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A STATISTICAL MODELLING OF PHYTOPLANKTON EUTROPHICATION IN THE EASTERN HARBOUR, ALEXANDRIA, EGYPT.

By

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ABSTRACT

The Eastern Harbour of Alexandria is a shallow semiclosed basin receives a constant high input of sewage effluent showing an eutrophication phenomena. The harbour is characterized by high nutrient load particularly phosphate, nitrtate and ammonia. Its oxygen content shows a wide variations between surface and near bottom water layer. The amount of dissolved organic matter and suspended particles are also high. As a result of excessive nutrient impact, the harbour sustained high density of phytoplankton attaining an average of 4.1 x 10^6 *unit.* l^{-1} *at surface layer. The community was characterized by the dominance of eutrophication tolerant algal species such as* ***Skeletonema costatum, Rhizosolenia fragilissima and R. delicalula.***

For over all analysis of eutrophication phenomenon in the Eastern Harbour, a stastical regression model describing the dependence of phytoplankton standing crop on the level of the most important environmental factor was stablished and discussed.

INTRODUCTION

Concerning eutrophication in the Egyptian Mediterranean Coast, the eastern area of Alexandria had regular natural eutrophication phenomenon during the present, the area receives a huge amount of brakish water contaminated with sewage, agricultural and industrial wastes through the Northern Delta Lakes and from the sewage sewers of the cities located on the coast. In the recent years, the problem of sewage pollution of Alexandria coastal waters has become a point of national concern, the coastal area in front of the city recives over 183 x 10^6 m^3/year of untreated sewage and wastewaters, (Zaghloul, 1994). About 35 x 10^6 m^3/year of this amount are discharged into the Eastern Harbour of Alexandria through eleven outfalls (Figure 1). This situation creates highly eutrophic phenomenon the effect of which is proportional to the ability of the harbour capacity to assimilate, degrade and disperse these pollutants (Zaghloul, 1995).

The sequence of water quality in the harbour including, the physico-chemical and trophic level changes have been studied by several authors starting by El-Maghraby & Halim (1965), and ended by Zaghloul (1995).

The aim of this work is to evaluate the eutrophication status in the Eastern Harbour after a period of partial closure of sewage outfalls into it.

MATERIAL AND METHODS

Sampling was performed monthly intervals from June 1990 to June 1991 at six selected stations (Figure 1). Samples were collected from three depths at each stations; surface, 2 meter (middle layer) and near bottom layer using Niskin bottle three liters capacity.

Water temperature was measured with an ordinary thermometer graduated to 0.1°C. The pH value was measured ***in situ*** using a pocket pH meter model Orion (research model 201/digital pH meter) previously adjusted with standard buffer solutions at pH 4 and pH 7. Water transparency was carried out by lowering slowly a white enameled Secchi disc 25 cm in diameter. Water salinity was measured using "Bechman Salinometer Model No. R.S. -7C'. Total alkalinity was measured by titration against standard Hcl. Dissolved oxygen, oxidizable organic matter, nutrient salts (NO_3, NO_2, NH_4, PO_4 and SiO_4) were determined according to the methods described by Strickland and Parsons (1972), and the results are expressed in µg at. l^{-1}. Water column stability was estimated according to UNESCO tables (1987). Specific alkalinity was calculated

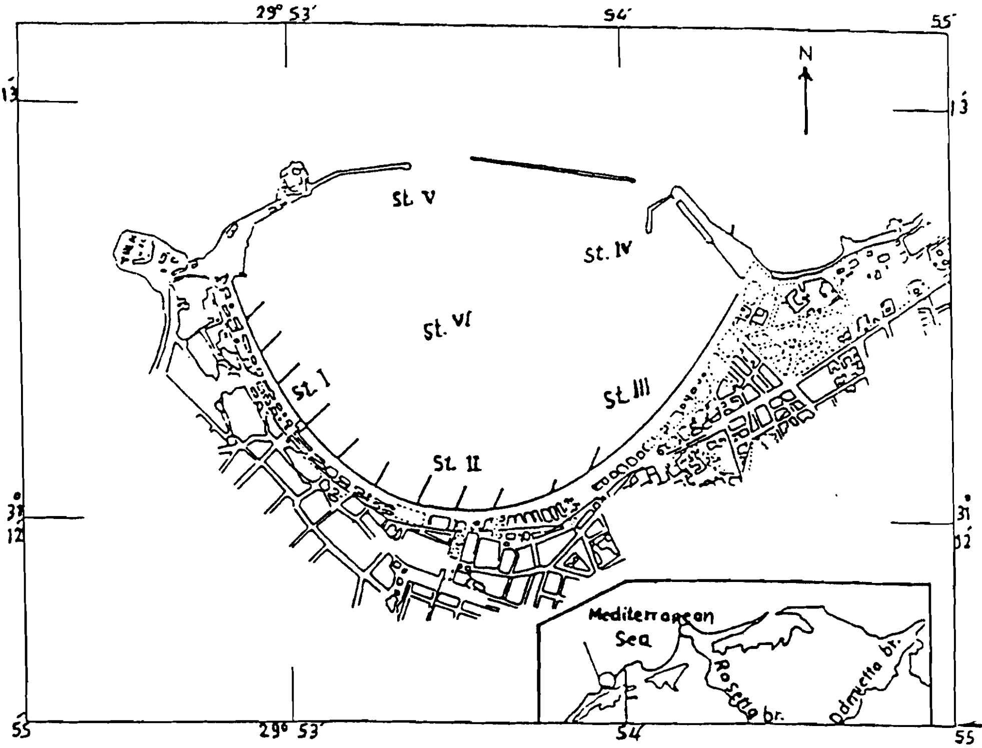


Fig.(1):Study area and sampling stations.

as the ratio of total alkalinity to chlorosity. Oxygen percent saturation was computed by using UNESCO table (1973). (The estimated physico-chemical parameters in this work is a part of two thesis, Hussein (1994) and Siam (1993) and both authers have the authority to use these data according to the need of the subject of their thesis).

