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Eutrophication stress on phytoplankton community in the Western Harbour of Alexandria, Egypt

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Abstract

The dynamics of phytoplankton community was studied monthly for a complete cycle in an eutrophic bay (the Western Harbour of Alexandria) and the results were compared with previous records to identify the modifications occurring in the community within the past decade. The study indicates serious qualitative and quantitative changes in the phytoplankton community. The species number increased from 68 to 107, with approximately complete replacement of the dominant species, the leader of which were the dinoflagellates *Alexandrium minutum* Halim and *Prorocentrum triestinum* J.Schiller and the diatom *Skeletonema cf. costatum* (Grev.) Cleve. The former species was known as predominant for about the past four decades in the Eastern Harbour of Alexandria, but it disappeared from that harbour in the recent records. During the present study, dinoflagellates became the more effective contributor to the standing crop (57%) than diatoms (41%), coincided with shifting of the blooming times towards the warmer period. An intimate association and significant correlation were reported between the dinoflagellate *A. minutum* and each of *Prorocentrum micans* Ehrenb and *P. triestinum* and the euglenophycean *Euglena acus* Ehrenb. Salinity and temperature were the controlling factors of dinoflagellate growth, while SiO_4 and PO_4 were promoting for the whole phytoplankton.

Keywords: Eutrophication, Phytoplankton, Diversity, Phytoplankton ecology, *Alexandrium minutum, Prorocentrum triestinum, Skeletonema cf. costatum*.

INTRODUCTION

The Western Harbour (WH) of Alexandria lies to the west of Alexandria City on the southeastern Mediterranean Coast. It is a shallow, semi-enclosed basin with an area of 7.4 km^2 and depth range of 5-16m. It receives directly freshwater as seasonal pulses from Noubaria Canal at its southern part and indirectly waste waters of varying quantity and quality through Mex Bay from Umoum Drain at its western side. These waters bring great amounts of nutrients as well as harmful materials, which altogether impact the ecological conditions in the harbour.

Phytoplankton plays a direct or indirect role in nutrient recycling and increase in organic matter by cell death, since the nutrient recycling includes the transference of any nutrient in different forms throughout the biogeochemical cycle in the aquatic habitat.

In the WH, phytoplankton study has attracted but little attention although several studies have been done on the water quality [1] and on phytoplankton community in different parts of Mex Bay, where the harbour lies ([2], [3], [4], [5], [6], [7]). The available study on phytoplankton in the WH was done in 1989 by Zaghloul [8], based on bimonthly samples.

The present study deals with an annual cycle of phytoplankton community, refocusing the species composition, standing crop, dominance pattern and diversity relative to the surrounding environmental conditions. It also highlights the long-term changes in the characteristics of the community structure and numerical density throughout the past decade.

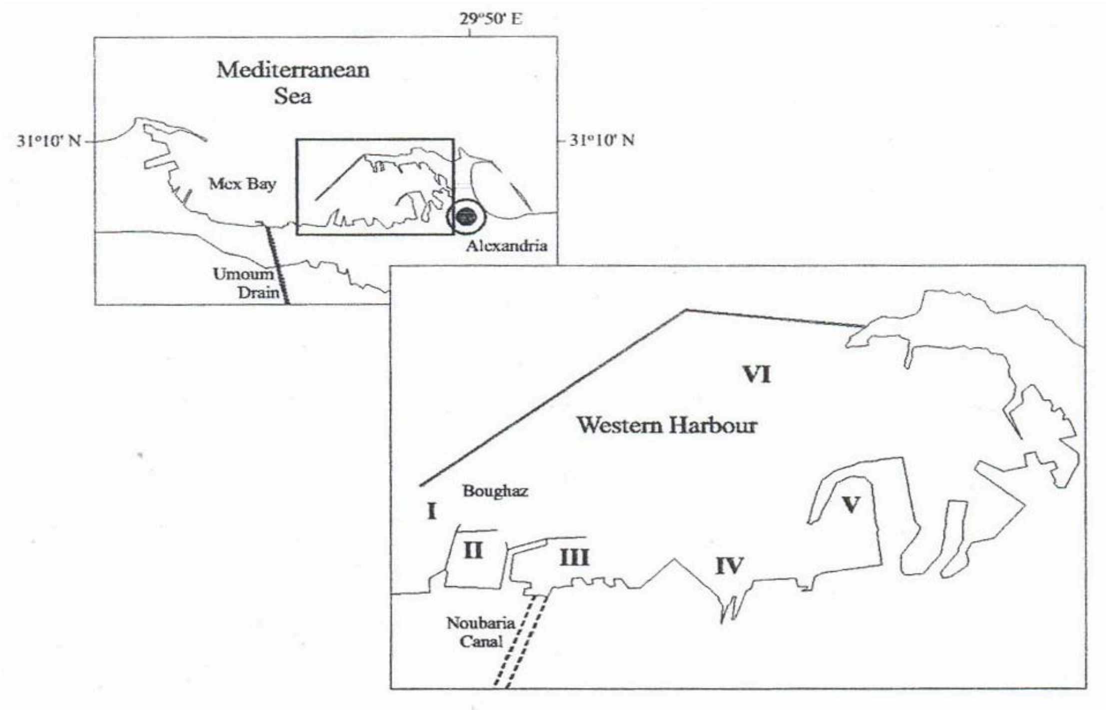

Figure 1: The sampling stations (I-VI) in the Western Harbour of Alexandria.

