Eutrophication problems in the Western Harbour of Alexandria, Egypt

OCEANOLOGIA, 46 (1), 2004.
pp. 25–44.

KEYWORDS
Alexandria Western Harbour
Eutrophication
Nutrients
Water quality
Plankton biomass

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Manuscript received 23 June 2003, reviewed 22 September 2003, accepted 5 January 2004.

Abstract

Eutrophication-related problems in the Western Harbour of Alexandria were studied monthly from April 1999 to March 2000. Variation in salinity appeared to be the key to all changes in water quality and plankton abundance in the harbour. Both at the surface and near the bottom the salinity was lower (annual average: 35.1 and 38.3 PSU respectively) than in the open sea (39 PSU). Dissolved oxygen levels indicated poor aeration conditions along the water column (2.3–3.98 mg l^{-1}). Average pH values were approximately similar in the two layers (8.1 and 8 respectively) but exhibited different ranges of variations. Nutrient salts varied widely, often occurring in high concentrations, with ranges of 0.12–5.7 and 0.06–2.6 μM at the surface and the bottom respectively for phosphate, 0.21–20.46 and 0.25–18.12 μM for nitrate, 0.29–3.3 and 0.23–1.66 μM for nitrite, 0.56–57.46 and 2.32–43.73 μM for ammonia and 0.3–36.3 and 0.48–38.4 μM for silicate. As a result of nutrient enrichment, phytoplankton growth was very intensive,

The complete text of the paper is available at http://www.iopan.gda.pl/oceanologia/

reflected by an abnormally high concentration of chlorophyll *a* (annual average: 33.82 μg l^{-1}). At the same time the death of large numbers of phytoplankton cells could be inferred from the relatively large amount of phaeopigment (annual average: 10.39 μg l^{-1}). The high levels of nutrient salts and phytoplankton biomass together serve as a good indicator of high eutrophication levels in the Western Harbour throughout the year. These conditions clearly affected the zooplankton stock, which varied between 5.8–93.6 $\times$ 10^3 indiv. m^{-3}, although for most of the time values remained at a low level (annual average: 26 728 indiv. m^{-3}).

1. Introduction

Eutrophication has become a persistent problem in the Western Harbour of Alexandria and was recorded for the first time in 1985. These problems came about as a result of the continuous enrichment of nutrients from different sources, including maritime activities, several land-based effluents consisting of mixed industrial, domestic and agricultural wastes as well as stored chemical fertilizers. Nutrient loads are directly dependent on human activities, which in turn depend on the growth of the world's human population. Consequently, human-induced eutrophication is in a way related to the increase in human population (De Jonge et al. 2002). In Alexandria City, the human population has just about doubled since the first record of eutrophication in the Western Harbour. This population increase has been associated with the intensive development of human activities, which directly or indirectly have led to the increase in nutrient enrichment in the harbour and the consequent increase in the level of eutrophication during the past two decades.

Numerous studies have been conducted on the physical, chemical and biological characteristics of the harbour (Farag 1982, El-Gindy 1986, Nessim & Tadros 1986, Nessim & Zaghloul 1991, Saad & Hemeda 1991, 1992a, b, Shriadah & Tayel 1992, Zaghloul 1994, 1996, Hassan & Saad 1996, Saad et al. 2000, 2001, 2002, 2003, Abdel-Aziz 2002). The majority of these studies were based on seasonal or bimonthly sampling. However, the rapid changes in water quality and biotic components require frequent follow-up at shorter time intervals. In the present work, the aim was to study the physico-chemical conditions and plankton stock in the harbour in order to record the changes that have occurred during the past two decades and to evaluate the changes in eutrophication-related problems in the harbour.

2. Material and methods

The Western Harbour of Alexandria is the largest and oldest harbour on the Egyptian Mediterranean coast, serving about three quarters of Egypt's international trade. It is a shallow, elliptically shaped, semi-enclosed basin with an area of 7.4 km^2 and depth range of 5.5–16 m. The harbour receives imported and exported materials such as coal, manufactured iron, cement, fertilizers, grains, food, textiles, chemicals, timber, as well as crude and refined oil. There is also an old dry dock and workshop for ship building and repairs. Located on the southern and eastern sides of the harbour, the quays for the various maritime activities (Fig. 1) divide these sides into several small semi-enclosed or open basins. Waste waters of varying quantity and quality are discharged into the harbour, mainly through the Umoum Drain (76.4 m^3 s^{-1}) and the Noubaria Canal (1 m^3 s^{-1}).

