

# Artificial reef influence on the surrounding infauna—north coast of Rio de Janeiro State, Brazil

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*There have been many efforts to appraise the extent to which artificial reefs affect the surrounding community, but few studies addressed whether benthic assemblages change with distance from the reef. We experimentally assessed the relationship between infauna abundance and richness with increased distance (0, 5, 25, 50, 100 and 300 m) from reefballs deployed on a flat and homogeneous bottom, 9-m deep, on the north coast of Rio de Janeiro, south-eastern Brazil. Benthic taxon richness and abundance varied significantly between surveys with higher values in February 2007. Both numerical indicators changed similarly with distance, but more noticeably between 300 m and the other distance treatments where abundance was highest. A non-metric multidimensional scaling ordination revealed that macrobenthic assemblages were very heterogeneous with significant differences between surveys but not among sampling distances. A canonical correspondence analysis including species, distances and sediment variables showed that the distances 5, 25 and 100 m were related to organic matter and mud (fine sediment), while 0 and 300 m distances were more related to the non-organic variables, such as the percentage of gravel, sand and calcium carbonate. Spatial variations in the parameters of the sediment alone did not explain the distribution of the associated infauna, given the similarity of the community at different distances. It is suggested that the influence of artificial reefs is quickly dissipated due to strong bottom sea currents, indicating a reduced impact or influence of these reefs on the surrounding infauna.*

**Keywords:** artificial reef, macrobenthic community, sediment, organic matter, Brazil

Submitted 24 January 2011; accepted 15 June 2011; first published online 19 August 2011

## INTRODUCTION

Artificial reefs are commonly used as a tool for fishery management (Caddy, 1999; Fabi *et al.*, 2002), protection of marine areas from illegal fishing, and more recently for the preservation and rehabilitation of natural habitats (Boaventura *et al.*, 2006). Artificial reefs are usually located on extensive sandy areas, isolated from natural rocky reefs, making them potential tools in the alteration of species abundance and distribution of the associated communities in the sediment around the reefs (Ambrose & Anderson, 1990).

The influence of artificial reef impacts may be relatively small or extend several hundred metres from the reef (Wilding & Sayer, 2002) and the environment may be impacted in several ways, including leaching of toxic fractions from the construction material through the interaction of the structure with the local current regime (Pickering, 1996; Boaventura *et al.*, 2006), modifying rates and processes of sedimentation, distribution and classification of grain size (Danovaro *et al.*, 2002), or even promoting alterations in the

wave marks in the sediment (Davis *et al.*, 1982). The physical presence of the reef structure and the water flux generated by waves and currents constantly remobilizes the nearby sediment, mainly in shallow areas (Reineck & Singh, 1973; Fritz & Moore, 1988). These modifications in the wave marks in the reef environment may promote alterations in the composition and abundance of benthic organisms, mainly those that live in the upper layers of the sediment, or at the sediment–water interface (Lorenzi, 2004). However, information on changes in the hydrodynamics induced by cement blocks is scarce (Ambrose & Anderson, 1990; Badalamenti & D’Anna, 1996; Danovaro *et al.*, 2002; Fabi *et al.*, 2002).

Decreases in current speed at the reef perimeter are likely to allow the sedimentation of fine material including organic particles with a subsequent decrease in mean particle size and concomitant nutrient enrichment (Guiral *et al.*, 1995). A higher quantity of algae and other organic material such as faecal material and dead organisms associated with the reefs also occurs, and increases the organic matter in the sediment (Ambrose & Anderson, 1990).

Danovaro *et al.* (2002) described how artificial reefs could affect the adjacent infauna community: (a) by altering the hydrodynamic regime and physical characteristics of the substrate; (b) by modification of the distribution and/or composition of food resources; and (c) by alteration of the biological interactions among different parts of the food chain. One of these factors may prevail over the others or

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the different forces may act simultaneously, resulting in complex responses of the infauna.

The reefs are not self-sustainable since many predators that are associated with these environments use the reef structures mainly for shelter and depend on the adjacent unconsolidated sediment to obtain food (Parrish & Zimmerman, 1977; Bray *et al.*, 1981; Nelson *et al.*, 1988; Hueckel *et al.*, 1989; Frazer *et al.*, 1991; Posey & Ambrose, 1994). The predation exerted by the ichthyofauna on the unconsolidated substrate community may form a trophic halo, reducing the occurrence of these preys close to the structures (Posey & Ambrose, 1994; Barros *et al.*, 2001; Lorenzi & Borzone, 2009). Ambrose & Anderson (1990) suggest that physical parameters may influence the infauna abundance pattern more than predation, and reef distance was considered the principal factor influencing the community.

Studies of artificial reefs have almost exclusively centred on attraction and feeding ecology of fish (Osenberg *et al.*, 2002; Relini *et al.*, 2002a) and on the colonization of the reef modules by epifauna and reef fish (Badalamenti *et al.*, 2002; Steimle *et al.*, 2002; Boaventura *et al.*, 2006). Knowledge on how benthic assemblages respond to increasing reef distance is restricted to few studies, mostly performed in the northern hemisphere (Danovaro *et al.*, 2002; Fabi *et al.*, 2002; Steimle *et al.*, 2002; Wilding & Sayer, 2002; Wilding, 2006). In Brazil, the studies have followed the same tendency in the State of Ceará (Conceição *et al.*, 2007) and in the north of the State of Rio de Janeiro (Zalmon & Gomes, 2003; Krohling *et al.*, 2006; Brotto & Zalmon, 2007; Krohling *et al.*, 2008; Santos *et al.*, 2010). Two exceptions are the studies of Soares-Gomes *et al.* (2000) that characterized the meiofauna around an oil rig off Rio de Janeiro and Lorenzi (2004) that characterized the infauna associated with an artificial reef employed in the south of Brazil.

The analysis of the influence of artificial marine reefs on the adjacent infauna, proposed here, is part of the research project 'Artificial reef program on the northern coast of the State of Rio de Janeiro' started in 1996. Here, we analyse the benthic assemblages in increasing distances from artificial reefs deployed along the north coast of Rio de Janeiro, south-eastern Brazil. Our purpose was to experimentally address whether soft benthic community structure was affected by increasing distance (0, 5, 25, 100 and 300 m) from the artificial reefs, and that this effect was linked to sediment particle size and the amount of organic carbon, as a function of proximity to the reef modules.

