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Eutrophication in Iskenderun Bay, north-eastern Mediterranean

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ABSTRACT

As is well known, the eastern Mediterranean is one of the most impoverished water bodies in the world: the level of nutrients are in the range of < 0.01–0.24 μg-at/l, 0.05–6.0 μg-at/l and 1.0–11.0 μg-at/l for PO_4-P, (NO_3+NO_2)-N, and reactive silicate, respectively. This is reflected in the concentration of chlorophyll *a* hence also in the standing crop of phytoplankton and primary productivity. The annual average of chlorophyll *a* concentration is less than 0.5 μg/l and the primary productivity has been estimated as low as 25 g C/m^2/y, excluding coastal areas enriched by terrestrial input. As expected total suspended particulate concentration is low, being less than 1 mg/l, so that the water is clear blue having extremely high light penetration, the average depth of 1% light transmission is about 100 m.

The Bay of Iskenderun, located in the north-eastern corner of Levantine Basin covers a relatively large area of continental shelf. The Bay is roughly rectangular, 60 km by 35 km, and differs from the common structure described above. The concentration of nutrients lies between 0.1–1.5, 0.5–12.0, 1–11.0 for PO_4P, (NO_3+NO_2)-N and reactive silicate, respectively, causing a relatively high phytoplankton population density, since chlorophyll *a* concentration is between 0–6.5 μg/l and the estimated primary production in the Bay is about 2–4 times higher than the offshore production in the region. The main reason for high primary production is the high terrestrial input and effective benthic–pelagic coupling of nutrients, since the average depth is around 70 m and the whole water column is illuminated. In spite of this situation, significant oxygen depletion and eutrophication does not occur in the Bay, apparently because the circulation system partially provides an exchange of oxygen rich open-sea water masses with the Bay and atmospheric input of oxygen can reach even the bottom by the strong wind-induced mixing.

INTRODUCTION

The present study was carried out in Iskenderun Bay and covered the period 1980–89. The Bay was visited at least every season; the hydrographic measurements were performed by CTD probe and chemical parameters were measured on board or at Institutes' laboratories. The Bay is influenced by the heavy discharges of man-made and natural sources as shown in Fig. 1 and the sampling stations are classified as coastal stations (C) and source stations (S) as illustrated in Fig. 1.

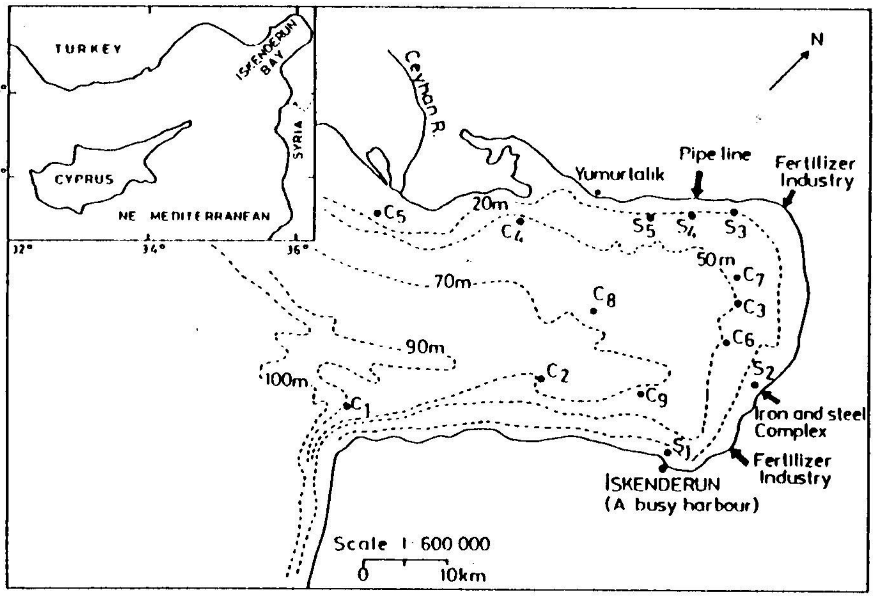

Fig. 1. The Iskenderun Bay: location map, sampling stations, bathymetry, and land-based sources.

