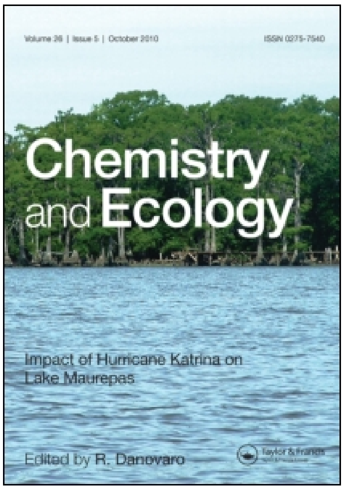

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IMPACT OF LAND-BASED SOURCES ON MARINE ENVIRONMENT: PHYTOPLANKTON BLOOMS WITHIN AN ANNUAL CYCLE

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The discharge water into the western region of Alexandria (Egypt), creates suitable conditions for the acceleration of the phytoplankton growth; daily replenishment of nutrients and development of density stratified water column. Water transparency and ammonia concentrations seem to be affecting the variations of the numerical standing crop. Eight phytoplankton bloom pulses of different causative species were observed. *Asterionella glacialis* represents a newly recorded red tide species in the neritic waters of Alexandria.

Keywords: Discharge water; phytoplankton variability; blooms

INTRODUCTION

In sheltered estuaries and shallow coastal waters, subjected to a massive source of nutrient inflow, there are large temporal and spatial variations in phytoplankton abundance, succession and chlorophyll *a* concentrations. These could be attributed to a diverse set of physical and biological factors including nutrients limitation (Nixon and Pilson, 1983), adaptation of phytoplankton cells to different vertical mixing conditions, independent of nutrient availability (Bowman *et al.*, 1981), high or low frequency perturbations of long duration (Harris, 1980), incident light (Hitchcock and Smadya, 1977), grazing (Malone and Neale, 1981), and others.

This study was designed, west of Alexandria (Egypt), to elucidate the contribution of daily land-runoff loaded with different pollutants on the phytoplankton standing crop and chlorophyll *a* variability during an annual cycle.

The Site

The study area extends for about 13 km along the coast, west of Alexandria City. Different sources dispose discharge water directly to the investigated area. Kayet Bey, the main sewer system of Alexandria, discharges a daily average of $170 \times 10^3\,m^3$ of domestic wastes. Mex Bay receives about $6.6 \times 10^6\,m^3 \cdot d^{-1}$ of drainage water from neighbouring Lake Maryout, through Umum Drain. This discharge water is mixed with agro-chemical, industrial wastes and municipal waste waters. Chemical wastes are also disposed directly into the western region of the Bay. The Bay is connected to the Western Harbour, the main harbour of Alexandria, and exposed to oil pollution and drainage water. Dekhila Harbour, established west of Mex Bay for the export of the manufactured iron and steel, represents an additional source of pollution.

The study area, influenced by the land-runoff, is of special interest. Intensive physico-chemical studies were carried out (Emara *et al.*, 1984; Dorgham *et al.*, 1987; Said *et al.*, 1991; Nessim and Tadros, 1992; Emara *et al.*, 1992). Nevertheless, the phytoplankton investigations were rather few (Dorgham *et al.*, 1987; El-Sherif, 1989; Samaan *et al.*, 1992; Zaghloul *et al.*, 1995).

MATERIAL AND METHODS

The study area and the location of the sampling stations are shown in Figure 1. Sampling collection was conducted at the 3 stations from April 1994 to May 1995, except for September, November and March. The water samples were taken at 50 cm below the surface. Over the bottom (15 m) temperature and salinity were also determined.

Temperature was measured by a thermometer accurate to ±0.1°C, salinity (salinity refractometer, S/Mill), transparency (Secchi disc, diameter of 25 cm). The inorganic nutrients (nitrate (NO_3) and nitrite

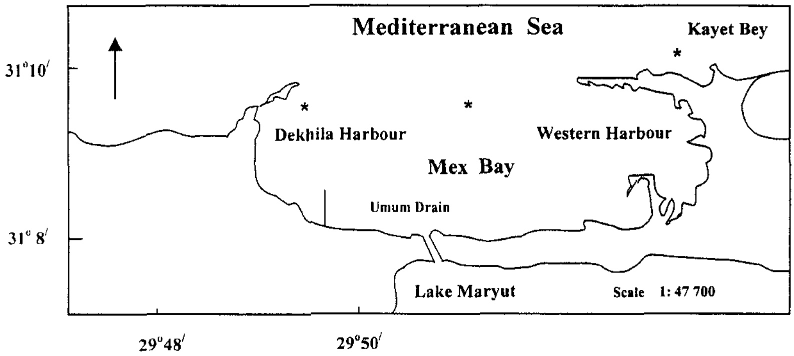

FIGURE 1 Study area and sampling stations (*).