## MATERIALS AND METHODS

### Study area

The north coast of Rio de Janeiro (south-eastern Brazil) (Figure 1) is naturally lacking rocky or other hard substrates, and is covered by extensive sandy beaches with variable amounts of mud and calcareous nodules (i.e. rhodolites; Zalmon *et al.*, 2002). This area is located in a transitional zone between warm and oligotrophic waters of the Brazil Current from the north and cold, nutrient-rich upwelling of the South Atlantic Central Water from the south (Valentin & Monteiro-Ribas, 1993). Primary productivity (chlorophyll-*a*) is low, Secchi depth does not exceed 4 m,

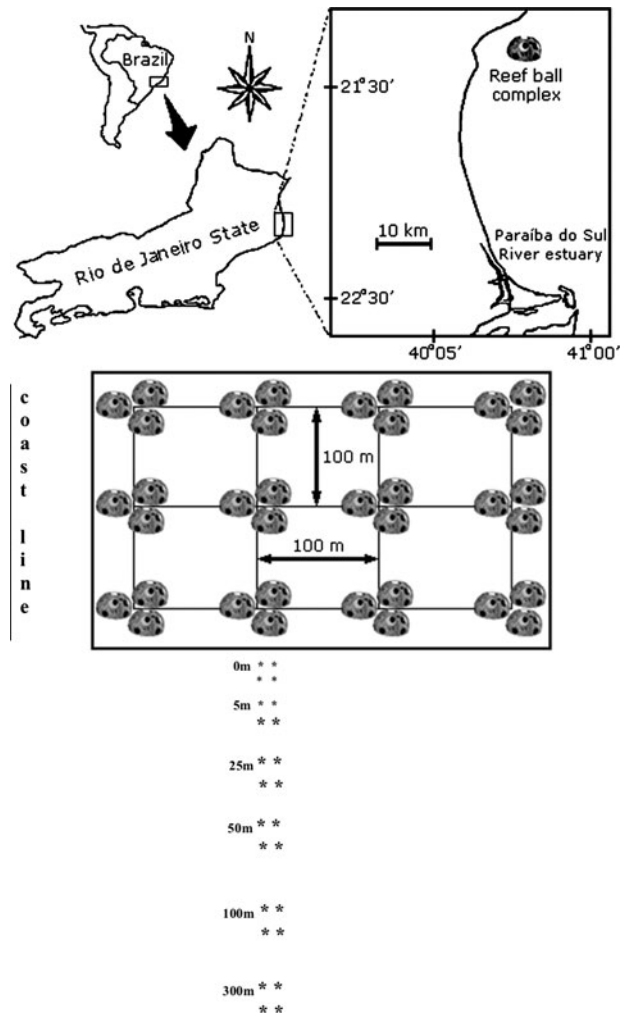


Fig. 1. Geographical location of the north coast of Rio de Janeiro (south-eastern Brazil), where the reef complex was deployed ( $21^{\circ}29'S$   $41^{\circ}00'W$ ). The spatial arrangement of the reef ball replicates and sets, and the transect disposal with the six sampling distances ( $N = 4$  sampling units/distance) are also shown.

and strong bottom currents are common (Krohling *et al.*, 2008). Although dominated by oligotrophic waters and homogeneous bottom relief, the north coast of Rio de Janeiro is often exploited by local inshore artisanal fishermen (Zalmon *et al.*, 2002).

Together with oceanic circulation, the north coast of Rio de Janeiro is also strongly influenced by weather and freshwater runoff. The outflow of the Paraíba do Sul River (the largest river in Rio de Janeiro State) is especially important during the rainy period (December to February), when a turbid (Secchi depth  $<0.5$  m) and polyhaline (18–33 psu) estuarine plume spreads over 15 km north from the river mouth, covering most of the continental shelf up to  $\sim 10$  km distant from the shore (Godoy *et al.*, 2002). This plume does not, however, reach the sea bottom during the rainy period, because the local trade winds lead to the intrusion of clearer and saline bottom waters. During the dry period (April to November), but mostly during winter, the intensity of south-west winds increases, stratification ceases and, consequently, water turbidity increases significantly near the bottom (Godoy *et al.*, 2002; Zalmon, personal observation).

## EXPERIMENTAL DESIGN

Thirty-six prefabricated concrete reef balls® (~1.0 m<sup>3</sup>; 0.5 ton) were deployed in January 2002 on a flat and homogeneous bottom, 9 m deep, and 10 km offshore of the Guaxindiba Beach (21°29'S 41°00'W), northern Rio de Janeiro coast (Figure 1). Artificial reefs were arranged in sets (following the terminology proposed by Grove *et al.*, 1991) of three reef balls (~0.5 m distance) and positioned 100 m apart from each other, in a 3 × 4 reef system configuration that covered ~60,000 m<sup>2</sup> of sea bottom (Figure 1). The reef balls' location were marked using global positioning system (GPS).

The surrounding infauna near the artificial reefs was surveyed in November 2006 (end of the dry period) and February 2007 (end of the rainy period) at six distances from the reefs: 0, 5, 25, 50, 100 and 300 m, on the reef side parallel to the coastline, following the main current (Brazilian Current). At each sampling period, three of ten reef sets, located on the periphery of the reef system were selected and surveyed at each of the six distances (following a virtual transect, orthogonal to the reef set, starting at the edge of the reef system and located on the middle of the square reef). Four sediment samples were collected up to 10 cm deep and 2–3 m distant from each reef set with a PCV tube with 15 cm diameter. Three sediment samples from each distance of the reef ball structure system were processed for macrofaunal identification (mean values) and one for particle size and geochemical analysis for organic content and carbonate (absolute values). Each sediment sample for macrofaunal analysis was washed using seawater through a 0.5 mm mesh and then preserved in borax buffered 4% formaldehyde solution containing 0.2 g/l rose Bengal (Sigma). The macrofauna identification followed Rios (1994), Amaral & Nonato (1996) and Melo (1996).

The particle size analysis is described in Suguio (1973) and the sediment was categorized according to Wentworth (1922). Carbonate analysis followed the method of Dean (1974) and organic content was processed with a CHNS/O Perkin Elmer (2400 serie II) Analyzer.

