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Status of macrobenthic communities in the hypersaline waters of the Gulf of Salwa, Arabian Gulf

T.V. Joydas [a,*], Mohammad A. Qurban [a], K.P. Manikandan [a], T.T.M. Ashraf [a], S.M. Ali [a], Khaled Al-Abdulkader [b], Ali Qasem [b], P.K. Krishnakumar [a]

[a] Center for Environment and Water, Research Institute, King Fahd University of Petroleum and Minerals (KFUPM/RI), P. B. No. 1995, Dhahran 31261, Saudi Arabia
[b] Environmental Protection Department, Saudi Aramco, Dhahran, Saudi Arabia

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ABSTRACT

The spatial extent of hypersaline marine ecosystems is very limited and therefore they have received only little scientific study. Here, we present the status of macrobenthic communities in a hypersaline water body, the Gulf of Salwa (Saudi Arabia part), in the Arabian Gulf and assess the natural stress, if any, in the communities. The Gulf of Salwa is nearly isolated from the main water body of the Arabian Gulf and shows a progressive southward increases in salinity (up to 63 during summer) and temperature (up to 40 °C during summer) due to the southward decrease in tidal flushing. The study reveals that the benthic communities in the southern region (south of 25° 10′ N) of the Gulf of Salwa are under natural stress, while the deeper, the northern, and the inner bay regions have healthier benthic communities than the south. In the southern region, there were 87 to 93% reduction in polychaete species, 49 to 57% reduction in species diversity of polychaetes and 70 to 71% in non-polychaete taxa compared to the northern region. The present study identified some opportunistic taxa such as *Fabricia* sp., *Heteromastus filiformis*, *Platynereis insolita* and *Nereis* sp. 1 and non-polychaetes such as chironomid larvae, podocops and cumaceans capable of adapting to the hypersaline environment in the Gulf of Salwa when salinity exceeded 60 and temperature exceeded 35 °C during summer.

1. Introduction

Salinity is one of the major environmental parameters controlling the distribution of marine organisms (Garrote-Moreno et al., 2014; Labonne et al., 2009; Riera et al., 2011; Sandoval-Gil et al., 2012; Telesh et al., 2013). Since marine organisms live in an osmotic balance with their environment, any increase in salt concentration may cause the death of larvae and young individuals due to the dehydration of cells and the decrease in turgor pressure (Einav et al., 2002). Hence, in the hypersaline environments, communities will be those capable of overcoming the physiological stresses and normally, unique communities may be observed in these environments (Abid et al., 2008; Das Sarma and Arora, 2002; Del Bene et al., 1994; Del Pilar-Ruso et al., 2008; MacKay et al., 2010; Riera et al., 2011). Hypersaline marine ecosystems occur on a very limited spatial extent in the world's oceans and therefore have received little scientific study (Bell and Laybourn-Parry, 1999; Elloumi et al., 2009; Meshal, 1987).

The Arabian Gulf (hereafter "the Gulf") is characterized by elevated levels of salinity and sea surface temperature (SST) due to its shallow nature, restricted water exchange and 1–2 m equivalent of evaporation per year (Coles, 2003; Sheppard et al., 1992, 2010). Because of these characteristics, the Gulf is generally considered to be a naturally stressed water body. The western region of the Gulf is characterized by numerous shallow enclosed bays, where, due to limited flushing and high evaporation rates, hypersalinity and extreme water temperature variations prevail compared to the open waters of the Gulf (Coles and Fadlallah, 1991; Coles and McCain, 1990; John et al., 1990; Jones et al., 1978; Price et al., 1993). The Gulf of Salwa is the best example of such an enclosed water body, which experiences the highest salinity and temperature variations in the western Gulf.

