Aquat Ecol (2015) 49:343–355
DOI 10.1007/s10452-015-9530-7

Impact of artificial patchy reef design on the ichthyofauna community of seasonally influenced shores at Southeastern Brazil

Pedro Gatts · Marcos Franco · Luciano dos Santos · Diogo Rocha · Fabrício de Sá · Eurico Netto · Phillipe Machado · Bruno Masi · Ilana Zalmon

Received: 2 December 2014 / Accepted: 11 June 2015 / Published online: 20 June 2015

Abstract To investigate how variations in the small-scale distance between patchy reef modules affect the structure and composition of the associated ichthyofauna, concrete reefballs were arranged in three distance configurations, 0.5, 5 and 15 m, at 9 m depth off the northern Rio de Janeiro coast. The ichthyofauna was sampled in the dry and rainy seasons using gillnets, and the composition, richness, diversity, abundance and biomass per distance unit were recorded. The availability of potential macrobenthic prey was evaluated using a stainless steel corer for each inter-module distance, and the results correlated with the stomach contents of the captured ichthyofauna. Community descriptors did not significantly change with treatments of reef distance. A canonical correspondence analysis revealed similar fish composition among reef distance treatments, but increased occurrence of exclusive species and habitat-dependent fish with increased distances among reef modules. Non-metric multidimensional scaling showed different composition of fish populations between sampling periods, with a predominance of Sciaenidae in the dry season and Ariidae and Carcharhinidae on the rainy season. The adjacent infauna was not directly related to the ichthyofauna but to the benthic prey, which were possibly using the structure interstices, and small fish. Significant effects of seasonal freshwater and sediment loads from large regional coastal rivers may override the effects of reef configuration, especially during rainy seasons with higher inflow. As the shorter reef distance exhibited generally the same richness and abundance compared with larger and more distant reefs, a patchy design with <5.0 m distances is thus recommended for the distribution of artificial reefs to increase fish biodiversity in coastal environments with homogeneous substrate and seasonally influenced by freshwater outflow and sediment from large rivers.

Keywords Artificial reef · Patchy design · Ichthyofauna · Community structure · Predation · Southeastern Brazil

Introduction

The use of artificial structures for habitat restoration has increased due to their promising potential and

Handling Editor: Thomas Mehner.

P. Gatts · M. Franco · D. Rocha · P. Machado ·
B. Masi · I. Zalmon (✉)
Centre of Biosciences and Biotechnology, University of North Rio de Janeiro State, Av. Alberto Lamego, 2000.
Campos, Rio de Janeiro 28013-602, Brazil
e-mail: ilana@uenf.br

L. dos Santos
Department of Ecology and Marine Resources, Federal University of Rio de Janeiro State, Rio de Janeiro,
RJ 22061-010, Brazil

F. de Sá · E. Netto
Ethica Ambiental Serviços e Consultoria Ltda,
Vila Velha, Espírito Santo 29101-230, Brazil

successful initiatives in rehabilitating fish stocks (Caddy 1999; Fabi et al. 2011; Feary et al. 2011; Simon 2011). In addition, artificial reefs may also be used as scientific research tools because they are easily manipulated, allow for the control of structure variables (e.g., size and complexity) and can be arranged in a variety of spatial distributions (Jan et al. 2003; Jordan et al. 2005). Therefore, artificial reefs facilitate the validation of ecological theories and development of theoretical and predictive models, many of which represent the foundation of practical programs and can be applied to reefs in marine environments at a large scale (Polovina 1991; Fabi et al. 2011).

Artificial habitats are constructed from a variety of materials, such as concrete, rubber and oil platforms (Baine 2001; Fabi et al. 2011). Concrete is generally selected because of its durability and ability to form several types of reef structures (e.g., cubes, pyramids, cones and reefballs), areas and volumes (Baine 2001; Jan et al. 2003; Fabi et al. 2011; Hackradt et al. 2011; Gatts et al. 2014). The complexity of the structures can influence the associated fish communities, with holes and crevices providing shelter, breeding habitat and refuge against predators (Anderson et al. 1989; Bohnsack 1989; Hixon and Beets 1989; Seaman 1996; Charbonnel et al. 2002; Sherman et al. 2002; Brotto and Zalmon 2007; Hackradt et al. 2011).

The replication and spatial arrangement of reefs might alter the complexity of the environment and structure of the associated fish communities (Lindberg 1996; Jordan et al. 2005). Experimental reef designs with different sizes, numbers, volumes, areas and modular distances have been investigated as tools in the management and conservation of coastal resources because they can attract/aggregate target species (Schroeder 1987; Frazer and Lindberg 1994; Baine 2001; Charbonnel et al. 2002; Baine and Side 2003; Jordan et al. 2005; Simon 2011).

Organisms in sandy substrates adjacent to reefs are important in the diet of associated piscivorous and/or invertivorous fish, suggesting that reef communities are dependent on the biological production of the associated sediment (Lindquist et al. 1994; Relini et al. 2002; Leitão et al. 2007). The optimal foraging theory suggests that when less energy is expended during foraging, the energy gain is greater, and the risk of an organism being preyed upon is lower; therefore, fishes are expected to feed on preys closer to the reef (MacArthur and Pianka 1966; Milinski 1986; Stephens and Krebs 1986). This behavior of ichthyofauna can lead to a halo-like distribution of preys surrounding reef units, with an increase in the prey availability with increasing distance from these structures (Randall 1965; Ogden 1976; Bortone et al. 1998; Campbell et al. 2011). Lindberg (1996) and Jordan et al. (2005) observed increasing fish abundances with distance isolation (up to 25 m). Bortone et al. (1998), Campbell et al. (2011) and Machado et al. (2013) observed a decrease in prey density closer to artificial reefs.

On the other hand, natural and artificial reefs of smaller size or number that have a patchy distribution and complexity (i.e., spaced reef modules) may exhibit greater fish abundance and richness than larger and isolated reefs on sandy bottoms (Nanami and Nishihira 2002; Jan et al. 2003; Morton and Shima 2013; Yamamoto et al. 2014). Because of these contrasting scenarios, studies focused on these topics can provide information on how artificial structures affect the composition and structure of associated fish communities and can be used in marine resources management and conservation projects (Santos et al. 2010, 2011; Gatts et al. 2014). Therefore, this study evaluated the influence of the spatial distribution of artificial reef modules along the northern coast of Rio de Janeiro State on the composition and structure of the associated ichthyofauna. The hypothesis tested was whether an increase in distance from 0.5 to 15 m among artificial reef units will reduce the overlap of trophic halos, promoting a greater availability of prey and a higher richness, diversity, number of individuals and biomass of the ichthyofauna compared with modules that are located more closely together. Thus, the aim of this study was to suggest the best spatial configuration for patchy artificial reefs in coastal environments with homogeneous and less complex substrates that are seasonally influenced by the inflow of freshwater and sediment from large rivers, which represents the typical environmental conditions of the northern coast of Rio de Janeiro.