## Data analyses

Richness and abundance were used as benthic community descriptors with increasing distances from the reef in both temporal surveys and evaluated by analyses of variance (ANOVAs). The sampling distances were considered as an orthogonal and fixed factor, while the surveys were an orthogonal and random factor. Log<sub>10</sub>(X + 1) transformations were applied for variances homogeneity (Underwood, 1998).

Differences in the community composition between the treatments (dry × rainy periods and distances) were visualized using non-metric multidimensional scaling (MDS) based on the Bray–Curtis dissimilarity matrix. These analyses were performed with the statistical package PRIMER® (V.6). Permutational multivariate analyses of variance (PERMANOVAs) were applied for multivariate comparisons of the benthic community composition among the six experimental reef distances. The Bray–Curtis similarity distance was chosen as the basis for all PERMANOVAs and data were permuted 9999 times per analysis at an  $\alpha$ -level of 0.05 (Manly, 1997). When significant differences were found, pair-wise *post-hoc* comparisons were performed using 9999

permutations (see Anderson, 2005 for further details). Data were square root transformed for PERMANOVAs.

The fauna composition and the sediment variables related to both surveys and to increasing distances were analyzed using canonical correspondence analysis with CANOCO® (V4.5). The significance of the measured environmental variables was tested using Monte Carlo permutation tests (Ter Braak, 1986), and only those variables making a significant ( $P < 0.05$ ) contribution to the species–environment ordination were included in the final analysis and the ordination diagram.

## RESULTS

### Sediment characterization

The sediments at the six distances were not visually distinct, predominating sand in November 2006 (Figure 2A) and gravel in February 2007 (Figure 2B). The particle size difference occurred mainly at the reef and at 100 m distance, with >60% of mud (Figure 2). On both surveys the carbonate percentages were similar at the reef and at 100 m distance with less than 50%, while at the other distances remained between 60 and 70% (Figure 3A). Organic content values were superior at the reef and at the higher distances 100 and 300 m, respectively (Figure 3B).

### BENTHIC COMMUNITY

In November 2006 a total of 15 taxa and 219 individuals were collected, including 8 taxa and 48 individual of polychaetes, 6 taxa and 165 individuals of Crustacea and 1 taxon and 6 individuals of Sipuncula in four distances: 5, 25, 100 and 300 m (Table 1). At the reef (0 m) and at 50 m no organism was collected during this sampling survey. The highest number of taxa ( $N = 12$ ), abundance ( $N = 180$ ) and Shannon diversity ( $H' = 0.7$ ) was registered at the 300 m distance (Figure 4A, B, C). The amphipod *Ampelisca* spp. represented 70% of the total number of individuals at this distance during the November sampling survey. At 5 and 100 m we collected only two taxa of polychaetes and at 25 m, four taxa of polychaetes and one Crustacea (Table 1).

In the February survey we collected 39 taxa and 334 individuals. These included polychaetes (27 taxa and 66 individuals), Crustacea (8 taxa and 35 individuals), Bivalva (2 taxa and 4 individuals), Sipuncula (1 taxon and 3 individuals) and Ophiuroidea (1 taxon and 2 individuals) at all the six distances sampled (Table 2) The highest richness of taxa ( $N = 18$ ) and diversity ( $H' = 0.8$ ) occurred at 100 m, followed by 300 m, where the highest number of individuals was found ( $N = 84$ ) (Figure 4A, B, C). As in the previous sampling survey, the amphipod *Ampelisca* spp. predominated at 300 m, accounting for 55% of the individuals. In the reefs and at 300 m, the crustaceans were the main components (61%), while at the other distances polychaetes were responsible for 70% of the individuals (Table 2).

Benthic taxa richness and abundance varied significantly between surveys ( $P = 0.01$ ) with higher values in the February 2007 samples (Table 3; Figure 4). Both numerical indicators changed similarly with reef distance, but more noticeably between 300 m and the other distance treatments for abundance (Figure 4). Also, ANOVA results revealed that abundance in the 300 m assemblage trended to be

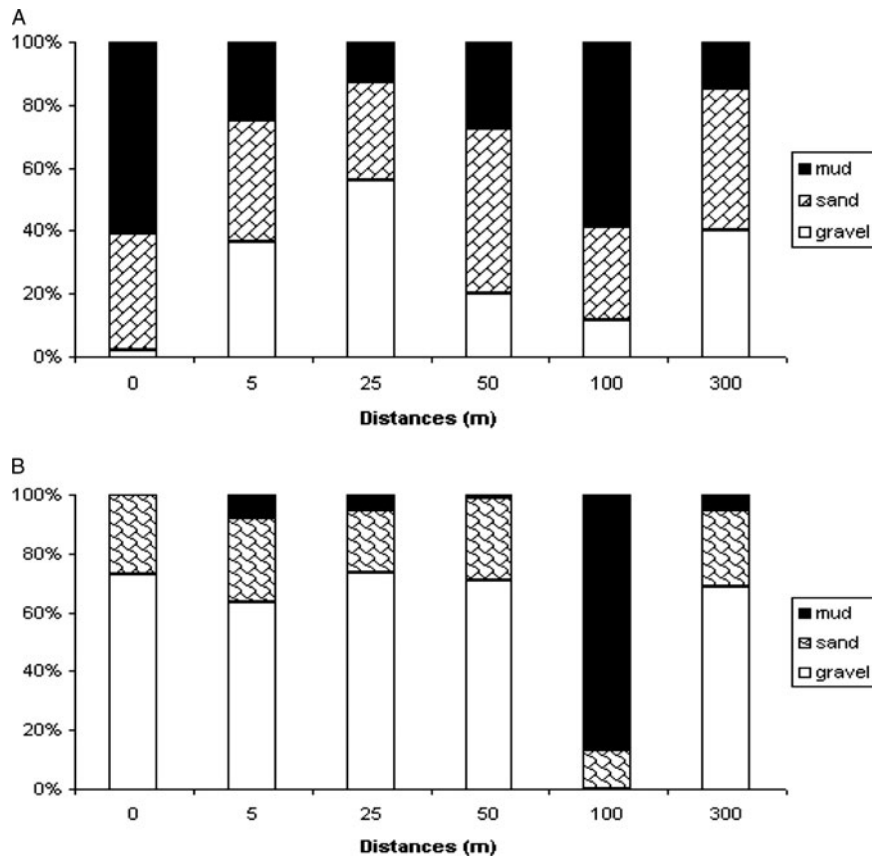


Fig. 2. Percentage absolute values for the granulometric composition of the sediment measured at six sampling distances around the reef complex in November 2006 (A) and February 2007 (B).

significantly higher ( $P = 0.05$ ) than those at the closer sites. No significant sampling survey  $\times$  reef-distance interaction was found ( $P > 0.05$ ), and these results indicated that changes in benthic assemblages with reef distance were not affected by the survey or sampling distance.

