system is a silicate limited area. Since N:P ratios (mean 9.11 ± 3.95) during the algal bloom are below the Redfield ratio (16:1) and Si:N ratios (average 3.03 ± 2.09) are above the Redfield ratio (1:1), the Dardanelles is limited for nitrogen, but for phosphate and silicate. It is known that diatom growth in marine waters is likely to be limited by dissolved silica when Si:N ratios are less than 1 according to Redfield ratios (Redfield *et al.*, 1963; Piehler *et al.*, 2004) or N:Si ratios above 1 (Roberts *et al.*, 2003).

Therefore, this may indicate that *E. huxleyi* growth was not nutrient limited. Additionally, in contrast to N:P, higher Si:P ratios in the lower layer than in the upper layer were due to the increase of silicate with depth. Consistent with these results diatoms dominated the lower layer. The chlorophyll-*a* maximum at 10 m depth during the algal bloom in the Dardanelles was mostly due to the abundance of diatoms and partly other dinoflagellates rather than *P. micans* and *Ceratium* species. In contradiction to some other studies (Balch *et al.*, 1991, 1996; Cokacar *et al.*, 2004) *E. huxleyi* and chlorophyll-*a* were well correlated in this study (Table 2). But, it is known that *E. huxleyi* cells are small and consist of 0.1×10^{-12} g chlorophyll-*a* cell^{-1} (Stolte *et al.*, 2000). The important positive relationship between *E. huxleyi* and chlorophyll-*a* can be explained due to a higher cell density during the bloom in the Dardanelles than in other areas such as the north-eastern Atlantic, subarctic Pacific and the south-eastern Bering Sea (Tyrrell & Taylor, 1995; Hattori *et al.*, 2004). Therefore, this bloom may be likely to have higher chlorophyll-*a* concentrations than the blooms of other areas.

Numerically, abundance of *E. huxleyi* during the study in the Dardanelles was higher than previous abundances in the north Aegean Sea (Aubert *et al.*, 1990; Turkoglu *et al.*, 2004a) and in the other parts of the Turkish Straits System such as the Bosphorus and Sea of Marmara (Aubert *et al.*, 1990), to the extent that the abundance was generally higher than previous ones in the Black Sea (Turkoglu & Koray, 2002, 2004; Cokacar *et al.*, 2004). It is known that the Turkish Straits System is a water passage between the Mediterranean and the Black Sea region (Besiktepe *et al.*, 1994). For instance, some of the biogenic organic matter such as bacterio-plankton and phytoplankton in the Black Sea can be naturally exported to the Sea of Marmara and then reach the eastern Mediterranean via the Dardanelles (Polat & Tugrul, 1996).

Although this study is not the first for the Dardanelles and Sea of Marmara, it is the first detailed study to present vertical

Table 2. Pearson correlations between coccolithophore *Emiliania huxleyi*, dinoflagellates *Prorocentrum micans*, *Ceratium* spp., other dinoflagellate species, diatoms and several environmental and biological variables in the surface (0.5 m), interface (25 m) and deep (50 m) layer of the Dardanelles. Significant correlation coefficients are shown (*: $P < 0.05$; **: $P < 0.01$) and non-significant relationships are indicated (n.s.: $P > 0.05$).

