Alexandrium minutum cysts in sediment cores from the Eastern Harbour of Alexandria, Egypt

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Abstract

Alexandrium minutum cysts were studied in sediment cores from its type locality, the Eastern Harbour of Alexandria, following the disappearance of the species from the plankton since 1994. Three cores were sampled in the summer of 1999 along the north-south axis of the harbour. The sediments were subjected to grain size analysis and their organic carbon content was determined. The sediments consisted of medium, coarse and very coarse sand. Grain size and organic carbon content were negatively and significantly correlated in core 1 but followed a parallel trend in cores 2 and 3. Seven dinoflagellate cysts, representing 6 genera were identified from the cores. Their relative abundance showed a remarkable difference. *A. minutum* cysts contributed a maximum of 17.4% to the total cysts. The distribution profile of *A. minutum* cysts in the cores reflects the bloom duration but not its productivity. The cyst distribution in the cores is the resultant of two opposite processes, the sedimentation rate and the continuous erosion of the bottom sediments, which is not related to sediment texture.

1. Introduction

Red tide blooms have become fairly frequent worldwide and dinoflagellates in particular are a subject of increasing interest. Their cyst stages allow for a better understanding of the mechanisms of occurrence, persistence and disappearance of many red tide blooms. The 'seed population' hypothesis of Steidinger (1975) has received worldwide acceptance. A 'seed population' consists of dinoflagellate resting cysts: dormant cells able to survive for long periods (even several years), which eventually inoculate the water column under favourable germination conditions (temperature, light, nutrients). In the Eastern Harbour of Alexandria this mechanism led to repeated outbreaks of *Alexandrium minutum* Halim blooms for many years in succession since the first observation in 1956 (Halim 1960). The recurrent heavy blooms and red tide outbreaks, caused mostly by this species, have been documented and described (Sultan 1975, Zaghloul 1988, Zaghloul & Halim 1990, Labib & Halim 1995). After its toxic outbreak in 1994 (Labib & Halim 1995) *A. minutum* appears to have gradually died out, being replaced by several other potentially harmful species. Its disappearance has been attributed by Ismael & Halim (2001) to erosional instability of the cyst-bearing bottom sediments due to active hydrodynamic forcing.

The present study is an attempt to answer a question of practical interest. Could the presence of *A. minutum* cysts in the deeper sediments of the Eastern Harbour eventually provide an inoculum leading to the reappearance of blooms. The paper describes, for the first time in Egypt, the distribution of *A. minutum* cysts in sediments from its type locality and examines the possible correlation between cyst accumulation and sediment texture.

2. Material and methods

The Eastern Harbour of Alexandria (E.H.) is a shallow, semi-enclosed embayment covering an area of about 2.8 km^2, located along the central part of Alexandria (Fig. 1). The southern part of the harbour has been reinforced by concrete blocks; the northern side is protected by an artificial breakwater with eastern and western inlets. It is bordered to the east by a land projection, El-Silsila, and to the northwest by a long causeway (El-Sayed & Khadr 1999). The bay has always been the recipient of large volumes of domestic waste water from several point sources. In 1996–1997, however, all outfalls but one were closed, the same volume of waste water now being disposed of through the remaining outfall on the south-west bay margin.

Three sediment cores 18 cm long, 3.5 cm in diameter were collected in the summer of 1999 from three equidistant stations along the north-south axis of the harbour (Fig. 1). The cores were immediately refrigerated until cyst analysis. Each core was sliced into 2 cm sections, subjected to grain size analysis following Folk & Ward (1957) and their organic carbon content

