Continental Shelf Research 132 (2017) 1–10

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Does human pressure affect the community structure of surf zone fish in sandy beaches?

Leonardo Lopes Costa[a], Júlia G. Landmann[a], Luiz R. Gaelzer[b], Ilana R. Zalmon[a,*]

[a] Laboratório de Ciências Ambientais, Universidade Estadual do Norte Fluminense, Campos dos Goytacazes, RJ, Brazil
[b] Instituto de Estudos do Mar Almirante Paulo Moreira, Departmento de Oceanografia – Divisão de Biologia, Arraial do Cabo, RJ, Brazil

ARTICLE INFO

Keywords:
Fish
Surf zone
Community structure
Human pressure
Predation
Sandy beach

ABSTRACT

Intense tourism and human activities have resulted in habitat destruction in sandy beach ecosystems with negative impacts on the associated communities. To investigate whether urbanized beaches affect surf zone fish communities, fish and their benthic macrofaunal prey were collected during periods of low and high human pressure at two beaches on the Southeastern Brazilian coast. A BACI experimental design (Before-After-Control-Impact) was adapted for comparisons of tourism impact on fish community composition and structure in urbanized, intermediate and non-urbanized sectors of each beach. At the end of the summer season, we observed a significant reduction in fish richness, abundance, and diversity in the high tourist pressure areas. The negative association between visitors' abundance and the macrofaunal density suggests that urbanized beaches are avoided by surf zone fish due to higher human pressure and the reduction of food availability. Our results indicate that surf zone fish should be included in environmental impact studies in sandy beaches, including commercial species, e.g., the bluefish *Pomatomus saltatrix*. The comparative results from the less urbanized areas suggest that environmental zoning and visitation limits should be used as effective management and preservation strategies on beaches with high conservation potential.

1. Introduction

Marine and coastal ecosystems provide a wide variety of goods and services, including vital food resources; however, they are vulnerable to anthropogenic impacts, particularly those related to the increasing urbanization of these environments (Small and Nicholls, 2003).

The surf zone of sandy beaches is the main area of wave energy dissipation, which contributes to the resuspension of sediment and infauna, providing food and shelter from predators to juvenile fish (Gibson, 1973; Lasiak, 1981, 1986; Benazza et al., 2015). The fish communities are dominated by a few species due to the harsh environment (Modde and Ross, 1981; Lasiak, 1984; Pessanha and Araújo, 2003). Spatial and temporal variations in surf zone fish communities depend on the interaction between physical features, such as wave exposure, turbidity, and water temperature, and biological features, such as competition, predation, reproductive periods, species migration, and food availability (Ross et al., 1987; Clark et al., 1996b).

The nursery functions of the surf zone for juvenile fish, including species of commercial importance, have been affected by habitat modifications, such as beach nourishment, pollution and seawall construction (Wilber et al., 2003; Pereira et al., 2015; Franco et al., 2016). Wilber et al. (2003) observed differences in the composition of fish assemblages after the nourishment of a beach in New Jersey, USA. Pereira et al. (2015) compared fish richness in an insular (preserved) and a continental (disturbed) beach and found a higher number of species in the former. Some authors suggested the use of indicator species to assess the degree of environmental degradation of surf zone areas (Franco et al., 2016).

Sandy beaches and their surf zones are coastal environments, which might be considered the most commonly used for human activities (Ross and Lancaster, 2002). Nevertheless, human pressure has caused severe environmental degradation and poses constant threats to the biodiversity of these environments (Defeo et al., 2009). The impacts, such as trampling, vehicles traffic, nourishment, coastal armoring, cleaning and grooming, have affected mainly intertidal macroinvertebrate communities in sandy beaches (Veloso et al., 2006; Bessa et al., 2014; Reyes-Martínez et al., 2015a, 2015b). These organisms are important feeding resources for vertebrates, such as shorebirds and surf zone fish (Nelson, 1986; Dugan et al., 2003; Niang et al., 2010; Turra et al., 2015). Wilber et al. (2003) described the avoidance response of *Pomatomus saltatrix* during beach nourishment opera-

* Corresponding author.
E-mail addresses: costa.ecomar@gmail.com, ilana@uenf.br (I.R. Zalmon).

http://dx.doi.org/10.1016/j.csr.2016.11.007
Received 2 August 2016; Received in revised form 31 October 2016; Accepted 14 November 2016
Available online 18 November 2016
0278-4343/

tions, which are associated with an increase in water turbidity and a reduction of visual feeding. Thus, the negative effects of urbanization on macroinvertebrates can propagate to influence predators' abundance (Dugan et al., 2003).

The use of surf zone fish communities for monitoring human impacts is not a typical approach in exposed sandy beaches, and most studies use macroinvertebrates as bioindicators (Veloso et al., 2008; Cardoso et al., 2016; Stelling-Wood et al., 2016). However, it is hypothesized that surf zone fish avoid urbanized beaches as a response to a decrease in their food resources (Wilber et al., 2003) or even human presence (Stelling-Wood et al., 2016).

The aim of this study was to assess if the surf zone fish community structure and composition differ on sandy beaches with different amounts of human pressure. We tested the hypothesis that the lower availability of macroinvertebrates (food) during the high tourist season at urbanized beaches could be associated with the lower richness, abundance, and diversity of surf zone fish.

2. Materials and methods

2.1. Study area

The study was performed in Grussaí(21°41'39.80"S; 41° 1′23.84"O) and Praia Grande (22°58'23.96"S; 42° 1′57.45"O) Beaches, located, respectively, in the northern and southeastern regions of the Rio de Janeiro State, Brazil (Fig. 1). Grussaí Beach is located in a region with a well-defined rainy season between October and April and a dry season between May and September (Marengo and Alves, 2005; Krüger et al., 2003). The rainy season corresponds to the higher outflow of the Paraíba do Sul River (Krüger et al., 2003). Praia Grande Beach is directly influenced by upwelling, which is more intense between November and March. During these months, the waters are colder, transparent and nutrient-rich (Valentin and Monteiro-Ribas, 1993).

In both beaches, we selected three sectors according to their associated level of human pressure as follows: urbanized, intermediate and non-urbanized. Urbanized sectors have a higher number of tourists because of better infrastructure, paved beach access, bars, and vendors. Non-urbanized sectors are protected areas that are difficult to access and have well-preserved dune vegetation. Intermediate sectors share characteristics with both of the other categories and act as a transition sector. The urbanized sector of Praia Grande beach is less hydrodynamic than the non-urbanized and intermediate ones because it is close to a rocky shore. All sectors were sampled twice at the end of winter 2015, during the low tourist season (June to October) and twice at the end of summer 2016, during the high tourist season (January to March).