Fig. 1. The sampling stations (I–VI) in the Western Harbour of Alexandria

MATERIALS AND METHODS

The present study depends mainly on quantitative samples collected monthly from April 1999 to March 2000 at six stations, representing different environmental conditions inside the harbour (Fig 1). The sampled stations were distributed in the harbour as follows: station I lies at the connection between the harbour and the open sea (Boughaz), station II near a quay for petroleum export , station III in front of the entrance of the Noubaria freshwater canal, station IV beside a quay for loading and unloading chemical fertilizers, station V near a quay occupied by heaps of coal and station VI in the central area of the harbour. One liter of sea water was collected from the subsurface layer at each station, immediately preserved in 4% neutralized formalin. After 3-4 days for settling, the supernatant water has been decanted .The samples were analysed according to Utermohl method [9] and for identification several literatures were used to identify the algae, mostly to species level [10], [11], [12], [13], [14], [15], [16], [17] [18], [19], [20] and [21].

The phytoplankton abundance was calculated from the average counts of three aliquots of 1 ml in a counting cell and was expressed in units/l according to Nwankwo [22]. The counting include all phytoplankton taxa, except the very minute-size cells, which were not easily seen under the light of microscope, like picoplankton cells. Diversity index (H') was calculated according to Shannon-Wiener equation [23]. Correlation coefficients between phytoplankton groups and environmental conditions were computed.

RESULTS

The hydrography and nutritional level of the WH were studied [1] parallel to the present study of the phytoplankton community and the results are summarized in Table 1, which demonstrated wide variations of all ecological parameters.

Relative to ecological variations, the phytoplankton community in the WH experienced pronounced changes in both species composition and numerical density during the present study. As shown in Table 2, diatoms appeared to be the most diversified group, comprising 57 species and dinoflagellates ranked the second diversified group (21 species). Also, several freshwater assemblages were found in the study area, belonging to Chlorophyceae (14 species), Cyanophyceae (10 species), Euglenophyceae (4 species) and Dictyochophyceae (1 species). Of 107 species (the total identified number in the WH), 34 species were recorded as perennial, existing in the harbour during all seasons, regardless of their abundance, 20 species occurred during three seasons and the rest numbers of species were found during one and/or two seasons (Table 2).

Table 1: Minimum, maximum and average values of different ecological Parameters in the surface water of the Western Harbour.

Present study (1999) *Zaghloul & Nessim (1991)*

Parameter	Min.	Max.	An.av.	Min	Max.	An. av.
Temp. (ºC)	15	29	22.6	16.5	30.5	
Salinity (‰)	26.3	40.7	35.1	29	39.3	36.26
Secchi Depth (cm)	30	350	135	60	350	180
Dissolved oxygen (mg/l)	1.7	9.6	4	0	12.2	6.4
PH	7.7	8.7	8.11	7.6	8.9	NR
NO_3 (μg at/l)	.21	20.46	5.73	0	13.4	4.8
NH_4 (μg at /l)	1.97	57.46	14.5	0	50.8	NR
PO_4 (μg at/l)	0.12	5.7	1.17	0.05	5.7	1.03
N/P	0.15	170.5	11.8	7.2	60	16
SiO_4 (ug at/l)	0.5	76.3	9.03	0	59	NR
Chl-*a*. (mg/m^3)	1.9	219.4	33.82	0.2	11	4.2
Phaeop (mg/m^3)	0.07	105.9	10.39	NR	NR	NR
Phytopl count (x10^3 unit/l	15	17898	980	300	20000	4700
Pytoplankton spp.			107			68
Zoopl.(indiv./m^3)	5780	93610	26730	NR	NR	NR

Regarding the phytoplankton composition, the outer part of the harbour (stations: I, II and III) under stress of the discharged wastewaters from Umoum Drain and Noubaria Canal was more diversified (66 - 79 species), while the inner part (stations IV, V and VI) relatively far from the discharged wastes was less diversified (58-62 species), as shown in Table 3. On the time scale, diatoms demonstrated the lowest number of species (25 species) in summer and the highest (44 species) in winter. On the other hand, the dinoflagellates, as well as other groups provided small seasonal variations in their diversity.

