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Research Article

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Potential impact of some abiotic parameters on a phytoplankton community in a confined bay of the Eastern Mediterranean Sea: Eastern Harbour of Alexandria, Egypt

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Abstract

The Eastern Harbour (E.H.) is sheltered from the sea by a breakwater with two main entrances through which exchange with the netitic Mediterranean water takes place. Some physico-chemical parameters of the study area showed that dissolved oxygen ranged from 6.57 to 11.4 mg l^{-1} at the open sea station and 5.08 to 11.71 mg l^{-1} for the E.H. stations. Higher nutrient concentrations were recorded in the E.H. than that at the open sea station, except for ammonia and nitrate.

The phytoplankton flora of the E. H. stations was much richer in species than the adjacent open sea station, attaining 96 and 74 species, respectively. As well as the average phytoplankton density, it was higher in the surface water than near the bottom water layer.

With regard to the total phytoplankton community, Bacillariophyceae dominated at all sites, whereas Dinophyceae, Chlorophyceae, Cyanophyceae and Euglenophyceae were rarely recorded. The highest average density of phytoplankton abundance was recorded during March, both at the surface and near bottom water layer.

Correlation coefficient of biological factors with some physico-chemical parameters and a series of stepwise multiple regression equations describing the dependence of phytoplankton density on the changes of most abiotic prevailing conditions are provided and discussed.

Keywords: Eutrophication; Eastern harbour; Nutrient salts; Phytoplankton; Diversity index.

Introduction

The coastal waters of Alexandria have recently become heavily polluted; over $183x10^6m^3$ of untreated domestic sewage and wastewater is discharged annually into the sea through several sewers along the coast. The Eastern Harbour (E.H) of Alexandria is a semi-enclosed bay connected with the Mediterranean Sea through the El-Boughaz and El-Silsila openings. The E.H. used to receive municipal sewage effluents through eleven submarine outfalls located mainly along its south and southwest inner margin. By 1998 only one outlet was left in the E.H. for rain discharge. Other pressures in the E.H. include fishing.

The increase of waste influxes from different sources has led to an increase of eutrophication levels. The impact of eutrophication on phytoplankton production and composition is well documented in literature. Phytoplankton composition and succession in relation to environmental parameters in the E.H have been studied over several annual cycles prior to and after the Aswan High Dam became functional (HASSAN, 1972; SULTAN, 1975; HALIM *et al.,* 1980). The chemical composition of the harbour water in relation to pollution has been assessed by SHRIDAH (1982).

The aim of the present study is to evaluate the eutrophic status of the E.H after closing the ten outlets, in relation to some physico-chemical parameters.

Materials and Methods

Sampling was carried out monthly throughout the period from October 2004 to October 2005 at two depths (surface and near bottom water layer). Nine stations were chosen, eight of them covered the different ecological areas of the harbour (Sts. 2 to 9), while the other one was situated outside the harbour; open sea station (St. 1) as shown in Figure (1).

Two litres of water samples were collected monthly by using a Rutiner bottle

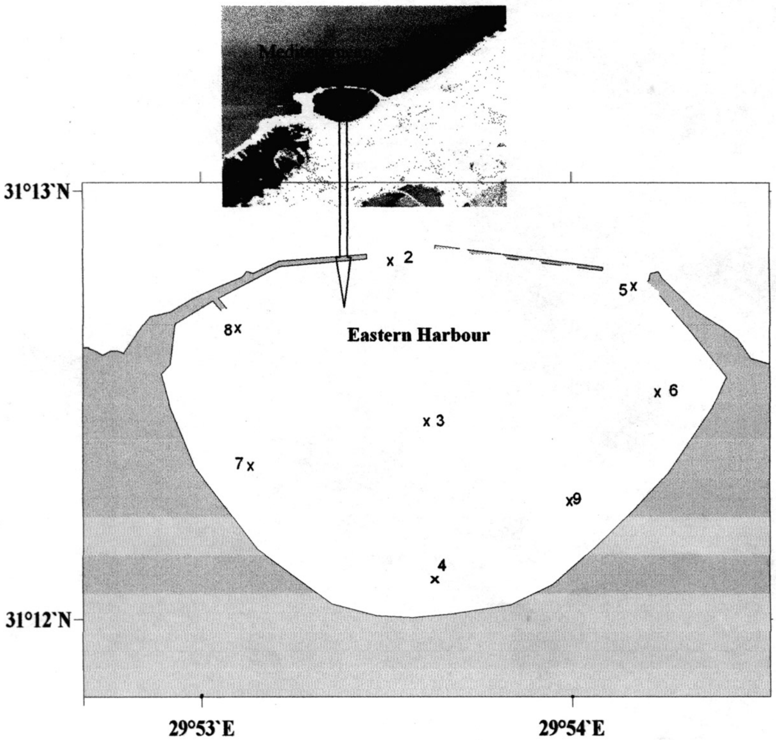

Fig. 1: Eastern Harbour of Alexandria with study stations.

sampler from each of the selected stations (1-9), one for estimation of chemical parameters and the other for estimation of phytoplankton abundance.