Estimation of phytoplankton standing crop was carried out by sedimentation method and the results expressed as unit per liter.

Statistical analysis including correlation coefficient between phytoplankton standing crop and physico-chemical parameters was done at the surface, middle and near bottom layer (n = 78 cases). Stepwise multiple regression equations at a confidence limit 95 % (P = 0.05) are performed using the statistical computer program Number Crunchier Statistical System (NCSS) by Hintze (1993). Correlation coefficents and regression equations are tested at confidence level 95%, P. = 0.05).

RESULTS AND DISCUSSION

I - Physico-chemical parameters :-

1- Temperature :

The water temperature of the Eastern Harbour (E. H.) showed limited regional variations due to its limited area and shallowness. The average surface water temperature was slightly warmer than the other two depths except during September and during winter monthes (January & March). In relation to eutrophication, temperature seems to have pronounced effect on the rate of phytoplankton photosynthesis as well as periodicity and abundance of phytoplankton species. Phytoplankton standing crop was positively correlated with temperature (r = 0.73, 0.43 & 0.69 at surface, middle and near bottom layers respectively), showing the burst growth at high temperature (June and October, 1990), with a pronounced peak in July. The diatom species ***Skeletonema costatum, Rhizosolenia fragilissima*** and ***R. delicatula*** were dominante in July at surface water temperature 27-28^{o}C. Also Cyanophyceae appeared during warm season with a peak of ***Anabaena*** sp. in September at temperature 26.5-27^{o}C. The maximum abundance of Dinophyceae in the E-H was recorded also during summer season particularly in July and August when the temperature of surface water ranged between 26.5-28.0^{o}C.

The indirect effect of temperature on eutrophication can be manifested through its effect on the water column stability and the viscosity of water which affect rate of sinking of suspended matter including planktonic organisms. In addition, variations in ambient temperature affects the activity of bacteria which play an important role in the decomposition of organic matter for nutrient recycling (Sieburth 1968) and liberation as well as the solubility of dissolved gases in sea water including oxygen.

2- Transparency :

Regarding the optical properties of the E.H. and its relation to eutrophication, the colour of water was brownish or brownish yellow particularly during July which is mainly due to the heavy growth of diatoms which was dominated by ***Skeletonema costatum***. The Secchi-disc readings fluctuated between 0.5m (St. II, July) and 4.0 m (St. IV, February) with an average of 2.25m (table 1). The higher transparency appeared at the center of the harbour and extended north-word to St. V (El-Boughaz opening). Phytoplankton standing crop was inversely correlated with Secchi-disc depth indicating the layer of eutrophication in the harbour (r = -0.28). Also a significant inverse correlation was found between Secchi-disc depth and chlorophyll-a (r = -0.329). The low correlation coefficient of Secchi-disc depth with phytoplankton standing crop can be attributed to the interference effect of non living suspended matter on Secchi-disc readings, which is indicated by the significant correlation of phytoplankton standing crop with oxidizable organic matter (r = 0.30), in spite of this interference Secchi-disc is one of the most recommended tool for monitoring eutrophication, (Cruzado, 1988).

3- Salinity and water column stability :

Water salinity in the E.H. is still affected by the sewage effluent. The average water salinity was 37.4, 37.8 and 38.3 ‰ at the surface, middle and near bottom respectively. A pronounced vertical gradient existed specially at marginal station II and El-Silsila (St. IV). The result of the present study showed that the change of water salinity was not correlated with phytoplankton standing crop except in the middle water layer (r = 0.25). On the other hand salinity was significantly correlated with the standing crop of most important recorded species in the E.H., e.g. ***Skeletonena costatum*** (r = -0.49), ***Rhizosolenia fragilissima***, (r = -0.36), ***Alexandrium minutum*** (r = 0.30) and ***Anabaena sp.*** (r = 0.22). Of course there is a positive relation between water column stability and the rate of phytoplankton increase, Vollenweider (1988) noted that the appearance of favourable conditions for eutrophication is strongly influenced by the behaviour of the low frequency current and there is experimental evidence which shows that eutrophication occur in association with water stagnation in coastal water, mainly during summer: The present data showed that during summer (July) at favourable meteorological conditions at temperature 27.7°C, high water column stability and very low wind speed or even wind stagnation, the maximum phytoplankton standing crop was observed in the E.H. It is to be noted that during this study the average surface salinity value and Secchi disc (37.3‰ and 2.25 m.) was higher than that previously recorded by Zaghloul, 1988, (35.8‰ and 1.43 m.) indicating less fresh water coming through sewage outfall due to its partial closure.

