Turkish Journal of Botany

Volume 26 | Number 2 Article 2

1-1-2002

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Recommended Citation

POLAT, SEVİM and IŞIK, OYA (2002) "Phytoplankton Distribution, Diversity and Nutrients at the North-eastern Mediterranean Coast of Turkey (Karataş-Adana)," *Turkish Journal of Botany*: Vol. 26: No. 2, Article 2. Available at: https://journals.tubitak.gov.tr/botany/vol26/iss2/2

Turk J Bot
26 (2002) 77-86

Research Article

Phytoplankton Distribution, Diversity and Nutrients at the North-eastern Mediterranean Coast of Turkey (Karataş-Adana)

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Received: 11.01.2001
Accepted: 18.10.2001

Abstract: Seasonal changes in phytoplankton composition and phytoplankton abundance and physico-chemical factors affecting these parameters were investigated in this study. Quantitative and qualitative phytoplankton and nutrient analysis were carried out between 1998 and 1999 at 12 sampling stations located from inshore to offshore of Karataş, situated in the north-eastern Mediterranean. A total of 135 taxa were determined, belonging to four algae classes: *Cyanophyceae, Bacillariophyceae, Dinophyceae* and *Dictyochophyceae. Bacillariophyceae* appeared to be the dominant group in terms of total species number and cell numbers during the research period. The number of phytoplankton species was high in winter and quite low in summer. The highest phytoplankton abundance determined in summer was due to the increase in the numerical abundance of *Hemiaulus membranaceus* Cleve from the diatoms. Phytoplankton diversity declined to the lowest level in the summer. Nutrient concentrations were high in winter but low in summer. The lowest and highest concentrations of NO_3+NO_2-N, PO_4-P and silicate were 0.20 and 8.09 µg-at l^{-1}, 0.04 and 0.57 µg-at l^{-1} and 0.33 and 8.20 µg-at l^{-1} respectively.

Key Words: Phytoplankton, species composition, diversity, nutrients, Mediterranean Sea

Kuzeydoğu Akdeniz (Karataş-Adana) Kıyısal Sularında Fitoplankton Dağılımı, Çeşitliliği ve Besleyici Elementler

Özet: Bu çalışmada, fitoplankton kompozisyonu ve yoğunluğunun mevsimsel değişimi ve bunları etkileyen fizikokimyasal faktörler incelenmiştir. Kuzeydoğu Akdenizde Karataş kıyılarında toplam 12 istasyonda 1998-1999 yılları arasında fitoplankton nitel ve nicel olarak incelenmiş, besleyici element analizleri yapılmıştır. Çalışmada, *Cyanophyceae, Bacillariophyceae, Dictyochophyceae* ve *Dinophyceae* olmak üzere dört alg sınıfına ait toplam 135 taxa saptanmıştır. Bacillariophyceae, tür ve hücre sayıları olarak baskın bulunmuştur. En yüksek fitoplankton yoğunluğu yaz döneminde diatomlardan *Hemiaulus membranaceus* Cleve türünün artışı ile saptanmıştır. Fitoplanktona ait diversite değerleri yazın en düşük düzeylere inmiştir. Besleyici element konsantrasyonları en yüksek kış, en düşük yaz döneminde bulunmuştur. NO_3+NO_2-N, PO_4-P ve silikatın en düşük ve en yüksek değerleri sırasıyla 0.20-8.09 µg-at l^{-1}, 0.04-0.57 µg-at l^{-1} ve 0.33-8.20 µg-at l^{-1} olarak bulunmuştur.

Anahtar Sözcükler: Fitoplankton, tür kompozisyonu, çeşitlilik, besleyici elementler, Akdeniz.

Introduction

The eastern Mediterranean is one of the most impoverished (oligotrophic) seas in the world in terms of nutrient concentrations and productivity (Berman et al., 1984; Krom et al., 1991; Salihoğlu et al., 1990). However, some parts of the eastern Mediterranean are more productive because of local enrichment by run-off from the land.

İskenderun Bay and its environs are productive area located in the corner of the north-eastern Mediterranean. Primary production in the bay is about 2-4 times higher than that in the north-eastern Mediterranean; average production is 115 gC/ m^2/ year (Yılmaz et al., 1992). Unfortunately, it is under threat from pollutants coming from highly populated cities, agricultural areas and industrial facilities. In addition, the inputs from one of the main regional rivers, the River Ceyhan contributes to the pollution to a great extent.

