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The response of benthic foraminifera to aquaculture and industrial pollution: A case study from the Northern Persian Gulf

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ABSTRACT

The aquaculture and industrial sewage impacts on benthic foraminifera investigated at two reefs across the northern Persian Gulf. The foraminifera assemblages at a single sewaged reef were compared with two non-sewaged reefs. A low-diversity assemblage, dominated by stress-tolerant species *Quinqueloculina* sp. and larger symbiont-bearing *Amphistegina* sp., was characteristic of the industrial sewaged reef. The opportunistic species *Ammonia* sp. and *Elphidium* sp. were common in aquaculture sewaged reef. The density of foraminifera in sewaged reefs was lower than non-sewaged reefs. The lower diversity was only detected in the industrial sewaged reef. Assemblage structure was significantly different between sewaged and non-sewaged reefs. The industrial sewaged reef displayed high FORAM Index values (> 4.0), reflecting favorable environments for supporting relatively healthy reefs. FORAM Index in aquaculture sewaged reef ranged from 2.0 to 4.0 indicated that the water with organic pollution may support living coral community, but any damage would not be followed by recovery.

1. Introduction

Foraminifera as large protists abundant in benthic and pelagic marine environments have been widely used as bioindicators of environmental conditions (e.g., Murray, 1971; de Rijk, 1995; Redois and Debenay, 1996; Debenay et al., 2000; Debenay and Guillou, 2002; Mojtahid et al., 2006; Morvan et al., 2004). The change in species composition and abundance of foraminifera and their morphological abnormalities have been used as bioindicators of pollution (e.g., heavy metals, sewage, oil) (Alve, 1991; Alve, 1995; Yanko et al., 1994, 1999; Samir, 2000; Samir and El-Din, 2001; Madkour and Ali, 2009a, 2009b; Jayaraju et al., 2011; Aloulou et al., 2012). The interest in employing foraminifers as bioindicators of different pollutants increased greatly following seminal work of Yanko et al. (1994) and Alve (1995) that recognized the broad applicability of foraminiferal assemblages in coastal environments. In particular, Alve (1995) proposed a model progression of responses of foraminiferal assemblages with increasing proximity to a point source of pollution.

Foraminifera are well recognized as bioindicators for marine and estuarine pollution in temperate regions and have been useful as indicators for coral reef water quality in tropical, subtropical, and temperate environments (Alve, 1995). The 'FORAM Index' (Hallock, 2000; Hallock et al., 2003) is based on grouping foraminifera into three functional groups: symbiotic, opportunistic and 'other small heterotrophs'. Temporal shifts in this Index coincided with general reef degradation caused by land runoff (Hallock et al., 2003). The FORAM Index has been shown to correspond well to a water quality gradient in the Great Barrier Reef, suggesting that decreased light and increased organic matter availability may cause a shift towards the higher contribution of heterotrophy (Uthicke and Nobes, 2008a, 2008b; Schueth and Frank, 2008).

The Persian Gulf coral communities exist in an adverse environment with respect to high salinity and sea surface temperature and also extreme low tides (Coles and Fadlallah, 1991; Sheppard et al., 1992). The regional and local disturbances of coral reefs in this region are caused by a complex combination of both environmental and anthropic stressors including those arising from climate change, diseases, predation, destructive fishing practices, storms and changes in water quality. Some coral reefs across the Northern Persian Gulf have been affected by nutrient and sediment inputs (Kavousi et al., 2011; Ghazilou et al., 2016; Mohammadizadeh et al., 2013a, 2013b) causing modified trophic structures, altered biodiversity and coral mortality (Fatemi and Shokri, 2001; Kabiri et al., 2013; Moradi et al., 2014; Nabavi et al., 2014; Ghazilou et al., 2016).

The few studies dealing with foraminifera in the Persian Gulf have mainly focused on taxonomy, distribution and diversity (Cherif et al.,

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1997; Sohrabi et al., 2006; Hariri, 2008; Saidova, 2010; Albadran and Issa, 2011; Karimi Mossadegh et al., 2012; Nabavi et al., 2014). Few studies have been conducted on the use of recent foraminifera as a tool for monitoring in the southern Persian Gulf (Al-Zamel et al., 2009; Alkahtany et al., 2015; Arslan et al., 2015; Arslan et al., 2017), yet the Iranian waters has been relatively neglected. Given the lack of any research dedicated to understanding the response of foraminifera to land-based pollutants, the present study aims to explore the impact of sewage from petrochemical and aquaculture industries on the foraminiferal community on two coral reef areas across the Northern Persian Gulf. The present study investigated the applicability of foraminiferal assemblages as bioindicators of pollution by testing four hypotheses: (1) diversity and density of foraminifera significantly differs between sewaged and non-sewaged reefs; (2) assemblage structure of foraminifera significantly differs between sewaged and non-sewaged reefs; (3) there are relationships between environmental variables (i.e., water and sediment properties) and benthic foraminiferal assemblages that can be used to assess the effectiveness of assemblage as an indicator of environmental quality (water and sediment) in two studied reef areas; and (4) the FORAM Index values are expected to reflect environmental conditions over the studied reefs.

2. Material and methods

2.1. Study area and sediment sampling

Sediment samples containing benthic foraminifera were collected in 2015 from two coral reef areas in Hengam Island (26°36′42″N, 55°51′46″E) and Nay Band Bay (27°25′60″ N, 52°37′13″ E), both located across the Northern Persian Gulf (Fig. 1). These areas were selected because they were subjected to different pollution sources including aquaculture sewage (Hengam Island) and petrochemical sewage (Nay Band Bay).