The Gulf of Salwa is surrounded by Saudi Arabian Coastline on the west and south and Qatar peninsula on the east and is nearly cut off from the main water body of the Gulf by the island of Bahrain and King Fahd Causeway between Saudi Arabia and Bahrain, and shallow water flats extending on either side. These shallow flats act as a tidal barrier to water movements, resulting in very low tidal amplitude. Tidal ranges, which are about 1.2 m at the northern coasts of Bahrain, are reduced to 0.5 m in the southern part of the Gulf of Salwa (Sheppard et al., 1992). This is a unique habitat due to the restricted circulation, long residence time and high evaporation (Basson et al., 1977; Purser and Siebold, 1973). These conditions result in high salinities ranging from about 55 at the entrance to the Gulf of Salwa to 70 in the south (Basson et al., 1977). Summer surface water temperatures in the Gulf of Salwa vary from 28 to 40 °C and winter temperatures from 17 to 25 °C, indicating high seasonal amplitude of ~23.0 °C

* Corresponding author. Tel.: +966 13 860 3229; fax: +966 13 860 1205.
E-mail address: tvjoydas@kfupm.edu.sa (T.V. Joydas).

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(Qurban et al., 2011). In such habitats, generally flora and fauna may be of low species diversity (Britton and Johnson, 1987; Coles and McCain, 1990; Riera et al., 2011).

The macrobenthic communities are important to the overall structuring and functioning of any marine ecosystem. They are considered to be good indicators of ecosystem health due to their sedentary nature, longevity, which provides long-term exposure to toxic substances, and the representation of diverse taxa which can respond to multiple types of stress (Jewett et al., 1999). Since relatively sessile, the status of wellbeing of marine benthic communities can be used to determine the response to several kinds of environmental conditions or effects of man-made perturbations (Borja et al., 2000; Guidetti et al., 2000; Hampel et al., 2009; Pearson and Rosenberg, 1978).

Very few benthic studies were reported from the western Gulf region (Al-Yamani et al., 2009; Basson et al., 1977; Bu-Olayan and Thomas, 2005; Coles and McCain, 1990; Jones et al., 1998; Joydas et al., 2011, 2012; McCain, 1984a,b) and the studies reported from south of Abu Ali in the Saudi coast of the Gulf are still fewer. Coles and McCain (1990) studied the benthic communities in the Saudi Coast of the Gulf including the Gulf of Salwa and reported a decreasing trend in both benthic density and species number from north to south owing to the southward increase in salinity. Therefore, the present study assesses the status and distribution pattern of benthic communities in this unique environment. As development pressure may soon reach this part of the Gulf, there is a need to generate baseline information on benthos that can be used to assess the potential impacts and utilize baseline data to formulate necessary protection and management efforts. Objectives of this benthic study were (i) to understand the community structure of macrobenthos with a focused study on the major macrobenthic group — polychaetes, (ii) to test whether any spatial or seasonal variations exist in the macrobenthic communities, (iii) to identify the stress on macrobenthos from hypersalinity and high temperature variations, and (iv) to verify from the salinity values and from the status of benthic communities, whether the entire or part of the Gulf of Salwa are under stress.

2. Methods

2.1. Study area

The Gulf of Salwa is located at latitudes 24° 40′–25° 50′ N and longitudes 50° 10′–50° 50′ E (Fig. 1). The 110 km long Gulf of Salwa is 45 km wide in the mouth and 11 km wide in the southern end. The water depth in the Saudi Arabia part of the Gulf of Salwa ranges from 1 to 17 m in depth and the depth decreases from north to south. There are two major inner bays near the mouth of the Gulf of Salwa, which are characterized by more extreme temperature variations and more elevated levels of salinity than the adjacent main water body of the Gulf of Salwa. The Gulf of Salwa is located at near tropical latitude and within an arid desert region, hence the air temperature and relative humidity in this area are high. High evaporation rates are associated with the prevalent high temperatures, strong winds and low precipitation. The tidal regime in the region is classified as mixed, predominantly semi-diurnal, and yielding two unequal tides each day.