2.2. Human pressure evaluation

The index of conservation value (CI) and the index of recreation potential (RI), ranging from 0 to 10, were used to confirm the degree of human pressure in the three beach sectors (McLachlan et al., 2013). CI was calculated by the sum of the value given to 1) dune vegetation preservation, 2) iconic and endangered species presence and 3) richness and abundance of macrofauna according to the morphodynamics/**beach width**. RI is calculated by the sum of 1) infrastructure

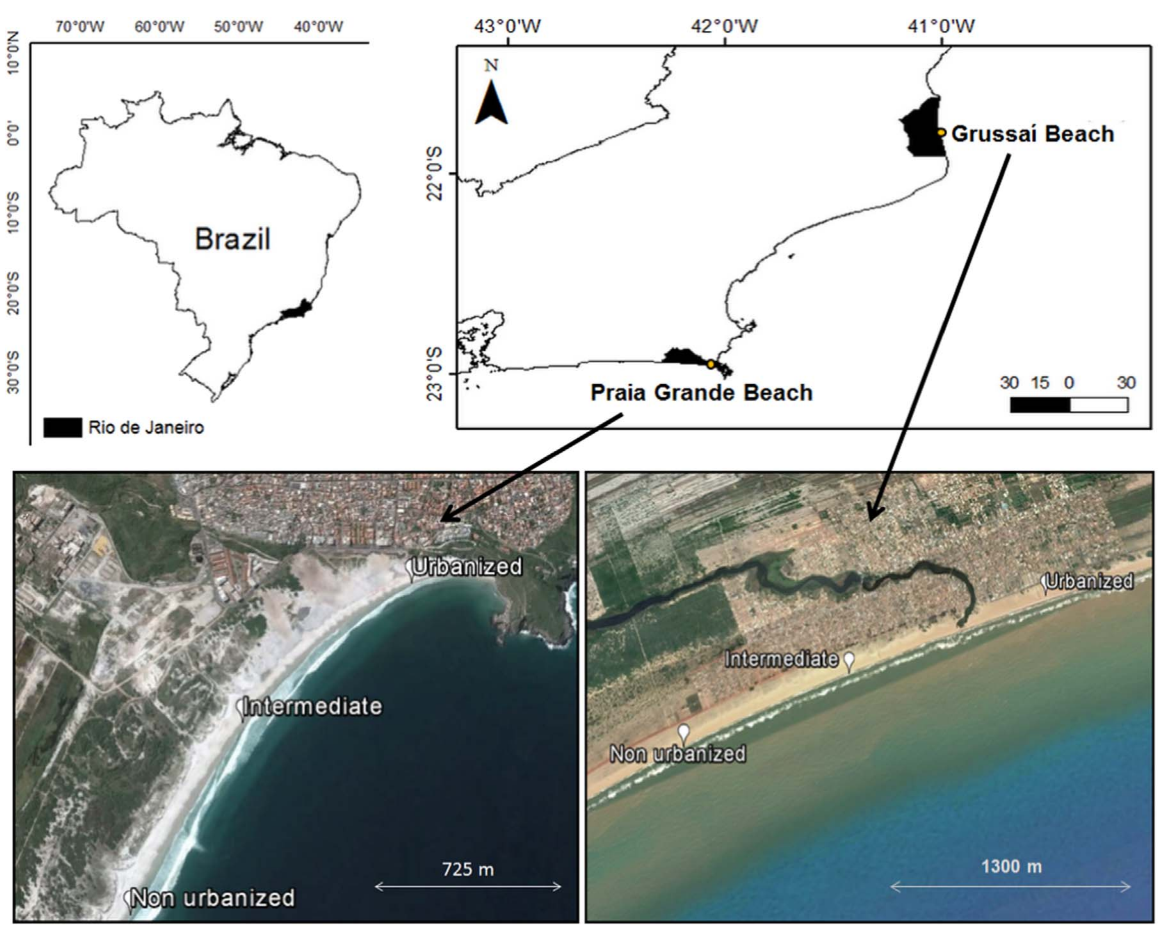

Fig. 1. Study area maps showing Grussaí and Praia Grande Beaches, located, respectively, in Northern and Southeastern Rio de Janeiro State. On Google Earth pictures, the urbanized, intermediate, and non-urbanized sectors have been indicated.

Table 1
Scoring of ecologic, social, and economic features for the calculation of index conservation value (CI) and index recreation potential (RI) (McLachlan et al., 2013).

Category	0	1	2	3	4	5
Index of conservation value (CI)						
Dunes vegetation	Absent, replaced by hard engineering structures	Severely disturbed and limited in extent	Extensive disturbance	Disturbed but largely intact	Well developed, little disturbance	Pristine and extensive
Endangeredand iconic species	Absent	Present in low numbers, not nesting	Present in good numbers, may be nesting	Nesting/spawning present in large numbers		
Macrobenthic diversity and abundance	Low abundance, reflective and/or short beach	Intermediate	Species rich and abundant, dissipative and/or long beach			
Total score	**Minimum score is 0+0+0=0; maximum score is 5+3+2=10**					
Index of recreation potential (RI)						
Infrastructure	No infrastructure, difficult access	No infrastructure, limited access	Modest infrastructure, reasonable access	Good access, some amenities	Good infrastructure and access	Excellent access, parking and amenities including lifesaving
Safety and health	Extremely hazardous and/or polluted	Hazardous and/or polluted	Moderate hazards and clean	Low bathing hazards, clean and totally pollution free		
	Limited, pocket beach, no backshore	Intermediate	Extensive beach with wide backshore			
Total score	**Minimum score is 0+0+0=0; maximum score is 5+3+2=10**					

availability, 2) beach safety and health status and 3) carrying capacity (Table 1). The categories with the highest scores represent those that are most relevant for the index calculation of human pressure in sandy beaches (McLachlan et al., 2013).

Human trampling of the intertidal zone was assessed in the winter and summer seasons by counting the visitors in the macrofauna sampling area between 09:00 AM and 15:00 PM every 30 min (Veloso et al., 2006).

2.3. Physical environment

The water temperature and salinity were measured using a Horiba U50 portable multi-parametric probe. The wave exposure indicators of wave height (by visual assessment) and period (chronometer) were assessed ten times on each sampling day by the same observer to prevent inter-observer differences (Machado et al., 2016). For each wave height measurement, we used a person with a known height as a visual reference.

2.4. Fish community

Fish were collected in the surf zone during the day and at flood tide with a beach seine net, 25 m long, 2.5 m high and with a stretched mesh size of 10 mm. The net was hauled parallel to the shore following the direction of the current at a maximum depth of 1.5 m. Fish were fixed in 10% formaldehyde, counted and identified (Figueiredo and Menezes, 1980; Menezes and Figueiredo, 1985). During each sampling campaign, **10 hauls** were completed, lasting five minutes each.

2.5. Food availability

The sampling of benthic macrofauna was performed in the intertidal zone along three transects perpendicular to the coastline, set 50 m apart. Three equidistant intertidal levels were determined in each transect (upper, middle and lower mesolitoral). At each level, three samples were collected, totaling 27 samples per sampling campaign (Machado et al., 2016). A corer 20 cm in diameter and 20 cm high ($0.188\ m^2$) was used to sample the sediment. The sand was sieved through a 1.0 mm mesh and fixed in 10% formaldehyde. In the laboratory, the remaining sediment was inspected by a stereomicroscope, and all macrofauna were quantified and identified (Amaral and Nonato, 1996; Serejo, 2004; Amaral et al., 2006).

