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Abundance and biomass of picoplanktonic *Synechococcus* (Cyanobacteria) in a coastal ecosystem of the northeastern Mediterranean, the Bay of İskenderun

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Abstract

Changes in abundance and biomass of *Synechococcus* were studied during five cruises carried out between November 2004 and September 2005 in the İskenderun Bay, northeastern Mediterranean. In addition, spatial and temporal variations in physico-chemical factors and Chl *a* were measured. Abundance ranged from 0.2×10^4 to 23.09×10^4 cells ml^{-1}, whereas the biomass ranged from 0.19 [1] to 23.01 μgC l^{-1} in the bay. *Synechococcus* was found most numerous during September 2005 in the shallower part of the bay while the population was observed least during November 2004 and January 2005. The contribution of <3 μm size fraction to total Chl *a* ranged between 48% and 74%, being low during the cold period and higher during the warm period. The observed spatial and temporal fluctuations in abundance seemed to be closely related to environmental conditions in the area. Small-sized phytoplankton dominated the bulk of biomass, at least for the summer period.

Key words: *İskenderun Bay, northeastern Mediterranean, picophytoplankton,* Synechococcus

Introduction

Picoplankton contributes to at least 10% of the total global aquatic net primary productivity (Agawin et al. 2000). In most oligotrophic and mesotrophic areas of the world's oceans, primary production is dominated by picophytoplankton (cells <2 μm in size) (Li et al. 1983). It contributes up to 90% of the phytoplankton biomass in oligotrophic areas, whereas lower contributions, $<30\%$ are recorded in eutrophic coastal waters (Modigh et al. 1996). Picoplankton is composed of heterotrophic bacteria, two types of photosynthetic prokaryotes, *Synechococcus* and *Prochlorococcus*, and picoeucaryotes (Jacquet et al. 1998; Guillou et al. 2001). Among them, the marine cyanobacterium *Synechococcus* is ubiquitous to both oligotrophic and mesotrophic ocean areas with abundances reaching 10^5 cells ml^{-1} (Jacquet et al. 1998). It is also one of the main components of picoplankton in the highly oligotrophic eastern Mediterranean (Li et al. 1993; Uysal 2006; Uysal & Köksalan 2006). The high surface to volume ratio of these small cells permits an efficient nutrient uptake system (Veldhuis et al. 2005) and gives small cells an advantage in oligotrophic waters (Agawin et al. 2000).

The Mediterranean is considered to be one of the least productive seas of the world and the eastern Mediterranean forms the most oligotrophic part of it (Azov 1991; Krom et al. 1991). The basin-wide cyclonic circulation of nutrient-depleted water, hot and dry climate and low land runoff contribute to the low productivity levels (Turley et al. 2000). Furthermore, phosphorus is considered to be the limiting nutrient for the eastern Mediterranean (Krom et al. 1991). Primary production is, on the average, three times lower in the eastern Mediterranean (151 mgC m^{-2} d^{-1}) than the northwestern basin (502.7 mgC m^{-2} d^{-1}) (Turley et al. 2000). The most important characteristic of this oligotrophic environment is that it sustains a microbial-dominated food web consisting of small unicellular phytoplankton, protozoa, bacteria and viruses (Thingstad & Rassoulazadegen 1999).

To date, a multitude of large-scale surveys on picophytoplankton have been carried out in the open ocean waters (Li 1998; Calvo-Diaz et al. 2004; Worden et al. 2004). Despite the large number of studies dealing with microphytoplankton in the eastern Mediterranean (Eker & Kideyş 2000; Polat & Piner 2002), little is known about the picophytoplankton community in the northern Levantine

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Basin (Uysal 2006; Uysal & Köksalan 2006). Moreover, no study has been conducted on the picophytoplankton abundance and composition in the İskenderun Bay prior to this study. Earlier studies in the bay mainly dealt with the taxonomy, ecology and biomass distribution of larger phytoplankton (Polat 2002; Polat & Piner 2002). However, studies are needed on heterotrophic bacteria and picophytoplankton to understand trophic interactions within the microbial food web. The aims of this study were to provide preliminary information on the abundance and biomass of *Synechococcus* in the area and explore possible environmental factors that control its dynamics in time and space.

Materials and methods

Study area

İskenderun Bay is located in the northeast corner of the Levantine Basin, eastern Mediterranean (Figure 1). The surface area of the bay is approximately 2275 km^2 and the average depth is around 70 m, while a maximum depth of 100 m is located at the entrance of the bay (Avşar 1999). The bay and its opening form one of the largest continental shelf areas in the eastern Mediterranean. The water column in the bay is stratified during summer due to warming and is homogenous during winter due to surface cooling and vertical mixing (Yilmaz et al. 1992). The hydrography of the bay is affected by the westerly flowing Asia Minor Current along the southwest Anatolian coast, having a wide opening to the open sea (Özsoy et al. 1993). Beside these, local storms as well as sporadic wind regimes control the hydrodynamics of the bay waters from time to time (Yilmaz et al. 1992). The coast can be regarded as highly industrialized with petroleum pipelines, iron-steel and fertilizer industries. In addition, the Ceyhan river drains significant amount of freshwater (180 $m^3 s^{-1}$) into the bay (Yilmaz et al. 1992).

Methods

Sampling was carried out on 3 November 2004, 4 January, 30 March, 24 June and 27 September 2005 at the west coast of the İskenderun Bay (35° 54′ E–36° 11′ E and 36° 35.5′ N–36° 44′ N) (Figure 1). Samples were collected from seven stations on a nearcoast–offshore gradient in the bay. Water samples for picophytoplankton, Chl *a* and nutrient analyses were taken with a Universal water sampler at 10 m intervals depending on the total depth. Water column temperature and salinity were measured with a YSI 6600 CTD probe (Yellow Springs, USA). Transparency was measured with a Secchi disc and the depth of the euphotic zone was calculated according to Parsons et al. (1984a).