RESULTS AND DISCUSSION

Physical characteristics of the region

Iskenderun Bay is influenced by the winds associated with the passage of storm systems over the Mediterranean, as well as local and regional winds. The sea breeze during the summer and a strong wind blowing through a gap in the mountain chain surrounding the Bay which occurs at almost any time during the year, affect the dynamics of the water masses in the Bay. The duration of this local wind varies between three to five days and the speed reaches up to 50 km (Latif et al., 1989).

The water column in the Bay has a two-layer temperature structure during summer as a result of radiation heating of the surface. In winter, the water column is almost homogeneous due to surface cooling and vertical mixing induced by the winds. The sea surface temperature varies from 16°C in February–March to about 29°C in August. The

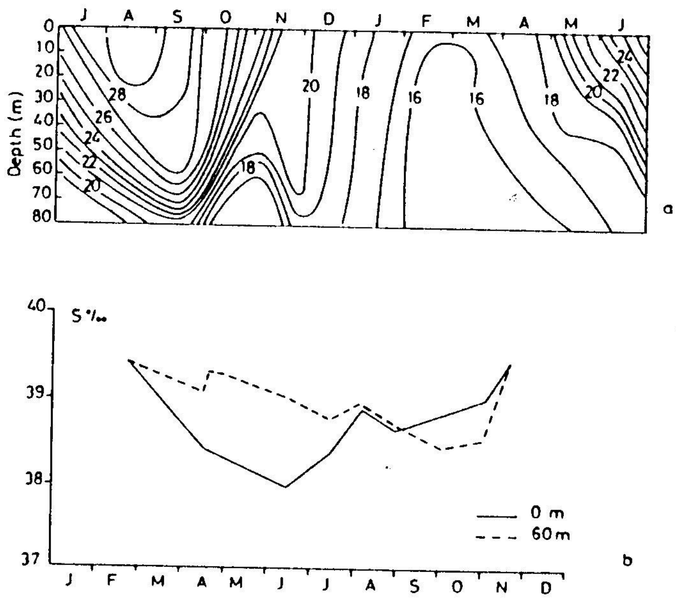

Fig. 2. (a) Annual variation of temperature with depth; isotherms in °C (after Iyiduvar, 1986). (b) Annual variation of salinity at the surface and at 60 m depth (after Iyiduvar, 1986).

salinity is approximately 39‰, with lower salinities of 37–38‰ observed near freshwater input. Annual variations of temperature in the water column and salinity at the surface and at 60 m are illustrated in Figs 2a and 2b, respectively. As is seen from the figure there is continuous stratification in the water column during summer months (July–August) with the surface temperature being 28–29°C, decreasing to 19°C at the bottom. The stratification disappears towards the end of November as a result of wind induced and convective mixing. In February the water column is homogeneous having a temperature of 16°C.

The surface salinity (Fig. 2b) is at a maximum (39–39.4‰) during November–February as a result of cumulative evaporation during the summer months. The salinity begins to decrease in March, as a result of inputs from rainfall and runoff and reaches a minimum of 38‰ in June. The salinity at the surface then exhibits a gradual increase related to evaporation in summer. The water column is homogeneous in winter and has uniform salinity.