Methodology

Study site

The study site (21°29′S, 41°00′W) was located on the continental shelf at the north of Rio de Janeiro State (Southeastern Brazil), and it is adjacent to the mouths of the Itabapoana and Paraíba do Sul rivers (Fig. 1).

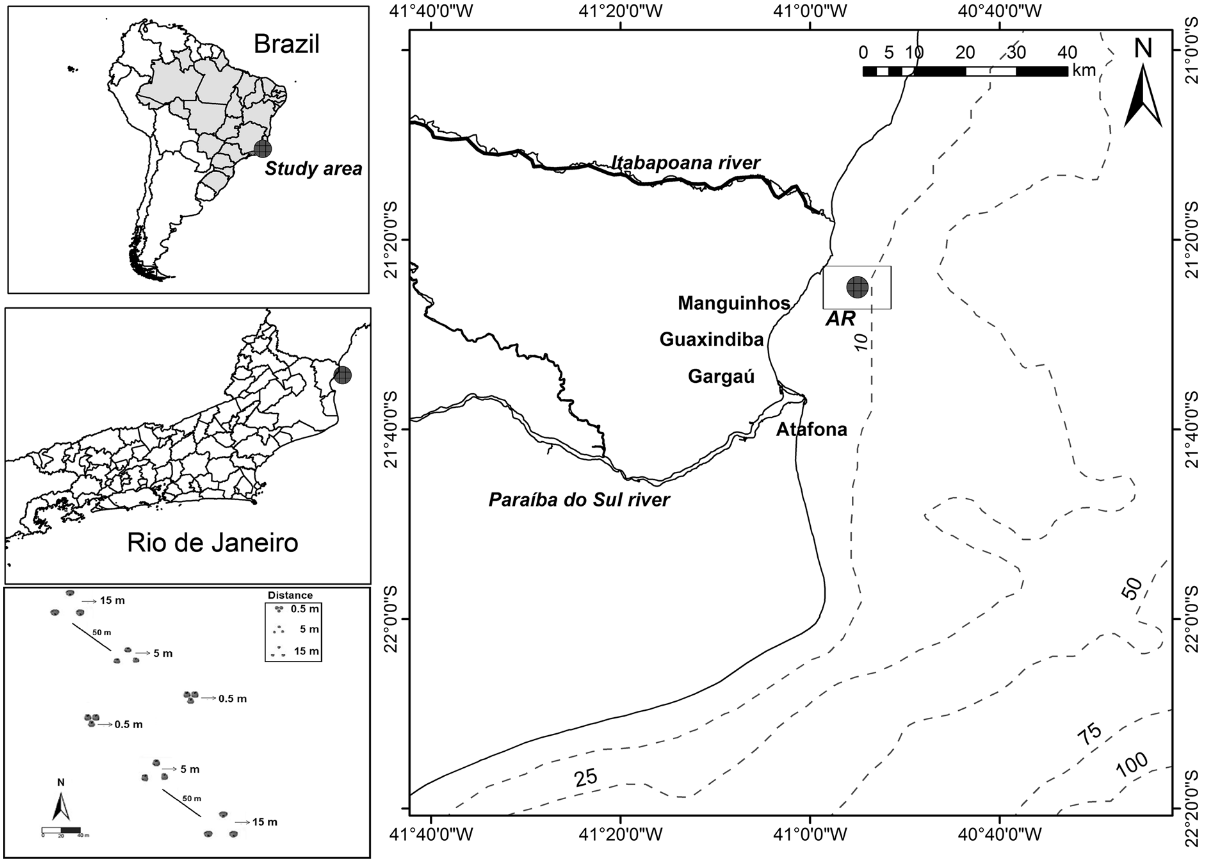


Fig. 1 Installation site and schematic drawing configuration of the artificial reefs (AR) along the northern coast of the Rio de Janeiro State

The northern coast of Rio de Janeiro is naturally depleted of rock substratum or other hard substrates, and it is covered by extensive sandy beaches with variable amounts of mud and calcareous nodules, such as rhodolites (Zalmon et al. 2002). Pluviometric precipitation in the Paraíba do Sul River drainage basin exhibits two distinct periods: a dry season from May to September and rainy season from October to April (Carvalho et al. 2002; see Gatts et al. 2014 for the monthly mean flow of the Paraíba do Sul River since 1995). Data on the average monthly flow of the Paraiba do Sul River in the region were obtained from the Laboratory of Environmental Science, University of North of Rio de Janeiro State.

Experimental design

The study was performed using concrete reefball modules (~1 m^3). These modules contain orifices of 20 cm diameter and have an approximate weight of 500 kg. In studies evaluating the spatial configurations of artificial reefs, Santos et al. (2010) suggested that the distance between reef modules of the same treatment should not exceed 50 m because beyond this distance, the abundance and species richness associated with the reef declines. The reef complex covers an area of 50,000 m^2, consisting of modular units and reef configurations randomly separated by >50 m to reinforce the independence among them. Moreover, the design was intended to allow for evaluations of spatial scale issues related to habitats of commercial interest to local artisanal fisheries. Therefore, to test how the degree of isolation of the artificial reefs affected the ichthyofauna, the modules were arranged at 9 m depth in equilateral triangular configurations of different distances (0.5, 5 and 15 m) (Fig. 1). This small-scale spatial design was defined based on the artificial reef spatial design investigated on FL, USA by Jordan et al. (2005). The precise location of the modules in the planned configurations was obtained using a geographic positioning system (GPS).

Sampling

The artificial reefs were assessed in four sampling periods according to the local seasonality (end of the dry season, September 2009 and October 2010, and end of the rainy season, April 2010 and April 2011) to reduce the influence of the transitional periods between seasons on the samples. The ichthyofauna were collected with gillnets ($N = 24$) of 25 m length and 3 m height with 30 mm of mesh between adjacent nodes. The nets were submerged for 24 h to capture diurnal and nocturnal species. The specimens were frozen on ice and taken to the laboratory for further analysis. The exclusive use of gillnets is justified because this fishing gear is the same as that used by artisanal fishermen in the region and the strong fluvial influence (Itabapoana River and, mainly, Paraíba do Sul River) restricts the subaquatic visibility (<0.5 m; Godoy et al. 2002) and prevents employing the visual census method. There was one gillnet per triangular artificial reef configuration per sampling period resulting in 12 gillnets for each period/reef configuration; see Gatts et al. (2014) for the arrangement of gillnets above the reef configurations.

Samples of the first 15 cm of sediment 1 m away from the units for each experimental distance ($N = 3$ replicates per treatment) were collected by divers using a stainless steel corer (0.018 m^2) during the same ichthyofauna-sampling periods to identify potential fish predators and their respective reef-associated benthic prey. Infauna were fixed in 10 % formaldehyde, sieved through a 500-µm mesh, sorted and identified to the lowest taxonomic level. The macrofauna identification followed the methods by Rios (1994), Amaral and Nonato (1996) and Melo (1996).