(NO_2), ammonia (NH_4) and phosphate (PO_4)), as well as chlorophyll *a* were determined according to Strickland and Parsons (1972). The settling method (Utermöhl, 1958) was applied for the quantitative estimation of the phytoplankton standing crop.

Water density (σt) was determined from tables (UNESCO, 1987), using the basis of temperature and salinity data and it was used to calculate water stability (Σ) by applying the formula:

$$\Sigma = 10^{-3}\ \Delta\sigma t/\Delta z,$$

where $\Delta\sigma t/\Delta z$ is the rate of change of σt with respect to depth (z).

The transparency of the water column was determined by the Secchi disc light-extinction equation:

$$k = 1.7/z,$$

where k is the extinction coefficient and z the Secchi disc depth. Sherwood and Gilbert (1974) have shown that this equation provides a sufficiently accurate estimate of light extinction in all types of water for many biological studies which lacked detailed light-profile measurements. This equation was used, in shallow highly eutrophic embayments by Ignatiades (1979).

A simple statistical method of "least squares" was applied to show the dependence of a variable on the values of other independent variables.

RESULTS

Physical and Chemical Condition

The measured physico-chemical parameters are shown in Figure 2.

The annual temperature cycle showed 3 distinct thermal regimes. The surface temperature, affected by spring warming, started to

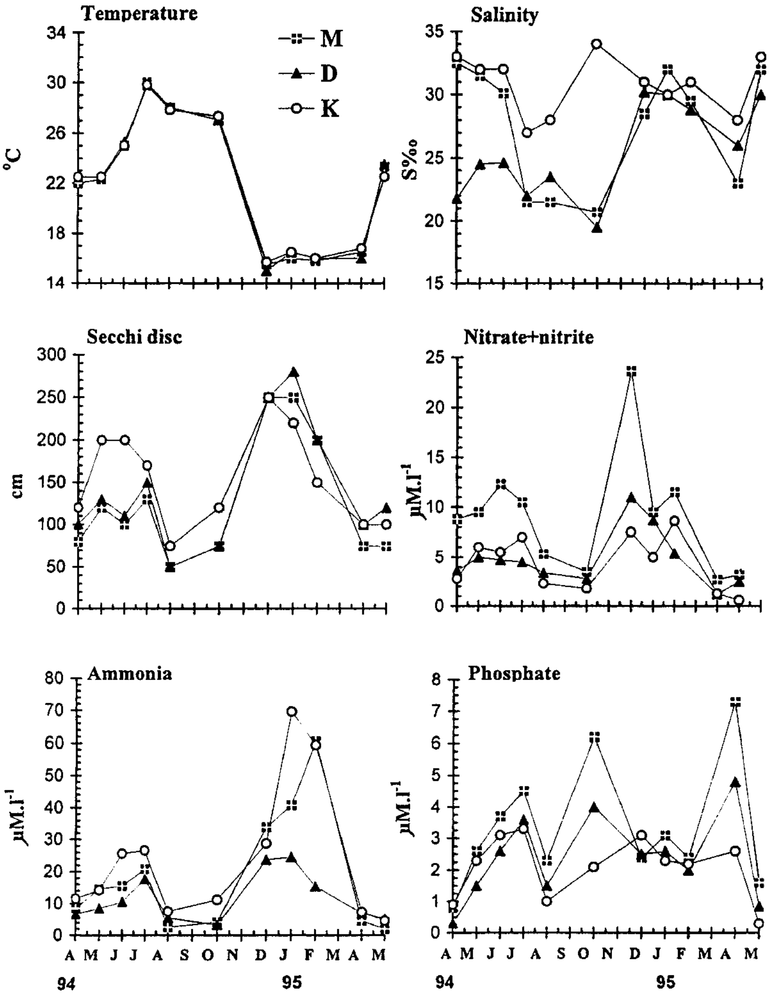

FIGURE 2 Surface physico-chemical measurements from April 1994 to May 1995. Mex (M), Dekhila (D), Kayet Bey (K).