Samples for picoplankton counting were fixed with filtered 2% glutaraldehyde and kept refrigerated until analysis. Aliquots of 10 ml from each sample were filtered onto 0.2 μm pore size, 25 mm diameter, black polycarbonate membrane filters. The filters were then placed onto glass slides, using

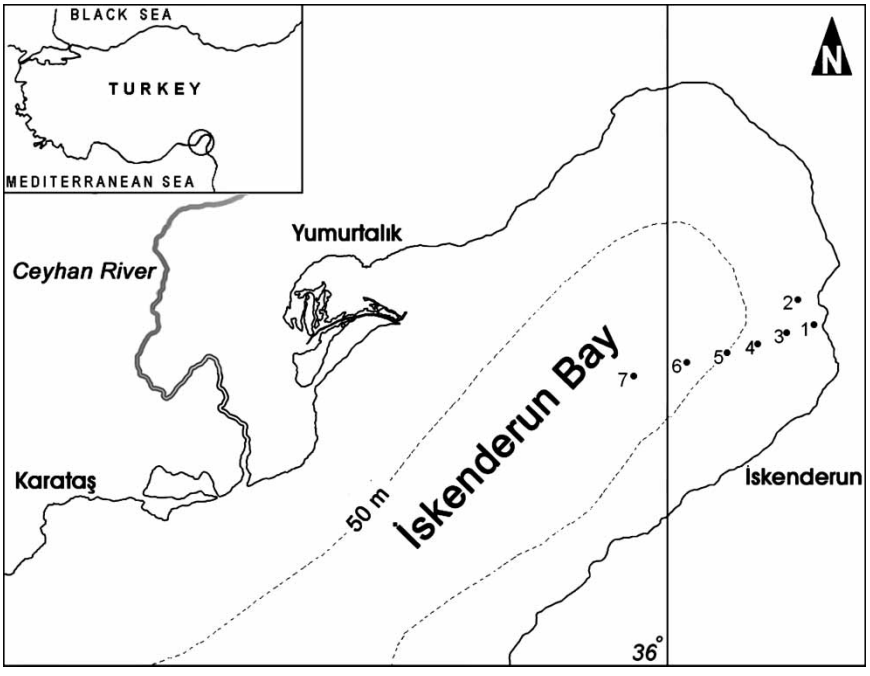

Figure 1. Map of the study area with sampling stations in İskenderun Bay.

immersion oil, for counting on an Olympus BX51 epifluorescent microscope with a filter combination of UMWB2 (blue excitation, DM 500, EX 460–490, BA 520) and UMWG2 (green excitation, DM 570, EX 510–550, BA 590). *Synechococcus* cells were identified by their size, shape and characteristic orange phycoerythrin-derived fluorescence under green light excitation. At least 20 microscopic fields randomly chosen at $\times 1000$ magnification were counted on each slide (on average, 150–200 cells).

Cell dimensions were measured using an image analysis system composed of a digital camera (Olympus DP 70), computer and the image analysis software (Image Pro Plus 5.1). Cell volumes were calculated using the volume formula for an ellipsoid (Sieracki et al. 1989). To convert the cell volume to carbon, 0.123 pg carbon per cubic micrometer was used (Waterbury et al. 1986).

Two litres of seawater were filtered through GF/F filters for Chl *a* analysis. For Chl *a* belonging to the <3 μm size fraction, parallel samples of seawater were filtered through <3 μm polycarbonate filters and the filtrates collected onto GF/F filters. Filtrates were then extracted into 90% acetone and kept refrigerated at 4°C overnight. Following extraction, Chl *a* concentration was determined spectrophotometrically according to Parsons et al. (1984b) using a spectrophotometer (Schimadzu model).

Water samples for nutrient measurements were collected into 500 ml polyethylene bottles that were pre-cleaned with 10% HCl and kept frozen at -20°C until analysis. Phosphate (PO_4^{-3}-P) and nitrate+nitrite (NO_3^--N+NO_2^--N) were determined according to methods given by Strickland & Parsons (1972). The Pearson correlation coefficient was applied to calculate relationships between *Synechococcus* abundance and biological, physical and chemical data.

Results

Physico-chemical data

The annual ranges and means of physico-chemical and biological data for all sampling stations and for the surface, 10 m and the water column are presented in Tables I and II. Horizontal distribution of nutrients at the surface and 10 m are shown in Figure 2. Profiles of the physico-chemical data for the deep station 7 are illustrated in Figure 3. Temperature varied in the range 17.6–29.2°C at the surface, and 17–28.4°C at 10 m depth (Figure 2)

The temperature dropped to a minimum of 16.6°C at 70 m of station 7 in March 2005 (Figure 3), while the maximum temperature (29.2°C) was measured at the surface of station 2 in September 2005. In November 2004, water column temperature was homogenous above 45 m and showed a significant decrease to as low as 18.2°C at 70 m depth. The water column was thoroughly mixed down to 70 m during the January–March 2005 period. The water column was stratified in June 2005, and a warmer surface mixed layer occupied the top 20 m due to increased solar heating in summer. The surface mixed layer extended farther down to 40 m in September being controlled much by the wind forcing (Figure 3). About 8–10°C temperature difference between surface and bottom waters was observed during November 2004, June and September 2005. Salinity varied from 35.3 to 39.9 in the bay (Table II). The highest values were recorded in November 2004 and January 2005. Salinity was measured as low as 35.9 and 35.3 at stations 1 and 3 (Table I), in June due to increased freshwater inflow during late spring and early summer. It remained almost constant at deeper parts of the offshore station in January and March 2005 (Figure 3). Secchi disc depth ranged between 5.4 and 26 m and the maximum euphotic zone depth was calculated to be around 70 m in September 2005 at the deep station.