Dissolved oxygen (DO) was analyzed according to the modified Winkler's method. The pH was measured in-situ using a portable pH meter (Orion pH-meter). The nutrients (nitrate; nitrite; ammonia; phosphate and silicate) were determined colorimetrically (A.P.H.A., 1995; GRASSHOFF, 1976) using a UV-Visible Spectrophotometer (Shimadzu double beam Model 150-02).

Estimation of the phytoplankton density was carried out by the sedimentation method, the sample was preserved in 4% neutral formalin. The different species were counted and the results expressed as unit per litre because Cyanophyceae contain filaments (20 cells long expressed as unit) and coemobia (100 cells expressed as unit), for this we estimate the total phytoplankton as unit per litre. Various key books and papers were consulted for the identification of phytoplankton species.

Correlation coefficient as well as stepwise multiple regression equations by using a Minitap programme at a confidence limit 95% ($P \leq 0.05$,) were estimated separately for the open sea station and the E.H. stations at both surface water (n= 79) and at near bottom water layer (n= 29) to determine the phytoplankton standing crop in relation to the most relative physico-chemical parameters.

Results and Discussion

I. Chemical Parametrs

Temperature is an important physical factor influencing the growth of planktonic plants. The annual average water temperature was 22.10°C with an amplitude of 14.9°C (EL-GEZIRY & MAIYZA, 2006). The diurnal and annual seawater temperature cycle is directly affected by solar radiation and seasonal change in air temperature. It seems to have a pronounced effect on the rate of phytoplankton photosynthesis as well as on its productivity and its community structure and species abundance.

The salinity variations are of particular significance as they reflect changes caused by the mixing of both fresh and sea water (TADROS *et al.,* 2005). During the investigation period the surface water salinity fluctuated between 36.77 psu during March and 38.66 psu in October 2005 (EL-GEZIRY & MAIYZA, 2006). The obtained data show that water salinity was negatively correlated with phytoplankton standing crop.

Generally the pH values were on the alkaline side and no significant difference was observed between the surface and near bottom water layer. In the open sea station (St. 1) pH ranged between 8.06 and 8.42 with an average of 8.25 ± 0.12 for surface water and between 8.4 and 8.47 with an average of 8.24 ± 0.14 for near bottom water layer. The highest pH value (8.47) was recorded in December (St.2), while the lowest (7.84) was recorded in October 2005 (St.4). Changes in pH values are mainly attributed to photosynthesis activities of phytoplankton, aquatic plants, respiration and variations in temperature.

Concentration of Dissolved Oxygen (DO) in natural water is generally changeable and represents a momentum balance between the rate of supply and consumption. The studied stations are well oxygenated with more content in the surface water than near the bottom layer. The open sea station had averages of 8.48

±1.75 mg/l for surface water and 7.40 ±1.87 mg/l for the near bottom layer. Inside the E.H., the concentration of DO in the surface water layer ranged between 5.08 mg/l at station 8 during May and 11.71 mg/l at station 6 during April with an average of 8.17 mg/l. There is a significant negative correlation between DO and water temperature (r = 0.27). A negative correlation between pH and DO was deduced. The DO contents clearly indicate that the present load of organic matter and nutrients reaching the harbour are below the level that can lead to oxygen deficiency. The DO content in the bottom water was lower than that of the surface water.

Nutrients

Ammonia is the nitrogenous end product of the bacterial decomposition of natural organic matter containing nitrogen (TADROS *et al.,* 2005). Ammonia content at station 1 was slightly lower than at those inside the EH. It ranged between 0.9 - 6.26 μM in the surface water and 0.27 – 2.57 μM in the near bottom water layer. A considerable monthly variation in ammonia levels was observed at the E.H. during the period of study. The values ranged between 18.90 μM (St. 2, October 05) and 0.41 μM (St. 9, August) in the surface water. The highest values were recorded in winter (December, January and February) and coincided with highest nitrite and nitrate (r = 0.24, 0.27, respectively) values. Generally, the level of ammonia was higher in the bottom water than that of the surface water. Ammonia has been recognized as an important alternative nitrogen source for various aquatic plants and in most environments may even be assimilated in preference to nitrate ABDEL-HALIM, 2004. Most species of phytoplankton utilize ammonium ions in preference to other inorganic nitrogen forms which clearly appeared during summer (HARVEY, 1974). This appears from the negative correlation between ammonia and total phytoplankton. Significant negative correlations were calculated between ammonia and both water temperature and pH (r = - 0.23 and -0.28, respectively).

