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Structure of macroalgal communities on tropical rocky shores inside and outside a marine protected area

Adriana Brizon Portugal [a,*], Fabrício Lopes Carvalho [b], Marcelo de Oliveira Soares [c,d], Paulo Antunes Horta [e], José Marcos de Castro Nunes [f]

[a] Universidade Federal da Bahia, Programa de Pós-Graduação em Ecologia e Biomonitoramento, Salvador, Bahia, Brazil
[b] Universidade Federal do Sul da Bahia, Grupo de Pesquisa em Carcinologia e Biodiversidade Aquática, Ilhéus, Bahia, Brazil
[c] Universidade Federal do Ceará, Instituto de Ciências do Mar, Labomar, Fortaleza, Ceará, Brazil
[d] Universitat Autònoma de Barcelona, Institut de Ciència i Tecnologia Ambientals, ICTA, Barcelona, Spain
[e] Universidade Federal de Santa Catarina, Centro de Ciências Biológicas, Departamento de Botânica, Laboratório de Ficologia, Florianópolis, Santa Catarina, Brazil
[f] Universidade Federal da Bahia, Instituto de Biologia, Departamento de Botânica, Laboratório de Macroalgas Marinhas, Salvador, Bahia, Brazil

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ABSTRACT

The structure of marine macroalgal communities and morpho-functional groups were investigated in a poorly characterized region on the Tropical Southwestern Atlantic coast, Brazil. The survey was conducted at six rocky shores located on the mainland and on coastal islands distributed inside a marine protected area (MPA) and outside the MPA (near a densely populated area). We hypothesized that tropical rocky shores inside the MPA and islands have higher species richness, diversity, and evenness of marine macroalgae. Results confirmed that species richness, diversity and evenness were significantly higher inside the MPA than in rocky shores outside the MPA. Only species richness was higher on islands than on the mainland. The results suggest that human impacts could lead to a competitive advantage and dominance in the articulated calcareous morphotype, resulting in community differences and lower benthic biodiversity in tropical ecosystems near urbanized sites.

1. Introduction

The macroalgae represent a phylogenetically diverse group of photosynthetic organisms, including red, green, and brown multicellular marine benthic algae (Lobban and Harrison, 1994). Algae are at the base of the food chain, serving as food to herbivores and providing habitat for other organisms such as non-photosynthetic bacteria, protists, invertebrates and fish (Potapova et al., 2005). By generating greater spatial habitat complexity along the rocky shores, they provide resources for the presence of a large number of species, and this ecosystem provides services that are of fundamental importance to the livelihoods and survival for many people (Costanza et al., 2014). While the rocky shore ecosystem is ecologically very important, disturbance (including from human sources) may play an important role in the distribution of the fauna and flora (Addessi, 1994; Portugal et al., 2016).

In recent years, loss of environmental quality in different aquatic ecosystems caused by different types of anthropogenic stressors has gained prominence (Crowe et al., 2000; Halpern et al., 2008, 2012; 2015). Although human impacts can be difficult to measure due to the complexity of numerous environmental variables (Addessi, 1994; Crowe et al., 2000), the composition and abundance of benthic macroalgae have been widely adopted as indicators of human impacts worldwide (Ballesteros et al., 2007; Guinda et al., 2014; Juanes et al., 2008; Orfanidis et al., 2001; Pinedo et al., 2007).

According to Veiga et al. (2013) species composition and abundance are the most common descriptors in studies of macroalgal communities. However, the identification of algal species is difficult and few specialists are capable of performing this function. The use of morpho-functional groups would reduce the time and resources required for research by making descriptions of macroalgal communities more straightforward (Veiga et al., 2013; Rubal et al., 2011). At the community level, algae as bioindicators can be split

* Corresponding author.
E-mail addresses: adrianabrizonportugal@gmail.com (A.B. Portugal), flcarvalho@ufsb.edu.br (F.L. Carvalho), marcelosoares@pq.cnpq.br (M.O. Soares), pahorta@hotmail.com.br (P.A. Horta), jmcnunes2000@gmail.com (J.M. de Castro Nunes).

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into morpho-functional groups (Steneck and Dethier, 1994). To evaluate disturbances on macroalgal communities, Steneck and Dethier (1994) suggested making use of these groupings, based on the sum of species biomasses with the same morphological and anatomical characteristics. These authors grouped algae into seven functional groups: microalgae, filamentous algae, sheetlike algae, cylindrical-corticated algae, leathery algae, articulated coralline algae and encrusting algae. By using this classification, they showed that high-productivity environments (i.e., those with higher biomass production) and low disturbance environments (i.e., those with less loss of biomass) have higher biomass and higher diversity of morpho-functional groups, but with higher abundance of large coriaceous (leathery) algae and corticated algae over the long term. This disturbance evaluation model is supported by studies in the Caribbean (Ferrari et al., 2012; Steneck and Dethier, 1994), North Atlantic (Veiga et al., 2013; Rubal et al., 2011; Steneck and Dethier, 1994), North Pacific (Steneck and Dethier, 1994), and Mediterranean (Benedetti-Cecchi et al., 2001), but there are few studies in the Tropical Southwestern Atlantic coast (*sensu* Spalding et al., 2007).

