Sains Malaysiana 42(10)(2013): 1493–1499

Variations of Planktonic Chlorophyll-*a* in Relation to Environmental Factors in a Mediterranean Coastal System (Iskenderun Bay, Northeastern Mediterranean Sea)

(Variasi Klorofil-*a* Plankton Berhubung dengan Faktor Alam Sekitar di Sistem Pantai Mediterranean (Teluk Iskenderun, Timur Laut Laut Mediterranean)

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ABSTRACT

*Chlorophyll-*a *is one of the most widely used parameters to estimate trophic state of an aquatic environment. The purpose of this study was to investigate the changes in the planktonic chlorophyll-*a *concentrations in relation to environmental parameters in the east part of Iskenderun Bay (Northeastern Mediterranean Sea). Monthly measurements of chlorophyll-*a *and inorganic nutrients were done on two transects at 6 stations across the Bay. In addition, variations in temperature, salinity and some meteorological factors were also investigated, their correlation with chlorophyll-*a *were analyzed. The highest chlorophyll-*a *concentration (3.8 µg* L^{-1}*) was found on coastal transect nearer to the bay. The first peak in chlorophyll-*a *occurred in May, a second smaller peak was recorded in September. The correlation of chlorophyll-*a *was significantly positive for Silicate-Si and Nitrate+nitrite-N but not important for Phosphate-P. No dramatic increase in chlorophyll-*a *levels was encountered in the area during the study period. It was concluded that, due to the hydrodynamic structure of the area, the land-based effects influence chlorophyll-*a *dynamics.*

*Keywords: Chlorophyll-*a*; dinorganic nutrients; eutrophication; İskenderun Bay; northeastern Mediterranean*

ABSTRAK

*Klorofil-*a *ialah salah satu daripada parameter yang digunakan secara meluas untuk menganggar keadaan trofik bagi suatu persekitaran akuatik. Tujuan penyelidikan ini ialah untuk mengkaji perubahan kepekatan dalam klorofil-*a *plankton berhubung dengan parameter alam sekitar di bahagian timur Iskenderun Bay (Timur laut Laut Mediterranean). Pengukuran bulanan klorofil-*a *dan nutrien tak organik telah dibuat pada dua transek di enam stesyen merentasi Teluk. Tambahan pula, variasi dalam suhu, saliniti dan beberapa faktor metereologi juga telah dikaji dan korelasinya dengan klorofil-*a *telah dianalisis. Kepekatan klorofil-*a *tertinggi (3.8 µg* L^{-1}*) telah didapati pada transek terdekat dengan teluk. Mercu pertama dalam klorofil-*a *berlaku pada bulan Mei, mercu kedua yang kecil telah direkodkan pada bulan September. Korelasi klorofil-*a *adalah positif secara signifikan bagi Silikat-Si dan Nitrat+nitrit-N tetapi tidak penting bagi fosfat-P. Tidak berlaku peningkatan yang mendadak dalam aras klorofil-*a *semasa tempoh kajian. Adalah dirumuskan bahawa oleh kerana struktur hidrodinamik kawasan itu, kesan bersandarkan daratan telah memberi kesan kepada kedinamikan klorofil-*a.

*Kata kunci: Eutrofikasi; klorofil-*a*; nutrien tak organik; Teluk İskenderun; timur laut Mediterranean*