Nitrite appears in water resulting from biochemical oxidation of ammonia (Nitrification) or the reduction of nitrate (Denitrification). It is the intermediate state between oxidation of NH_4^+ to NO_3^- in nitrification and the reduction of NO_3^- to either N_2O/N_2 - molecules or NH_4^+ in denitrification or N - immolization. As shown in Table 1, the nitrite levels at the open sea station were relatively low. The highest concentration (4.15 μM) was measured at station 6 during January 2005 while the lowest level (0.02 μM) was measured at station 7 during March 2005 in the surface water. Both forms of NO_2 and NH_4 are positively correlated. The levels of nitrite in the bottom water were slightly higher than those of the surface water and ranged between 0.05 μM found during October 2005 and 5.90 μM measured during January at station 5. Generally, low nitrite levels were detected among all samples collected during productive months (March, April, May and June), which may be attributed to the consumption by phytoplankton in agreement with NESSIM *et al.,* 2005.

Nitrate is the most stable form of inorganic nitrogen in oxygenated water. It is the end product of the nitrification process in natural water. The average values in station 1 were 5.49 μM ± 7.70 for the surface water and 2.40 μM ±2.45 for the near bottom water, with the highest value of 23.18

μM detected in the surface water during December. Nitrate concentrations in the surface water of the E.H. stations were usually higher than those of the near bottom layer. They ranged between 0.01 μM (St. 6, June) and 28.57 μM (St. 9, December) with an average of 4.00 μM.

The nitrate concentration at station 1 showed the highest value of 23.18 μM during December in the surface water. The averages for the nitrate at the open sea station were 5.49 μM ± 7.70 and 2.40 μM ±2.45 for the surface and near bottom waters, respectively. In the E.H. stations the minimum concentration was 0.01 μM recorded at station 6 during June. The maximum nitrate concentration, 28.57 μM, was determined at station 9 during December in the surface water. It is observed that the nitrate content near the bottom layer was lower than that of the surface water and ranged between 0.38 – 31.0 μM (the annual averages were 4.00 and 3.53 μM for the surface and near bottom water, respectively). The highest concentrations of nitrate were determined in the winter months, while the lower nitrate contents were determined during the summer months (Table 1).

Reactive Inorganic Phosphate

Phosphorus is a very important factor for the growth and reproduction of phytoplankton. The environmental significance of phosphorus arises out of its role as a major nutrient for both plant and micro organisms. Variations of inorganic reactive phosphate are shown in Table 1. Reactive phosphate concentrations were lower at the open sea station than in the E.H. In the E.H. phosphate concentrations were usually below 1 μM, with the exception of 3.36 and 2.11 μM measured at stations 8 and 2 respectively during December,. found in the western part of the harbour, which is suffering from the activities of a large number of fishing boats. Based on the average variation of reactive inorganic phosphate, there is a decreasing trend with depth (0.51 and

Table 1
The mean, minimum and maximum values of nutrients (in μM) of surface and bottom waters in the Eastern Harbour (EH) and the open station.

Nutrient salt	EH		Open station	
	surface (Year mean) min-max	bottom (Year mean) min-max	surface (Year mean) min-max	bottom (Year mean) min-max
Ammonia	(3.27) 0.041 – 18.90	(3.81) 1.44 – 30.60	(3.76) 0.95 – 6.26	(1.54) 0.27 -2.57
nitrite	(0.37) 0.02 – 4.15	(0.56) 0.05 – 5.90	(0.25) 0.05 – 0.47	(0.16) 0.07 – 0.31
nitrate	(4.00) 0.01 – 28.57	(3.53) 0.38 – 31.00	(5.49) 0.54 – 23.18	(2.40) 0.45 – 7.46
phosphate	(0.51) ND – 3.36	(0.44) ND – 1.60	(0.41) 0.05 – 1.10	(0.58) 0.05 – 1.21
silicate	(2.95) 0.29 – 8.44	(4.31) 0.35 – 26.08	(2.27) 0.91 – 4.39	(2.89) 0.34 – 9.98

0.44 μM for surface and near bottom water, respectively). When reactive inorganic phosphate is present in large quantities, it causes eutrophication to certain extent, after which it becomes a potential pollutant.

Reactive silicate

The silicate content in the open sea station was lower in the surface water compared to the E.H. It fluctuated between 0.9 – 4.39 μM and 0.34 – 9.98 μM for surface and near bottom waters, respectively. The changes in silicate values at the E.H. were found to follow more or less those of phosphate. In surface water, the content of silicate ranged between 0.29 and 8.44 μM recorded during February at station 9 and station 2 respectively, during December. The values of the silicate content in the bottom water showed a wide variation and ranged between 0.35 and 26.08 μM determined at station 2 and 5, respectively, during June. Generally, the near bottom water content of silicate was higher than that of the surface water, this may be attributed to the precipitation process or to silicate absorption from the particulate matter.