The freshwater forms were mostly restricted to low salinity near the outlets, with the dominance of the cyanophycean genera *Oscillatoria, Spirulina,* chlorophycean genera *Scenedesmus, Ankistrodesmus* and the euglenophycean genus *Euglena.*

Table 2: Temporal distribution of species number of different phytoplankton groups.

Duration	Bacillarioph.	Pyrroph.	Other groups	Total
4 seasons	19	11	3	33
3 seasons	11	3	7	21
Spr. & Win.	7	0	0	7
Spr. & Sum.	0	1	1	2
Spr. & Aut.	2	2	1	5
Sum. & Aut.	0	0	3	3
Sum. & Win.	0	0	3	3
Aut. & Win.	2	0	0	2
Spring	6	1	3	10
Summer	0	1	2	3
Autumn	3	2	1	6
Winter	7	0	5	12

Table 3: Spatial distribution of species number of different phytoplankton groups.

Phytoplankton group	St. I	St. II	St. III	St. IV	St. V	St. VI	Total
Bacillariophyceae	41	37	39	35	31	38	57
Pyrrophyceae	18	14	18	15	19	17	21
Chlorophyceae	8	6	3	1	5	3	14
Cyanophyceae	7	6	5	5	1	2	10
Euglenophyceae	4	3	2	2	2	2	4
Dictyochophyceae	1	0	0	0	0	0	1
Total	79	66	67	58	58	62	107

The phytoplankton diversity index over the whole harbour fluctuated between 0.1 and 2.63, attaining the lowest value at station II in June and the highest at station III in November. The monthly distribution of the index showed different patterns among stations, but May, July and December sustained comparatively low values at most stations, while November, January and February provided relatively higher diversity (Fig. 2). On the spatial scale, the diversity index showed relatively slight differences between the stations (1.39 – 1.73), with the highest value at the marginal station I and the lowest value at station V.

The WH was characterized by pronouncedly high phytoplankton counts all the year round, demonstrating wide variations among stations ($439.4x10^3$ - $1960.4x10^3$ units/l). Station V harbored the highest count and station I had the lowest count. Throughout the WH, different abundance cycles were reported at the different stations, whereas the highest peak appeared at station I in March, at station II in June, at station III in May, but at stations IV-VI it was recorded in July (Fig.3). *Skeletonema cf. costatum* was the absolute dominant component of the highest peaks at stations I, II and III, forming 73-98.7% of the total count, while *A. minutum* and *P. triestinum* shared the dominance by 50.4-59.5% and 38.2-44.4% of the total count of July peaks at stations IV and V, respectively and *A. minutum* extremely dominated the peak of July (92.5%) at station VI. Generally speaking, the abundance of the diatoms and dinoflagellates as the major groups, provided substantial succession in space and time. Diatoms illustrated absolute dominance throughout the harbour in winter like the dominance of *Pseudonitzschia seriata* Cleve (72-92%) in December, or they were predominant at some stations and co-dominant at others during spring and autumn. With a few exceptions, the summer months could be assigned as the months of dinoflagellates.

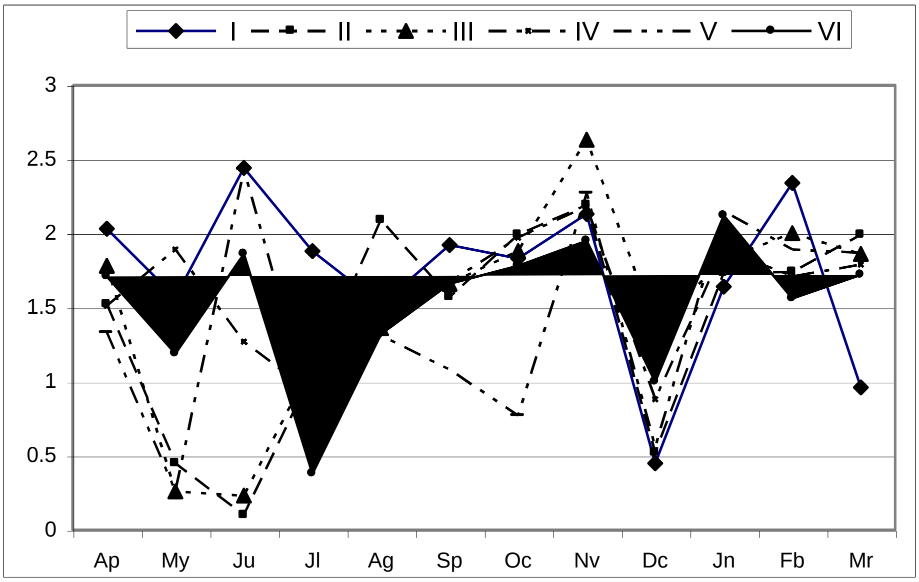

Figure 2: Monthly variations of diversity index at the sampled stations.
Fig. 2- Monthly variations of diversity index at the sampled stations.