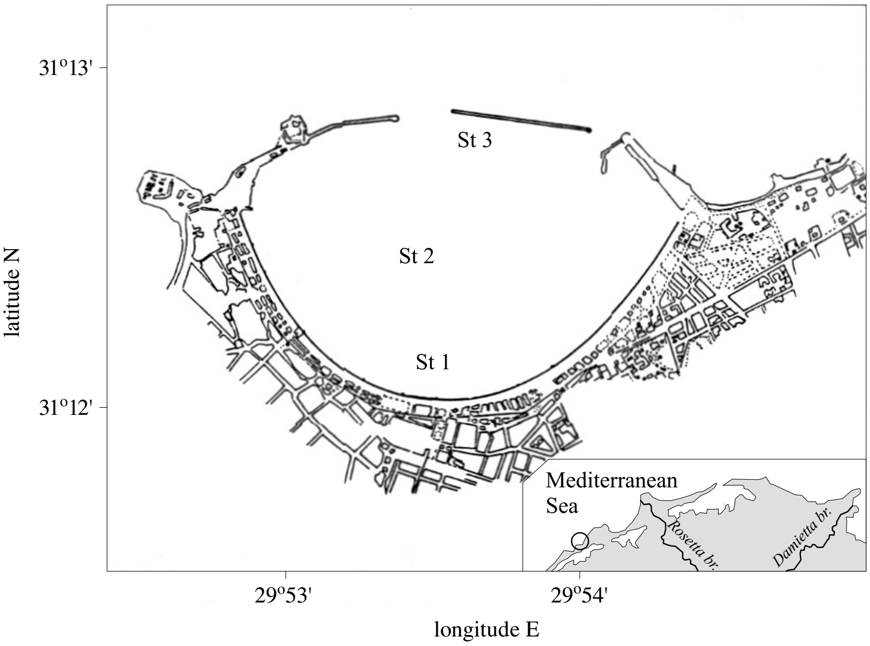

Fig. 1. Location of sampling sites in the Eastern Harbour during summer 1999

determined according to El-Wakeel & Riley (1957). The fractions retained by a 20 μm sieve were sonicated for 2 minutes to dislodge detrital particles and then examined microscopically under an inverted microscope (Matsuoka et al. 1989). In the meantime, subsamples were oven-dried at 60°C to obtain the wet/dry weight ratio. The results are given as the number of cysts per gram dry weight of the sediment (Matsuoka 2001). All statistical correlations were applied using the Excel program version 5.

3. Results

The study of the three cores reveals that core 1 is totally different in sediment texture and OC content from the other two. It is located in the sink area, immediately downstream from the outfall. In this core, there is a gradual increase in grain size from top to bottom. In the surface layers the finer size, expressed as silt, is the most abundant one. The grain size becomes coarser with depth until it reaches medium sand size. The OC% decreases from 5.4% in the uppermost layer to 0.7% in the bottom layer. There is a clear-cut seasonal trend in OC content, the sinking rate accelerating during summer, the season of maximum sewage outflow. Winter brings an apparent reversal in the OC%, as the oxidation rate at the sediment-water interface exceeds the rate of sewage deposition. In cores 2 and 3, medium, coarse and very coarse sand are the only three classes present. The OC% in both cores are low and comparable, from 0.35 to 0.54. The OC% increased in the deepest layer in core 3 (14 to 18 cm), reaching 1.38%. While there is a negative and significant correlation between OC% and grain size in core 1, the OC% in cores 2 and 3 follows the grain size distribution along the two cores. The organic carbon increased in the grain size range from 0.4 to 0.5 μm (Fig. 2). There is a striking coincidence between the OC% and the stratification of the dinoflagellate