These tropical areas are characterized by high biodiversity and productivity on the mainland and coastal islands (Horta et al., 2001; Martins et al., 2012; Scherner et al., 2013). According to Horta et al. (2001), the coastal environments most diverse in macroalgae are located on the southeast coast of Brazil in latitudes between 18° and 25°. Floristic studies in the State of Espírito Santo show that marine macroalgae are well characterized and have the highest species richness (ca. 500 species) in Brazil, due to the overlap between species' ranges from the southern and northeastern coastal environments (Fujii et al., 2008). As a result, this coastal zone is considered a biodiversity hotspot (Marchese, 2015). However, the biodiversity of marine benthic macroalgae is under severe threat due to the proximity of urbanized and industrialized coastal areas, including the studied region (Ballesteros et al., 2007; Crowe et al., 2000; Pinedo et al., 2007; Portugal et al., 2016; Scherner et al., 2013).

We tested whether macroalgae (structure of assemblage and diversity), using species and morpho-functional groups, can be used to detect areas under different levels of human disturbances (e.g., inside and outside of marine protected areas) in tropical rocky shorelines. The aims of this study were: 1) to use the structure and distribution of marine macroalgal communities and morpho-functional groups to evaluate human disturbances in six rocky shorelines inside and outside of a marine protected area (MPA) on the mainland and islands of the Tropical Southwestern Atlantic coast; and 2) to evaluate possible differences between the morpho-functional groups and species composition to detect differences inside and outside of a marine protected area.

2. Material and methods

2.1. Study area

This study analyzed intertidal rocky shores located in the State of Espírito Santo coast, Southeastern Brazil (Tropical Southwestern Atlantic). This region is characterized by a tropical and humid climate (Leão and Dominguez, 2000) and a large urban population of 3.5 million (IBGE, 2010). Tidal amplitude is smaller than 2 m. Prevailing winds are from the east-northeast and east-southeast quadrants. The first are associated with the trade winds, which blow through most of the year, while the second are related to cold fronts that regularly come to Espírito Santo coast, usually during the winter months (Bandeira et al., 1975).

Six intertidal rocky shores were sampled in November 2010. Three were located inside the MPA of Setiba (Guarapari city, population 105,208 IBGE, 2010), and the other three were located outside the MPA of Setiba, near a densely populated area (Vitória city, population 327,801, and Vila Velha city, population 414,586; IBGE, 2010). There are harbor terminals and urban sewage effluents on the estuarine system of Vitoria Bay, near the sampling points outside the MPA (Sterza and Fernandes, 2006; Zalmon et al., 2011). The main chronic anthropogenic threats were identified as pollution by urban effluents, including heavy metals and hydrocarbons from the industries and cities (Jesus et al., 2004; Joyeux et al., 2004). A map of the study area including locations of the rocky shores is given in Fig. 1. The rocky shores located in the MPA of Setiba and its buffer zone, established at the mainland–sea interface, were Pedra da Tartaruga (mainland), Rocha do Setibão (mainland) and Três Ilhas (an island approximately 3.5 km from the coastline). This MPA is called Setiba EPA (environmental protected area) and is classified by international nomenclature in Class V of the International Union Conservation Nature (IUCN). This type of MPA aims to reconcile conservation with the sustainable use of resources (Santos and Schiavetti, 2014). The rocky shores of Pedra da Sereia (mainland), the island of Ilhas Itatiaia (approximately 1 km from the coastline) and the island of Ilha dos Pacotes (approximately 3.4 km from the coastline) are located outside the MPA of Setiba, near a densely populated area that encompasses the cities Vila Velha and Vitória, the capital of Espírito do Santo State. This area was designated as Out-MPA (outside of the marine protected area).

2.2. Sampling design and data collection

A survey was conducted at six rocky shores with a similar gently sloping topography and exposure to prevalent wind and waves, a typical granitic substratum and a semi-diurnal tidal regime. Sample collections were made in the same period (November 2010). These uniform characteristics were selected in order to minimize the effects of other sources of natural variability (Oigman-Pszczol and Creed, 2011; Portugal et al., 2016). At each rocky shore, sampling was carried out in the intertidal zone, which was itself subdivided into high, middle and lower as measured from the lowest limit of the intertidal zone (Portugal et al., 2016). Each sub-zone was delimited by dominant bioindicator species, which were visually identified.

Stratified sampling was performed at each rocky shore using three horizontal transects of 10 m, with one transect for each sub-zone so as to avoid over estimations of the biological community due to the effects of larger sampling areas influencing species richness (Oigman-Pszczol and Creed, 2011; Portugal et al., 2016). Each transect was subdivided into 20 consecutive points with distances of 50 cm between points. A distance of 50 cm between the points was used to allow a minimum distance between sampled quadrats. Five points were randomly selected to position five replicate quadrats from each transect where the samples were taken, totaling 15 quadrats at each tropical rocky shore.

Algal genus and species were identified following nomenclature set out by Wynne (2011). Algae were separated by species and dried in an oven at 60 °C for approximately 72 h. Samples were then weighed until a constant weight. Biomass of each species was estimated to 0.001 g accuracy.

2.3. Statistical analysis

Species composition and biomass data were used to calculate Simpson's diversity and evenness (Krebs, 1989; Simpson, 1949). The data were transformed using $\log_e (x + 1)$ to reduce the effects of dominant species and the number of zeroes in the data set.

PERMANOVA analysis based on the Bray-Curtis similarity index (transformed data $\log_e x{+}1$) was used to compare the marine macroalgal community structure between MPA of Setiba and Out-