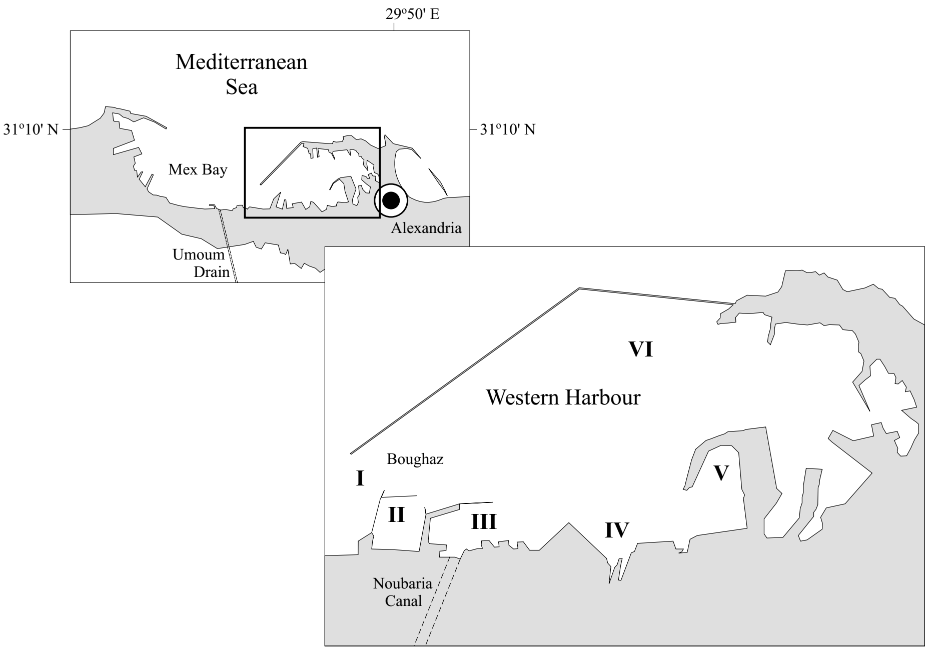

Fig. 1. The sampling stations (I–VI) in the Western Harbour of Alexandria

The present study was carried out at 6 stations every month from April 1999 to March 2000. The samples for hydrographic measurements and nutrient analysis were collected from the surface and the near-bottom waters. The water temperature was measured with an ordinary thermometer, while salinity, pH, dissolved oxygen and nutrients (phosphate, nitrate, nitrite, ammonia and silicate) were determined according to the methods mentioned in Strickland & Parsons (1972). Chlorophyll *a* in the surface water was extracted with 90% acetone and measured spectrophotometrically using the SCORE UNESCO equation given in Strickland & Parsons (1972), and the abundance of zooplankton was calculated from the average of three counts of 5 ml aliquots. The factor analysis and similarity test was also done using the Statistica.5 program.

3. Results

The hydrographic conditions, the eutrophication parameters and plankton abundance varied widely during the study period. However, the **water temperature** did not deviate from the seasonal fluctuations normal on Egypt's Mediterranean coast (15–29°C). Although the harbour is a shallow basin subject to vigorous mixing during much of the year, the water at the bottom was colder than at the surface by 0.5–2°C, the largest difference being reported in spring and early summer and the smallest one in autumn and winter. No spatial variation in the surface water temperature could be detected.

The **salinity** variations in the water column reflected the effect of the different wastes discharged into the harbour all the year round. At the surface it fluctuated between 26.3 and 36.8 PSU for most of the year, except

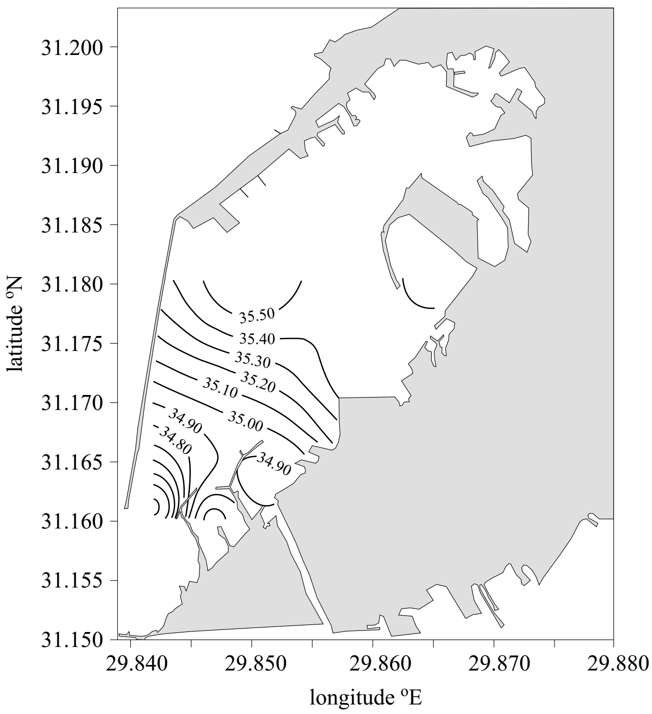

Fig. 2. Distribution of the surface salinity in the Western Harbour

for higher values (38.8–39.1 PSU) in November, December and March, whereas near the bottom it was higher than at the surface but still lower than in the open sea; the lowest monthly average (36.3 PSU) was measured in February. From the surface distribution two different salinities could be distinguished in the harbour: one (< 35 PSU) in the area affected by the wastes discharged through the Umoum Drain and Noubaria Canal (stations: I, II, III), the other (> 35 PSU) in the inner harbour (stations: IV, V, VI), which is some distance away from the impact of the discharged wastes (Fig. 2).

The **transparency** of the harbour water was relatively low for almost the whole year, with Secchi disc readings varying from 60 to 270 cm. The water was more turbid (60–85 cm) in April, May, July, September and February, but relatively clear (250–275 cm) during December and January.

The surface **pH** values varied over rather a wider range (7.7–8.7) than near the bottom (7.5–8.3) but with negligible differences between stations.

An obvious feature of the harbour water was the low **oxygenation**; dissolved oxygen at the surface, however, fluctuated between 1.8 (40% saturation) and 6 mg l^{-1} (135% saturation) but for most of the year it was between 3 and 4 mg l^{-1}, while near the bottom the values dropped to 1–3.9 mg l^{-1} (saturation: 22–85%). The vertical gradient of dissolved oxygen demonstrated a difference of up to 0.6 mg l^{-1} between surface and bottom from October 1999 to March 2000 and 1.3–3.8 mg l^{-1} during the warm period (June–September).