A relatively low silicate content observed during October 2004 and February may be attributed to utilization of silicate by the phytoplankton whose population was increased. This is confirmed with a significant negative correlation between silicate content and total phytoplankton population (r = - 0.33). The uptake of silicate by diatoms during winter affected its content where low content was recorded. The same observation was recorded in Alexandria coastal water NESSIM, 1991; ABOU-TALEB, 2004.

During the study period, stations 2, 8 and 9 showed high concentrations of silicate. This may be attributed to wastewater inflow and/or to the fishing activities at those stations.

A strong significant correlation between silicate and ammonia, nitrite and nitrate was calculated (r = 0.26, 0.21 and 0.32 respectively).

II. Biological Parametrs

Community structure of phytoplankton

A total of 116 taxa, comprising 71 Bacillariophyceae, 24 Dinophyceae, 8 Chlorophyceae, 9 Cyanophyceae and 4 Euglenophyceae, were collected from both the open sea and the E.H. stations. (Table 2). Out of these, 19 and 40 taxa were limited to the open sea station and the E.H. stations, respectively, whereas 55 taxa (40 diatoms, 8 Dinophyceae, 1 Chlorophyceae, 4 Cyanophyceae and 2 Euglenophyceae) were common to both open sea and the E.H. stations.

Bacillariophyceae contributed 50 and 61 taxa, Dinophyceae 13 and 18 species, Chlorophyceae 3 and 6 species, Cyanophyceae 6 and 7 species and Euglenophyceae 2 and 4 species, respectively to a total taxa content of 74 at the open sea station and 96 at the E.H. stations.

The majority of species presented in Table 2 have been previously recorded in the Alexandria coastal waters. Of these, only four species are recorded as dominant and four as frequent. Compared with a previous study in the E.H (HUSSIEN, 1994) only five species were newly recorded as rare forms in this study.

Generally, phytoplankton density (Table 3) was much higher in the surface water of E.H. and open sea stations than near bottom water layer. This phenomenon is well known for coastal waters (RAO & MOHANCHAND, 1988) and reflects the

Table 2
Check list of phytoplankton taxa in the study area.
(R): Rare (F) frequent and (D) dominant species.

BACILLARIOPHYCEA	E.H.	St. 1
Achanthus sp.	R	R
Actinoptychus splendens (Shad.) Ralfs.	R	-
Amphora turgida Grég.	-	R
Amphora proteus Grég.	R	-
Amphora grevilleana var. contracta Clevé.	-	R
Amphiprora gigantea (O Meara) Clevé *.	R	R
Asterionella glacialis Castracane.	F	F
Bacteriastrum hyalinium Lauder.	-	R
Bacteriastrum delicatulum Clevé.	R	-
Bellerochia malleus (Brightwell) Van Heurick.	-	R
Biddulphia mobilliensis Bail.	-	R
Bidulphia aurita Lyngbyei. Bréb & God.	R	R
Ceratulina bergonii Péragallo.	R	-
Chaetoceros borealis Bail.	R	R
Chaetoceros socials Lauder.	-	R
Chaetoceros curvisetus Clevé.	D	D
Chaetoceros affinis Lauder.	R	R
Chaetoceros didymus Ehr.	R	R
Chaetoceros decipience Clevé.	-	R
Chaetoceros muelleri Lemm.	R	-
Cocconeis scutellum Ehr.	-	R
Coscinodiscus excentricus Ehr.	R	R
Coscinodiscus oculus iridis Ehr.	R	-
Coscinodiscus radiatus Ehr.	-	R
Cyclotella meneghiniana Kűtz.	R	R
Cyclotella nana Hustedt	R	-
Cyclotella kutzingiana Thw.	R	R
Climacosphenia moniligera Ehr.	-	R
Diploneis bombus (Ehr.) Clevé.	R	-
Diploneis smithii (Bréb.) Clevé.	R	R
Grammatophora marina (Lyng.) Kűtz.	R	-
Grammatophora angulosa Ehr.	R	R
Gyrosigma attenuatum (Kz.) Cleve.	R	R
Hemiaulus sinensis Greville.	R	-
Hemiaulus hauckii Grunow.	R	R
Hyalodiscus laevis	R	R
Lauderia porealis Gran.	R	R
Leptocylindrus danicus Cleve.	F	F
Licmophora paradoxa Lyngb.	R	-
Licmophora lyngbyei Kűtz. Grunow.	R	R
Lithodesmium undulatum Ehr.	R	R

(continued)

Table 2 (continued)