4- Hydrogen ion concentration :

The pH values in the E.H. lie on the alkaline side, ranging between 7.01 to 8.53. The values of surface water pH were slightly higher than those of middle and near bottom layers. The relatively high values recorded during warm

Table (1) : Range and mean values of some hydrographic and biological parameter at the surface, middle and near bottom water layers of the Eastern Harbour of Alexandria during June 1990 - June 1991.

Parameter	*surface*		*Middle*		*Near bottom*	
Depth	*Range*	*Mean*	*Range*	*Average*	*Range*	*Average*
Transparancy cm	50-400	225	-	-	-	
Temperature °C	17 - 28	22.8	17 - 27.7	22.7	17 - 27.5	22.6
Salinity ‰	35 - 39	37.36	35.5 - 39	37.81	37 - 39.5	38.27
pH /	7.06 - 8.53	7.91	7.01 - 8.41	7.86	7.03 - 8.29	7.86
Total Alkalinity (mgq.l^{-1})	2.8 - 4	3.05	2.1 - 4	2.98	2.4 - 3.4	2.9
Dissolved oxygen (mlO$_2$.l^{-1})	0.95 - 5.17	2.43	0.78 - 4.96	2.43	0.6 - 4.24	2.06
Biological oxygen demand (ml O$_2$.l^{-1})	0.0 - 5.17	1.89	0.0 - 3.7	1.44	0 - 3.53	1.31
Oxidizable organic matter (mg O$_2$ l^{-1})	0.0 - 11.9	4.55	0.0 - 9.3	3.71	0 - 12.4	3.61
Nitrate (µg at. l^{-1})	0.23 - 13.69	3.75	0.01 - 11.0	3.41	0.04 - 12.35	3.48
Nitrate (µg at. l^{-1})	0.05 - 1.88	0.75	0.05 - 2.05	0.74	0.05 - 1.7	0.73
Ammoni (µg at. l^{-1})	0.13 - 11.69	4.02	0.13 - 16.25	3.58	0.13 - 15.31	4.39
Phosphate (µg at. l^{-1})	0.0 - 2.4	0.59	0.0 - 2.3	0.48	0.0 - 2.3	0.51
Silicate (µg at. l^{-1})	2.3 - 14.9	7.87	0.87 - 13.1	7.32	0.82 - 11.7	5.73
Phytoplankton standing crop (units. l^{-1})	43×10^3 - 23529.6×10^3	4079.4×10^3	31.5×10^3 - 30940×10^3	3504.1×10^3	36×10^3 - 16905×10^3	2326.4×10^3
- Bacillariophyceae (cells. l^{-1})	34.4×10^3 - 13205.5×10^3	2419.0×10^3	18×10^3 - 10600×10^3	1797.2×10^3	27×10^3 - 7186×10^3	1394.3×10^3
- Cyanophyceae (units. l^{-1})	0 - 21081.6×10^3	1197.9×10^3	0 - 23211.6×10^3	1322.2×10^3	0 - 12696×10^3	685.2×10^3
- Dinophyceae (cells. l^{-1})	0 - 4352.4×10^3	407.9×10^3	0 - 2130×10^3	342.3×10^3	0 - 1230×10^3	217.7×10^3
- Euglenophyceae (cells. l^{-1})	0 - 396.0×10^3	40.9×10^3	0 - 375×10^3	24.1×10^3	0 - 180×10^3	20.2×10^3

months were mostly correlated with the rise in temperature which stimulates phytoplankton photosynthetic activity causing more consumption of carbon dioxide and the rise of pH. Possitive correlation coefficient between pH and temperature was observed specially at middle water layer (r = 0.92). The data of the present work showed also a direct correlation between pH value and dissolved oxygen (r = 0.22). In natural habitates the increase of pH value represents a stress factor, giving the chance to a shift to blue-green algal dominance (Lathrop, 1988). In the present study, during August, September and October the blue-green alga (***Anabaena sp.***) showed an increase with simulatanously of pH values (r = 0.31).

5 - Total alkalinity :

The average values of total alkalinity (Table 1) showed a slightly small difference between surface and near bottom water, relevant to the decrease in pH value near the bottom and the subsequent increase in CO_2 which stimulate the dissolve of more carbonate from bottom sediment. The calculated specific alkalinity (Table 1) showed higher values than that of the open sea water (0.126), (Morcos, 1970), indicating that the E.H water in still affected by the lower salinity sewage water.

6 - Dissolved oxygen (D.O.)

In eutrophic aquatic ecosystems, due to photosynthetic activity oxygen supersaturation is often observed. On the other hand, due to sinking of particulate matter and respiratory activity, oxygen is consumed and may even be totally depleted in the lower layers of the water column. These two processes are greatly inhanced in eutrophic ecosystems causing the dislocation of the above mentioned production cycle that makes eutrophication undesirable. The vertical distribution of dissolved oxygen in the E.H. is typical similar to that in eutrophic coastal areas. Dissolved oxygen concentration decreased sharply with depth (table 1). During phytoplankton bloom, surface water was super saturated specially in July at St. VI (5.2 ml $O_2.l^{-1}$ corresponding to 116.8% saturation). while near the bottom water suffered from deficiency of oxygen or hypoxia. which reflect a symptom of eutrophication. Dissolved oxygen in the E.H. showed wide monthly variation, which was related to the effect of temperature on oxygen solibility, which can be indicated through the negative correlation between dissolved oxygen and temperature specially at surface water (r = -0.27).