The MDS ordination indicated that macrobenthic assemblages, including all taxa in both surveys and at the six sampling distances, were very heterogeneous (Figure 5). Agreeing with the previous results, PERMANOVA also indicated significant differences (Table 4) in macrobenthic assemblages between surveys ( $F_{1,47} = 3.951$ ,  $P = 0.0029$ ) but not among sampling distances ( $F_{5, 47} = 1.596$ ,  $P = 0.1259$ ), in which none differed significantly from each other (PERMANOVAs pair-wise *post-hoc* tests;  $P > 0.05$ ). No significant sampling survey  $\times$  reef-distance interaction was found ( $P > 0.05$ ).

Two significant canonical axes were extracted in the canonical correspondence analysis (Table 5). The first one explained 15% of the species variation, of which 32% could be attributed to the sediment variables. The concentration of  $\text{CaCO}_3$  showed the highest correlation with the first axis and the disposition of the points in relation to the artificial reef revealed this effect at the 300 m distance in the February sampling survey. The highest abundances of *Pionosyllis*, *Ophiuroidea* and *Glicinde* contrasted with the low abundances at 0, 50 and 100 m distances from the reefs, both in November and February surveys (Figure 6). The second canonical axis was also significant, according to the Monte Carlo test, explaining 13% of the variance in the species abundance. The organic matter concentration in the

sediment had the highest correlation with this axis (Figure 6). The samples disposition (distance from the reef) also showed this effect at the 300 m distance in the November sampling survey compared to the other distances in both surveys (November and February). Both axes had a gradient related to distance from the reefs. In November at 300 m there was an increase in the abundance of *Microcerberus*, *Excorallanidae* and *Ampelisca* sp. 1.

## DISCUSSION

The sampling point located in the reef complex had more silt than the ones farther away, except for the 100 m sampling distance, indicating that reefs may have an influence on fine sediment deposition. Danovaro *et al.* (2002) showed that a direct consequence of the lower sandy fraction near reefs in the Adriatic Sea was a reduction in the current velocity around the reef modules. However, these authors did not observe this effect near Mediterranean reefs. In shallow waters in southern California, Davis *et al.* (1982) found a perceptible physical effect only in small areas in the immediate vicinity of the reef structures, without measurable effects in the undulation patterns in the sediment, grain size and organic carbon. Langlois *et al.* (2005; 2006) studied the effect of artificial reefs on the surrounding region at three sites in north-eastern New Zealand and also did not verify differences in the sediment around any of the study sites.



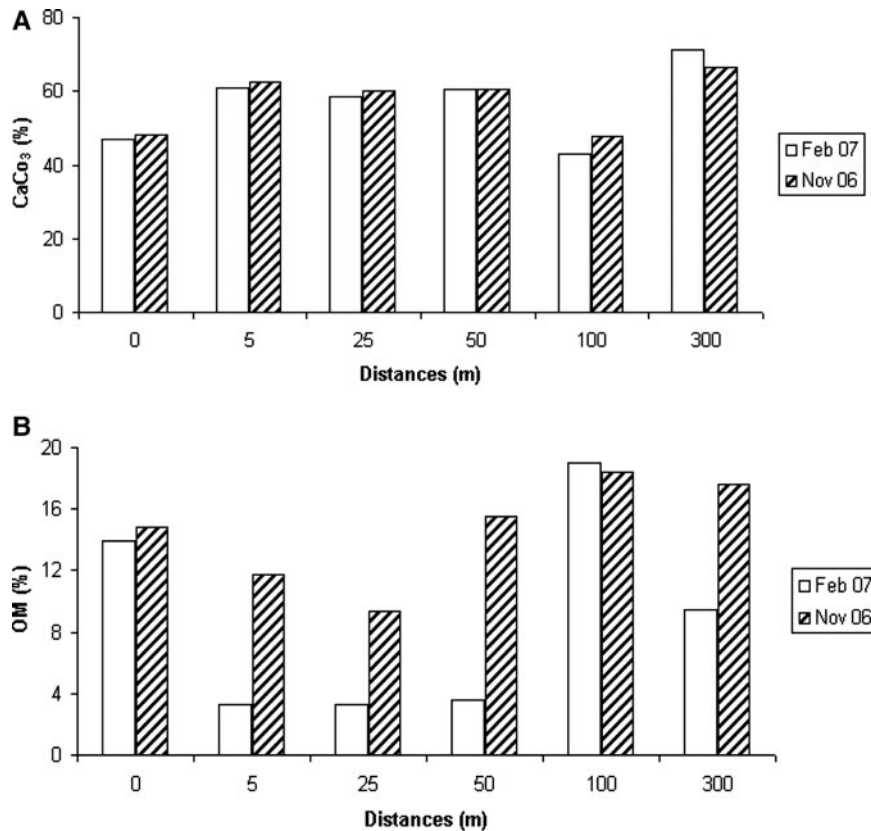


Fig. 3. Percentage absolute values for the geochemical variables carbonate (A) and organic matter (B) of the sediment measured at six sampling distances around the reef complex in November 2006 and February 2007.

In contrast to the previously cited studies, Ambrose & Anderson (1990), Posey & Ambrose (1994) and Barros *et al.* (2001) recorded a higher percentage of coarse sediment in areas near the reefs, while a higher fraction of fine sediment was found only in samples collected more than 10 m distant from the reef complexes. Barros *et al.* (2001) attributed this effect to the artificial reef structures that acted as a source of calcium carbonate for the closer sediment, due to the molluscs and crustaceans associated with the reefs. In artificial reefs deployed on the north coast of Rio de Janeiro, the epifauna of the modules is mainly composed of cnidarians such as arborescent hydrozoans and the *Octocorallia Carijoa* sp., while molluscs (*Ostrea* sp.) and crustaceans (Cirripedia) predominated in the initial stages of colonization (Zalmon & Gomes, 2003; Krohling *et al.*, 2006), justifying the absence of shells (the large fraction of the coarse sediments) and the lower percentage of CaCO<sub>3</sub> in the surrounding areas of these reefs. Other organisms could contribute to higher percentage of CaCO<sub>3</sub>, like planktonic or benthic foraminifera, typically found in tropical warm waters, and their deposition could be related to a reduction in current velocities for example. However, the local current velocity is always >1.0 knot (Godoy *et al.*, 2002).