INTRODUCTİON

Nutrient increase in coastal environments by various processes enhance phytoplankton growth and biomass. However, high level of nutrient loading to coastal areas may cause eutrophication. Nitrogen and phosphorus in agricultural and domestic inputs and river run off support phytoplankton growth to the level where other nutrients become growth limiting (Ornolfsdottır et al. 2004). Response of phytoplankton growth and biomass to eutrophic conditions provide information for establishing the effects of eutrophication in the related environment. From this viewpoint, levels of chlorophyll-*a* are commonly used as an indicator of trophic status. In recent years scaling of chlorophyll-*a* has been proposed by some researchers to classify the ecological status of seas (Ignatiades 2005). The Mediterranean is one of the least productive seas of the world and the eastern Mediterranean forms the most oligotrophic part of it (Azov 1991). The deep waters of eastern Mediterranean are characterized by high N:P ratios and low primary productivity especially caused by phosphorus limitation (Krom et al. 1991; Thingstad et al. 2005). However, many coastal areas in the Mediterranean are exposed to land based pollution sources, mainly from agricultural, domestic and industrial effluents and/or river runoff. Iskenderun Bay is located in the northeastern side of the Levantine Basin, in the eastern Mediterranean. The surface area of the bay is approximately 2275 km^2 and the average depth is around 70 m. The bay and its opening form one of the largest continental shelf areas in the eastern Mediterranean. The hydrography of the bay is affected by the local winds and current systems prevailing in the eastern Mediterranean (Yilmaz et al. 1992). The coasts of the bay can be regarded intensely industrialized with petroleum pipelines, iron-steel and fertilizer industries and this industrialization is increasing day by day. In addition, Ceyhan River, one of the major rivers on the south coast of Turkey discharges significant amount of freshwater (180 $m^3 s^{-1}$) into the bay (Yilmaz et al. 1992). The aim of this study was to investigate the spatial and temporal changes in planktonic chlorophyll-*a* and to discuss its response to different environmental factors of the studied area.

MATERIAL AND METHODS

Sampling was performed at monthly interval on the east part of the bay on two transects at 6 sampling stations (Figure 1). Water samples for chlorophyll-*a* and nutrient analysis were collected from the surface of all stations and the standard depths (10, 20, 30, 40 and 50 m) of the deepest station (st B3) by using a water sampler. Chlorophyll-*a* analysis was done according to Parsons et al. (1984). For the analysis, two liters of seawater were filtered through GF/F filters. Filters were stored at -20°C till the pigment determination. The pigments on the filter were then extracted using 90% acetone solution and absorbance of chlorophyll-*a* measured with a Schimadzu spectrophotometer. Phosphate, Nitrate+nitrite and Silicate were determined spectrophotometrically according to the methods given by Strickland and Parsons (1972). Seawater temperature and salinity were measured during the sampling operations with a YSI salinity and temperature probe. Water transparency was estimated using a Secchi disc.

Some meteorological data such as monthly mean wind speed and monthly total rainfall of the area (Iskenderun province) covering the study period were provided by the Turkish State Meteorological Service. Chlorophyll-*a*, nutrients and other physico-chemical data were given as mean values of each transect. The values of each of the three stations were averaged for each transect in order to establish different patterns of two transects. The Spearman correlation was applied to find out the relationship among chlorophyll-*a* and environmental parameters. Moreover, stepwise regression was used to evaluate the effect of variables on chlorophyll-*a* variation (Sokal & Rolf 1981).

RESULTS

PHYSICOCHEMICAL DATA

No pronounced difference was observed between two transects in terms of temperature and salinity. Seawater temperature showed seasonal cycle with lowest values (15-16°C) during February-March and the highest (32.8°C) in July. Salinity was generally lower on transect A and relatively low levels of salinity during the study (33.6-37.2 ‰) show freshwater input in the study area. Total rainfall and wind speed values of the region for the study period are shown in Figure 2. The periods with highest rainfall is February and March; followed by a dry period during July and August. The lowest rainfall in summer period coincided with the highest wind speed values. Secchi disc depth ranged between 3 and 17 m and the maximum depth was measured in