Analysis of the structure of the phytoplankton community in any area is very important for commercial fisheries. Phytoplankton are the primary producers of the pelagic marine ecosystems and some of the phytoplankton species may also reflect the ecological changes in the environment, acting as an indicator organism. Unfortunately, there are few studies carried out on the phytoplankton succession and composition in Turkish coastal areas of the eastern Mediterranean compared to other coastal areas in Turkey. The first phytoplankton study in the region was carried out by Gökalp (1972) and a more recent one was performed by Polat et al. (2000). Similar studies were carried out on the Turkish coast of the Aegean Sea by Koray (1987, 1995) and on the Black Sea by Fevzioğlu and Tuncer (1994) and by Uysal and Sur (1995). Therefore, this study was carried out to investigate the composition, diversity and numerical abundance of phytoplankton and to study the nutrients and physico-chemical factors and their impacts on the abundance of the phytoplankton by seasonal samplings in the coastal area of Karataş, which is one of the main fishery centres in the region.

Materials and Methods

The study was carried out in the coastal area of Karataş, located in the north-western part of İskenderun Bay, north-eastern Mediterranean, from inshore to offshore to a sea depth of 70 m (between lat. 36°33'N, long 35°23' E and lat. 36°23' N, long 35°22'E). Twelve sampling stations were selected in the area. The location of the research area and sampling stations are shown in Figure 1.

Sampling was carried out (four times a year) in November for autumn, January for winter, April for spring and July for summer between 1998 and 1999. A standard Hydro-Bios plankton net with 55-µm mesh size was used for phytoplankton sampling. Phytoplankton samples were fixed in formaldehyde (4% final concentration). Net samples were used for the qualitative examinations. For quantitative phytoplankton analysis, 2 l of seawater was left to settle for one week and phytoplankton in concentrated samples enumerated by a using Sedgwick-Rafter cell counter. An Olympus BX-50 and CK-40 model microscopes were used for examination of the phytoplankton. The identification of the species and their taxonomic categories were given according to Tregouboff and Rose (1957), Rampi and Bernhard (1980), Sournia (1986), Ricard (1987), Delgado and Fortuna (1991), and Tomas (1997).

Temperature and salinity measurements were taken by a YSI model SCT meter during the sampling period. Nutrient (NO_3+NO_2-N, PO_4-P and silicate) analysis were performed by using an LKB 4050 model spectrophotometer according to the standard procedure of Parsons et al., (1984) and the results were expressed as µg-at l^{-1}.

Shannon-Weaver (H') and Pielou-evenness (J') indices were calculated according to Omori and Ikeda (1984) in

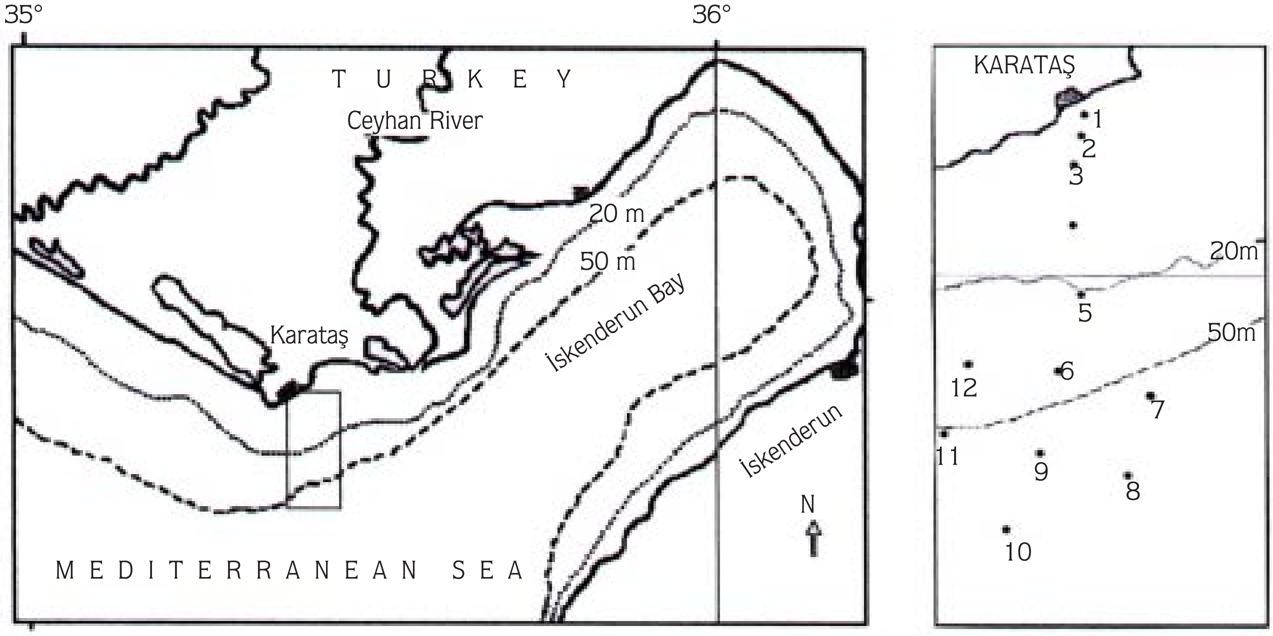

Figure 1. Sampling area and location of stations.

