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FULL LENGTH ARTICLE

Tolerance of benthic foraminifera to anthropogenic stressors from three sites of the Egyptian coasts

Amani Badawi *, Wafaa El-Menhawey

National Institute of Oceanography and Fisheries (NIOF), Al Anfushi 21556, Alexandria, Egypt

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Abstract Surely the coupling of natural and anthropogenic stressors combined with a lack of regulation resulted in the current threat to a large part of coastal marine biodiversity as well as coastal human societies, particularly in highly populated regions. The distribution pattern of benthic foraminifera as sensitive bio-indicator is utilized to assess human-induced impact on the coastal area, at Alexandria, Port Said and Suez cites of Egypt. Twenty-two benthic foraminiferal genera were identified and complied by principal component analysis into four factors through cluster analysis. Cross correlation of the generic composition, distribution and relative abundance of common genera in the three investigated cores revealed three different coastal environments entities. The categorized environment ranged from light human impact as Alexandria site to heavily impacted by human activities as Port Said and Suez sites. Fauna of Alexandria site reflects an increase in unpolluted water activity revealing high-energy erosive environment. The second entity involves Port Said site, which represents a highly stressed coastal environment, corresponding to high-energy transport conditions influenced by fresh water flush from local Manzala Lake via Bougaz El Gamel outlet while Suez site is influenced by marine hypersaline water coupling with intensified levels of industrial and domestic pollution, attributed to the anthropogenic impact.

Introduction

Benthic foraminifera are good ecosystem monitors due to the comprehensive information on their ecology from different marine environments, which provide many valuable clues to their ecosystems. In addition, they are abundant as they are widely distributed in all marine environments and relatively diverse populations, are durable as their tests are known to exhibit a high fossilization potential (Murray, 1991), and are easy to collect and separate from sediment samples. Benthic foraminifera represent a group of bottom-dwelling single-celled marine organisms, which either prefers to live at the sediment/water interface (epifaunal) or in the sediment (infaunal). Several studies used benthic foraminifera, as environmental variation factors that clearly impacted benthic foraminiferal distribution and frequencies, particularly productivity, bottom water oxygenation, thermo-haline structure of the water body and its bottom-water circulation (e.g. Duplessy et al., 1988; Mackensen et al., 1994; Hemleben et al., 1996; Schmiedl et al., 1998; Bickert and Wefer 1999; Badawi et al., 2005; Hamouda and Awad, 2012; Hamouda et al., 2014 and Badawi, 2015).

* Corresponding author.
E-mail address: amani_badawi@yahoo.com (A. Badawi).
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The increasing destruction of natural habitats causes huge impacts to ecosystems across the globe (Roberts and Hawkins, 1999).

In Egypt, Intense coastal development and the inevitable consequence of economic progress, associated with improper management have been affecting the biodiversity of pelagic and benthic communities, followed by possible extinctions. Several studies were focused on coastal water pollution by trace metals, mainly resulting from disposal of industrial wastes, and agricultural runoff into marine water, (e.g. El-Sayed et al., 1979; El-Nady, 1996a,b; El-Rayis et al., 1997; Fahmy et al., 1997; Hamouda et al., 2014). Unlikely, little concern has been paid to the study of benthic foraminifera from the Egyptian coasts (e.g. Said and Kamel, 1954, 1957; Samir and El-Din, 2001).

The present work is devoted to study the coastal ecosystem along three studied sites (two sites along the Egyptian Mediterranean coast and one site from the Gulf of Suez) which presented independent geographic locations and consequently different environmental conditions, concerning mainly, wind intensity, sea-level changes and erosion. The regional comparison between the two sites located along the Mediterranean Sea and one site from Suez Canal indicates a distinct gradient in ecosystem and controlling factors.

Historically speaking, Red Sea and Mediterranean were linked through artificial Suez Canal, (constructed in 1869) and created the first salt-water passage between the Red Sea and Mediterranean allowing the faunal migration through it. Moreover, Egyptian Mediterranean coast recently suffered from severe erosion, in particular after the construction of Aswan High Dam in 1964 (Frihy et al. 1991; Hamouda and Abdel-Salam 2010; Hamouda et al., 2014). Significant coastal changes have been reported due to the reduction in the Nile sediment discharge, which diminished to near zero, combined with natural factors including delta subsidence, sea level rise and strong coastal current processes (Stanley, 1990; Stanley and Warne 1993 and Fanos et al., 1995). The objective of this study is to generate cross correlation of the coastal ecosystem variations along the three selected significant sites in Mediterranean coast and Gulf of Suez, in terms of the temporal distribution of benthic foraminifera to define the specific anthropogenic stressors influencing each ecosystem.