The continuous nutrient enrichment resulting from the discharged wastes and other human activities raised the fertility in the Western Harbour to a high level. However, the concentrations of nutrient salts displayed different ranges of variations relative to those occurring in the supplying sources.

Phosphate was present in the lowest concentrations and the narrowest range of variations as compared to the other nutrients, fluctuating within a range of 0.12–5.7 μM in the surface water and 0.12–2.6 μM near the bottom, with respective annual averages of 1.17 and 0.83 μM. Having decreased gradually from April to June, the surface phosphate concentrations then varied in an irregular manner in summer and early autumn, after which it increased from December to April (Fig. 3). The monthly averages fall within a relatively narrow range (0.28–1.11 μM) for most of the year, increasing to 1.66–2.7 μM in April, July, September 1999 and March 2000. Near the bottom, the pattern of monthly variations was mostly similar to that at the surface. On a spatial scale, phosphate reached its maximum in the surface water at stations I and II, which are affected by the discharge of the Umoum Drain and at station IV, near the chemical fertilizers quay.

The highest near-bottom phosphate was measured opposite the outlet of the Noubaria Canal and was higher than at the surface, while at stations I, II and IV the concentrations were markedly lower than at the surface. This indicates that the major part of allochthonous phosphate in the Western Harbour is derived from the Umoum Drain and chemical fertilizers.

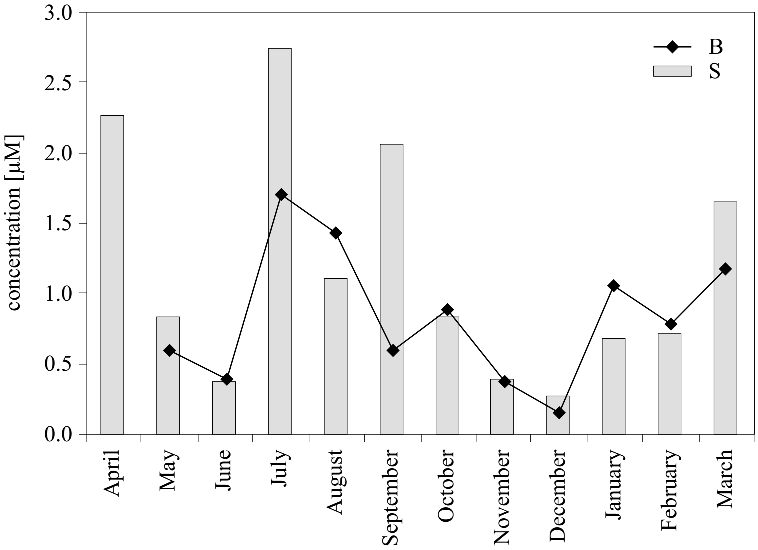

Fig. 3. Monthly average concentrations of phosphate in the surface (S) and near the bottom (B) waters

Nitrate values varied widely at the surface as well as near the bottom (0.21–20.46 μM and 0.25–18.12 μM respectively). As shown in Fig. 4, surface nitrate was < 3 μM from May to October, but starting from November until April concentrations remained high (5.1–14.33 μM) with a distinct peak in January–February. The monthly distribution near the bottom resembles that at the surface but values were high (5.6–13.83 μM) from December to March. Spatially, the highest surface nitrate (6.67 μM) was found at station II, while at the other stations the concentrations were approximately the same, varying between 5.01 μM and 5.8 μM. At the same time, the bottom water contained the highest amounts of nitrate at stations III, IV and V and the lowest ones at station VI.

As an intermediate between nitrate and ammonia, **nitrite** was recorded in low concentrations in both the surface (0.55–1.69 μM) and near-bottom (0.41–1.2 μM) waters, which indicates a high rate of nitrification and denitrification processes in the harbour. Although monthly nitrite distributions differed slightly in the two layers (Fig. 5), the spatial pattern of nitrite

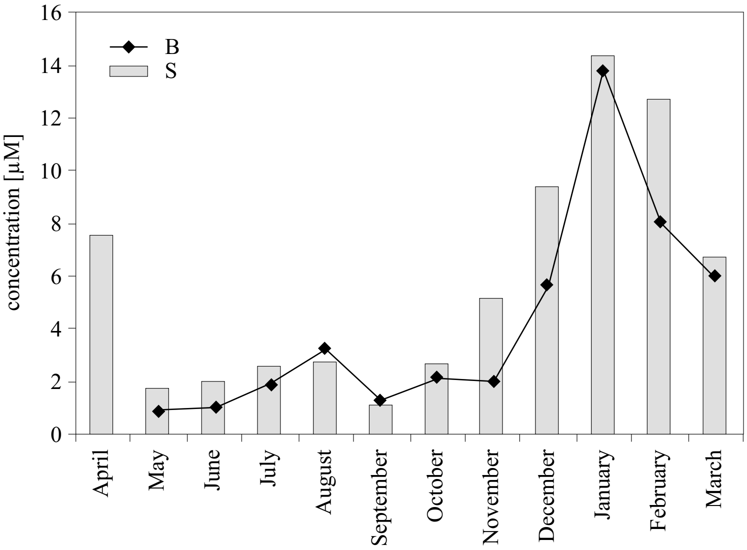

Fig. 4. Monthly average concentrations of nitrate in the surface (S) and near the bottom (B) waters