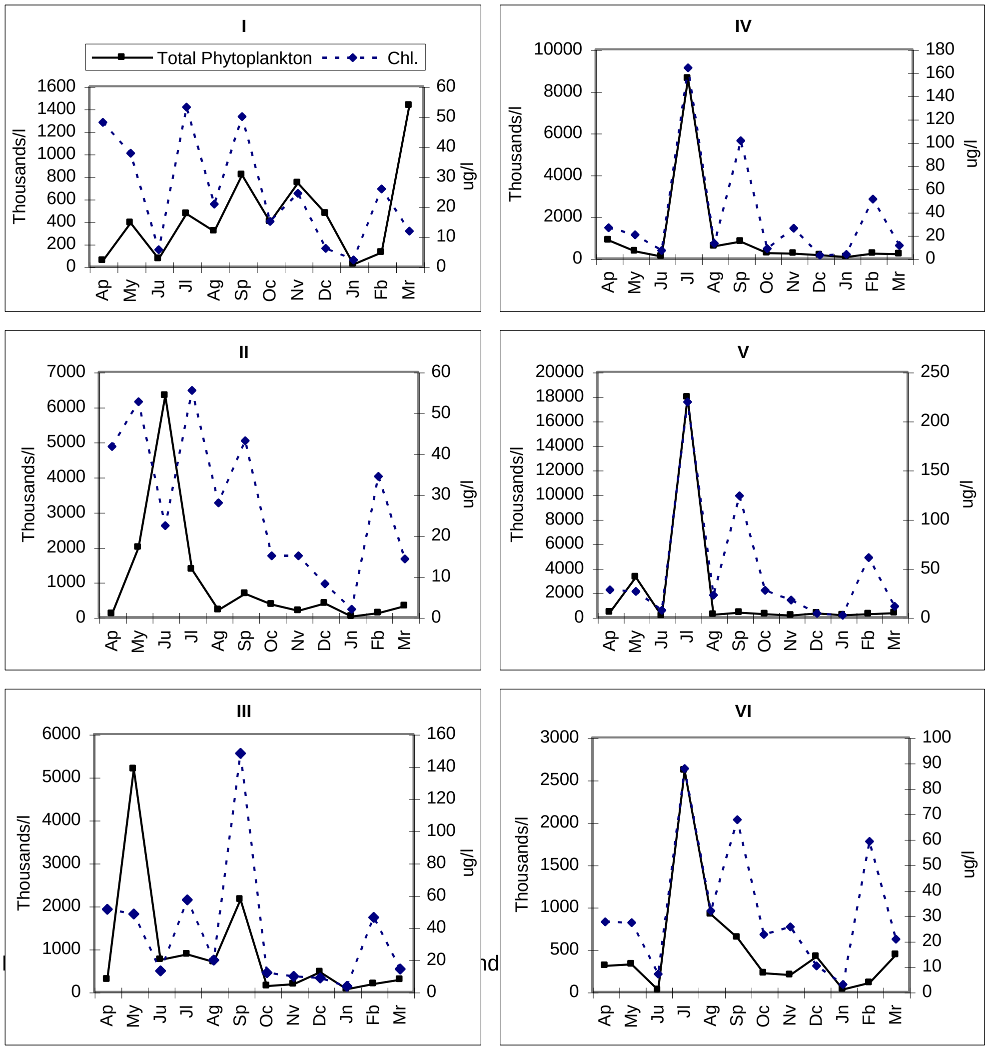

Figure 3: Monthly variations of phytoplankton count and chlorophyll a at different stations.

Fig. 3- Monthly variations of phytoplankton count and chlorophyll *a* at different stations.

Chlorophyll-*a* demonstrated extremely high concentrations in the harbour, having monthly averages between 25 and 45.65 μg/l. Similar to the cell count, chlorophyll *a* did not follow a particular seasonal trend at any stations (Fig 3) and it showed great differences throughout the study area (2.58-106.1 μg/l). In many occasions, the monthly fluctuation of chlorophyll-*a* coincided with that of the standing crop, while in several others there was an inverse relationship.