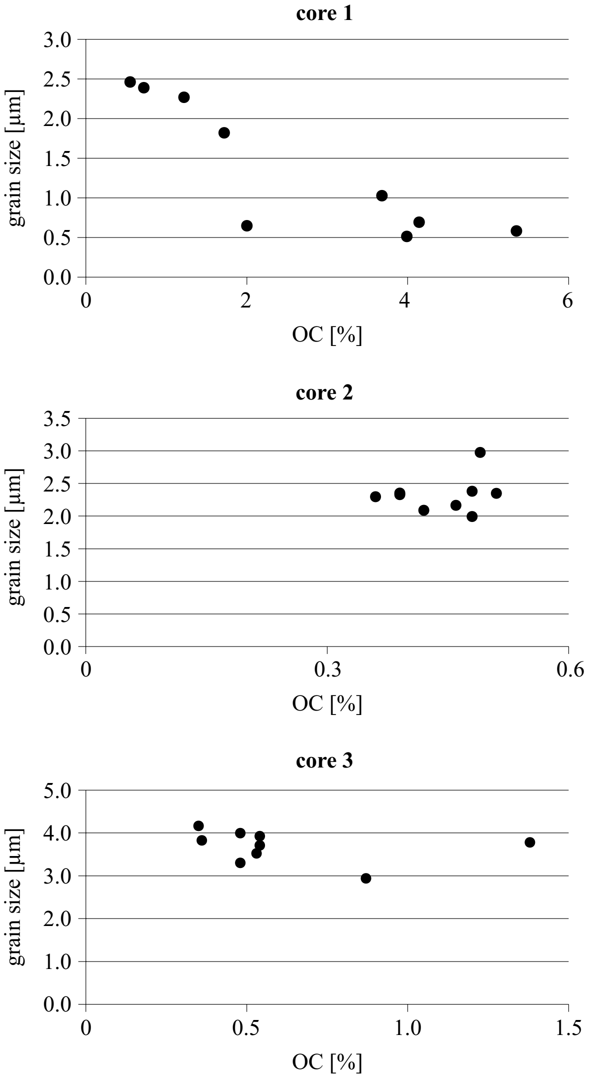

Fig. 2. Distribution of organic carbon content (OC%) and grain size in the cores

cysts in core 1. The profile of cyst abundance is also seasonally clear-cut in this core, with an increased rate of cyst deposition at the end of the summer blooming season followed by a slowdown in winter (Fig. 3).

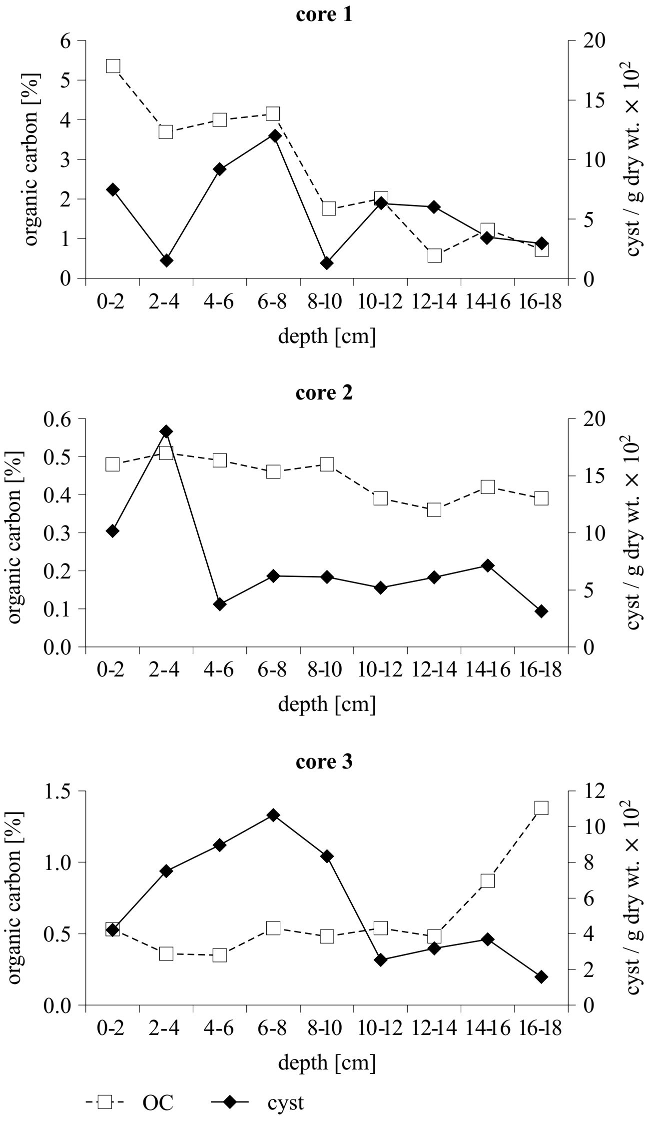

Fig. 3. Distribution of organic carbon content (OC%) and dinoflagellate cysts in the cores

