Pol. J. Environ. Stud. Vol. 26, No. 3 (2017), 969-984
DOI: *10.15244/pjoes/68157*

Original Research

Benthic Foraminifera in Eastern Bahrain: Relationships With Local Pollution Sources

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Received: 13 November 2016
Accepted: 29 December 2016

Abstract

This preliminary study tracks the response of living benthic foraminifera at a polluted site in eastern Bahrain, with the aim to determine the effects of recent anthropogenic pollution on their distribution patterns and morphological deformities. The boat harbor in Askar, Bahrain is subjected to pollution by nutrients, organic matter, and hydrocarbons. Foraminiferal density is found to be higher at the polluted site compared with a nearby unpolluted site, suggesting a possible higher amount of available nutrients for the benthic foraminifera. Seven taxonomical groups were recognized in the polluted transect, including *Ammonia*, *Glabratellina*, *Murrayinella*, *Elphidium*, *Brizalina*, miliolids, and peneroplids. By comparing the foraminiferal assemblages with a nearby unpolluted transect, the genus *Murrayinella* appeared to be a dominant and pervasive taxon, as it was able to proliferate in the organically polluted environment. The results are contradictory to previously published findings on modern foraminiferal assemblages in the Arabian Gulf, as *Murrayinella* is rarely reported. However, the population of miliolids was drastically reduced at the polluted site due to high organic matter pollution, which might support the sensitive nature of this taxonomic group. In any case, the miliolids can be considered as a pollution proxy for future biomonitoring studies in the region.

Keywords: Arabian Gulf, pollution, benthic foraminifera, foraminiferal density, *Glabratellina*, *Murrayinella*

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Introduction

Benthic foraminifera have been widely exploited as bio-indicators for the environmental quality assessment of marine ecosystems [1-3]. Their distributional patterns are influenced by natural marine environmental conditions and by the possible presence of different sources of pollution [4]. Benthic foraminifera might respond to adverse environmental conditions in terms of abundance and diversity changes, the appearance of opportunistic taxa, changes in foraminiferal assemblage composition, and morphological abnormalities [5-6].

Many studies have documented increased numbers of foraminiferal tests in organic-rich areas [7-9]. In fact, benthic foraminifera might benefit from the presence of organic matter that directly represents a source of food and might indirectly reduce predation and/or competition, particularly when sediments experience oxygen deficiency [10]. The availability of organic material and its quality promote an increase in the overall foraminiferal density [8]. However, excess organic matter may lead to oxygen deficiency with the consequence of the disappearance of the most sensitive taxa, an increase in opportunistic taxa, a decrease in diversity, and a change in microhabitat succession [11]. As a consequence, an increased flux of organic matter may cause an alteration of natural foraminiferal assemblages [12]. In addition to foraminiferal density, oxygen-deficient environments can also limit foraminiferal diversity [13]. As in other marine groups, several species have been found to be tolerant or opportunistic to various pollution sources, including organic matter, heavy metals, and chemicals [14]. Based on such criteria, a distinction has been developed to differentiate pollution-tolerant taxa from pollution-sensitive taxa [15]. A previous seasonal survey of living benthic foraminifera in a relatively unpolluted site offshore in eastern Bahrain revealed the maximum foraminiferal density (FD) during the winter season, attributed to an increased number of juveniles [16]. A pronounced seasonality effect in the benthic foraminiferal populations has also been observed. The proportion of juveniles increased in the offshore direction. The current preliminary study is a follow-up to this previous study and aims to document the response of benthic foraminiferal assemblages in a polluted transect and compare it with a nearby unpolluted locality. To the best of our knowledge, this is the first report of its kind from the eastern coastline of the Kingdom of Bahrain in the Arabian Gulf.

Materials and Methods

Study Area and Sampling Strategy

The study was conducted in a polluted transect next to the boat harbor in the town of Askar on the eastern coast of Bahrain in the Arabian Gulf (26°14'13.811"N,50°34'5.158"E). The sea floor in the area is characterized by carbonates with fine to coarse-grained sediments. The offshore coastal area is microtidal (<1 m) with a diurnal rhythm [16]. The foreshore is wide and slopes very gently, and is characterized by silty, sandy carbonate sediments. The water temperature varies between 17º and 31ºC, and salinity is approximately 45-46 throughout the year. Recently, boat traffic and

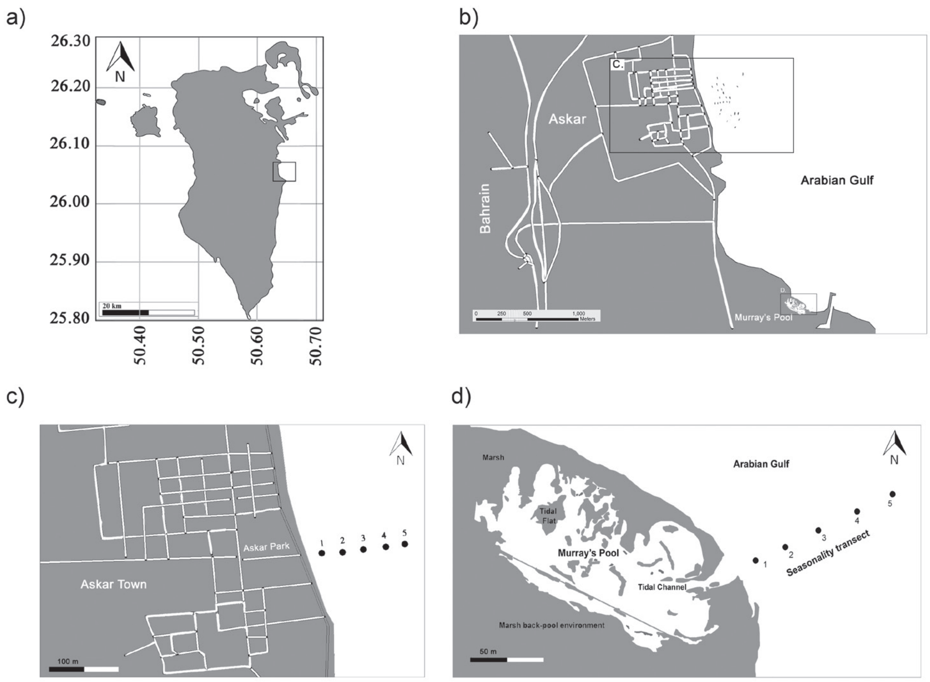

Fig. 1. Geographical context of polluted and unpolluted transects in the Arabian Gulf: a) location map showing study area in eastern Bahrain, b) polluted and unpolluted transects in eastern Bahrain, c) the polluted transect along the boat harbor, and d) the unpolluted transect along Murray's pool.

domestic sewage discharge has resulted in the deterioration of environmental quality of the site (Fig. 1).

Sampling was performed during winter (29 January 2015) and five samples were collected from the transect in the offshore direction. The selection of season has been primarily based on our previous findings, where the highest standing crop was found in winter [16]. The bottom water and sediment samples were collected from the coastline to 250 m offshore, from water depths of 0.4 m to 1.0 m. The transect was compared with a nearby one in an unpolluted site previously studied by Arslan et al. [16].

Water was collected by dipping well-rinsed glass jars at each station prior to sediment sampling to avoid any alteration of physicochemical parameters. Sediment samples with a depth of 1.0 cm (volume ~ 57.6 cm^3) were collected with a spatula (taking care not to disturb the sediment floor) and placed into plastic storage boxes fitted with a lid that was secured under ambient seawater. A layer of aluminum foil was placed over the jar mouth to avoid sediment contact with the plastic cap. Both water jars and sediments boxes were transported to the laboratory on the same day for analyses. Sample processing was carried out at the Research Institute and Environmental Sciences labs at King Fahd University of Petroleum and Minerals (Saudi Arabia). Both sediment and water samples were preserved at 4ºC until analyses were performed.

Physicochemical Parameters of Water

Salinity, conductivity, temperature, dissolved oxygen, total dissolved solids, and pH were measured *in situ* using a YSI multi-probe water monitoring unit (YSI, USA).