Surface	***E. huxleyi***	***P. micans***	***Ceratium* spp.**	**Dinoflagellates**	**Diatoms**
	(N = 6)	**(N = 6)**	**(N = 6)**	**(N = 6)**	**(N = 6)**
Temperature (°C)	n.s.	n.s.	n.s.	n.s.	−0.848*
Salinity (ppt)	n.s.	−0.877*	−0.880*	n.s.	n.s.
pH	n.s.	n.s.	−0.832*	n.s.	n.s.
DO (mg l^{-1})	n.s.	n.s.	0.871*	n.s.	n.s.
PO_4^{-3}	n.s.	0.913*	n.s.	0.841*	n.s.
$NO_2 + NO_3$	n.s.	n.s.	n.s.	n.s.	n.s.
SiO_4	n.s.	−0.925**	−0.822*	−0.842*	n.s.
Chlorophyll-*a*	0.980**	n.s.	n.s.	n.s.	n.s.
Interface					
Temperature (°C)	n.s.	−0.831*	n.s.	n.s.	−0.891*
Salininity (ppt)	n.s.	n.s.	n.s.	n.s.	n.s.
pH	n.s.	−0.942**	n.s.	n.s.	0.984**
DO (mg L^{-1})	n.s.	n.s.	n.s.	n.s.	n.s.
PO_4^{-3}	n.s.	0.859*	n.s.	n.s.	−0.893*
$NO_2 + NO_3$	n.s.	n.s.	n.s.	n.s.	n.s.
SiO_4	n.s.	−0.927**	n.s.	n.s.	0.911*
Chlorophyll-*a*	0.851*	n.s.	n.s.	n.s.	n.s.
Deep					
Temperature (°C)	n.s.	n.s.	n.s.	−0.850*	n.s.
Salininity (ppt)	n.s.	n.s.	n.s.	n.s.	n.s.
pH	n.s.	n.s.	n.s.	n.s.	n.s.
DO (mg L^{-1})	n.s.	n.s.	n.s.	n.s.	n.s.
PO_4^{-3}	n.s.	n.s.	n.s.	0.899*	n.s.
$NO_2 + NO_3$	n.s.	n.s.	n.s.	n.s.	n.s.
SiO_4	n.s.	n.s.	n.s.	n.s.	n.s.
Chlorophyll-*a*	n.s.	n.s.	n.s.	n.s.	n.s.

distribution of *E. huxleyi* and the interaction of this species with other phytoplankton groups in the Dardanelles. Previous studies have shown the appearance and density of this species in the Turkish Straits System (Aubert *et al.*, 1990; Uysal, 1995; Unsal *et al.*, 2003; Turkoglu *et al.*, 2004a, b, d) and the Black Sea since the 1980s (Mikaelyan, 1997; Moncheva & Krastev, 1997; Cokacar *et al.*, 2001; Turkoglu & Koray, 2002, 2004). Therefore, this study may also indicate advancing of this species from the Black Sea through the Sea of Marmara and the Dardanelles under favourable 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 artefact of the transport of this species by the help of a two-layer flow regime in the Dardanelles. Further monitoring of the system in terms of anomalies in the temperature and salinity changes as well as the phytoplankton species composition is needed to better understand the bio-ecological significance of this species in and around this system.

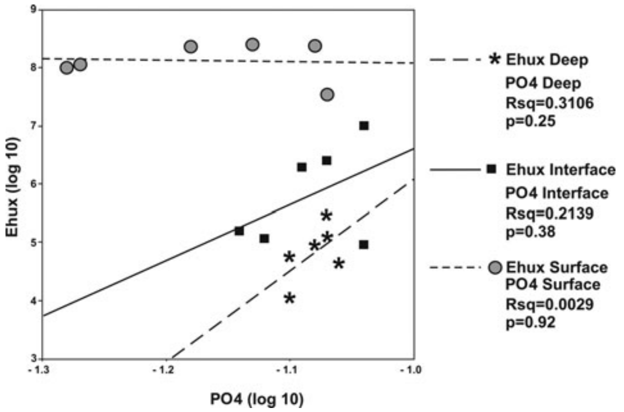

Fig. 7. Relationships between *Emiliania huxleyi* and PO_4^{-3} in the surface (0.5 m), interface (25 m) and deep (50 m) layer of the Dardanelles. For each regression, the coefficients of determination (r^2) and the significance levels (P) are shown.

ACKNOWLEDGEMENTS

This study was supported by the Turkish Scientific and Technical Research Council (TUBITAK, YDABAG, project number 101Y081). We thank Norman Kuring of the NASA SeaWiFS Project and the Goddard Earth Sciences Distributed Active Archive Center for producing and providing the images. Thanks are extended to Sandra E. Shumway and anonymous referees for their critiques on the previous version of this manuscript.

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