Study area

The studied areas include three sites, first site located along the Alexandria coast, at 31.28701°N, 30.0187°E, 15 m water depth, with a core recovery of 79 cm. Second site located Port Said coast, at 31.27858°N, 32.3268°E, 2.5 m water depth, with a core recovery of 80 cm. While the third one is located in Suez coast, at 29.88322°N, 32.60167°E, 15 m water depth, with a core recovery of 60 cm (Fig. 1).

Materials and methods

The recovered sediment cores were sampled at 5 cm intervals with the top 1 cm of each interval split separately for foraminifera study, with 37 sediment samples. For micro paleontological analysis, each sample (3–5) g of sediment was wet sieved through a 63 mm mesh sieve, and oven dried at 40 °C. Subsequently, the samples will be dry-sieved into the fractions < 125 mm and investigated for their benthic foraminiferal content. Benthic foraminifera genera were identified according to Loeblich and Tappan (1988), and counted with the aid of a binocular microscope. The recorded data sets are treated statistically and interpreted relative to environmental parameters to provide an image of the coastal bottom ecosystems in different locations. Relative abundance was calculated to facilitate the comparison of the data sets providing percentage of the most frequent genera with respect to the total numbers of benthic foraminifera in those samples.

Statistical methods (principal component analysis)

Multivariate statistical analyses (R-mode factor analysis and Q-mode cluster analysis) were applied to the statistically significant fractional abundance values. Statistically significant genera were considered as those with abundance $\geqslant$5% even in one sample or 2% in at least 2 samples, (Schmiedl et al., 1998). Q-mode cluster analysis was performed by using Ward's method (Schubö and Ühlinger, 1986) using Euclidean distance as similarity index. Factor analysis is a multivariate statistical technique that is used to compile applied data set to a few main components (factors) that represent the relationship among sets of many interrelated variables.

R-mode factor analysis was carried out on the benthic foraminiferal data set, using the program Statistica, V.5.1 (1996).

Results

The sediments of the three cores consist primarily of gray to pale brown fine grain sediments with high carbonate content. Visually the lithological changes were minor along the studied cores., Alexandria short core is composed of a mixture of shell, shell fragments (mollusks and pelecypods), foraminifera and quartz grains of coarse sands size (typical buff color of Alexandria beach sands). While Port Said short core is composed of silts of gray color mixed with few pelecypod shells and shell fragments (typical of Nile Delta deposits). Port Said core is characterized by 3–6 cm thickness common with Pteropod ooze, pelecypod shell and shell fragments at 53 cm depth from the top of the core. Suez short core is composed of light gray mud mostly clays. There is no variation in the lithology of the core from top to bottom.

Foraminiferal populations mainly consisted of benthic species. Planktonic species were very rare, due to the shallow water in the investigated areas. Totally, 22 benthic foraminiferal genera were recorded in the investigated cores. Significant variations in benthic foraminiferal number and relative abundance have been recorded along the investigated cores, suggesting a geographic gradient of environmental conditions. In General, Benthic foraminiferal fauna primarily composed of porcellaneous and hyaline forms comprising of 73% and 27%, respectively. Alexandria core exhibits the highest dominance of foraminiferal population compared to the Suez one, which is considered moderate. Port Said core sediments are reported very poor in foraminiferal fauna with minor vertical variation. In Alexandria core, the predominant genera are *Quinqueloculina, Triloculina, Amphistegina*, *Elphidium*, *Adelosina* and *Peneroplis*. The benthic foraminiferal number is generally decreased from the core bottom to the surface samples, associated with a rather constant diversity, (Fig. 2). The