Surface nutrient concentrations were highest at nearcoastal stations 1 and 2. The mean value for nitrate+nitrite at the surface was 1.59 μM with a maximum level of 6.5 μM that occurred in March 2005 (Figure 2). The minimum surface nitrate+nitrite concentration was recorded in November 2004 at station 7 as 0.38 μM. The mean value for 10 m depth was 1.20 μM with minimum and maximum levels of 0.43 and 3.87 μM found in November 2004 and January 2005, respectively (Figure 2).

At station 7, nitrate+nitrite concentrations were low between the surface and 40 m and showed a pronounced increase at 50 m depth in November 2004 (Figure 3). In January and March 2005, water column nitrate values varied in the range 0.52–1.42 μM. During this period, the difference in terms of nitrate+nitrite concentration between surface and 70 m was less than 0.5 μM. In contrast, in June 2005, surface nitrate+nitrite concentrations were high at the surface (2.66 μM) but decreased to 0.81 μM at 50 m and increased again below 50 m. In September 2005, nitrate concentration slightly increased with depth, and the highest level was reached at 50 m.

The lowest and highest phosphate concentrations were found to be 0.05 and 0.76 μM, with a mean value of 0.24 μM at the surface. At 10 m depth, phosphate concentrations were found between 0.05 and 0.62 μM with a mean value of 0.25 μM (Table II). Timely changes in phosphate at the surface and at 10 m mimic each other. Lowest levels were

Table I. The minimum, maximum and mean values (mean ± SD) of physical, chemical and biological parameters at the seven stations during five sampling periods.

	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7
Total depth (m)	12	11	22	32	44	53	72
Temperature (°C)	17.3–28.7	17.4–29.2	17.1–28.6	16.8–28.4	16.7–28.3	16.6–28.3	16.6–28.2
	(23.4 ± 4.60)	(23.4 ± 4.7)	(23.1 ± 4.60)	(22.9 ± 4.50)	(22.9 ± 4.50)	(22.4 ± 4.2)	(21.5 ± 4.10)
Salinity	35.9–39.7	37.3–39.8	35.3–39.8	38.3–39.8	37.8–39.8	38.1–39.9	36.9–39.8
	(38.6 ± 1.23)	(38.8 ± 0.73)	(38.6 ± 1.28)	(39.03 ± 0.53)	(38.8 ± 0.65)	(39.02 ± 0.56)	(38.7 ± 0.75)
Nitrate + nitrite (μM)	1.62–4.77	0.84–6.50	0.55–1.94	0.20–1.68	0.43–1.97	0.46–4.02	0.38–2.66
	(2.77 ± 0.99)	(1.83 ± 1.7)	(1.13 ± 0.43)	(0.78 ± 0.34)	(1.13 ± 0.43)	(1.12 ± 0.71)	(1.06 ± 0.51)
Phosphate (μM)	0.05–0.62	0.05–0.76	0.05–0.43	0.05–0.52	0.05–0.57	0.04–0.62	0.05–0.62
	(0.27 ± 0.16)	(0.33 ± 0.21)	(0.22 ± 0.14)	(0.24 ± 0.13)	(0.24 ± 0.13)	(0.27 ± 0.15)	(0.28 ± 0.15)
Total Chl *a*	0.45–2.86	0.54–1.71	0.24–1.05	0.16–1.35	0.15–1.50	0.10–0.76	0.13–0.65
(μg l^{-1})	(1.33 ± 0.74)	(0.98 ± 0.35)	(0.52 ± 0.26)	(0.42 ± 0.28)	(0.42 ± 0.27)	(0.34 ± 0.15)	(0.34 ± 0.12)
Chl *a* (<3μm)	0.27–1.30	0.29–1.17	0.11–0.61	0.12–0.67	0.10–0.65	0.11–0.47	0.06–0.46
(μg l^{-1})	(0.73 ± 0.38)	(0.58 ± 0.25)	(0.33 ± 0.18)	(0.26 ± 0.15)	(0.29 ± 0.16)	(0.24 ± 0.11)	(0.21 ± 0.09)
Synechococcus	0.79–23.09	0.79–17.9	0.91–7.05	0.76–6.81	0.7–8.2	0.91–6.81	0.20–7.82
(cells $ml^{-1} \times 10^4$)	(7.67 ± 8.21)	(6.43 ± 5.72)	(3.2 ± 2.20)	(2.59 ± 1.84)	(2.63 ± 2.07)	(2.43 ± 1.48)	(2.04 ± 1.68)
Carbon biomass	0.78–23.01	0.69–13.4	0.64–7.29	0.33–6.54	0.45–8.03	0.60–3.31	0.19–5.57
(μgC l^{-1})	(6.70 ± 7.76)	(5.49 ± 4.17)	(2.78 ± 2.2)	(2.12 ± 1.61)	(2.24 ± 1.98)	(1.73 ± 0.78)	(1.52 ± 1.07)
n (number of samples)	10	10	15	20	25	30	40

attained in November 2004, whereas the highest values were observed in June 2005 for both depths. Except in June 2005, water column phosphate concentration remained below 0.5 μM throughout the sampling period. Phosphate showed noticeable fluctuations in June 2005 and increased to 0.62 μM at 60 m of station 7, while it was distributed almost evenly from surface to bottom in September 2005 (Figure 3).