Data treatment and analysis

Fish were identified, weighed and separated into groups, and their stomachs were removed. According to Morton and Shima (2013), numerical descriptors per standardized distance unit can reflect different responses of the fish assemblages associated with the reefs. Therefore, absolute and relative [i.e., standardized per distance unit (m)] values of species richness, total number of individuals (n) and biomass (g) were evaluated to detect variations in the structure of the ichthyofauna associated with each experimental distance (0.5, 5, and 15 m) and season (dry and rainy). Absolute values of Shannon's diversity (H'), Simpson's dominance (D), fish size (TL mm) and importance percentage (IP) index, which considers the occurrence frequency, number of individuals and percentage of biomass of each species (Zar 1999), were also assessed. Generalized linear models (GLM) were applied to test for differences in these descriptors [$\log_{10}(x + 1)$-transformed data, except for diversity and IP indexes] among different reef distance arrangement and sampling periods. GLM were computed with the statistical package SPSS 15 (SPSS 2006). The effects of reef distance on species composition were assessed with canonical correspondence analysis (CCA). This technique constrains the ordination of species composition to be a linear function of the environmental variables, thus using the environmental and fish composition matrices simultaneously in a single analysis (Lepš and Šmilauer 2003). Canonical correspondence analysis was performed with CANOCO 4.5 (Lepš and Šmilauer 2003), down-weighting rare species. Seasonal changes in the composition and structure of the ichthyofauna associated with the different reef distances were assessed with a non-metric multidimensional scaling ordination analysis, using Bray–Curtis distance as a measure of similarity (Clarke and Warwick 2001).

The effect of fish predation on the macroinvertebrate community was analyzed through the taxonomic composition of food items in the stomachs of the fish captured on each sampling distance (0.5, 5 and 15 m), period (dry and rainy) and year (1 and 2). The index of relative importance (IRI) was calculated for the main prey categories using the following equation: IRI $i = (\%W_i + \%N_i) \times \%F_i$, where I is the prey item, $\%W$ is the percentage of weight, $\%N$ is the percentage of individuals and $\%F$ is the frequency of occurrence of prey type in ichthyofauna stomach contents (Zar 1999). Fish predation was evaluated by Pearson's correlation coefficient between the number of captured fish at the 0.5, 5 and 15 m reef sets and total number of infauna at each distance, and between the ichthyofauna food items and the reef-associated infauna at each respective distance. Kolmogorov–

Smirnoff tests were performed before the correlations to test for data normality (Zar 1999).

Results

Composition and structure of the ichthyofauna

A total of 24 species from 12 families were recorded during the four sampling campaigns, and the following five species accounted for 56.1 % of the associated ichthyofauna (Table 1): *Cynoscion virescens* (16.3 %), *Aspistor luniscutis* (12.6 %), *Paralonchurus brasiliensis* (8.2 %), *Larimus breviceps* (8.1 %), *Isopisthus parvipinnis* (5.8 %) and *Cynoscion jamaicensis* (5.1 %). Fish species composition was similar among the distances tested, with two, three and four taxa exclusive to the 0.5-, 5-, and 15-m distance treatments, respectively (Table 1). *C. virescens* was the predominant species at the three distances (IP: 0.5 m = 13.5 %, 5 m = 18.9 % and 15 m = 16.9 %), followed by *I. parvipinnis* (12.6 %) and *A. luniscutis* (12.0 %) at 0.5 m; *A. luniscutis* (17.7 %) at 5 m; and *L. breviceps* (13.7 %) and *P. brasiliensis* (12.6 %) at 15 m (Table 1).

The relationship between species composition and reef distance was summarized by the two first CCA axes, which explained 4.0 % (eigenvalue = 0.26) and 3.1 % (eigenvalue = 0.04) of the variation (total inertia = 6.1), respectively. The CCA biplot showed that the three reef treatments shared similar fish assemblages, as most species (*N* = 15; 62.5 %) were distributed near the central portion of the diagram (Fig. 2). Still, some species' associations occurred exclusively in a specific treatment, such as *C. jamaicensis* and *Menticirrhus americanus* with reef modules spaced 0.5 m, *Pellona harroweri*, *Sphyraena*

Table 1 Composition and importance percentage (IP) of the ichthyc species captured at each reef distance (0.5, 5 and 15 m) and in total

Family	Species	IP			
		0.5 m	5 m	15 m	Total
Ariidae	*Aspistor luniscutis*	11.98	17.74	8.90	12.61
	Bagre marinus	3.04	8.49	3.51	5.01
	Genidens genidens	2.65	3.54	4.45	3.56
Carangidae	*Chloroscombrus chrysurus*	5.43		3.26	3.16
Carcharhinidae	*Rhizoprionodon porosus*	3.00	7.62		2.73
Centropomidae	*Centropomus parallelus*			3.54	1.13
Clupeidae	*Odontognathus mucronatus*			3.20	1.04
	Opisthonema oglinum	2.94	7.61		3.54
Engraulidae	*Anchovia surinamensis*			7.51	5.29
Haemulidae	*Haemulon steindachneri*			3.68	1.16
	Orthopristis ruber	5.69		4.03	2.58
Pomatomidae	*Pomatomus saltatrix*		4.67		1.55
Pristigasteridae	*Pellona harroweri*		3.27		1.04
Sciaenidae	*Cynoscion microlepidotus*	2.59			0.17
	Cynoscion jamaicensis	5.37	5.58	4.85	5.06
	Cynoscion sp.	2.59		3.15	2.04
	Cynoscion virescens	13.49	18.86	16.90	16.23
	Isopisthus parvipinnis	12.62	3.40		5.76
	Larimus breviceps	5.94	7.43	13.69	8.09
	Menticirrhus americanus	3.04			1.13
	Paralonchurus brasiliensis	8.15	4.15	12.57	8.19
	Stellifer rastrifer	8.79		3.54	4.43
Sphyarenidae	*Sphiarena* sp.		3.75		1.21
Stromateidae	*Peprilus paru*	2.68	3.88	3.23	3.31
Total		100.00	100.00	100.00	100.00

sp. and *Pomatomus saltatrix* with modules at 5 m apart and *Odontognathus mucronatus*, *Centropomus parallelus*, *Haemulon steindachneri* and *Anisotremus surinamensis* with reefs distanced 15 m apart. These results revealed a small increase in the number of exclusive species (i.e., two to four) and habitat-dependent fish (i.e., none to three) with increased distances among reef modules (i.e., 0.5–15 m).

Seasonal effects of reef usage patterns

Species richness, total number of individuals, biomass of fish, size, Shannon's diversity (H') and dominance did not significantly differ among the three reef distances (0.5, 5 and 15 m) and seasons (dry and rainy) (Table 2).