The concentration of carbonate and the grain size varied together, and sampling points with higher percentages of gravel (5, 25 and 300 m) also had higher percentages of carbonate, which suggest a biodetritric source. Also, the amount of organic matter was associated with the percentage of silt. Silty sediments generally had a higher organic matter content than sediments with coarser grain size, since

organic matter tends to be associated with sediment deposition in slower moving water (Snelgrove & Butman, 1994). This effect might be related to the reef complex influence on the deposition of fine sediments with a subsequent increase in the concentration of organic matter. Fabi *et al.* (2002) also verified that an artificial reef complex on a Mediterranean coast favoured the silt deposition (fine sediment) and the accumulation of organic matter within the reef area. Airoidi *et al.* (2005) considered the artificial reef impacts on a local scale as the change in grain size and organic matter content, aside from the reduction in habitats in consolidated substrate. On a time scale, these authors evaluated that, in general, the grain size of the sediment decreased while the organic matter content increased.

The higher values of organic matter at the reef and at 100 and 300 m initially suggest that the influence area of the artificial reefs might surpass 300 m. The organic matter in the reefs may be derived from the remains of the organisms that grow on the experimental modules (Krohling *et al.*, 2006), faecal matter from the fish, principally juveniles, that use the reefs for shelter or feeding (Brotto *et al.*, 2006) or others that visit these structures and have a wider distribution (Zalmon *et al.*, 2002). The similarity of the infauna at the different sampling points suggests our hypothesis that the influence of the artificial reefs is rapidly 'lost', being dissipated due to strong marine currents at the site (Godoy *et al.*, 2002). Currents higher than 1.0 knot are commonly registered in the area during the year (Godoy *et al.*, 2002) and the size of the reef complex (300 × 200 m) suggests a reduced influence or impact of

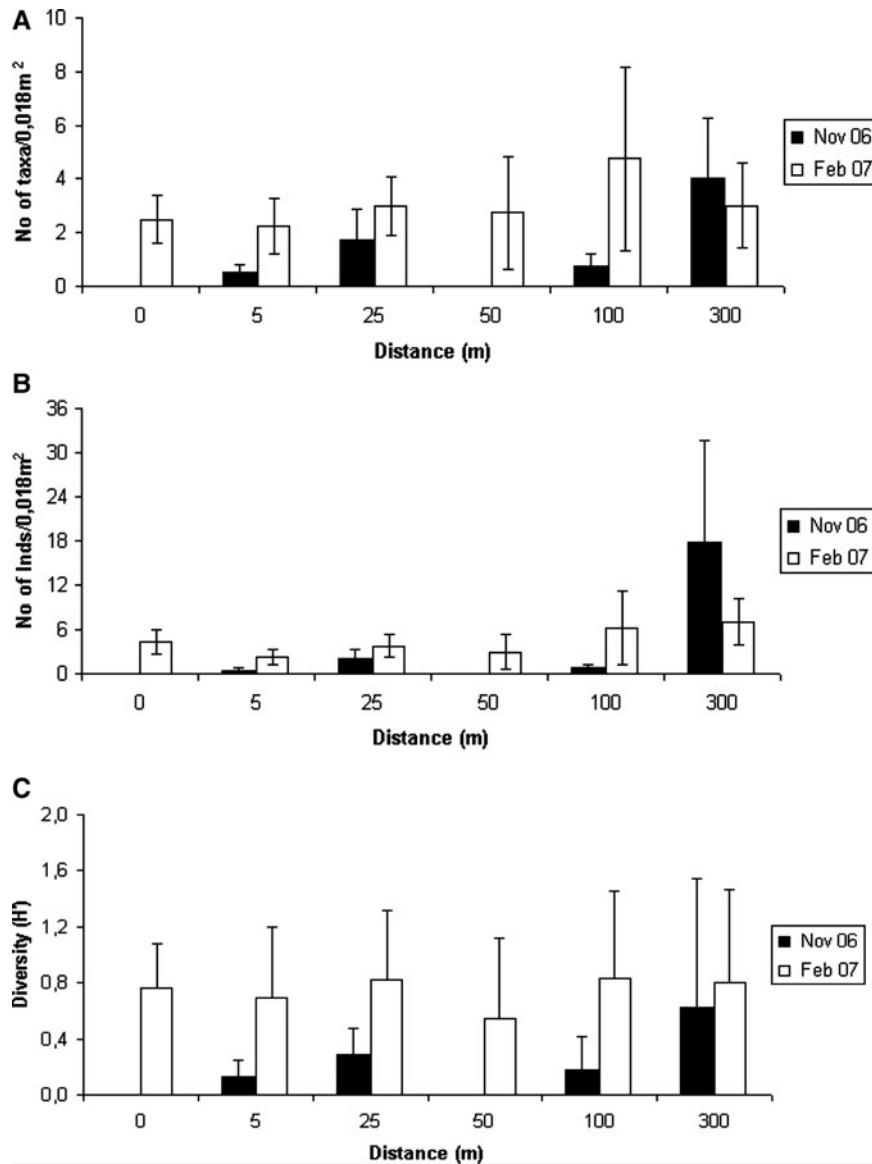


Fig. 4. Mean and standard deviation ( $N = 3$  samples) for richness, mean number of individuals and Shannon diversity ( $H'$ ) at the six sampling distances in November 2006 and February 2007.

the experimental modules on the adjacent macrobenthic community.

Davis *et al.* (1982) in southern California showed a very small influence of artificial reefs on the surrounding infauna, being present only in samples very close to the reef. These authors suggest that the macrofauna is less sensitive to effects associated with the reefs than the larger sessile epifauna, and the life history of the infauna (e.g. high larval recruitment frequency) allows a rapid recuperation of the areas impacted by the reef structures. Barros *et al.* (2001) and Langlois *et al.* (2006) also did not verify an impact of reefs on the infauna either for total abundance or diversity of the communities at the distances sampled. The artificial reefs in this study were initially deployed on the north coast of Rio de Janeiro in 1996 and this is the first study concerning the local infauna and the results indicated an increasing tendency in the richness, abundance and diversity values along a distance gradient from 0 to 300 m, but without significant differences in the community composition. Common and

abundant taxa, for example the polychaete *Lumbrineris* sp., occurred at all the distances, while other taxa predominated in the reefs and the farthest point, such as the amphipod crustacean *Ampelisca* spp.

