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Regional generalisations about the relationships between the environment and foraminifera along the SW Cape coast, South Africa ☆

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ABSTRACT

Factors influencing the composition of shallow water benthic foraminifera along the SW coast of South Africa at two locations (Table Bay, TB; St Helena Bay, SHB) ~200 km from each other were examined. Small taxa dominated in both locations; living assemblages from SHB (28 species, *Ammonia parkinsoniana* dominant) differed from TB (34 species, *Elphidium articulatum* dominant). Environmental parameters were similar in both areas. Patchiness in assemblage structure was pronounced, differences between pipeline and non-pipeline sites within locations were evident in environmental parameters. Diversity was significantly correlated with grain size, the nitrogen and heavy metal content (especially Cd). These data represent the first for extant benthic Foraminifera from the southern Benguela upwelling area and is the first attempt at using foraminifera as indicators of pollution in this region. The data stressed the need for more than one sampling location to better understand the factors influencing foraminiferal assemblages in any regional context.

1. Introduction

Foraminifera may be important components of the meiofauna, where their biomass can exceed that of nematodes and harpacticoid copepods (Bernhard et al., 2008). Like other meiofauna, their abundance and diversity varies with the environment in a way that tends to reflect driving and attendant processes (Murray, 1991; Murray and Pudsey, 2004). The shape and composition of sediment grains provide the micro-habitat for small infaunal organisms; coarse sediments provide a number of micro-habitats due to their larger interstitial spaces and they are usually well oxygenated, while sediments with smaller grain sizes trap more organic matter providing more food (Fricke and Flemming, 1983). Organic matter in the oceans is produced as a result of phytoplankton and macroalgal and macrophyte production and the benthic environment receives this input in the form of sinking detritus (Fricke and Flemming, 1983). Benthic organisms respond to the increased organic matter input by increasing in numbers (Mojtahid et al., 2009) or in assemblage structure (Smith et al., 2006). The diversity of benthic marine assemblages has also been found to be related to depth; shallow areas being typically less diverse due to a dominance of opportunistic species that are adapted to high disturbance and the fluctuating environment (Flint and Holland, 1980). In most cases, there is an interaction between the different environmental factors influencing assemblage structure so that, for example, in upwelling areas the high productivity leads to a fine, organic-rich sediment subject to hypoxia in which Foraminifera may be abundant but species poor (Rathburn and Corliss, 1994; Ashckenazi-Polivoda et al., 2010).

To date, approximately ~2140 extant benthic foraminiferal species have been formally described, 701 from marginal marine environments, 989 from the shelf and 831 from the deep sea (Murray, 2007). Only 33% of these have been found in large abundance (>10%) while 67% are of minor abundance, most species being rare and endemic and a few being cosmopolitan (Murray, 2007). Typically, opportunistic taxa tend to dominate in environments that have been stressed in an anthropogenic way, as those with a limited tolerance range are driven to local extinction (Culver and Buzas, 1995). Cultural eutrophication results in an alteration to the structure of foraminifera assemblages, and whilst most studies indicate a negative relationship between organic inputs and assemblage abundance and diversity, some show positive impacts which are mostly linked to the distance away from the outfall (Mojtahid et al., 2008). Topping et al. (2006) have suggested that

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the associated changes in dissolved oxygen levels or grain size may mask the effects of an increase in organic matter, making interpretation of in situ data difficult. Unlike the variable effects of pollution by sewage, only negative impacts have been observed from heavy metal and hydrocarbon contamination, both in the field (Yanko et al., 1994; Scott et al., 2001; Ferraro et al., 2006; Frontalini et al., 2009) and in the laboratory (Alve and Olsgard, 1999; Gustafsson et al., 2000)

Most studies that have focussed on describing the relationship between the structure and composition of foraminifera assemblages and their environment have been conducted at single locations (e.g. Ferraro et al., 2006; Albani et al., 2007; Mojtahid et al., 2008), and this hampers our understanding of anthropogenic impacts in a regional context. Here we set out to (1) describe the shallow water foraminifera assemblages occurring along the SW coast of South Africa for the first time, and (2) to examine the relationships between the assemblage and assemblage attributes and the environment. We have explicitly chosen two locations some 200 km apart from each other in order to determine the role of geographic location on assemblage structure and hence on the generality of observations.

2. Materials and methods

2.1. Study sites

2.1.1. St Helena Bay

St Helena Bay (SHB) is north of the main upwelling centres at Cape Point and Cape Columbine along the SW coast of South Africa (Supplementary data Fig. 1). It is a semi-closed bay, and an anti-cyclonic gyre traps water for up to 25 days within, as opposed to a retention time of 3–5 days outside (Walker and Pitcher, 1991). There are three fish factories in St Helena Bay that process mainly anchovy and sardine. The area studied is around a fish factory (operating since the 1940s) that processes ~150,000 tons of fish annually (Fish factory manager, pers. comm.), and ~18,000 m^3 waste water are discharged daily (during operations) through a pipe extending 30 m offshore at about 4 m depth. Water discharged from the factory contains blood, scales and some small bones from fish processing, although, an attempt is made to filter the water discharged (Fish factory manager, pers. comm.).