2.6. Data analysis

The univariate descriptors of species richness, abundance and Shannon-Wiener diversity ($H'log_e$) were compared among the different sectors and tourist seasons. The effects of human pressure on the fish community and macrofauna prey were **modified** according to the BACI (Before-After-Control-Impact) design (Underwood, 1992) to compare the urbanized sector of each beach with the other less urbanized sectors. Winter and summer were considered the conditions before and after the impact of tourism, respectively (Reyes-Martínez et al., 2015a, 2015b).

Permutational analysis of variance (PERMANOVA) based on Euclidian distance was performed to compare macrofaunal density; fish richness, abundance and diversity among beaches (fixed factor); and tourist seasons (fixed factor). The pair-wise PERMANOVA test was chosen to discriminate differences between the seasons in each sector.

Non-metric multidimensional scaling (nMDS) was used to compare the fish assemblage structure during different tourist seasons in each beach sector. Abundance data was square root transformed on a similarity matrix with the Bray-Curtis coefficient. PERMANOVA analysis was performed to assess significant differences in the fish structure assemblages. SIMPER analysis assessed the percentage contribution of the different fish species to the dissimilarity between the tourist seasons.

Canonic Correspondence Analysis (CCA) was used to assess the relationship between environmental variables (temperature, salinity, wave height and period) and biotic variables (macrofauna and fish abundance), and the human pressure proxy (maximum number of visitors), taking into consideration all the beach sectors and tourist seasons. The conservation and recreation potential indexes were not included in this analysis because they did not change among seasons. The percentage of explication and the significance of the canonic axes were determined by the Monte Carlo test with 999 permutations. Only fish species with $< 5\%$ occurrence frequency were used since rare species contributed little to the understanding of general patterns. The relationship between macrofaunal density and maximum number of visitors was tested independently through a regression analysis because it was crucial for understanding the role of human pressure on food availability for surf zone fish.

Table 2
Index of conservation value (CI) and index of recreation potential (CI) scores for non-urbanized, intermediate and urbanized sectors of Praia Grande and Grussaí Beaches.

	Praia Grande Beach			Grussai Beach		
	Non-urbanized	Intermediate	Urbanized	Non-urbanized	Intermediate	Urbanized
Index of conservation value (CI)						
Dune vegetation	4	3	1	4	3	1
Endangered and iconic species	2	2	1	2	0	0
Macrobenthic diversity and abundance	2	2	2	1	1	1
Total score	**8**	**7**	**4**	**7**	**4**	**2**
Index of recreation potential (RI)						
Infrastucture	0	1	5	2	2	5
Safety and health	2	2	2	2	2	2
Physical and carrying capacity	2	2	2	2	2	2
Total score	**4**	**5**	**9**	**6**	**6**	**9**
Visitants in winter (mean ± SD)	**1 ± 1**	**1 ± 2**	**5 ± 5**	**1 ± 1**	**1 ± 1**	**0 ± 0**
Visitants in summer (mean ± SD)	**1 ± 1**	**9 ± 5**	**72 ± 56**	**3 ± 2**	**2 ± 1**	**225 ± 83**

3. Results

3.1. Human pressure

The urbanized sectors of Grussaí and Praia Grande Beaches have the lowest conservation index (CI=2 and 4) and the highest recreation potential values (RI=9), compared with the intermediate (CI=4 and 7; RI=6 and 5) and non-urbanized sectors (CI=7 and 8; RI=6 and 4) (Table 2). Urbanized sectors showed the highest number of visitors during the summer months (Table 2).

3.2. Physical environment

In the non-urbanized sector of Praia Grande Beach, the wave heights were significantly higher (46–61 cm) than those in the intermediate (39–61 cm) and urbanized (29–46 cm) areas. In all sectors, the wave periods were significantly longer in the winter (Appendixes A and B). The difference in water temperature between the summer and winter seasons was significant in the urbanized sector of the beach. Salinity did not vary significantly among the sectors or between the seasons (Appendixes A and B).

Grussaí Beach waves were higher in the winter, mainly in the intermediate and non-urbanized sectors (Appendixes A and B). Higher temperature and lower salinity values were recorded during the summer ($T \geq 27$ °C e $S \leq 32$) than during the winter ($T \leq 24$ °C e $S > 36$) in all sectors (Appendixes A and B).

3.3. Food availability

The macrofaunal density at Praia Grande Beach was significantly different among the sectors in all sampling campaigns, with the highest values in the non-urbanized sector, followed by the intermediate and the urbanized sectors (Fig. 2). In the latter sectors, the macrofaunal density was significantly lower in the summer months than in the winter (Fig. 2; Table 3). Additionally, Grussaí Beach showed lower macrofaunal abundance in the summer with no significant differences among the sectors (Fig. 2; Table 3).

3.4. Fish community composition

At Praia Grande Beach, a total of 726 individuals belonging to 21 species and 15 families were sampled. *Trachinotus carolinus* (Carangidae) (48%), *Menticirrhus americanus* (Scianidae) (20%), *Dactylopterus volitans* (Dactylopteridae) (15%), *Mugil* sp. (Mugilidae) (13%) and *Pomatomus saltatrix* (Pomatomidae) (10%) were the species with the highest frequencies. *Harengula clupeola* (Clupeidae) (22%), *T. carolinus* (18%), *D. volitans* (14%), *P. saltatix* (9%) and *Diplodus argenteus*

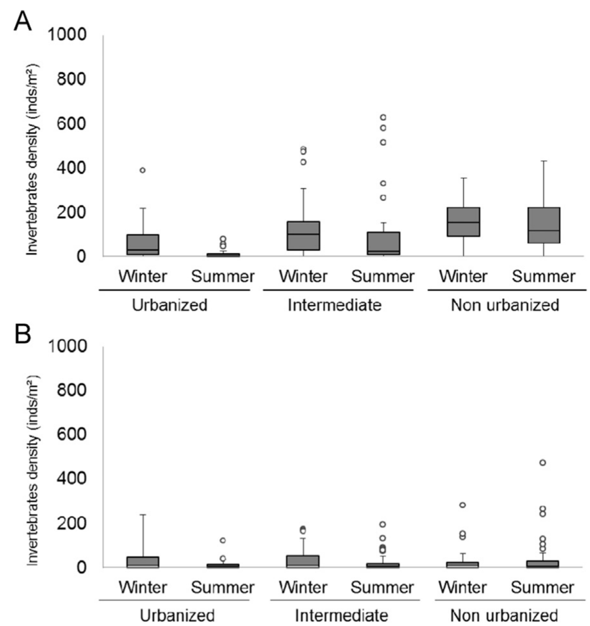

Fig. 2. Boxplot of intertidal macrofaunal density (inds/m^2) at Praia Grande (A) and Grussaí(B) Beaches during the winter and summer campaigns. The black line and boxes represent the median values and interquartile range, respectively; the line bars are standard deviations; dots are outliers.