Significant differences in taxon richness, abundance and macrobenthic assemblages between surveys with higher values in February 2007 suggest the influence of the Paraiba do Sul River (the largest river in Rio de Janeiro State). The outflow of this river with its associated organic nutrients is especially important during the rainy period (December to February), covering most of the continental shelf up to ~10 km distant from the shore (Godoy *et al.*, 2002; Souza *et al.*, 2010).

Warwick & Clarke (1993) observed that the degree of variability among samples collected in impacted areas was higher than in less impacted areas. Significant differences in the community only between surveys reinforce the hypothesis of a large influence of the input from the Paraiba do Sul River, mainly in the rainy season of 2007 and a smaller influence of

**Table 1.** Benthic macrofauna recorded in November 2006 at the six sampling distances from the artificial reef on the north coast of Rio de Janeiro, south-eastern Brazil. Average number of individuals ( $\pm$ SD) at each distance (N = 3 sampling units/distance).

Taxa/sampling distances (m)	0	5	25	50	100	300
Phylum Annelida						
Class Polychaeta						
<i>Chaetacanthus</i> sp. Seidler, 1924	–	0.75 ( $\pm$ 1.5)	0	–	0	0.75 ( $\pm$ 1.5)
<i>Lumbrineris</i> sp. Blainville, 1878	–	0	0.75 ( $\pm$ 1.5)	–	0	0.75 ( $\pm$ 1.5)
<i>Lumbrineriopsis</i> sp.	–	0	1.50 ( $\pm$ 1.8)	–	0.75 ( $\pm$ 1.5)	0
<i>Owenia</i> sp. Delle Chiaje, 1841	–	0	0	–	1.50 ( $\pm$ 3.0)	0
<i>Paraprionospio</i> sp.	–	0	0	–	0	0.75 ( $\pm$ 1.5)
<i>Pherusa</i> sp.	–	0	0.75 ( $\pm$ 1.5)	–	0	1.50 ( $\pm$ 3.0)
<i>Streblosoma</i> sp. Sars, 1872	–	0.75 ( $\pm$ 1.5)	0.75 ( $\pm$ 1.5)	–	0	0
<i>Tharys</i> sp. Webster & Benedict, 1887	–	0	0	–	0	0.75 ( $\pm$ 1.5)
Phylum Arthropoda						
Class Crustacea						
<i>Amakusanthura</i> sp. Nunomura, 1977	–	0	0	–	0	0.75 ( $\pm$ 1.5)
<i>Ampelisca</i> sp1 Kröyer, 1842	–	0	1.50 ( $\pm$ 3.0)	–	0	7.50 ( $\pm$ 11.5)
<i>Ampelisca</i> sp2 Kröyer, 1842	–	0	0	–	0	34.50 ( $\pm$ 45.0)
<i>Ampelisca</i> sp3 Kröyer, 1842	–	0	0	–	0	1.50 ( $\pm$ 1.8)
Exocorallanidae	–	0	0	–	0	1.50 ( $\pm$ 3.0)
<i>Microcerberus</i> sp. Karaman, 1933	–	0	0	–	0	1.50 ( $\pm$ 3.0)
Phylum Sipuncula						
Sipuncula	–	0	0	–	0	2.25 ( $\pm$ 5.5)

**Table 2.** Benthic macrofauna recorded in February 2007 at the six sampling distances from the artificial reef on the north coast of Rio de Janeiro, south-eastern Brazil. Average number of individuals ( $\pm$ SD) at each distance (N = 3 sampling units/distance).

Taxa/sampling distances (m)	0	5	25	50	100	300
Phylum Annelida						
Class Polychaeta						
<i>Isolda</i> sp. Müller, 1858	0.75 ( $\pm$ 1.5)	0.75 ( $\pm$ 1.5)	0.75 ( $\pm$ 1.5)		0.75 ( $\pm$ 1.5)	
<i>Schistocomus</i> sp. Chamberlin, 1919					0.75 ( $\pm$ 1.5)	
<i>Terebellides</i> sp. Sars, 1835	0.75 ( $\pm$ 1.5)		0.75 ( $\pm$ 1.5)			
<i>Lepdonotus</i> sp. Leach, 1816	0.75 ( $\pm$ 1.5)					
<i>Chaetacanthus</i> sp. Seidler, 1924					0.75 ( $\pm$ 1.5)	
<i>Lumbrineris</i> sp. Blainville, 1878	1.50 ( $\pm$ 3.0)	0.75 ( $\pm$ 1.5)	2.25 ( $\pm$ 4.5)	1.50 ( $\pm$ 3.0)	1.50 ( $\pm$ 1.8)	2.25 ( $\pm$ 4.5)
<i>Kimbergonuphis</i> sp. Fauchald, 1982				0.75 ( $\pm$ 1.5)		
<i>Ophelia</i> sp. Savigny, 1818	0.75 ( $\pm$ 1.5)		0.75 ( $\pm$ 1.5)			
<i>Exogone</i> sp. Oersted, 1845		1.50 ( $\pm$ 1.8)				
<i>Autolytus</i> sp. Grube, 1850				0.75 ( $\pm$ 1.5)	1.50 ( $\pm$ 3.0)	
<i>Typosyllis</i> sp. Langerhans, 1879			0.75 ( $\pm$ 1.5)	0.75 ( $\pm$ 1.5)	2.25 ( $\pm$ 4.5)	0.75 ( $\pm$ 1.5)
<i>Pionosyllis</i> sp. Malmgren, 1867				0.75 ( $\pm$ 1.5)		0.75 ( $\pm$ 1.5)
<i>Paraonis</i> , Cerruti, 1909		1.50 ( $\pm$ 1.8)		0.75 ( $\pm$ 1.5)		
<i>Paradoneis</i> sp. Grube, 1873				0.75 ( $\pm$ 1.5)		
<i>Aedicira</i> sp. Fauchald, 1977					0.75 ( $\pm$ 1.5)	
<i>Glycinde</i> sp. Müller, 1858		0.75 ( $\pm$ 1.5)				0.75 ( $\pm$ 1.5)
<i>Trichobranchus</i> sp. Malmgren, 1865		0.75 ( $\pm$ 1.5)	0.75 ( $\pm$ 1.5)			0.75 ( $\pm$ 1.5)
<i>Magelona</i> sp. Müller, 1858			1.50 ( $\pm$ 3.0)		1.50 ( $\pm$ 1.8)	0.75 ( $\pm$ 1.5)
<i>Sabellaria</i> sp. Savigny, 1818			0.75 ( $\pm$ 1.5)			
<i>Hipponoe</i> sp. Audouin & Milne-Edwards, 1830			0.75 ( $\pm$ 1.5)			
<i>Tharyx</i> sp. Webster & Benedict, 1887			0.75 ( $\pm$ 1.5)	0.75 ( $\pm$ 1.5)		
<i>Streblosoma</i> sp. Sars, 1872				0.75 ( $\pm$ 1.5)		0.75 ( $\pm$ 1.5)
<i>Eupolytnia</i> sp. Verrill, 1900					0.75 ( $\pm$ 1.5)	
<i>Nicolea</i> sp. Malmgren, 1865					1.50 ( $\pm$ 3.0)	
<i>Lisylla</i> sp. Malmgren, 1865					0.75 ( $\pm$ 1.5)	
<i>Owenia</i> sp. Delle Chiaje, 1841					1.50 ( $\pm$ 1.8)	
<i>Rhodine</i> sp. Malmgren, 1865						0.75 ( $\pm$ 1.5)
Phylum Arthropoda						
Class Crustacea						
<i>Ampelisca</i> sp. Kröyer, 1842	3.75 ( $\pm$ 7.5)				0.75 ( $\pm$ 1.5)	11.75 ( $\pm$ 22.5)
Caprellidae					0.75 ( $\pm$ 1.5)	
<i>Amakusanthura</i> sp. Nunomura, 1977	0.75 ( $\pm$ 1.5)			0.75 ( $\pm$ 1.5)		0.75 ( $\pm$ 1.5)
Exocorallanidae						0.75 ( $\pm$ 1.5)
<i>Microcerberus</i> sp1 Karaman, 1933	2.25 ( $\pm$ 1.5)				2.25 ( $\pm$ 1.5)	