Melosira granulata var. angustissima Mũller.	R	R
Navicula humerosa Bréb.	R	-
Navicula dicephala Nm. Sm.	R	R
Navicula lyra Ehr.	R	-
Navicula abrupta Grég.	R	-
Navicula distans W. Smith.	R	R
Nitzschia longissima (Bréb.) Ralfs.	R	-
Nitzschia closterium (Ehr.) Smith.	R	R
Nitzschia delicatisma Clevé.	R	-
Nitzschia microcephala Grunow.	F	-
Nitzschia paradoxa (Gmelin) Grun.	R	-
Nitzschia sigma (Kűtz.) Smith.	R	R
Nitzschia serriata Clevé.	D	D
Plagiogramma vanheurckii Grunow.	R	R
Pleurosigma decorum Smith.	R	-
Pleurosigma elongatum Smith.	R	R
Rhisosolenia alata Brightwell.	R	R
Rhisosolenia fragilissima Bergon.	D	D
Rhisosolenia delicatula Clevé.	F	-
Rhisosolenia stalterfothii Peragallo.	R	R
Rhisosolenia styliformis Brighwell *.	R	-
Rhisosolenia hepatata Bail. – Grun.	R	R
Skeletonema costatum Greville.	D	D
Streptotheca thamenses Shrubsole.	R	R
Surirella striatula Turp.	R	R
Synedra Ulna (Nitz.) Ehr.	R	R
Thalassiosira rotula Meunier.	R	R
Thalassiothrix frauenfeldii (Grun). Clevé.	R	R
Thalassionema nitschoides Grun.	R	R
Triceratium alternans (Bail.) Grunow.	R	R
DINOPHYCEAE		
Alexandrium minutum Halim.	R	R
Ceratium furca Ehr. (Clap.) & Lachm.	R	-
Ceratium fusus Ehr.	R	R
Dinophysis acuta Ehr.	-	R
Gonyaulax turbynei Murr. and Whitt.	R	-
Gyrodenium fusiform Kof. and Swezy.	R	R
Oxytoxium constrictum (Stain) Butschli *.	R	-
Oxytoxium elegans Pavillard.	R	-
Prorocentrum triastinum Schiller.	R	R
Prorocentrum cordatum (Oustenf.) Apé.	-	R
Prorocentrum dentatum Stain.	R	-
Prorocentrum micans Ehr.	R	R
Protoperidinium conicum (Gran) Balech.	R	-

(continued)

Table 2 (continued)

Protoperidinium granii (Ostenf.) Balech.	R	-
Protoperidinium breve Paulsen.	R	-
Protoperidinium nipponicum Apé. Balech.	-	R
Protoperidinium oblongum (Aurivillus) Balech.	-	-
Protoperidinium alexandrinum Halim.	R	-
Protoperidinium curvipes (Ous.) Balech.	-	R
Protoperidinium minutum (Kofoid) Balech.	R	R
Protoperidinium steinii (Jorgen.) Balech.	R	-
Protoperidinium depressum (Bail.) Balech.	-	R
Pyrophacus horlogicum Stain.	R	R
Scrippsiella faeroense (Paul.) Balech.	R	R
CHLOROPHYCEAE		
Ankistrodismus falcatus (Corda) Ralfs.	R	R
Crucigenia tetrapedia (Kirchn.) W and G. S. West.	-	R
Crucigenia rectangularis (A. Brawn) Gay.	R	-
Pediastrum clathratum (Schoet) Lemm.	R	-
Pediastrum.simplex Meyen.	R	-
Scenedesmus dimorphus Turp.	-	R
Scenedesmus quadricauda (Turp.) Breb.	R	-
Staurastrum paradoxum Meyen.	R	-
CYANOPHYCEAE		
Anabaena circularis (G.S. West.) Wol. & Miller.	R	R
Chroococcus turgidus (Kg.) Naeg.	R	-
Chroococcus disperses (Keissl.) Lemm.	R	R
Gomphosphaera oponina Kg.	R	-
Lyngbya limnetica Lemm.	-	R
Merismopedia punctata Meyen.	-	R
Microcystis aeraginosa Kűtz.	R	-
Oscillatoria tenuis V. Levis Gardn.	R	R
Spirulena platensis (Nordst.) Geitter.	R	R
EUGLENOPHYCEAE		
Euglena acus Ehr.	R	R
Euglena granulata (Klebs.)	R	-
Euglena codata Hübner.	R	-
Euglena gracilis (Klebs.)	R	R

eutrophication status in the Eastern Harbour. The average phytoplankton abundance at the open sea station was 3.1×10^6 and 2.5×10^6 Units. l^{-1} in the surface and near bottom layer, increased at the E.H. stations to reach respectively an average of 4.3×10^6 and 3.4×10^6 Units.l^{-1} (Table 3).

As shown in Table 3, Bacillariophyceae, is the dominant group at both the open sea station and the E.H. stations. It showed the same percentage frequency in the two layers constituting 89.8% at the open sea station and 88.7% at the E.H. stations.

