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Original article

Sediment oxygen demand and benthic foraminiferal faunas in the Arabian Gulf: A test of the method on a siliciclastic substrate

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ABSTRACT

In this study, we investigated the relationship between environmental parameters (water and sediment) and benthic foraminiferal assemblages found in nearshore siliciclastic sediment in the Arabian Gulf. Nearshore marine water and sediment samples were collected from a beach on the Gulf of Bahrain located south of Al Khobar, Saudi Arabia. The water samples were analyzed for biochemical oxygen demand (BOD_5) and other chemical analyses. The sediment samples were tested for sediment oxygen demand (SOD) and heavy metal analysis. Results showed the BOD_5 levels were below the detection limit (<1 ppm), while the mean SOD value was 0.97 ± 0.08 g/m^2·day. The water and sediments were unpolluted and free of eutrophic enrichment, while the sediment was anoxic. The two most common genera in the benthic foraminiferal assemblage, *Ammonia* and *Elphidium*, are typical of shallow water sandy substrates. This is the first reported comparison between SOD and benthic foraminiferal assemblages.

1. Introduction

Due to their short-life cycles and sensitivity to a variety of environmental conditions, foraminifera can be used as effective bioindicators in a wide range of marine environments. Benthic foraminifera are increasingly being investigated to monitor, characterize, and generate baseline data to understand natural and anthropogenic influences on marine environments. Causes of environmental changes in marine ecosystems include changes in water quality due to effluents from industrial, domestic and natural pollution sources (Jones, 2013) and anthropogenic eutrophication and anoxia (Van Der Zwaan and Jorissen, 1991). Foraminiferal responses to anthropogenic organic pollution and eutrophication have been well documented in the literature (Frontalini and Coccioni, 2008; Martins et al., 2015; Nikulina et al., 2008; Prazeres et al., 2016; Prazeres and Pandolfi, 2016).

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Researchers often monitor and evaluate changes in foraminiferal assemblages as a practical method for assessing marine environmental changes. Foraminifera may respond to changes in their environment caused by pollution by undergoing community level structural and compositional changes, such as decreased diversity and increased dominance (i.e., opportunistic species), higher frequencies of test deformities, or mass mortality (Jones, 2013). In oxygen-depleted basins and in the oxygen minimum zone, reduced overall diversity along with dominance by a few species are commonly observed in benthic foraminiferal communities (Phleger and Soutar, 1973; Douglas, 1981; Sen Gupta and Machain-Castillo, 1993; Kaminski et al., 1995; Bernhard et al., 1997).

The first comprehensive study of foraminiferal response to eutrophication was conducted by Jorissen, who explored the distribution of benthic foraminiferal assemblages in the Adriatic Sea (Jorissen, 1988, 1987). The Po and other Italian rivers deposit enormous quantities of nutrients and organic detritus into a mud-belt along the western coast of the Adriatic Sea. This nutrient-rich input has leads to algal blooms and the rapid consumption of oxygen, which ultimately causes oxygen depletion in the bottom waters (Boldrin et al., 2005). Jorissen reported that these circumstances could lead to the presence of foraminiferal species with an opportunistic life strategy, such as *Nonionella turgida*, *Bulimina marginata* and *Valvulineria bradyana*. The foraminiferal assemblages reveal the occurrence of anoxic/dysoxic conditions at the sediment/water

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interface, characterized by low diversity and opportunistic species. These authors reported microhabitats and the degree of tolerance to oxygen deficiency of selected benthic foraminiferal taxa.