2.1.2. Table Bay

Table Bay (TB) is situated north of the Cape Point upwelling centre along the west coast of South Africa, and is far more open than SHB (Supplementary data Fig. 2). Tidal currents in the bay are weak (average of 20 cm s^{-1}) and because of the high wind velocities and shallowness of the bay, surface currents are thought to be wind-driven and the residence time of water varies from 15 to 190 h (Van Ieperen, 1971). Winds vary greatly in speed and direction throughout the year, being mostly from the SSE, but from the N during winter (Jury and Bain, 1989). A sewage outfall from the eastern side of Robben Island was constructed in 2002 and it discharges ~550 m^3 of waste daily through a pipeline c. 400 m long at a depth of 6 m. An attempt was made to sample at approximately 4 m depth, however, the TBD sites around Robben Island were at a maximum depth of 9 m (TBD).

2.1.3. Field sampling

Sampling in SHB took place during September 2003. Nine sites were randomly selected within a 150 m radius of the fish factory outfall (Supplementary data Fig. 1) and these are hereafter referred to as pipeline sites. Three additional, non-pipeline sites were selected at 3.6 km (SPA), 1.5 km (SPB) and 0.9 km (SPC) away from the outfall. All samples were collected at a depth of 4 m.

Sampling in TB took place during February 2004. Five pipeline sites were randomly selected, four within a 400 m radius of the outfall and one at 700 m from the outfall: three additional, non-pipeline sites, two of which were on the western side of the harbour 1.05 km and 1.56 km from the pipeline and one on the same side as the pipeline but 1.8 km away. All sites were at a depth of 4 m (Supplementary data Fig. 2).

Because Foraminifera are known to be patchily distributed, a number of replicates are required to provide an overall picture of distribution in the area (Harrad et al., 2008). Six modified *Hagge corers* (Fleeger et al., 1988) of 30 cm length and 3.57 cm internal diameter (10 cm^2 cross sectional area) were collected by SCUBA at each site. Samples were kept on ice immediately after collection and transferred to the freezer on return to the laboratory, within 5 h.

2.1.4. Laboratory analysis

Cores were defrosted, and the top 5 cm was removed for examination of the Foraminifera (most living Foraminifera are found in this surface layer (Murray, 1991)), and the analysis of environmental factors. A subsample of the layer was homogenised and used for the determination of nitrogen and trace metal content.

Sediments from the top 5 cm were first preserved in 70% ethanol and stained with Rose Bengal (24 h). Foraminifera were separated from the sediments by floatation using carbon tetrachloride (Murray, 1991) and 300 specimens (where possible) were mounted onto a slide for identification and determination of species diversity under a microscope at x 80 magnification. Specimens were separated into live (stained) and dead individuals, and all were identified to species or morpho-species, where possible. Some *Fissurina*, *Oolina* and *Lagena* were identified only to genus, whilst bolivinids were identified as elongated or perforated. Species richness and diversity (Shannon Index; Magurran, 2004) were determined for each core. All foraminifera in the sediments were counted and abundance data were expressed as numbers/g sediment. After the removal of the 300 Foraminifera, the sediment was dried (60 °C, 24 h), and sieved through meshes of 500 μm, 250 μm, 125 μm and 63 μm diameter in order to determine the granular size structure. The weight of sediment retained on each mesh was determined and the data were expressed as proportions. Mean sediment grain size (phi units) was calculated using GRADISTAT software (Blott, 2010). While it could be argued that the removal of the Foraminifera from the samples might have impacted the size structure of the sediments, this would largely relate to the tests of dead specimens, which made up a maximum of 30% of the total individuals examined at each core.

The nitrogen content (% N) of sediments was determined per site and not per core. Approximately 5 g of freshly defrosted sediment (i.e. before staining and extraction of Foraminifera and granulometry) from each core per site was dried (60 °C, 24 h), pooled and homogenised. A subsample was subsequently combusted in the presence of oxygen in order to determine the wt (%) of total nitrogen using a Eurovector EA CHN Analyser. Detection limits for the Analyzer were 0.1 wt (%). Calibration was performed using certified Eurovector standards, accepting a margin of error of 0.02%. Although samples were not acid-digested and, therefore, the percentage organic carbon could not be determined, the relationship between total nitrogen and organic carbon in sediments from SHB (at least) is strongly significant and positive ($r = 0.919$, $DF = 29$, $p = 0.0001$) (Supplementary data Fig. 3). It can thus be argued that % N is a proxy for organic carbon in St Helena Bay. In order to determine the trace metal concentrations in sediments, sub-samples from each core were dried (60 °C, 24 h) and ground to homogeneity. Approximately 2 g of sediments were then digested using an acid mixture of 4:1 ($HCl:HNO_3$) at 110 °C on a Gerhardt digestion block for 3 h following Morton and Roberts

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