Table 3
PERMANOVA and pair-wise test related to macrofaunal density among sectors (non-urbanized, intermediate and urbanized) and between seasons (W: Winter 2015, S: Summer 2016) in Praia Grande and Grussaí Beaches.

	Praia Grande beach			Grussai beach		
Source	perms	Pseudo-F	p (perm)	perms	Pseudo-F	p (perm)
Sector	998	45.254	0.001*	998	0.288	0.836
Season	999	26.007	0.001*	999	27.065	0.091
Sector x season	998	5.353	0.001*	998	11.901	0.312
Pair-wise test	Groups	t	p(perm)	Groups	t	p(perm)
Non-urbanized	S×W	10.262	0.375	S×W	0.350	0.899
Intermediate	S×W	27.795	0.003*	S×W	12.286	0.204
Urbanized	S×W	46.283	0.001*	S×W	18.813	0.061

* $p < 0.05$.

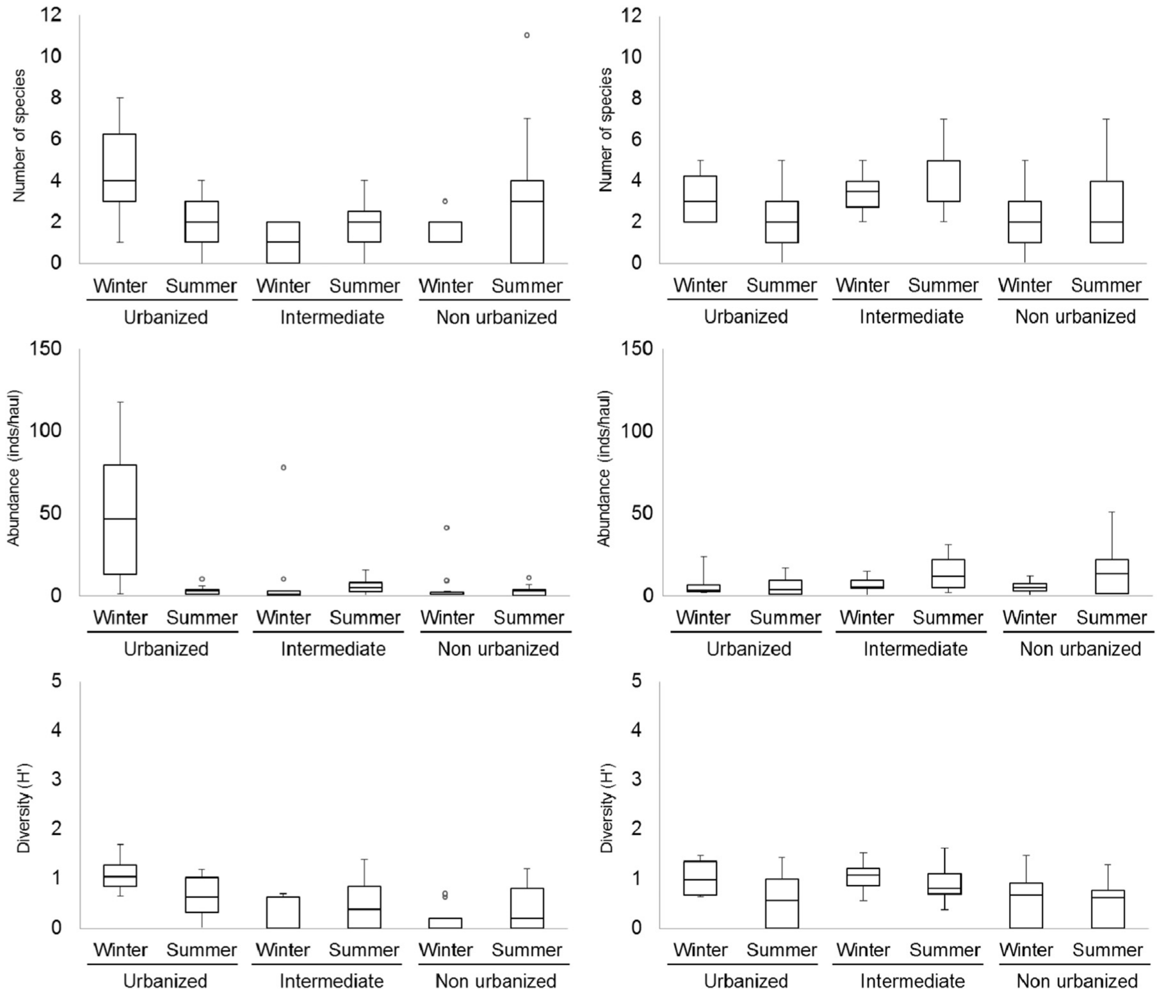

Fig. 3. Boxplot of species richness, abundance and diversity index of surf zone fish communities in the urbanized, intermediate and non-urbanized sectors of Praia Grande (left) and Grussaí(right) Beaches in the winter 2015 and summer 2016 surveys. The black line and boxes represent the median values and interquartile range, respectively; the line bars are standard deviations; dots are outliers.

(Sparidae) (9%) were the most abundant. *Dactyloscopus* sp., *D. argenteus*, *P. saltatrix* and *Umbrina coroides* were found exclusively in the urbanized sector.

At Grussaí Beach, we collected 660 individuals belonging to 21 species and 11 families. *Anchoviella* sp. (Engraulidae) (49%), *Trachinotus falcatus* (Carangidae) (39%), *Polydactylus virginicus* (Polynemidae) (36%), *Mugil* sp. (24%) and *Atherinella brasiliensis* (Atherinidae) (24%) were the species with the highest frequencies; *Anchoviella* sp. (46%), *Mugil* sp. (10%), *T. falcatus* (10%), *Polydactylus virginicus* (8%), *A. brasiliensis* (6%) and *M. americanus* (6%) were the most abundant.

3.5. Fish community structure

The fish richness, abundance, and diversity values at Praia Grande Beach were significantly lower in the urbanized sector during the summer campaigns (Fig. 3; Table 4). Grussaí Beach did not show significant differences in the descriptor values, either between the seasons or among the sectors (Fig. 3; Table 4).

The fish assemblage associations at Praia Grande Beach varied significantly among the sectors and between the seasons (Fig. 4; Table 5). In the urbanized sector, *M. americanus* (22%), *U. coroides* (14%), *P. saltatrix* (10%) and *T. carolinus* (9%) contributed to 96% dissimilarity between the seasons. All species were significantly less abundant in the summer campaigns. In Grussaí Beach, the fish assemblage associations differed among the sectors and between the seasons (Table 5). *Anchoviella* sp. was the species that contributed the most (~30%) to dissimilarity among the sectors (25%) and sampling seasons (~80%), being most abundant in the non-urbanized sector during the summer.