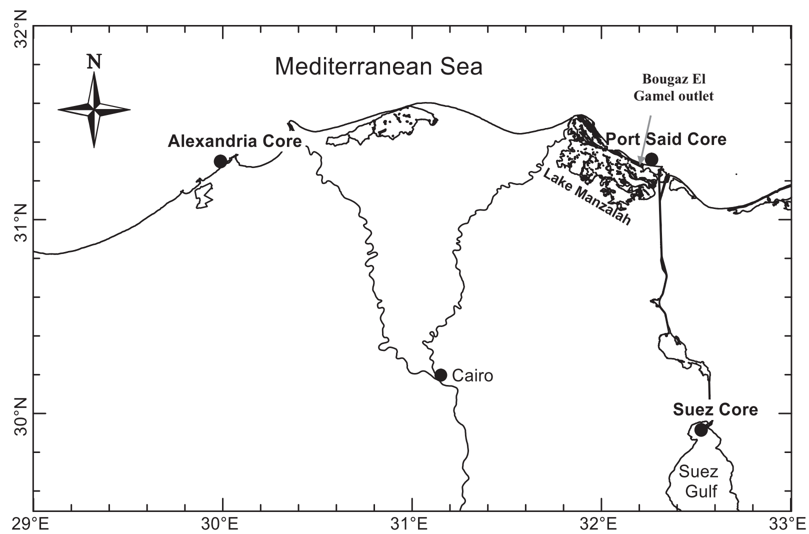

Figure 1 The location of the three collected short core samples along the study area.

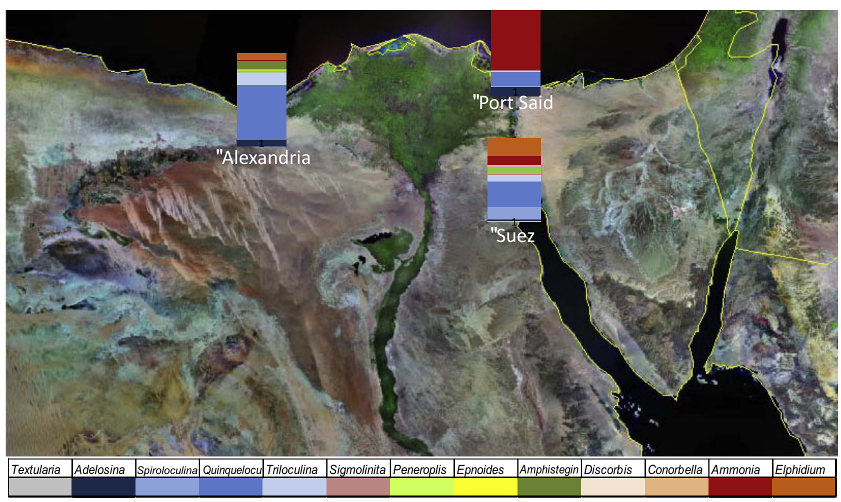

Figure 2 Percentage of the most common foraminiferal genera in the investigated short-cores.

fauna is dominated by *Quinqueloculina*, which represents 58.8% of the total assemblage, as the most abundant and widely distributed genus. *Adelosina*, *Triloculina* and *Elphidium* are homogenously distributed with an abundance ranging from 5% to 18% of the total assemblage. The vertical distribution of *Amphistegina* and *peneroplis* fluctuated throughout the core length, *Amphistegina* reaching about 19% of the total assemblage at surface sample, while *Peneroplis* reaching about 8% of the total assemblage at 30 cm core depth. Port Said core is characterized by poor to very poor benthic foraminiferal abundance, which is represented mainly by small specimens with weak and fragile tests. The faunas of Port Said differ considerably from those at Alexandria site. The identified predominant genera are *Ammonia* which comprises of 70.2% of the total fauna, followed by *Quinqueloculina* and *Adelosina* with 16% and 10.9%, respectively, (Fig. 2). The core sediments were characterized by the highest value of sand content (100%) and the lowest value of clay (0%). In addition, extremely low organic carbon and carbonate content were recorded. In Suez core, the predominant genera are *Quinqueloculina* (29.3%), *Elphidium* (20.3%), *Spiroloculina* (14.3%), *Ammonia* (10.9%), *Triloculina* (7.8%), *Peneroplis* (7.8%) and *Adelosina* (2.1%) (Fig. 2). *Quinqueloculina* is the most frequent genus throughout the core, it is more frequent at the bottom of the core (50 cm) in somewhat coarser-grained sediment, and decreased upward, which are characterized by relatively finer sediment. *Elphidium* vertical distribution exhibits upward increasing trend, it ranges from 9.2% at 50 cm core depth to 27.8% at 15 cm. On the other hand, *Adelosina* and *Triloculina* have upward decreasing trend, with frequency ranging from maximum of 13.9% and 11.3% and minimum of 2.7% and 5.4% respectively. *Peneroplis* ranges from 7.4% at 15 cm to 12.9% at the top of the core. *Ammonia* is represented at the top section of the core, from the sample at 15 cm to the surface one. Down to 15 cm core depth, its occurrence is poor and represented mainly by small specimens, with weak and fragile tests. The vertical variation in the distributional pattern of the most common genera demonstrates three different assemblages and each of them represents a certain site with remarkable faunal changes (Fig. 3). Alexandria assemblage is richer