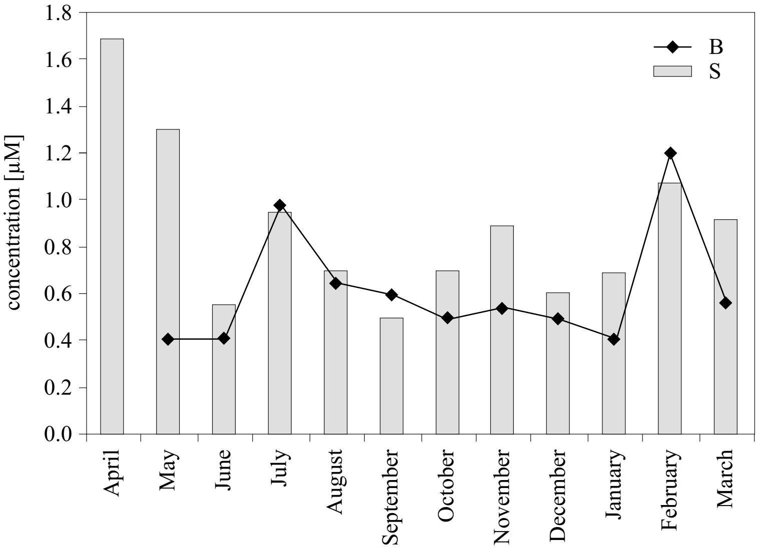

Fig. 5. Monthly average concentrations of nitrite in the surface (S) and near the bottom (B) waters

appeared to be associated with the distribution of surface salinity. In the area of lower salinity (stations I, II, III) the surface nitrite concentration (0.97–1.08 μM) was about double that recorded near the bottom

(0.52–0.58 μM), but in the area of higher salinity (stations IV, V, VI) surface nitrite (0.69–0.78 μM) was only slightly higher than the bottom value (0.59–0.69 μM).

Ammonia was the principal representative of dissolved inorganic nitrogen (69%), displaying the widest range of variations in both surface (1.97–57.46 μM) and bottom waters (2.32–43.73 μM) as compared to the other nutrients, but with approximately similar annual averages in the two layers (14.53 μM and 15.05 μM respectively). As the monthly distribution shows (Fig. 6), ammonia concentrations were > 10 μM along the water column for most of the year, but peaked once at the surface in January –February and twice near the bottom in August and November. In contrast to the other nutrients, ammonia demonstrated a pronounced spatial variation, attaining in surface water a minimum (8.95 μM) at station VI and a maximum (18.33 μM) at station I; in bottom water, the minimal concentration (9.43 μM) was also found at station VI, but the maximum value (18.55 μM) occurred at station IV.

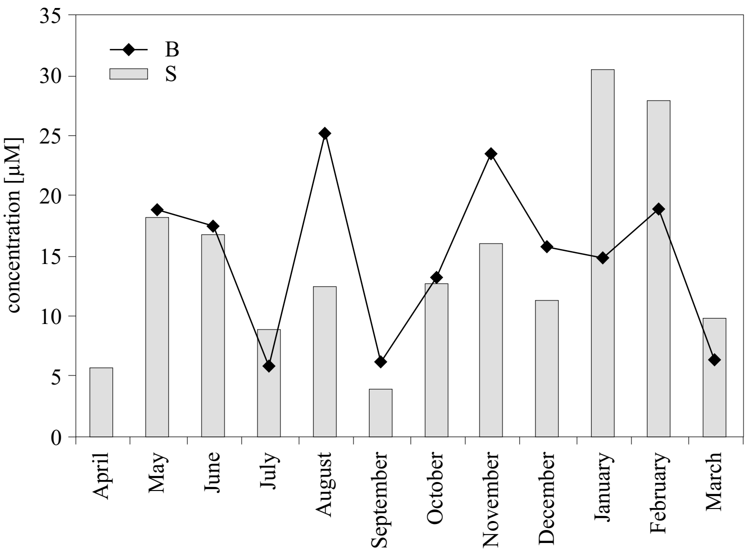

Fig. 6. Monthly average concentrations of ammonia in the surface (S) and near the bottom (B) waters

The considerable temporal and spatial variability of nitrate and phosphate in the Western Harbour markedly influenced the **N/P** ratio, which was considerably higher and lower (0.3–170.5) than the Redfield values for the open sea. Monthly distributions at the surface and the bottom were similar, the highest values being attained in late autumn and winter. In the surface water, however, the ratio showed a wider range of variations and was greater (annual average: 11.8) than that at the bottom (annual average: 8.2).

Like nitrate and ammonia, **silicate** was subject to wide variations at the surface (0.3–36.3 μM) and near the bottom (0.5–38.4 μM), and demonstrated the same monthly distribution pattern in the two layers; July and August were characterized by abnormally high concentrations (Fig. 7). Between stations, the highest silicate in surface and bottom waters was found at station III but with greater concentrations at the bottom. Richer silicate near the bottom also occurred at stations V and VI, which are less affected by the freshwater discharges, while stations I, II and IV contained higher amounts of silicate in the surface water, which is indicative of the impact of freshwater at these stations.