The general circulation characteristics of the Bay are affected by the prevailing currents in the open sea (north-eastern Mediterranean), because of its connection through the wide opening and by the regional and local winds. The characteristic surface circulation patterns in the north-

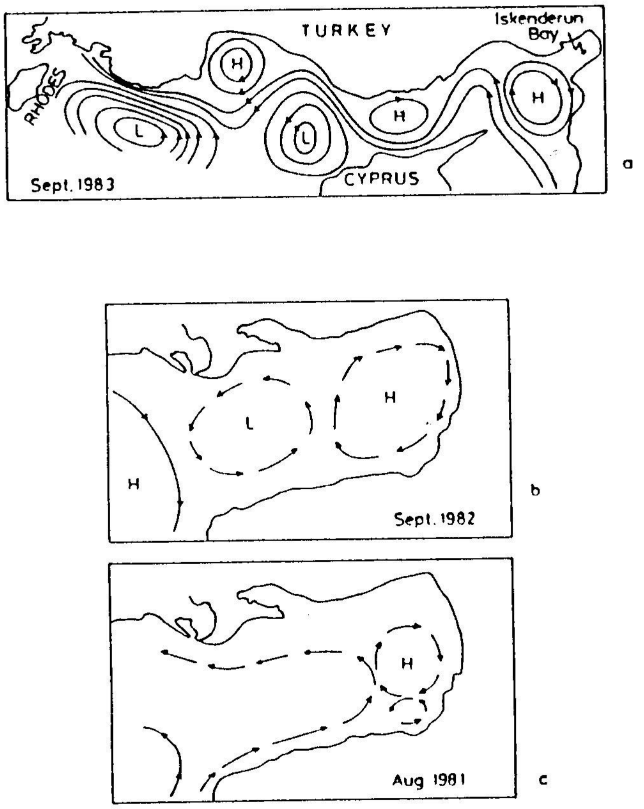

Fig. 3. (a) Surface circulation patterns in the NE Mediterranean (after Öszoy et al., 1986). H: high pressure system, L: low pressure system. (b) Surface circulation in Iskenderun Bay: the case of two gyres system (after Iyiduvar, 1986). (c) Surface circulation in Iskenderun Bay: the case of one cell in the corner of the Bay and thepresence of a tongue of open sea waters in the Bay (after Iyiduvar, 1986).

eastern Mediterranean and Iskenderun Bay are presented in Fig. 3 (Özsoy et al., 1986; Iyiduvar, 1986). The current pattern in the Bay indicates existence of two cells or gyres, with other smaller eddies. Possible mechanisms for the generation of the gyres maybe the shear of the prevailing circulation at the mouth of the Bay which is, in general, an anticyclonic gyre. Thus the first cell is usually a cyclonic and the second or inner one is an anticyclonic gyre (Fig. 3b). The surface circulation system is significantly influenced by the winds in the Bay; the changing wind directions may change the directions of the circulation patterns and/or decompose the cells. In the latter case the overall flow pattern consists of one cell encompassing the inner part of the Bay while in the rest of the Bay the current enters from one end of the opening and leaves from the other end (Fig. 3c.). This latter flow pattern contributes

TABLE 1

The concentration range of nutrient elements in the eastern Mediterranean

Nutrient		Concentration range (μg-at/l)	
		SE Mediterranean[1]	NE mediterranean[2]
Inorganic phosphate (PO_4-P)	U	<0.01	<0.01–0.02
	L	0.24	0.2–0.24
Total oxidized nitrogen [(NO_3+NO_2)-N]	U	0.05–0.7	<0.05–1.0
	L	5.5–6.0	4.0–6.0
Reactive silicate [$Si(OH)_4$-Si]	U	—	1.0–2.0
	L	—	8.0–11.0

[1]Krom et al., 1991; [2]Present study.

to a partial flushing and/or cleaning of the Bay but ventilation of the Bay by the strong local winds is more effective with respect to renewals by the currents.

Chemical environment and eutrophication problems in the Bay

The eastern Mediterranean has oligotrophic characteristics mainly due to the low levels of available nutrients which are essential for primary producers. The concentration range of nutrient elements in the eastern Mediterranean are presented in Table 1 and the level of primary production values in Table 2.