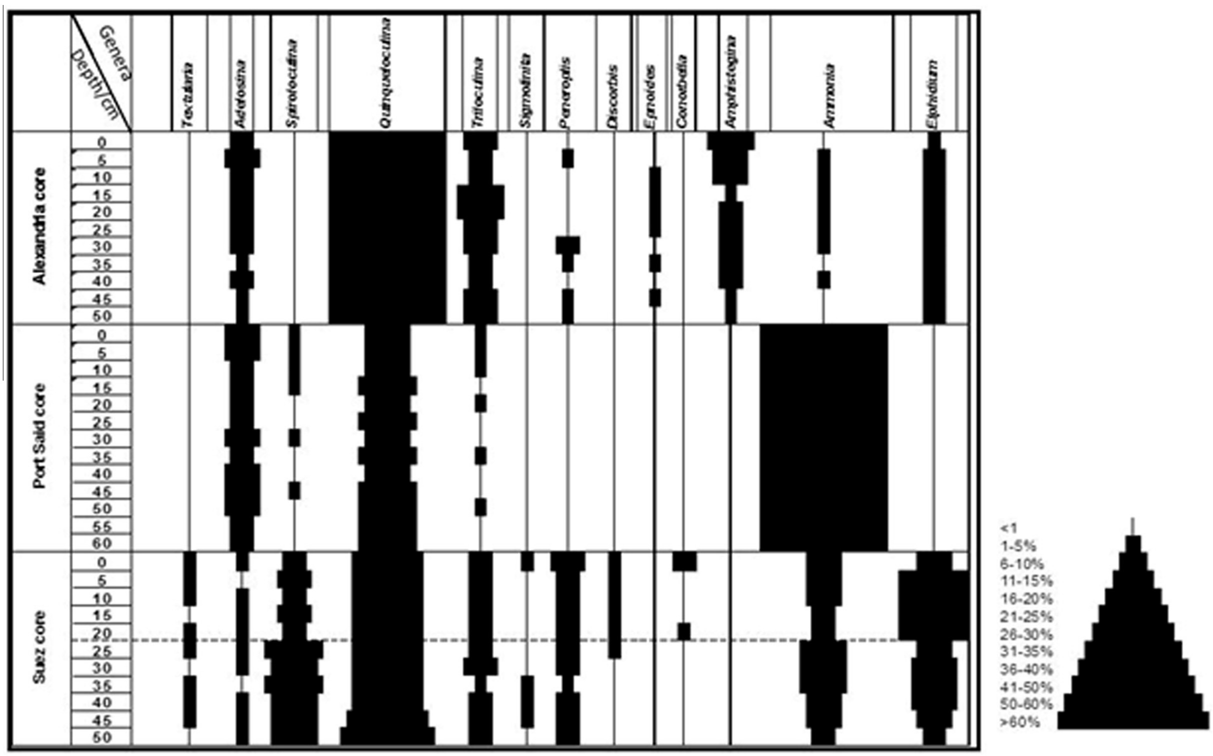

Figure 3 Vertical distribution Pattern of the most common genera in the investigated short-cores.

in forms related to genus *Adelosina*, *Quinqueloculina* and *Triloculina*. It is found that *Amphistegina* is confined to Alexandria site since it has not been recognized from either Port Said or Suez core samples. Port Said assemblage characterized by extreme poverty of foraminiferal faunas represented mainly by *Ammonia* In Suez core assemblage some genera like *Spiroloculina*, *Peneroplis* and *Elphidium* remarkably increased in their abundance, while other genera as *Sigmolinita* and *Discorbis* were only significant to Suez site as they were not detected in neither Alexandria nor Port Said cores.

