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Environmental health in southwestern Atlantic coral reefs: Geochemical, water quality and ecological indicators

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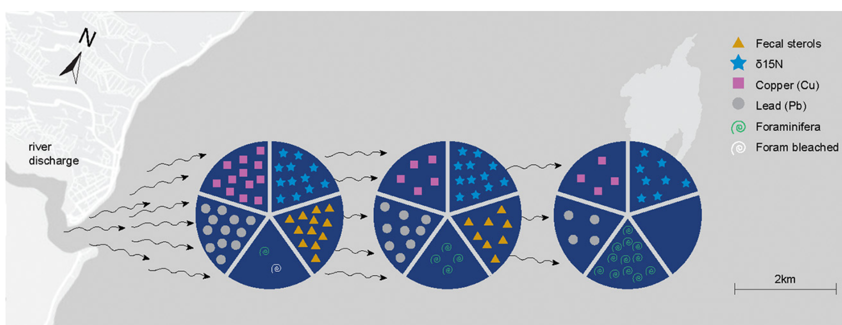
HIGHLIGHTS

- Runoff and pollution effects are understudied in South Atlantic coral reefs.
- Isotopes, sterols and metal levels indicated sewage contamination near the coast.
- Alterations in *Amphistegina* populations indicated detrimental ecological effects.
- Foraminifera as bioindicators of impacts of river influence
- Multidisciplinary indicators used are effective tools to assess reefs health.

GRAPHICAL ABSTRACT



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ABSTRACT

Climate change, pollution and increased runoff are some of the main drivers of coral reefs degradation worldwide. However, the occurrence of runoff and marine pollution, as well as its ecological effects in South Atlantic coral reefs are still poorly understood. The aim of the present work is to characterize the terrigenous influence and contamination impact on the environmental health of five reefs located along a gradient of distance from a river source, using geochemical, water quality, and ecological indicators. Stable isotopes and sterols were used as geochemical indicators of sewage and terrigenous organic matter. Dissolved metal concentrations (Cu, Zn, Cd, and Pb) were used as indicators of water quality. Population density, bleaching and chlorophyll α content of the symbiont-bearing foraminifer *Amphistegina gibbosa*, were used as indicators of ecological effects. Sampling was performed four times during the year to assess temporal variability. Sediment and water quality indicators showed that reefs close to the river discharge experience nutrient enrichment and sewage contamination, and metals concentrations above international environmental quality guidelines. Higher levels of contamination were strongly related to the higher frequency of bleaching and lower density in *A. gibbosa* populations. The integrated evaluation of stable isotopes, sterols and metals provided a consistent diagnostic about sewage influence on the studied reefs. Additionally, the observed bioindicator responses evidenced relevant ecological effects. The water quality, geochemical and ecological indicators employed in the present study were effective as biomonitoring tools to be applied in reefs worldwide.

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1. Introduction

Human activities have reduced the environmental quality of marine ecosystems worldwide (Wilkinson, 2008). Coral reefs are highly productive and valuable ecosystems which are being severely affected by anthropogenic stressors at global and local scales (Ban et al., 2014; Hoegh-Guldberg, 2014; Wilkinson, 2008). Climate change, overfishing, pollution, and increased runoff due deforestation and urban development are some of the main drivers of degradation of coral reefs worldwide (Birkeland, 2015; Norstrom et al., 2016).

Rivers are the main sources of terrigenous sediment, nutrients and contaminants to inshore reefs (van Dam et al., 2011). A huge effort has been employed to assess the ecological effects of sediment and contaminant runoff in coral reef areas, such as the Caribbean and Great Barrier Reef. Also, strategies to minimize the loads of terrigenous material to these fragile ecosystems have been developed (Bartley et al., 2014; Brodie et al., 2017; Takesue et al., 2009; Takesue and Storlazzi, 2017). Nevertheless, the effects of runoff in South Atlantic reefs are poorly understood. Moreover, southwestern Atlantic reefs are naturally exposed to higher levels of terrigenous sediment compared to Caribbean and Indo-Pacific reefs (Castro et al., 2012; Castro and Pires, 2001; Leão et al., 2003; Rodríguez-Ramírez et al., 2008). There is an overall lack of knowledge about water quality, as well as a poor description of the chemical contaminants affecting South Atlantic reefs. Characterization of water and sediment quality parameters in these reefs is an important step for scientific and management purposes. Also, the use of reliable bioindicators integrated with measurements of abiotic parameters increases the ecological relevance of environmental impact assessments.

Foraminifera, as well as corals and other reef-dwelling species, can be adversely affected by river-related environmental stress, including sedimentation, changes in quality of organic matter (Barbosa et al., 2016; Dessandier et al., 2015), sewage input and metal contamination (Emrich et al., 2017; Prazeres et al., 2012a). In fact, foraminifera are widely used as monitors of environmental changes, including a well-established application of foraminifera as bioindicators of coral reef water quality. Monitoring of symbiont-bearing species is particularly relevant, since they have similar physiological requirements to corals, which are the main reef builders, but respond faster to environmental changes (Barbosa et al., 2016; Cooper et al., 2009; Emrich et al., 2017; Hallock et al., 2003; Marques et al., 2017; Ross and Hallock, 2014). *Amphistegina* spp. are diatom-bearing foraminifera found abundantly in reefs worldwide (Langer and Hottinger, 2000), that have been considered as reliable bioindicators of anthropogenic impacts (Marques et al., 2017; Prazeres et al., 2016, 2012b; Ross and Hallock, 2014).