order to obtain more information on the phytoplankton community, using the data on species and cell numbers. Correlation coefficients between physicochemical data and phytoplankton abundance were computed. In addition, nutrient concentration data was analysed statistically (two way analysis of variance) for detection of differences among seasons and stations. Statistical analysis was performed using SPSS 8.0.

Results

Physico-chemical Factors

Seasonal changes in temperature and salinity in different sampling stations are shown in Figures 2 and 3. The lowest temperature (15.5°C) was recorded in January, whereas the highest, in July, was 29°C. As a result of the increase in rain and freshwater input from the land, salinity dropped to the lowest level (33‰) in January (Fig. 3), but it reached 39.2‰ again in November as a function of the climatic characteristics of high evaporation and lack of rain in the summer months.

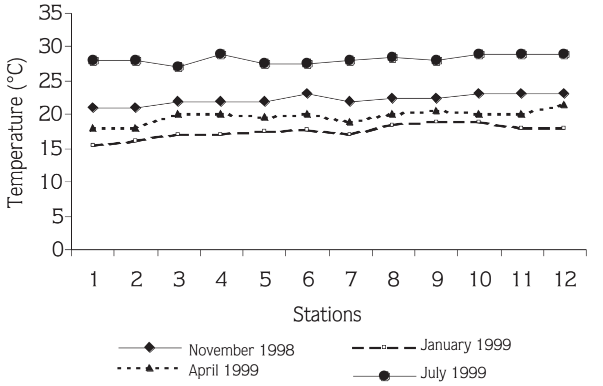

Figure 2. Seasonal changes in surface water temperature at sampling stations.

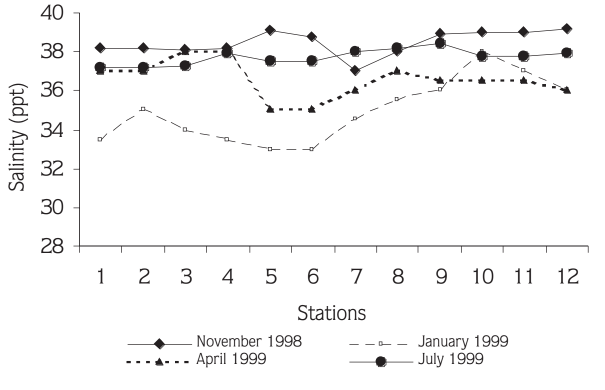

Figure 3. Seasonal changes in surface water salinity at sampling stations.

Nutrients showed important seasonal cycles. The differences among seasons were statistically significant for all nutrients (nitrate+nitrite, phosphate and silicate) ($p<0.01$). The lowest (0.20 μg-at l^{-1}) and highest (8.09 μg-at l^{-1}) nitrate+nitrite concentrations were found in July and January respectively (Fig. 4).

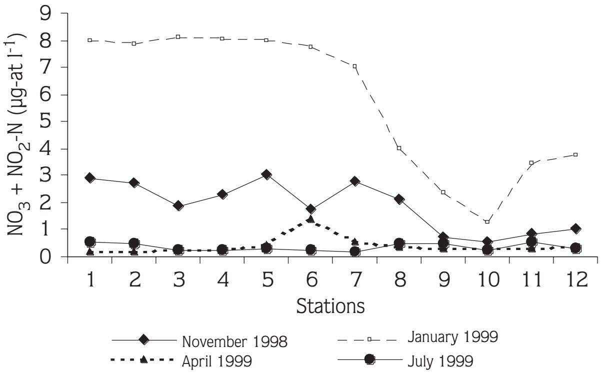

Figure 4. Seasonal changes in surface nitrate+nitrite concentrations at sampling stations.

The lowest and the highest phosphate concentrations were 0.04 μg-at l^{-1} in July and 0.57 μg-at l^{-1} in November. Fluctuations in phosphate concentrations among the stations were lower in November and July than in January and April (Fig. 5). The changes in phosphate concentrations among the stations were not significant ($p>0.01$).