Eutrophication Pollution Analysis

The eutrophication indicators (SO_4^{-2}, PO_4^{-2}, NO_3, and NO_2^-) were measured in the laboratory using ion chromatography (IC-Metrohm 850 Professional system, Switzerland). The seawater samples were prepared by performing 1,000-fold dilution in ultra-pure water. Prior to analysis, standard solutions of 10 ppm concentration were prepared for each ion and then injected into the system to assess the performance and calibration of the instrument [17].

Grain Size Analysis

The grain-size distribution of sediments along depth transect was determined as per the ASTM D422 guidelines (astm.org/Standards/D422). Samples were first treated with an H_2O_2 solution to remove the organic matter. The analysis was then performed by taking 50 grams of each sample followed by manual sieving and drying at 60°C. The grain size distributions were statistically and graphically summarized to understand the porosity and permeability for later analysis as per the guidelines of ASTM, 1984 (astm.org/DIGITAL_LIBRARY/STP/PAGES/STP30216S.htm).

Total Organic Carbon

The total organic carbon (TOC) analysis was performed as per the EPA 415.1/9060 standard method [Ref.]. Approximately 200 mg of the dried and ground sample was weighed and placed in ceramic boats. The sample was suspended in a diluted hydrochloric acid solution thrice a day to break down all the carbonates present in the sample, resulting in the removal of total inorganic carbon (TIC). Finally, the suspensions were injected and analyzed for TOC content in a Shimadzu TOC-Vcsh Total Organic Carbon Analyzer. The standards and samples were weighed in duplicate, and five calibration points were taken to construct a calibration curve.

Heavy Metals Analysis

In order to determine the heavy metal contents in the sediments, 5 g of each sample was dried under a light bulb at low temperature to prevent the evaporation of heavy metals, then reduced to fine powder. Thereafter, the heavy metals content was investigated in all samples by Activation Laboratories Ltd. (Ontario, Canada; actlabs.com). The samples were analyzed for 63 elements using inductively coupled plasma mass spectrometry (ICP/MS). 0.5 g of the sample material was digested in aqua regia (0.5 ml H_2O, 0.6 ml concentrated HNO_3, and 1.8 ml concentrated HCl) at 90ºC for 2 hours. Digested samples were diluted and analyzed by Perkin Elmer Sciex ELAN 9000 ICP/MS.

Hydrocarbon Analysis

Total hydrocarbons content (THC) of the samples was determined using EPA 8015/3510 standard method while the poly aromatic hydrocarbons (PAHs) were measured as per the EPA 3510/8040/610/8310 standard methods. Initially, hydrocarbon extraction from the sediments was performed using the Dionex accelerated solvent extraction system (ASE 200), a new procedure that extracts organic solvents at high temperature and pressure above the boiling point as described as Method 3545 in U.S. EPA SW-846. Representative samples of 5 g of sediment from each station were taken and homogenized equally with commercially available hydrant for removal of water content to perform the analysis. The mixture was directly enclosed in the sample cells, which were subsequently installed on the system to statically extract the hydrocarbons under 100°C and 500 psi pressure for 20 min. Finally, compressed gas allowed for the extraction of hydrocarbon from the sample cell to the collection vessel using n-hexane. For quality control, samples were run in duplicate and surrogate spiking was performed to assess extraction efficiency.

Analyses of the extracts were performed using an Agilent 7890A gas chromatography flame ionization detector (GC/FID). Separations were performed using a 30 m × 0.32 mm internal diameter Varian capillary column. The carrier gas used was helium with column flow rate of

25 mL/min, and the pressure was regulated by hydrogen and air flowing at rates of 30 mL/min and 300 mL/min, respectively. The initial column temperature was set at 60ºC for 1 min, and then increased to 150ºC at 10ºC/min for 12 min. The detector temperature was maintained at 200ºC. Peaks were integrated using a Chrom Card system (CE Instruments). Finally, quantification of THC was performed using a hydrocarbon window of C10 to C36 calibration standards.

Benthic Foraminifera Analysis

In the laboratory, 5 cm^3 of sediment was taken from each box. The sample was sieved through a 63 µm mesh sieve, and the sediment split using a wet-microsplitter to ensure statistically meaningful counts of living individuals. Each sample was washed carefully with natural seawater. Finally, the entire residue was microscopically analyzed and the total numbers of living foraminifera (both adults and juveniles) were picked under a reflected-light binocular microscope based on the presence of protoplasm. We distinguished visually between "living" (protoplasm-full) and "dead" (protoplasm-empty) as described previously [16, 18]. Assemblage parameters including the adult/juvenile ratio (individuals with diameter less than 150 µm were considered juveniles), foraminiferal density (FD, number of living individuals), and generic diversity indexes (richness, H' and Fisher-α) were calculated. Foraminifera were taxonomically identified at the genus level using the monographs of Hottinger et al. [19], Loeblich and Tappan [20] and Hayward et al. [21]. As the current study attempts to compare the foraminiferal density with the data published by Arslan et al. [16], we did not attempt to resolve species taxonomy.

Statistical Analyses

Prior to statistical analyses, all the available biotic and abiotic data of the two transects (polluted: P and unpolluted: UP) were logarithmically transformed log(1+X) and tested for normality through the Kolmogorov-Smirnov test. As most of the variables fail for normality, nonparametric statistics were applied. The Mann-Whitney U test, a nonparametric test, was used to check for significant differences between the two transects for any parameters ($p<0.01$) [22]. In order to evaluate the relationships among variables, a correlation matrix (Spearman's rho) was calculated for all the biotic and abiotic data. These two analyses were performed in Statistica v. 6.0. Non-metric multi-dimensional scaling (nMDS) ordinations derived from Bray-Curtis similarity matrices were used to document the differences among the two transects in the abiotic parameters and in the benthic foraminiferal assemblages. Furthermore, the significance of the differences in either the benthic foraminiferal assemblages and/or abiotic parameters was tested by means of the analysis of similarity (one way ANOSIM). In order to define the contribution of each biotic and abiotic parameter to the observed is the similarity between the two transects using a SIMPER (similarity percentages) analysis. For this analysis, a fourth-root transformation of the data was applied. The nMDS, ANOSIM, and SIMPER analyses were carried out in PRIMER v. 5.2.9.

Results

Environmental Characterization of the Two Transects

Physicochemical parameters of water showed minor variations between the sampling stations and the two transects. Accordingly, salinity ranged between 43.9 and 45.9 (45.4±0.7), and temperature varied between 20.1 and 21.8 (20.9±0.8) (Table 1S). Results of grain size analysis revealed the prevalence of medium-grained sand followed by fine sand (i.e., 43.5% and 40.8%, respectively). The coarser sand fraction increased in the seaward direction, whereas the fine fraction (silt and clay) diminished (Table 1S). Further examination of coarser particles under a stereomicroscope revealed that the fraction size >63 µm was mainly constituted by reworked bioclasts.

The level of nitrates was higher in the polluted Askar boat harbour than at the unpolluted site, without any significant trend along the transect, whereas sulfate showed an opposite pattern (Table 2S). The TOC averaged 10,448 mg/kg (=1.05%) in the polluted transect, which is higher than at the unpolluted one (7,296 mg/kg) (Table 2S). Similarly, THC was also found to be higher in the polluted transect (average of 67.37 mg/kg) than in the unpolluted one (2.24 mg/kg). Compared to the ER-L (effect range – low) and ER-M (effect range – median) values reported for the United States Environmental Protection Agency's (USEPA) sediment guidelines, none of the considered heavy metals were beyond the permitted standards in either transect, except strontium (Supplementary Material 2). The concentration factor (CF) of selected heavy metals (Cr, Ni, Cu, Zn, As, Ag, Cd, Hg, V, Mn, Fe, Co, and Pb) and the pollution load index (PLI) were calculated following Martins et al. (2013).