As is seen from Table 2, and when compared with the Black Sea values, the eastern Mediterranean is a very impoverished body of water. The north-eastern Mediterranean, has, in general, a euphotic layer which is low in nutrients; this is reflected on standing stocks of phytoplankton and hence on the chlorophyll *a* concentration. The range of chlorophyll *a* concentration is between 0.05–0.35 in the north-eastern Mediterranean excluding the regions of high terrestrial input: one of the examples being Iskenderun Bay and local upwelling areas such as Rhodes cyclonic gyre (Salihoglu et al., 1990). As a result the transparency is high in the water column, having Secchi disk values up to 40 m and/or the average depth of 1% light transmission up to 100 m. The whole water column in the north-eastern Mediterranean is well oxygenated, even the bottom waters have saturation values greater than 70%.

TABLE 2

The average annual primary production values in the eastern Mediterranean (g C/m^2/year)

Location	Production	Source
North-eastern Mediterranean (the whole basin)	24*	Yilmaz, 1986
North-eastern Mediterranean (central parts of cyclonic systems)	60*	Salihoglu et al., 1990
North-eastern Mediterranean (centralparts of anticyclone)	33*	Salihoglu et al., 1990
Eastern Mediterranean	25	Murdoch and Onuf, 1974
The Black Sea	250	Sorokin, 1983

*Estimated from chlorphyll *a* data.

TABLE 3a

The range of nutrient elements in the coastal stations in Iskenderun Bay

Nutrient	Concentration (μg-at/l)
PO_4-P	0.1–1.5
[(NO_3+NO_2)-N]	0.5–12.0
[$Si(OH)_4$-Si]	1.0–11.0

TABLE 3b

Average daily and annual primary production in Iskenderun Bay*

Time	Average primary production (mg c/m^2/day)
January 1988	140
May 1988	640 + bloom time
October 1988	220
November 1988	250
Total (g C/m^2/year)	115

*Estimated from chlorophyll *a* data. Concentration range of chlorophyll *a* in the Bay: 0–6.5 μg/l (average, 1.10 μg/l).

While the general structure of north-eastern Mediterranean is as briefly described above the north-east corner of this basin — Iskenderun Bay — has different chemical properties. First of all this Bay and its opening covers relatively the largest continental shelf area in the eastern Mediterranean (excluding the Nile Delta). The average depth is 70 m and the whole water column is illuminated. The average Secchi disk depth is 20 m (the range being 7–33 m) and the average depth of 1% light transmission is 50 m (the range being 40–70 m).

On the other hand, the coasts of the Bay are intensely industrialized when compared with the Mediterranean coasts of Turkey. As shown in Fig. 1 these are mainly iron and steel complexes, fertilizer industries, a pipe-line terminal (crude oil), petroleum loading stations, and a very busy harbour, and they generally discharge their wastes into the Bay. The Ceyhan River, one of the three major rivers on the southern coast of Turkey, discharges into the Bay near Yumurtalik (Fig. 1). The average discharge of the Ceyhan River is 180 m^3/s. The peak discharge takes place during March–April, and the river carries the material of the very productive agricultural areas into the Bay.

The concentration range of available nutrients are presented in Table 3a and the average primary production values estimated from chlorophyll *a* are shown in Table 3b for the Bay of Iskenderun. The vertical distribution of nutrient elements and chlorophyll *a* and the hydrographic data are presented in Fig. 4 for selected coastal stations on a seasonal base. As can be seen from Fig. 4 in late autumn and in winter the water column is homogeneous and the nutrient concentrations are relatively low because of consumption for phytoplankton growth. As a consequence the level of chlorophyll *a* is relatively high in winter and reaches its maximum value in May. In the summer months the water is stratified and nutrients are made available by active regeneration at deeper layers; the chlorophyll *a* concentration is relatively low in this season. Thus one can say that natural seasonal nutrient cycles are not influenced in the Bay. There are source of nutrients from terrestrial input being both allochthonous and autochthonous in the Bay, effective benthic–pelagic coupling of nutrients and continuous regeneration provide a continuous production in the Bay. In particular, PO_4 and NO_3-NO_2 concentrations are extremely high at source stations where the sewage outfalls and the fertilizer industrial wastes are discharged. Such examples of high nutrient injection from land-based sources are presented in Fig. 5. The concentration level of available nutrients are relatively high (Table 3a) when compared with the open sea values of the north-eastern Mediterranean values (Table 1); thus the primary production is relatively high i.e. 2–4 times higher than the north-eastern Mediterra-