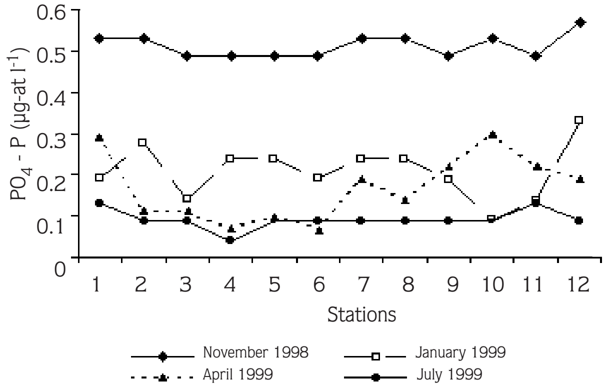

Figure 5. Seasonal changes in surface water phosphate concentrations at sampling stations.

The lowest and highest silicate concentrations were 0.33 μg-at l^{-1} in July and 8.20 μg-at l^{-1} in January (Fig. 6). In April, the silicate level declined to 3.81 μg-at l^{-1}. In

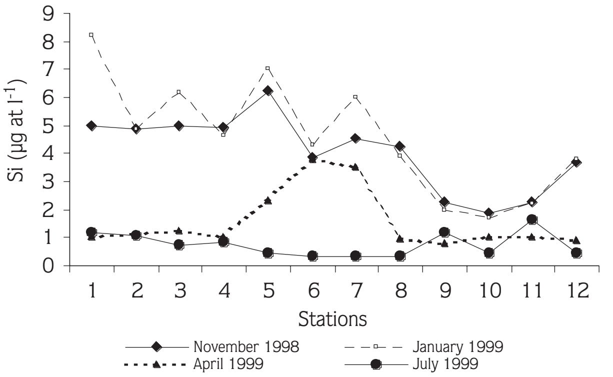

Figure 6. Seasonal changes in surface water silicate concentrations at sampling stations.

November and January, the silicate concentrations were higher at inshore than at offshore stations. However, differences among the stations were not statistically significant ($p>0.01$).

Phytoplankton Composition and Abundance

A total of 135 taxa of phytoplankton were identified during the study. These include 69 taxa belonging to 34 genera of *Bacillariophyceae*, 64 taxa belonging to 16 genera of *Dinophyceae*. *Cyanophyceae* and *Dictyochophyceae* classes were represented by only one species each (Table 1).

Diatoms were dominant in terms of the number of species and their abundance. The highest number of

Table 1. List and frequency distribution of phytoplankton species between 1998 and 1999 (V = very abundant, 61-100%; A= abundant, 41-60%; C=common, 16-40%; R=rare, 1-15%; X= present occasionally).

Species	Nov.	Jan.	Apr.	Jul.
CYANOPHYCEAE				
Oscillatoria sp.	A	V	-	V
DINOPHYCEAE				
Amphisolenia bidentata Schröder	R	R	-	-
Ceratium arietinum var. *arietinum*	-	V	-	-
C. biceps Claparede et Lachmann	C	V	C	V
C. candelabrum (Ehrenberg) Stein	C	V	V	V
C. carriense var. *volans*	C	-	C	-
C. concilians Jörgensen	C	C	-	-
C. contortum var. *karstenii* (Pavillard) Sournia	C	C	R	C
C. contortum var. *contortum* (Gourret) Cleve	-	R	-	-
C. declinatum f. *majus* Jörgensen	-	A	-	R
C. euarcuatum Jörgensen	R	-	R	-
C. furca (Ehrenberg) Claparede et Lachmann	C	R	V	-
C. fusus (Ehrenberg) Dujardin	C	V	C	-
C. hexacanthum Gourret	R	R	C	-
C. horridum (Cleve) Gran	A	V	R	-
C. inflatum (Kofoid) Jörgensen	C	R	C	-
C. kofoidii Jörgensen	A	V	V	R
C. longirostrum Gourret	-	R	R	-
C. macroceros (Ehrenberg) Cleve	C	A	A	C
C. massiliense (Gourret) Jörgensen	C	A	V	X
C. pentagonum Gourret	-	V	-	-
C. ranipes Cleve	-	R	-	-
C. symetricum Pavillard	-	A	C	-
C. trichoceros (Ehrenberg) Kofoid	V	C	V	V
C. tripos var. *atlanticum* (Ostenfeld) Paulsen	V	C	A	C
C. tripos var. *pulchellum* (Schröder) Lopez	R	C	R	A
C. teres Kofoid	V	V	C	-
Ceratocorys gourreti Paulsen	-	R	-	-
C. horrida Stein	R	C	-	V
Dinophysis caudata Saville-Kent	-	C	V	-
D. odiosa (Pavillard) Tai and Skogsberg	-	R	-	-