7 - Biological oxygen demand. BOD.

The average BOD value in the present work was amounted to be 1.9, 1.4 and 1.3 ml O_2. l^{-1} for the three depths respectively (table 1) which were significantly lower than those mentioned for the E.H. by Shriadah, 1982 (3.83 and 1.98 mg O_2· l^{-1}) and by Aboul-Kassim, 1987 (3.86 and 1.76 mg O_2. l^{-1}) for surface and near bottom water respectively. This may be due to the partial closure of sewage outfalls into the harbour. Significant correlations were observed between BOD and each of phytoplankton standing crop (r = 0.2). Water temperature (r = 0.244) and D.O. (r = 0.48).

8 - Oxidizable organic matter. (O.O.M.)

The average values of O.O.M in the harbour water was 4.6, 3.7 and 3.6 mg O_2. l^{-1} (table 1), for the three depths respectively. The higher values of O.O.M. were observed during August (9.5, 8.0 and 7.9 mg O_2. l^{-1} at the same depths), which was accompanied by lower oxygen content during this month. A significant inverse correlation was noticed between O.O.M. and D.O. (r = -0.27 and -0.3 for surface and near bottom water layers respectively). In the E-H, the average total bacteria count during the period of investigation was 6.5 x 10^6 cell. l^{-1} indicating an important role in the recycling of these organic matter, (Siam, 1993). A wide range of organic substances, released by bacteria, algae or produced as products of bio or chemical degradation of the oxidizable organic matter, which plays an important role in the promotion of phytoplankton growth (Stirn 1988). This fact was indicated in the present work through the positive correlation between O.O.M. and phytoplankton standing crop (r = 0.30, 0.35 and 0.32 for the three depths respectively).

9 - Nutrients :

a - Nitrate :

The average values of nitrate were 3.8, 3.4 and 3.5 µg at. l^{-1} for the three depths respectively. The variations of nitrate concentration in harbour water were affected by different factors such as, uptake by phytoplankton. An inverse correlation was detected between phytoplankton standing crop and nitrate concentration (r = -0.32 and -0.32 for surface and near bottom waters). The relatively low nitrate values during warm months, (average of surface water were 1.3 and 1.8µg at.l^{-1} during June and September 1990) may be due to the increase of nitrate uptake by phytoplankton blooming. Strickland *et al.*(1970) attributed the increase in plant nutrients utilization to heating of water column which stimulate plankton growth. In the harbour water this fact is indicated with the inverse correlation between temperature and nitrate concentration (r = -0.28 and -0.32 for surface and near bottom water layers).

b- Nitrite :

The average concentrations of nitrite in the E-H were 0.75, 0.74 and 0.73 μg at.l^{-1} for the three depths respectively (table 1). During the low temperature period (October-January), nitrite concentration increased with depth, which may be attributed to nitrate reduction in the relatively oxygen-poor bottom water.

c- Ammonia :

Ammonia can be used as a good indicator for the degree of pollution. Ammonia also in-principle is the preferred form of nitrogen for algae and aquatic plants. The average concentrations of ammonia in the E-H were 4.0, 3.6 and 4.4 μg at l^{-1} for the three depths respectively (table 1). Ammonia concentration in the harbour is four fold higher than the normal concentration in sea water given by Riley and Chester (1971). Ammonia contents were relatively high in the near bottom water layer specially during July (8.3 μg at l^{-1}) and August (9.9 μg at.l^{-1}), indicating the allochthonous source of ammonia derived from sewage discharge particularly at stations I, III and IV during July and at station I and II during August.

d - Orthophosphate :

The average concentration of phosphate in the euphotic layers of productive temperature coastal waters is around 0.3 μg at. l^{-1} and significantly lower after periods of phytoplankton blooms. In the Mediterranean Sea, values are extremely low, typically below 0.05 μg at. l^{-1} in the euphotic zone (Stirn, 1988). In our study the average concentrations of phosphate were 0.6, 0.5 and 0.5 μg at. l^{-1} at the three depths respectively (table 1), which are extremely higher if compared with these given for the Mediterranean Sea. Generally, eutrophic areas contaminated with sewage water, are fairly steadily receiving total phosphorus supplies, at levels approaching the optimum needed for the growth of mixed phytoplankton populations at an eutrophic level (0.3 to 0.5 μg at. l^{-1}), given by Stirn, 1988. The maximum monthly average of phosphate during this study were recorded during summer particularly in July and September (0.9, 0.8 & 0.5 and 0.7, 0.9 & 1.3 μg at. l^{-1} for the two months of the three depths respectively). These high values occampaning the phytoplankton summer peak are presumably related to the increase in the amount of sewage discharges and the high rate of phosphorus recycling by bacteria at high temperature (Siam, 1993).

e - Nitrogen-phosphorus ratio :