The results of the CCA allow us to identify an environmental gradient at Praia Grande Beach associated with the first axis (eigenvalue=40%), where the most important variables were wave height (species-correlation=51%) and wave period (species-correlation=44%). The species *S. brasiliensis, H. clupeola, U. coroides, M. americanus, P. saltatrix* and *D. argenteus* were positively associated with the lower wave heights and higher wave periods and negatively associated with the number of visitors in the urbanized sector (Fig. 5). The second axis (eigenvalue=18%) expressed a negative correlation between the macrofaunal density and the number of visitors (regression analysis: $R=-0.53$; $R^2=0.28$; $p=0.07$) and showed a positive association between the macrofaunal density and *D. volitans* and *T. carolinus*, mostly in the non-urbanized sector (Fig. 5). Summer species,

Table 4
PERMANOVA and pair-wise test related to species richness, abundance, and Shannon-Wiener diversity index among sectors (non-urbanized, intermediate and urbanized) and between seasons (W: Winter 2015, S: Summer 2016) in Praia Grande and Grussaí Beaches.

Praia Grande	**Richness**			**Abundance**			**Diversity**		
Source	perms	Pseudo-F	p (perm)	perms	Pseudo-F	p (perm)	perms	Pseudo-F	p (perm)
Sector	999	7.798	0.001*	998	12.234	0.001*	999	10.348	0.002*
Season	996	1.147	0.298	996	12.102	0.002*	995	0.076	0.783
Sector×season	999	6.099	0.008*	998	14.533	0.001*	999	1.867	0.002*
Pair-Wise test	Groups	t	p (perm)	Groups	t	p (perm)	Groups	t	p (perm)
Non-urbanized	S×W	0.402	0.694	S×W	0.3446	0.688	S×W	0.946	0.322
Intermediate	S×W	1.894	0.065	S×W	0.782	0.510	S×W	1.064	0.299
Urbanized	S×W	2.768	0.011*	S×W	5.116	0.001*	S×W	1.362	0.026*
Grussaí	**Richness**			**Abundance**			**Diversity**		
Source	perms	Pseudo-F	p (perm)	perms	Pseudo-F	p (perm)	perms	Pseudo-F	p (perm)
Sector	997	2.633	0.071	998	1.455	0.223	999	4.550	0.008
Season	993	0.097	0.770	996	3.476	0.074	994	2.779	0.123
Sector×season	999	0.708	0.119	999	1.764	0.186	999	1.738	0.183

* $p < 0.05$.

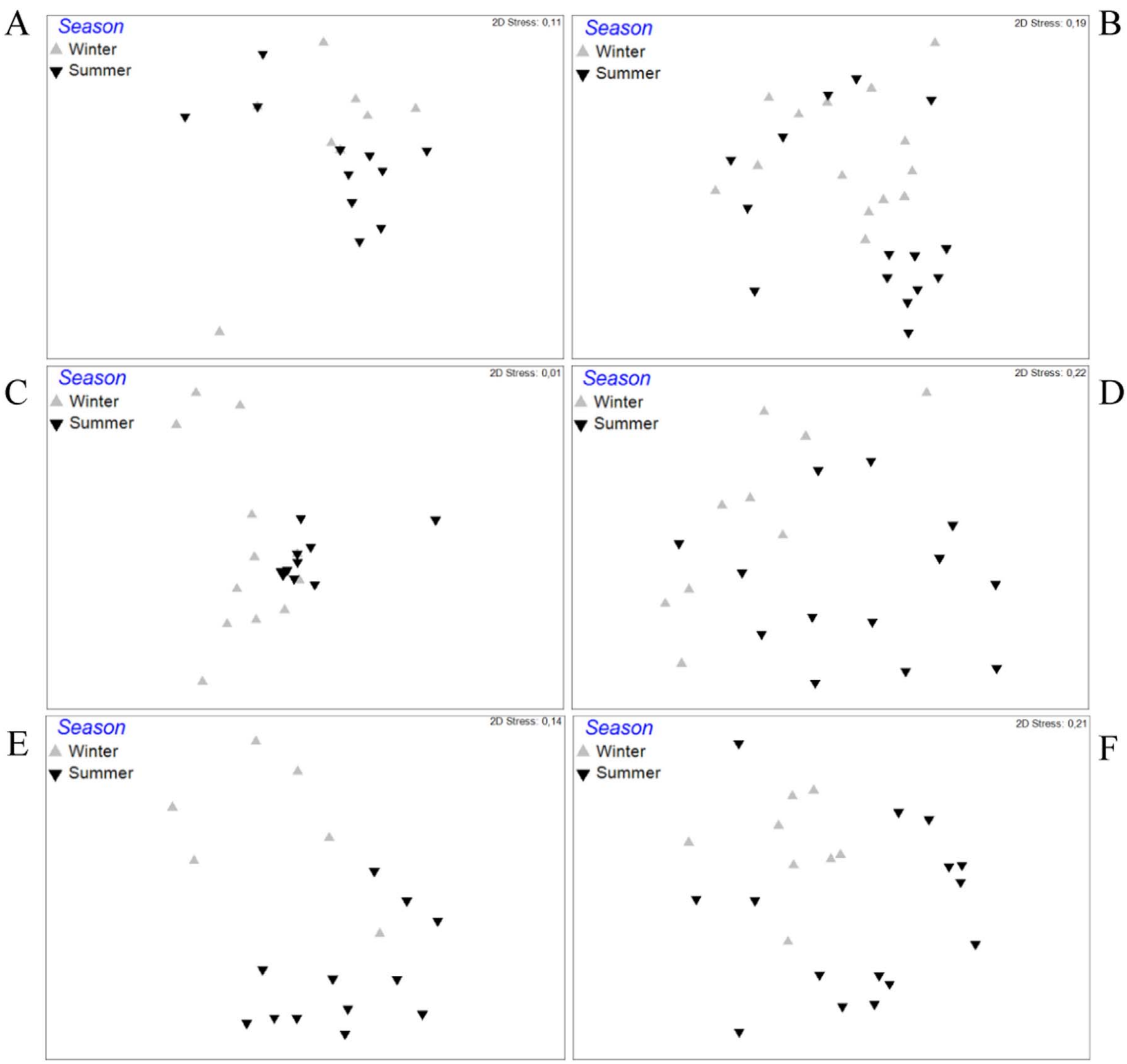

Fig. 4. nMDS ordination from species abundance of the fish community in Praia Grande (left) and Grussaí(right) Beach sectors (non-urbanized, intermediate and urbanized). Gray triangles: before impact (winter) and black triangles: after impact (summer). A and B (non-urbanized); C and D (intermediate); E and F (urbanized).

Table 5
PERMANOVA results and pairwise comparison of the fish communities from the surf zone between sectors (non-urbanized, intermediate and urbanized) and seasons (W: winter, 2015 and S: summer, 2016) in Praia Grande and Grussaí Beaches.