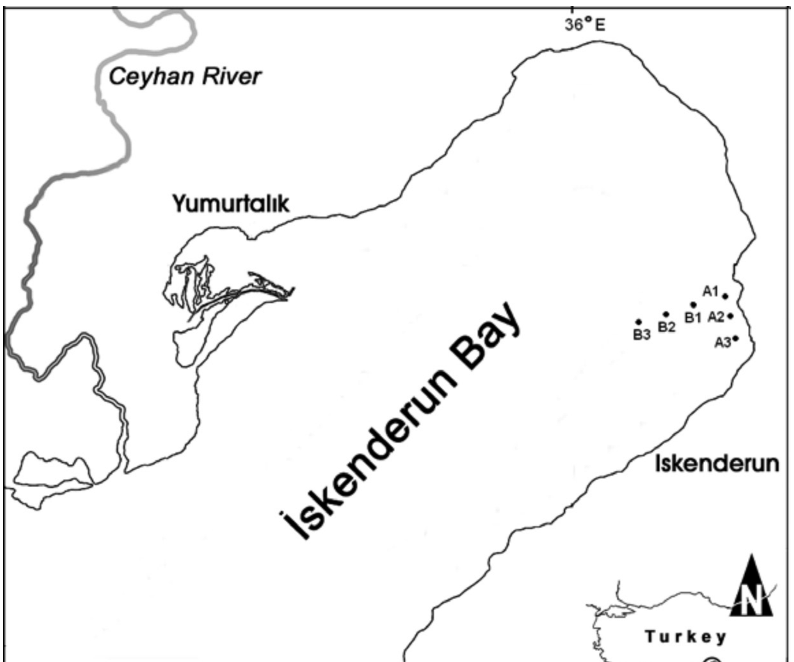

FIGURE 1. Study area and sampling points

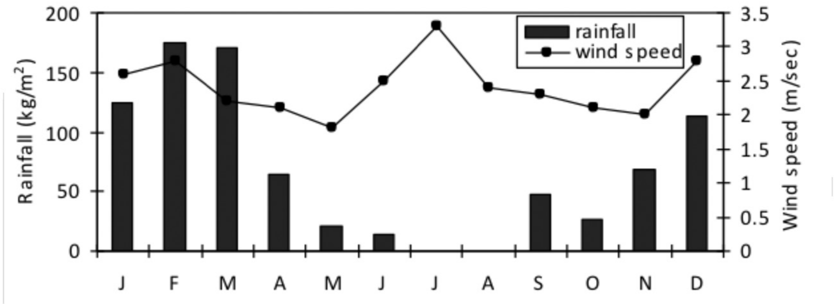

FIGURE 2. Monthly variations of rainfall and wind speed in the study area

the month of January at station B2. The surface nutrient concentrations on two transects are shown in Figure 3. Vertical distribution of nutrients at the station B3 are presented in Figure 4.

Mean concentrations of Nitrate+nitrite-N were higher at transect A during all the months except April (Figure 3). However the fluctuation patterns were similar at two transects during this study. Maximum surface Nitrate+nitrite-N concentration was found in September as 11.5 μM on transect A. Except May, water column Nitrate+nitrite-N concentration remained below 4 μM throughout the sampling period (Figure 4). The Nitrate+nitrite-N values reached 7 μM at 40 m in May. Mean Phosphate-P concentrations were found to be similar at two transects except for in February and December when higher values were detected on transect A during these periods (Figure 3). The lowest and highest Phosphate-P concentrations were found as 0.09 and 1.13 μM. The lowest levels were attained in January, whereas the highest values were observed in December. Depth profile of Phosphate-P showed clear fluctuations for most of the sampling times (Figure 4). Mean Silicate concentrations were higher on transect A during all periods. Silicate-Si ranged from 1.42 to 18.9 μM, with the highest concentration in March on transect A at station A1. In April, Silicate-Si was highest at the surface and tended to decrease with depth while in July, it slightly increased with depth and reached a