The N/P ratio is a useful indicator for eutrophication. Mediterranean Sea in generally is classified as oligotrophic sea, its N/P ratio as a role significantly higher than the assimilatory optimal N/P (16 : 1), usually above 19 : 1. According to Chiaudani and Vighi (1978) marine algae in the Mediterranean are phosphorus limited when the N/P ratio is higher than 6 and nitrogen limited when the ratio lower than 4.5, while in the range from 6 to 4.5 the two nutrients are near the optimal assimilative proportion. In the E.H., N/P ratio varies from one location to the other depending on the variability of water quality discharged into the harbour at the different times. The average ratio was high during winter particularly in January (40 : 1), while during the other season this ratio was low attaining its minimum value (6 :1) in September when phytoplankton count was the maximum. Only surface water N/P ratio showed a negative correlation with phytoplankton standing crop ($r = -0.39$) while at the other two depth no correlation was detected.

f- Silicate :

Generally, silicate is a good indicator of fresh water despersion and the potential for diatom blooms. The average silicate concentrations in the harbour were 7.87, 7.82 and 5.74 µg at. l^{-1} (table 1) for the three depths respectively. Comparatively with Saronikos Gulf (east Mediterranean) which is considered as eutrophic area (Friligos, 1988) having a maximum silicate content 0.18 µg at. l^{-1}, it seems that E-H is richer in silicate and So silicate content can not be considered as limiting element in the harbour. The minimum average silicate concentration (2.75, 1.77 and 1.79 µg at. l^{-1}) was recorded during June. This may be due to the heavy growth of phytoplankton (mainly diatom) which assimilate silicate and deposit it in their frustules. ($r = -0.27$).

The maximum silicate concentration was recorded during winter and late autumn particularly in November with an average of 16.5, 14.8 and 12.0 µg at. l^{-1} for the three depths respectively.

II - ***Phytoplankton standing crop*** :

Distribution and monthly variations :-

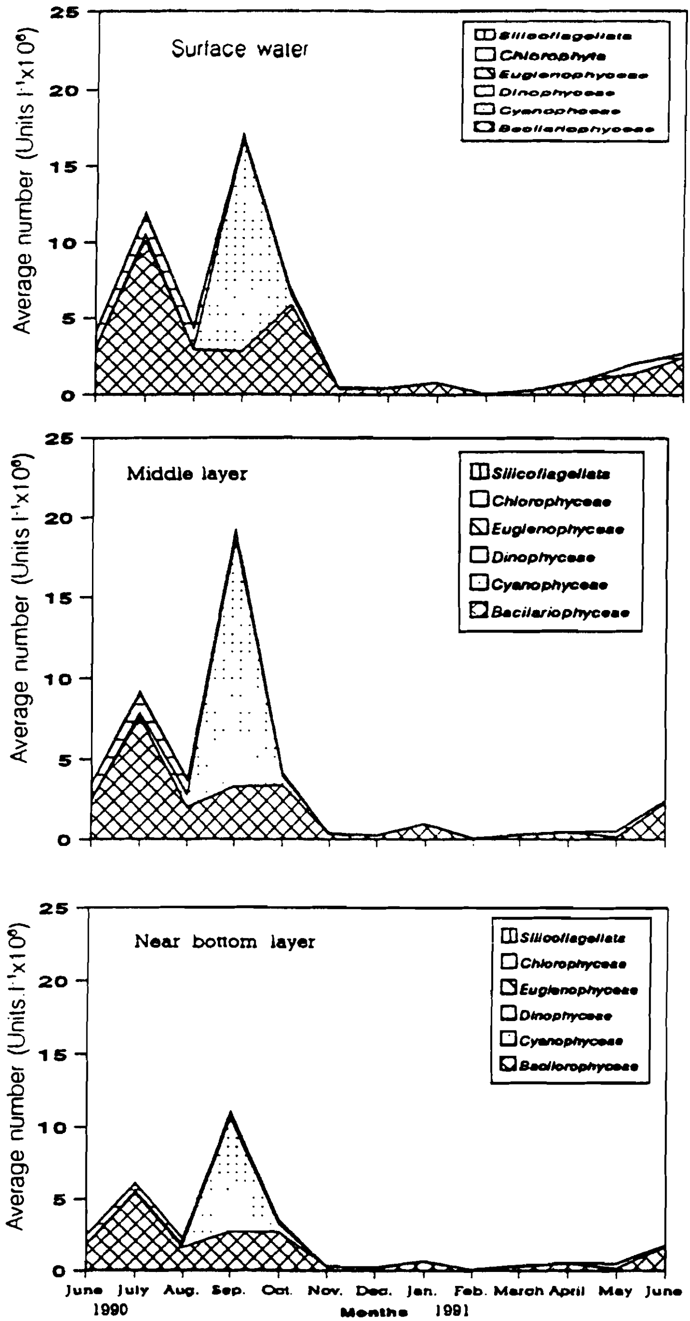
Phytoplankton standing crop is good estimate of the current degree of eutrophication. Generally the standing crop in eutrophic area shows high irregularities. The occurrence of algal blooms may indicate possible impacts of anthropogenic inputs on the ecosystem. Reduction in the number of dominant species and species diversity and the increase in cell count of one or two resistant algae are some of the changes observed in the phytoplankton populations of domestic and industrially polluted environments (Umanhes ware Rao & Mohanchand, 1988). In the present study, the average of phytoplankton standing crop and its main different groups are given in table (1), while monthly average variations of total phytoplankton standing crop and its main components are given in Figure 2.

The average standing crop records during this study (4.1×10^6 and 2.3×10^6 cell. l^{-1} for surface and near bottom water respectively) are similar to the previously recorded during 1986-1987 by Zaghloul & Halim (1992), who gave an average count of 4.3×10^6 and 1.5×10^6 cells l^{-1} for the same layers.