Multivariate statistical analyses

The Q mode cluster analysis applied to the investigated sites, as they contain genera with relative abundances higher than 1% of total abundance, resulting in grouping the samples into three separate clusters (A, B and C) where each of them represents a specific area. Cluster A includes Alexandria site whereas Cluster B embraces Suez site, and cluster C represents Port Said site, (Fig. 4). Out of 22 foraminiferal genera were observed in this study, only those deemed statistically significant (13 genera) were used in the factor and cluster analyses. Factor analysis reduced the data set of benthic fauna to four factors as shown in (Fig. 5). R-mode factor analysis was carried out based on the percentages of the significant genera (13 genera). The factor-loading matrix is useful in establishing a quantitative link between generic assemblages and aspects of the environment. Genera with strong loadings ($\geqslant$0.5 positive or negative) were used in identifying the most effective environmental factors. R-mode factor analysis revealed that 85.5% of total variance could be explained by the first four factors in particular, the eigenvalues of factor 1 (47.5% of

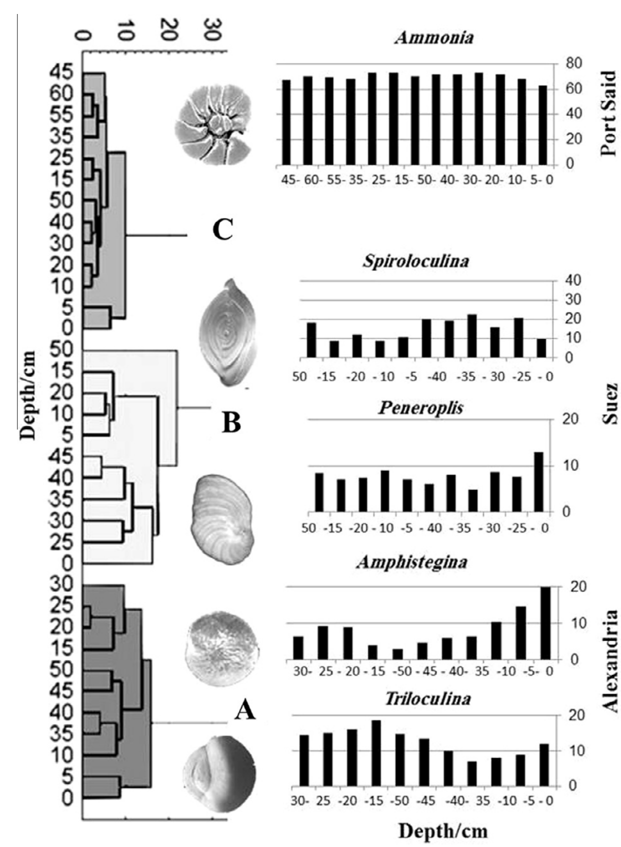

Figure 4 Dendrogram of Q-mode cluster analysis in the investigated short-cores.

