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Bloom succession of phytoplankton in relation to coastal engineering along alexandria coast, Egypt

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ABSTRACT

The investigated area extends for 3 km and was subjected to three phases of coastal alterations which affected not only the topography of the area but also the water quality, productivity and phytoplankton communities of coastal area. Beaches have been protected since 1934 in order to prevent further erosion and to provide new recreational beaches. After 1998, protective wave breakers were built parallel to some of the beaches. This resulted in the formation of relatively large semi-closed, shallow lagoons. Due to their shallow depth, these lagoons became a suitable environment for algal blooms. From 2010, other processes were done to reduce the harmful effect caused by the previous coastal modification in the area. The composition of the phytoplankton population was totally different for the two periods of coastal modifications. The most important bloom caused by *Micromonas pusilla* forming green tide. This bloom was accompanied by the bloom of *P. quinquecorne*. Although there were no fish or invertebrate mortality in 2007, this bloom caused economical losses for internal tourism.

In the absence of Environmental Assessment, the coastal engineering increased the harmful algal blooms in Alexandria coastal waters even with corrective steps to mitigate the harmful effects.

KEYWORDS

Coastal engineering;
Artificial lagoons;
Harmful algae;
Alexandria coast;
Egypt.

INTRODUCTION

Coastal areas are remarkably dynamic environments rich in natural resources, biological diversity and with high potential for all kind of commercial activities. The rising pressure over the coastal zone at the global level has been broadly dealt with the scientific literature[1]. The junction of multiple interests, such as fisheries, tourism, ports and industrial activities make these areas the most populated of the world, demanding efforts of protection of the productivity and quality of the coastal resources and human health of coastal communities[2].

Alexandria coasts are certainly areas where both human activities and environmental pressures are at a maximum. Erosion and deposition of solid materials by the action of water movement are continuous processes along the shore line. As a result, beaches had to be protected since 1934 in order to prevent further erosion and to provide new recreational beaches[3]. A series of groins and detached breakwaters were built during the last two decades to mitigate hot spot beach erosion. At a later stage this area was subjected to further successive coastal engineering works which affected not only the topography of the area but also the water quality, productivity and phytoplankton communities of coastal area. As a later stage, it soon appeared that corrective measures have to be taken to mitigate the negative impacts of the coastal works which had been carried out. Three phases therefore have to be distinguished.

Phase (1): 1998 to 2003 (Figure 1a)

A series of groins and detached breakwaters were built perpendicular to the coast line. But these structures soon proved to be ineffective in preventing beach erosion.

Phase (2): Protective works 2003-2007 (Figure1 b)

T-shaped breakwaters were built extending for 400m parallel to the coast in front of El- Mandara (stations 1 & 2)120m offshore, all structures being 3 meters in elevation above sea level. Several artificial beach nourishment projects were also carried out with the addition of no less than 250cu.m sand per meter length. In addition, groins perpendicular to the beach and protective wave breakers were also built. As a result, relatively large semi-closed shallow lagoons about 3m depth for swimming and recreation were created[4].

Phase (3): Corrective works after 2007 (Figure 1c)

After completing the second phase of coastal engineering, it appeared that wave action causes strong erosion in front of El-Mandara (stations 1 & 2) and that erosion extended to the Corniche (the sea front) wall in the unprotected segments. Following the recommendations of the Organization for planning of the Alexandria region, all breakwaters were submerged below sea level. This change led to minimizing the impact on marine life, erosion and sedimentation.

At any given time and place, the degree of diversity and amount of biomass in a natural assemblage of phytoplankton represents a balance among numerous environmental factors including irradiance, temperature, salinity, grazing and nutrient input. When these factors undergo rapid change, the new conditions may be favorable to some species and unfavorable to others. Shifts within the plankton assemblage may be gradual, occurring over the course of several weeks or can sometimes occur within just a few days[5].

The aim of the present study is to investigate the impact of successive coastal engineering processes on the phytoplankton along Alexandria coast during the two phases of modifications (2007 & 2011).

MATERIAL AND METHODS

Sample collection was carried out biweekly during the period from 26 June to 15, September 2007 and from 16 June to 17 August 2011 from Miami Beach (St. 4) to El-Mandarah (St. 1 and 2) along about 3 km of coast (Figure1).