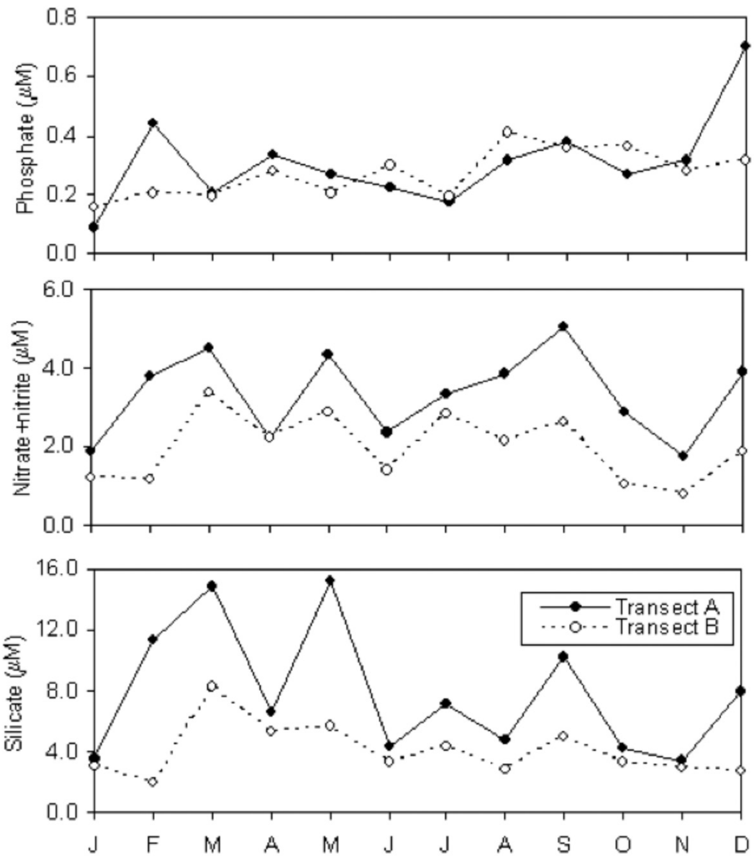

FIGURE 3. Monthly variations of nutrients on two transects in the study area

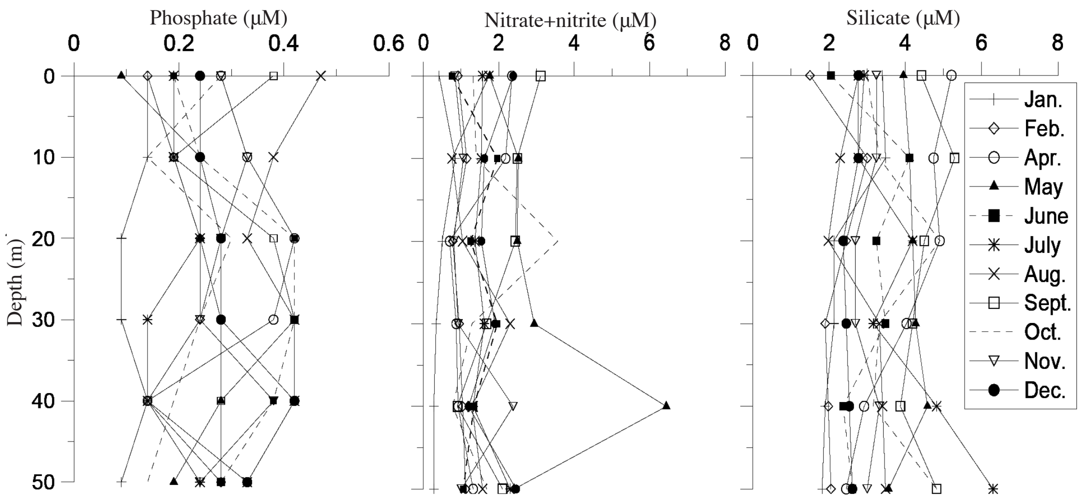

FIGURE 4. Depth profiles of nutrients during sampling periods at station B3

highest level at 50 m. The molar ratios of Nitrate+nitrite- to Phosphate (N:P) ranged between 2.9 and 21.8. The highest ratio was found in March and the lowest in November. On the other hand, the lowest and the highest mean Si:P ratios were found as 7 and 67.7 in August and March, respectively (Figure 5).

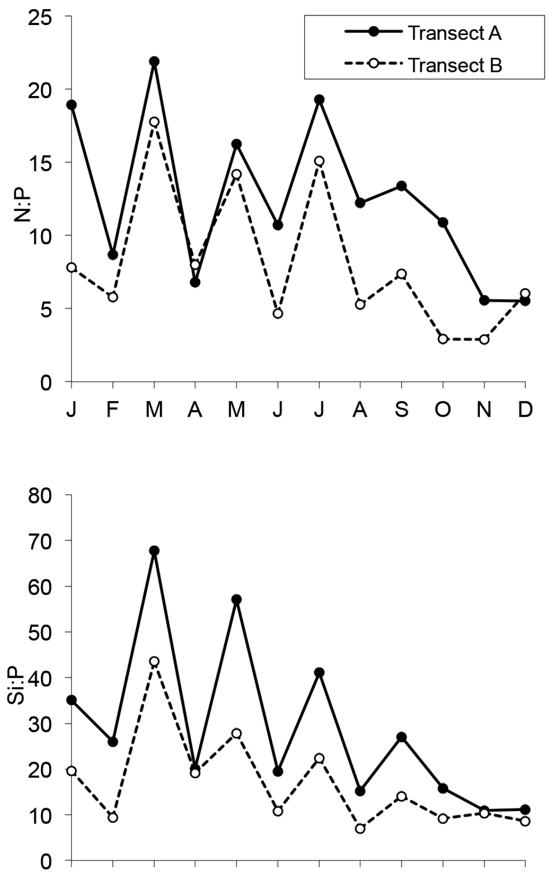

FIGURE 5. Monthly variations of N:P and Si:P ratios on two transects in the study area