Chl a

Chl *a* concentrations were found to be approximately 2–3-fold higher at the coastal stations (stations 1 and 2) compared to the offshore stations during the study period except March 2005. Total Chl *a* concentration varied from 0.11 to 2.86 μg l^{-1} with a mean value of 0.75 μg l^{-1} at the surface (Table II). Surface Chl *a* content was found to be highest in March and lowest in June 2005. At 10 m depth, the minimum and maximum Chl *a* concentrations were 0.15 and 1.78 μg l^{-1}, respectively. The mean Chl *a* value at 10 m was 0.53 μg l^{-1} (Table II). In general, surface Chl *a* content was higher compared to concentrations at 10 m (Figure 4). However, its spatial distribution pattern for both depths was similar. For station 7 in November 2004, Chl *a* had a sub-maximum at 30 m and decreased below (Figure 5). In March 2005, when temperature and salinity values were almost homogenous below 20 m, Chl *a* concentration was highest at the surface and tended to decrease with depth. In June, concentrations were almost homogenous between the surface and 50 m and showed a pronounced increase at 60 m. Fluctuations in Chl *a* content occurred with depth in September 2005.

Chl *a* content of the <3 μm fraction varied between 0.06 and 1.30 μg l^{-1}. The lowest value was found in June and the highest in March 2005 (Figure 4). The distribution of <3 μm fraction in the water column was similar to total Chl *a*. The minimal contribution of <3 μm fraction to total Chl

Table II. The minimum, maximum and mean values (mean ± SD) of physical, chemical and biological parameters for the surface, 10 m and whole depths.

	Surface (*n* = 35)	10 m (*n* = 35)	Whole depths (*n* = 150)
Temperature (°C)	17.6–29.2 (23.4 ± 4.45)	17.0–28.4 (23.0 ± 4.55)	16.6–29.2 (22.5 ± 4.39)
Salinity	36.9–39.9 (38.9 ± 0.67)	35.9–39.8 (38.9 ± 0.76)	35.3–39.9 (38.8 ± 0.83)
Phosphate (μM)	0.05–0.76 (0.24 ± 0.14)	0.05–0.62 (0.25 ± 0.13)	0.04–0.76 (0.26 ± 0.15)
Nitrite + nitrate (μM)	0.38–6.50 (1.59 ± 1.25)	0.43–3.87 (1.20 ± 0.71)	0.20–6.50 (1.22 ± 0.83)
Total Chl *a* (μg l^{-1})	0.11–2.86 (0.75 ± 0.60)	0.15–1.78 (0.53 ± 0.38)	0.10–2.86 (0.49 ± 0.39)
Chl *a* (<3 μm) (μg l^{-1})	0.06–1.30 (0.32 ± 0.25)	0.07–1.18 (0.33 ± 0.23)	0.06–1.30 (0.33 ± 0.25)
Synechococcus (cells $ml^{-1} \times 10^4$)	0.80–23.09 (4.05 ± 4.73)	0.76–22.7 (3.87 ± 4.16)	0.20–23.09 (3.06 ± 3.34)
Carbon biomass (μgC l^{-1})	0.49–23.01 (3.41 ± 4.34)	0.57–19.0 (3.22 ± 3.55)	0.19–23.01 (2.48 ± 2.93)

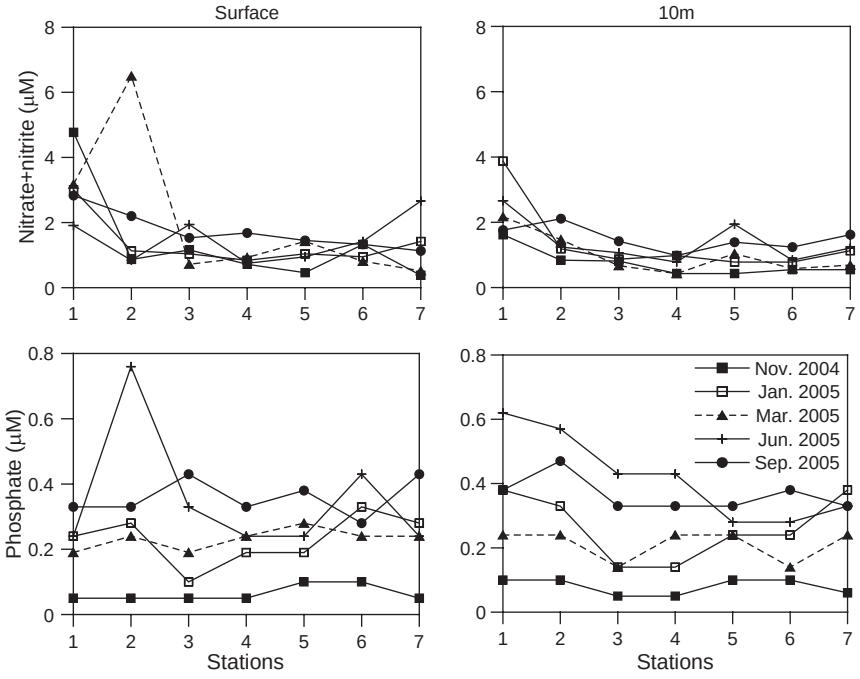

Figure 2. Phosphate and nitrate+nitrite levels at the surface and at 10 m depth of all the sampling stations.