	Praia Grande beach			Grussai beach		
Source	perms	Pseudo-F	p (perm)	perms	Pseudo-F	p (perm)
Sector	998	3.633	0.002*	998	1.850	0.047*
Season	999	5.790	0.001*	999	6.424	0.001*
Sector×season	999	3.781	0.001*	998	1.543	0.104
Pair-wise test	Groups	t	p(perm)			
Non-urbanized	S×W	1.345	0.128	998	1.915	0.008*
Intermediate	S×W	2.050	0.003*	997	1.723	0.012*
Urbanized	S×W	2.340	0.001*	996	1.792	0.005*

* p < 0,05

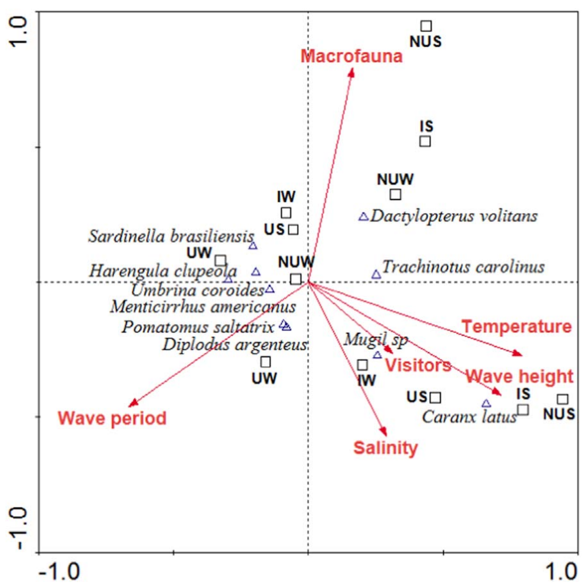

Fig. 5. Factorial diagram of the canonical correspondence analysis, including the environmental variables wave period and height, water temperature and salinity, intertidal macrofaunal density, maximum number of visitors and most abundant fish species (triangles) during the summer and winter campaigns (squares) at Praia Grande Beach. W: winter, S: Summer, U: urbanized, I: intermediate NU: non-urbanized.

such as *Mugil* sp. and *Caranx latus,* were associated with higher water temperatures, higher wave height and higher visitor numbers (Fig. 5).

At Grussaí Beach, the first canonical axis (eigenvalue=15%) of the CCA showed an environmental gradient, where salinity (species-correlation=51%) and temperature (species-correlation=58%) were the most important variables. The higher temperature and lower salinity values during the summer months were associated with *C. latus*, *Mugil* sp. and *Anchoviella* sp. (Fig. 6). The second canonical axis (eigenvalue=11%) expressed a negative association between the macrofaunal density and the number of visitors (regression analysis: $R=-0.31$; $R^2=0.19$; $p=0.09$) and showed a positive correlation between the macrofaunal density and *P. virginicus*, *M. americanus* and *T. falcatus* (Fig. 6).

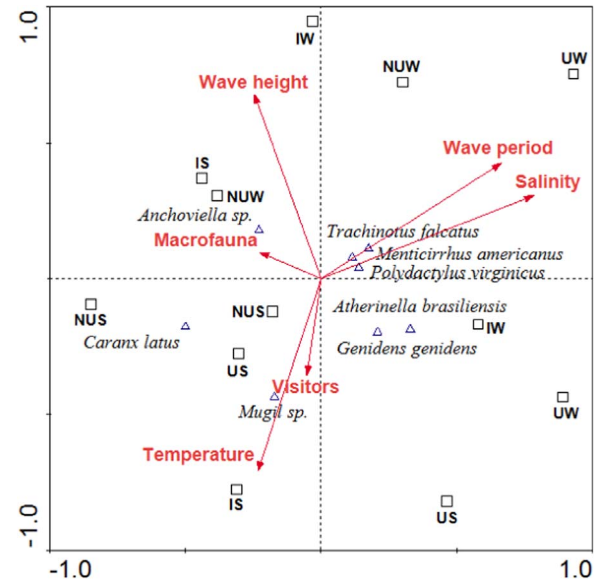

Fig. 6. Factorial Diagram of the canonical correspondence analysis, including the environmental variables wave period and height, water temperature, most abundant fish species (triangles) and intertidal macrofauna of the intertidal zone found during the summer and winter campaigns (squares) in the Grussaí Beach. W: winter, S: Summer, U: urbanized, I: intermediate e NU: non-urbanized.

4. Discussion

The absence of physical obstacles on sandy beaches suggests that fish move constantly along the coastlines; however, surf zone fish seem to prefer some specific and limited areas (Ross and Lancaster, 2002). Therefore, localized human alterations of sandy beaches close to urbanized areas, such as erosion, beach nourishment, coastal armoring and dune vegetation suppression, can affect the use of these areas by surf zone fish with small-scale movements and seasonal migrants (Pereira et al., 2015).

Both Praia Grande and Grussaí Beaches have urbanized sectors affected by human pressure, with high recreation potential and low conservation indexes. The increasing use of urbanized sectors and, consequently, the severe trampling pressure were confirmed by the large number of visitors, mostly during the high tourist season. An average number of 200 persons have been observed in the 100-meter long intertidal zone, where the benthic macrofauna were sampled. The BACI experimental design noted that human pressure significantly influenced the fish community, particularly in the Praia Grande Beach, which is well known for its tourism potential (Fonseca, 2011) of almost 400,000 visitors during the summer season.

In the urbanized sector of Praia Grande Beach, the fish richness, abundance, and diversity values were higher during the low tourist season, when the hydrodynamic conditions were lighter. Additionally, three exclusive species, *P. saltatrix*, *D. argenteus,* and *U. coroides,* were positively associated with lower wave exposure (longer period and smaller wave height) due to the proximity of a rocky shore. Other studies have already described a higher fish diversity in sheltered beaches (Clark, 1996a, 1996b; Gaelzer and Zalmon, 2003; Oliveira and Pessanha, 2014; Franco et al., 2016). Rocky substrates increase the availability of micro-habitats and offer protection against severe wave action (Lasiak, 1986; Ayvazian and Hyndes, 1995) and predators. Thus, the urbanized sector of Praia Grande was positively associated with surf zone fish in the low season due to the lower wave action and rocky shore proximity in addition to the lower number of visitors. In contrast, the high number of visitors and their trampling pressure showed a negative effect on both macrofauna and fish abundance. It is possible that fish do not use this area during the summer months because of the high human presence and/or low prey availability. The species negatively affected by intense tourism, such as *M. americanus*, *T. carolinus* and *U. coroides*, feed on beach macroinvertebrates (Zahorcsak et al., 2000; Niang et al., 2010; Turra et al., 2012). It is unlikely that their decreasing abundance during the summer months in the urbanized sectors have resulted from a seasonal migration since they are not winter migrants but are typical surf zone residents (Modde and Ross, 1981; Brown and McLachlan, 2010). Furthermore, the availability of intertidal macroinvertebrates had already been reported as the main controller of fish abundance in sandy beaches (Robertson and Lenanton, 1984; Nelson, 1986). De Lancey (1989) also claimed that benthic prey abundance had a strong influence on the movement of surf zone fish in South Carolina, USA. These results suggest that the tourist impact at Praia Grande Beach is not yet chronic for the surf zone fish community. Mitigating procedures are still possible to improve the urbanized sector of the Praia Grande Beach as a nursery area for commercially relevant species, such as *Pomatomus saltatrix*.