TEMPORAL AND SPATIAL DISTRIBUTION OF CHLOROPHYLL-*A*

The surface chlorophyll-*a* distribution is shown in Figure 6 for the study period on two transects. Chlorophyll-*a* concentrations showed a clear pattern of spatial fluctuation. The highest value (3.8 μg L^{-1}) was found on transect A at station A1 which was close to the coast. On the other hand, the highest mean concentration of chlorophyll-*a* on this transect was found as 2.4 μg L^{-1}. Chlorophyll-*a* values at the stations on transect B usually did not exceed 1 μg L^{-1} and moreover, the mean concentrations of chlorophyll-*a* were lower than 1 μg L^{-1} on transect B (Figure 6). On transect A, the first peak was observed in May, when rainfall and wind speed were low, a second and small peak occurred in September. On transect B, a small peak occurred in September. Vertical distribution of chlorophyll-*a* generally showed fluctuations during the year. Water column chlorophyll-*a* values ranged between 0.06 and 0.46 μg L^{-1}. In February and October, chlorophyll-*a* were almost homogenous between surface and 50 m, but in December, August and September it showed increase at 40-50 m depth (Figure 7).

Total chlorophyll-*a* values were positively correlated with Silicate-Si and Nitrate-N among the nutrients and negatively correlated with salinity and secchi depth on transect A (Table 1). Similarly, chlorophyll-*a* showed positive correlation with Silicate-Si and negative with secchi depth on transect B. No correlation was observed with salinity and Nitrate-N on transect B. The correlation of chlorophyll-*a* with seawater temperature and Phosphate-P were not significant on both transects. The correlation of chlorophyll-*a* with total rainfall and wind speed too were not significant. The relationship between chlorophyll-*a* and environmental variables was evaluated by stepwise regression analysis. It was found that, 56% of chlorophyll-*a* variation is explained by Silicate-Si and salinity for transect A (log Chl-*a* = 9.41+0.301 logSilicate - 6.06 logSalinity, R^2=0.56). On the other hand, for transect B the whole data belonging to both transects 26% (log Chl-*a* = -0.03+0.22

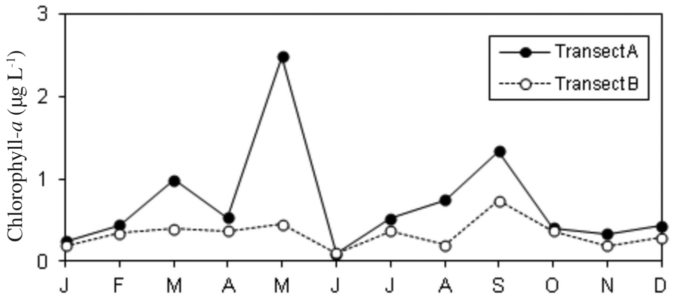

FIGURE 6. Monthly variations of chlorophyll-*a* on two transects in the study area

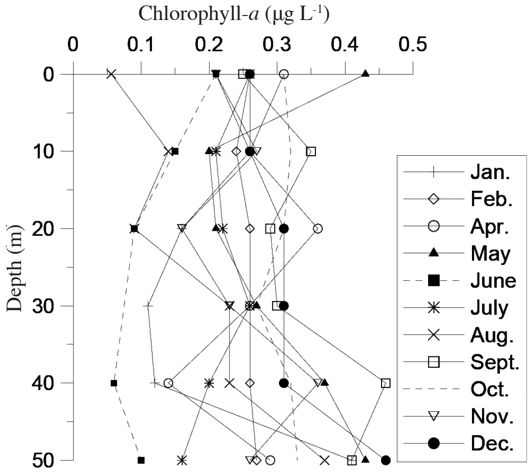

FIGURE 7. Depth profiles of chlorophyll-*a* during sampling periods at station B

TABLE 1. Correlation matrix to correlate chlorophyll-*a* and some physico-chemical variables

		Salinity	Nitrate+nitrite	Silicate	N:P	Si:P	Secchi depth
Transect A	Chl-*a*	-0.538**	0.490**	0.716**	0.399	0.503	-0.418*
Transect B	Chl-*a*	-0.092	0.307	0.537**	0.596*	0.459	-0.388*
Whole data	Chl-*a*	-0.314**	0.506**	0.705**	0.510*	0.536**	-0.515**

(**p<0.01, *p<0.05) (The correlations of found statistically insignificant among chlorophyll-*a* and temperature, Phosphate and meteorological parameters were not shown)

logSilicate, R^2=0.26) and 48% (log Chl-*a* = -0.126+0.372 logSilicate, R^2=0.48), of variation in chlorophyll-*a*, respectively, were found to be related to Silicate.