The non-metric multidimensional scaling indicated that there was a greater association between the fish community and sampling season than reef (Fig. 3).

Temporal variations in the species association pattern were observed at all distances, which revealed a seasonal distribution of the main species in the region (Fig. 4a–d). *A. luniscutis* was caught exclusively during the rainy season, whereas *C. microlepidotus* and *P. brasiliensis* were observed only in the dry season (Fig. 4).

Predation

A total of 13 fish species that were captured at the artificial modules contained small fish and macrofaunal specimens in their stomachs, with the former showing the highest IRI values in the fish diets followed by crustaceans, mollusks and polychaetes (Table 3). The correlation of reef-associated infauna at the different distances with the fish stomach contents was not significant ($r < 0.2$; $P > 0.05$). Similarly, no significant relationship was found between the abundance of benthic species and fish captured near the modules at reef distances of 0.5, 5 and 15 m ($P > 0.05$).

Discussion

Limitations in the use of gillnets must be considered because the size of the mesh restricts the sampling of

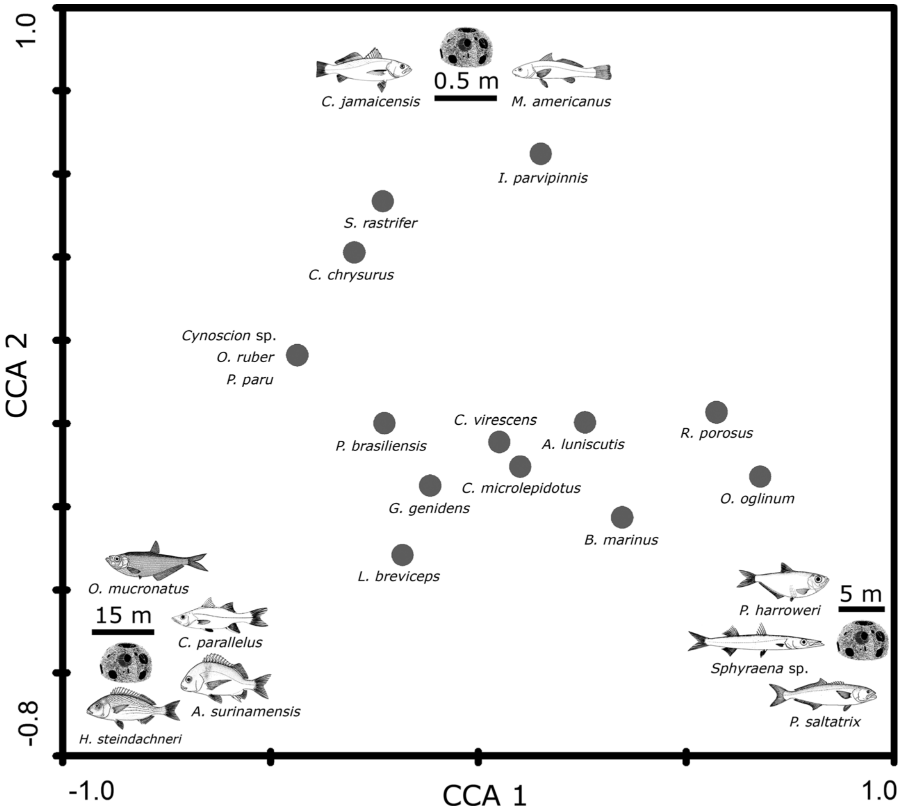


Fig. 2 Canonical correspondence analysis of fish composition (abundance) with reef distance treatment (0.5, 5 and 15 m). The species–environment correlations for the two axes were 0.57 and 0.43, respectively

Table 2 Generalized linear models (GLM) results for richness, abundance, biomass, Shannon's diversity (H'), Simpson's dominance (D) and size (TL mm) of the ichthyofauna captured at each reef distance (0.5, 5 and 15 m) and sampling period (dry and rainy)

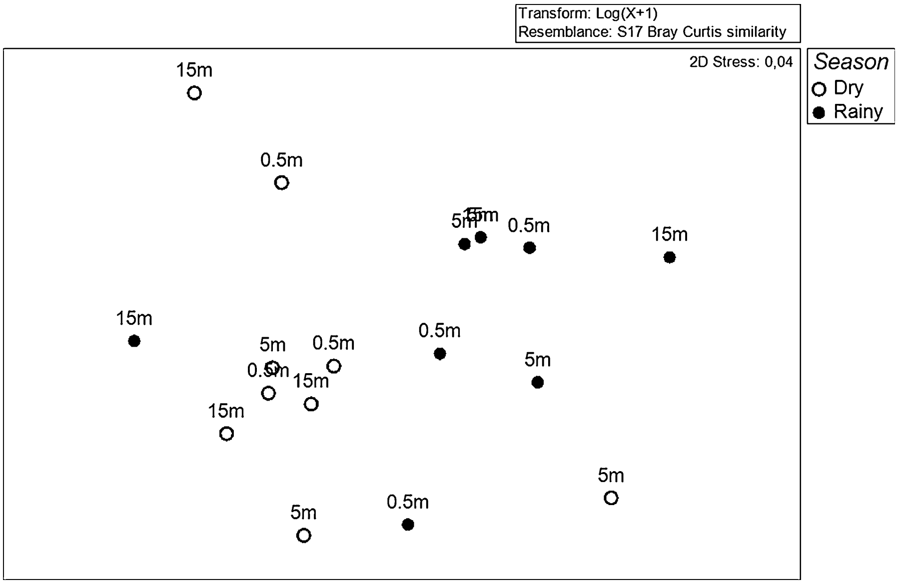
Factor	*df*	Wald test	*P*
Abundance (*n*)			
Distance	2	0.054	0.974
Period	1	0.180	0.671
Distance × period	2	0.018	0.991
Residual	18		
Total	23		
Biomass (*g*)			
Distance	2	0.039	0.981
Period	1	0.148	0.700
Distance × period	2	0.031	0.984
Residual	18		
Total	23		
Size (TL mm)			
Distance	2	0.087	0.769
Period	1	0.132	0.936
Distance × period	2	0.015	0.992
Residual	108		
Total	113		
Species richness			
Distance	2	0.080	0.961
Period	1	0.117	0.733
Distance × period	2	0.033	0.984
Residual	18		
Total	23		
Shannon's diversity (H')			
Distance	2	0.738	0.691
Period	1	1.214	0.271
Distance × period	2	0.337	0.845
Residual	18		
Total	23		
Simpson's dominance (D)			
Distance	2	0.076	0.963
Period	1	0.531	0.466
Distance × period	2	0.342	0.843
Residual	18		
Total	23		

individuals according to their length (Acosta and Appeldoorn 1995; Acosta 1997). These nets select fishes with different habits, including transient, pelagic or demersal, from the unconsolidated substrate adjacent to reefs (Fabi and Fiorentini 1994; Brotto and Zalmon 2007). Gillnets have been traditionally used in the State of Rio de Janeiro by local artisanal fishermen (Garcez 2007), and strong fluvial influences (Itabapoana and Paraíba do Sul rivers) also explain the use of gillnets in scientific studies (Zalmon et al. 2002; Brotto and Zalmon 2007; Santos et al. 2010; Franco 2013).