Benthic Foraminifera

All the studied samples from both transects contained abundant and well-preserved living benthic foraminifera. The overall FD was higher in the polluted Askar boat harbour than in the unpolluted transect. More specifically, FD varied between 176 to 309 individuals (average of 254) in the polluted transect, whereas in the unpolluted transect FD ranged between 62 and 215 individuals (average of 153). Furthermore, the polluted transect showed an increase of FD up to the third station and then decreasing values, whereas the unpolluted exhibited a clear increasing trend seaward (Table 3S). In addition, an opposite trend of juveniles was observed where a gradual decrease was found for the polluted transect and a steady increase for the unpolluted one (Table 3S). Seven groups (i.e., *Ammonia*, *Glabratellina*, *Murrayinella*, *Elphidium*, *Brizalina*, *miliolids*, and *Peneroplidae*) were identified in the polluted transect, with the addition of the genus *Murrayinella*, which was absent in the unpolluted transect (Table 3S). Considering the relative abundance in all samples, the most abundant groups in the polluted transect were *Ammonia*, *Glabratellina*, and *Murrayinella*, whereas the unpolluted transect was mainly characterized by *Ammonia*, *Glabratellina*, and miliolids. *Ammonia* was consistently present in both transects and dominant, representing 35.1% on average in the foraminiferal assemblages of the polluted transect, which is somewhat lower compared with the unpolluted transect (41.5% on average). The second most abundant group was the *Glabratellina*, which represented 30.7% of the living assemblage in the polluted transect and was slightly less abundant in the unpolluted transect (26.0%). Miliolids were significantly less abundant in the polluted transect compared with the unpolluted transect, representing 1.8% and 28.3% of the living assemblages, respectively (Table 3S). The dominance of *Ammonia* and *Glabratellina* was nearly constant in both the polluted and unpolluted transects with no specific trend. *Murrayinella* was observed only in the polluted transect, the relative percentage of which increased up to the third station and then decreased in the more seaward direction. By contrast, miliolids were abundant in the unpolluted transect with increasing population in the offshore direction, whereas their numbers were significantly reduced in the polluted transect with the exception of station 1 (Table 3S). However, due to their lower numbers in the polluted transect, it is difficult to compare and correlate their transect behaviors with the unpolluted transect. *Elphidium* represents a minor component of the living assemblages in both transects, and its abundance is relatively higher in the nearshore stations and decreased in the offshore direction.

The Shannon-Weaver H' values showed opposite trends with respect to each transect. The highest H' values were observed at station 1 in the polluted transect and a gradual decrease was observed along the transect length. On the other hand, in the unpolluted transect, lowest H' values were observed in station 1, and H' values increased gradually in the offshore stations. By contrast, higher values of Fisher-α were observed at the nearshore stations for both polluted and unpolluted transects; however, the value was highest in the third station for polluted transect and at the second station in the unpolluted transect. The results of richness illustrate no significant variations in each transect, whereas high evenness values are observed in nearshore stations, and values decreased horizontally for both transects (Table 3S).

Statistical Analysis

Results of the Mann-Whitney U Test show substantial differences between the two transects. More specifically,

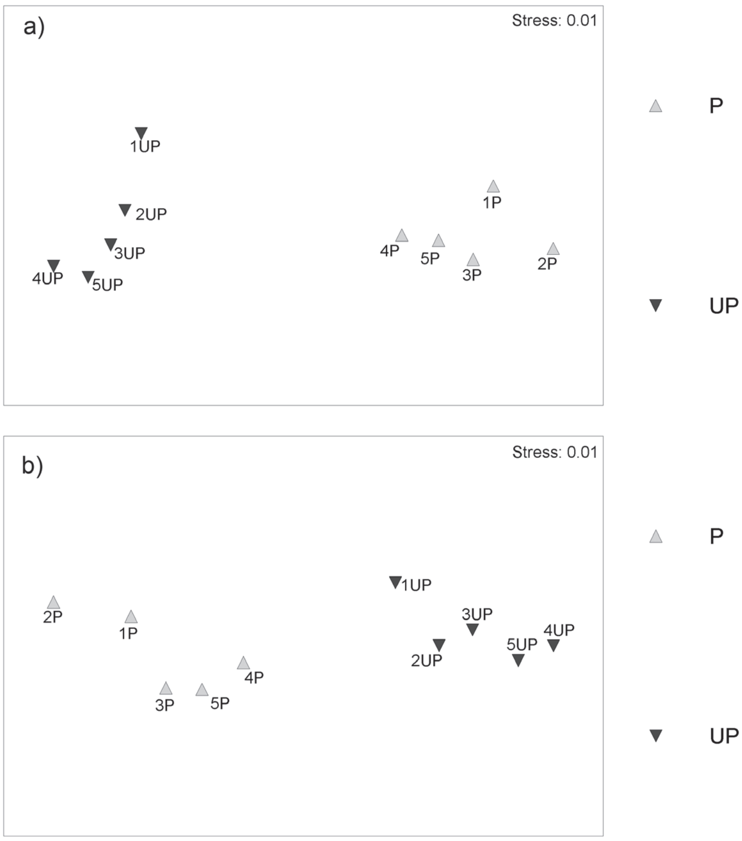

Fig. 2. The non-metric multidimensional scaling (nMDS) ordination for polluted and unpolluted transects: a) nMDS considering all variables and b) nMDS considering foraminifera.