increase by April. The warmer surface than that of the near bottom lasted till October. The maximum difference in temperature between surface and 15 m depth occurred in July (4°C, surface temperature reaching 29.8 – 30°C). A sharp temperature decrease was recorded in December, where surface temperature fell to its yearly minimum (15 – 15.7°C). In January 1995, temperature varied within 1°C between the cool surface and the slightly warmer water over the bottom (17°C). The homogeneous vertical distribution was recorded in February, within 0.2°C between surface and near bottom temperature. The spatial distribution showed a very limited regional temperature variations.

Water salinity showed remarkable variations in space and time. The surface values fluctuated between a minimum in Dekhila (19.5 UPS) during October and a maximum (34 UPS) in the same month in Kayet Bey area. The water column was always halo-stratified. Salinity over the bottom ranged between 38.5 UPS in Dekhila during December and 39.9 UPS in Mex in June. The area of Kayet Bey was always more saline, except in January. Dekhila generally gained intermediate salinity values.

The stability of the water column was mainly related to the salinity variations, rather than temperature changes. However, the low temperature in January and February reduced the stability to its minimum ($\Sigma = 4-5$). The more stratified periods ($\Sigma = 20.7-21.5$) in July, August and October coincided with the occurrence of surface waters of lower salinity and higher temperature.

The Secchi disc readings showed its lowest values in August and but was less so in October, accompanying the massive phytoplankton blooms. The cold period with low phytoplankton occurrence from December to February sustained the highest values (1.5 to 2.8 m).

The extinction coefficient (k) ranged between 0.68 and $3.4\,\mathrm{m}^{-1}$. The highest values in August and October associated the strong stratification of the water column and the dense phytoplankton blooms. The values in April and May were also relatively high ($2.12-2.2\,\mathrm{m}^{-1}$, Mex).

The nutrient concentrations exhibited large space-time variations. Nitrate + nitrite concentrations decreased away from Mex. The major peak in Mex appeared in December ($23.6\,\mu\mathrm{M\,l}^{-1}$), and the concentrations were also high in June – July and January – February. A severe reduction occurred during the phytoplankton bloom periods, with nitrate+nitrite reaching the minimum of 0.6 $\mu M\,l^{-1}$ in May, Kayet Bey.

Ammonia concentrations were higher in Kayet Bey, except at times of massive algal blooms. The cold periods from December to February was the higher along the whole area, with a maximum of 69.6 $\mu M\,l^{-1}$ during January, Kayet Bey. Moderate values were measured between May and July (8.5–25.6 $\mu M\,l^{-1}$). Ammonia fell to its minimum of 1.9 $\mu M\,l^{-1}$ in May, Mex, associated with the most dense phytoplankton bloom.

Phosphate concentrations were always higher in Mex than others, with 2 distinct peaks in October (6.2 $\mu M\,l^{-1}$), and April 1995 (7.3 $\mu M\,l^{-1}$), accompanied with dinoflagellate blooms. Phosphate showed a similar distribution pattern to that of nitrate and nitrite during June–July and January–February. The lowest concentrations were measured in April, 1994 (0.3–0.9 $\mu M\,l^{-1}$), and May, 1995 (0.3–1.6 $\mu M\,l^{-1}$).

Phytoplankton Standing Crop, Community Structure

The phytoplankton standing crop, chlorophyll *a* and the relative frequency (%) of the different groups and are shown in Figure 3.

The phytoplankton standing crop exhibited marked temporal and spatial variations. Mex was the most productive area (annual average of 2.58 10^6 unit · l^{-1}), followed by Dekhila (2.3 10^6 unit · l^{-1}), and Kayet Bey (0.39 10^6 unit · l^{-1}). The phytoplankton community consisted of fresh, brackish and marine species.