DISCUSSION

The oligotrophy derived from the scarcity of nutrients in the eastern Mediterranean leads to low plankton biomass in this system. High evaporation, low terrestrial inputs and lower amount of precipitation in the Mediterranean cause hydrological imbalances. Nutrient depleted surface Atlantic waters flow into the Mediterranean through the Straits of Gibraltar and exit as deep water after circulating the basin (Turley 1999). This hydrological cycle causes the Mediterranean to become poorer in terms of nutrients. However, in recent years eutrophication has been experienced in many coastal waters of Mediterranean (Puigserver et al. 2002). This process is especially seen in enclosed coastal bays which receive anthropogenically-enhanced nutrient loads from rivers and the direct discharges of untreated waste waters (EEA 1999). In this respect, the coasts of the Iskenderun Bay are under risk of pollution due to increased agricultural activities, human settlements and establishment of many industries.

The investigated parameters showed spatial and temporal variations. The low salinities found during the study were probably due to freshwater input. Inorganic nutrient level is one of the most variable components of coastal waters (Gilbes et al. 1996). High surface nutrient concentrations with clear fluctuations were observed at transect A. On the other hand, water column nutrient concentrations showed remarkable fluctuations at transect B. In Iskenderun Bay, nutrient levels have been reported as 0.1-1.5, 0.5-12 and 1-11 μM for Phosphate-P, Nitrate+nitrite-N and Silicate-Si, respectively (Yilmaz et al. 1992). Polat (2006) found Phosphate-P, Nitrate+nitrite-N, and Silicate-Si concentrations as 0.04-0.47, 0.05-1.6 and 1.12-6.5 μM, respectively, in north part of Iskenderun Bay. The level of nutrients in the present study are higher than those found by Polat (2006). Furthermore, Silicate values are also higher than those of found by Yilmaz et al. (1992). The considerable fluctuations and high values in the Silicate especially on transect A is probably a result of the freshwater input. Turkish rivers in the Cilician Basin seem to be the main freshwater and nutrient sources for the entire Levantine Basin of the Eastern Mediterranean (Ozsoy & Sozer 2006). Indeed, the discharge of Ceyhan River is the main freshwater input to the bay. The N:P:Si molar ratio required for balanced phytoplankton growth in ocean waters is 16:1:16 (Brzezinski 1985; Redfield et al. 1963). Deviations of these ratios can be used in determining the nutrient limitations. In the Mediterranean, phosphorus is limiting nutrient and N:P ratio increases from west to east basin reaching the value of 27-29:1 (Krom et al. 1991). The high N:P and Si:P ratios in some periods of this study may be regarded as an evidence for phosphate limitation. However, low N:P (<10) and Si:P ratios in some periods reveals that N and Si limitation also occurs in the area.

The results stress that the conditions of transect A are more favourable for a phytoplankton biomass increase compared with the transect B. Indeed, chlorophyll-*a* concentration was high and showed clear fluctuations on transect A. Spring bloom in the Mediterranean can occur from March to June depending on hydrological conditions (Vidussi et al. 2000). In the present study, while chlorophyll-*a* biomass showed a bimodal increase pattern with a major peak in spring (May) and lower peak in September on transect A, it showed a slight increase only in September on transect B. In Mediterranean, DCM (deep chlorophyll maximum) is typical feature of basin waters. It occurs at shallower depths (40-50 m) in cyclonic areas and at deeper layers in the anticyclonic basins (Ediger & Yilmaz 1996). In this study chlorophyll-*a* was almost homogeneously distributed in the water column in February and October and increased at 40-50 m depths during December-January and August-September, but due to the absence of samples below 50 m depth a well defined chlorophyll-*a* peak couldn't be observed.