The associated ichthyofauna did not clearly change with experimental patchy reef distances (0.5, 5 and 15 m). Our findings did not thus agree with the general hypothesis of increasing richness and abundance with distance of reef modules (Nanami and Nishihira 2002; Jan et al. 2003; Morton and Shima 2013; Yamamoto et al. 2014). It might be possible that differences among reef distance treatments were hidden by the non-mutually effects of the Paraíba do Sul and Itabapoana rivers on fish species composition and structure, especially during rainy season with higher outflows, and the relative low number of our treatment replicates. Therefore, further studies performed during the prevalence of clear and more saline waters, and with a greater sampling replication or effort or replication would be of great value to validate our findings for the fish assemblages associated with patchy artificial reefs on the northern coast of Rio de Janeiro.

Several authors (Randall 1963; Lindberg 1996; Nelson and Bortone 1996; Bortone et al. 1998; Jordan et al. 2005; Campbell et al. 2011) have stated that the greater availability of prey (fish and invertebrates) on reefs that are farther apart (25 m) compared with those closer (0.33 m) is a result of the lower overlap of trophic halos, which increased the richness of species and abundance of fishes in communities at greater distance. According to Randall (1963), the prey density is lower near the reef because benthivorous fishes forage in areas closer to the refuge to reduce the risk of being predated upon by transient fishes. Although certain reef predators directly reduce the infauna abundance near a reef through direct predation, transient predators increase such abundance by indirectly feeding on larger organisms, such as crab and fish (Lindberg 1996). The infauna in the sediment adjacent to the artificial reef at all tested distances is composed of annelids, mollusks and crustaceans. The presence of fish populations near the structures is not directly related to these organisms (Zalmon et al. 2014) but to larger benthic prey, such as decapod

Fig. 3 Non-metric multidimensional scaling of the ichthyic community in each reef distance (0.5, 5 and 15 m) and sampling season (dry and rainy)



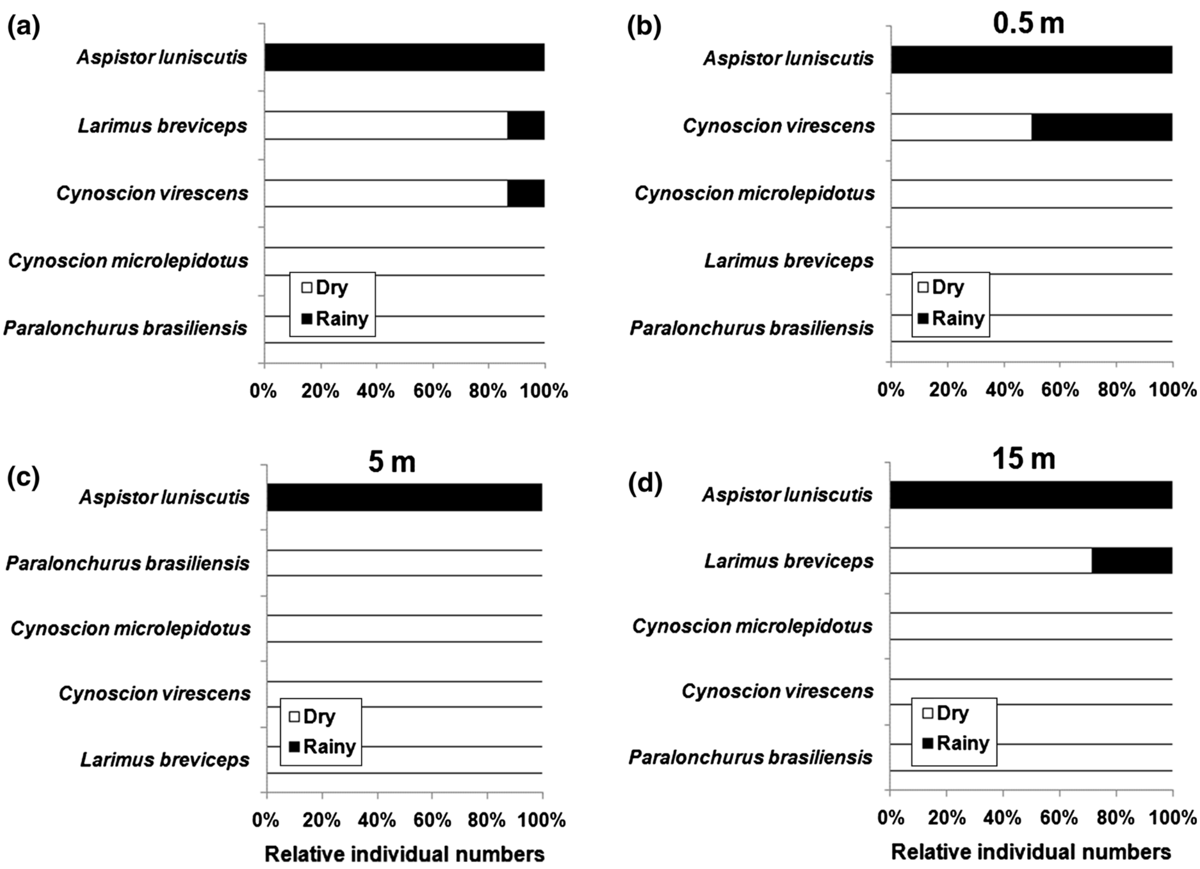


Fig. 4 Relative distribution of the number of individuals (%) of the most representative species (importance percentage index >5 %) on the dry and rainy seasons: **a** all reef distances; **b** 0.5 m; **c** 5 m; **d** 15 m

Table 3 Index of relative importance (IRI) for the main prey categories of fish at distances of 0.5, 5 and 15 m per sampling period (dry 1: September 2009; dry 2: September 2010; rainy 1: April 2010; rainy 2: April 2011) ($N = 3$ replicates per treatment)

Year 1	Dry 1						Rainy 1		
0.5 m	*Bagre marinus*	*Cynoscion virescens*	*Cynoscion microlepidus*	*Stellifer rastrifer*			0.5 m	*Aspistor luniscutis*	
OST		20000.0	7467.7	14984.1			OST	4324.3	
CRUS	20000.0		2532.3				CRUS	1809.4	
5 m	*Bagre marinus*	*Cynoscion virescens*	*Cynoscion microlepidus*	*Larimus breviceps*	*Genidens genidens*		5 m	*Aspistor luniscutis*	
OST	14655.0	17680.5	5066.7				OST	1317.5	
CRUS	5345.0	155.0		20000.0	20000.0		CRUS	6864.9	
MOL		308.9	14933.3				MOL	386.3	
15 m	*Bagre marinus*	*Cynoscion virescens*	*Cynoscion microlepidus*	*Larimus breviceps*	*Genidens genidens*	*Paralonchurus brasiliensis*	15 m	*Aspistor luniscutis*	*Rhizoprionodon porosus*
OST	20000.0	20000.0	20000.0				OST		13629.0
CRUS					20000.0	18233.2	CRUS	2912.5	
ANNEL				20000.0					
MOL						441.7			