Diatoms represented the main constituent of the community (annual average of 1.3 10^6 cell · l^{-1}, 69.3% to the total standing crop), culminating in 3 major peaks (red tides), in April, August 1994 and May 1995. Dinoflagellates ranked the second (0.36 10^6 cell · l^{-1}, 18.55%), forming 2 intensive red tide blooms in October 1994 and April 1995. Euglenophyceae contributed 9.1% to the total, with their main occurrence in October associated with a dinoflagellate red tide bloom, the highest density (2.25 10^6 cell · l^{-1}) was observed in Dekhila. Chlorophycean species (2%) showed high densities in October at Mex (0.15 10^6 cell · l^{-1}), and less so at Kayet Bey in May 1995 (0.047 10^6 cell · l^{-1}). Cyanophyceae contributed numerically

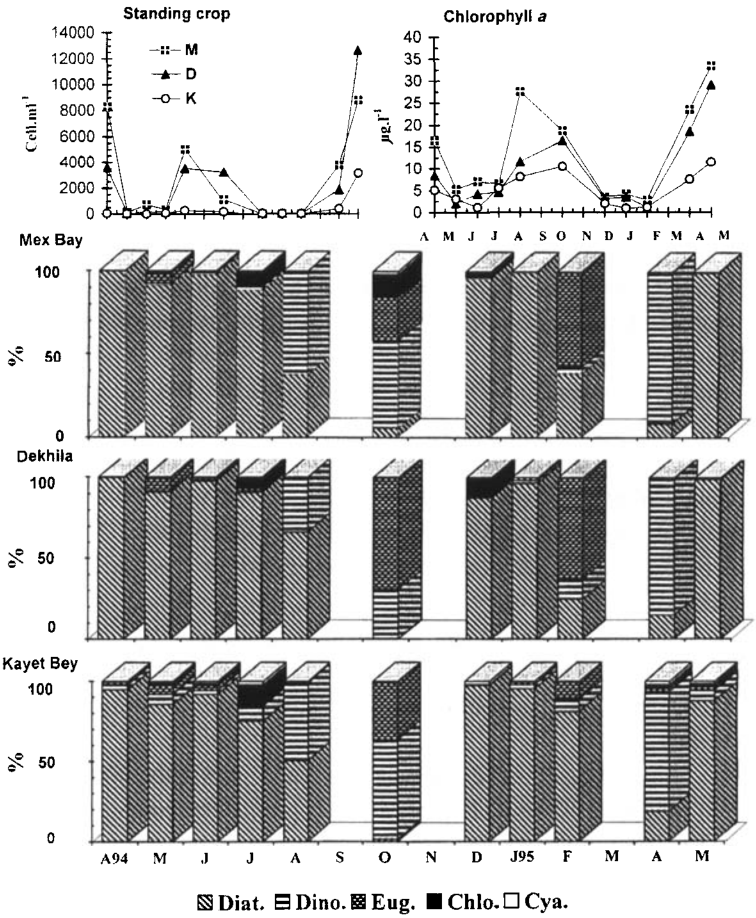

FIGURE 3 Phytoplankton standing crop, chlorophyll *a* and frequency distribution (%) from April 1994 to May 1995.

0.99% to the total, with their main occurrence in May, Kayet Bey (47 filament l^{-1}). Their filaments were counts as units, hence their apparent low contribution.

The distribution pattern of chlorophyll *a* content showed time coincidence between its peaks and cell counts. Very low levels were measured from December to February in Kayet Bey ($0.9-2\,\mu g \cdot l^{-1}$), and 2 major peaks of 33.5 and 29.1 $\mu g\, l^{-1}$ in Mex and Dekhila during May, respectively.

Phytoplankton Blooms Within an Annual Cycle

The dominant phytoplankton species and their relative frequency (%) are given in Table I.

Eight bloom pulses were observed, five of which caused water discoloration (April, August, October 1994, as well as April and May, 1995). Other minor blooms were recorded during May, June and July.

The first bloom in April occurred with the spring warming, density stratified water column, moderate concentrations of nitrate and nitrite, ammonia and low phosphate ($0.3-0.9\,\mu M\,l^{-1}$). The bloom was mainly observed in Mex and Dekhila ($8.3\;10^6$ and $3.6\;10^6$ cell $\cdot\,l^{-1}$, respectively), where the diatom species, *Asterionella glacialis*, was the causative organism (65% and 75.56% to the total, respectively). The diatoms, *Chaetoceros danicum* and *C. curvisatum*, were the minor components of the community. The first species contributed 56% to the total in Kayet Bey. Accompanied chlorophyll *a* reached $16.5\,\mu g\,l^{-1}$ in Mex.