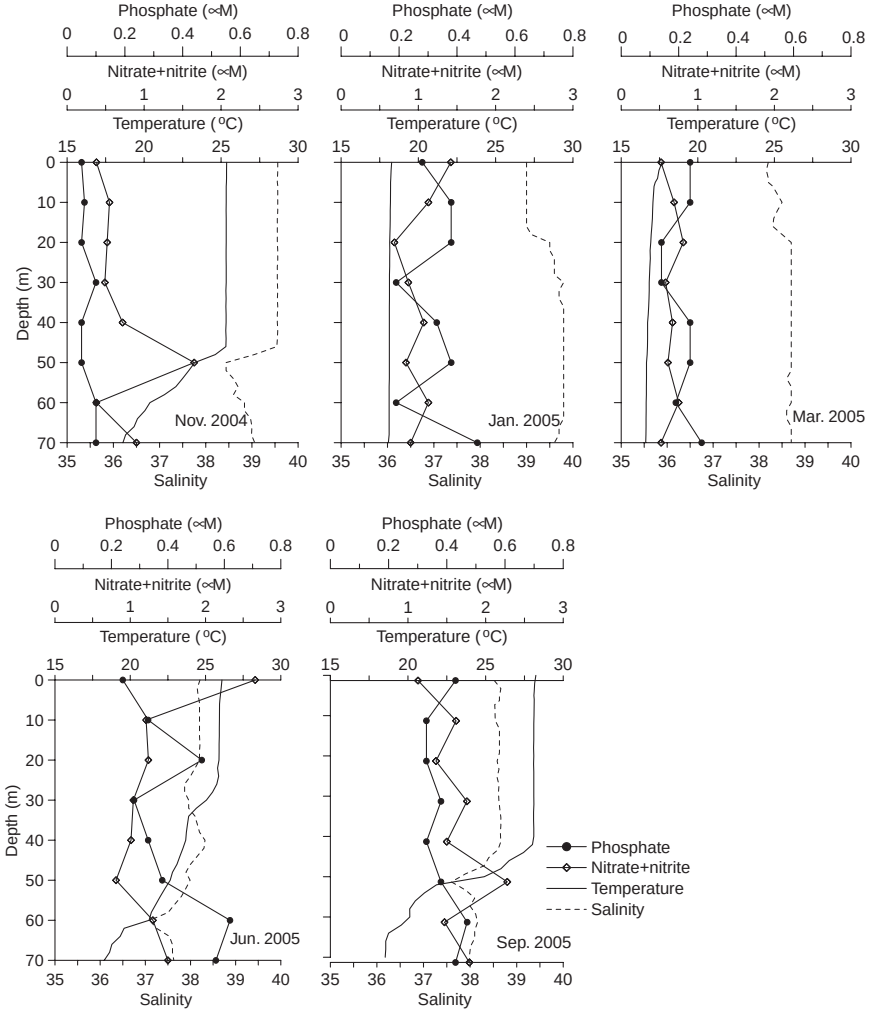

Figure 3. Depth profiles of nutrients, temperature and salinity at station 7.

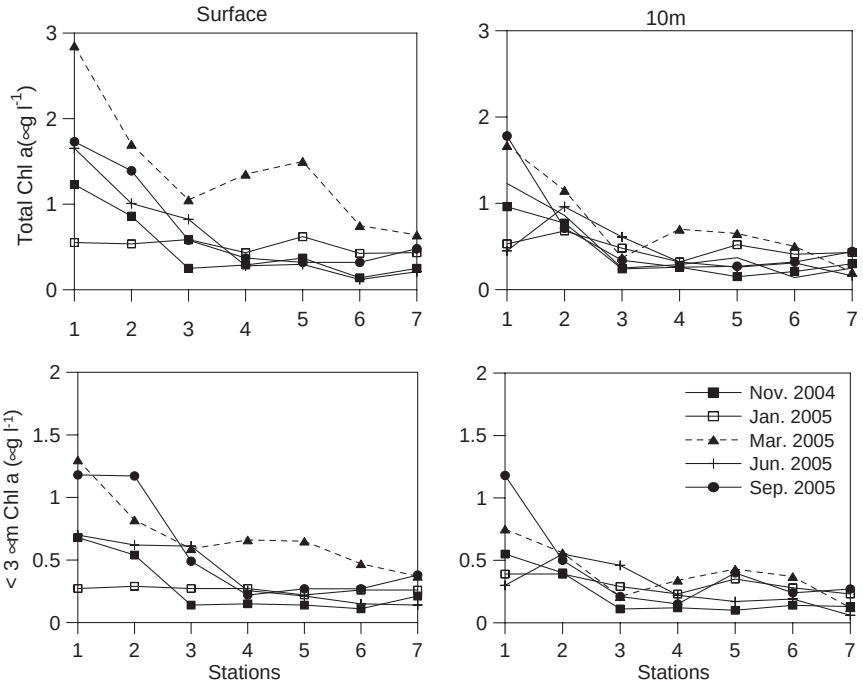

Figure 4. Total Chl *a* and size fractionated (<3 μm) Chl *a* concentrations at the surface and at 10 m depth of all the sampling stations.

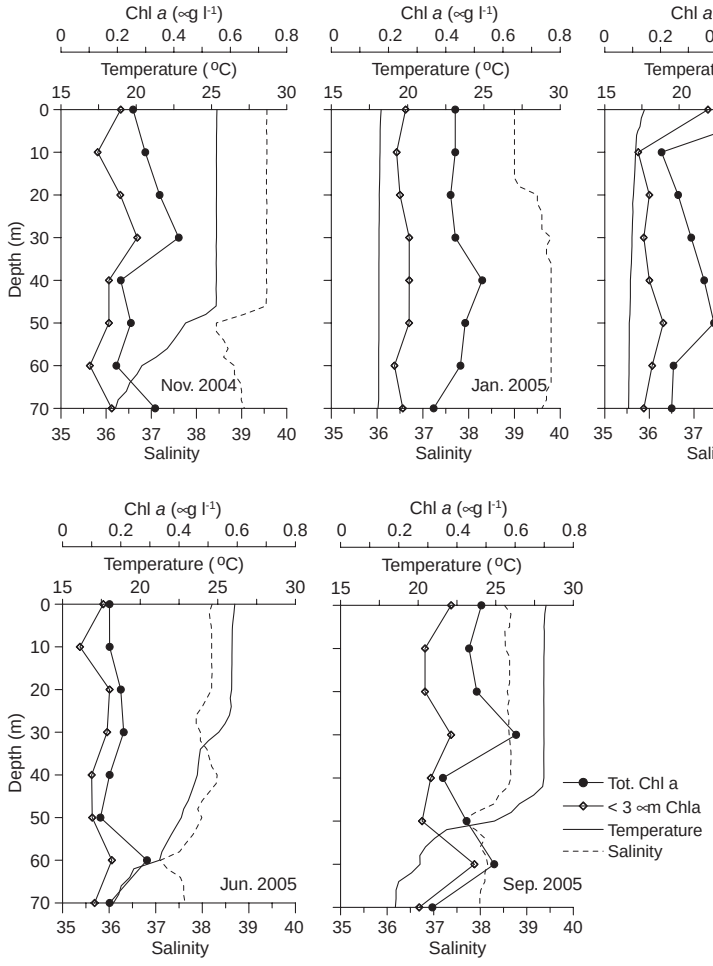

Figure 5. Changes in total and size fractionated (<3 μm) Chl *a* concentrations with depth in relation to temperature and salinity at station 7.

a occurred in March (48%), while its maximal was found in September (74%).