Year 2	Dry 2	Rainy 2						
0.5 m	*Cynoscion jamaiscenses*	0.5 m	*Aspistor luniscutis*	*Chloroscombrus chrysurus*	*Orthopristis ruber*	15 m	*Larimus breviceps*	*Odontognathus mucronatus*
OST	19970.7	OST	197.8			OST	8333.3	
MOL	12500.0	CRUS	1473.9	20000.0	3797.8	CRUS	11666.7	20000.0
		MOL	670.9					
		ANNEL			1994.5			
		5 m	*Rhizoprionodon porosus*					
		OST	5137.7					

OST osteichthyes, *CRUS* crustacea, *MOL* molluska, *ANNEL* annelida crustaceans, bivalve mollusks and small fishes, which likely use the interstices of the artificial structures; this result was confirmed by the diet analysis.

Morton and Shima (2013) argued that increased reef spacing (5 m) decreased fish recruitment between structures, whereas closer treatments (1 m) essentially concentrate larger number of fishes. In the present study, smaller individuals (<30 cm) of the most representative species, *C. virescens,* occurred on the reefs spaced 0.5 m between modules, and larger individuals were captured at the 5- and 15-m distance treatments, indicating that proximal structures concentrated recruits compared with reefs spaced at greater distances.

In FL, Jordan et al. (2005) observed that the richness and abundance of fish were highest in patchy reefs spaced 0.33 m apart. Along the northern coast of Rio de Janeiro State, artificial structures with a patchy configuration at distances of 0.5 m apart may concentrate more fish compared with larger distances because such configurations have a greater complexity related to the availability of refuges and crevices between the closer modules, which have the potential to concentrate a greater abundance of resident prey, including epifauna and piscivorous predators (Krohling et al. 2006). These species can also use the crevices as refuge from predation related to transient fishes attracted to the site (Major 1978; Hixon and Beets 1989, 1993; Jordan et al. 2005).

The species belonging to the families Sciaenidae, Carangidae and Ariidae were most abundant in the reefs spaced more closely together, and they were classified by Santos et al. (2010) as piscivores (*C. microlepidotus*, *C. jamaicensis*, *C. virescens*, *I. parvipinnis* and *L. breviceps*) and invertivores (*M. americanus*, *P. brasiliensis*, *S. rastrifer*, *C. chrysurus*, *A. luniscutis*, *B. marinus* and *G. genidens*); these species seem to be most likely attracted by smaller fish concentrated in the crevices and surroundings of the more clustered structures as well as by the associated invertebrates (Hixon and Beets 1989; Jordan et al. 2005; Brotto and Zalmon 2007).

The presence of reef modules in a patchy configuration creates a more complex environment by offering a larger quantity of shelter (Brotto et al. 2006) in addition to concentrating a larger density of potential prey both on the reef itself and in the surrounding area (Krohling et al. 2006). Artificial reefs tend to attract the adjacent substrate organisms that are important in the diet of piscivorous and invertivorous fish, suggesting that transient shoals of opportunistic fishes are directly affected by the biological productivity of the associated sediments (Lindquist et al. 1994; Relini et al. 2002; Zalmon et al. 2002; Leitão et al. 2007). Optimal foraging theory suggests that when less energy is expended during foraging, the predation risk is reduced because the organism remains exposed for less time (MacArthur and Pianka 1966; Milinski 1986; Stephens and Krebs 1986; Bortone et al. 1998). Transient, small-sized opportunistic fishes, such as *P. harroweri* and *O. oglinum*, or juveniles of species whose adults generally reach greater sizes, such as *C. jamaicensis* and *A. luniscutis*, likely feed on prey that is closer to the reef.

The higher densities and species richness of the infauna and fishes assemblages at the tested reefs with the shortest distance suggest that the haloes of large-bodied infauna (>5 mm: 500 µm mesh) around reefs are not consistent, particularly for reefs located on open coast sediment that is influenced by seasonal inflows of freshwater and sediments from large rivers (Zalmon et al. 2014). Herrera et al. (2002) emphasized that predation pressure is less evident at sites that do not have resident predator species, which is a consistent with characteristics of many species of the studied areas (Santos et al. 2010, 2011).

The ichthyofauna association pattern observed in the present study was related to sampling period, highlighting the potential effect of the Paraíba do Sul and Itabapoana rivers. This seasonal influence, combined with the differentiation in the temporal distribution pattern of the main species in the region, may be masking potential differences among the reef distance treatments. As noted by Brotto and Zalmon (2007), adverse environmental conditions (strong bottom currents, turbid waters and the presence of polyhaline plumes) are likely the key factors affecting the colonization patterns of fishes in artificial reefs along the northern coast of Rio de Janeiro State (Zalmon et al. 2002; Krohling and Zalmon 2008; Santos et al. 2010).

In general, the main species of Sciaenidae captured on artificial reefs in the northern coast of Rio de Janeiro are coastal species that live in proximity to the mouths of major rivers and are predominant in the region throughout the year (Gomes et al. 2003; Fulgêncio 2004; Souza and Chaves 2007; Militelli et al. 2013), with adults and juveniles using shallow and estuarine areas for growth and feeding habitat (Menezes and Figueiredo 1980; Godefroid et al. 2004). These species are found in beach environments during periods of reproduction and recruitment, which occurs from spring to autumn (Godefroid et al. 2004). Thus, the migratory behavior of Sciaenidae species could explain their dominance in artificial reefs during the dry season.

In summary, increasing distance between artificial patchy reefs in the range of 0.5–15 m led to few or none effects on fish richness, abundance, biomass and diversity of the associated ichthyofauna. As the shorter reef distance exhibited generally the same richness and abundance compared with larger and more distant reefs, it is suggested that 1-m^3 artificial reefs placed individually and dispersed in a patchy configuration at <5 m apart should be preferentially used in management programs designed to increase fish biodiversity in physically homogeneous and structurally simple coastal environments that are seasonally influenced by freshwater outflows and sediments from large rivers.

Acknowledgments This work was funded by the Research Foundation of Rio de Janeiro—FAPERJ (E-26/110.437/2010)—and the Brazilian Agency for Research Development—CNPq (470997/2010-9).