Table 1. continued

Species	Nov.	Jan.	Apr.	Jul.
D. parvula (Schütt) Balech	-	R	-	-
D. recurva Kofoid et Skogsberg	X	-	-	-
Diplopsalis lenticula Bergh	-	-	-	R
Gonyaulax polygramma Stein	C	C	R	-
G. polyedra Stein	R	-	-	-
G. diegensis Kofoid	R	C	R	-
G. spinifera (Claparede et Lachmann) Diesing	C	-	R	-
Heteraulacus polyedricus (Pouchet) Drugg et Loeblich	V	V	A	A
Kofoidinium velelloides Pavillard	-	R	R	R
Ornithocercus magnificus Stein	A	C	-	-
O. quadratus Schütt	R	R	-	-
Oxytoxum scolopax Stein	-	R	R	R
Oxytoxum sp.	C	C	R	R
Podolampas bipes Stein	C	C	-	-
P. spinifera Okamura	R	R	R	-
Prorocentrum micans Ehrenberg	-	A	C	R
P. compressum (Bailey) Abe	C	R	-	R
Protoperidinium brochi (Kofoid et Swezy) Balech	-	-	C	-
P. conicum (Gran) Balech	-	R	A	C
P. depressum (Bailey) Balech	R	-	R	C
P. divergens (Ehrenberg) Balech	R	C	V	A
P. globolus (Cleve) Balech	-	C	-	-
P. mediterraneum (Kofoid) Balech	R	V	-	-
P. oceanicum (Vanhöffen) Balech	-	-	C	-
P. pedunculatum (Schütt) Balech	-	C	-	-
P. pellucidum (Bergh) Balech	C	R	-	-
P. pyriforme (Paulsen) Balech	-	V	-	-
P. quarnerense (Schröder) Balech	C	V	R	-
P. steinii (Jörgensen) Balech	V	A	C	R
P. subinerme (Paulsen) Balech	C	R	-	-
Protoperidinium sp.	-	R	R	-
Pyrophacus steinii (J.Schiller) Wall et Dale	-	-	-	A
Scrippsiella trochoidea (Stein) A.R. Loeblich	A	V	C	-
Spiraulax jollifei Murray et Whitting)Kofoid	-	C	-	-
DICTYOCHOPHYCEAE				
Dictyocha fibula Ehrenberg	A	V	C	-
BACILLARIOPHYCEAE				
Asteromphalus flabellatus (Brebisson) Greville	A	V	-	-
A. heptactis (Brebisson) Ralf in Pritchard	R	R	-	-
Amphiprora sp.	X	-	-	-
Asterolampra grevillei (Wallich) Greville	-	R	-	R
Asterolampra marylandica Ehrenberg	C	C	-	-
Asterionellopsis glacialis (Castracane) Round	-	V	C	-
Bacteriastrum delicatulum Cleve	-	A	V	-
Bacteriastrum hyalinum Lauder	-	-	-	R
Biddulphia puchella Gray	R	-	-	-
Campylodiscus sp.	X	-	-	X
Climacosphaenia moniligera Ehrenberg	R	-	-	-
Chaetoceros affinis Lauder	R	C	V	-
C. atlanticus Cleve	-	R	C	-
C. compressus Lauder	-	-	C	-
C. costatum Pavillard	-	-	V	-