Continued

Table 2. Continued

Taxa/sampling distances (m)	0	5	25	50	100	300
<i>Microcerberus</i> sp2 Karaman, 1933	0.75 ( $\pm 1.5$ )					
Penaeidae				0.75 ( $\pm 1.5$ )		
Porcellanidae	0.75 ( $\pm 1.5$ )					
Phylum Mollusca						
Class Bivalvia						
<i>Bivalvia</i> .		0.75 ( $\pm 1.5$ )		0.75 ( $\pm 1.5$ )	0.75 ( $\pm 1.5$ )	
<i>Semele casali</i> Doello-Jurado, 1949	0.75 ( $\pm 1.5$ )					
Phylum Echinodermata						
Class Ophiuroidea						
Ophiuroidea			0.75 ( $\pm 1.5$ )			0.75 ( $\pm 1.5$ )
Phylum Sipuncula						
Sipuncula		0.75 ( $\pm 1.5$ )	0.75 ( $\pm 1.5$ )		0.75 ( $\pm 1.5$ )	

**Table 3.** Analysis of variance results. F and P values for sampling distance and survey variables related to abundance (N, number of individuals/0.018 m<sup>2</sup>) and richness (S, taxon richness/0.018 m<sup>2</sup>).

	N		S	
	F	P	F	P
Survey	7.31	0.01	9.40	0.004
Distance	2.35	0.05	1.17	0.34
Survey $\times$ distance	0.78	0.57	0.71	0.62

**Table 4.** Permutational multivariate analysis of variance results applied to a Bray–Curtis similarity matrix considering the sampling distances and surveys as a hierarchical factor.

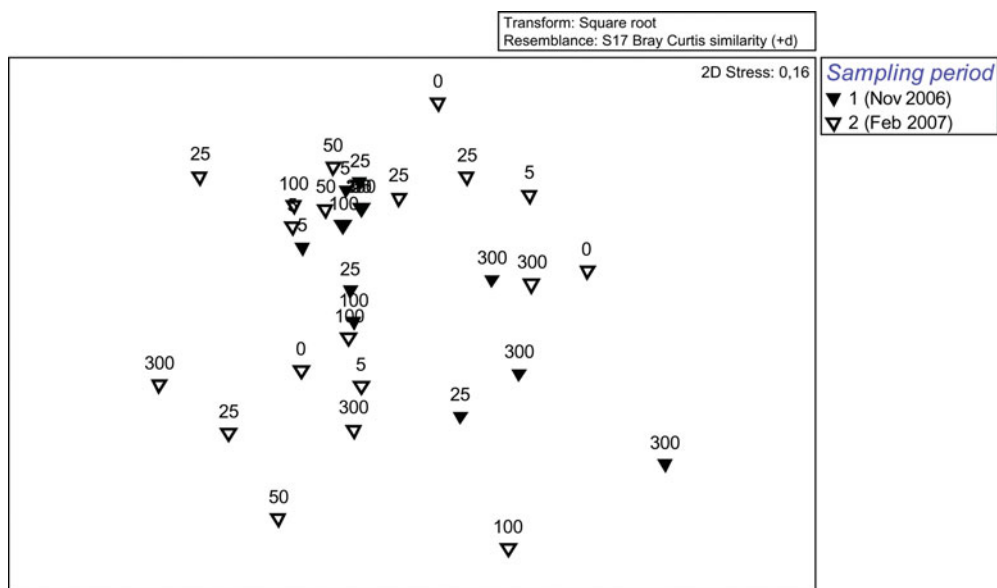
	df	F	P (permut)	P (MC)
Survey	1	3.951	0.0029	0.0031
Distance	5	1.596	0.1259	0.0827
Survey $\times$ distance	5	0.939	0.5486	0.5564
Residual	36	–	–	–
Total	47	–	–	–

the experimental modules on the surrounding infauna. It is noteworthy that this seasonality on the river input could turn the environment extremely variable among years.