References

Acosta AR (1997) Use of multi-mesh gillnets and trammel nets to estimate fish species composition in coral reef and mangroves in the southwest coast of Puerto Rico. Caribb J Sci 33:45–57

Acosta AR, Appeldoorn RS (1995) Catching efficiency and selectivity of gillnets and trammel nets in coral reefs from southwestern Puerto Rico. Fish Res 22:175–196. doi:10.1016/0165-7836(94)00328-T

Amaral ACZ, Nonato EF (1996) Annelida Polychaeta: características, glossário e chaves para famílias e gêneros da costa brasileira. Ed. UNICAMP, Campinas

Anderson TW, DeMartini EE, Roberts DA (1989) The relationship between habitat structure, body size and distribution of fishes at a temperature artificial reef. Bull Mar Sci 44:681–697

Baine M (2001) Artificial reefs: a review of their design, application, management and performance. Ocean Coast Manag 44:241–259. doi:10.1016/S0964-5691(01)00048-5

Baine M, Side J (2003) Habitat modification and manipulation as a management tool. Rev Fish Biol Fish 13:197–199. doi:10.1023/B:RFBF.0000019480.95010.67

Bohnsack JA (1989) Are high densities of fishes at artificial reefs the result of habitat limitation or behavioral preference? Bull Mar Sci 44(2):631–645

Bortone SA, Cody RP, Turpin RK, Bundrick CM (1998) The impact of artificial reef fish assemblages on their potential forage area. Ital J Zool 65:265–267. doi:10.1080/11250009809386830

Brotto DS, Zalmon IR (2007) The effect of artificial reef structural complexity and benthic colonization on gill net fish assemblages. Trop Oceangr 35:1–16

Brotto DS, Krohling W, Brum S, Zalmon IR (2006) Usage patterns of an artificial reef by the fish community on the northern coast of Rio de Janeiro, Brazil. J Coast Res 39:1122–1125

Caddy JF (1999) Fisheries management in the twenty-first century: Will new paradigms apply? Rev Fish Biol Fish 9:1–43

Campbell MD, Rose K, Boswell K, Cowan J (2011) Individual-based modeling of an artificial reef fish community: effects of habitat quantity and refuge. Ecol Model 222:3895–3909. doi:10.1016/j.ecolmodel.2011.10.009

Carvalho CEV, Salomão MSMB, Molisani MM, Rezende CE, Lacerda LD (2002) Contribution of a medium-sized tropical river to the particulate heavy metal load for the South Atlantic Ocean. Sci Total Environ 284:85–93. doi:10.1016/S0048-9697(01)00869-5

Charbonnel E, Serre C, Ruitton S, Harmelin JG, Jensen A (2002) Effects of increasing habitat complexity on fish assemblages associated with large artificial reef units (French Mediterranean coast). J Mar Sci 59:208–213. doi:10.1006/jmsc.2002.1263

Clarke KR, Warwick RM (2001) Change in marine communities: an approach to statistical analysis and interpretation, 2nd edn. Primer-E, Plymouth

Fabi G, Fiorentini L (1994) Comparison between an artificial reef and a control site in the Adriatic Sea: analysis of four years of monitoring. Bull Mar Sci 55:538–558

Fabi G, Spagnolo A, Bellan-Santini D, Charbonnel E, Çiçek BA, García JJG, Jensen AC, Killianoites A, Santos MN (2011) Overview on artificial reefs on Europe. Braz J Ocean 59:155–166

Feary DA, Burt JA, Bortholomew A (2011) Artificial marine habitats in the Arabian Gulf: review of current use, benefits and management implications. Ocean Coast Manag 54:742–749. doi:10.1016/j.ocecoaman.2011.07.008

Franco MAL (2013) Uso de ferramentas múltiplas na investigação do impacto de um recife artificial sobre uma assembleia de peixes transientes no norte do estado do Rio de Janeiro. Thesis, North Rio de Janeiro University

Frazer TK, Lindberg WJ (1994) Refuge spacing similarly affects reef-associated species from three phyla. Bull Mar Sci 55:388–400

Fulgêncio AG (2004) Levantamento da ictiofauna associada à foz principal do Rio Paraíba do Sul e área marinha adjacente. Monography, North Rio de Janeiro University

Garcez DS (2007) Caracterização da pesca artesanal autônoma em distintos compartimentos fisiográficos e suas áreas de influência, no estado do Rio de Janeiro. Thesis, Federal University of Rio de Janeiro

Gatts PV, Franco MAL, Santos LN, Rocha DF, Zalmon IR (2014) Influence of the artificial reef configuration on transient ichthyofauna—Southeastern Brazil. Ocean Coast Manag 98:111–119. doi:10.1016/j.ocecoaman.2014.06.022

Godefroid RS, Spach HL, Santos C, MacLaren G, Schwarz R (2004) Mudanças temporais na abundância e diversidade da fauna de peixes do infralitoral raso de uma praia, sul do Brasil. Iheringia Sér Zool 94:95–104. doi:10.1590/Soo73-47212004000100017

Godoy EAS, Almeida TCM, Zalmon IR (2002) Fish assemblages and environmental variables on an artificial reef—Rio de Janeiro, Brazil. ICES J Mar Sci 59:138–143. doi:10.1006/jmsc.2002.1190

Gomes MP, Cunha MS, Zalmon IR (2003) Spatial and temporal variations of diurnal ichthyofauna on surf-zone of São Francisco do Itabapoana beaches, Rio de Janeiro state, Brazil. Braz Arch Biol Technol 46:653–664. doi:10.1590/S1516-89132003000400020

Hackradt CW, Félix-Hackradt FC, García-Charton JA (2011) Influence of habitat structure on fish assemblage of an artificial reef in southern Brazil. Mar Environ Res 72:235–247. doi:10.1016/j.marenvres.2011.09.006

Herrera R, Espino F, Garrido M, Haroun RJ (2002) Observations on fish colonization and predation on two artificial on two artificial reefs in the Canary Islands. ICES J Mar Sci 59:69–73. doi:10.1006/jmsc.2002.1291

Hixon MA, Beets JP (1989) Shelter characteristics and Caribbean fish assemblages: experiments with artificial reefs. Bull Mar Sci 44:666–680

Hixon MA, Beets JP (1993) Predation, prey refuges, and the structure of coral-reef fish assemblages. Ecol Monogr 63(1):77–101. doi:10.2307/2937124

Jan RQ, Liu YH, Chen CY, Wang MC, Song GS, Lin HC, Shao KT (2003) Effects of pile size of artificial reefs on the standing stocks of fishes. Fish Res 63:327–337. doi:10.1016/S0165-7836(03)00081-X

Jordan LKB, Gilliam DS, Spieler RE (2005) Reef fish assemblage structure affected by small-scale spacing and size variations of artificial patch reefs. J Exp Mar Biol Ecol 326:170–186. doi:10.1016/j.jembe.2005.05.023

Krohling W, Zalmon IR (2008) Epibenthic colonization on an artificial reef in a stressed environment off the north coast of Rio de Janeiro State, Brazil. Braz Arch Biol Technol 51:215–223. doi:10.1590/S1516-89132008000100025