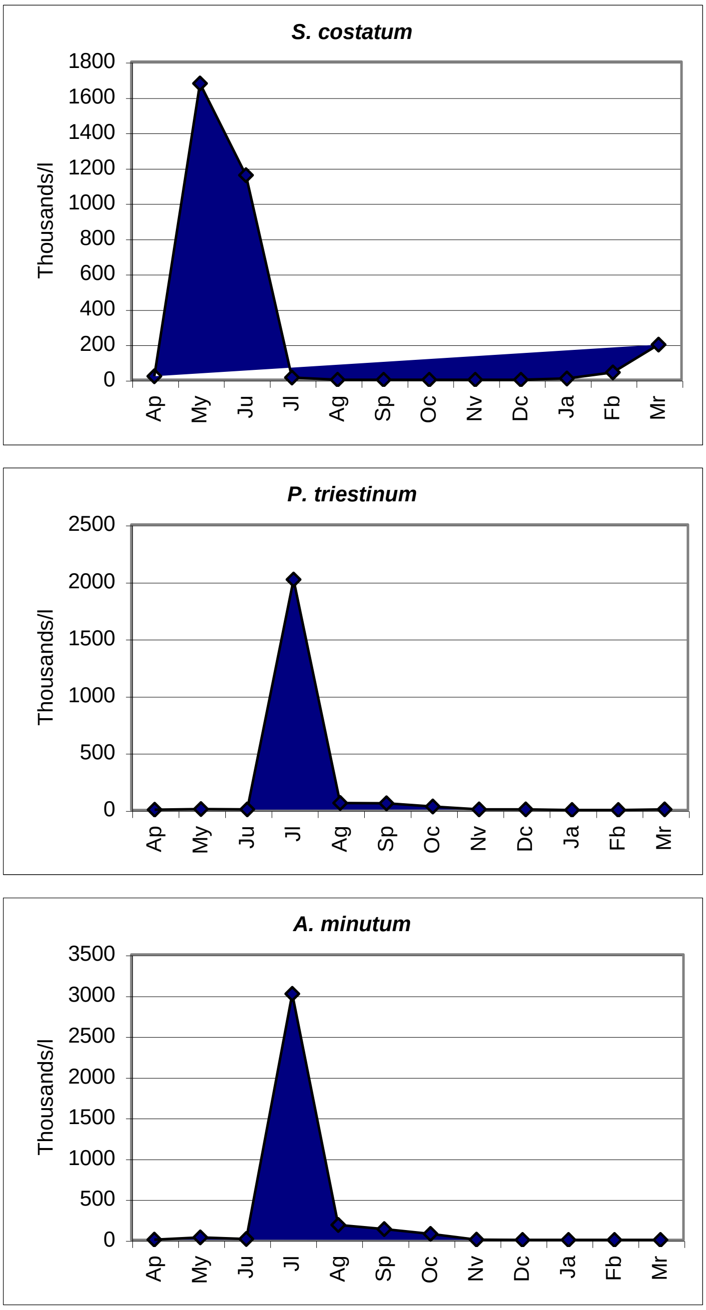

Figure 4: Monthly abundance of the predominant species.
Fig.4- Monthly abundance of the predominant species.

The phytoplankton bloom in the WH was caused mainly by three species, which had extremely outstanding growth with more or less different seasonal cycles (Fig. 4). The dinoflagellate *A. minutum* flourished from May to October, showing a clear peak in July and reached a maximum of $10.6x10^6$ units/l at station V. The diatom *Skeletonema cf. costatum* extended during the whole winter and spring, attaining a peak in May-June and absolute dominance ($4.9x10^6$ units /l)at station III in May and ($6.3x10^6$ units/l) at station II in June. The dinoflagellate *P. triestinum* provided intensive growth during the warm period from July to October having a peak in July with the highest count of $6.8x10^6$ units/l at station V. Thirty three other species participated actively in the phytoplankton bloom for a certain time or intermittently either at limited parts or in the whole harbour at different temperature ranges (Table 4).

Table 4: Thermal affinities of the dominant species in the Western harbour.

Species	**Tolerant range**	**Optimum range**
Cyclotella meneghiniana Kutz	15 - 29	19 – 29
Chaetoceros affinis Lauder	15 - 28	15 - 28
Euglena acus Ehrenb.	18 - 29	21 - 29
Prorocentrum triestinum J.Schiller	15 - 29	27 - 29
Alexandrium minutum Halim	19 - 29	27 - 29
Scripsiella trochoidea (Stein) Loeb.	15 - 29	27 - 28
Gyrodinium falcatum Kofoid & Swezy	19 - 29	27 – 29
Nitzschia sigma (Kutz)G.Sm.	15- 28	27 - 28
Cylindrotheca closterium W.Sm.	19 - 28	27 - 28
Nitzschia longissima (Breb.)Ralfs	27 - 28	28
Cyclotella striata (Kutz) Grun	21 - 29	29
Ankistrodesmus setigerus (Schrod.) G.S.West.	27 - 28	27 – 28
Ankistrodesmus falcatus (Corda) Ralfs	27	27
Skeletonema cf.costatum (Grev.) Cleve	15 - 28	25 - 28
Prorocentrum micans Ehrenb.	15 - 29	18 – 21
Asterionella japonica Cleve & O.F.Mull.	15 – 25	15 - 21
Chaetoceros curvisetus Cleve	15 - 21	21
Pseudonitzschia delicatissima (Cleve) Heiden	18	18
Leptocylindrus minimus Gran	19 - 28	19
Leptocylindrus danicus Cleve	18 – 28	19
Rhizosolenia setigera Brightw	15 - 28	19
Exuviaella marina Cienk	18 - 29	19
Nitzschia palea (Kutz) W.Sm.	18 – 28	18
Pseudonitzschia seriata Cleve	18 - 28	19
Nitzschia microcephala Grun	15 - 28	15