Eutrophication of marine environments can be monitored through a number of different environmental indicators including biochemical oxygen demand (BOD), sediment oxygen demand (SOD), and chemical analysis of the seawater and sediment. BOD measures the equivalent amount of oxygen required to biologically oxidize organic compounds in water, which is an indication of organic pollution that can be degraded biologically. BOD may be defined as a ratio of the amount of oxygen taken up through respiration per volume of sample when incubated at a specified temperature and for a specified time (Jouanneau et al., 2014). Typically, BOD measurements are conducted at 20 °C for 5 days (BOD_5) and are expressed as mg O_2 per liter (Rice et al., 2012). SOD may be defined as the total oxygen removal from the overlying water due to biological respiration and/or chemical oxidation of organic substances in the surficial sediments. High SOD values indicate that oxygen depletion due to sediment uptake may continue to cause significant impacts on water quality long after pollution control measures have remediated other sources of nutrients. More importantly, eutrophication of the overlying waterbody may persist for long periods of time (Hu et al., 2001).

Despite the fact that the potential impact of SOD on water quality and benthic organisms is widely recognized, there is no universal standard for measuring or determining SOD values (Rong et al., 2016). While chambered *in situ* measurements are the most common methodology and considered to provide the best results, these techniques suffer from a number of drawbacks including the expense of the equipment. Laboratory-based methodologies have been effectively used to measure SOD (Rong et al., 2016; Seiki et al., 1994). Previous comparison studies between *in-situ* and laboratory SOD measurements have shown that significant differences do not exist between the *in-situ* SOD and laboratory approaches when testing fine-grained material (Truax et al., 1995). In order to perform SOD measurements in the laboratory, undisturbed core sediment must be collected and transported to the laboratory under controlled conditions (Bowman and Delfino, 1980). Longaker and Poppe previously reported the design of an apparatus and the methodology for measuring SOD in the laboratory (Longaker and Poppe, 1986).

Since benthic foraminifera live on and within the surficial sediment, the sediment (benthic) oxygen demand (SOD) is likely to have a greater influence on the composition of the benthic community than the BOD. However, to the best of our knowledge, there have been no studies into the relationships between foraminiferal assemblages and SOD. The primary goal of this preliminary research was to examine the composition of benthic foraminifera faunas in the Arabian Gulf with respect to environmental indicators of eutrophication in the water (BOD) and in the sediment (SOD).

Water circulation and nutrient cycling in the Gulf are primarily determined by exchange of water through the Strait of Hormuz with the Indian Ocean (Al-Said et al., 2019; Swift and Bower, 2003). Although the Gulf would be expected to be nutrient-depleted under pristine conditions, anthropogenic sources of nutrients, including sewage and industrial discharges, have stimulated the growth of microphytoplankton (Al-Said et al., 2019). Furthermore, the geospatial distribution of elevated levels of total organic carbon observed in the northern Arabian Gulf near Kuwait indicates that there is a significant contribution from anthropogenic sources (Al-Said et al., 2018). Although there have been a number of recent studies on benthic foraminifera in the region (Amao et al., 2019; Fiorini et al., 2019; Garrison, 2019; Kaminski et al., 2021, 2020), very little is known about the response of the foraminiferal faunas in the Arabian Gulf to anthropogenic organic enrichment. To date, there has been one study by Arslan et al. that investigated the response of benthic foraminifera to organic enrichment in a boat harbor in Bahrain attributed to waste discharge from local fishing vessels (Arslan et al., 2017).

For this study, we selected an accessible location on the Saudi Arabian coast of the Arabian Gulf with an unpolluted, fine-grained siliciclastic substrate that had been previously studied for benthic foraminifera (Arslan et al., 2016). An earlier study by Arslan et al. had reported that the study site was relatively free of organic and chemical pollution (Arslan et al., 2016), and therefore we expected that both the SOD measurements and foraminiferal assemblages are representative for such an environment in the western Gulf region. We conducted laboratory-based SOD measurements on sediment cores collected from an accessible location in the Arabian Gulf that has previously been studied for both substrate parameters and living foraminifera (Arslan et al., 2016).