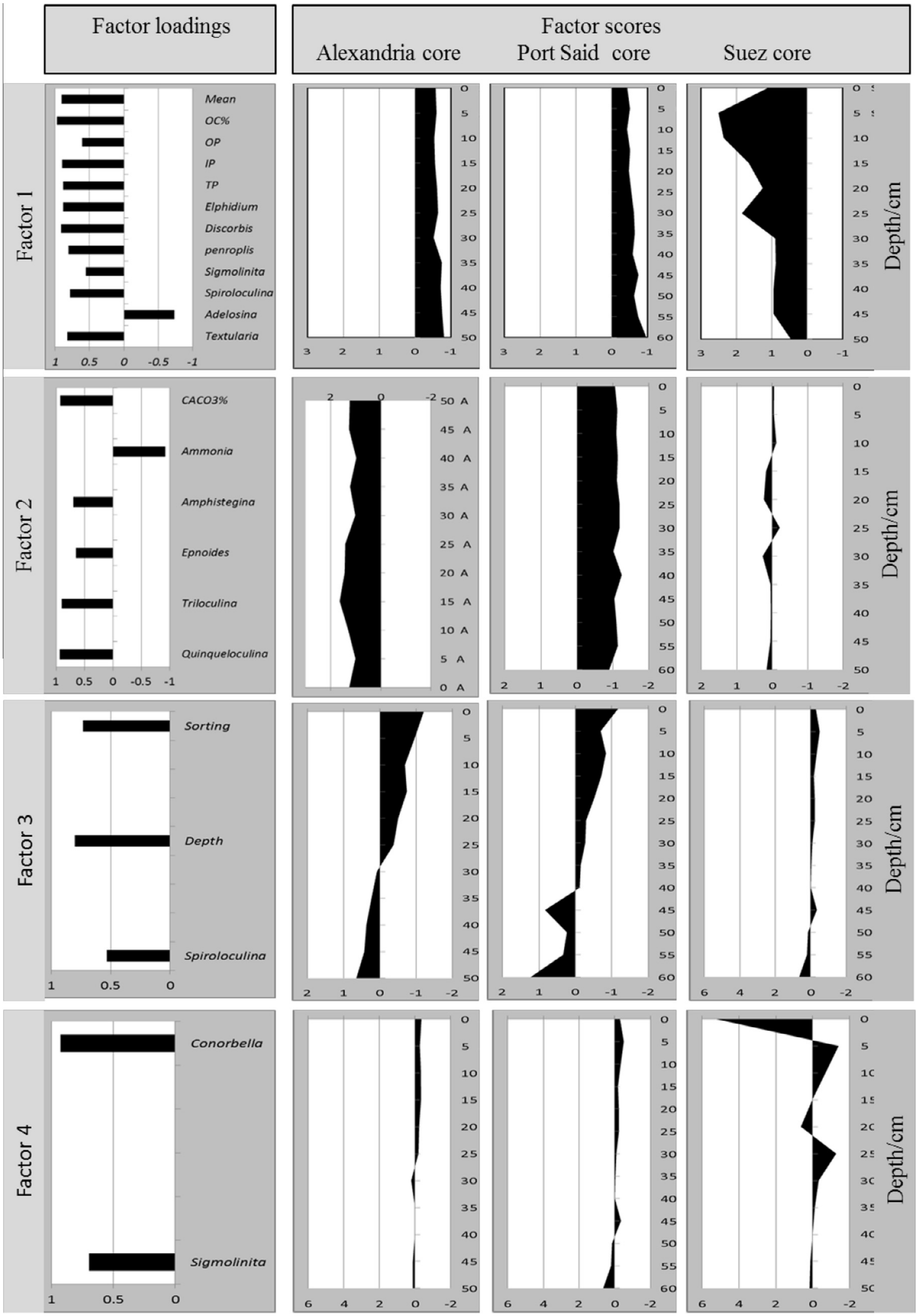

Figure 5 Factor Analysis of the investigated short-cores.

the total variance), factor 2 (22.4% of the total variance), factor 3 (9.5% of the total variance) and factor 4 (6% of the total variance).

Factor 1 (Peneroplis, Discorbis and Elphidium with nutrient and OC%)

The predominant elements in the first factor are *Textularia, Spiroloculina, Sigmolinita, Peneroplis, Discorbis* and *Elphidium*. Factor scores plotting is best developed within the upper samples of Suez core (0–25 cm).

Factor 2 (Quinqueloculina, and Amphistegina with CaCo3)

The contributions to the second component are due mainly to *Quinqueloculina, Triloculina* and *Amphistegina* Factor scores plotting, shows that the highest significant values are typical for samples from carbonate inner-shelf with highest percentage of *Amphistegina*, which are recorded at the upper samples in Alexandria core (0–35 cm).

Factor 3 (Spiroloculina with depth and sorting)

Spiroloculina dominated the third component with core depth and sorting. The factor scores plotting shows that this factor is more significant below 25 cm core depth in Suez area.

Factor 4 (Sigmolinita and Conerbella)

Sigmolinita and *Conerbella* are the predominant elements in the fourth factor. Factor scores plotting shows that the highest significant values are typical for the upper most sample at Suez core.

Discussion

Environmental variability is the main limiting factor for the benthic fauna abundance and distribution. The test of foraminifers has high preservation potential, as such; it provides useful proxy for the long as well as short-term temporal variation in the marine environments, in particular the near-shore coastal areas. Knowing that the reproduction cycle of foraminifera is relatively short, ranging from 3 months to 2 years, short-term environmental changes are recorded in the sediment by its calcified tests. In an area of a high sedimentation rate such as "2 mm/year", (Frihy et al., 1991), a sediment core of 20 cm length represents about 100 years of sedimentation, and consequently associated foraminiferal test-layer reflects its relevant environmental conditions. According to (Frihy et al., 1991), it is assumed that Alexandria core roughly covered the last 275 years, while Port Said core and Suez core might cover about the last 300 and 250 years, respectively.