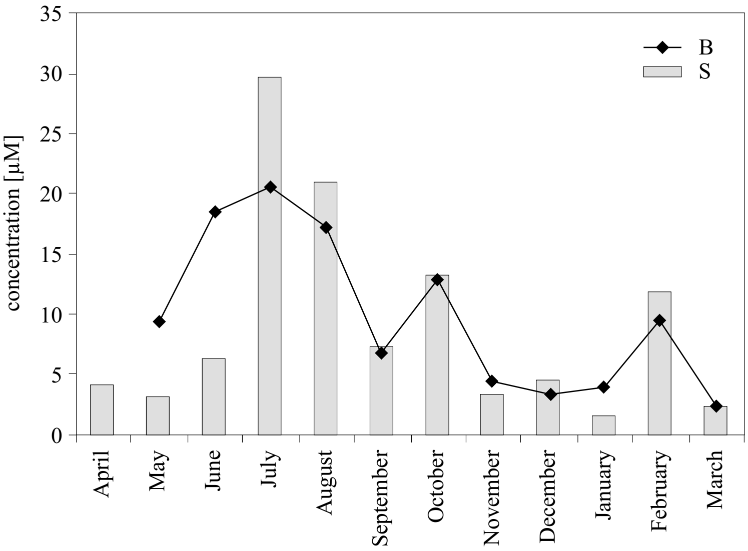

Fig. 7. Monthly average concentrations of silicate in the surface (S) and near the bottom (B) waters

The phytoplankton biomass (**chlorophyll *a***) was abnormally high all the year round, reflecting a high primary production in the harbour. There were four unequal peaks, two high ones in July and September, and two low ones in April–May and February (Fig. 8). The April–May peak was caused by abnormally high values of chlorophyll *a* at stations I, II and III with a salinity range of 26.3–33.5 PSU occurring in the vicinity of the Umoum Drain outfall. In contrast, the July and September peaks were due mainly to large amounts at stations IV and V (salinity: 30.7–36.64 PSU), which lie near the discharge of the Noubaria Canal and the chemical fertilizers quay. In February, the highest chlorophyll *a* was recorded at stations IV, V and VI, a reflection of the collective effects of the three sources mentioned above. Relative to the abnormally intensive phytoplankton blooms, a high concentration of phaeopigment (annual average: 10.4 μg l^{-1}) was recorded in the harbour, which at times reached extremely high values (105.9 μg l^{-1}). Their seasonal distribution coincided with that of chlorophyll *a*, indicating the high degradability of phytoplankton pigment under the prevailing environmental conditions.

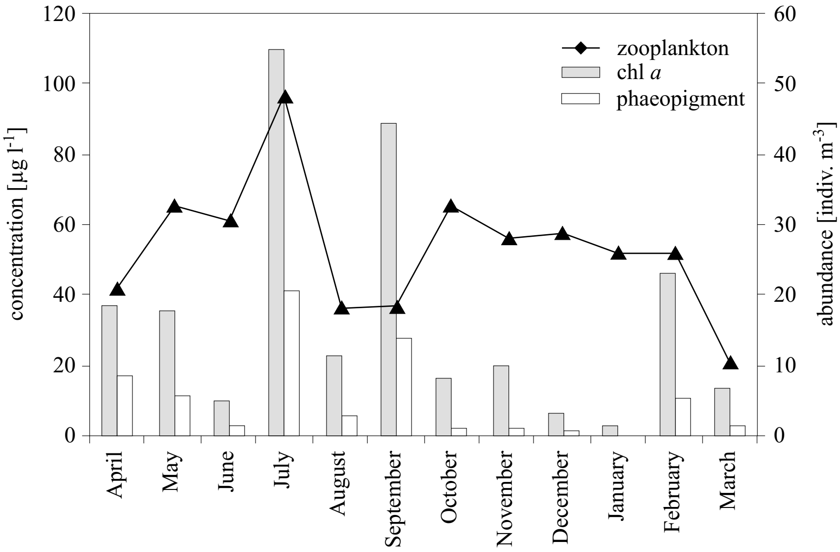

Fig. 8. Monthly average contents of chlorophyll *a*, phaeopigment and zooplankton count

Represented by an annual average of 26 700 indiv. m^{-3}, zooplankton production in the Western Harbour was generally poor. As shown in Fig. 8, the standing crop amounted to less than 30 000 indiv. m^{-3} almost all the year round, except for a peak in July (48 400 indiv. m^{-3}) attributable to the active contribution of freshwater protozoans.

4. Discussion

The different human activities that bring large amounts of nutrient salts and harmful substances to the harbour appear to have a pronounced impact on the physico-chemical characteristics and plankton abundance in the Western Harbour. The current regime there effectively controls the temporal and spatial variations of the ecological parameters. There are two currents between the harbour and the open sea (Farag 1982). One flows from the harbour out to sea in the upper 5 m layer towards the southeast and southwest during summer and autumn, and westwards and southwards during winter and spring. The other enters the harbour at a depth of 10 m from a northerly to north-easterly direction in winter and summer and from the south-west to north in autumn and spring. Moreover, the water exchange between the harbour and the sea exerts a considerable influence on the environmental and biological characteristics of the harbour, since one such cycle takes about 30 days to complete (El-Gindy 1986, Hassan & Saad 1996).

The spatial distribution of surface salinity was in fact a better reflection of the effect of the Umoum Drain discharge than that of the Noubaria Canal: the latter usually occurs as seasonal pulses and with a smaller volume. In the long term, salinity decreased gradually from 37 PSU in 1985 (Nessim & Tadros 1986) to 35.3 PSU during the present study, indicating the chronic impact of the land-based effluents.

Although mixing processes caused by ship traffic and land-based runoff are the major cause of water turbidity in the harbour, abnormally intensive phytoplankton blooms also substantially reduced water transparency; the two variables showed an inverse relationship all the year round.

In spite of the extremely high phytoplankton production in the Western Harbour, dissolved oxygen was generally low along the whole water column with a relatively small vertical gradient. The decrease in dissolved oxygen with depth is attributed to its consumption in oxidation of organic matter and the stagnation conditions prevailing in summer (Nessim & Tadros 1986). The inter-annual records of dissolved oxygen testify to the continuing deterioration of water quality during the past two decades: its concentration fell from 7–11 mg l^{-1} in 1980 (Farag 1982) to < 4 mg l^{-1} during the present study. It is therefore important to notice that the oxygen concentrations in the surface water of the study area was comparable to the threshold level of well oxygenation (< 4 mg l^{-1}) proposed by Huet (1973) and near the bottom it resembled the hypoxia condition stated by Stachowitsch & Avcin (1988). Accordingly, the Western Harbour is categorized as an area with critical limits of dissolved oxygen (3.5–4.2 mg l^{-1}) necessary for healthy growth of biota in both cold and warm waters (Grundy 1971, Arin 1974).