The densities decreased sharply in May (average $0.087\;10^6$ unit l^{-1}). The diatoms, *Thalassionema decipiens*, and *Skeletonema costatum*, dominated in Mex and Dekhila, while *Thalassionema nitzschioides* in Kayet Bey.

Two minor peaks were recorded in June and July, maximum of $0.73\;10^6$ and $0.34\;10^6$ unit $\cdot\,l^{-1}$, in Mex, with. *Skeletonema costatum* and *Thalassionema decipiens* were leaders. The chlorophycean, *Crucigenia tetrapedia* contributed 14% to the total in Kayet Bey.

A massive red tide bloom triggered in August, the dinoflagellate, *Scrippsiella trochoidea*, was the responsible species. Severe impoverishment of the nutrients occurred, phosphate dropped drastically to $1.5\,\mu M\,l^{-1}$ and $1\,\mu M\,l^{-1}$ in Dekhila and Kayet Bey, respectively. The bloom spread over the whole area, but with different degrees, *Scrippsiella trochoidea* at $1.15\;10^6$ cell $\cdot\,l^{-1}$ in both Mex and Dekhila (62.59% and 32.17% to the total, respectively), and $0.117\;10^6$ cell $\cdot\,l^{-1}$ in Kayet Bey (41.76%). The bloom was shared in active role by *Skeletonema costatum*, which contributed 60.14% and 43.1% to the total in the last two stations. Chlorophyll *a* attained its highest of $27.6\,\mu g\,l^{-1}$ in Mex.

TABLE I Dominant phytoplankton species and their relative frequency (%) from April 1994 to May 1995

		Stations					
		Mex		*Dekhila*		*Kayet Bey*	
Month	*Dominant species*	*Cell* l^{-1}	%	*Cell* l^{-1}	%	*Cell* l^{-1}	%
1994							
April	*Asterionella gracialis*	5395490	65	2805320	75.56		6
	Chaetoceros danicum	1410770	17	486600	13.1	30830	56
	C. curvisatum	1307660	15.75	308545	8.3	17200	8
May	*Thalassiosira decipiens*	86850	57.27	37600	46.48		
	Skeletonema costatum	47250	31.57	27500	34	25150	71
	Thalassionema nitzschioides					8150	23
June	*Skeletonema costatum*	680800	88.31	142560	92.47	15350	76.75
	Cyclotella meneghiniana	18770	2.4				
	Nitzschia longissima	12770	1.66				
July	*Thalassiosira decipiens*	277345	83.27	117390	63.9		
	Crucigenia tetrapedia	27215	8.17	12275	6.7	10275	14
	Cyclotella meneghiniana			34775	18.9		
	Rhizosolenia fragilissima					49365	58
August	*Scrippsiella trochoidea*	1158210	62.59	1150000	32.17	117250	41.76
	Skeletonema costatum	1886095	37.38	2150000	60.14	120890	43.1
October	*Gymnodinium catenatum*	604800	53.13	1001270	30.77	85650	43.1
	Euglena granulata	302400	26.56	2252000	69.22		
	Protoperidinium depressum					33175	16.7
December	*Cyclotella meneghiniana*	30100	93.2	29550	83.26		
	Hemiaulas hauckii					6250	94.84

TABLE I (Continued)

		Stations					
		Mex		*Dekhila*		*Kayet Bey*	
Month	*Dominant species*	*Cell l*$^{-1}$	%	*Cell l*$^{-1}$	%	*Cell l*$^{-1}$	%
1995							
January	*Asterionella gracialis*	9830	30.33	21990	61.86	4505	51.5
	Melosira ganulata	7950	24.52				
	Skeletonema costatum			9830	27.65		
	Chaetoceros curvisatum					2270	25.94
February	*Phacus triqueter*	4140	51	2160	62.6		
	Lithodesmium undulatum					1980	35.7
	Rhizosolenia styliformis					1980	35.7
April	*Prorocentrum triestinum*	3400000	89.98	1566000	83.7	290250	73
	Rhizosolenia fragilissima	317300	8.4	174400	9.3	73955	18.6
May	*Skeletonema costatum*	8600000	98.8	1.2E+07	93.2	2562850	81.7
	Cyclotella meneghiniana	170000	1.15	750000	5.9		