Benthic foraminiferal assemblages of Alexandria core well reflect site environment variability, represent typical near-shore environments that are clear from industrial pollution as well as impacted by domestic wastes. In General, un-polluted, oligotrophic and well-ventilated environment is clearly posted by the dominance of epifaunal, marine shelf and pollution-sensitive taxa, as miliolids (*Quinqueloculina* and *Triloculina*), (Fig. 6). They are living in marine hypersaline water (32–65%), (Murray, 1991), and reported as less tolerant to pollution, (Rao and Rao, 1979). Factor scores plotting of factor 2, showed that the highest significant values are typical for samples from carbonate inner-shelf with highest percentage of *Amphistegina* that are recorded at the upper samples in Alexandria core (0–35 cm). *Amphistegina* is a phytal, epifaunal genus living free on coarse carbonate sediments in marine environment with temperature generally > 20 °C and water depth range of 0–130 m. *Amphistegina* is particularly abundant and flourishes in warm, clean shallow water with sea grasses (Reiss and Hottinger, 1984; Murray, 1991). Accordingly, factor 2 represents normal marine inner shelf having active water energy, hard substrate (algae) and carbonate bottom sediments. Flourishing of algal-bearing foraminifera as *Amphistegina* and *Peneroplis* at top samples as demonstrated by factor 2, and poverty of fauna reflect increase in water activity revealing high-energy erosive environment. Improvement in water clarity and transparency at younger samples could be corresponding to the diminishing of Nile river discharge to Mediterranean coast post construction of Aswan High Dam in 1964.

Port Said study area has specific characters; it is very shallow, under the direct influence of Manzala Lake freshwater discharge via Bougaz El Gamel outlet, (Fig. 1). It is indicative of freshwater discharge resulting in strong and continuous wash out of sea bed sediment. The faunas of Port Said core differ considerably from those at Alexandria site, although both sites are located along Mediterranean cost, (Fig. 6). These faunas are characterized by none-to rare retrieval of foraminifera, low density, reduce diversity and poorly preserved tests, (abraded and rounded). The fauna is dominated by salinity and temperature-tolerant shallow infaunal genera *Ammonia*.

Ammonia is living freely in muddy sediments with water depth of 0–50 m and water salinity 0–70% (brackish to hypersaline). It is considered as eurotrophic- euhaline and Isobathal genus indicative of coastal area, (Murray, 1991). Port Said core samples recorded high negative scores with factor 2 with predominant of *Ammonia* genus. It has been reported to dominate in areas close to outfalls discharging (Seiglie, 1971), chemical and thermal influents (Seiglie, 1975), fertilizer byproducts (Setty, 1976; Setty and Nigam, 1984). Frequent abundance of *Quinqueloculina* and *Adelosina* genera were recorded. According to Melis and Stanley (2006), these genera are isobathyal as indicative genus for coastal area associated with proximal high-energy transport conditions in nearshore environments. This site could be considered as highly stressed environment influenced by fresh water flush, rapid sedimentation, temperature and salinity fluctuations associated with low organic matter content. The factor scores plotting shows that factor 3 dominated by *Spiroloculina* is more significant below 35 cm core depth in Alexandria and Port Said cores. *Spiroloculina* is epifaunal, free or clinging, living in marine-hypersaline temperate-warm water with depth range from 0–40 m. It flourished in lagoons and inner shelf environment, (Melis and Stanley, 2006) consequently, bottom section of Alexandria and particularly, Port Said cores indicating hypersaline environment before the effect of Industrial and domestic pollution.

Suez site is considered as the most polluted areas along the investigated sites, (Hamed and Said, 2000), it receives substantial amounts of pollutants from the surrounding industrial area, agricultural and domestic effluents, with common