The content of phosphate increased during the present study (annual average: 1.18 μM) as compared to the values recorded by Nessim & Tadros (1986) and Zaghloul (1996) (0.84 μM and 0.46 μM, respectively); however, its distribution varied seasonally. On the other hand, the lower values near the bottom are attributed to the ready adsorption of phosphorus on fine sediments (Lucotte & d'Anglejan 1983) under low aeration conditions (Mortimer 1971), while the higher phosphate in the surface water was due to enrichment by the discharged wastes which, being less saline, are usually confined to the surface.

The seasonal distribution of nitrate in the surface water dropped in late spring and summer owing to its intensive uptake by the abnormal phytoplankton blooms. Although the difference in **nitrate** between surface and bottom waters may be related to the effect of discharged wastes at the surface, it is probable that nitrification and mineralization of nitrate take place at different rates in the two layers. This concurs with the monthly distribution of surface nitrate at all the stations, which reflects the ecological conditions prevailing at each one in different seasons. At stations I and II, nitrate attained its maximum concentration in April, July and October, when salinity dropped to its lowest value during the year; meanwhile, station IV sustained the highest value for several months, possibly as a result of the dissolution of stored chemical fertilizers. The nitrate contents in the harbour water sometimes exceeded by a factor of 5 the low limit of eutrophication criteria (4 μM) adopted by Vucak & Stirn (1982), Franco (1983) and Marchetti (1984), while at other times they dropped well below this limit. Although the present values of nitrate are similar in their temporal pattern to those of Nessim & Tadros (1986), they were higher (annual average: 5.73 μM) than those of the latter authors (annual average: 4.06 μM). Such an increase means that the eutrophication level in the Western Harbour has increased considerably during the past two decades.

Nitrite levels in sea water can be regarded as a measure of the rate of nitrification and denitrification processes, which are also related to salinity variation. In the study area, the difference in **nitrite** between surface and bottom indicates that in the low salinity area, these processes occurred at the surface and the bottom at two different rates, while in the higher salinity area they took place at approximately similar rates. This suggests that nitrification occurred more rapidly in the former area, while denitrification was the faster process in the latter; this is confirmed by the higher level of nitrate than ammonia in the former area and the inverse relationship in the latter.

High concentrations of **ammonia** were recorded in the Western Harbour both during the present study and earlier: Nessim & Tadros (1986) recorded a roughly similar level of ammonia (15 μM) to that found during the present study, but Zaghloul (1996) found much lower values (7.05 μM). In winter, the surface water captures more ammonia as a result of domestic wastes being raised to the surface by winter mixing. During August and November, values were higher near the bottom owing to the decomposition of organic matter accumulated during the summer stagnation (Nessim & Tadros 1986). The level of ammonia recorded in the Western Harbour during the present study reflected pollution conditions, since its concentration was 15 times that usually found in seawater (Riley & Chester 1971) and about 7 times greater than the criteria (> 2 μM) adopted by Vucak & Stirn (1982), Franco (1983) and Marchetti (1984) for high levels of eutrophication.

Extreme variability of N/P is common along the Mediterranean coast of Egypt, particularly in areas exposed to land-based runoff (Nessim & Tadros 1986, Nessim & Zaghloul 1991, Zaghloul 1996, Abdel-Aziz et al. 2001). According to Chiaudani & Vighi (1978), when N/P lies in the 4.5–6 range the assimilation of the two elements by marine algae is nearly optimal, but at a ratio of > 6, phosphorus becomes the limiting element and when N/P < 4.5, nitrogen is the limiting factor. In the present study the N/P ratio was < 4.5 at most stations from March to October but, abnormally, > 6 from November to February. However, there is no evidence of nitrogen or phosphorus limitation in the Western Harbour; indeed, chlorophyll *a* concentrations reflected an extremely high phytoplankton production all the year round. Furthermore, the minimal chlorophyll *a* in December and January (6.6 and 2.6 μg l^{-1} respectively) coincided with the maximum N/P ratios in the surface water of the harbour (58 and 23 respectively). It therefore seems that a variable N/P ratio is not an indication of nitrogen or phosphorus limitation; the species composition of the phytoplankton community, the available concentrations of both nitrogen and phosphorus, and environmental factors, all together give rise to the variations in the N/P ratio. Historical records of N/P show a continuous decrease during the past two decades from 23 (Nessim & Tadros 1986) to 16 (Zaghloul 1996) and 11.8 during the present study.

Although the drainage waters have been reported as the principal source of silicate in the harbour and play a significant part in its spatial and temporal distribution, it was phytoplankton growth that was actually regulating the silicate level. During spring and autumn silicate concentrations were low due to the high rate of uptake by phytoplankton which sustained high biomass and was dominated by diatoms during both seasons. In summer, silicate reached maximum levels in parallel with the high phytoplankton biomass. This abnormal relationship is explained by the active contribution of freshwater cyanobacteria, which do not need silicate for growth, and also by silicate enrichment from the discharged wastes, which increased during summer as indicated by the low salinity. The present silicate levels at the surface and bottom (9.03 and 10.06 μM respectively) were three times that (3.04 μM) found by Zaghloul (1996), but markedly lower than the results (23.6 μM) of Nessim & Tadros (1986).