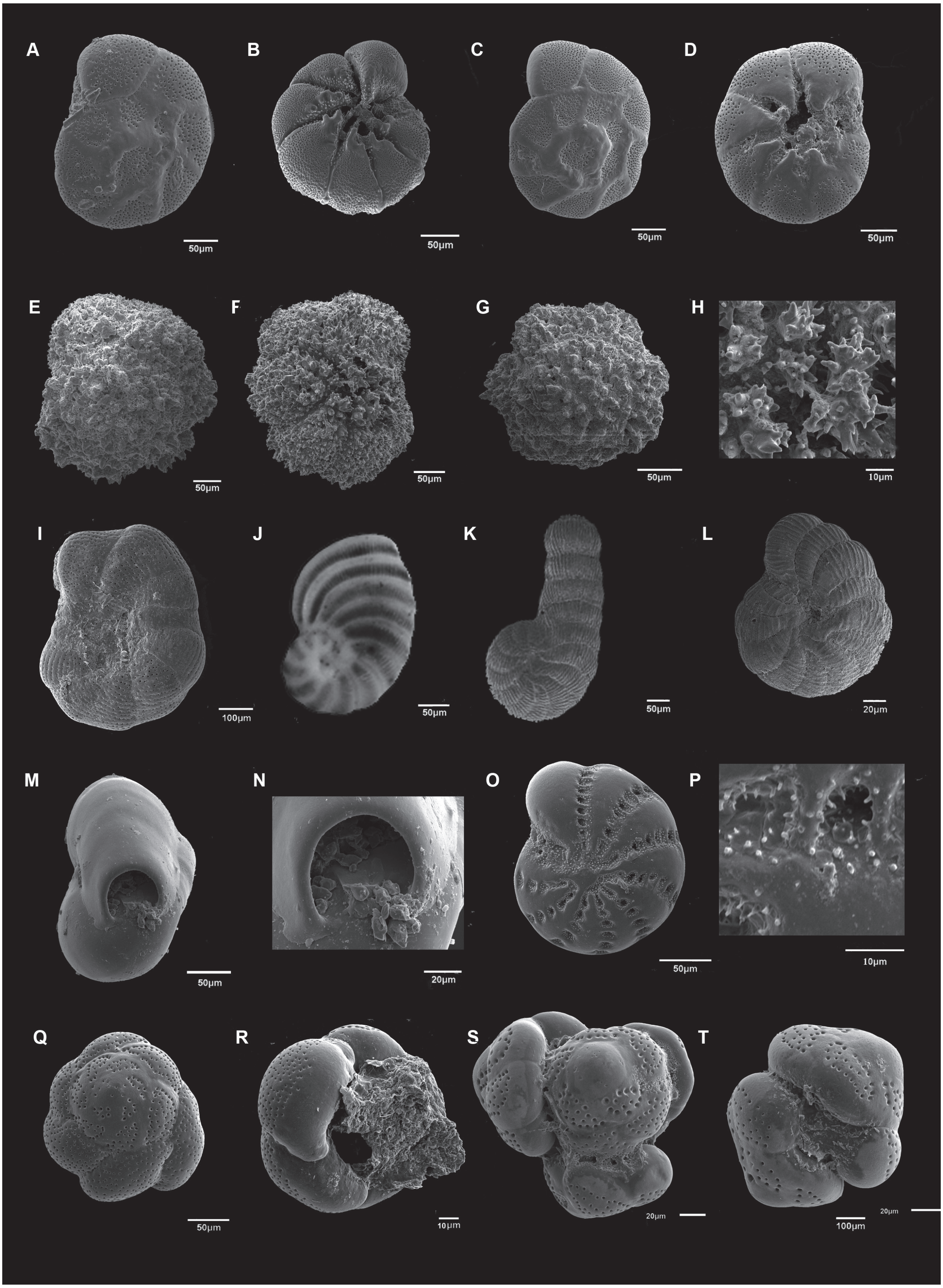

Plate 1. Scanning electron micrographs of the selected foraminiferal specimens. **A, C.** *Ammonia cf. A. parkinsoniana* (dorsal view) **B, D.** *Ammonia cf. A. parkinsoniana* (ventral view) **E, G.** *Murrayinella* sp.1 (dorsal view), **F** *Murrayinella* sp.1 (ventral view); **H.** *Murrayinella* sp.1 spicules (closer view) **I.** *Coscinospira* sp. 1; **J.** *Peneroplis proteus*; **K, L.** *Monalysidium* sp. 1; **M, N.** *Quinqueloculina cf. seminula* (front view); **O.** *Elphidium advenum* (dorsal views); **P**. *Elphidium advenum* (closer view); **Q,** *Glabratellina* sp. 1; **R.** *Glabratellina* sp. 1 (post-plastogamic specimen); and **S, T.** *Glabratellina* sp. 1 (plastogamic clusters).

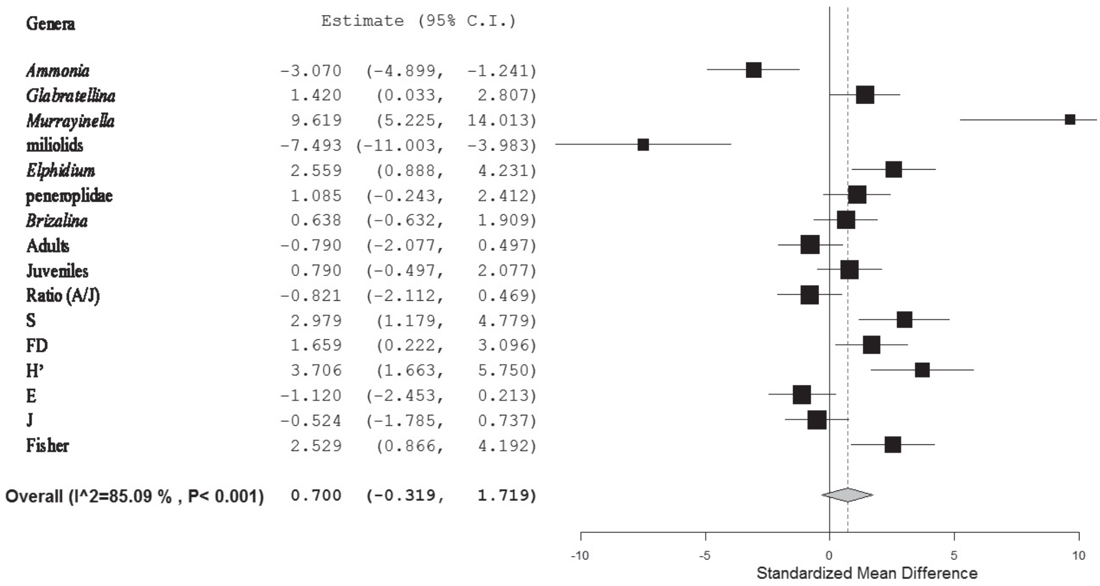

Fig. 3. Comparison of two transects illustrated by Forest Plot: the horizontal bars touching central mea reflect no statistical differences among the transects for the corresponding species.

the parameters of temperature, pH, fine sand, medium sand, nitrates, sulfates, THC, Cr, Cu, As, Pb, CF, PLI, *Ammonia, Murrayinella,* miliolids*, Elphidium*, S, H', and Fisher-α index are significantly different between the polluted and the unpolluted transects ($p<0.01$) (Table 4S). Spearman's rho correlation analysis shows significant correlation among major abiotic and biotic variables ($P<0.05$) (Table 5S). Regarding abiotic factors, TOC, THC, and selected trace elements such as Cr, Cu, As, V, Mn, Fe, and Pb are strongly positively correlated with the fine grain substrate (i.e., silt and clay, fine sand), whereas a strong negative correlation is observed with the medium grain substrate (medium sand). It is important to mention here that the majority of abiotic factors did not show strong correlation with coarse-grained substrate except for a few trace elements (V, Mn, Fe, and Co) that show a strong negative correlation with coarser particles.

For biotic factors, *Ammonia* and miliolids are found to be strongly negatively correlated with the fine-grained substrate, strongly positively correlated with the medium-grained substrate, and weakly positively correlated with the coarse-grained substrate. In contrast, *Murrayinella* and *Elphidium* showed strong positive correlation with the fine-grained substrate, strong negative correlation with the medium-grained substrate, and weak negative correlation with the coarse-grained substrate. *Glabratellina* and *Brizalina* did not show any strong correlation with the substrate parameters, but a moderate positive correlation was found with the fine-grained substrate, a moderate negative correlation was found with the medium-grained substrate, and a moderate to weak negative correlation was found with the coarse-grained substrate. Additionally, peneroplids showed weak negative correlation with silt and clay, weak positive correlation with the fine sand, weak negative correlation with the medium sand, and moderate positive correlation with the coarse sand.

In addition, correlation analysis with nitrates, sulfates, TOC, and THC were also performed. Strong negative correlations were observed for *Ammonia* and miliolids with nitrates and THC, whereas a strong positive correlation was found for *Glabratellina*, *Murrayinella*, and *Elphidium*. For sulfates, *Murrayinella, Elphidium,* and peneroplids showed strong negative correlation and *Ammonia* showed strong positive correlation. Lastly, TOC had strong positive correlation with *Murrayinella*, but strong negative correlation with miliolids.

The nMDS, which simultaneously considers all the variables, separated the samples into two distinct groups (stress 0.01) that reflect the transect either when all variables or foraminiferal ones are considered (Fig. 2). The separation of the two groups is significant as revealed by ANOSIM ($p<0.001$, $R = 0.98$) either for all variables or for aminiferal ones. The SIMPER analysis applied to abiotic parameters reveals that ca. 13.1% of dissimilarity between the two transects and identifies CF, THC, sulfates, Pb, PLI, and TOC as the parameters most responsible for this dissimilarity (Table 6S). On the other hand, the average dissimilarity of foraminiferal variables is 10.9% and is mainly due to *Murrayinella*, miliolids, and FD (Table 7S).

Discussion

The current study attempts to explain the assessment of local pollution sources on benthic foraminiferal assemblages at a polluted locality in eastern Bahrain along with its comparison with a nearby unpolluted locality. Both of the localities reflect the same environmental conditions and substrate parameters, as the distance between both localities is less than 1 km. The unpolluted locality was initially investigated by Arslan et al. [16], in which six foraminiferal groups (*Ammonia*, *Glabratellina*, *Elphidium*, miliolids, peneroplids, and *Brizalina*) were observed along with no background pollution, i.e., heavy metals, hydrocarbons, and organic matter. Moreover, *Brizalina* was found to be a seasonal genus as it was only present during spring and autumn.