Seven dinoflagellate cysts, representing 6 genera, were identified from the cores. Their relative abundance showed remarkable differences between the three cores (Fig. 4). *Pyrophacus* sp. cysts were dominant in core 1, but

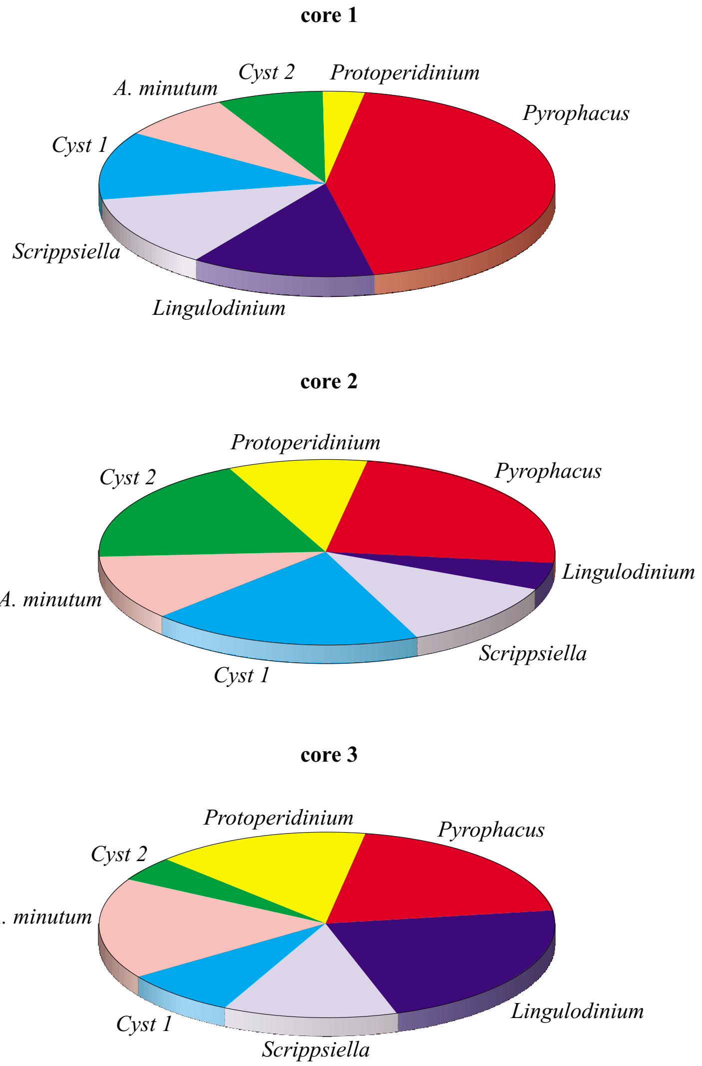

Fig. 4. The distribution of dinoflagellate cysts in the cores

decreasing in both cores 2 and 3. *Protoperidinium* sp. and *A. minutum* cysts followed the opposite trend, while *Scrippsiella* sp. cysts were comparable in abundance between the three cores. *Pyrophacus* sp. ranged from 19.7% to 44%, *Lingulodinium* sp. from 4.7 to 22.5%, undetermined cyst 1 from 8.4 to 19.2%, undetermined cyst 2 from 4.3 to 18.8%, *Scrippsiella* sp. from 11.8 to 12.5%, and *Protoperidinium* sp. from 3 to 15.4%. On the other hand, *A. minutum* cysts ranged from 8 to 17.4%. Their highest percentage occurred in core 3, the lowest in core 1. The vertical stratification of *A. minutum* cysts displayed two peaks (Fig. 5). The duration of the two