The extremely high phytoplankton biomass in the Western Harbour over the year represented by chlorophyll *a* (annual average: 33.8 μg l^{-1}) dramatically exceeded the level given by Carlson (1977) as a good indication of acute eutrophication and very much in excess of the ranges (0.5–1.0 μg l^{-1}) suggested by Friligos (1988) and Stirn (1988) for a severely eutrophic system. The present amount of chlorophyll *a* was 8 times that reported by Zaghloul (1996), indicating a dramatic increase in the eutrophication level in the harbour during the past few years.

The relationship between phytoplankton biomass and zooplankton abundance showed two different patterns during the study period: a direct one from May to August and an inverse one from September to February. Although these patterns may reflect the feeding relationships between phytoplankton and zooplankton components at different times of the year, it is probable that the abnormally high phytoplankton production and other eutrophication conditions, particularly the lack of suitable amounts of dissolved oxygen, caused a pronounced drop in zooplankton production in the harbour. This was evident from the low zooplankton crop during the present study (26 700 indiv. m^{-3}) as compared to that found in Abu Qir Bay (90 700 indiv. m^{-3}) by Abdel-Aziz (2000). The lowest stock (19 650 indiv. m^{-3}) was recorded at station IV, where the highest concentration of ammonia (17.03 μM) was measured.

The dendrogram for different ecological parameters versus stations showed two major clusters, each of which comprised two sub-clusters (Fig. 9). Within cluster I, salinity and chlorophyll *a* lay at the same linkage distance as that for zooplankton and temperature. This means that the zooplankton distribution coincided with that of temperature, and the distribution of chlorophyll *a* was associated with salinity. In cluster II, the highest similarity was observed between pH and silicate, indicating the effect of pH on silicate formation. Similarity is also high between transparency and phosphate, revealing an indirect relationship between them, since transparency is usually affected by the density of phytoplankton cells and nonliving suspended matter transported by discharged wastes; both are important sources of phosphate. The similarity between dissolved oxygen and nitrate in cluster II suggests that nitrification affects dissolved oxygen in the harbour.

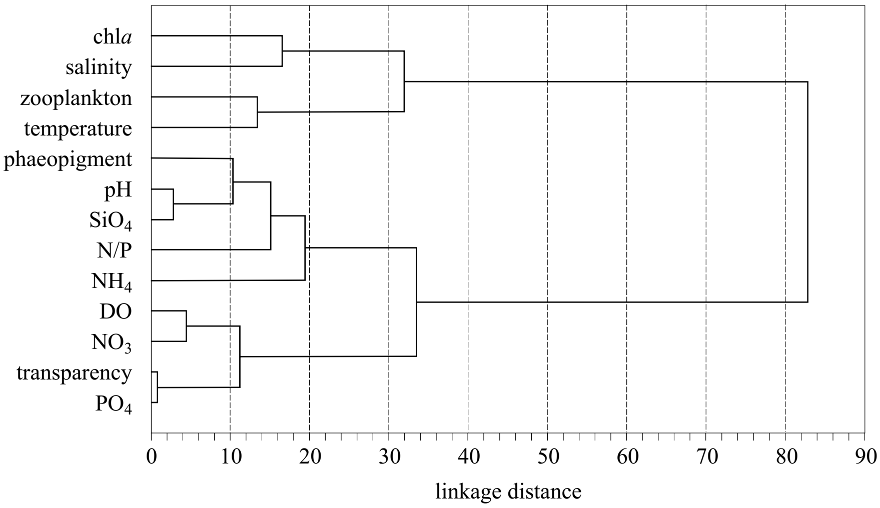

Fig. 9. Tree diagram for different parameters versus different stations (complete linkage Euclidean distance)

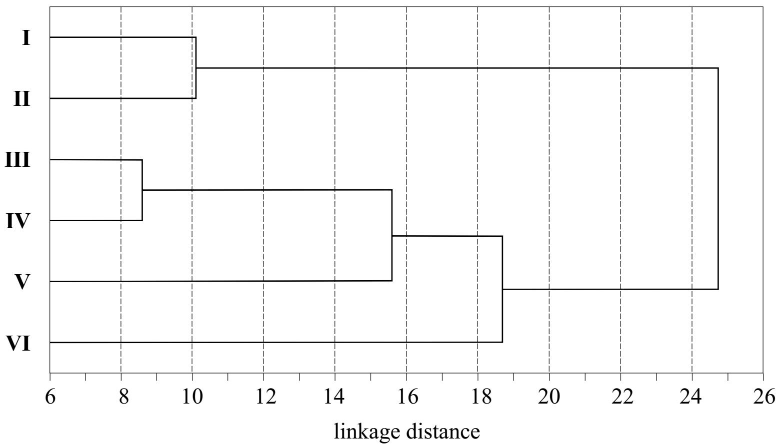

Fig. 10. Tree diagram for 6 stations versus different parameters (complete linkage Euclidean distance)

On the spatial scale, cluster analysis showed the highest degree of similarity between stations III and IV, and less so between stations I and II (Fig. 10). Such a pattern indicates that water exchange between stations III and IV is more active than with stations I and II.