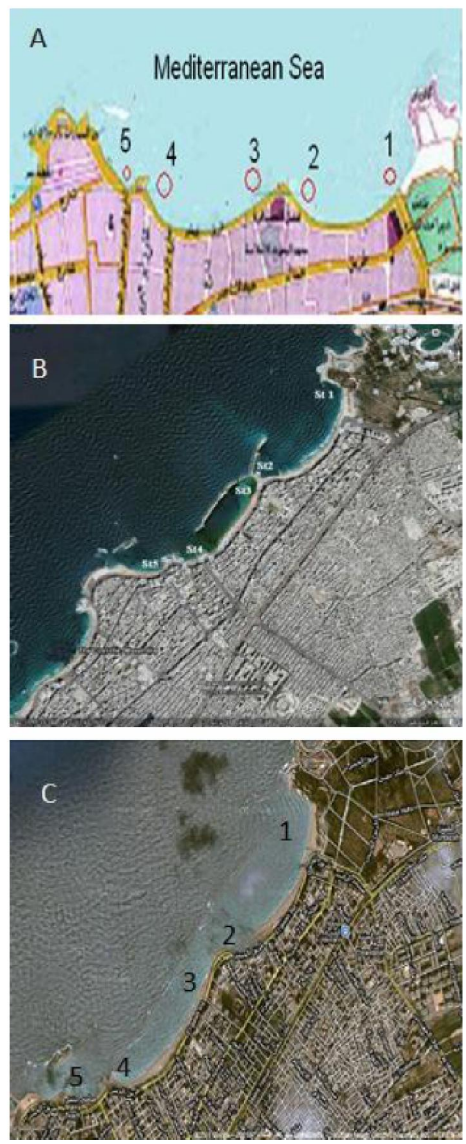

Figure 1: Station position during the three phases of coastal engineering; A: phase 1 (1998-2003); B: phase 2 (2003-2007); C: phase 3 (after 2007)

Environmental parameters

Salinity, temperature and pH were measured insitu using HANA instruments; salintest model HI 98203 and pH-°C model HI 98127. In addition, one liter of water sample from each site was collected in plastic bottle for nutrient analysis. Nitrate, nitrite and dissolved phosphate were measured according to Standard Methods[6].

Plankton samples

One liter of water samples for qualitative and quantitative study of phytoplankton was collected from each site of the study area. All samples were preserved in 4% formalin, left to sediment, and counted using an inverted microscope[7] and Olympus microscope. In addition, macroalgae were collected where present from all sites to study epiphytic dinoflagellates present according GEOHAB[8].

RESULTS AND DISCUSSION

Water quality

The results of water quality are summarized in TABLE 1. Comparison between the pH, salinity and temperature during the three phases showed that there are no significant variations between them. The pH values are on the alkaline side ranging from 7.6 to 8.7, which fall within the normal range of sea water. Salinity ranged from 37 to 39.6 spu at all phases. The lower salinity was recorded during phase (2). Temperature in the three phases ranged from 26.2 to 31.2°C, the maximum temperature were recorded during phase (3).

On the other hand, nutrient concentrations showed remarkable differences between the three phases (TABLE 1). The lower nitrate concentrations were recorded during phase (1), ranging from 0.32 to 2.56 μmol^{-1}. A remarkable increase in nitrate was detected during phase (2), ranging from 3.43 to 22.37 μmol^{-1}. The higher concentrations were recorded at station (4), while the lower concentration was recorded at station (1). At phase (3), nitrate concentration began to decrease as the rate of exchange with the open sea increased. It ranged from 3.47 to12.67 μmol^{-1}. Although the nitrate concentrations were less than during phase (2), station (4) still characterized by its highest nitrate values.

Phosphate concentrations showed the same trend. Phosphate was very low during phase (1), ranging from 0.03 to 0.04 μmol^{-1}. It increased to reach 2.89 µmol-1during phase (2), decreased again at phase (3) with maximum concentration 2.4 µmol-1 (TABLE1). Nitrite concentration was low during phase (1), ranged from 0.01 to 0.03 μmol^{-1}, and increased during phase (2) and (3) until reaching 1.94 μmol^{-1}.

During phase (2), therefore higher nutrient concentrations and lower salinity values were recorded at the semi-closed areas (St 1 and 4).