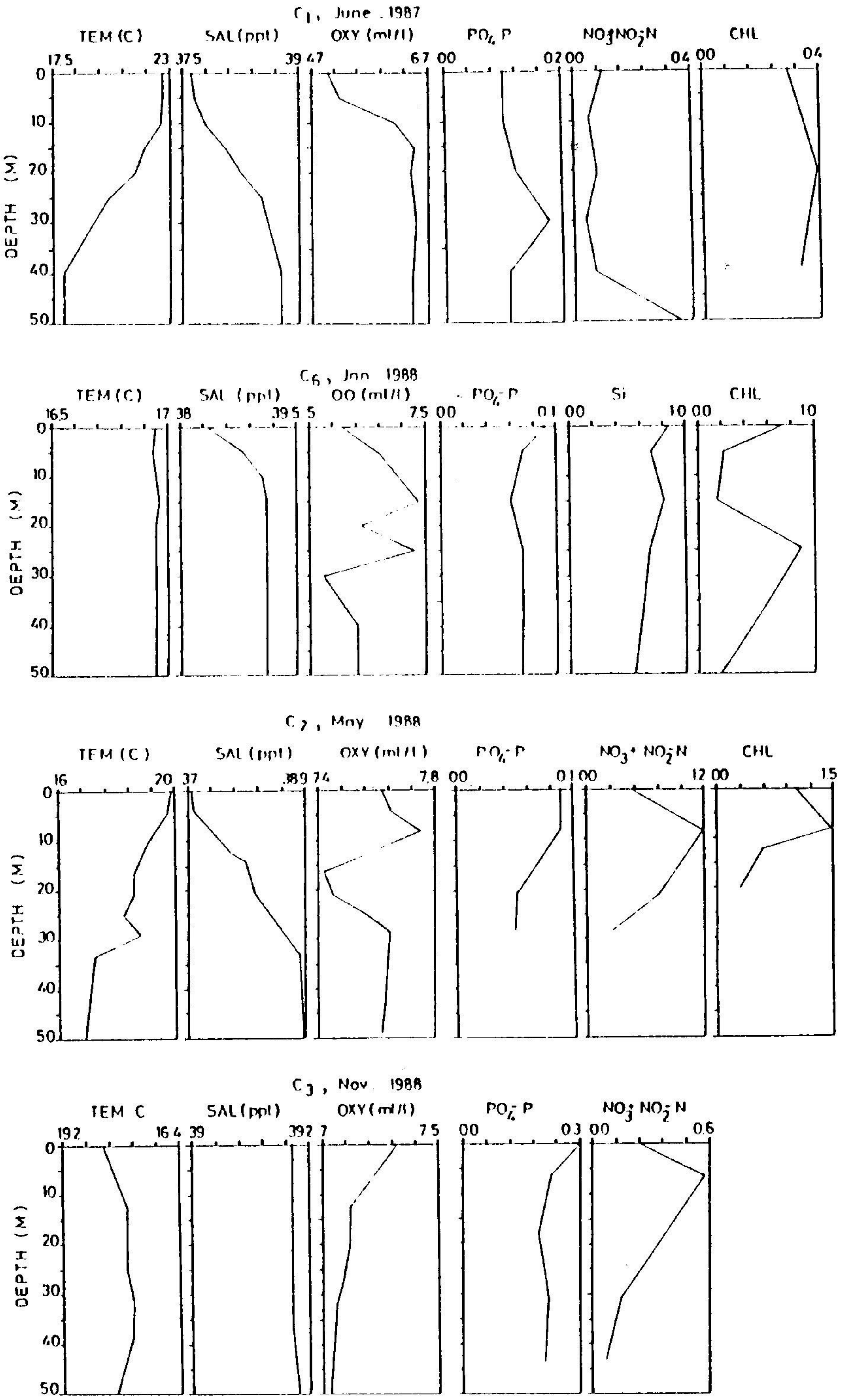

Fig. 4. Vertical distribution of temperature, salinity, dissolved oxygen, inorganic phosphate, total oxidized nitrogen, reactive silicate and chlorophyll *a* in Iskenderun Bay coastal stations.

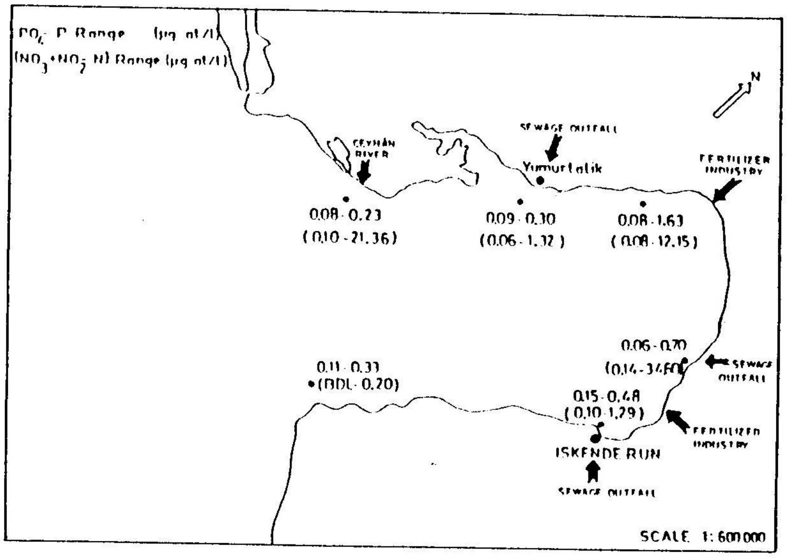

Fig. 5. Locations of terrestrial inputs of nutrient elements and their example concentration ranges (January 1988–October 1989).

nean production (Table 3b), the average being 115 g C/m^2/year.

On the other hand, oil pollution is seriously high in Iskenderun Bay because of the pipe-line terminal, petroleum loading stations and high sea traffic. The locations of hot points in terms of oil pollution are presented in Fig. 6. As is seen from Fig. 6, up to 100 µg/l concentration of Dissolved/Dispersed Petroleum Hydrocarbon (DDPH) has been measured in front of the pipe-line terminal and the concentration is also relatively high at the source station in front of the iron and steel complex when compared with a reference value at the centre of the Bay (Fig. 6).

The increase in accumulating input of nutrients like nitrogen and phosphorus via land run off, rivers and man-made sources should result in a fertilization of the sea water in coastal regions and subsequently in enhanced phytoplankton and phytobenthos production. When dead, the plant biomass produced sinks by microbial degradation and remineralization of such surplus dead organic substances and if there is an extra load of organic material as in the case of Iskenderun Bay there should be consumption of extra amounts of oxygen. Oxygen depletion is then the consequence of eutrophication. Fortunately, however, the situation is not as expected in Iskenderun Bay, where there is no eutrophication problem.