2. Study area

The study area is at a public beach south of Al Khobar, Saudi Arabia. The site is located on the peninsula separating the northeastern portion of Half Moon Bay from the Arabian Gulf (50° 09.620′E; 26° 06.222′N) (Fig. 1). The coastal areas in this region includes localities where sand dunes enter the sea, and as a result the beaches are comprised of nearly pure quartz sand (Arslan et al., 2016). At these beaches, the foreshore is wide with a gentle slope, and the sea floor consists of loose rippled sand with no sea grass coverage. Symmetrical wave-formed ripples with wavelengths several meters in length were oriented parallel to the shoreline.

3. Methods

3.1. Field sampling

Core samples were collected from the sandy substrate approximately 25 m from the beach in the same location as that was previously sampled by Arslan et al., in a water depth of approximately 1 m (Arslan et al., 2016). Eight core samples were collected by manually inserting 15.0 cm long plastic tubes with an internal diameter of 7.0 cm into the substrate. The tubes were extracted from the sediment by hand and sealed under water using neoprene stoppers (size #13.5). The core samples were transported to the laboratory in an upright position inside an ice chest. Concurrently with the collection of the sediment cores, seawater was sampled, filtered on site using paper filters to remove particulates, and transported to the laboratory in 20 L plastic carboys. Upon arrival in the laboratory, the sediment cores were immediately transferred to the SOD testing apparatus, and the apparatus was carefully filled with the filtered seawater as to not disturb the sediment. A redox boundary was observed in the cores at an average depth of 6 cm below sea floor.

4. Chemical analysis

4.1. BOD

The 5-day Biochemical Oxygen Demand (BOD_5) was conducted according to established methods (Rice et al., 2012). The technique involves measuring the dissolved oxygen (DO) of a sample at onset (initial DO) and after incubation at 20 °C for five days (final DO). The amount of oxygen depleted by microorganisms is used to calculate the BOD_5 of the sample. A 100 mL aliquot of seawater sample is transferred to a 300 mL BOD bottle and 5 mL of seed is added to each sample and completed to volume with dilution water. The initial DO was then measured by the YSI multi-parameter DO

Fig. 1. Location of sample site on the Gulf of Bahrain, near Khobar, Saudi Arabia. Maps are from Google Earth.

probe. The sample was then placed in the incubator for 5 days at 20 °C. After 5 days, the final DO measurement was taken by the probe and the BOD_5 value was calculated using the standard BOD formula.

4.2. Ion concentration analysis

Ion concentrations in the seawater were measured using a dual column Metrohm 850 Professional IC (Metrohm, Switzerland). The instrument was calibrated with 5-point standards for anions and cations prior to analysis. Sodium carbonate solution and dilute HNO_3 were used as the eluent solutions for anions and cations, respectively. The following instrument settings were used for the analysis: eluent flow rate of 0.9 mL/min, pressure setting of 8 MPa, column temperature of 45 °C.

4.3. Metals analysis using ICP-MS

Prior to trace metal analysis, the sediment sample was digested in as per EPA 3051A (Microwave) (Method 3051A (SW-846): Microwave Assisted Acid Digestion of Sediments, Sludges, and Oils, 2007). In summary, 0.5 g of homogenized oven-dried sediment was placed in the digestion vessel and 10 mL of concentrated HNO_3 was added. After allowing the fume to escape, the vessels were tightly closed and placed into a Microwave Digestion System (MARS 6, supplied by CEM Corporation, USA). The samples were heated to 175 °C over a time span of 5.5 min and then cooled down within the remaining 4.5 min. All water samples were treated with diluted HNO_3 in order to make all the trace metals available in solution prior to analysis by ICPMS. Trace metals were then analyzed by the ICP-MS (iCAP-RQ, Thermo Scientific, UK). High purity (99.999%) argon gas was used for plasma generation while high purity (99.999%) helium gas was included in order to limit interferences at the KED mode. Samples were measured as the standard method EPA 6020A (ICP-MS).