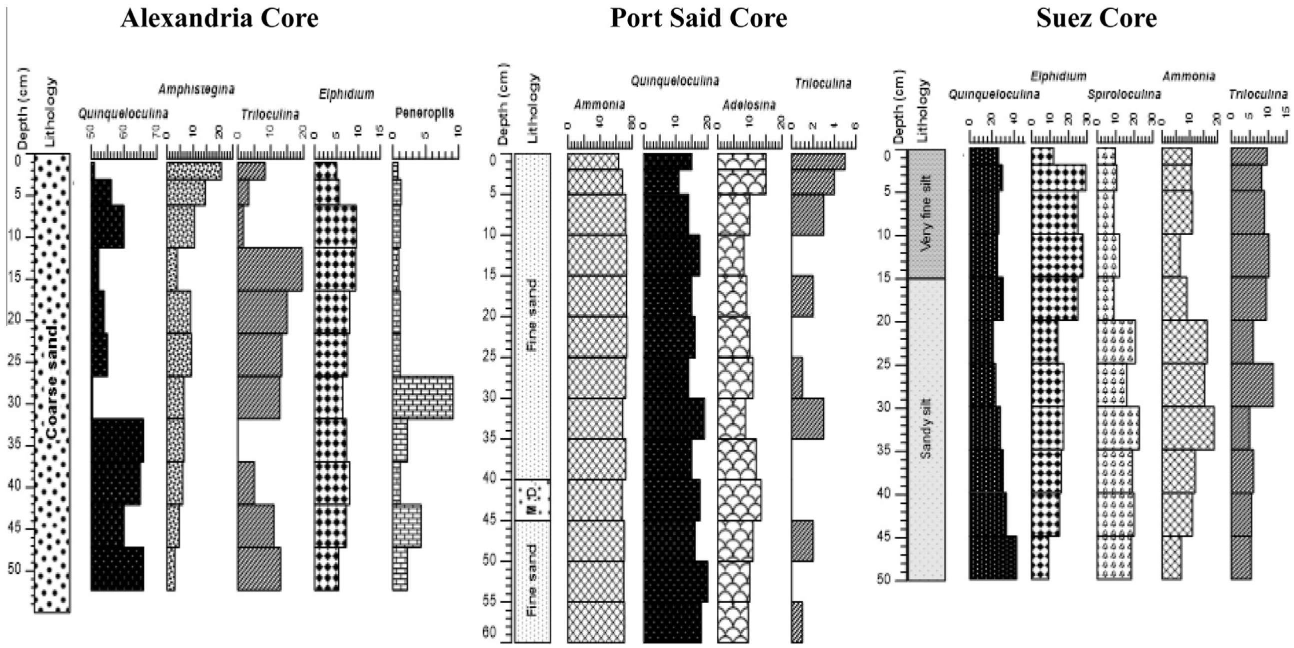

Figure 6 Cross correlation of the common genera of benthic foraminifera in the investigated cores.

increasing trend from the bottom to up, indicated for prompt propagation of anthropogenic influence time a head. Foraminiferal assemblages (Factor 1) well reflected this stressed environment by the dominance of the pollution-tolerant genera *Elphidium* and *Ammonia*, (Fig. 6). *Elphidium* is epifaunal, it has free mobility, its environmental preference is sand, vegetation, and herbivore, within marine inner shelf temperate-warm from 0–5 m, as well as lagoons (Murray, 1991). Several studies illustrated that *Elphidium* exhibits particular tolerance to various contaminants and compete successfully in polluted near-shore environments, (Schafer, 1973; Buckley et al., 1974; Schafer and Young, 1977; Bates and Spencer, 1979; Schafer et al., 1991). In addition, *Ammonia* is commonly encountered in restricted environments under stress, (Setty and Nigam, 1984). Suez core, reflects warm, shallow, and hypersaline inner-shelf environment with high levels of nutrients as reflected by the dominance of *Peneroplis* and *Discorbis* genera. Reiss and Hottinger (1984) have showed that *Peneroplis* normally occurs in shallow vegetated hypersaline marine environments in protected shoals. *Discorbis* is reported as epifaunal, clinging or attached, firm substrate, temperate to warm marine inner-shelf (Murray, 1991). This is characteristic of confined environment under stress, where the significant increase in nutrients availability associated with high organic matter in clay sediments of Suez core linked to intensified levels of industrial and domestic pollution leading to enhanced organic matter fluxes and low bottom and pore water oxygen. Consequently, the influence of industrial pollution is the controlling factors which strongly influence the distribution of foraminifers in the Suez site. Factor scores plotting of factor 4 showed that the highest significant values are typical for the upper most sample at Suez core.) It is worthy to say that the dominant genera which came up from factor 4 is *Sigmolinita* that, is recorded in warm hypersaline inner shelf of Arabian Gulf, according to Murray (1991). As such, hypersaline environment is a significant parameter in Suez site as represented by factors 1 and 4. Maximum intensification of anthropogenic impact is detected in the uppermost section of Suez core (from 25 cm to surface sample), indicated by low-diverse benthic foraminiferal assemblages, and represented mainly by small specimens with weak and fragile tests, and dominated by faunal taxa which are adapted to high organic matter fluxes, low oxygen level and hypersaline environment as represented by factor 1. On the contrary, the bottom section of the core emphasizes hypersaline environment as a major environmental parameter, which most probably corresponds to the period prior to industrial and domestic discharge.

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