As explained above, the Bay is physically dynamic. The oxygen-rich Mediterranean waters (open sea waters) enter the Bay, circulate and return by flushing the Bay. On the other hand the stormy local wind is quite effective for vertical mixing; thus the water column is almost

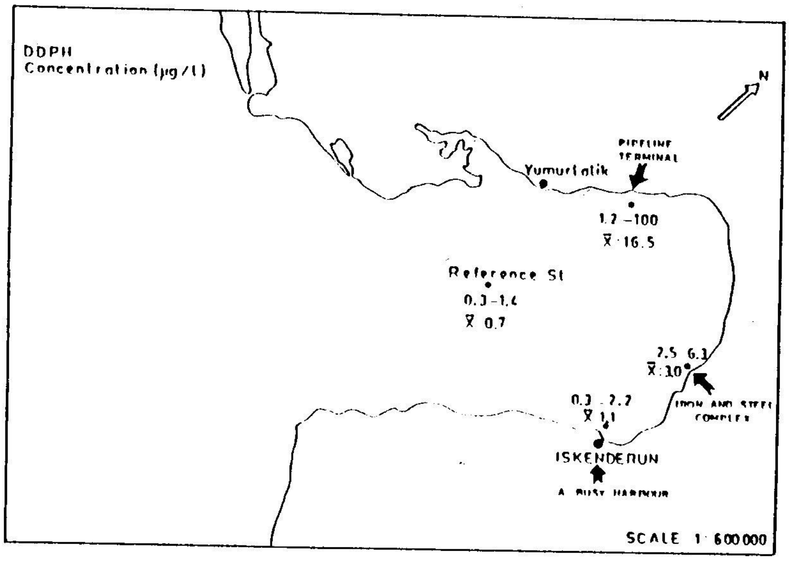

Fig. 6. Map of oil pollution in Iskenderun region (May 1988–October 1989 data).

saturated with dissolved oxygen. The bottom waters never drop below the 75–80% saturation value. In Fig. 7 there are some examples of vertical distribution of SDO–DO values of previous and present data and for bloom time and for degradation–regeneration time period. SDO–DO values have negative values in late winter and in spring which coincide with the local bloom time (Fig. 7a, Table 3b). Usually subsurface production maxima are observed and dissolved oxygen is produced by the photosynthetic reaction resulting in negative SDO–DO values. On the other hand there may be contribution of the presence of well-oxygenated open sea waters in this respect. In summer months, in general, there is bacterial degradation throughout the water column since the nutrient generation is more effective in summer months and continues throughout the year. Figure 7b represents the effectiveness of the bacterial degradation in consequence of positive SDO–DO values. At the surface waters the SDO–DO values are higher because of high temperature in similar months which affects the solubility of dissolved oxygen. At the bottom waters benthic utilization of dissolved oxygen is also significant. SDO–DO values never exceed +2 mg/l value. This means that the Bay waters are well oxygenated for the whole column and for the whole year. Up to present time (between 1980–1989), a minimum value of 5.7 mg/l dissolved oxygen value was measured which is above the critical value.

Regeneration processes of nutrient elements are continuous throughout the year in the Bay. There is a linear relationship between Apparent