4.4. Total organic carbon

Total organic carbon (TOC) was measured in surficial sediment using a high temperature combustion analyzer (multi N/C 3100, Analytik Jena 3100, Germany), which analyzes TOC using oxygen as the inlet gas. The equipment was calibrated using potassium hydrogen phthalate (KHP) and sodium carbonate as reference standards.

4.5. Total petroleum hydrocarbons

Analysis of total petroleum hydrocarbons (TPH) in the water samples was conducted using Varian 450 gas chromatography with flame ionization detector (GC/FID). Helium was used as carrier gas at a rate of 1.0 mL/min. Capillary column type is VF-1 ms, 15 m, 0.25 mm, 0.25 μm was used for separation. The separation was carried out at initial temperature of 40 °C with holding time 3 min then gradually increased to 325 °C degrees at rate of 35.0 °C/min. The injector and FID detector are kept at 300 °C degrees.

4.6. Siliciclastic vs. Biogenic

The composition of the sand faction was determined by spreading a small split of the unpicked sample into a picking tray that is marked into a grid and undertaking a point count of grains in random squares in the tray. The proportions of biogenic particles, clear quartz, colored quartz, and mafic grains were determined by counting a minimum of 1000 grains in each sample.

4.7. Sediment oxygen demand

A SOD apparatus (Fig. 2) was constructed based on a modified design of the previously reported apparatus by Longaker and Poppe (1986). High-density polyethylene (HDPE) carboys (Hünersdorff GmbH, Germany) with a wide-mouth opening were purchased. The dimensions of the carboy were approximately 16 × 33 × 46 cm (LxWxH) with an actual volume capacity of 24.14 L. Hose fittings were installed on opposite sides of the container approximately 25 cm from the bottom of the container. Constant circulation (120 L/h) in the apparatus was maintained by connecting a small aquarium pump 1/4″ flexible tubing to the hose fittings. A 2 cm diameter fitting was installed on the highest point of the carboy to function as a trapped air exit port and as a port for the BOD probe. When not taking BOD readings, the fitting was tightly sealed. Periodic DO measurements were recorded using a YSI Polarographic Self-Stirring BOD Probe connected to a YSI Pro Plus Multi-Parameter Instrument (YSI Inc., United States).

4.8. Foraminiferal analysis

Foraminiferal samples were collected using 125 mL wide-mouth sample jars (4 cm internal diameter) by hand-dragging the open jar along the sediment surface, thereby capturing the top 1–2 cm of the sediment. Three replicate samples were collected within approximately one meter of each other. Sample jars were filled halfway, yielding approximately 60 mL of sediment. Samples were stained using an alcohol-Rose Bengal solution (5 g Rose Bengal per liter of alcohol), and after 2 weeks sieved over a 63-μm sieve and oven-dried at 60 °C. Foraminifera were picked from the >125-μm fraction and mounted into cardboard microscope slides. Specimens with red-stained protoplasm were counted as "living". Although typical protocol for foraminiferal analysis is to use a microsplitter to divide the dried sample into equal fractions, the entire volume of each sediment sample was picked for foraminifera due to the low abundances of living foraminifera.

a

b

Fig. 2. Apparatus for measuring sediment oxygen demand in the laboratory.

5. Results

5.1. BOD

BOD results for the seawater samples were repeated for 5 times and the BOD_5 levels for all measurements were below 1 ppm. This indicates that sampling site has extremely low levels of biodegradable organic materials and can be considered free of biological contamination. This is expected due to the usual high dilution rates and the absence of clear source of contamination. In such cases, extremely low levels of BOD in seawater are commonly reported (around 2 ppm) (Simon et al., 2011).

5.2. Chemical analysis

Water samples were tested for pH, conductivity, total alkalinity, salinity, ion concentrations, and heavy metal concentrations (Table 1). Sediment samples were tested for TOC, TPH, and heavy metals (Table 1). The TOC and TPH results were below detection limits, which indicate the siliciclastic sediment have not polluted by petroleum hydrocarbons or by sewage. The results (mean ± SD) are shown below in Table 1.