Synechococcus *abundance and biomass*

The lowest and highest *Synechococcus* cell concentrations were found to be 0.8×10^4 and 23.09×10^4 cells ml^{-1}, with an annual mean level of 4.05×10^4 cells ml^{-1} at the surface (Table II). Maximum *Synechococcus* abundance at the surface was observed in September 2005 (Figure 6). *Synechococcus* was found to be less abundant in November 2004 and January 2005. With regard to the spatial distribution of *Synechococcus*, higher abundances were found at the two shallow stations in September, whereas in other periods, the abundance distribution within the stations looked similar. *Synechococcus* abundance was quite similar at the surface and 10 m. At 10 m, the observed lowest and highest abundances were 0.76×10^4 and 22.7×10^4 cells ml^{-1}, with a mean value of 3.87×10^4 cells ml^{-1}. The maximum abundance of *Synechococcus* at 10 m depth was observed in September 2005, as was the case for the surface.

Synechococcus abundance and biomass profiles are given only for Station 7 (Figure 7). Profiles of temperature and salinity are also included for comparison. Generally, cells were found to be more abundant at or near the surface. In November 2004, the majority of the population occupied the upper 40 m of the water column. Due to mixing of the water column in January and in March, differences in abundance with depth were insignificant despite the minor highs observed near the surface. In June and September 2005, cell abundances were higher in the warmer surface layers, and showed small fluctuations towards the bottom (Figure 7). Cell size (length) of *Synechococcus* varied in the range of 0.8–2.3 μm with an average size of 1.30 μm.

Synechococcus abundance and carbon biomass distribution with depth were similar. Higher biomass was observed at the two coastal stations. At the surface, the lowest biomass value of 0.49 μgC l^{-1} was obtained in January 2005 and it started to increase in March 2005. In June 2005, biomass increased to 6.29 μgC l^{-1}. Afterwards, the highest biomass value of 23.01 μgC l^{-1} was reached at the surface in September 2005 (Figure 6). The lowest and highest biomass values were found as 0.57–19 μgC l^{-1} at 10 m. Trends for the surface and 10 m were similar with lower values at 10 m. Since the cell size did not vary significantly with depth and in time, the distribution of both the abundance and biomass resembled each other (Figure 7). Thus, a significant positive correlation ($n = 150$, $r = 0.947$, $p < 0.01$) was measured between the biomass and the abundance. Carbon biomass was also positively correlated with Chl *a* ($n = 150$, $r = 0.355$, $p < 0.01$).

Considering all data, *Synechococcus* abundance was found to be positively correlated with temperature ($n = 150$, $r = 0.467$, $p < 0.01$), nitrate+nitrite ($n = 150$, $r = 0.417$, $p < 0.01$) and phosphate ($n = 150$, $r = 0.448$, $p < 0.01$) and negatively correlated with salinity ($n = 150$, $r = -0.587$, $p < 0.01$).

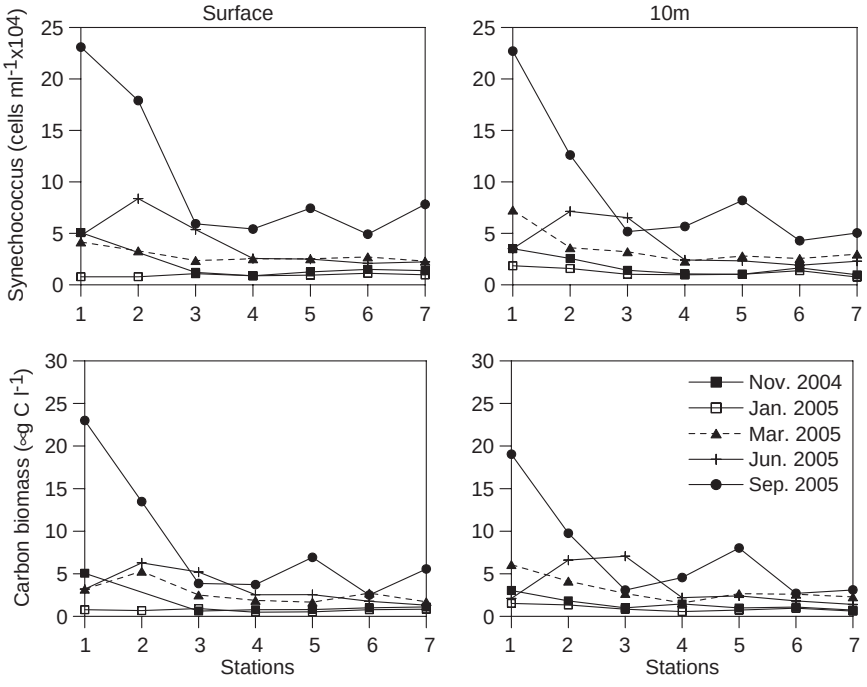

Figure 6. *Synechococcus* abundance and carbon biomass levels at the surface and at 10 m depth of all the sampling stations.