Table 1. continued

Species	Nov.	Jan.	Apr.	Jul.
C. curvisetus Cleve	C	C	A	-
C. dadayi Pavillard	R	X	-	-
C. decipiens Cleve	R	V	C	-
C. didymus Ehrenberg	R	R	R	R
C. diversus Cleve	-	R	C	-
C. laciniosus Schütt	R	A	C	-
C. lorenzianus	R	C	A	-
C. peruvianus Brightwell	-	-	R	-
C. pseudocurvisetus Mangin	R	R	R	R
C. tetrastichon Cleve	C	C	-	C
C. tortissimus Gran	-	-	A	-
Cerataulina pelagica (Cleve) Hendey	R	V	A	R
Coscinodiscus perforatus Ehrenberg	R	-	R	-
C. radiatus Ehrenberg	R	C	-	-
Cylindrotheca closterium (Ehrenberg) Reimann et Lewin	R	R	C	-
Dactyliosolen mediterraneus H. Peragallo	C	R	-	-
Eucampia zodiacus Ehrenberg	-	A	C	C
Gyrosigma balticum (Ehrenberg) Rabenhorst	R	-	-	-
Gyrosigma sp.	R	-	-	-
Guinardia flaccida (Castracane) H. Peragallo	V	V	V	A
Hemiaulus hauckii Grunow in Van heurck	V	V	V	V
Hemiaulus membranaceus Cleve	-	-	-	V
Hemiaulus sinensis Greville	R	A	R	A
Leptocylindricus danicus Cleve	-	C	R	C
Leptocylindricus minimus Gran	-	C	-	C
Licmophora abbreviata Agardh	C	R	R	R
Lithodesmium undulatum Ehrenberg	R	-	-	-
Navicula sp.	-	-	R	-
Nitzschia longissima (Brebisson in Kützing) Ralf in Pritchard	-	R	X	-
Nitzschia paradoxa Grunow in Cleve	R	R	R	-
Nitzschia sigma (Kützing) W. Smith	R	-	-	R
Odontella mobiliensis (Bailey) Grunow	R	-	-	R
Pleurosigma elongatum W.Smith	C	-	R	R
Pleurosigma normanii Ralfs in Pritchard	C	V	A	R
Pseudonitzschia delicatissima (Cleve) Heiden in Heiden and Kolbe	-	R	C	-
P. pungens (Grunow ex P.T.Cleve) Hasle	C	R	-	-
Rhizosolenia alata f. *gracillima* (Cleve) Gran	V	A	V	V
R. alata f. *indica* (H.Peragallo) Gran	-	A	A	V
R. calcar-avis Schultze	V	V	A	V
R. imbricata var. *shrubsolei* (Cleve) Schröder	A	V	A	C
R. robusta Norman in Pritchard	C	R	A	A
R. setigera Brightwell	C	-	C	-
R. stolterfothii H.Peragallo	A	V	V	R
R. sytliformis Brightwell	R	R	R	-
Surirella fastuosa Ehrenberg	-	R	-	-
Stephanopyxis sp.	R	-	C	-
Striatella unipunctata (Lyngbye) Agardh	R	-	-	C
Synedra ulna (Nitzsch) Ehrenberg	C	-	-	-
S. undulata (Bailey) Gregory	R	R	-	X
Thalassionema nitzschioides (Grunow) Mereschkosy	-	V	-	-
Thalassiothrix fraunfeldii Grunow	R	V	V	C
T. mediterranea Pavillard	R	V	V	C
Thalassiophysa hyalina (Greville)	X	-	-	-
Triceratium sp.	R	-	-	-

species was found in winter and only during this period was the number of the dinoflagellate species higher than that of diatoms (Fig. 7). The lowest phytoplankton species number was determined in July.

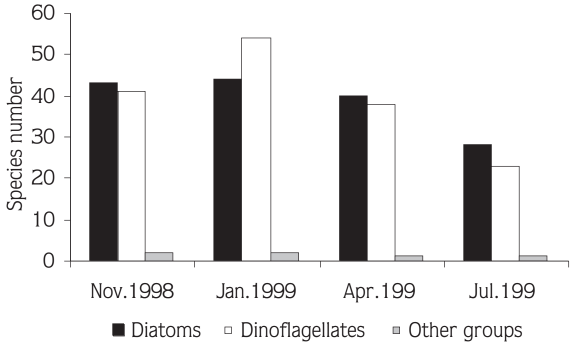

Figure 7. Species number of identified phytoplankton groups in sampling periods.

In phytoplankton succession, the most abundant species in November were the diatoms *Guinardia flaccida* (Castrac.) H.Perag., *Hemiaulus hauckii* Grunow in Van Heurck and *Rhizosolenia alata* f. *gracillima* (Cleve) Gran and the dinoflagellates *Ceratium* spp., and in winter the diatoms *Thalassiothrix mediterranea* Pavill. and *Thalassiothrix fraunfeldii* Grunow and the dinoflagellates *Ceratium* spp. and *Protoperidinium* spp. In April, the genus *Chaetoceros* Ehrenb. became dominant in terms of the number of the species and abundance. *Chaetoceros* was also a major genus of diatoms with 15 species.

In the summer, in addition to *H. membranaceus Cleve*, *H. hauckii* and *Rhizosolenia calcar-avis* Schultze from the diatoms, species of *Ceratium* Schrank and *Protoperidinium* Bergh from the dinoflagellates were dominant species. The genus *Ceratium* was represented by the highest number of species (23 species) during the study.