5.3. Siliciclastic vs biogenic

The composition of the sand fraction at the studied locality consists of ca. 99% quartz grains. Mafic mineral grains and biogenic particles are very rare and make up less than 1% of the grain compositions. Approximately 3% of the quartz grains have orange, brown, or greenish coloration. In order of decreasing relative abundance, the biogenic particles consist of mollusk fragments, foraminifera, ostracod valves, fragments of serpulid worm tubes, and juvenile clam shells. The sediment can be characterized as nearly pure siliciclastic quartz sand with a very minor biogenic component.

5.4. SOD

Dissolved oxygen measurements of the filtered seawater inside the SOD chamber were collected twice daily until the dissolved oxygen concentration dropped below 2.0 mg/L. To calculate the SOD, the dissolved oxygen content (mg/L) was plotted as a function of time (h). A representative plot of one the trials is shown in Fig. 3.

SOD was calculated using the following equation, as described in the method reported by Longaker and Poppe (1986):

$$SOD = b * \frac{V}{A} * 0.024$$

where the units of SOD are given in $g/m^2 \cdot day$, *b* is the slope of the slope of the SOD curve in $mg/L \cdot h$, *V* is the volume of the apparatus system in liters, A is the total surface area of the sediment cores in m^2, and the constant 0.024 is a conversion factor between $g/m^2 \cdot day$ and $mg/L \cdot h$.

Table 1
Summary of chemical analysis of water and sediment samples.

Parameter	Water		Sediment	
	Result	Unit	Result	Unit
pH	7.95	pH Unit		
Conductivity	77,000 ± 200	µS/cm		
Total Alkalinity	119 ± 1	mg $CaCO_3$/L		
Bicarbonate Alkalinity	119 ± 1	mg $CaCO_3$/L		
BOD_5	<1	ppm		
Salinity	54.76 ± 0.06	PSU		
TOC	ND	–	207 ± 47	ppm
TPH	ND	–	ND	mg/Kg
Sodium (Na^+)	12560 ± 219	mg/L		
Potassium (K^+)	479 ± 9	mg/L		
Magnesium (Mg)	1770 ± 47	mg/L		
Calcium (Ca^{2+})	670 ± 128	mg/L		
Ammonium (NH_4^+)	ND	mg/L		
Fluoride (F^-)	26180 ± 460	mg/L		
Chloride (Cl^-)	ND	mg/L		
Nitrite (NO_2^-)	6990 ± 60	mg/L		
Bromide (Br^-)	12560 ± 219	mg/L		
Nitrate (NO_3^-)	105.3 ± 1.3	mg/L		
Phosphate (PO_4^{3-})	85.5 ± 9.3	mg/L		
Sulfate (SO_4^{2-})	ND	mg/L		
Boron (B)	3419 ± 195	µg/L	8.9 ± 0.9	mg/Kg
Aluminum (Al)	ND	µg/L	1282 ± 24	mg/Kg
Cobalt (Co)	ND	µg/L	0.94 ± 0.02	mg/Kg
Vanadium (V)	5.7 ± 0.2	µg/L	5.6 ± 0.1	mg/Kg
Manganese (Mn)	ND	µg/L	34.2 ± 0.7	mg/Kg
Nickel (Ni)	ND	µg/L	6.5 ± 0.1	mg/Kg
Copper (Cu)	ND	µg/L	1.10 ± 0.01	mg/Kg
Zinc (Zn)	ND	µg/L	1.8 ± 0.1	mg/Kg
Arsenic (As)	ND	µg/L	1.37 ± 0.03	mg/Kg
Iron (Fe)	2006 ± 22	µg/L	1837 ± 50	mg/Kg
Selenium (Se)	ND	µg/L	0.49 ± 0.06	mg/Kg
Chromium (Cr)	10.94 ± 0.38	µg/L	6.2 ± 0.2	mg/Kg
Strontium (Sr)	9544 ± 43	µg/L	127.8 ± 2.0	mg/Kg
Lead (Pb)	ND	µg/L	0.90 ± 0.02	mg/Kg
Mercury (Hg)	0.76 ± 0.16	µg/L	0.10 ± 0.02	mg/Kg
Molybdenum (Mo)	12.51 ± 0.50	µg/L	0.042 ± 0.005	mg/Kg
Cadmium (Cd)	ND	µg/L	0.010 ± 0.002	mg/Kg
Barium (Ba)	7.06 ± 0.57	µg/L	7.98 ± 0.17	mg/Kg