The phytoplankton density in the E.H

during the present study is similar to that recorded during 1986-87 (ZAGHLOUL & HALIM, 1990) and 1990-91 (HUSSEIN, 1994) and less than that recorded during 1991-92 (ZAGHLOUL, 1995) (Table 4). This may be attributed to the reduction of sewage outfalls discharging into the E.H. It is further confirmed by the low number of fresh water phytoplankton species, recorded in the harbour during the present study.

Concerning the percentage frequency of Bacillariophyceae to the total phytoplankton density in the Eastern Harbour, this class formed about 92% of the total community during 1972-73 (SULTAN, 1975). This ratio decreased to 66% during 1986-87 due to the more frequent presence of other species of Dinophyceae or Cyanophyceae and it reached 24% in 1991-92. Then it rose to 88.7% during the present study; this is presumably attributed to the stress of eutrophication on the community structure.

Although numerous species were recorded in the E.H. stations, few of them formed the main bulk of phytoplankton

Table 3
Average numbers of the different phytoplankton groups (x102 until 1^{-1}) and their percentage frequenciesat both open sea station and Eastern Harbor of Alexandria during the period of October 2004-October 2005.

Site / groups	Open sea station				Eastern Harbor			
	Surface water		Near bottom layer		Surface water		Near bottom layer	
	Average no.	%	Average no.	%	Average no.	%	Average no.	%
1- Bacillariophyceae	2757	89.8	2236	89.8	3854	88.7	3136	88.9
2- Dinophyceae	254	8.3	225	9.0	4406	9.4	349	10.0
3- Chlorophyceae	16	0.5	8	0.4	21	0.5	10	0.3
4- Cyanophyceae	20	0.7	10	0.4	27	0.6	15	0.4
5- Euglenophyceae	24	0.7	10	0.4	36	0.8	15	0.4
Total phytoplankton	3071	100	2488	100	4344	100	3526	100

Table 4
Average abundance of the different phytoplankton groups (Unit. l^{-1} x 106) and their percentage frequencies recorded in the surface water of the Eastern Harbor during different years (ZAGHLOUL, 1995) compared with the present study.

Group	1986-1987		1990-1991		1991-1992		2004-2005	
	Av. No.	%	Av. No.	%	Av. No.	%	Av. No.	%
Bacillariophyceae	2.853	66.04	2.419	59.3	2.003	24	3.854	88.7
Dinophyceae	0.954	22.09	0.408	10.0	6.321	75.9	0.406	9.4
Cyanophyceae	0.036	0.84	1.198	29.4	0.003	-	0.027	0.6
Chlorophyceae	0.013	0.28	0.014	0.29	0.004	0.1	0.021	0.5
Euglenophyta	0.064	1.49	0.041	1.0	0.002	-	0.036	0.8
Silicoflagellata	-	-	0.0001	0.01	-	-	-	-
Chrysophyceae	0.400	9.26	-	-	-	-	-	-
Total	4.321	100	4.079	100	8.333	100	4.344	100

abundance (Table 5). *Skeletonema costatum; Rhizosolenia* sp.; *Chaetoceros* sp. and *Nitzschia* sp., formed the main component at the open sea station and the E.H. stations at the two water layers. Generally *S. costatum;* and *Chaetoceros* sp. were more abundant in the surface water layer than in the near bottom water layer except *Rhizosolenia* sp. which was less common in the open sea than the E.H. stations. *Nitzschia* sp. was more abundant in the E.H stations than the open sea stations in the two layers. Earlier observations in the E.H. indicated that, *S. costatum* was quantitavely the most common species during 1972-73 (SULTAN, 1975). In 1986-87 (ZAGHLOUL & HALIM, 1990) this species was only recorded in February in the middle water layer of the E.H. During 1991-92 (ZAGHLOUL, 1995), *S. costatum* was widely distributed in the Mediterranean Sea with a maximum occurrence in spring (WAWRIK, 1961). The occurrence of *S. costatum* gives an indication of eutrophication (MIHNEA, 1985). *Rhizosolenia fragillisma* one of the most dominant species, is presumably carried into the E.H. by inflowing sea water (ZAGHLOUL & HALIM, 1992). The genus *Chaetoceros* is dominated by *Chaetoceros curvisetus* has been, frequently recorded in the E.H in the past (HALIM *et al.,* 1980). The genus *Nitzschia* was dominated by *Nitzschia serriata.* The members of the genus *Nitzschia* are highly eurythermic and flourished well at temperatures ranging between 10° C and 27° C (GOLDMAN, 1977). This explains the non-dependence of the genus growth on temperature variations. *Nitzschia serriata,* gives an indication for eutrophication (REVELANTE & GILMARTIN, 1985).

Distribution and monthly variations

Phytoplankton abundance was recorded at most stations particularly stations 5 and 6 (4.81×10^6 and 4.84×10^6 Units.l^{-1} respectively). This is may be due to the effect of exchange water through Boughaz El-Silisila (St. 5).