In the polluted transect, the overall concentrations of pollutants – particularly organic carbon, hydrocarbons, and trace elements in the sediment samples – were found to be significantly higher compared with the unpolluted transect. The relatively high concentrations of pollutants could be attributed to boat traffic, domestic sewage discharge, and waste coming from mariculture (i.e., the National Mariculture Center). In addition, the biological decomposition of sewage waste produces biological nutrients, especially nitrates, along with liberation of organic carbon under aerobic conditions [23]. It has been well-established that the distribution of foraminifera in coastal environments is a function of nutrients, organic matter, and hydrocarbons as well as other physico-chemical parameters [24]. The high standing crop in the polluted transect could be due to the higher availability of biodegradable organic matter that might have promoted the increase of the foraminiferal population [8, 9, 25]. Accordingly, some studies indicate that the organic matter favors higher foraminiferal populations directly by providing food and indirectly by reducing predation and/or competition [26]. The presence of plastogamic clusters of living foraminifera in the sampled stations might suggest a possible effect of organic carbon as well as seasonality effect (Plate 1) [18]. The highest FD values in the third station with a gradual decrease in both directions might be attributed to the THC.

The presence of seven foraminiferal taxa with the addition of the genus *Murrayinella* in the polluted transect suggest its appearance, possibly, as an opportunistic pervasive taxon in the organically polluted environment as it can tolerate eutrophic environments and can withstand fluctuating temperatures, turbidity, and salinities [27]. However, other factors may also be responsible for its appearance in the region, but available limited information cannot lead to appropriate deduction. Besides, strong correlations of *Murrayinella* with nitrates, sulfates, TOC, and THC might suggest the opportunistic behavior of the taxon. Taxonomically, the species appears to be a variety of *Murrayinella murrayi*, whose occurrence in the Arabian Gulf is of a pervasive nature [28]. The genus has been reported as of lower abundance (<12%) from the Abu Dhabi coastline, and throughout those observed in the Pleistocene samples, even in samples with few other taxa. Nevertheless, the genus has not been recorded and catalogued by Cherif et al. [29] and Saidova [30], even under a different name such as *Glabratella* or *Pararotalia*. Over and above, no modern examples of an assemblage dominated by *Murrayinella* has been ever reported from the Arabian Gulf, although the taxon is common throughout the sub-tropical to tropical Indo-Pacific (i.e., northern Australian margin: Chivas et al. [31]; Parker [32]; Japan: Nomura and Takayanagi [33]; Thailand: Melis and Violanti [27]).

Ammonia and *Glabratellina* were abundant at all the stations of both the polluted and unpolluted transects. This reflects their resistant nature toward high organic matter and supports the finding that some of the rotaliids are capable of surviving and reproducing rapidly in every environment. For instance, some species of the genus of *Ammonia* such as *A. tepida* have been reported to have an opportunistic behavior along the Mediterranean coast in the vicinity of a sewage sludge disposal site and other sources of pollution [5, 34, 35]. By contrast, very few miliolids were found in the polluted transect, which suggests that the group is adversely affected by organic pollution when compared with an unpolluted transect [24, 36]. *Elphidium,* peneroplids, and *Brizalina* represent a minor component of the living assemblages in both transects, which supports the earlier finding of lower FD in the unpolluted transect [16]. A general comparison of both transects for each foraminiferal group (i.e., genera) can be seen in the forest plot prepared by OpenMEE (Fig. 3).

Conclusions

Our study concludes that the Askar boat harbor samples contain assemblages dominated by *Ammonia*, *Glabratellina*, and *Murrayinella* in sediments with higher organic matter content. The sediments with high organic matter loadings show a significant reduction of the miliolid population, whereas *Murrayinella* appeared as a pervasive resistant taxon when compared to the unpolluted transect and previous studies from the Arabian Gulf. Population density is higher at the polluted site, probably due to the higher amount of food available for the benthic foraminifera. A greater proportion of juveniles was found at the unpolluted locality. The foraminiferal distribution is likely to be patchy, and hence our study may not have captured the full range of natural variability. Nevertheless, our observations represent a preliminary investigation, and a future sampling program that focuses on seasonal aspects may unravel additional details. Heterogeneity is always expected based on seasonal variations in the foraminiferal populations and different environmental conditions in each transect.

Acknowledgements

We thank Fabrizio Fonrtalini for continuous help in manuscript writing and statistical analysis; Eiichi Setoyama and Heinz Scheifinger (formerly from KFUPM) for assistance in the field; and Justin Parker for advice on the taxonomy. We gratefully acknowledge the helpful comments offered by two anonymous reviewers, and financial support from the Deanship of Scientific Research, KFUPM, through research grant IN121028. We further acknowledge the financial support from the Brian J. O'Neill Memorial Scholarship awarded by the Grzybowski Foundation.

Table 1S. Comparison of environmental parameters among polluted and unpolluted localities.

		1P	2P	3P	4P	5P	1UP	2UP	3UP	4UP	5UP	mean	sd	min	max
Water depth	cm	25,0	29,0	42,0	55,0	70,0	40,0	52,0	71,0	96,0	102,0	58,2	26,3	25,0	102,0
Salinity		45,8	45,8	45,9	45,6	45,5	45,8	45,7	45,4	44,1	43,9	45,4	0,7	43,9	45,9
Temperature	°C	21,6	21,6	21,8	21,7	21,4	20,2	20,1	20,1	20,1	20,1	20,9	0,8	20,1	21,8
pH		8,7	8,9	8,9	8,4	8,3	8,2	8,2	8,2	8,2	8,2	8,4	0,3	8,2	8,9
Silt and Clay	%	10,6	11,2	11,7	10,7	8,9	10,6	6,9	4,4	3,0	2,8	8,1	3,5	2,8	11,7
Fine Sand	%	48,5	51,0	50,8	45,3	43,6	40,7	37,4	32,5	29,2	29,3	40,8	8,4	29,2	51,0
Medium Sand	%	38,2	35,3	30,5	34,6	35,6	48,3	50,4	52,1	55,6	54,8	43,5	9,6	30,5	55,6
Coarse Sand	%	2,7	2,7	7,0	9,4	11,9	0,4	5,3	11,0	12,2	13,1	7,6	4,6	0,4	13,1

Table 2S. Concentrations of nitrates and sulphates on bottom water; total organic carbon total hydrocarbon content (THC), and heavy metals in sediment samples.

		1P	2P	3P	4P	5P	1UP	2UP	3UP	4UP	5UP	mean	sd	min	max
Nitrates	ppm	197,80	189,50	203,30	201,80	189,90	142,40	140,90	138,90	139,10	138,40	168,20	30,12	138,40	203,30
Sulphates	ppm	1461,00	1487,00	1495,00	1489,00	1456,00	4450,00	4365,00	4273,00	4124,00	3944,00	2854,40	1457,49	1456,00	4450,00
TOC	mg/kg	8540,00	9143,00	12525,00	11300,00	10730,00	9321,00	10035,00	8642,00	5105,00	3379,00	8872,00	2765,78	3379,00	12525,00
THC	mg/kg	50,15	49,67	87,88	77,53	71,62	9,18	1,70	0,10	0,10	0,10	34,80	36,24	0,10	87,88
Cr	ppm	14,00	30,00	39,00	9,00	10,00	7,00	5,00	4,00	1,00	1,00	12,00	12,69	1,00	39,00
Ni	ppm	10,10	25,60	5,60	6,10	5,10	13,50	13,00	11,10	11,40	10,80	11,23	5,89	5,10	25,60
Cu	ppm	117,00	52,90	18,20	8,41	13,00	3,85	4,89	2,88	1,70	3,92	22,68	36,49	1,70	117,00
Zn	ppm	64,90	115,00	20,40	17,80	27,20	8,50	11,40	8,10	6,60	18,90	29,88	34,40	6,60	115,00
As	ppm	3,10	6,90	3,40	2,40	2,70	1,80	1,90	1,70	1,40	1,60	2,69	1,62	1,40	6,90
Ag	ppm	0,16	0,36	0,06	0,05	0,04	0,04	0,03	0,03	0,02	0,08	0,09	0,11	0,02	0,36
Cd	ppm	0,01	0,09	0,05	0,01	0,07	0,06	0,09	0,08	0,05	0,09	0,06	0,03	0,01	0,09
Hg	ppb	110,00	90,00	20,00	20,00	30,00	10,00	10,00	20,00	10,00	10,00	33,00	36,22	10,00	110,00
V	ppm	10,00	29,00	8,00	7,00	8,00	7,00	4,00	3,00	2,00	3,00	8,10	7,81	2,00	29,00
Mn	ppm	63,00	177,00	51,00	50,00	47,00	58,00	27,00	26,00	11,00	16,00	52,60	47,24	11,00	177,00
Fe	%	0,42	0,97	0,23	0,29	0,25	0,28	0,20	0,18	0,13	0,15	0,31	0,25	0,13	0,97
Co	ppm	1,30	3,30	0,70	0,90	0,70	1,30	1,00	0,90	0,70	0,70	1,15	0,79	0,70	3,30
Pb	ppm	4,83	18,50	9,72	3,79	14,50	0,07	0,07	0,07	0,02	0,05	5,16	6,82	0,02	18,50
CF		376,23	1096,82	564,23	226,87	773,08	40,02	36,18	32,10	18,24	32,29	319,60	379,46	18,24	1096,82
PLI		252,16	430,54	308,80	195,81	361,46	82,24	78,20	73,65	55,51	73,87	191,22	139,23	55,51	430,54