Species	**Tolerant range**	**Optimum range**
Rhizosolenia delicatula Cleve	15 - 28	15
Thalassiosira decipiens (Grun.) C.Jorg.	15 – 21	15
Chaetoceros didymus Ehrenb.	15 – 28	15
Lauderia borealis Grun	15 – 28	15
Thalassiosira rotula Meunier	15	15
Melosira jurgensii Ag.	15	15
Bellerochea malleus (Brightw.) H.V.H	15	15
Lithodesmium undulatum Ehrenb.	15	15
Guinardia flaccida (Castr.) H.Peragallo	15	15
Navicula hyalina Donk.	15	15
Hyalodiscus stelliger Bail.	15	15

DISCUSSION

The WH is a dynamic system with distinct structural properties, subjected to continuous environmental changes due to intensive maritime activities and great amounts of daily discharged wastes. The dispersal patterns of these wastes are controlled by ships traffic and the current regime between the harbour and the open sea. Farag [24] measured two currents between the harbour and the open sea, one flows from the harbour out to the open sea in the upper 5m layer and the other enters the harbour at a depth of 10m and both currents show different seasonal directions. The discharged waste waters bring great amounts of nutrients as well as harmful materials, which all impact the ecological conditions of the harbour. Therefore, the waste waters and current regime effectively govern the temporal and spatial variations of the environmental characteristics of the WH, which in turn influence the structure and abundance of phytoplankton.

The high allochthonous injection of nutrients causes abnormal dense blooming of phytoplankton and consequently increases eutrophication. Dorgham *et al* [1] stated that eutrophication has become a persistent problem in the harbour, with increasing level during the past two decades. The high level of eutrophication reported in the WH during the present study may be detected from the low oxygen concentration (down to 1.7 mg/l), low water transparency (Secchi disc: down to 30 cm), wide ranges of nutrients (nitrate: up to 20.46 µg at/l, ammonium: up to 57.46 µg at/l, phosphate: up to 5.7 µg at/l, silicate: up to 76.3 µg at/l) and abnormally high concentrations of chlorophyll-a (up to 219.4 µg /l).

The distribution of surface salinity throughout the harbour indicated the occurrence of two water masses, the outer part (Stations I-III) with surface salinity <35 ‰ and the inner part (Stations IV-VI) with salinity > 35 (‰) [1]. In accordance with this division, the present study illustrates that phytoplankton community in the outer part was more diversified (67-79 species) than the inner part (58-62 species). The larger number of diatoms and freshwater species are responsible for the higher phytoplankton diversity in the outer part. However, the spatial differences in the community structure seem to be relatively small, whereas the number of species at the different stations varied between 58 species at station IV and 67 species at station III. However, station I appeared to be the most diversified part in the harbour (79 species). In addition, the structure of phytoplankton community showed little variations among the different seasons, except the drop in the number of diatom species in summer. Such pattern may be related to well mixing of the water masses throughout the harbour due to ship traffic and water circulation system. Furthermore, the occurrence of 51% of the phytoplankton assemblages during 3-4 seasons indicate a type of stability in a large part of the community in WH, which means that these assemblages have capability to tolerate the variations of the environmental conditions in the harbour regardless of their numerical densities. On the other hand, diatoms demonstrated more effective contribution to the total phytoplankton count in the outer part, while dinoflagellates shared by greater count in the inner part (Fig. 5).

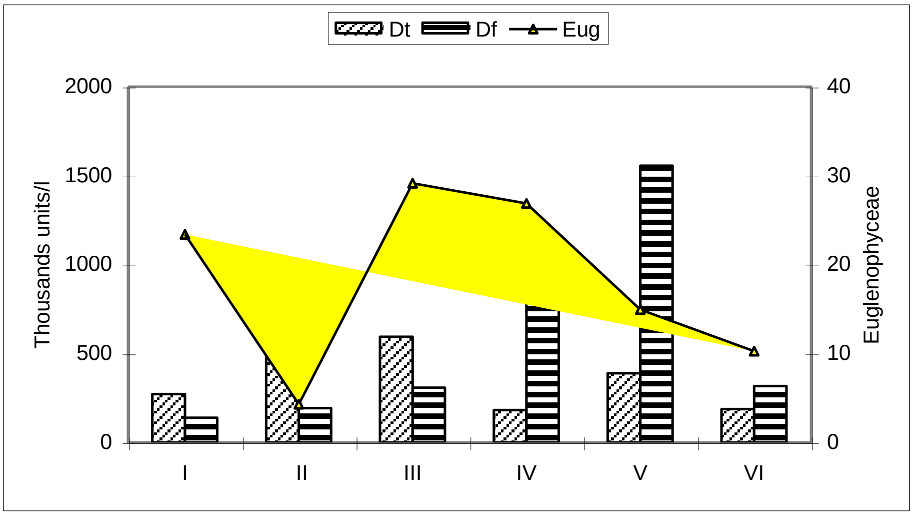

Figure 5: The annual average abundance of phytoplankton groups at different stations.