Asymmetrical sampling designs, known as Beyond BACI design (Underwood, 1994), using one putatively perturbed and several control sites, can detect a variety of environmental impacts (e.g., Lardicci et al., 1999; Levin and Tolimieri, 2001; Gladstone et al., 2006; Nemati et al., 2015). Likewise, in the present study differences in benthic foraminifera assemblages of a sewaged reef (impact site) were tested against two non-sewaged reefs (control sites) located away from the impact site.

In Hengam Island, one shrimp farm is located along the northeast coast of the island and covers approximately 38 ha of seven ponds and it yields twice a year. During the rearing phase, water exchange into the ponds is implemented by pumping water from the coastal zone. Water passing through the ponds is then enriched with chlorophyll-α, suspended organic solids and dissolved organic matter and may significantly contribute to high organic matter loads in the coastal environment where patchy corals occur in the depth range of 2 to 10 m. The corals of Hengam Island is directly exposed to the oceanic currents entering through the Strait of Hormuz that affect them by the influx of cooler, less saline, clearer and more nutrient rich waters (Pous et al., 2004). These currents can provide favorable conditions for the prevalence of different coral species in Hengam Island. The coral fauna of the Hengam Island is dominated by branching *Acropora* corals followed by *Porites* and *Platygyra* (Rezai et al., 2010). The results of Manta tow survey (English et al., 1994) demonstrated that live hard coral cover was 35%, 3%, and 21% at the sewaged reef, non-sewaged reef-1 and non-sewaged reef-2, respectively. The three sampling sites in Hengam Island included the sewaged reef (3 m depth) located in the vicinity of shrimp farm effluent, non-sewaged reef-1 (3.5 m depth), 5 km away from the sewaged reef, and non-sewaged reef-2 (3.5 m depth), 7.5 km further away from the sewaged reef (Fig. 1).

In Nay Band Bay, the three nearshore coral patch reefs were located at an increasing along-shore distance from a petrochemical industry established in 1998. The three sampling sites included the sewaged reef (4 m depth) located in the vicinity of industry, non-sewaged reef-1 (4 m depth), 7 km away from the sewaged reef (4 m depth), and non-sewaged reef-2, 13 km further away from the sewaged reef (Fig. 1). The currents in the area are mainly tide-driven and in some conditions wave-driven. The currents follow two different patterns according to the tidal regime. In ebb, they are long shore from northwest to southeast direction and vice versa during flood tides. The overall residual current along the coastline is in southeastern direction. In the depths > 10 m, the currents are mainly longshore and in the depths < 10 m they tend towards the shore. Therefore, any pollution, which is released in depths < 10 m, will travel to the shore line area. The coral fauna of the study areas is dominated by *Porites* and *Platygyra* at ca. 5 m depth (Ghazilou et al., 2016). The results of Manta tow survey demonstrated that live hard coral cover was 17%, 23%, and 65% at the sewaged reef, non-sewaged reef-1 and non-sewaged reef-2, respectively.

The sediment samples were collected in five replicates from each location using mini-corers (cut-off 60 ml syringes with 3 cm in diameter); only the top 1 cm of sediment was used. On board, samples were immediately fixed in 100% ethanol. In the lab, sediment samples were stained with Rose Bengal solution in order to distinguish living foraminifera from the dead.

2.2. Environmental sampling

The environmental variables measured in sediments were total organic content (%), grain size (%), sedimentary chlorophyll-α (in $\mu g \cdot g^{-1}$ dry weight) and sedimentary non-photosynthetic pigments (phaeopigments) (in $\mu g \cdot g^{-1}$ dry weight). For the sedimentary pigments, the top 1-cm layer of the sediment was taken in triplicate in each location using a cut-off 60 ml syringe and placed in a centrifuge tube in order to supply 5*g* wet sediment. The centrifuge tubes were stored in the dark at −20 °C prior to pigment extraction and measurement in the lab. Sedimentary pigments were measured in the laboratory by extracting the fat-soluble pigments into acetone and measuring the optical density of the acetone extract using a spectrophotometer before and after acidification (Gambi and Dappiano, 2004). For the organic content and grain size, the sediment samples, collected by a SCUBA diver, were dried at 70 °C for 24 h and separately analyzed for organic content by the ignition method (Gambi and Dappiano, 2004).

For grain size distribution analysis, the samples were dried in the oven at 70 °C for 24 h prior physical sieving (MOOPAM, 2010). The dried samples were continued with sieve analysis on sieve shakers for 10 min, using a sieve series of 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, 0.063 mm. The grain size of sediments was classified into seven fractions: gravel (> 2 mm), very coarse sand (1–2 mm), coarse sand (0.5–1 mm), medium sand (0.25–0.5 mm), fine sand (0.125–0.25 mm), very fine sand (0.063–0.25 mm), and silt and clay (< 63 mm).

The environmental variables measured in the water column were nitrate (NO_3^-), nitrite (NO_2^-), phosphate (PO_4^{3-}), water salinity, water temperature, water pH, dissolved oxygen, and transparency. For nutrient concentration analyses, water samples were collected from bottom and surface waters, mixed, filtered and immediately frozen and brought to the laboratory. Nitrate (NO_3^-), nitrite (NO_2^-) and phosphate (PO_4^{3-}) concentrations were analyzed following the Manual of Oceanographic Observations and Pollutant Analysis Methods (MOOPAM, 2010). Water salinity, temperature, pH, and dissolved oxygen were measured in triple replicate using a portable analyzer (Horiba Ltd., Kyoto, Japan). Water transparency was measured using a Secchi disk.

2.3. Data analysis

For foraminiferal community analysis, the abundance data were calculated as a number of individuals per square meter. The difference