The present study showed bimodal peaks, during summer season particularly in July (12×10^6 units.l^{-1}) and in early autumn, (17×10^6 units. l^{-1}). Beside these two distinguished peaks other small ones were observed during January, April and June 1991. The increasing frequency of phytoplankton blooms is perhaps the best indication of the on set of eutrophication which is inagreement with the concept of Cruzado (1988).

The present study showed that the harbour water was not only productive but also diversified in phytoplankton species. Although numerous species were encountered (131 taxa) , yet few of them formed the main bulk of the community.

The significant input of eutrophying substances into the E.H. inevitably induces ecosystem modifications on the level of community structure and species abundance, also the appearance of species tolerant to eutrophication which is known as species indicator, which is one of the most useful critira of eutrophication. In relation to that Bacillariophyceae were more dominat in the previous records in the E.H. forming about 92% of the total community



ıg. (2): Monthly average variation of Total phytoplankton standing crop and main components (10^6 units.l^{-1}) in the Eastern Harbour.

(Sultan, 1975). The decrease in the ratio of diatoms in the present investigation (59.3 %) to the total phytoplankton counts and the increase of the blue green algae (29.4 %) and dinoflagellates (10.0 %) may be attributed to the stress of eutrophication on the community structure. According to Stirn (1988), the most characteristic impact of eutrophication on community structure is the change of algal flora from diatoms assemblage to green and blue-green, which are usually favoured by increased nutrients and dissolved organic material.

In the E.H. Bacillariophyceae were represented by 76 species allover the year. It was mainly dominated by the genera ***Skeletonema, Rhizosolenia*** and ***Nitzschia*** (Fig. 2) which constituted altogether about 42.85 %, 35.28 % and 42.75 % of the total phytoplankton counts for the three depths respectively. ***Skeletonema costatum*** has two peaks. In July constituting 24.45% and in October, 46.37% of the total phytoplankton. This mainly related to the affinity of this species to low salinity, Therefore the species counts were negatively correlated with salinity ($r = -0.49$) ***Skeletonema costatum*** constituted about (20.68 %, 14.22 % & 20.45 %) of the total average annual phytoplankton. The predominance of ***S. costatum*** in the E.H. was previously mentioned by Sultan, (1975), Halim ***et al.*** (1980). ***Skeletonema costatum*** is known to be dominant in dilute organically polluted water. Mihnea (1985) supposed that the dominance of any species in polluted water for one season or more constituting about 10 % of the total community may be considered as indicator species. The occurrence of ***S. Costatum*** is considered as indicator of eutrophication (Smayda, 1965; Mihnea, 1985 and Umamaheswara. Rao and Mohanchand (1988) indicated that ***S. costatum*** is a pollution tolerant and bloom forming species with an abundance of 52% to 99% of the total cells in Visakhapatmcem harbour. Mingazzini ***et al.*** (1992) considered it as one of the species responsible for blooming in the northern Adriatic coastal waters.

The genus ***Rhizosolenia*** represented 15.94 %, 15,26 % and 16.15 % to the total phytoplankton standing crop. The genus was represented by six species, dominated by ***R. fragilissima*** and ***R. delicatula***, which formed together the main bulk of the genus counts. They appeared mainly during summer and autumn, with a peak in July, Halim ***et al.*** (1980) mentioned that ***R. fragilissima*** and ***R. delicatula*** are considered to be intolerant to pollution and restricted to the recovery zone of the harbour (off-shore area), while in the present study the two species were recorded at all stations but with higher counts at the northern area of the harbour, which indicate that the two species are euryhaline marine forms can tolerate pollution. The two species were also considered as indicator for eutrophication by Zaghloul (1994). ***Rhizosolenia fragilisma*** was positively correlated with temperature (r = 0.46), PO_4, (r = 0.22), NO_2 (r = 0.26), BOD r = 0.37 and with water column stability (r = 0.20), while it was negatively correlated with transparency (r = -0.43) pH, (r = -0.49) water salinity (r = -0.36) silicate (r = -0.26) and with N/P ratio (r = -0.28). ***Rhizosolenia delicatula*** showed more or less the same correlations with the previous environmental factors except with phosphate, silicate and N/P ratio.

Cyanophytes appeared all the year round particularly during summer and autumn showing maximum persistence in autumn with an out standing peak in September mainly due to ***Anabaena spp.*** various author have related the appearance of cyanophytes in natural habitats to the ratio of the total inorganic nitrogen to the total phosphorus (N/P). Low concentrations of inorganic nitrogen and relatively high phosphate content favours the development of cyanophytes (Sammer *et al.* 1986). This coincided with the present seasonal distribution of blue-green algae in the E.H., where the peak occurred in September when the inorganic phosphorus was relatively high (0.96 µg at L^{-1}) and the total inorganic nitrogen was relatively low (3.8 µg at l^{-1}) compared with the other months of the year.