TABLE 1 : Range of environmental parameters recorded during the three phases of coastal engineering

Parameter	Phase 1[9, 10]	Phase 2	Phase 3
Salinity (SPU)	37.8 – 39.2	37 – 39.6	37.8 – 39.5
Temperature (°C)	26.6 – 30.2	26.5 – 30	26.1 – 31.2
pH	7.64 – 8.34	8.1 – 8.6	8.1 – 8.7
Nitrate ($\mu mol\ l^{-1}$)	0.32 – 2.56	3.43 – 22.37	3.47 – 12.67
Nitrite ($\mu mol\ l^{-1}$)	0.01 – 0.03	0.35 – 1.91	0.82 – 1.91
Phosphate ($\mu mol\ l^{-1}$)	0.03 – 0.04	1.66 – 2.89	0.68 – 2.4

Phytoplankton community

Phase (1)

Information concerning phytoplankton community and distribution during this phase are completely absent. The monitoring program (CWMP) established in 1999 by the Egyptian Environmental Affair Agency (EEAA) and the Danish International

Development Assistance (DANIDA) monitored the hydrographical conditions (water temperature, dissolved oxygen, salinity and pH), bacteriological parameters (total coliform, *E. coli* and faecal *Streptococci* bacteria), in addition to eutrophication parameters (chlorophyll-a, total suspended matter, transparency, total nitrogen, nitrate, nitrite, ammonium, reactive and total phosphate and reactive phosphate). The monitoring results demonstrated that the public beaches of Alexandria were clean and unpolluted[9]. The measurement of eutrophication parameters reflected oligotrophic conditions in this area[10]. This area was also characterized by a well established and diversified macroalgal community[11].

Phase (2)

This phase was characterized by phytoplankton blooms as the nutrient concentrations were high. With increasing temperature during summer, these artificial lagoons became a suitable environment for algal blooms. Eighty eight species were recorded belonging to 6 groups; bacillariophyceae, dinophyceae, cyanophyceae, euglenophyceae, chrysophyceae and prasinophyceae. Among them 22 species are known to be potentially harmful (TABLE 2). These species are responsible for blooms at all stations during this phase.

The phytoplankton abundance during this phase ranged from 14 x 10^3 to 31.7 x 10^6 cell l^{-1} (Figure 3A). The density of the blooms was governed by the rate of exchange with the open sea. Lagoons with only one outlet to the sea were outstanding in their bloom density, in contrast with lagoons with more than one opening. The two openings in St 2 and 3 allowed the exchange of water and as a result the phytoplankton standing crop decreased.

TABLE 2 : Potentially harmful species and their range of abundance during the two phases. cells X 10^3. NR= not recorded

Harmful species	Phase 2	Phase 3
Cyanophyta		
Oscillatoria acutissima	0.17 – 806	0.18 – 0.64
Oscillatoria nigroviridis	0.26 – 1	0.17 – 0.4
Diatoms		
Asterionellopsis glacialis	0.11 – 82.4	NR
Bacillaria paxillifera	0.13 – 2.3	0.17 – 5.9
Bellerochea horologicalis	0.15 – 4020	0.12 – 6.2
Cyclotella meneginiana	0.15 – 27.4	0.16 – 0.54
Cylindrotheca closterium	0.15 – 300	NR
Leptocylindrus minimus	0.15 – 15.3	NR
Melosira nummuloides	0.54 – 23.8	1.9 – 2.1
Pseudonitzschia sp.	0.17 – 1702	0.4
Skeltonema costatum	0.12 – 63	NR
Dinoflagellates		
Alexandrium sp.	0.26 – 0.8	0.17 – 4.95
Amphidinium klebsii	0.42 – 99.6	NR
Lingulodinium polyedrum	0.17 – 0.31	NR
Ostreopsis sp.	NR	0.15 – 41.8
Peridinium quinquecorne	0.51 – 9909	0.17 – 2.98
Prorocentrum lima	0.11 – 9.1	0.12- 0.25
Prorocentrum micans	0.14 – 18.3	0.44
Prorocentrum minimum	0.27 – 2.2	0.18 – 6.1
Scrippsiella trochoidea	0.13 – 91.5	0.16 – 8
Euglenophytes		
Euglena sp.	0.15 – 0.45	0.17 – 13.9
Eutreptia sp.	0.27 – 2465	0.36- 13.9
Prasinophytes		
Micromonas pusilla	1.7 – 21792	0.54 - 905