Table 3S. Benthic foraminiferal assemblage parameters and relative abundances of the recognized taxa with minimum, maximum, and mean values, and calculated mean values for comparison among polluted and unpolluted localities.

		1P	2P	3P	4P	5P	1UP	2UP	3UP	4UP	5UP	mean	sd	min	max
Ammonia	%	34,1	35,3	33,7	35,6	36,7	43,5	40,2	44,4	40,6	38,6	38,3	3,8	33,7	44,4
Glabratellina	%	32,4	29,4	28,5	29,9	33,3	32,3	26,5	23,1	23,3	25,1	28,4	3,8	23,1	33,3
Murrayinella	%	19,3	25,3	27,2	27,4	21,5	0,0	0,0	0,0	0,0	0,0	12,1	12,9	0,0	27,4
Miliolids	%	4,0	1,5	1,0	1,1	1,3	21,0	29,9	27,8	30,7	32,1	15,0	14,3	1,0	32,1
Elphidium	%	8,0	7,8	8,1	4,6	5,1	3,2	2,6	4,1	4,0	2,8	5,0	2,2	2,6	8,1
Peneroplidae	%	2,3	0,7	1,3	1,4	2,1	0,0	0,9	0,6	1,5	1,4	1,2	0,7	0,0	2,3
Brizalina	%	0,0	0,0	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,3
Adults		46,0	46,1	53,4	59,4	56,5	75,8	71,9	51,5	51,0	52,6	56,4	10,1	46,0	75,8
Juveniles		54,0	53,9	46,6	40,6	43,5	24,2	28,1	48,5	49,0	47,4	43,6	10,1	24,2	54,0
Ratio (A/J)	%	0,9	0,9	1,1	1,5	1,3	3,1	2,6	1,1	1,0	1,1	1,5	0,8	0,9	3,1
S		6,0	6,0	7,0	6,0	6,0	4,0	5,0	5,0	5,0	5,0	5,5	0,8	4,0	7,0
FD		176,0	269,0	309,0	281,0	237,0	62,0	117,0	169,0	202,0	215,0	203,7	76,1	62,0	309,0
H'		1,5	1,4	1,4	1,3	1,4	1,2	1,2	1,2	1,3	1,2	1,3	0,1	1,2	1,5
E		0,7	0,7	0,6	0,6	0,6	0,8	0,7	0,7	0,7	0,7	0,7	0,1	0,6	0,8
J		0,8	0,8	0,7	0,7	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,0	0,7	0,8
Fisher α		1,2	1,1	1,3	1,1	1,1	1,0	1,1	1,0	0,9	0,9	1,1	0,1	0,9	1,3

Table 4S. Mann-Whitney U Test comparing single variable at a time.

Mann-Whitney U Test By variable Factor Marked tests are significant at p <.01000										
	Rank Sum - Group 1	Rank Sum - Group 2	U	Z	p-level	Z - adjusted	p-level	Valid N - Group 1	Valid N - Group 2	2*1sided - exact p
Salinity	35	20	5	1,5667	0,117186	1,58604	0,112731	5	5	0,150794
Temperature	40	15	0	2,61116	**0,009024**	**2,70281**	**0,006876**	5	5	**0,007937**
pH	40	15	0	2,61116	**0,009024**	**2,62714**	**0,008611**	5	5	**0,007937**
Silt and Clay	39	16	1	2,40227	0,016294	2,40227	0,016294	5	5	0,015873
Fine Sand	40	15	0	2,61116	**0,009024**	**2,61116**	**0,009024**	5	5	**0,007937**
Medium Sand	15	40	0	-2,61116	**0,009024**	**-2,61116**	**0,009024**	5	5	**0,007937**
Coarse Sand	24	31	9	-0,73113	0,464703	-0,73113	0,464703	5	5	0,547619
Nitrates	40	15	0	2,61116	**0,009024**	**2,61116**	**0,009024**	5	5	0,007937
Sulphates	15	40	0	-2,61116	**0,009024**	**-2,61116**	**0,009024**	5	5	**0,007937**
TOC	35	20	5	1,5667	0,117186	1,5667	0,117186	5	5	0,150794
THC	40	15	0	2,61116	**0,009024**	**2,6434**	**0,008208**	5	5	**0,007937**
Cr	40	15	0	2,61116	**0,009024**	**2,61911**	**0,008816**	5	5	**0,007937**
Ni	20	35	5	-1,5667	0,117186	-1,5667	0,117186	5	5	0,150794
Cu	40	15	0	2,61116	**0,009024**	**2,61116**	**0,009024**	5	5	**0,007937**
Zn	39	16	1	2,40227	0,016294	2,40227	0,016294	5	5	0,015873
As	40	15	0	2,61116	**0,009024**	**2,61116**	**0,009024**	5	5	**0,007937**
Ag	36	19	4	1,77559	0,075801	1,781	0,074914	5	5	0,095238
Cd	21,5	33,5	6,5	-1,25336	0,210076	-1,27679	0,201678	5	5	0,222222
Hg	39	16	1	2,40227	0,016294	2,51117	0,012034	5	5	0,015873
V	39,5	15,5	0,5	2,50672	0,012186	2,52982	0,011413	5	5	0,007937
Mn	37	18	3	1,98449	0,047203	1,98449	0,047203	5	5	0,055556
Fe	38	17	2	2,19338	0,028281	2,19338	0,028281	5	5	0,031746
Co	29	26	11	0,31334	0,754023	0,3254	0,744882	5	5	0,84127
Pb	40	15	0	2,61116	**0,009024**	**2,6434**	**0,008208**	5	5	**0,007937**
CF	40	15	0	2,61116	**0,009024**	**2,61116**	**0,009024**	5	5	**0,007937**
PLI	40	15	0	2,61116	**0,009024**	**2,61116**	**0,009024**	5	5	**0,007937**
Ammonia	15	40	0	-2,61116	**0,009024**	**-2,61116**	**0,009024**	5	5	**0,007937**
Glabratellina	37	18	3	1,98449	0,047203	1,98449	0,047203	5	5	0,055556
Murrayinella	40	15	0	2,61116	**0,009024**	**2,78543**	**0,005346**	5	5	**0,007937**
Miliolids	15	40	0	-2,61116	**0,009024**	**-2,61116**	**0,009024**	5	5	**0,007937**
Elphidium	40	15	0	2,61116	**0,009024**	**2,61116**	**0,009024**	5	5	**0,007937**
Peneroplidae	34	21	6	1,35781	0,174526	1,35781	0,174526	5	5	0,222222
Brizalina	30	25	10	0,52223	0,601509	1	0,317311	5	5	0,690476
Adults	24	31	9	-0,73113	0,464703	-0,73113	0,464703	5	5	0,547619
Juveniles	31	24	9	0,73113	0,464703	0,73113	0,464703	5	5	0,547619
Ratio (A/J)	24	31	9	-0,73113	0,464703	-0,73113	0,464703	5	5	0,547619
FD	38	17	2	2,193378	0,028281	2,193378	0,028281	5	5	0,031746
S	40	15	0	2,61116	**0,009024**	**2,78543**	**0,005346**	5	5	**0,007937**
H'	40	15	0	2,61116	**0,009024**	**2,61116**	**0,009024**	5	5	**0,007937**
E	19	36	4	-1,77559	0,075801	-1,77559	0,075801	5	5	0,095238
J	22	33	7	-1,14891	0,250593	-1,14891	0,250593	5	5	0,309524
Fisher α	40	15	0	2,61116	**0,009024**	**2,61116**	**0,009024**	5	5	**0,007937**

Table 5S. Spearman correlation matrix of environmental parameters.

