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Can patterns in benthic communities be explained by an environmental pressure index?

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ABSTRACT

Many studies have assessed in unison specific biological attributes and certain environmental impacts but few studies have analyzed multiple biological variables and pressures from multiple sites at the same time. Our study's goal was to quantify the major potential human pressures in the shallow subtidal rocky reefs along a tropical Atlantic coast; propose a relative environmental pressure index and investigate the relationships between environmental pressures, the benthic community and coral population attributes. The analysis of human pressures suggests that one-third of sites were under high or very high proportional stress. Sites with high human pressure had lower live cover, higher percent of recent mortality and density of *Siderastrea stellata*. These relations were species specific. The coral species *S. stellata* seemed to be the best indicator of present environmental stress. These findings demonstrate the need to include multiple species and stressors in monitoring programs designed to contribute to coastal management initiatives.

1. Introduction

Coastal marine ecosystems, along with the goods and services they provide, are threatened by human activities and are deteriorating worldwide as a result of various natural and anthropogenic impacts: coastal development, tourism, overexploitation, destructive fishing, agricultural runoff, pollution and climate change (Bellwood et al., 2004; Crowe et al., 2000; Davenport and Davenport, 2006; Gardner et al., 2003; Grigg and Dollar, 1990; Halpern et al., 2008; Hoegh-Guldberg et al., 2007; Hughes et al., 2003; Jackson et al., 2001; Kramer et al., 2005; Pandolfi et al., 2003; Richmond, 1993).

Although geographically widespread, many of these problems are often localized, primarily near centers of human population (Bryant et al., 1998; Smith et al., 2008). Since single stresses are rarely found in the real world, multiple stresses are usually the norm. Such stresses may act simultaneous or consecutively and the cumulative effect of multiple stressors on ecological communities impact natural systems in a multitude of ways (Crain et al., 2008). What is abundantly clear is that through the combined direct and indirect effects of human activities the last several hundred years have witnessed direct pressure on entire functional groups of organisms in oceans, estuaries and on coral reefs (Jackson et al., 2001).

Environmental assessment studies usually identify the anthropogenic stressor(s) and use different levels of biological organization, organism, species, community, stress responses, or combine biotic indices and diversity measures as indicators of environment stress (Borja et al., 2000; Carballo and Naranjo, 2002; Carballo et al., 1996; Hallock et al., 2004; Salas et al., 2004; Smith et al., 2008). There are many studies which assess both biological and environmental stressor approaches simultaneously, however few simultaneous analyses of biological and stress factors from multiple sites and multiple stressors have been carried out *in situ* (Edgar and Barrett, 2000; Hoffmann, 2002; Rodgers et al., 2003).

Major impediments are related to the general lack of baseline data on marine ecosystems prior to large-scale human impacts and to substantial gaps in knowledge on the current distribution (Fraschetti et al., 2008; Halpern et al., 2008; Sanchez-Cabeza and Druffel, 2009). Almost all studies on marine threats, from regional to global scales, have been entirely qualitative and generally based on expert opinion (Bryant et al., 1998; Halpern et al., 2007; Selkoe et al., 2009). Claudet and Fraschetti (2010) reviewed the literature and developed a meta-analytical approach to quantify overall effects of various stressors on different Mediterranean habitat types and compare the relative importance of different impacts across a range of habitats. They argued that although the "expert opinion" approach can be used as a proxy for assessing true impacts on habitats, they are not as meaningful as quantitative assessments, which are grossly lacking.

Pressure assessments based on *in situ* measurements and low cost bioindicators can provide resource managers with essential tools for deciding where management actions to protect or restore marine resources should be focused. The relative importance of co-occurring local factors should be understood since many of these factors can be effectively managed within a community.

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Therefore the need for new tools to assess the environmental status of coastal systems have encouraged researchers to develop new indexes and methodological approaches which need to be tested as widely as possible in different geographical areas to assess their applicability (Borja et al., 2006; Salas et al., 2004; Sardá et al., 2005).

Although Marine Rapid Assessments have been conducted worldwide, they usually focus on the biota and generally do not use similar systematized approaches to quantify stressors throughout the region under study. The present study demonstrates a simple approach, which simultaneously includes a spatially comprehensive assessment of coastal marine threats and a biodiversity assessment of multiple sites that can provide decision makers with information for posterior application to coastal zone management. Our goal was to quantify the major potential human pressures in the marine coastal zone. This involved developing a method for integrating heterogeneous pressures into single integrative value (an index) by assigning a value and a weighting for each pressure component in order to obtain a relative environmental pressure index. Finally, we aimed to compare this index with community and population attributes (indicators of state) in order to identify the degree of relationship between the biota and environmental pressures. The underlying hypothesis is that sites under high human pressure in Búzios will demonstrate (1) a shift in community from coral to benthic filter feeders and macroalgae; (2) a reduction in the density and/or coral cover and/or coral colony size and (3) an increase in coral partial mortality (old and recently dead corals).