With respect to the variations in parameters versus months (Fig. 11), there were two further major clusters. Cluster I comprised the same parameters observed in Fig. 9 with the same pattern of similarity. Cluster II is divided into three sub-clusters: within them dissolved oxygen and phosphate showed the closest linkage distance, followed by that between pH and nitrate, phaeopigment and silicate, and ammonia and the N/P ratio. These analyses indicate a relationship between each pair of parameters mentioned above: dissolved oxygen affects the formation of phosphate, and pH controls the nitrification process in sea water, while the similarity between phaeopigment and silicate expresses the intimate relationship between the quantity of dead phytoplankton cells as a source of silicate and concentration of the latter. At the same time, although ammonia was not taken into consideration in the calculation of the N/P ratio, it appeared from cluster analysis that ammonia was related to pH, particularly through its relation to the nitrate content by nitrification and denitrification.

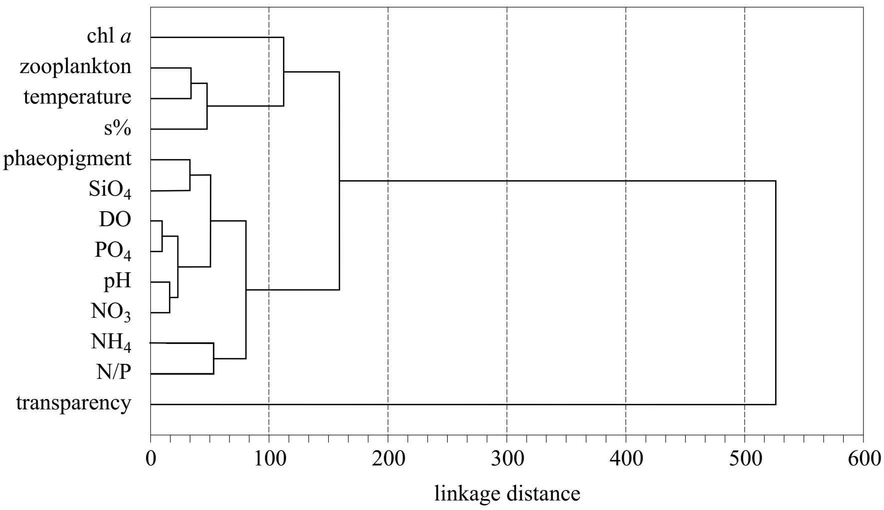

Fig. 11. Tree diagram for different months versus different parameters (complete linkage Euclidean distance)

The cluster of monthly variations of all parameters (Fig. 12) also revealed two main groups, each of which includes more than one subgroup, but all of them indicate bimonthly similarity of the parameters throughout the harbour. The highest similarities occurred in October–November, August –September and April–May. This pattern demonstrated evident seasonality in the variations of the ecological characteristics of the Western Harbour.

Factor analysis of the different environmental parameters (Table 1) indicates that, of the eleven ecological parameters studied here, only five played a crucial part in the variations of water quality in the Western Harbour; together these make up 57.5% of the total number of parameters

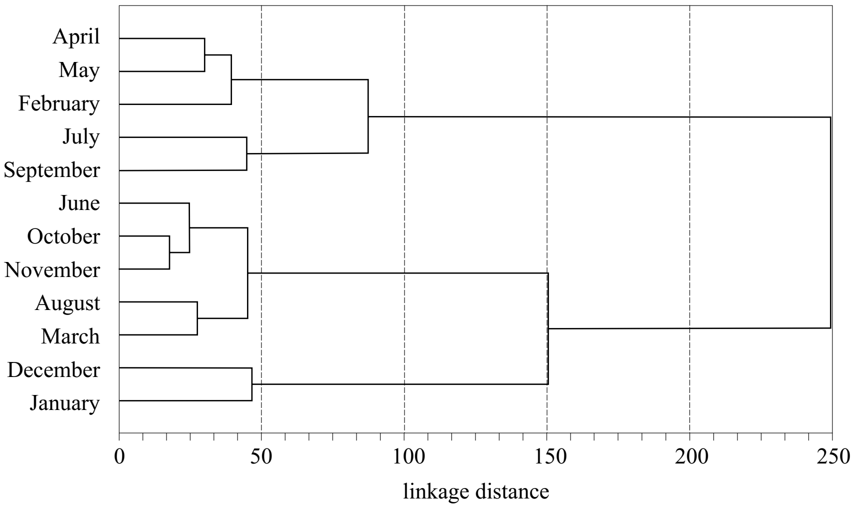

Fig. 12. Tree diagram for different parameters versus different months (complete linkage Euclidean distance)

Table 1. Factor analysis of the ecological parameters in the Western Harbour (Extraction: maximum likelihood factors, marked loadings are > 0.700000)

	Factor analysis	
Variables	**Factor 1**	**Factor 2**
Salinity (S [PSU])	–0.973596	0.013215
Dissolved oxygen (DO)	–0.989945	–0.010444
Temperature	–0.415827	0.050150
Chlorophyll *a*	–0.419401	0.820474
Silicate (SiO_4)	0.512951	0.286219
Phaeopigment	–0.502097	–0.284052
pH	–0.415881	0.086379
Phosphate (PO_4)	–0.841233	–0.032608
Nitrate (NO_3)	0.367205	–0.917457
Ammonia (NH_4)	0.460832	–0.495399
N/P	–0.593419	0.155105
Explained variance	**4.371892**	**1.958313**
Proportion of total	**0.397445**	**0.178028**

studied. Factor 1 includes salinity, dissolved oxygen and phosphate, which together constitute 39.7%, and Factor 2 comprised chlorophyll *a* and nitrate (17.8%). This kind of analysis showed up the crucial role of salinity in the variation of the different ecological parameters, as it is closely related to the variations in the quality and quantity of the discharged (waste) waters. Accordingly, the other six parameters are of less importance in similar studies and can be neglected.

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