Chlorophyll-*a* variations mainly depend on nutrient availability, temperature changes and turbulence events (Ediger & Yılmaz 1996; Lakkis et al. 2003). In the present study, chlorophyll-*a* increase occurred when Nitrate+nitrite-N and Silicate-Si levels were high. As a result, the correlation of chlorophyll-*a* was significant for Silicate-Si and Nitrate+nitrite-N among nutrients. However, no statistically significant correlation was found between chlorophyll-*a* and temperature. On the other hand, negative correlation with salinity indicate freshwater influence. It is known that meteorological factors such as wind speed and air temperature influence phytoplankton biomass (Henson et al. 2006; Villate et al. 2008). According to Vidussi et al. (2000) wind force can enhance phytoplankton production in short term by redistribution of water, on the contrary, it can cause a decrease in the long term due to sinking of cells and grazing pressure. Moreover, high stability following the storms can induce phytoplankton blooms (Puigserver et al. 2002). However, no correlation was found between chlorophyll-*a* and meteorological factors in this study.

Chlorophyll-*a* values found in this study were higher than those of the values of many earlier studies in the bay, but the values were very low in comparison with eutrophic ecosystems such as Adriatic Sea coasts and Amvrakikos Gulf in the Mediterranean Sea (Table 2). Due to a short distance from the coast, near coastal transect was more influenced by land-based effects such as freshwater discharges and anthropogenic factors. However, relatively high values of transect A are not only the result of land based inputs but may also be due to deep mixing, deriving from shallowness of the water. Indeed, the effect of water column mixing as well as terrestrial runoff in nutrient enrichment of coastal waters have been discussed in many works (Yilmaz et al. 1992).

TABLE 2. Chlorophyll-*a* values along the Turkish coasts and different coastal parts of the Mediterranean Sea

Location	Sampling date	Sampling intervals	Chlorophyll-*a* (μg l^{-1})	Reference
Iskenderun Bay	Oct. 1994-Oct. 1995	monthly	0.17-2.78	(Polat 2002)
Iskenderun Bay	Jan. 2002-Nov. 2002	seasonal	0.07-0.75	(Polat 2006)
Mersin Bay	Jan. 1998-Jan. 1999	weekly	0.08-2.93	(Uysal & Köksalan 2006)
NE Mediterranean	1991-1994	one sampling per year	0.01-3.07	(Ediger & Yılmaz 1996)
Izmir Bay	Jan. 2003-Dec. 2003	monthly	0.54-12.82	(Sunlu et al. 2008)
Amvrakikos Gulf (Ionian Sea)	Feb. 1987-Nov. 1987	seasonal	0.11-44.80	(Panayotidis et al. 1994)
Adriatic Sea	Feb. 2000-Dec. 2000	monthly	0.58-58.03	(Penna et al. 2003)
Naples Bay	Nov. 1985	single	<0.3-7.07	(Zingone et al. 1995)
Mediterranean Sea	Jun. 1999	single	0.03-0.96	(Ignatiades et al. 2009)

Conclusion

The values of chlorophyll-*a* and nutrients not reaching high levels as in eutrophic environments besides all the effects shows that, the area has a dynamic structure. In fact, due to effective wind systems and circulation patterns in the region water column is well oxygenated and mixed. These processes contribute to renewal of waters and prevent the formation of eutrophic conditions. However, continuous and detailed studies are needed, in order to define complex factors which affect phytoplankton biomass in coastal environments where human activities are severe.

References

Azov, Y. 1991. Eastern Mediterranean-A marine desert? *Marine Pollution Bulletin* 23: 225-232.

Brzezinski, M.A. 1985. The Si:C:N ratio of marine diatoms: Interspecific variability and the effect of some environmental variables. *Journal of Phycology* 21: 347-357.

Ediger, D. & Yılmaz, A. 1996. Characteristics of deep chlorophyll maximum in the northeastern Mediterranean with respect to environmental conditions. *Journal of Marine System* 9: 291-03.

EEA (European Environment Agency). 1999. State and pressure of the marine and coastal Mediterranean environment. *Environmental Assessment Report* No 5.

Gilbes, F., Jose, M.L. & Yoshioka, P.M. 1996. Spatial and temporal variations of phytoplankton chlorophyll-*a* and suspended particulate matter in Mayaguez Bay, Puerto Rico. *Journal of Plankton Research* 18: 29-43.