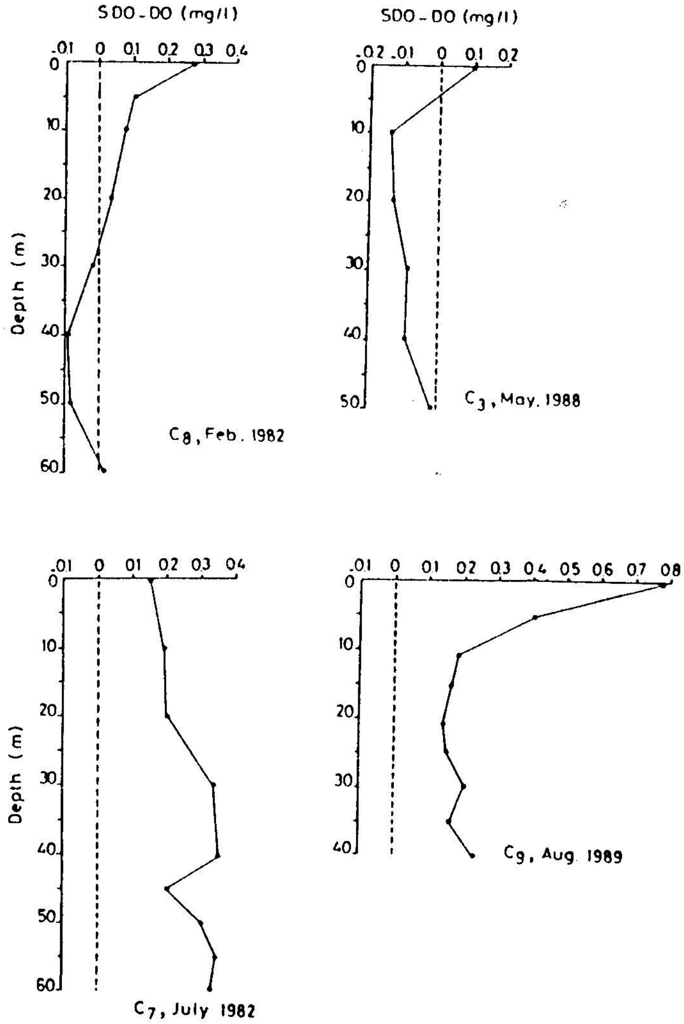

Fig. 7. Vertical distribution of SDO–DO values in the water column in Iskenderun Bay (Old data (1982) and present data (1988–89)). (a) Oxygen production time (February–May). (b) Oxygen consumption time (July–August).

Oxygen Utilization (AOU = mg/l) and inorganic phosphate ($PO4_4P$ = µg-at/l).

Figure 8a represents the whole AOU data vs. PO_4-P having a linear equation of

$$AOU = 5.87 (PO_4\text{-}P) - 0.71$$

When the respiration exceeds the production (Fig. 8b), AOUs are positive and the linearity is

AOU = 7.91 (PO_4-P) − 0.41

Figure 8c represents the case when the production exceeds the respiration and results in a linear equation of

AOU = 0.76 (PO_4-P) − 0.60

The observation of low AOUs and of negative AOUs represents effective ventilation of the Bay, nutrient regeneration is continuous and the concentration level of nutrients is relatively high.

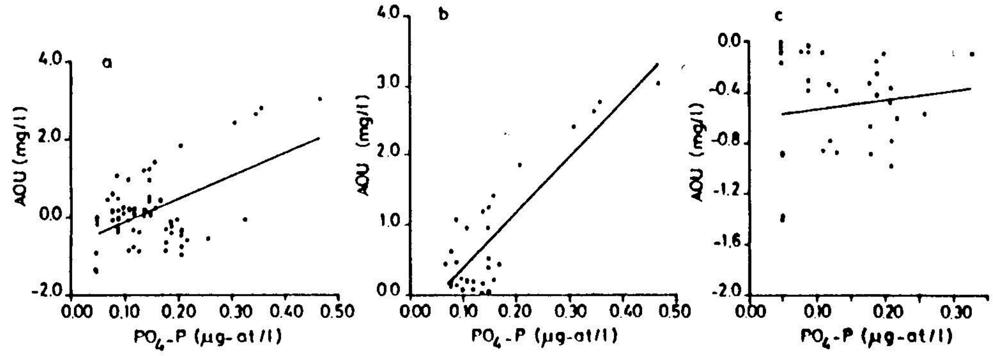

Fig. 8. Apparent Oxygen Utilization (AOU) versus inorganic phosphate in Iskenderun Bay. (a) All AOU data vs. PO_4-P. (b) Positive AOU data vs. PO_4-P. (c) Negative AOU data vs. PO_4-P.

CONCLUSION

All the reasons for eutrophication are persistent: heavy land-based sources (both man-made and natural); high nutrient input from rivers and fertilizer industries; high pelagic–benthic coupling of nutrients; relatively high primary production because of high levels of available nutrients. However, the Bay is physically dynamic. The local stormy wind system makes the water column well mixed and well oxygenated. Circulation patterns in the north-eastern Mediterranean partially affect the Bay: from time to time open sea waters flushes the Bay. Consequently there is no eutrophication in Iskenderun Bay.

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