The October red tide bloom was attributed to the combination of the dinoflagellate, *Gymnodinium catenatum*, and the euglenophycean, *Euglena granulata*. The bloom consumed most of the nutrients, but phosphate was high in Mex (6.2 $\mu M\,l^{-1}$). It was mainly restricted to the area between Mex and Dekhila, more dense in the first station (*G. catenatum* at 0.61 10^6 cell $\cdot\, l^{-1}$, 53.13% to the total). *Euglena granulata* dominated the community in Dekhila (2.25 $\cdot\, 10^6$ cell l^{-1}, 69.2%). In Kayet Bey area, despite the low density of *G. catenatum*, it formed 43.1% to the total, associated with the dinoflagellate, *Protoperidinium depressum* (16.7%). The accompanied chlorophyll *a* content with the bloom fluctuated between 10.5–18.7 $\mu g \cdot l^{-1}$ for the whole area.

A sharp reduction in the standing crop was recorded during the period from December to February. The dominant species were different, the diatoms, *Cyclotella meneghiniana*, dominated between Mex and Dekhila in December, while *Hemiaulas hauckii* in Kayet Bey. *Asterionella glacialis* was leading in January, followed by several species. The euglenophycean, *Phacus triqueter*, dominated in both Mex and Dekhila in February, while the diatoms, *Lithodesmium undulatum* and *Rhizosolenia styliforms*, contributed about 70% to the total community in Kayet Bey. Chlorophyll *a* was at its minimum level in the last month (1.1–2.8 $\mu g \cdot l^{-1}$).

By April, an intensive dinoflagellate bloom took place, *Prorocentrum triestinum* was the causative species. The bloom was seen to cover the whole area, *Prorocentrum triestinum*, culminating its peak in Mex (3.4 10^6 cell $\cdot\, l^{-1}$, about 90% to the total). The density decreased towards both the east and the west, yet this species contributed its main bulk of the community in Dekhila and Kayet Bey (83.7% and 73%, respectively). The bloom maintained very low nitrate and nitrite and ammonia, but extremely high phosphate level (7.3 $\mu M\,l^{-1}$). The diatom, *Rhizosolenia fragilissima*, succeeded to achieve high numbers, 0.075 10^6–0.32 10^6 cell $\cdot\, l^{-1}$. Accompanied chlorophyll *a* ranged between 7.5 $\mu g\,l^{-1}$ in Kayet Bey and 23.5 $\mu g\,l^{-1}$ in Mex.

The May red tide bloom, the most dense one, was a mono-species. *Skeletonema costatum* overwhelmingly dominated, with its major peak of 12 10^6 cell $\cdot\, l^{-1}$, 93.2% to the total in Dekhila, and less so in Mex (8.6 10^6 cell $\cdot\, l^{-1}$, about 99%), and in Kayet Bey (2.56 10^6 cell $\cdot\, l^{-1}$, 81.7%). Nitrate and nitrite and phosphate were almost exhausted in

Kayet Bey ($0.6\,\mu M\,l^{-1}$ and $0.3\,\mu M\,l^{-1}$, respectively). This bloom resulted in abnormal biomass increase, chlorophyll *a* at 33.5, 29.1 and $11.5\,\mu g\,l^{-1}$ for Mex, Dekhila and Kayet Bey, respectively.

The statistical analyses showed:

$$
\begin{aligned}
\text{the standing crop } (\text{cell}\cdot l^{-1}) &= -425+99.2\cdot \text{Temperature } (r = 0.167)\\
&= 2427 - 23.9\cdot \text{Salinity } (r = 0.034)\\
&= 4963 - 22.3\cdot \text{Secchi disc } (r = 0.490)\\
&= 3521 - 33.5\cdot \text{Stability } (r = 0.296)\\
&= 2890 - 185\cdot NO_3 + NO_2 \ (r = 0.276)\\
&= 3159 - 76.8\cdot NH_4 \ (r = 0.440)\\
&= 3010 - 478\cdot PO_4 \ (r = 0.242)\\
&= 937 + 288\cdot \text{Chlorophyll } a \ (r = 0.838)
\end{aligned}
$$

Secchi disc and ammonia concentration seem to have strong influence on the numerical variations of the phytoplankton. A positive significant correlation was found with chlorophyll *a*.