Higher phytoplankton density at St. 5 and 6 is attributed to lower counts of zooplankton (ZAKARIA, 2006), low ammonia concentration (2.50 and 2.45 μM), nitrite (0.29 and 0.29 μM), and high silicate concentration (2.77 and 3.42 μM), phosphate concentration (0.44 and 0.36 μM), dissolved oxygen (8.57 and 7.96 mg l^{-1}) for the two stations, respectively.

Generally, the average monthly variations of phytoplankton density at both the open sea station and the Eastern Harbour stations showed the same distribution pattern. A high pronounced peak appeared during March (7.6×10^6 and 5.2×10^6 Units.l^{-1} at the surface and 6.2×10^6 and 4.5×10^6 Units.l^{-1} at the near bottom water

Table 5
Dominant species and their percentage frequencies.

Station / Dominant forms	Open sea station (Surface)	Open sea station (Bottom)	E. H stations (Surface)	E. H stations (Bottom)
Skeletonema costatum	29.00%	31.40%	23.69%	22.80%
***Rhizosolenia* sp.**	21.90%	17.20%	21.20%	19.20%
***Chaetoceros* sp.**	12.00%	13.20%	9.60%	10.04%
***Nitzschia* sp.**	3.00%	3.10%	9.70%	10.00%

layer, respectively) in addition, the main component was similar since Bacillariophyceae ranked as the main constituent throughout the year. The maximum phytoplankton density during March is attributed to the dominance of Protozoa and Rotifera (GOLDMAN, 1977), low concentrations of nitrite (0.12 μM), nitrate (0.66 μM), phosphate (0.2 μM), and silicate (1.4 μM). Lower silicate concentration during the outstanding peak was due to increased numbers of diatoms, which are considered as the main consumer of silicate in sea water. The minimum phytoplankton density at both the open sea station and the Eastern Harbour was recorded during December (1.16 x 10^6 and 1.25 x 10^6 Units.l^{-1} at the surface water and at the near bottom water layer was 0.97 x 10^6 and 1.1 x 10^6 Units.l^{-1}). This is mainly attributed to low silicate concentration (1.71 μM), low water temperature (17.7˚C) and high water salinity (38.39 psu) (EL-GEZIRY & MAIYZA, 2006). At the open sea station lower phytoplankton density (3.1 x 10^6 Units.l^{-1}) was accompanied by the dominance of Copepods outside the harbour (ZAKARIA, 2006).

In 1972-73 in the absence of Nile bloom, the spring bloom became the major one with its minimum recorded in October 1972 (SULTAN, 1975), as happens regularly in most Mediterranean localities. During the period from 1977 to 1978 (HALIM *et al.*, 1980), the quantitative cycle of phytoplankton reflects both the absence of the Nile outflow in autumn and the increased eutrophication, which does not follow any seasonal trend. Instead of a bimodal cycle, it is characterized by successive blooms; blooms occurred in early and in late spring, in early and late summer and in mid-winter. In 1986-87, blooms occurred all the year round except during mid-winter (mixing period) (ZAGHLOUL & HALIM, 1990). During 1990-91 (HUSSEIN, 1994) the blooms were observed in July and September 1990. Apart from these two peaks, other small ones were observed during January, April and June 1991. In 1991-92 (ZAGHLOUL, 1995), blooms occurred throughout the year except in winter and late spring. In the present study and after closing the eleven outlets, a pronounced high peak appeared during March with standing crop 7.6 x 10^6 Unit.l^{-1} at the surface and 6.2 x 10^6 Unit.l^{-1} at the near bottom water layer.

As shown in Figure 2, the community composition at the E.H stations and the open sea station showed significant variations from one month to the other (graph not shown here). Thus, *Rhizosolenia* spp. dominated in February (37.6% and 31.4%), March (28.6% and 25.3%) and April (25.7%) by number to the total phytoplankton at the E.H and open sea station, respectively. On the other hand, *Skeletonema costatum* was the main constituent during March (35.7% and 38.2%); April (38.4%); May (28.8% and 35.2%) and June (29.6% and 28.1%). *Chaetoceros* spp. dominated during December (24.4% and 25.2%) and January (25.4% and 20.8%). At the same time *Nitzschia* spp. ranked as the main form during August (35.2%) and October 2005 (42.6%).

Phytoplankton structure and environmental parameters

Phytoplankton growth depends on the level of nutrients in the marine ecosystem. In the present study the phytoplankton abundance was negatively correlated with all measured nutrient salts, NO_3 (-0.59), NO_2 (-0.35), ammonia (-0.28), PO_4 (-0.34), silicate (-0.33) indicatingt eutrophication phenomena in the E.H.