During the period of investigation ***Anabaena spp***. formed numerically about 28.7 %, 36.5 % and 28.7 % of the total phytoplankton counts at the three depths respectively, thus it can be considered as indicator species of eutrophication. The intensive bloom of ***Anabaena*** reached its maximum value in September and the declined due to a decrease in phosphate content. This result is inagreement with the observations of Lin (1972). High concentration of soluble phosphate seems to promote blooms of heterocystous species as well as nitrogen fixation activity as demonstrated by Wurtsbaugh (1988). ***Anabaena*** count was positively correlated with temperature (r = 0.34), salinity (r = 0.22) pH, (r = 0.29), while it was negatively correlated with D.O. (r = -0.27) nitrite (r = -0.25) nitrate (r = -0.25) ammonia r = -0.25 and with N/P ratio (r = -0.35).

The blooming of some members of dinoflagellates may be considered as indication of eutrophication. Pagon (1985) recorded ***Protoperidinium spp***. ***Prorocentrum micans*** and ***Gonyaulax spp.*** as species indicator of eutrophication. ***Alexndirum minutum*** and ***Prorocentrum triestinum*** are also considered as indicator of eutrophication (Zaghloul & Halim, 1990). In the present study, ***Protoperidinium trachoideum, Prorocentrum micans*** and ***Prorocentrum triestinum*** were recorded with high counts at marginal stations.

Dinoflagellates were positively correlated with temperature (r = 0.56) and organic matter (r = 0.40 and negatively correlated with transparency (r = -0.43), pH (r = -0.42), total alkalinity (r = -0.30). D.O (r = -0.263 and with N/P ratio (r = -0.26).

Euglenophyta flourished at the marginal stations and at El- Silsila area than other stations in the E.H. This may be due to the high organic load at these locations. Palmer, (1969) recorded dense blooms of ***Euglena*** in small and organically polluted bodies of water. Munawar (1972) mentioned that ***E. acus*** grows abundantly in sewage ponds and euglenoids are usually used as biological indicator of organically polluted water and the mass occurrence of the species was conditioned by the abundance of organic matter which is also indicated in this study by the possitive correlation of organic matter with the abundance of ***E. acus*** (r = 0.34) Palmer (1969) noted that the genus ***Euglena***, tops a list of sixty most tolerant genera to pollution. In the present study the genus Euglena was represented by ***E. acuse*** and ***E. granulata.*** Euglenophyta was positively correlated with temperature (r = 62), NH4 (r = 0.26) organic matter (r = 0.41) and BOD (r = 0.43) while it was negatively correlated with transparency (r = -0.49) pH, (r = -0.40) and with silicate (r = -0.36).

For analysis of the overall eutrophication phenomena, a series of simple statistical regression models were calculated according to Hintze (1993) describing the dependence of phytoplankton standing crop on the measured abiotic factor controlling eutrophication in the Eastern Harbour.

These models are as follows :

Dependance of phytoplankton standing crop on the measured abiotic factors at the different depths.

Surface water :

Phytoplankton standing crop (units.l^{-1} x 10^6) = -0.213E + 08 + 1206848 temperature - 58654.61 total alkalinity - 149117.3 NO_3 - 216909.7 organic matter - 22347.66 N/P. (M.R. = 0.55).

Middle water layer :

Phytoplankton standing crop (units.l^{-1} x 10^6) = -119988.7 + 725268.5 temperature + 2397513 pH - 854184.4 S ‰ + 5100889 PO_4 - 865478.1 NO_3 + 1779035 NO_2 (M.R. = 0.58).

Near bottom water layer :

Phytoplankton standing crop (units. l^{-1} x 10^6) = 0.444E + 08 + 677262.1 temperature + 3032507 pH - 2083445 total alkalinity + 370003.7 S ‰ + 1215234 PO_4 - 275549.9 NO_3. (M.R. = 0.67).

These models are adequate at a significant level 95% (P = 0.05). Comparison of observed and calculated values for the three depths (Figure 3), showed a small average error except during the outstanding peak in September, this may be due to the interference of other factors not incoporated in the model equation. The degree of importance of each parameter included in the model equation to phytoplankton standing crop (Egin values) for the three depths are shown in Figure (4). Temperature was the most effective environmental factor controling phytoplankton standing crop at the three levels. Total alkalinity had an inverse effect at both surface and near bottom layers, indicating the input of wastewater which stimulate the growth of marine diatom. The positive effect of phosphate concentration was clearly appeared at both middle and near the bottom layers, while this effect was missed at the surface layer which can be attributed to the relatively high phosphate content at this layer. At these layers, the negative effect of the nitrogen phosphorus ratios was pronounced which again indicat the positive effect of the phosphorus on the phytoplankton standing crop.