DISCUSSION

The study area is subjected to continuous environmental changes. The discharge water creates suitable conditions for the acceleration of the phytoplankton growth and daily replenishment of nutrients and development of density stratified water column. According to the trophic classification of OECD (1982), this area can be considered as eutrophic. However, hypertrophic condition (chlorophyll *a* > $27\,\mu g\,l^{-1}$) occurred in August and May 1995, red tide bloom periods.

Stabilisation of the water column was a constant character during the phytoplankton blooms, while the ambient nutrient concentrations changed.

Nutrient concentrations were mainly regulated by the discharge water input, exchange with the adjacent Mediterranean waters and consumption by phytoplankton. Comparing the present data with that carried out during 1982–1983 in Kayet Bey area (Dorgham *et al.*, 1987), the maximum concentrations of the nitrate and nitrite and ammonia increased by about 3 and 1.75-fold, respectively. Phosphate has not significantly changed. On the other hand, nitrate and nitrite concentrations in Mex showed no considerable changes compared with the previous records (Anon, 1989; Said *et al.*, 1991), but lower than that of Emara *et al.* (1992). However, the values of nitrate and nitrite and phosphate are nearly similar to that measured in the Western Harbour (Nessim and Tadros, 1992).

The Secchi disc readings, affected mainly by the discharge water input and the phytoplankton growth were relatively low. The extinction coefficient range ($k = 0.68-0.85\,\mathrm{m}^{-1}$), calculated between December and February, is typical for coastal waters (Ignatiades, 1979). The strong thermo-haline stratification and the massive phytoplankton blooms increased k values.

The phytoplankton community consisted of brackish and marine forms. *Asterionella glacialis* overwhelmingly dominated in April, representing a newly recorded red tide organism in the neritic waters of Alexandria. This species is a well known red tide form elsewhere (Park, 1991). *Skeletonema costatum* was the major component in June, forming a massive bloom in May 1995. This species is known as an indicator of eutrophication (Mihnea, 1985), recorded as a red tide species, with occurrence closely related to land drainage in the Eastern Harbour of Alexandria (Labib, 1994), as well as elsewhere (Revelante and Gilmartin, 1985). It is very common in the Egyptian Mediterranean waters (Zaghloul and Halim, 1992), previously recorded in Mex Bay as numerically significant component of the community (Dorgham *et al.*, 1987; El-Sherif, 1989; Samaan *et al.*, 1992). The mechanism of *S. costatum* blooms in relation to its ecological conditions was studied by several authors (*e.g.*, Hitchcock and Smayda, 1977). *Scrippsiella trochoidea*, in combination with *S. costatum* contributed August bloom. The first species is well known a red tide form (Kim *et al.*, 1990; Park, 1991; Koray, 1992), previously recorded with a major peak in late spring in the Eastern Harbour of Alexandria (Labib, 1994). *Gymnodinium catenatum*, associated with *Euglena granulata*, caused water discoloration in October. The latter one was the major constituent in Dekhila. The bloom maintained a high phosphate concentration. *Gymnodinium catenatum* was reported a toxic red tide species in the neritic Mediterranean waters of Spain (Estrada *et al.*, 1988). Its occurrence and ambient environmental conditions were followed during the 4 years survey 1993–1996 (Labib, 1998). *Euglena granulata* is common in Eastern Harbour (Labib, 1994) and Mex Bay (Dorgham *et al.*, 1987; El-Sherif, 1989). It is considered as a biological indicator for organic pollution (Munawar, 1972). *Prorocentrum triestinum* was previously recorded a common red tide species in Alexandria coastal waters, under similar physical and chemical conditions, culminating in a population peak of 71 10^6 cell · l^{-1} in the Eastern Harbour during April 1993 (Labib, 1996).

Although, the statistical analyses proved an important contribution of both the Secchi disc and ammonia concentrations on the seasonal variations of the numerical standing crop, it failed to define a limiting growth factor(s). However, any statistical conclusion must remain tentative. The matter is more complicated, since the phytoplankton variations are affected by the interfering of several factors simultaneously.

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