At Grussaí Beach, the lack of significantly lower values of fish richness, abundance, or diversity during the high tourist season suggests that the surf zone of both urbanized and non-urbanized areas are similarly used by fish. However, fish assemblages were affected by season. Typical summer species, such as *Anchoviella* sp., *Mugil* sp. and *C. latus,* were associated with higher water temperatures and lower salinity values, which were related to the larger outflow of the *Paraiba do Sul* River and higher pluviosity rates (Krüger et al., 2003), and resulted in a higher abundance of the euryhaline/estuarine fish species (Froese and Pauly, 2012).

Lacerda et al. (2014) stressed the temporary use of the surf zone during the summer by *Mugil* sp. and the contemporary presence of predatory species *C. latus*. The higher water temperature seems to be favorable for reproduction, spawning, and fish recruitment associated with the increase in marine productivity (Castillo-Rivera et al., 2010). Our results showing a greater abundance of the invertebrate-feeding fish species, such as *M. americanus, P. virginicus* and *T. falcatus,* during the winter disagree with other studies (Godefroid et al., 1999, 2001; Adams et al., 2006) but might be associated with a decrease in benthic macrofauna in the three sectors of the beach during the summer months. Seasonal turnover of species, even in the urbanized sector, suggests a reduced perturbation of Grussaí Beach compared to Praia Grande. Low human pressure environments usually display more evident seasonal differences in species composition given the temporal partition of the niches (Pereira et al., 2015). Human disturbance at Grussaí Beach seems, therefore, to be punctual, without any significant impact on its use by the surf zone fish.

Fish monitoring programs frequently detect modifications at more than one level of the biological organization (cellular, individual, population or community) of several aquatic ecosystems (Whitfield and Elliott, 2002). Estuaries and freshwater ecosystems are the most affected by human interference of water quality, such as organic or industrial pollutions, heavy metals or eutrophication (Grizzetti et al., 2012; Manfrin et al., 2016). Ocean sandy beaches seem to be more resilient to these contaminations when they are moderate because of the high renovation rate of the environment. Nevertheless, unplanned urbanization, tourism, and coastal occupation expose several beaches to erosion and the subsequent necessity of management actions, such as coastal armoring and beach nourishment (Defeo et al., 2009; Bessa et al., 2014). Studies of human impacts on sandy beach communities focus mainly on intertidal macroinvertebrates (Veloso et al., 2006; Bessa et al., 2014; Reyes-Martínez et al., 2015a, 2015b). Fisheries research should include surf zone populations and juveniles of commercial species belonging to the families Clupeidae, Mugilidae, Scianidae and Pomatomidae, which often use this area for feeding and shelter from predators but can avoid them due to habitat modifications (Pereira et al., 2015).

In summary, we found natural and human-induced changes in the fish community structure of the surf zone ecosystem. At Grussaí Beach, the seasonal variations in surf zone assemblages were more conspicuous than those caused by human pressures. The intense tourism at Praia Grande Beach had a negative and chronic impact on the intertidal macroinvertebrates. The abundance of prey during the winter months was favorable to the invertivorous fishes. However, our results note that severe human pressure and lower food availability render the surf zone an unfavorable habitat for juvenile fish, mostly in the summer months. Mitigation actions are still possible and include 1) the implementation of protected areas in sandy beaches sheltered from waves, with restrictions to human access and use and 2) a reduction in human trampling in urbanized beaches through some dispersion strategies of recreational activities. Furthermore, fish with a commercial importance that use the beaches as juveniles for sheltering and feeding, such as the bluefish *P. saltatrix*, should be used as iconic species in the conservation and management programs for these environments.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgments

This work was funded by the Research Foundation of Rio de Janeiro — FAPERJ (E-26/111.395/2012) and the Brazilian Agency for Research Development — CNPq (470142/2013-8). We acknowledge Davi Castro Tavares who cooperated with statistical analysis and the Laboratory of Environmental Sciences for logistic support.

Appendix A

See Table A1.

Table A1
Mean values (± SD) of environmental parameters monitored in the urbanized, intermediate and non-urbanized sectors of Praia Grande and Grussaí Beaches during the winter 2015 and summer 2016 sampling campaigns.

	Non urbanized		Intermediate		Urbanized	
	Winter	Summer	Winter	Summer	Winter	Summer
Praia Grande						
Salinity	34.4 ± 1.8	35.6 ± 1.3	32.4 ± 1.3	34.6 ± 1.7	34.6 ± 2.2	33.6 ± 3.2
Water temperature (°C)	19.2 ± 0.25	21.2 ± 1.3	19.3 ± 1.9	20.1 ± 4.5	16.9 ± 1.9	22.8 ± 3.0
Wave height (cm)	46.0 ± 20.1	61.0 ± 23.7	39.0 ± 31.9	61.5 ± 16.2	29.0 ± 16.1	46.0 ± 20.4
Wave period (s)	7.4 ± 2.7	5.5 ± 2.1	7.2 ± 2.7	5.3 ± 2.6	9.3 ± 2.6	4.6 ± 2.1
Grussaí						
Salinity	36.6 ± 0.1	29.8 ± 0.2	36.4 ± 0.4	32.3 ± 0.6	36.4 ± 0.5	30.4 ± 1.2
Water temperature (°C)	23.8 ± 0.8	27.2 ± 0.9	24.0 ± 1.2	27.3 ± 0.2	23.9 ± 1.1	27.5 ± 0.7
Wave height (cm)	96.5 ± 12.7	69.5 ± 36.8	87.5 ± 11.0	57.5 ± 19.0	68.0 ± 10.2	78.0 ± 16.1
Wave period (s)	4.4 ± 1.0	4.7 ± 0.9	5.1 ± 1.6	4.2 ± 0.9	6.1 ± 2.2	5.2 ± 0.7

Appendix B

See Table B1.

Table B1
PERMANOVA results and pairwise analysis of the environmental parameters considering sectors (NU: non-urbanized, I: intermediate and U: urbanized) and seasons (W: winter/2015 and S: summer/2016) at Praia Grande and Grussaí Beaches.