It was clear that diatoms were dominant in terms of cell numbers. The abundance of diatoms increased and reached 28,362 cells l^{-1} in July. The increase in the cell numbers of *Hemiaulus membranaceus* was attributed to an increase in diatoms in summer. The abundance of diatoms was low in November and January (Fig. 8).

Dinoflagellates were similar to diatoms in terms of species numbers but lower in terms of cell numbers (Fig. 9). In November and January, dinoflagellate cell numbers were at the lowest level (700 cells l^{-1}). Only in April were dinoflagellate cell numbers higher than those of diatoms at the first sampling station due to an increase in the cell numbers of *Scrippsiella trochoidea* (Stein) A.R. Loebl. Dinoflagellate cell numbers reached 11,834 cells l^{-1} during this period, whereas in July they declined to quite a low level (27 cells l^{-1}).

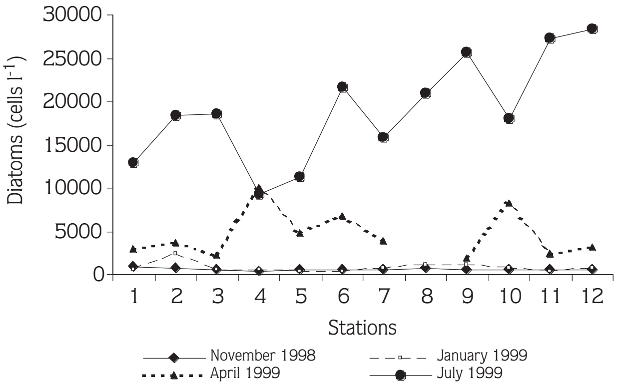

Figure 8. Seasonal changes in diatom cell numbers at sampling stations.

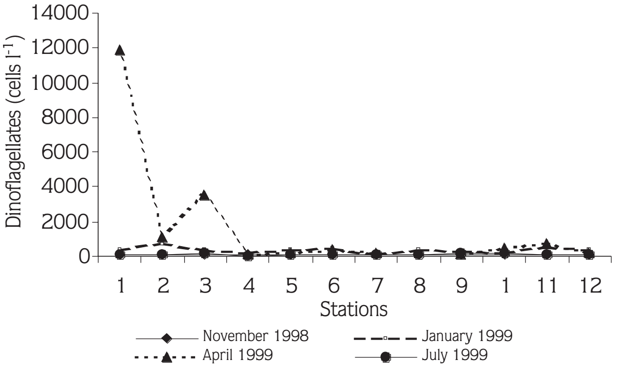

Figure 9. Seasonal changes in dinoflagellate cell numbers at sampling stations.

Shannon-Weaver diversity and evenness indices were calculated by using the data on phytoplankton species and numerical abundance (cell number). Seasonal changes in diatom and dinoflagellate cell numbers and diversity indices are shown in Figure 10.

The highest values were 2.64 for Shannon–Weaver diversity indices and 0.74 for evenness indices in winter, when the highest number of species was determined. The lowest values were 0.13 and 0.04 in July, when a low number of species and a high number of individuals were determined.

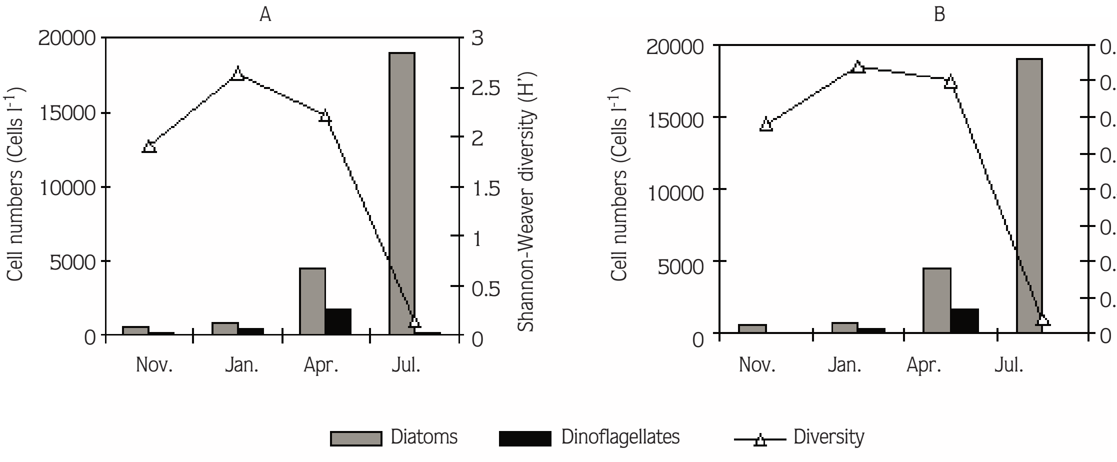

Figure 10. Variations in the mean diatom and dinoflagellat cell numbers and diversity. A. Shannon-Weaver, B. Evenness.