2.2. Field sampling and laboratory analyses

Measurements of *in situ* hydrographical parameters and sampling for sediment grain size and macrobenthos were conducted at 17 stations (with non-vegetated seabed) in the Gulf of Salwa (Fig. 1) during winter (February–April) and summer (October) seasons of 2009. However, samplings could not be conducted in Stations 3, 12 and 14 during winter and Stations 2 and 6 during summer due to some technical reasons. Duplicate samples were collected from each station for the macrobenthic study using a van Veen grab (0.1 m^2 area). Sediment samples meant for the macrobenthic study were sieved onboard the vessel using 500 μm (0.5 mm) mesh and the residual sediment containing organisms was preserved in 5–7% buffered formalin. A separate grab sample was also obtained for sediment grain-size analysis. *In situ* hydrographical parameters such as temperature, salinity (measured using Practical Salinity Scale) and DO were measured using a YSI Multiprobe Environmental Monitoring System (YSI Multi Parameter Water Quality Sonde, Model 6600 V2).

Prior to the analyses, macrobenthic samples were stained with Rose Bengal solution overnight and washed with copious freshwater. All the macrobenthic organisms were picked out, sorted down to major groups followed by a counting of individuals. Being the predominant group, polychaetes were identified down to species level (Day, 1967; Fauchald, 1977; World Register of Marine Species (WoRMS, http://www.marinespecies.org/)). Wet weight of polychaete species was determined for preparing the Abundance Biomass Comparison (ABC) plot. The wet weight for most species records were estimated based on some real measurements. The real measurements were obtained by weighing several individuals of each species and calculating the average individual wet weight of that specific species. The wet weight values of that species in other samples were based on this individual wet weight calculations, by multiplying it with the abundance in a given station. Feeding guilds of identified polychaetes were determined as per Fauchald and Jumars (1979).

Samples for sediment grain size analysis were dried at room temperature and were wet sieved and further pipette analyzed to estimate silt and clay percentages (Carvar, 1971). Materials coarser than 4 Φ (>63 μm — sand fractions) were analyzed at one-phi intervals (−2 to 4 Φ) and fine grained at 8 Φ (silt) and 14 Φ (clay) classes. Sediment textural types were identified using Sheppard's (1954) classification. Mean grain size (MGS) was calculated using the Folk and Ward (1957) method.

2.3. Data analyses

Univariate and multivariate (Principal Component Analysis, PCA and one way analysis of similarity, ANOSIM) analyses and graphical method (Abundance Biomass Comparison — ABC) were carried out using PRIMER (Plymouth Routines in Multivariate Ecological Research) (version 6.1.5) (Clarke and Warwick, 2001) with the polychaete species abundance matrix. Univariate measures included are Shannon–Wiener (H′) (Log_2) for species diversity and Simpson dominance (Lambda′) for species dominance. Normalized variables (depth, temperature, salinity, DO and sediment mean grain size (MGS)) were used for PCA. The ABC method, which is based on the k-dominance curves of abundance and biomass in the same scale in one plot, facilitates determining the levels of disturbance on the macrobenthic communities (Warwick, 1986).

Canonical correspondence analysis (CCA; ter Braak and Verdonschot, 1995) was performed to identify relationships among environmental variables and polychaete assemblage structure by using XLStat (Version 2013.4.07, Addinsoft). Only the polychaete species that contributed ≥1% of the total polychaetes (16 species from winter and 14 species from summer samples) were included in this analysis. CCA included a Monte Carlo permutation test (with 999 unrestricted permutations) to determine the significance of species–environment relationships.

The discrimination of station groups in plots of PCA and CCA were carried out as *a priori*, based on geographical expert knowledge. The groups are (i) deeper (Stations 5, 6 and 11, having 10–17 m depth), (ii) northern (Stations 2–4, 7, 8, 10, 12 and 13 located in the 'northern' region, having 1.5–9 m depth), (iii) inner bay (Stations 1 and 9 located in the 'inner bays' having 1–1.5 m depth), and (iv) southern