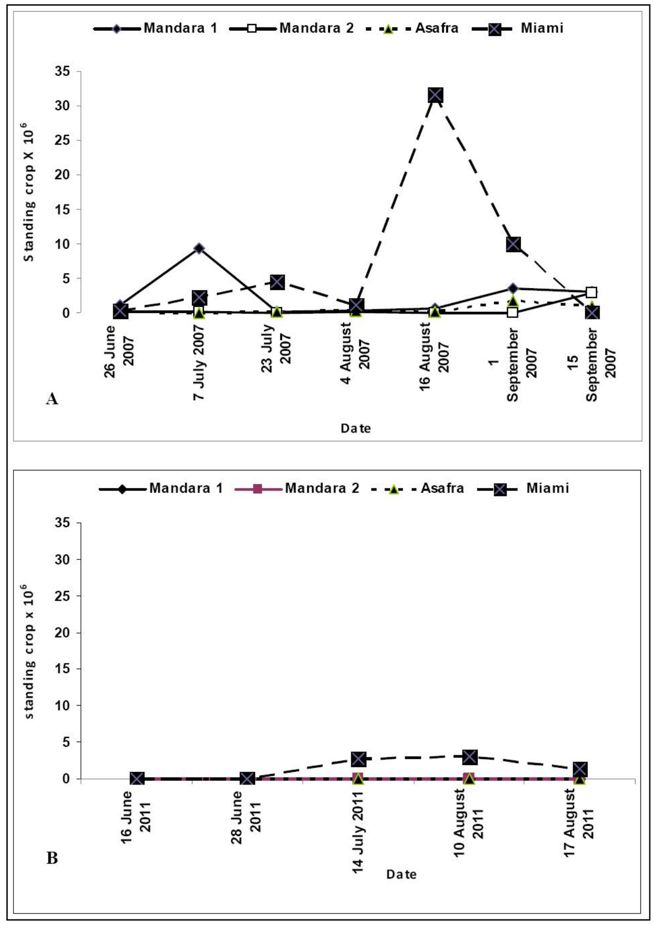

Figure 2 : Total phytoplankton abundance. A: phase 2 and B: phase 3

This phase was characterized by:

a) The first record of *Micromonas pusilla* (Figure 4a) in Alexandria waters forming a green tide, with a maximum standing crop reaching 21.8 x 10^6 cell l^{-1} at station (4).

b) The presence of *Peridinium quinquecorne* in the study area forming 4 blooms with maximum density 9.9 x 10^6 cell l^{-1}. According to the previous studies[12,13] the species was restricted to the Eastern Harbour west to this area with cysts of the species recorded from the harbor sediment[14]. It is the first record of this species in the open waters of Alexandria. This may be due to the transport of sediment with the species cyst to the area during this phase.

c) The blooms of *Micromonas pusilla* were always accompanied with the blooms of *Peridinium* *quinquicorne* (Figure 4b).

d) The dominant species were; *Micromonas pusilla*, *Peridinium quinquecorne*, *Pseudonitzschia* spp., *Bellerochea horologicalis*, *Oscillatoria acutissima* and *Eutreptia* sp.

e) Absence of macroalgal community.