Discussion and Conclusions

The 135 identified phytoplankton taxa given in Table 1 include the species previously identified in different parts of the Mediterranean by Gökalp (1972), Dowidar (1974), Lakkis and Lakkis (1980) and Polat et al. (2000). Diatoms and dinoflagellates comprised 88.9% and 11.09% as cell numbers respectively. As this result shows, the cell number of diatoms was the highest among the groups. The highest phytoplankton species number was found in winter. The number of species in this study was lower than in earlier works on Yumurtalık Bight (Avşar et al., 1998), İskenderun Bay (Polat et al., 2000) and Mersin Bay (Eker and Kıdeyş, 2000). This could be due to the seasonal sampling programme of this research. Eker and Kıdeyş (2000) found 175 species in Mersin Bay and they suggested that this might be the result of the weekly sampling regime that they used in their study.

In the present study, phytoplankton cell number showed significant fluctuations in different seasons. Cell numbers decreased in November and January but an increase started in April. The highest cell number was found during the summer cruise when relatively larger individuals were dominant. The summer increase was attributed to the increase in the cell number of *Hemiaulus membranaceus*, which reached 28,480 cells l^{-1}. Azov (1986) stated that larger phytoplankton species respond faster to favourable conditions and dominate the population at the time of bloom.

Dinoflagellate abundance was quite low. Phytoplankton cell numbers found in this study were lower than those previously reported by Lakkis and Lakkis (1980), Polat et al., (2000) and Eker and Kıdeyş (2000) for the eastern Mediterranean. In general, large phytoplankton species were dominant but they did not reach high concentrations. However, it is likely that small size groups, such as picophytoplankton (<2 µm), have great importance in warm oligotrophic waters (Agawin et al., 2000). Berman et al., (1986) also reported that picophytoplankton was generally the major algal biomass component in the eastern Mediterranean (Israeli coasts). The high level of production found in the Red Sea despite low phytoplankton cell numbers was attributed to nano- and picophytoplankton by Shaikh et al., (1986).

The number of phytoplankton species was high in autumn and winter but lower in the summer; this may be a result of the dominance of a diatom, *H. membranaceus*. Ignitiades (1969) reported that the diversity index declined to a minimum level when one or a few species were dominant in phytoplankton blooms. Therefore, in our research the lowest diversity value for phytoplankton communities was found in summer.

In contrast to many previous findings (Gotsis-Scretas and Friligos, 1985; Kıdeyş et al., 1989) from the Mediterranean, a significant positive relationship was found between temperature and phytoplankton abundance ($r=0.75$, $p<0.01$). The reason is that phytoplankton abundance increased in our research in summer instead of late winter and spring as previously reported for different parts of the Mediterranean by Kıdeyş et al., (1989) and Delgado (1990).

Salinity decreased due to rain and freshwater input in winter and no relationship was found between salinity and phytoplankton abundance. Nutrient concentrations recorded in this research were lower than previous findings of Yılmaz et al., (1992) in İskenderun Bay. Our research area is located at the north-western entrance of İskenderun Bay and is under the effects of winds and water current prevailing in the north-eastern Mediterranean (Avşar, 1999). In present study, nutrient concentrations did not reach to high levels in this area, probably as a result of current and circulation events in the Northeastern Mediterranean. In fact, higher nutrient values had been expected considering nutrient input from the Ceyhan River discharging close to the research area. Nitrate+nitrite levels were relatively high in the stations near the coast. Nitrate+nitrite and silicate concentrations reached their highest level in winter while phosphate reached its highest level in autumn. Nutrient concentrations in general decreased to their lowest level in summer due to an increase in phytoplankton abundance. In general, significant negative relationships were found between phytoplankton abundance and nutrient concentration (nitrate+nitrite $r = -0.47$, $p<0.01$; phosphate $r = -0.58$, $p<0.01$ and silicate $r = -0.63$, $p<0.01$).

It may be concluded that the relatively high levels of nutrients measured at coastal stations were due to the land run-off and vertical mixing process. Exceptional increases in phytoplankton, as was the case in July in this study, may be related to all the processes prevailing in the research area.

Further research is necessary to understand the relationships between phytoplankton and environmental properties in the north-eastern Mediterranean.

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