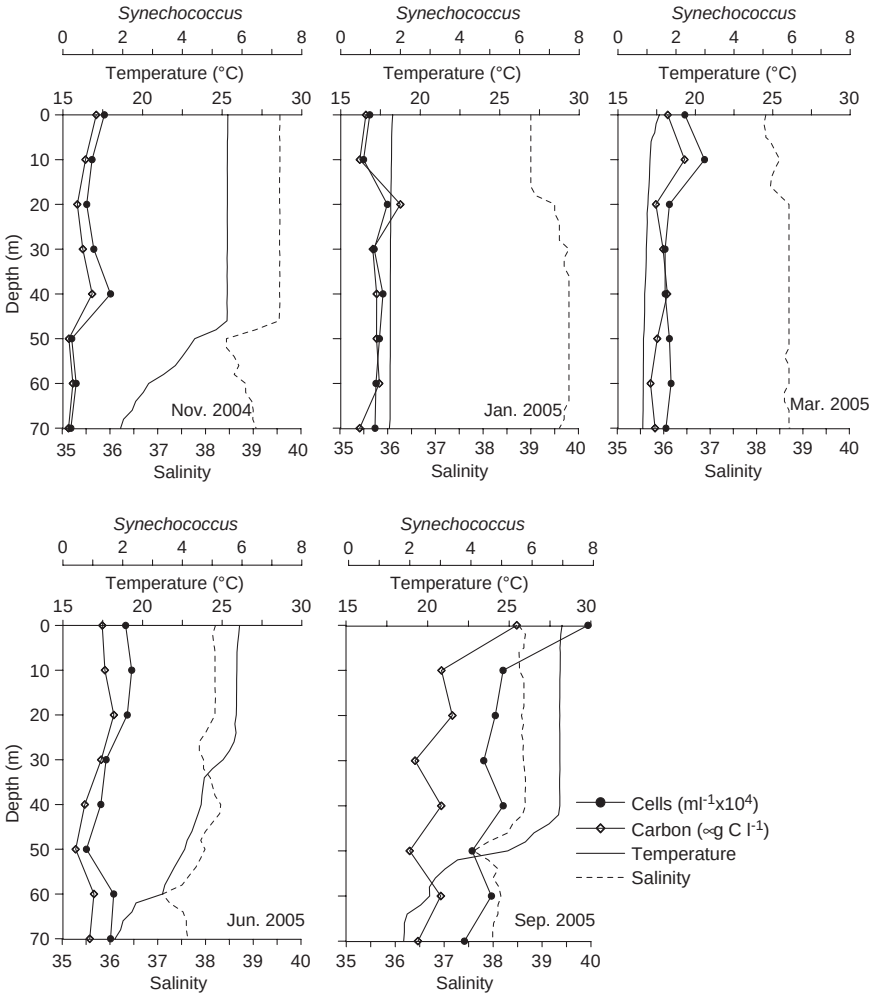

Figure 7. Changes in *Synechococcus* abundance and biomass with depth in relation to temperature and salinity at station 7 (*Synechococcus* abundance and carbon biomass are shown on the same axis).

Discussion

Seasonal changes in light, temperature, stratification and nutrients are among the most important factors affecting plankton dynamics in the marine environment. Changes in such factors can be more rapid, severe and frequent in the coastal areas. The study region, İskenderun Bay, receives a substantial amount of anthropogenic loads – a mixture of agricultural, industrial and domestic wastes – via the Ceyhan River flowing to the central basin, in addition to direct injections from the plants and settlements located in the periphery. Moreover, the land topography with very steep mountains and deep canyons leads to a constant wind pressure over the bay for most of the year. Because of the prevailing strong winds and existing current regime, the bay waters do not experience eutrophication over the year (Yilmaz et al. 1992). All the processes mentioned above in combination affect the microbial communities and production levels. Primary production in the bay was estimated to be 2–4 times higher than open waters of the eastern Mediterranean (Yilmaz et al. 1992).

The seasonal cycle of *Synechococcus* in the bay seem to be similar to those from many other coastal environments (Li 1998; Ribes et al. 1999; Mihalatou & Moustaka-Gouni 2002; Uysal & Köksalan 2006). *Synechococcus* abundance was low in November, January and March, but it was at its highest level at the end of the summer (September). Many similar studies show that high temperature stimulates its abundance and its annual maxima coincide with the warmest period (Caroppo et al. 2006; Uysal & Köksalan 2006). However, although the temperature was remarkably high in November (average 25°C), *Synechococcus* abundance was found to be low in this study. This points out that growth of *Synechococcus* was limited by other factors in this period. Chang et al. (2003) indicated that temperature was not the only factor controlling the growth of