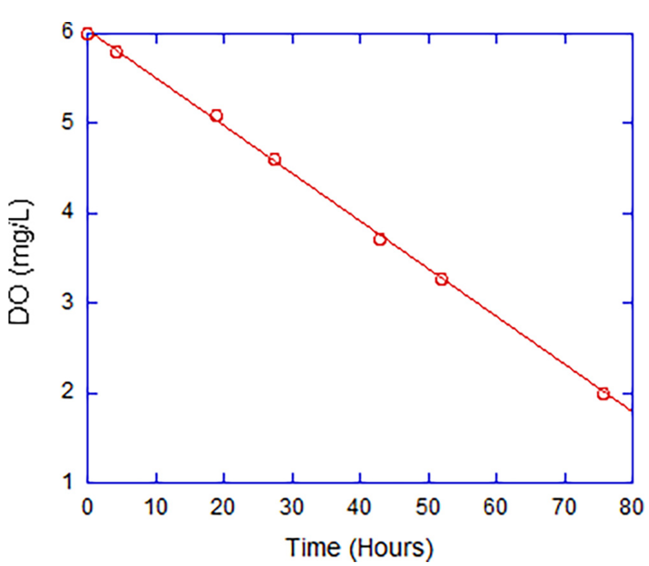

Fig. 3. Representative plot of dissolved oxygen versus time from the SOD test for the locality. For this trial, the slope of the linear regression curve is −0.0531 and the R^2 value was 0.9993.

We found that our test of shallow marine siliciclastic sediment yielded SOD values of 0.97 ± 0.08 $g/m^2 \cdot day$. The measurements were conducted in triplicate, and high correlation coefficients (>0.99) were obtained. This value was within the range of SOD values reported by Longaker and Pope in their protocol paper (Longaker and Poppe, 1986).

5.5. Foraminiferal analysis

The living benthic foraminiferal assemblage at the sampled site consists of five species belonging to five genera (*Ammonia, Elphidium, Cycloforina, Quinqueloculina* and *Coscinospira*). The abundances of the recovered live (Rose Bengal stained) and dead (unstained)

Table 2
Numbers of Live/Dead benthic foraminifera recovered from the studied samples.

Species	S1	S2	S3
Ammonia tepida	11/48	25/38	13/42
Elphidium advenum	8/38	13/28	9/17
Quinqueloculina spp.	2/46	4/28	0/26
Cycloforina sp. (thin)	3/3	8/5	3/0
Coscinospira hemprichii.	1/25	6/19	2/21
Rosalina sp.	1/0		0/2
Porosononion sp.	0/15	0/9	0/2
Peneroplus pertusus	0/20	0/19	0/27
Spiroloculina sp.	0/1		0/1
Pseudotriloculina sp.	0/3	0/1	
Adelosina sp.		0/1	
Agglutinella kaminskii		0/1	0/1
Elphidium gerthi	0/1	0/1	
Murrayinella sp.		0/2	
Reophax sp.	0/1	0/1	

specimens are given in Table 2. The foraminiferal abundances observed in September 2019 were very low (28–47 ind./60 cc), and many of the living specimens were juveniles. Although dead specimens of *Peneroplis* were found in the washed residues, no living specimens were observed at the time the samples were collected. The dominant living species at the locality was *Ammonia tepida*, followed by *Elphidium advenum* and *Coscinospira hemprichii*. Living smaller miliolids are rare, consisting of a several specimens of *Cycloforina* and a small unornamented species of *Quinqueloculina*. Only juvenile specimens of live *Coscinospira hemprichii* were observed – the adult specimens were unstained by Rose Bengal. The dominant species observed in our samples are in agreement with the faunal composition previously reported for this location (Arslan et al., 2016).