The high contribution of diatoms in the outer area was accompanied by lower salinity (34.3-34.9 ‰), higher SiO_4 (9.09 – 10.05 µg at /l), PO_4 (1.02 – 1.42 µg at /l), NO_3 (5.01 – 6.67 µg at /l), NH_4 (11.7 – 18.4 µg at /l) and higher zooplankton count ($25.8x10^3$ – $30x10^3$ organisms /m^3). In the inner part, the dominance of dinoflagellates appeared at relatively higher salinity (35.5 – 35.6%^{o}), lower SiO_4 (7.88 – 8.83µg at /l), PO_4 (0.87 – 1.28 µg at /l), NO_3 (5.62 – 5.66 µg at /l), NH_4 (9.16 – 17.03 µg at /l) and lower zooplankton count ($19.6x10^3$ – $30.8x10^3$ organisms /m^3). Therefore, salinity appeared to be the most pronounced factor moderating all other factors, which control phytoplankton composition and growth as indicated from its significant correlation with species number (r = 0.4199, n = 72, p < 0.001) and phytoplankton count (r = -0.2674, n = 72, p ≤ 0.0.05).

The diatom *S. cf. costatum* was the leader species in the outer part, flourished at a temperature range of 15-28 °C, reaching the maximal density at salinity range of 31.8-32.3 ‰, N/P: 0.67-0.36 and Si/P: 2.36-11.8. This agrees with Huang *et al*. [25], who stated that *S. cf. costatum* is euryhaline and eurythermal and can grow quickly under eutrophic conditions. The species is known as indicator of eutrophication every where [2], [4], [26], [27], [28], [29], [30]. It is very common in the Egyptian coastal Mediterranean waters, particularly in low salinity areas [31], [32], [33], [34], [30], [4], [5], [35], [36].

Table 5: Dominant phytoplankton species in the Western Harbour during the past decade.

Present study (1999-2000)	Zaghloul, 1994 (1989)
Alexandrium minutum	*Cyclotella meneghiniana*
Skeletonema cf. costatum	*Pseudonitzschia delicatissima*
Prorocentrum triestinun	*Prorocentrum cordatum*
Pseudonitzschia seriata	*Prorocentrum micans*
Scripsiella trochoidea	*Euglena granulata*
Asterionella japonica	
Prorocentrum micans	

In the inner part of the harbour, the dinoflagellates *A. minutum* and *P. triestenum* were the predominant species, and both attained their maximum at stations IV and V in July, where salinity showed the lowest value throughout the harbour (30.6-31 %°) with high temperature (28°C), high phosphate (1.74 –5.7 µg at/l) and nitrate (1.99-4.05 µg at/l). This indicates that the two species prefer high temperature and they are euryhaline. Similar observations were given by Ismael [37] in the Eastern Harbour of Alexandria for *A. minutum* and total dinoflagellates. The blooms of some dinoflagellate species in the study area indicate its eutrophication, since these species like *Protoperidinium spp., P. micans, Gonyaulax spp*. and *P. triestinum* were considered as indicator of eutrophication in different areas [38] [39]. The appearance of *A. minutum* as predominant during the present study reflects more deterioration of the water quality in the WH, which also could be indicated from the low dissolved oxygen (annual average of 4 mg/l). This species was described as a new genus in the

Eastern Harbour by Halim [40] and became the most predominant species, which caused water colouration in the harbour and neritic waters of Alexandria for many successive and intermittent years, reaching a maximum of $24x10^6$ cells/l [41]. It is widely known and its blooms lead to shellfish and fish mortality in many localities [42], [43], [44]. During the past few years, this species has completely disappeared from the Eastern Harbour due to the cessation of waste water discharges into the harbour during the past few years [45].