In a review of artificial reefs, Svane & Petersen (2001) considered that their effect on the surrounding area was secondary, because most studies did not register measurable effects on wave patterns in the sediment, on organic matter, in the grain size or on the composition of the infauna. However, they considered that the artificial reefs affected the surrounding environment principally due to the attraction that the reefs had on the ichthyofauna that came into the reefs to

**Table 5.** Eigenvalues, explanation percentages, species  $\times$  axis correlation and Monte Carlo result for the canonical significance.

	Axis 1	Axis 2
Eigenvalues	0.28	0.26
Percentage	14.50	13.17
Cumulative percentage	14.30	27.67
Cumulative constraint percentage	31.80	60.60
Species–environment correlations	0.95	0.94
F calculation—Monte Carlo	13.48	9.89
P—Monte Carlo	0.01	0.01



**Fig. 5.** Non-metric multidimensional scaling of the benthic community at different sampling distances, considering the three sampling units at each distance of the reef ball structure system in November 2006 and February 2007.



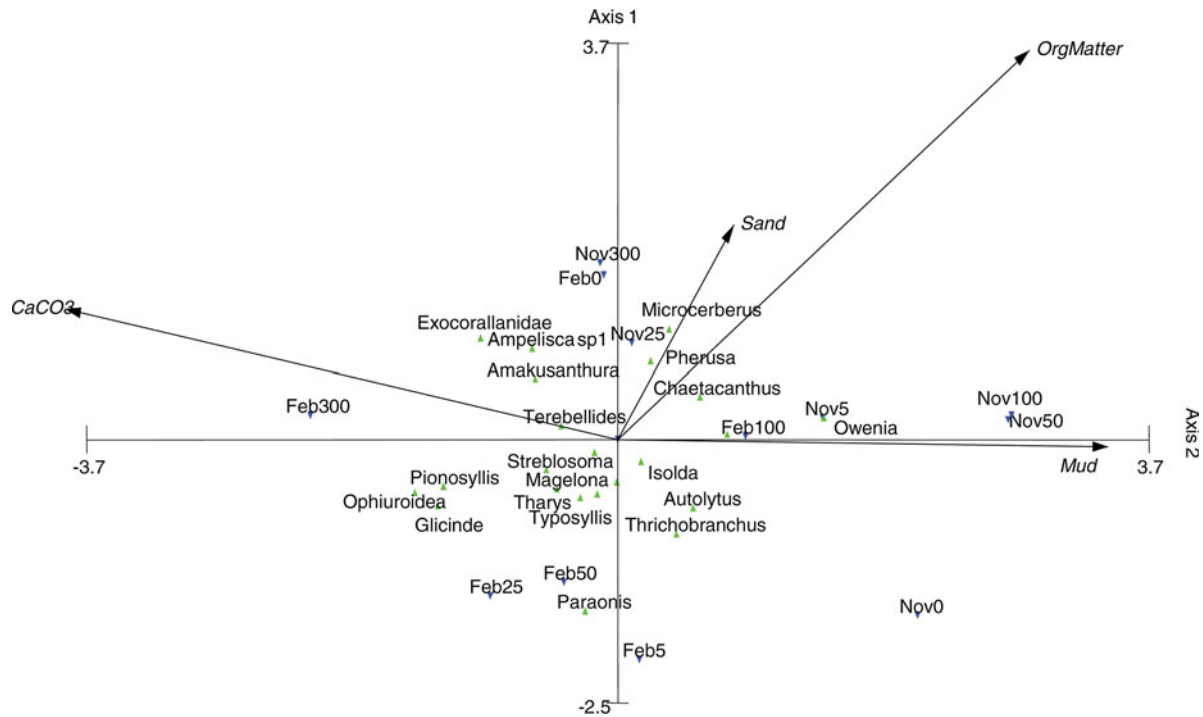


Fig. 6. Canonical correspondence analysis including sampling distance (0, 5, 25, 50, 100 and 300 m from the reef), sediment variables (CaCO<sub>3</sub>, sand, mud and organic matter) and taxa in November 2006 (Nov) and February 2007 (Feb).

feed on the epifauna and/or the infauna or to hide. In other studies on the artificial reefs deployed on the north coast of Rio de Janeiro, Brotto *et al.* (2006) and Brotto & Zalmon (2007) stressed the importance of biological interactions, such as predation of the macrofauna by fish attracted to the reef complex, as a structuring factor of the associated fish community.

In our reef complex, Santos *et al.* (2010) verified that fish abundance and richness were significantly higher at distances up to 50 m from the reefs than distances of 300 m, and these authors concluded that the patterns found should be related to a halo of decreasing density of benthic prey items approaching the reef, as a result of a greater overlap of fish feeding grounds. Indeed, our abundance and richness infauna data showed lower values at <100 m reef distance in both surveys, although with no significant differences.

In their review, Snelgrove & Butman (1994) observed that the relation between the infauna and the sediment is much more variable than traditionally proposed, without evidence that proves that parameters such as granulometry, organic matter content, and presence of microorganisms, food availability or bioturbation may, separately, determine the distribution of the infauna. Independent of the type of sediment, the composition in a specific site is not static, but is in dynamic equilibrium with the local conditions.

Compared to artificial reefs employed in Europe, the US and Japan, covering more than 20 hectares (Santos & Monteiro, 1997; Furukawa, 2000; Relini *et al.*, 2002b; Reed *et al.*, 2006), the reef complex studied here can be considered to be small and essentially experimental. Along with the size, the environment of the region is characterized by strong hydrodynamic processes, such that the potential changes in the sediment, such as increase in organic matter content and subsequent enrichment of nutrients due in large degree to rapid

colonization by fish and the epifauna, are rapidly diluted. The spatial variations in the sediment parameters monitored do not explain, by themselves, the distribution of the associated infauna, given the similarity in the community composition at the different sampling points, and reinforce the hypothesis of the major influence of the input from the Paraíba do Sul River.

However, we emphasize that the effects of employment of artificial reefs clearly depends on the type and size of the structure, the degree of isolation of the reefs, aside from the surrounding environment as attributes of the habitat that are capable of altering the structure and dynamics of the associated infauna.

## ACKNOWLEDGEMENTS

We are grateful to MSc Bruno P. Masi for diving assistance. We thank the Brazilian agencies FAPERJ (grant number E26/152.540/2006) and CNPq (grant number 470396/2006-7).

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