Synechococcus. They suggest that when temperature limitation is weak during the warm period, nutrients appear to be an important factor. *Synechococcus* need high nitrogen concentrations for their nitrogen-rich phycobilisomes (Moore et al. 2002); therefore, the lower nitrate levels may limit *Synechococcus* blooms (Fuller et al. 2005). Additionally, due to high cell phosphate quotas of *Synechococcus* (Bertilsson et al. 2003), their proliferation may be limited under low phosphate concentrations (Vaulot et al. 1996; Fuller et al. 2005). Low nutrient concentrations in the water column in November 2004 may have limited the population growth. Although surface nutrient concentration increased to a certain level with the help of deep mixing in January and March, *Synechococcus* abundance did not increase remarkably as the surface temperature was as cold as 17–18°C. In March 2005, the abundance of *Synechococcus* was just two-fold higher than the amount reached in January, whereas total Chl *a* concentration experienced its highest of that year. This increasing trend in Chl *a* is consistent with the spring phytoplankton bloom in the Mediterranean (Delgado 1990). However, the Chl *a* concentration was observed to decrease to half in June, when *Synechococcus* abundance did not change significantly compared to March. This indicates that larger phytoplankton had contributed greatly to Chl *a* in March and only slightly during June. *Synechococcus* abundance was at its highest in the surface mixed layer in September, when the temperature and euphotic zone depth were maximum. The contribution of <3 μm fraction to total Chl *a* was also the highest in this period and the *Synechococcus* maxima coincided with high nutrient concentrations in September. Elevated nutrient levels in this month may either be a product of regeneration processes or river input, or a combination of both. The pronounced thermocline below 40 m delimits sinking of particles to the bottom and hence promotes regeneration processes within the surface mixed layer. Moreover, compared to November and January, reduced salinities in the water column highlight considerable freshwater input during September. In addition to the fact that physico-chemical factors provided convenient conditions for *Synechococcus* increase, less competition with other phytoplankton may also have contributed to this increment in September 2005. Li (1998) stated that temperatures higher than 14°C do not affect *Synechococcus* dynamics any further and other factors can be important at higher temperature. However, in this study, the temperature was constantly above 14°C, and yet further increase in temperature at times when nutrient concentrations and light availability were favourable seemed to promote *Synechococcus* growth. The positive relationship between temperature and *Synechococcus* abundance ($r=0.467$, $p<0.01$) indicates the role of temperature on the population dynamics. However, Delgado et al. (1992) suggested that the coincidence of abundance peaks at times when the temperature is at its highest may be due not only to temperature, but also to the differences in growth rate and predation pressure. Mihalotou & Moustaka-Gouni (2002) showed that low picoplankton concentrations in winter and spring may be because of grazing, if there are no other environmental limitations. However, since the effect of grazing was not studied in this study, we cannot comment on this subject.

Although *Synechococcus* plays an important part in phytoplankton biomass and productivity of oligotrophic environments (Fogg 1995), it may also be abundant in the nutrient-rich, coastal waters (Jochem 1986; Partensky et al. 1999). In this study, considering its spatial distribution, *Synechococcus* was observed to have higher abundance in the coastal stations that have higher nutrient levels due to terrestial inputs. Unlike the findings of many studies (Kormas et al. 2002; Mihalotou & Moustaka-Gouni 2002), significant relationships between nutrients and *Synechococcus* were found in the present study, which may signify that the nutrient pulses caused by wind-driven mixing and coastal freshwater runoff in the area are influencing *Synechococcus* dynamics. Regeneration processes also contribute positively to the nutrient budget during stratification periods. *Synechococcus* abundance in İskenderun Bay is similar to that given for the adjacent Mersin Bay (3.2×10^3–1.6×10^5 cells ml^{-1}) by Uysal & Köksalan (2006). However, our results are higher than those found for the northwest Mediterranean by Delgado et al. (1992) and Agawin et al. (1998) (0.008–7.3×10^4 cells ml^{-1} and 5.2×10^2–7×10^4 cells ml^{-1}, respectively). Additionally, the mean abundance found in this study (2.9×10^4 cells ml^{-1}) is higher than that found for the northeastern Mediterranean ($2.24\pm0.09\times10^4$ cells ml^{-1}) by Ribes et al. (1999), but lower than the abundance observed by Jacquet et al. (1998) in the northwestern Mediterranean (43×10^3 cells ml^{-1}). It was found that *Synechococcus* were abundant in the upper layers and reached its maximum at the surface, which is akin to the results of Kuosa (1988) in the Baltic Sea and Uysal (2006) in the Black, Marmara, Aegean and eastern Mediterranean Seas.

Synechococcus cells in İskenderun Bay were spherical or elliptical in shape and their size varied in the range 0.8–2.3 μm. Uysal & Köksalan (2006) found similar sizes (0.8–2 μm) for *Synechococcus* in the adjacent Mersin Bay. However, sizes measured in

this study were larger compared to many other studies. Modigh et al. (1996) stated that the size of *Synechococcus* is typically 1 μm, and El Hag & Fogg (1986) reported that the size increases towards the coast. The presence of large-sized cells in this study may be due to the fact that all the stations are generally located within a shallow bay. Another factor could be the time of sampling during the day. Cells are rather elongated and greatest in size prior to dividing during the afternoon. So, it is possible that cells at different stages of development could have been sampled during the day. Cell sizes did not vary significantly over time in the bay. Thus, the observed fluctuations in biomass are controlled by changes in abundance rather than changes in biovolume. As a result, biomass showed similar trends like the cell numbers throughout the year. Changes in Chl *a* did not match the changes in *Synechococcus* abundance. Despite the highest Chl *a* concentration measured in March, the highest *Synechococcus* abundance was observed in September. This indicates that the contribution of *Synechococcus* to total Chl *a* increases with increasing temperature and euphotic zone depth. Although the euphotic layer is found greatest in September, the relatively high Chl *a* content could be composed of a few but healthy, young cells. Similarly, the maximum contribution of pico- and nanoplankton to total Chl *a* occurred during summer in Maliakos Bay in the eastern Mediterranean (Kormas et al. 2002). In this study, Chl *a* of <3 μm fraction accounted for 48% of the total Chl *a* in March, whereas this amount increased as high as 74% in September 2005. Modigh et al. (1996) stated that picoplankton fraction becomes more important at times when Chl *a* concentration is less than 1 μg dm^{-3}. In general, the <3 μm fraction was proportionally higher when the concentration of Chl *a* was lower in the present study.

In conclusion, it was shown that the abundance of *Synechococcus* has shown considerable spatial and temporal variability in the İskenderun Bay. Although most of this variability may be attributable to variations in temperature and nutrient supply, local hydrographic conditions such as wind and circulation systems and biological processes may also play a significant role in determining *Synechococcus* dynamics in this area. In the present study, small-sized phytoplankton was found to dominate the bulk at least for the summer period. As a reflection of the oligotrophic Mediterranean ecosystem, *Synechococcus* comprised an important fraction of the phytoplankton biomass in the bay. In this coastal ecosystem, further field and laboratory studies are needed for a better understanding of the microbial community dynamics and influence of environmental perturbations on them.

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