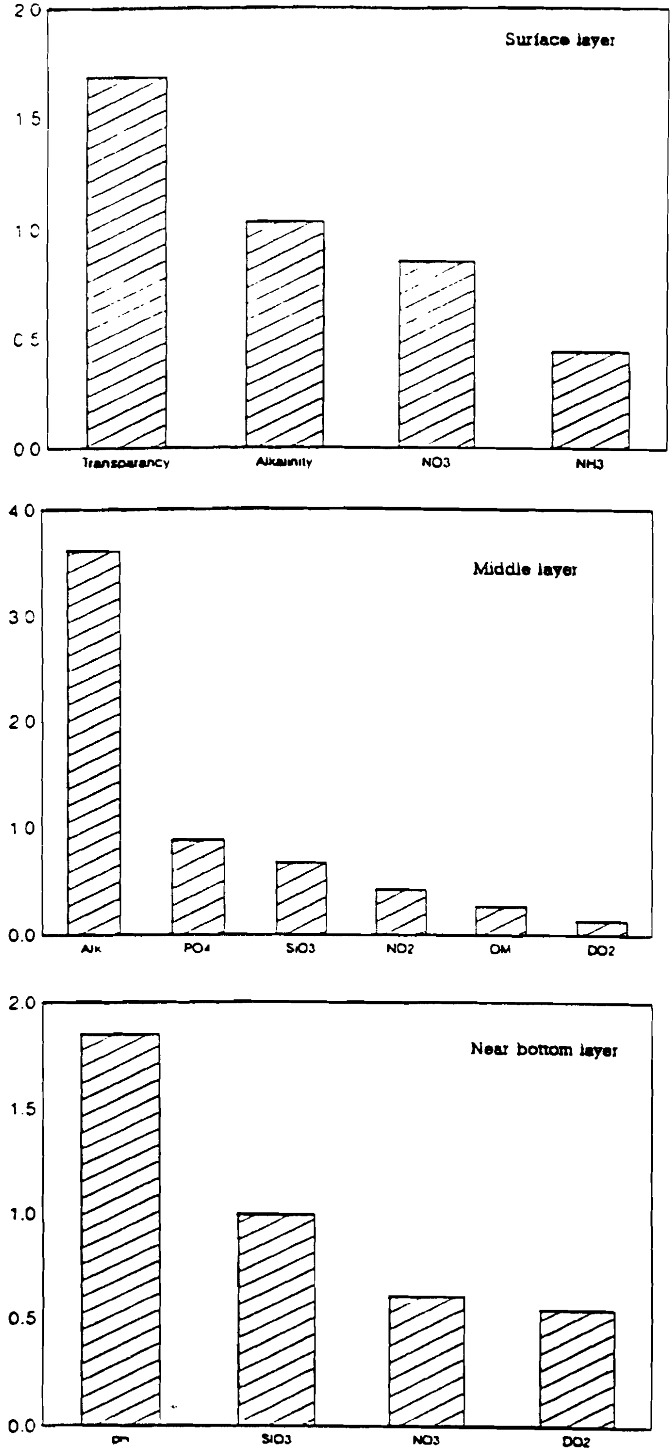


Fig. (3): Eginvalues of total phytoplankton standing crop at different depths.

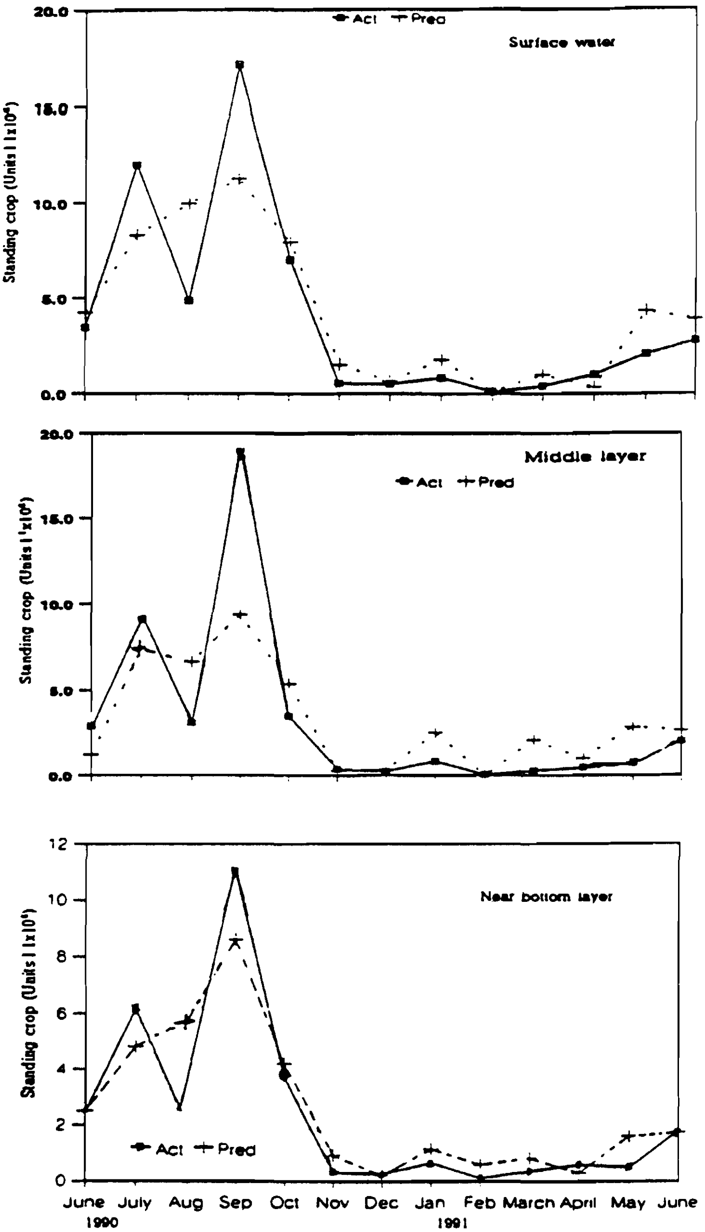


Fig. (4): Comparison of the observed phytoplankton standing crop with the calculated values as determined by a multiple regression analysis of the relationship between phytoplankton and environmental factors.

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