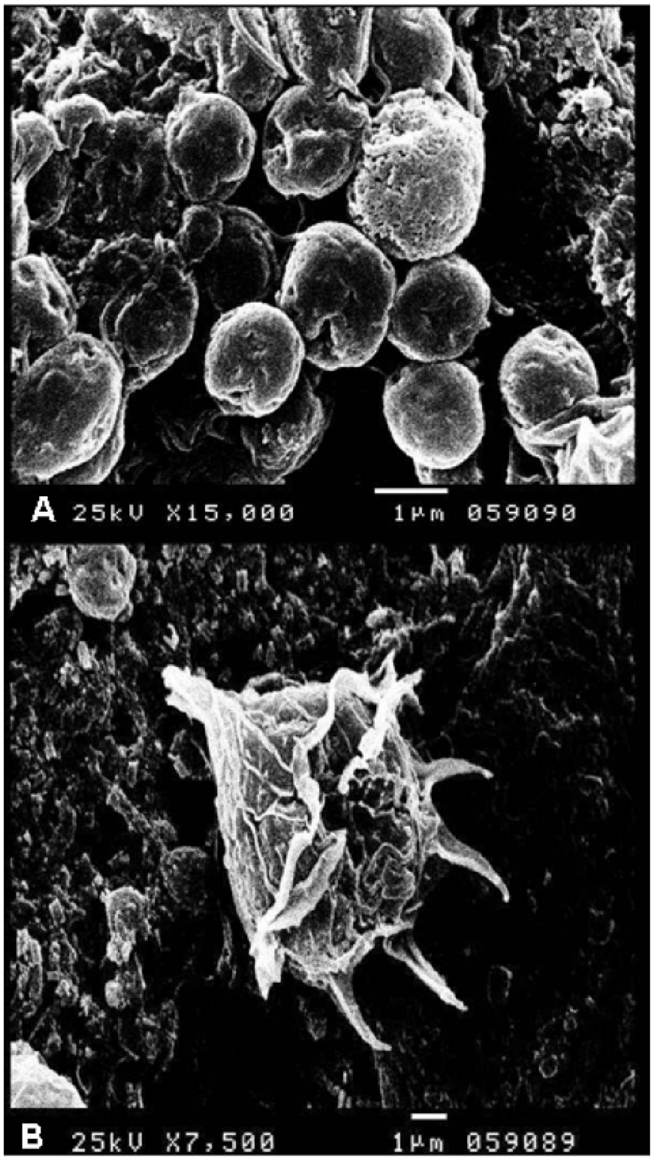

Figure 3 : SEM a) Micromonas pusilla b) Peridinium quinquecorne

The vital Egyptian industry that has a vulnerability to harmful algal blooms is local tourism. Historically, the bathing beaches and numerous cultural attractions in the Alexandria region have drawn over one million visitors each year[15]. The popularity of these tourist attractions is threatened by eutrophication and the increasing number of harmful species in the area[16]. The negative impacts of HABs on the tourism industry can be dramatic, with large scale economic losses to hotels and restaurants and other businesses in the immediate area, as well as more widespread depression of tourism in the region. Although the coastal engineering works in this phase were done to protect the beaches and encourage tourism, the effect was opposite. These artificial lagoons became subjected to different water quality problems leading not only to economic losses for the internal tourism sector, but also to human health threat from intake of pathogenic micro-organisms (bacteria and harmful dinoflagellates); direct contact with polluted sea water and beach sand; and consumption of seafood contaminated by toxic dinoflagellates, especially in bioaccumulating organisms such as filter feeders.

After 2007, the regional authority launched an innovative policy, aimed at reducing the harmful effects caused by the previous coastal modifications along the area of about 3.75 km.

Phase (3)

This phase was characterized by the remarkable decrease in phytoplankton abundanceand richness. The phytoplankton richness decreased to 55 species and the potentially harmful species decreased to 17 species (TABLE 2). The standing crop of phytoplankton ranged from 1.4×10^3 to 3×10^6 cell l^{-1} (Figure 3B), the decrease in abundance accompanied the decrease in nutrient concentrations. In addition, *Asterionellopsis glacialis*, *Cylindrotheca closterium*, *Leptocylindrus minimus*, *Skeltonema costatum*, *Amphidinium klebsii* and *Lingulodinium polyedrum* are completely absent (TABLE 2). During this phase, station (4) was the only station that supported phytoplankton blooms especially; *Micromonas pusilla* and *Peridinium quinquecorne*. The number of blooms dropped to three times only and there abundance decreased to 0.91×10^6 cell l-1 and 2.98×10^6 cell l^{-1}, respectively. Although this phase was characterized by a reduced number of harmful species, *Peridinium quinquecorne* became higher in its abundance than *Micromonas pusilla* presumably as its cysts became well established in the area.

Comparison between the dominant species reported during phases (2) and (3) showed that, although *Micromonas pusilla* formed a green tide during phase

(2) with 3 blooms recorded (Figure 6a), it dropped during phase (3) to one bloom (905 x 10^3 cell l^{-1}) recorded at St (4). *Pseudonitzschia* sp. which dominated the phytoplankton community during mid-September 2007 at St (1) with maximum abundance of 1.7 x 10^6 cell l^{-1}, it was recorded only once at St. (1) with a much lower abundance (400 cell l^{-1}) during phase (3). In addition, the continuous coastal engineering in the area leads to an increase in the harmful algal species along the Egyptian Mediterranean coast from 29 species[17] to 38 species.

CONCLUSIONS

A major problem along Alexandria shore line is beach erosion. Accordingly, the coast was subjected to coastal engineering modifications in order to prevent erosion and establish new recreational beaches (phases 1 and 2). Phase 3 consisted of corrective measures to mitigate the negative effects which appeared after phases 1 and 2.

During phase (1), the water quality and eutrophication parameters reflect oligotrophic conditions along the area of study. The coastal processes during phase (2) were done without preliminary impact assessment and lead to negative environmental effects. Semiclosed artificial lagoons were established and a green tide was formed for the first time along these lagoons due to their shallowness and the increase in nutrient concentrations.

In addition, several potentially harmful species became dominant in the area, leading to economical losses to the internal tourism.

The rate of water exchange with the open sea is the major factor affecting the density of the harmful blooms in these lagoons. Improving the water quality, minimizing the impact of harmful blooms and erosion were the main goals of phase (3). All elevated breakwaters, along stations (1), (2) and (3) became submerged to increase the water exchange with the offshore waters.

Although this phase showed a remarkable decrease both in nutrient concentrations and phytoplankton abundance, some harmful species remain well established in the area. This is a typical case showing the impacts of coastal modifications in the absence of well informed environmental assessment, involving the biological effects of partial stagnation.

In this particular case, successful corrective measures were taken to mitigate these impacts. The measures taken improved water exchange with the open sea, putting an end to the effects of partial stagnation of coastal lagoons.

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