The response of planktonic food webs

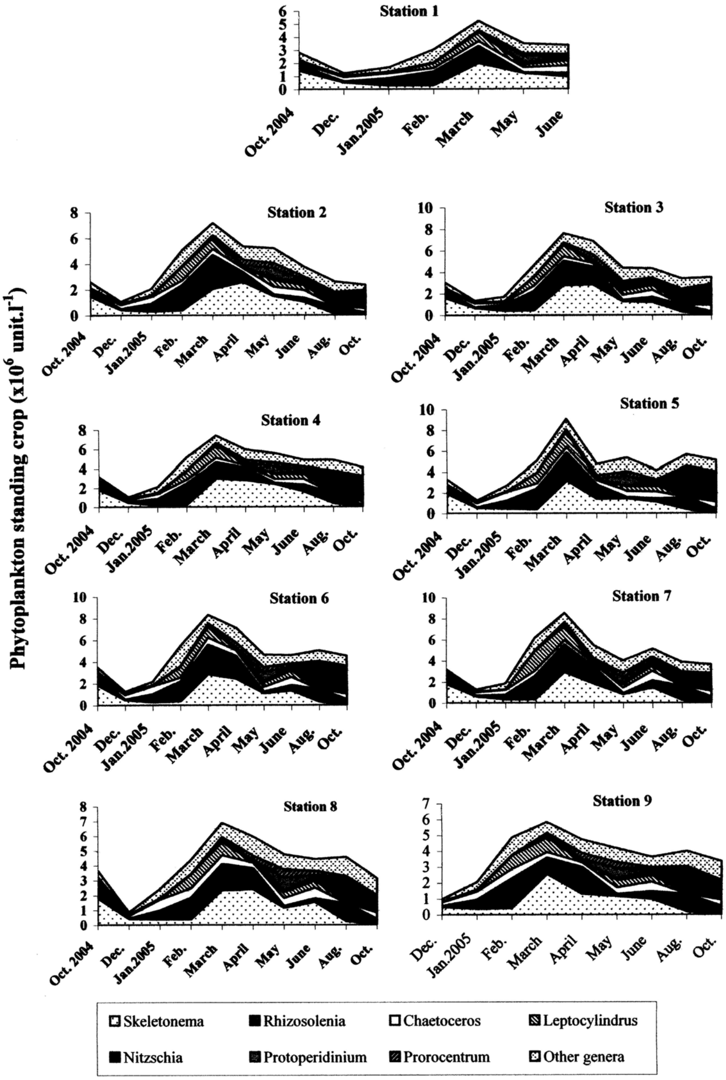

Fig. 2: Monthly variation of total phytoplankton and dominant genera at the surface water of the open sea station (St.1) and Eastern Harbour (Sts. 2-9) during October 2004-October 2005.

to nutrient enrichment in coastal marine ecosystems varies widely worldwide due to the broad range of both direct and indirect effects of the eutrophication process. However, the response of ecosystems to an increase of nutrient load differs widely because biological control mechanisms of the eutrophication process are not always the same (RAYMONT, 1980).

The corresponding regression equations were developed at the surface water layer of the E.H stations to investigate the possible correlations between phytoplankton abundance and the environmental conditions during different years (Table 6).

These equations illustrate that the environmental factors which affect the magnitude of the phytoplankton standing crop vary from one year to the other according to the amounts of waste water discharged into the E.H.

In conclusion, the Eastern Harbour is a eutrophic bay characterized by a relatively high concentration of nutrients, heavy phytoplankton density especially in the surface layer and a high percentage frequency of diatoms. The seasonal cycle of phytoplankton is different from one month to the other according to the prevailing environmental factors.

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Table 6
The multi-regression equations between phytoplankton abundance and the environmental parameters during different years.

Year	Relation	r^2
1986-87	St.C =-14060718.41+2229.99 Stab. + 1903903.9 pH + 205639.8 Alk. + 1027906.15 PO_4	0.63
1990-91	St.C = - $0.21x10^8$ + 1206848 Temp. – 58654.6 Alk. – 149117.3 NO_3 - -216909.7 OM - 2347.7N/P	0.55
1991-92	St.C = -22717940.23 + 8911032 PO_4 + 209218.45 NH_4	0.99
2004-05	St.C = 22102 – 134 NO_3 – 715 NO_2 – 749 PO_4 -439 Salin.	0.44

St. C = standing crop
Stab. = Stability
Alk. = Total alkalinity (milli. $Eq.l^{-1}$)
Salin.= Water salinity ‰
NO_3 = Nitrate concentration (μM)
NH_4 = Dissolved ammonia (μM)
N/P= nitrogen phosphorus ratio
r2 = Multiple regression
Temp. = Water temperature (°C)
PO_4 = Phosphate concentration (μM)
DO = Dissolved oxygen (ml $O_2.l^{-1}$)
OM = Oxidizable organic matter (μM)
NO_2 = Nitrite concentration (μM)

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