	Salinity	Temp.	pH	Silt and Clay	Fine Sand	Medium Sand	Coarse Sand	Nitrates	Sulphates	TOC	THC	Cr	Ni	Cu	Zn	As	Ag	Cd	Hg	V
Salinity	1,00																			
Temperature	0,72	1,00																		
pH	0,64	0,92	1,00																	
Silt and Clay	0,88	0,93	0,85	1,00																
Fine Sand	0,83	0,90	0,82	0,95	1,00															
Medium Sand	-0,73	-0,95	-0,95	-0,94	-0,92	1,00														
Coarse Sand	**-0,85**	-0,41	-0,31	**-0,66**	**-0,64**	0,45	**1,00**													
Nitrates	0,73	0,95	0,94	0,89	**0,83**	**-0,92**	-0,42	**1,00**												
Sulphates	-0,13	-0,60	-0,60	-0,42	-0,59	0,54	-0,10	-0,56	**1,00**											
TOC	0,56	**0,65**	**0,80**	**0,68**	0,56	**-0,81**	-0,31	**0,75**	-0,15	**1,00**										
THC	**0,68**	**0,94**	**0,98**	**0,87**	**0,83**	**-0,95**	-0,35	**0,98**	-0,60	**0,80**	**1,00**									
Cr	**0,85**	**0,89**	**0,85**	**0,94**	**0,97**	**-0,91**	-0,58	**0,87**	-0,60	0,62	**0,87**	**1,00**								
Ni	0,07	-0,43	-0,50	-0,15	-0,16	0,39	-0,47	-0,50	0,58	-0,39	-0,57	-0,27	**1,00**							
Cu	0,66	0,77	0,74	**0,75**	**0,89**	**-0,76**	-0,44	**0,73**	**-0,76**	0,36	**0,74**	**0,88**	-0,31	**1,00**						
Zn	0,47	**0,63**	0,63	0,59	**0,79**	**-0,64**	-0,30	0,54	**-0,81**	0,19	0,60	**0,77**	-0,26	**0,94**	**1,00**					
As	**0,79**	**0,83**	**0,81**	**0,89**	**0,98**	**-0,88**	-0,58	**0,79**	**-0,64**	0,56	**0,80**	**0,97**	-0,20	**0,93**	**0,84**	**1,00**				
Ag	0,47	0,60	0,44	0,56	**0,71**	-0,52	-0,38	0,40	-0,53	-0,02	0,42	0,60	-0,04	**0,77**	**0,83**	**0,65**	**1,00**			
Cd	-0,26	-0,55	-0,41	-0,38	-0,23	0,34	0,07	**-0,64**	0,28	-0,24	-0,52	-0,28	0,49	-0,17	0,04	-0,13	-0,01	**1,00**		
Hg	0,41	**0,63**	0,50	0,60	**0,75**	-0,60	-0,29	0,58	**-0,83**	0,18	0,56	**0,74**	-0,33	**0,80**	**0,77**	**0,78**	0,56	-0,26	**1,00**	
V	0,77	0,79	0,74	0,83	0,95	-0,80	-0,64	**0,74**	**-0,67**	0,42	**0,75**	**0,94**	-0,14	**0,92**	**0,88**	**0,95**	**0,72**	-0,16	**0,81**	**1,00**
Mn	**0,87**	**0,74**	0,61	**0,85**	**0,90**	**-0,73**	**-0,85**	**0,67**	-0,38	0,37	**0,64**	**0,85**	0,12	**0,77**	**0,68**	**0,84**	**0,71**	-0,21	**0,65**	**0,92**
Fe	0,69	**0,73**	0,63	**0,79**	**0,87**	**-0,73**	**-0,75**	**0,67**	-0,52	0,37	**0,66**	**0,78**	0,04	**0,77**	**0,70**	**0,81**	**0,67**	-0,25	**0,72**	**0,89**
Co	0,54	0,16	0,01	0,40	0,45	-0,19	**-0,87**	0,11	0,08	-0,04	0,04	0,32	**0,64**	0,34	0,26	0,40	0,39	0,10	0,33	0,50
Pb	**0,64**	**0,77**	**0,78**	**0,80**	**0,91**	**-0,85**	-0,45	**0,73**	**-0,72**	0,57	**0,78**	**0,92**	-0,28	**0,85**	**0,83**	**0,95**	0,56	-0,07	**0,83**	**0,93**
CF	0,67	0,79	0,83	0,81	0,92	**-0,85**	-0,48	**0,75**	**-0,71**	0,55	**0,80**	**0,92**	-0,25	**0,88**	**0,88**	**0,94**	**0,65**	-0,07	**0,73**	**0,95**
PLI	**0,67**	**0,79**	**0,83**	**0,81**	**0,92**	**-0,85**	-0,48	**0,75**	**-0,71**	0,55	**0,80**	**0,92**	-0,25	**0,88**	**0,88**	**0,94**	**0,65**	-0,07	**0,73**	**0,95**
Ammonia	-0,57	**-0,83**	**-0,81**	**-0,73**	**-0,81**	**0,76**	0,21	**-0,78**	**0,75**	-0,37	**-0,78**	**-0,81**	0,45	**-0,90**	**-0,83**	**-0,82**	**-0,73**	0,33	**-0,64**	**-0,76**
Glabratellina	0,50	0,60	**0,66**	0,54	0,61	-0,60	-0,45	**0,67**	-0,58	0,42	**0,71**	**0,63**	-0,32	**0,65**	0,61	0,60	0,41	-0,37	0,53	**0,75**
Murrayinella	0,49	**0,93**	**0,92**	**0,83**	**0,82**	**-0,92**	-0,19	**0,87**	**-0,70**	**0,67**	**0,90**	**0,80**	-0,50	**0,72**	0,63	**0,78**	0,51	-0,43	**0,64**	**0,69**
Miliolids	**-0,66**	**-0,93**	**-0,91**	**-0,89**	**-0,84**	**0,96**	0,36	**-0,93**	0,56	**-0,82**	**-0,95**	**-0,88**	0,50	**-0,66**	-0,53	**-0,81**	-0,36	0,47	**-0,63**	**-0,73**
Elphidium	0,57	**0,83**	**0,68**	**0,76**	**0,79**	**-0,73**	-0,24	**0,77**	**-0,73**	0,36	**0,73**	**0,84**	-0,47	**0,73**	**0,65**	**0,78**	0,52	-0,49	**0,84**	**0,75**
Peneroplidae	-0,21	0,21	0,28	-0,05	0,03	-0,05	0,43	0,32	**-0,70**	-0,10	0,29	0,09	**-0,65**	0,35	0,32	0,09	0,08	-0,51	0,35	0,13
Brizalina	0,53	0,54	0,53	0,52	0,41	-0,52	-0,06	0,52	-0,06	0,52	0,53	0,52	-0,41	0,29	0,17	0,41	0,17	-0,24	0,06	0,23
Adults	0,08	-0,04	0,18	0,01	-0,14	-0,14	-0,13	0,08	0,47	0,59	0,18	-0,12	-0,04	-0,28	-0,35	-0,16	-0,36	0,08	-0,54	-0,19
Juveniles	-0,08	0,04	-0,18	-0,01	0,14	0,14	0,13	-0,08	-0,47	-0,59	-0,18	0,12	0,04	0,28	0,35	0,16	0,36	-0,08	0,54	0,19
Ratio (A/J)	0,08	-0,04	0,18	0,01	-0,14	-0,14	-0,13	0,08	0,47	0,59	0,18	-0,12	-0,04	-0,28	-0,35	-0,16	-0,36	0,08	-0,54	-0,19
S	0,46	**0,84**	**0,83**	**0,72**	**0,78**	**-0,81**	-0,05	**0,81**	**-0,81**	0,52	**0,82**	**0,81**	-0,61	**0,81**	**0,72**	**0,81**	0,51	-0,37	**0,74**	**0,69**
FD	0,14	**0,70**	**0,71**	0,53	0,53	**-0,66**	0,25	0,58	**-0,66**	0,42	**0,63**	0,52	-0,54	0,49	0,52	0,52	0,44	-0,23	0,41	0,39
H'	0,40	**0,73**	**0,64**	0,60	**0,70**	-0,60	-0,05	**0,68**	**-0,87**	0,16	**0,64**	**0,73**	-0,50	**0,81**	**0,76**	**0,72**	0,60	-0,44	**0,80**	**0,69**
E	-0,19	-0,55	**-0,70**	-0,50	-0,48	**0,70**	-0,15	-0,54	0,42	**-0,75**	**-0,63**	-0,50	0,50	-0,39	-0,35	-0,53	-0,11	-0,01	-0,30	-0,31
J	-0,13	-0,38	-0,55	-0,36	-0,30	0,55	-0,19	-0,43	0,19	**-0,75**	-0,51	-0,33	0,49	-0,24	-0,13	-0,36	0,09	-0,02	-0,11	-0,10
Fisher α	**0,72**	**0,81**	**0,80**	**0,81**	**0,85**	**-0,83**	-0,39	**0,87**	**-0,66**	0,62	**0,85**	**0,92**	-0,49	**0,85**	**0,70**	**0,90**	0,41	-0,37	**0,79**	**0,83**