6. Discussion

In this study, we examined the relationship between benthic organisms in the Arabian Gulf and environmental indicators of eutrophication, including dissolved oxygen (DO) content, TOC, TPH, BOD, and SOD. Moreover, the extent of sediment contamination with salts (cations and anions) and trace heavy metals was also examined in the study. Analysis of the seawater showed that there were high levels of DO in the water (>98%), while the TOC and TPH analyses indicated minimal traces of organic pollution. Furthermore, the BOD_5 values were below detection limits (<1 ppm). The sediment samples showed low levels of trace metals such as Zn, Ni, Cu, V, Cr, Pb, Mo, Cd and Hg. The low levels of the hazardous trace metals indicate that the site where the sediment samples were collected is relatively clean (Ranjbar Jafarabadi et al., 2017).

A comparison between the SOD and BOD values reveals that at the sample site, the oxygen uptake by the sediment (0.97 $g/m^2 \cdot day$) far exceeds that of the sea water. A BOD analysis of the sea water filtered on site revealed values below the detection limit (<1 ppm), which means the oxygen uptake in the reaction vessel is entirely due to the sediment in the cores, and not the sea water used in the vessel. BOD analyses of unfiltered sea water yielded values below 1 ppm. Although these values are likely to fluctuate both seasonally and geographically, our findings indicate the sediment rather than the water column constitutes the greater sink for oxygen in unpolluted siliciclastic sediment located in nearshore areas of the Arabian Gulf.

SOD was a better indicator of anoxic sediment conditions than other environmental parameters such as the dissolved oxygen content of the sea water, or the total organic content of the sediment. Based on the minimal amount of organic material in the sediment and the low SOD values, the subsurface redox boundary was likely caused by chemical processes instead of eutrophication of surficial waters.

Benthic foraminifera are known to show substrate preferences, as well as varying tolerances for dysoxic conditions. For example, *Ammonia tepida*, the most abundant species observed living at this locality, is known to be an opportunist that has a higher tolerance for dysoxic conditions (Murray, 2006). Furthermore, the genus *Elphidium* which was the second most abundant genus observed living, is known to prefer sandy substrates (Arslan et al., 2016). The diversity and abundance of the living foraminiferal fauna were consistent with the siliciclastic substrate and the presence of dysoxic sediment conditions. The dead assemblage is more abundant and more diverse than the living fauna, and several genera (e.g., *Reophax*, *Porosononion, Peneroplis, Spiroloculina*, *Agglutinella, Pseudotriloculina, Adelosina* and *Murrayinella*), were only found as dead specimens. The dead assemblage reflects the multi-year average fauna at this locality, but can also include specimens that have been transported by currents.

7. Conclusions

This study reports the first investigation of the relationship between benthic foraminifera and sediment oxygen demand (SOD) from nearshore siliciclastic sediment at a locality in the Gulf of Bahrain (Arabian Gulf). While the water and sediment samples at this location were unpolluted and not eutrophic, the sediment was anoxic at depth, and likely caused by chemical processes. SOD was found to be a better indicator of the presence of anoxic sediment conditions compared to the other environmental parameters analyzed. Future work includes measuring SOD at locations with different substrate types and at locations with elevated levels of petroleum hydrocarbons (i.e., oil seeps and spills) or with anthropogenic organic enrichment (i.e., sewage runoff).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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