2. Methods

2.1. Study area

This study was carried out at Armação dos Búzios peninsula (hereafter Búzios), state of Rio de Janeiro (22°44′S, 41°52′W), a tropical region on the southeastern Brazilian coast. The coastal morphology of alternating sandy beaches in bays between headlands is repeated right around the peninsula. Water temperature ranges from 19 to 29 °C (Gonçalves, J.E.A unpublished data) and the region receives an influx of sediment from the Una, São João and mostly Macaé rivers (Godiva et al., 2010).

The human population of Búzios has increased 5-fold in the past 30 years and it is recognized that during the summer months this number can increase 10-fold (FGV, 2004) as Búzios is one of the most visited destinations in Brazil, receiving approximately 250.000 international tourists per year (6% of international tourists visiting Brazil) (EMBRATUR, 2005). The coastal zone is used mainly for fishing, watersports and beachgoing (FGV, 2004). This peninsula is an area with an expanding human population, which is suffering adverse effects of coastal zone development, tourism, fishing, and pollution (Barbosa, 2003; Mendes et al., 1999; Oigman-Pszczol and Creed, 2007).

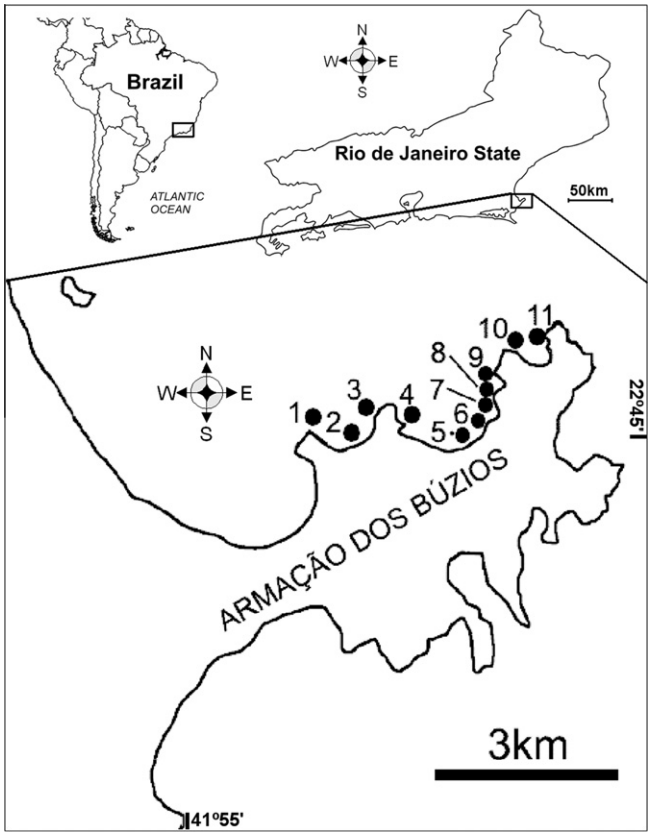

Fig. 1. Location of Armação dos Búzios, RJ, Brazil and the eleven survey sites (rocky shores) in 8 beaches. 1 – Tartaruga L 2 – Tartaruga C 3 – Tartaruga R 4 – Canto 5 – Ilha do Caboclo 6 – Ossos L 7 – Ossos R 8 – Azeda 9 – Azedinha 10 – JoãoFernandes 11 – JoãoFernandinho.

Table 1
The most significant human pressures identified and measured for the environmental pressure index at eleven studied sites at Armação dos Búzios state, RJ, Brazil.

Pressures	Method	References
Urban development	Calculated the proportion of urbanized area within the terrestrial microbasin (small basin abutting each site defined by local watersheds and the position of entry of local streams into the sea). These were identified from aerial photographs of the region (1:2000) and contours on topographic maps (1:50,000)	2002 Nautilus S.A. (IBGE, 1963)
Littoral construction	Counts of the number of water pipes, vending stands, rainwater outfall pipes and other constructions (for instance, a fish market) on the shoreline	
Sewage discharge	Counts of the number of restrooms with soak-aways, sewage discharge pipes and other soak-aways characteristic of sewage	
Litter	All of the visible pieces of man-made debris (number of items) found on each belt transect at the beaches and subtidal environment were identified *in situ* and recorded.	Oigman-Pszczol and Creed (2007)
	Counts of Litter deposit and trash dumps	
Fishing	Estimative of the number of fishing gear litter items observed on the rocky reef bottom; and observing beach-seining activity.	Oigman-Pszczol and Creed (2007)
Recreational activities	Counts of the abundance of beach visitors and bathers carried out hourly during the four days of survey, from 9 am to 6 pm.	
	Counts of the number of dive gear rental outlets, snorkel and SCUBA diver densities in the water estimated from observation of incoming and outgoing divers, as instantaneous counts of abundance during the four days of survey, from 9 am to 6 pm	
Boating related pressures	Estimative of instantaneous counts of the abundance of waterborne craft (taxi boats, speedboats, and tourist schooners) at hourly intervals during four days, from 9 am to 6 pm.	
	Counts of Maritime gas stations, yacht clubs and jetties	