In light of the background above, the aim of the present study was to identify and characterize the impact of terrigenous influence and contamination on the environmental health of five South Atlantic reefs located along a gradient of distance from a river mouth, using geochemical (stable isotopes and sterol levels), water quality (metals concentrations) and ecological (foraminifera population density, bleaching frequency and chlorophyll α content) indicators. Carbon and nitrogen stable isotopes are effective tools to evaluate the source of organic matter, reflecting river-ocean gradients, as well as nutrient contamination and environmental quality status (Claudino et al., 2015; Jona-Lasinio et al., 2015). Furthermore, stable isotopes can be effectively applied in combination with other techniques (Carreira et al., 2015b; Cordeiro et al., 2018; Derrien et al., 2017). Many organic compounds, such as steroids and aliphatic hydrocarbons, also known as molecular biomarkers, have been successfully applied to trace sources of organic matter and sewage contamination (Derrien et al., 2017; Emrich et al., 2017; Martins et al., 2014). In turn, concentrations of metals such as Cu, Zn, Cd and Pb can indicate the presence of some human activities. Additionally, they are also used to assess environmental health, based on criteria established by water quality guidelines (Martins et al., 2012; Prazeres et al., 2012b; Rocha et al., 2017). Finally, ecological effects of environmental stressors can be evaluated by assessing population and/or physiological responses in bioindicator species, such as the benthic foraminifera *Amphistegina* spp.

Our hypothesis is that markers of terrestrial influence and contamination, evaluated through stable isotopes, steroids and metals concentration, will be correlated with the distance between the reef and the river mouth, and will be related to lower *A. gibbosa* densities and higher bleaching frequency.

2. Material and methods

2.1. Study area

The Buranhém River is part of the largest hydrographic basin in southern region of the Bahia state (northeastern Brazil), flowing into the Atlantic Ocean at Porto Seguro coast (Sarmento-Soares et al., 2008), one of the most touristic area in South America and an important area for reef conservation (Seoane et al., 2012). Along the 148 km of river course, there are diffuse sources of untreated sewage input, as well as several points of potential water contamination with pesticides and industrial waste. These environmental pressures are related to the unplanned urban occupation and land use in the area, which involves activities such as agriculture, eucalyptus forestry, cellulose pulp industry and the severe ongoing deforestation of the Atlantic Forest (Bomfim, 2012; Oberling et al., 2013; Santos, 2013; Silva, 2016).

Previous studies suggested a gradient of influence of the Buranhém River plume in the coral reefs of the *Parque Natural Municipal do Recife de Fora* (PNMRF) (Leite et al., 2018; Seoane et al., 2012). The PNMRF is a Marine Conservation Area located 8 km offshore from Porto Seguro city (Bahia state, northeastern Brazil), with a complex reef system (17.5 km^2) composed mainly of sea grass beds, coralline algae, and corals (Seoane et al., 2012; Zilberberg et al., 2016).

The occurrence of an environmental quality gradient between reefs exposed to the Buranhém River plume was assessed by selecting five reef sites (S) between the river mouth area and the PNMRF region (Fig. 1). Three sampling sites were in reef patches outside the PNMRF [S1 (*Itassepocu Reef*): 16°26.0349′S–039°02.4140′W; S2 (*Pedra Carapindauba*): 16°25.7138′S–039°01.4990′W; and S3 (*Baixio Cerca*): 16°25.6938′S–039°00.4080′W]. The other two sampling sites were in reefs located inside the area of the marine park [S4 (*Recife de Fora-SW*): 16°25.0910′S–038°59.4502′W; and S5 (*Recife de Fora-NW*): 16°23.8428′S–038°59.0832′W]. Sampling was performed at the four different seasons in order to assess temporal variability (winter - August 2013; spring - December 2013; summer - February 2014; autumn - May 2014), carried out by scuba diving at mean depths of 5.9, 6.8, 7, 5.5 and 4 m for reefs 1, 2, 3, 4 and 5.

Air temperature and rainfall data during the period of study were acquired by an automatic station (code 86745) of the Brazilian National Institute of Meteorology (INMET) located in Porto Seguro (Bahia state, northeastern Brazil), and were expressed as daily means.

2.2. Collection methods

2.2.1. Sediment and seawater sampling

Sediment samples (n = 3, ~5 g of superficial sediment per sample) were collected and kept frozen (−80 °C) until analysis. Seawater (n = 3 per sampling site at each season, 10 mL each sample) were collected, filtered (45 μm), acidified (1% HNO_3 final concentration), kept in the dark and frozen (−20 °C) until analysis.

2.2.2. Foraminifera sampling

Pieces of reef rubble were manually collected at each sampling site, placed into labeled plastic bags (n = 3 per sampling site at each season) containing local seawater, transferred to the Coral Vivo Research facility at Arraial d'Ajuda (Porto Seguro, Bahia state, northeastern Brazil), and scrubbed with small brushes to detach the associated sediment and fauna. Residues obtained were distributed in 150-mm *Petri* dishes