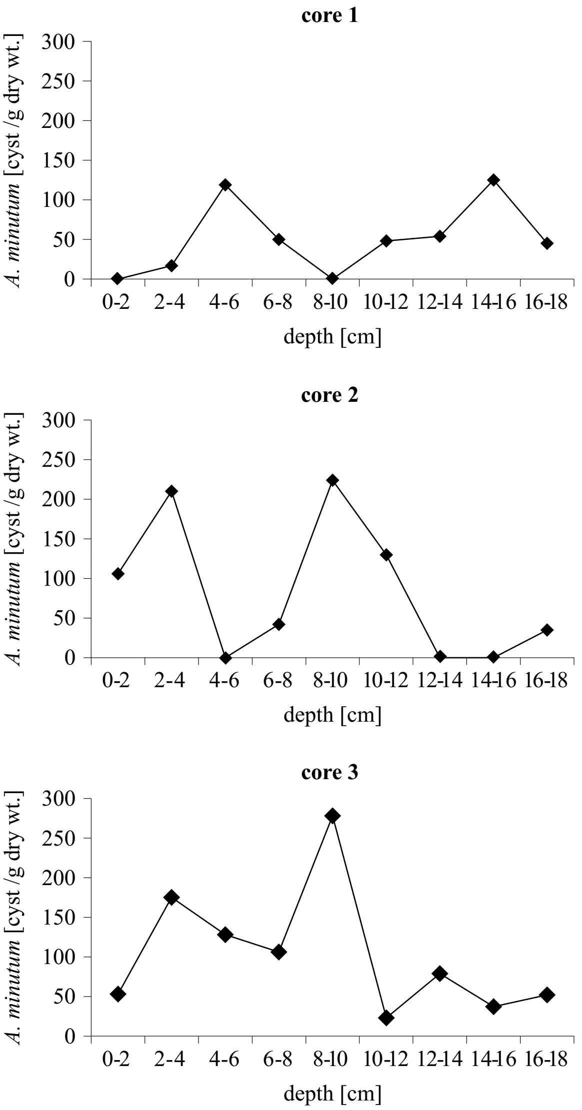

Fig. 5. Vertical distribution of *Alexandrium minutum* cysts in the cores

peaks was comparable for cores 2 and 3, but different in core 1. In core 1, the two peaks (119 and 125 cyst g^{-1} dry wt.) were found at the respective depths of 4–6 cm and 14–16 cm. No *A. minutum* cysts were found in the uppermost layer. The cyst abundance in the other layers did not exceed 45 cyst g^{-1} dry wt. In the other two cores, the two peaks of *A. minutum* cysts were found at the corresponding depths of 2–4 cm and 8–10 cm (224 and 210 cyst g^{-1} dry wt. in core 2 and 278 to 175 cyst g^{-1} dry wt. in core 3 respectively). The uppermost layer, corresponding to the sampling year 1999, is poorer (105 and 53 cyst g^{-1} dry wt. respectively in cores 2 and 3). Between the two peaks, the cyst concentration dropped to zero in core 2 and to 106 cyst g^{-1} dry wt. in core 3.

4. Discussion

The Eastern Harbour of Alexandria is subjected to two opposite processes. One is the continuous inflow of waste water at a rate of 15×10^3 m^3 d^{-1} (Nessim 1994), which has resulted in a high sedimentation rate in the sink area of about 6 cm $year^{-1}$ (Ismael et al. 2001). The other factor is the continuous erosion of the bottom sediments along the mid-harbour. The long-term average rate of erosion along the central axis of the harbour was found to be about 13 cm $year^{-1}$ (El-Fishawi et al. 1993). On the other hand, the rate of cyst deposition is governed by cyst productivity, current transport and bioturbation, as also stated by Matsuoka (2001). In the present study, it was difficult to determine the sedimentation rate from core samples and also impossible to estimate the biological and hydrodynamic disturbance occurring there. The organic carbon content in continental shelf sediments is estimated to be generally less than 2%, but could exceed 3 or 4% near waste water discharge outlets (Fernex et al. 2001). The OC% content in the three sediment cores studied showed contrasting results. With the continuous sewage inflow, the OC% was high in the sink area (core 1), but very low in the other two cores in comparison with previous observations in the Eastern Harbour and offshore (Table 1).