Spearman Rank Order Correlations (Data for Fabry.sta) MD pairwise deleted Marked correlations are significant at $p < .05000$

Table 5S. Continued.

Mn	Fe	Co	Pb	CF	PLI	*Ammonia*	*Glabratellina*	*Murrayinella*	Miliolids	*Elphidium*	Peneroplidae	*Brizalina*	Adults	Juveniles	Ratio (A/J)	S	FD	H'	E	J	Fisher α
1,00																					
0,94	1,00																				
0,72	**0,72**	**1,00**																			
0,77	**0,78**	0,31	**1,00**																		
0,81	**0,81**	0,30	**0,96**	**1,00**																	
0,81	**0,81**	0,30	**0,96**	**1,00**	**1,00**																
-0,59	-0,56	-0,04	**-0,71**	**-0,76**	**-0,76**	**1,00**															
0,68	**0,76**	0,30	**0,64**	**0,75**	**0,75**	-0,48	**1,00**														
0,56	**0,64**	0,02	**0,78**	**0,77**	**0,77**	**-0,81**	0,50	**1,00**													
-0,65	**-0,66**	-0,08	**-0,83**	**-0,79**	**-0,79**	**0,67**	-0,60	**-0,91**	**1,00**												
0,61	0,56	0,06	**0,78**	**0,71**	**0,71**	**-0,77**	0,43	0,77	-0,79	1,00											
-0,13	0,02	-0,40	0,10	0,14	0,14	-0,47	0,36	0,29	-0,13	0,33	**1,00**										
0,17	-0,06	-0,36	0,29	0,29	0,29	-0,52	-0,06	0,43	-0,52	0,52	-0,06	**1,00**									
-0,09	-0,08	-0,09	-0,14	-0,05	-0,05	0,31	0,19	-0,06	-0,12	-0,48	-0,36	0,06	**1,00**								
0,09	0,08	0,09	0,14	0,05	0,05	-0,31	-0,19	0,06	0,12	0,48	0,36	-0,06	**-1,00**	**1,00**							
-0,09	-0,08	-0,09	-0,14	-0,05	-0,05	0,31	0,19	-0,06	-0,12	-0,48	-0,36	0,06	1,00	-1,00	1,00						
0,46	0,48	-0,12	**0,79**	**0,74**	**0,74**	**-0,91**	0,39	**0,90**	**-0,81**	**0,87**	0,47	0,56	-0,31	0,31	-0,31	**1,00**					
0,18	0,22	-0,38	0,53	0,54	0,54	**-0,73**	0,14	**0,85**	**-0,65**	**0,64**	0,35	0,52	-0,20	0,20	-0,20	0,83	1,00				
0,48	0,48	-0,04	**0,68**	**0,66**	**0,66**	**-0,89**	0,41	**0,73**	-0,61	**0,90**	0,61	0,41	-0,61	0,61	-0,61	0,91	0,70	1,00			
-0,09	-0,15	0,32	-0,57	-0,50	-0,50	0,52	-0,07	**-0,76**	**0,68**	-0,43	-0,08	-0,52	-0,18	0,18	-0,18	**-0,73**	**-0,79**	-0,39	**1,00**		
0,08	0,03	0,36	-0,36	-0,27	-0,27	0,36	0,09	-0,58	0,54	-0,24	-0,02	-0,52	-0,31	0,31	-0,31	-0,58	-0,60	-0,20	**0,94**	**1,00**	
0,66	0,62	0,15	**0,87**	**0,81**	**0,81**	**-0,79**	0,58	**0,76**	**-0,84**	**0,85**	0,31	0,52	-0,16	0,16	-0,16	**0,87**	0,49	**0,78**	-0,55	-0,45	1,00

Table 6S. Similarity percentages for abiotic factors calculated using SIMPER.

	Group Polluted	Group Unpolluted				
Species	Av. Abund	Av. Abund	Av. Diss	Diss/SD	Contrib %	Cum. %
CF	607,44	31,76	1,88	3,81	14,37	14,37
THC	67,37	2,24	1,48	3,6	11,33	25,7
Sulphates	1477,6	4231,2	1,42	23,61	10,85	36,55
Pb	10,27	0,06	0,95	4,9	7,29	43,84
PLI	309,75	72,69	0,95	4,29	7,27	51,11
TOC	10447,6	7296,4	0,81	1,12	6,23	57,34
Cu	41,9	3,45	0,74	1,62	5,69	63,03
Cr	20,4	3,6	0,57	1,82	4,37	67,39
Hg	54	12	0,55	1,44	4,23	71,62
Zn	49,06	10,7	0,55	1,49	4,22	75,84
Mn	77,6	27,6	0,52	1,48	3,97	79,81
V	12,4	3,8	0,34	1,53	2,57	82,39
Water depth	44,2	72,2	0,31	1,48	2,38	84,76
Coarse Sand	6,72	8,4	0,29	1,32	2,23	86,99
Silt and Clay	10,61	5,54	0,24	1,62	1,84	88,83
Nitrates	196,46	139,94	0,23	8,48	1,77	90,61

Average dissimilarity = 13.08

Table 7S. Similarity percentages for biotic factors calculated using SIMPER.

	Group Polluted	Group Unpolluted				
Species	Av. Abund	Av. Abund	Av. Diss	Diss/SD	Contrib %	Cum. %
Murrayinella	24,14	0	4,31	27,88	39,62	39,62
Miliolids	1,75	28,3	2,31	7	21,18	60,8
FD	254,4	153	1,07	1,35	9,85	70,65
Peneroplidae	1,57	0,87	0,66	0,81	6,07	76,71
Elphidium	6,71	3,34	0,49	2,16	4,54	81,25
Juveniles	47,72	39,44	0,37	1,17	3,4	84,66
Brizalina	0,06	0	0,29	0,49	2,66	87,32
Ratio (A/J)	1,12	1,78	0,28	1,17	2,54	89,86
Adults	52,28	60,56	0,27	1,31	2,48	92,34

Average dissimilarity = 10.89

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