Although several environmental factors, like light intensity, nutrient concentrations, pH, etc., control the phytoplankton abundance during different seasons, temperature appeared to be the most effective factor during the present study. As shown in Table 3, several species demonstrated frequent flourishing at different temperatures (15 – 29^{o}C) throughout the year, while others dominated either in the cold period (15 - 19^{o}C) or in warm period (27 - 28^{o}C). Such patterns of dominance suppose that some of eurythermal species flourish at different temperatures throughout the year, such as *Cyclotella meneghiniana, Chaetoceros affinis* and *Euglena acus*, while others flourish only near the high limit of their tolerance range like *A. minutum, P. triestenum, Scripsiella trochoidea, Gyrodinium falcatum, Nitzschia sigma and Cylindrotheca closterium.* It is to be noted that the phytoplankton community was characterized by the co-occurrence of multi-dominant species most of the year.

The diversity index may be used as suitable criteria for water quality [46]. The values of diversity index are related to evenness, while they are not affected by the (richness) species number [47], [36]. In contrast, the present study provides a clear relation between diversity index, degree of dominance, species richness and total standing crop. For example, the lowest diversity (0.1) was recorded at station II in June with absolute predominance of *S. cf. costatum* and low number of species (13 species), while the highest diversity index (2.63) appeared at station III in November, due to multi-dominance and high number of species (32 species). Positive significant correlation ($r = 0.3414$, $n=72$, $p\leq 0.05$) was found between diversity index and species number (richness) and negative significant correlation was reported between diversity index and standing crop ($r = -0.42308$, $n = 72$, $p < 0.001$). Gharib & Dorgham [48] reported similar observations in the west Noubaria Canal, west of Alexandria. The values of diversity index were affected also by the environmental conditions; the highest values appeared at the entrance of the harbour (Station I) and at the outfall of Noubaria Canal (Station III), which both were pronouncedly affected by land-based effluents. Rao & Mohanchand [49] stated that reduction in the number of dominant species and species diversity and the increase in cell count of one or two resistant algae were some of the changes observed in the phytoplankton populations in domestic and industrially polluted environments.

The values of diversity index in the WH (0.1 – 2.63 bits) are close to those (1 –2.5 bits) found by Margalef [50, 51] in the actively growing coastal populations and eutrophic lakes, supporting that with a few sporadic exceptions the harbour suffered from eutrophication all the year round. Approximately similar values (0.8 – 2.4 bits) were reported by Ismael & Dorgham[36] in Dekhaila Harbour, another eutrophic area inside the Mex Bay. It should be mentioned that the values of phytoplankton diversity index obtained during the present study are underestimated, since micro-flagellates and other minute phytoplankton cells were not considered in the count.

The previous study on phytoplankton and environmental conditions of the WH [8] was based on bimonthly sampling, which means lacking of some data on the missed months. However, comparison of the present data with the previous may give some light on the changes occurred in the ecological characteristics and phytoplankton community in the WH throughout the past decade. As shown in Table 1, the present study reported a marked decrease in the phytoplankton abundance during the past decade, associated with change of peaks timing from June and October in 1989 to July and September in 1999-2000. The contribution of dinoflagellates to total phytoplankton count increased from 25% in 1989 to 57% in 1999-2000 while that of diatoms decreased from 70% to 41% and the number of species became 107 instead of 68 species. Although this increase can be attributed to monthly sampling during the present study against bimonthly one in 1989 it is also related to changes occurred in the environmental conditions during the past ten years. The increasing role of dinoflagellates during the present study, which usually prefer relatively high temperature, explains the recent shifting in the peak timing of phytoplankton bloom towards the warmer period (27-29^{o}C) in the harbour (July and September). Furthermore, the dominance of species experienced complete changes during 1999 (Table 4), which again indicates serious change in the characteristics of the harbour's water.

Although dinoflagellates flourished in the WH during the warm period, with the exception of *P. micans,* the dominant species demonstrated different contributions to the total phytoplankton with salinity changes. Accordingly, it seems that temperature and salinity are the main factors controlling the growth of dinoflagellates in the harbour. Silicate and phosphate also had a pronounced role in promoting phytoplankton bloom. The zooplankton grazing has also pronounced stress on phytoplankton abundance, but unfortunately no experimental studies have never been done in this context during the present investigation. Furthermore, the phytoplankton crop during the present study dropped drastically to 19% of that measured in 1989, but chlorophyll-a was multiplied by 5 folds. The great increase in chlorophyll-*a* was not related only to the change in species composition but also to large amounts of picoplankton cells which unfortunately were not counted during the present study but they were found in high concentrations in Dekhaila Harbour.

Association of dominant species was a frequent phenomenon in the WH like that between the dinoflagellate *A. minutum* and each of *P. micans, P. triestinun* and the euglenophycean *Euglena acus* Ehrenb and that between *P. triestinum* and both *P. micans* and *E. acus*. (Fig. 6).

CONCLUSIONS

The ecological conditions of the Western Harbour are of great variability due to interaction of several factors, including maritime activities, discharged waste waters and water exchange between the harbour and the sea. This variability caused high eutrophication, drop of dissolved oxygen content, decrease in water transparency, increase in phytoplankton diversity and marked changes in species dominance.

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