Table 1. Average percentage of organic carbon in surface sediments along the Egyptian Mediterranean Coast

OC content	Site	Reference
	Eastern Harbour	present study
5.4	Sink area	
0.51	Central axis	
3.4	Eastern Harbour	El-Wakeel & El-Sayed (1978)
0.57	Mex Bay	Badr El-Din (1998)
0.39	Miami beach	
0.16	West from Alexandria	Dughiem (2002)

El-Sayed & Khadr (1999) found the texture of the harbour sediments to vary from fine to coarse sand, with a mean size of 1.92 φ unit. The silty sand deposits covering the central part of the harbour are an exception. This is confirmed by the present results, as the grain size analysis showed that, except for core 1, medium, coarse and very coarse sand are predominant in the harbour. Our results show that there is no relationship between the sediment texture and the cyst distribution in the cores. The sedimentation rate and the continuous erosion are the only factors affecting the distribution of *A. minutum* cyst in the harbour sediments.

Two questions arise:

1. Does the abundance of *A. minutum* cysts in the sediments reflect the real productivity of blooms and their duration?

The cyst profile of *A. minutum* showed two peaks in both cores 2 and 3, which can be safely assumed to correspond to the blooms of 1987 and 1994. In 1987, an extensive bloom developed in May–June reaching an average of 6×10^6 cells l^{-1} (Zaghloul & Halim 1992), while in 1994 (the last major bloom of this species in the Eastern Harbour) standing crop reached 24×10^6 cells l^{-1} (Labib & Halim 1995). The period between the two peaks showed a remarkable decrease in cyst concentration. This is compatible with plankton observations. In 1989–1990, *A. minutum* did not exceed 7500 cells l^{-1} in the harbour (Ismael 1993), and no blooms were observed in 1991 (Labib 1994). On the other hand, the abundance of cysts during the two peaks is not proportional to the magnitude of the respective blooms. This may be due to the hydrodynamic forces affecting the bottom sediment and current transport. The cyst abundances in the cores appear to reflect bloom duration rather than bloom productivity. This is in agreement with Matsuoka (2001), who concluded that cyst concentrations are not a direct measure of productivity.

2. Does the distribution of *A. minutum* cysts in sediments confirm their disappearance from their type locality?

In their study of the distribution pattern of *A. minutum* cysts in sediment cores from the Brittany Coast, France, Erard-Le Denn et al. (1993) found the spatial distribution of resting cysts to be in a direct relationship with the occurrence of toxic blooms. Cyst distribution was higher at 7 cm. They also found that the high sedimentation rate tends to bury the cysts but the effects of resuspension, sedimentation, tidal scour and bioturbation were found difficult to differentiate. Given the unstable conditions of the bottom sediments in the Eastern Harbour, there is a dynamic and unstable equilibrium between erosion and sedimentation. Given the depth and time interval between the two peaks (depth interval in both cores – 60 mm, time interval – 7 years), it appears that the resultant rate of sedimentation is 8.5 mm year^{-1}. El-Fishawi et al. (1993) found that in the long term, about

70% of the eroded material escapes from the harbour while the remaining 30% becomes deposited in the marginal areas of the harbour. This pattern leads us to think of two likely scenarios. According to the first one, the surface layer will eventually be scoured, so that the cyst-bearing layer below it will become exposed and reinoculate the water column. In the second, the scoured material, including the cyst-bearing sediment, will be transported to marginal areas, where it would be rapidly reburied under more scoured material and other material carried in by inflowing waste water. With the absence of the species from the plankton samples since 1994 (Ismael & Halim 2001, Jammo 2001), the latter process appears to be the more likely one.

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