Henson, S.A., Robinson, I., Allen, J.T. & Waniek, J.J. 2006. Effects of meteorological conditions on interannual variability in timing and magnitude of the spring bloom in the Irminger Basin, North Atlantic. *Deep Sea Research I* 53: 1601-1615.

Ignatiades, L. 2005. Scaling the trophic status of the Aegean Sea, eastern Mediterranean. *Journal of Sea Research* 54: 51-57.

Krom, M.D., Kress, N., Brenner, S. & Gordon, L.I. 1991. Phosphorus limitation of primary productivity in the eastern Mediterranean Sea. *Limnology Oceanography* 36: 424-432.

Lakkis, S., Jonsson, L., Zodiatis, G. & Soloviev, D. 2003. Remote sensing data analysis in the Levantine Basin: SST and chlorophyll-a distribution. In *Oceanography of Eastern Mediterranean and Black Sea. Similarities and Differences of Two Interconnected Basins*, edited by Yılmaz, A. 14-18 October 2002, Ankara: TÜBİTAK Publishers.

Ornolfsdottır, E.B., Lumsden, S.E. & Pinckney, J.L. 2004. Phytoplankton community growth-rate response to nutrient pulses in a shallow turbid estuary, Galveston Bay, Texas. *Journal of Plankton Research* 26: 325-339.

Ozsoy, E. & Sozer, A. 2006. Forecasting circulation in the Cilician Basin of the Levantine Sea. *Ocean Science Discussion* 3: 1481-1514.

Parsons, T.R., Maita, Y. & Lalli, C.M. 1984. *A Manual of Chemical and Biological Methods for Seawater Analysis*. Oxford: Pergamon Press.

Polat, S. 2006. Size fractionated distribution of the phytoplankton biomass in the İskenderun Bay, Northeastern Mediterranean Sea. *Fresenius Environmental Bulletin* 15: 417-423.

Puigserver, M., Ramon, G., Moya, G. & Martinez-Taberner, A. 2002. Plankton chlorophyll a and eutrophication in two Mediterranean littoral systems (Mallorca Island, Spain). *Hydrobiologia* 475-476: 493-504.

Redfield, A.C., Ketchum, B.H. & Richards, F.A. 1963. The influence of organisms on the composition of sea-water. In *The Sea*, edited by Hill, M.N. vol. 2, New York.

Sokal, R.R. & Rohlf, F.J. 1981. *Biometry*. 2nd ed. NewYork: W.H. Freeman.

Strickland, J.D.H. & Parsons, T.R. 1972. *A Practical Handbook of Seawater Analysis*. Canada: Bull. Fish Res. Board.

Thingstad, T.F., Krom, M.D., Mantoura, R.F.C., Flaten, G.A.F., Groom, S., Herut, B., Kress, N., Law, C.S., Pasternak, A., Pitta, P., Psarra, S., Rassoulzadegan, F., Tanaka, T., Tselepides, A., Wassmann, P., Woodward, E.M.S., Riser, C.W., Zodiatis, G. & Zohary, T. 2005. Nature of phosphorus limitation in the ultraoligotrophic eastern Mediterranean. *Science* 309: 1068-1071.

Turley, C.M. 1999. The changing Mediterranean Sea- a sensitive ecosystem?. *Progress in Oceanography* 44: 387-400.

Vidussi, F., Marty, J.C. & Chiaverini, J. 2000. Phytoplankton pigment variations during the transition from spring bloom to oligotrophy in the northwestern Mediterranean Sea. *Deep Sea Research I* 47: 423-445.

Villate, F., Aravena, G., Iriarte, A. & Uriarte, I. 2008. Axial variability in the relationship of chlorophyll a with climatic factors and the North Atlantic Oscillation in a Basque coast estuary, Bay of Biscay (1997-2006). *Journal of Plankton Research* 30(9): 1041-1049.

Yilmaz, A., Basturk, O., Saydam, C., Ediger, D., Yilmaz, K. & Hatipoglu, E. 1992. Eutrophication in Iskenderun Bay, northeastern Mediterranean. Science of Total Environment (Special Issue). In *Marine Coastal Eutrophication*, edited by Vollenweider, R.A. Marchetti, R. & Viviani, R. Amsterdam: Elsevier.

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Received: 14 April 2013
Accepted: 12 May 2013