Krohling W, Brotto DS, Zalmon IR (2006) Functional role of fouling community on an artificial reef at the northern coast of Rio de Janeiro. Braz J Oceangr 54:183–191. doi:10.1590/S1679-87592006000300002

Leitão F, Santos MN, Monteiro CC (2007) Contribution of artificial reefs on the diet of the White sea bream (*Diplodus sargus*). ICES J Mar Sci 64:1–6. doi:10.1093/icesjms/fsm027

Lepš J, Šmilauer P (2003) Multivariate analysis of ecological data using CANOCO. Cambridge University Press, Cambridge

Lindberg WJ (1996) Fundamental design parameters for artificial reefs: interaction of patch reef spacing and size. Florida Department of Environmental Protection, Florida

Lindquist DG, Cahoon LB, Clavijo IE, Posey MH, Bolden SK, Pike LA, Burk SW, Cardullo PA (1994) Reef fish stomach and prey abundance on reef and sand substrata associated with artificial and natural reefs in Onslow bay, North Carolina. Bull Mar Sci 55(2–3):308–318

MacArthur RH, Pianka ER (1966) On optimal use a patchy environment. Am Nat 100:603–609

Machado PM, Sá FS, Rezende CE, Zalmon IR (2013) Artificial reef impact on macrobenthic community on south-eastern Brazil coast. Mar Biodivers Rec 6:1–9. doi:10.1017/S1755267213000183

Major PF (1978) Predator-prey interactions in two schooling fishes, *Caranx ignobilis* and *Stolephorus purpureus*. Anim Behav 26:760–777. doi:10.1016/0003-3472(78)90142-2

Melo GAS (1996) Manual de identificação dos Brachyura (caranguejos e siris) do litoral brasileiro. Ed. Plêiade, São Paulo

Menezes NA, Figueiredo JL (1980) Manual de peixes marinhos do sudeste do Brasil, vol IV. Museu de Zoologia—USP, São Paulo **(Teleostei (3))**

Milinski M (1986) A review of competitive resource sharing under constraints in sticklebacks. J Fish Biol 29:1–14. doi:10.1111/j.1095-8649.1986.tb04994.x

Militelli MI, Macchi GJ, Rodrigues KA (2013) Comparative reproductive biology of Sciaenidae family species in the Río de la Plata and Buenos Aires coastal zone, Argentina. J Mar Biol Assoc UK 93(2):413–423. doi:10.1017/S0025315412001488

Morton DN, Shima JS (2013) Habitat configuration and availability influences the settlement of temperate reef fishes (*Tripterygiidae*). J Exp Mar Biol Ecol 449:215–220. doi:10.1016/j.jembe.2013.09.017

Nanami A, Nishihira M (2002) The structures and dynamics of fish communities in an Okinawan coral reef: effects on coral-based habitat structures at sites with rocky and sandy sea bottoms. Environ Biol Fish 63:353–372. doi:10.1023/A:1014952932694

Nelson JS, Bortone SA (1996) Feeding guilds among artificial-reef fishes in the northern Gulf of Mexico. Gulf Mex Sci 2:66–80

Ogden JC (1976) Some aspects of herbivore-plant relationships on Caribbean reefs and seagrass beds. Aquat Bot 2:103–106. doi:10.1016/0304-3770(76)90013-9

Polovina JJ (1991) Fisheries applications and biological impacts of artificial reefs. In: Seaman W, Sprague LM (eds) Artificial habitats for marine and freshwater fisheries. Academic Press, San Diego, pp 153–176

Randall JE (1963) An analysis of the fish populations of artificial and natural reefs in the Virgin Islands. Carib J Sci 3(1):31–47

Randall JE (1965) Grazing effect of seagrasses by herbivorous reef fishes in the Virgin Islands. Ecology 46:255–260. doi:10.2307/1936328

Relini G, Relini M, Torchia G, De Angelis G (2002) Trophic relationships between fishes and an artificial reef. ICES J Mar Sci 59:36–42. doi:10.1006/jmsc.2002.1212

Rios EC (1994) Seashells of Brazil, 2nd edn. Universidade Federal do Rio Grande, Rio Grande

Santos LN, Brotto DS, Zalmon IR (2010) Fish responses to increasing distance from artificial reefs on the Southeastern Brazilian Coast. J Exp Mar Biol Ecol 386(1–2):54–60. doi:10.1016/j.jembe.2010.01.018

Santos LN, Brotto DS, Zalmon IR (2011) Assessing artificial reefs for fisheries management: a 10-year assessment of Northern coast of Rio de Janeiro. In: Bortone SA, Brandini FP, Fabi G, Otake S (eds) Artificial Reefs in Fisheries Management. CRC Press, Boca Raton, pp 125–140

Schroeder RE (1987) Effects of patch size and isolation on coral reef fish recruitment. Bull Mar Sci 41:441–451

Seaman W (1996) Does the level of design influences success of an artificial reef? In: Proceedings of the 1st Conference of the European Artificial Reef Research Network. Ancona, Italy. p 96

Sherman RL, Gilliam DS, Spieler RE (2002) Artificial reef design: void space, complexity, and attractants. ICES J Mar Sci 59:S196–S200. doi:10.1006/jmsc.2001.1163

Simon TE (2011) Target fishes on artificial reefs: evidences of impacts over nearby natural environments. Sci Total Environ 409:4579–4584. doi:10.1016/j.scitotenv.2011.07.057

Souza LM, Chaves PT (2007) Reproductive activity of fish (Teleostei) and closed season to shrimp trawling off the northern coast of Santa Catarina, Brazil. Rev Bras Zoo 24(4):1113–1121. doi:10.1590/S0101-81752007000400031

SPSS (2006) SPSS 15.SPSS, Chicago, IL, USA

Stephens DW, Krebs JR (1986) Foraging Theory. Princeton University Press, Princeton

Yamamoto KC, Freitas CEC, Zuanon J, Hurd LE (2014) Fish diversity and species composition in small-scale artificial reefs in Amazonian floodplain lakes: refugia for rare species? Ecol Eng 67:165–170. doi:10.1016/j.ecoleng.2014.03.045

Zalmon IR, Novelli R, Gomes MP, Faria VV (2002) Experimental results of an artificial reef program on the Brazilian Coast North of Rio de Janeiro. ICES J Mar Sci 59:S83–S87. doi:10.1006/jmsc.2002.1273

Zalmon IR, Sá FS, Netto ED, Rezende CE, Machado PM, Almeida TM (2014) Impacts of artificial reef spatial configuration on the infauna community structure—Southeastern Brazil. J Exp Mar Biol Ecol. doi:10.1016/j.jembe.2014.01.015

Zar JH (1999) Biostatistical analysis, 2nd edn. Prentice-Hall inc, New Jersey