	Salinity		Water temperature		Wave height		Wave period	
Praia Grande	Pseudo-F	p	Pseudo-F	p	Pseudo-F	p	Pseudo-F	p
Sector	15.379	0.235	0.103	0.003*	3.551	0.030*	10.091	0.367
Season	1.270	0.280	12.571	0.072	24.489	0.010	43.710	0.001*
Sector×season	18.976	0.191	35.966	0.050*	0.649	0.511	51.314	0.009*
Pair-wise test	t	p	t	p	t	p	t	p
NU (W×S)	ns	ns	ns	ns	ns	ns	2.546	0.012*
I (W×S)	ns	ns	ns	ns	ns	ns	2.167	0.014*
U (W×S)	ns	ns	10.458	0.001*	ns	ns	7.617	0.001*
	Salinity		Water temperature		Wave height		Wave period	
Grussaí	Pseudo-F	p	Pseudo-F	p	Pseudo-F	p	Pseudo-F	p
Sector	12.008	0.001*	53.339	0.015*	28.804	ns	75.284	0.001*
Season	10.469	0.001*	88.662	0.001*	15.114	0.001*	36.617	ns
Sector×season	15.774	0.001*	64.657	0.007*	10.188	0.001*	27.844	ns
Pair-wise test	t	p	t	p	t	p	t	p
NU (W×S)	78.544	0.005*	7.007	0.006*	3.885	0.002*	ns	ns
I (W×S)	17.171	0.002*	2.635	0.023*	3.748	0.001*	ns	ns
U (W×S)	13.306	0.004*	6.520	0.001*	1.720	ns	ns	ns

ns: not significant.
* $p < 0.05$.

References

Adams, A.J., Wolfe, R.K., Kellison, G.T., Victor, B.C., 2006. Patterns of juvenile habitat use and seasonality of settlement by permit, Trachinotus falcatus. Environ. Biol. Fishes 75 (2), 209–217.
Amaral, A.C.Z., Nonato, E.F., 1996. Annelida Polychaeta: características, glossário e chaves para famílias e gêneros da costa brasileira. UNICAMP Publishing Company, São Paulo, 124.
Amaral, A.C.Z., Nallin, S.A.H., Steiner, T.M., Forroni, T.O., Gomes Filho, D., 2006. Catálogo das espécies de Annelida Polychaeta do Brasil. Catálogo das espécies dos Annelida Polychaeta do Brasil.
Ayvazian, S.G., Hyndes, G.A., 1995. Surf-zone fish assemblages in south-western Australia: do adjacent nearshore habitats and the warm Leeuwin Current influence the characteristics of the fish fauna? Mar. Biol. 122 (4), 527–536.
Benazza, A., Selleslagh, J., Breton, E., Rabhi, K., Cornille, V., Bacha, M., Lecuyer, E., Amara, R., 2015. Correction: environmental control on fish and macrocrustacean spring community-structure, on an intertidal sandy beach. PLoS One 10 (6), e0128961. http://dx.doi.org/10.1371/journal.pone.0128961.
Bessa, F., Gonçalves, S.C., Franco, J.N., André, J.N., Cunha, P.P., Marques, J.C., 2014. Temporal changes in macrofauna as response indicator to potential human pressures on sandy beaches. Ecol. Indic. 41, 49–57.
Brown, A.C., McLachlan, A., 2010. The ecology of sandy shores. Academic Press, San Diego, CA, USA.
Cardoso, R.S., Barboza, C.A., Skinner, V.B., Cabrini, T.M., 2016. Crustaceans as ecological indicators of metropolitan sandy beaches health. Ecol. Indic. 62, 154–162.
Castillo-Rivera, M., Zárate-Hernández, R., Ortiz-Burgos, S., Zavala-Hurtado, J., 2010. Diel and seasonal variability in the fish community structure of a mud-bottom estuarine habitat in the Gulf of Mexico. Mar. Ecol. 31 (4), 633–642.
Clark, B.M., Bennett, B.A., Lamberth, S.J., 1996a. Temporal variations in surf zone fish assemblages from False Bay, South Africa. Mar. Ecol. Prog. Ser. 131 (1), 35–47.
Clark, B.M., Bennett, B.A., Lamberth, S.J., 1996b. Factors affecting spatial variability in seine net catches of fish in the surf zone of False Bay, South Africa. Mar. Ecol. Prog. Ser. 131 (1), 17–34.
De Lancey, B.L., 1989. Trophic relationship in the surf zone during the summer at Folly beach, South Carolina. J. Coast. Res. 5 (3), 477–488.
Defeo, O., McLachlan, A., Schoeman, D.S., Schlacher, T.A., Dugan, J., Jones, A., Lastra, M., Scapini, F., 2009. Threats to sandy beach ecosystems: a review. Estuar. Coast. Shelf Sci. 81 (1), 1–12.
Dugan, J.E., Hubbard, D.M., McCrary, M.D., Pierson, M.O., 2003. The response of macrofauna communities and shorebirds to macrophyte wrack subsidies on exposed sandy beaches of southern California. Estuar., Coast. Shelf Sci. 58, 25–40.
Figueiredo, J.L., Menezes, N.A., 1980. Manual de peixes marinhos do sudeste do Brasil. Universidad de São Paulo. Mus. Zool., 51.
Fonseca, M.A.P., 2011. Turismo e divisão territorial do trabalho no polo costa o sol/rj (tourismand territorial division of labor Pole in Costa do Sol/Rio de Janeiro). Revista Mercator, 10 (21), 121-a.
Franco, A.C.S., Ramos Chaves, M.C.N., Castel-Branco, M.P.B., Neves Dos Santos, L., 2016. Responses of fish assemblages of sandy beaches to different anthropogenic and hydrodynamic influences. J. Fish. Biol.. http://dx.doi.org/10.1111/jfb.12889.
Froese, R., Pauly, D., 2012. FishBase. World Wide Web Electronic Publication, version

02/2014www.fishbase.org.
Gaelzer, L.R., Zalmon, I.R., 2003. The Influence of wave gradient on the Ichthyofauna of southeastern Brazil: focusing the community structure in surf-zone. J. Coast. Res. 35, 456–462.
Gibson, R.N., 1973. The intertidal movements and distribution of young fish on a sandy beach with special reference to the plaice (Pleuronectes platessa L.). J. Exp. Mar. Biol. Ecol. 12 (1), 79–102.
Godefroid, R.S., Hofstaetter, M., Spach, H.L., 1999. Larval fish in the surf zone of Pontal do Sul beach, Pontal do Paraná, Paraná, Brazil. Rev. Bras. Zool. 16 (4), 1005–1011.
Godefroid, R.S., Santos, C., Hofstaetter, M., Spach, H.L., 2001. Occurrence of larvae and juveniles of Eucinostomus argenteus, Eucinostomus gula, Menticirrhus americanus, Menticirrhus littoralis, Umbrina coroides and Micropogonias furnieri at Pontal do Sul beach, Paraná. Braz. Arch. Biol. Technol. 44 (4), 411–418.
Grizzetti, B., Bouraoui, F., Aloe, A., 2012. Changes of nitrogen and phosphorus loads to European seas. Glob. Change Biol. 18 (2), 769–782.
Krüger, G., Carvalho, C., Ferreira, A.G., Gonçalves, E., Truccolo, E., Schettini, C.A.F., 2003. Dinâmica de carbono orgânico dissolvido no estuário do Rio Paraíba do Sul, RJ, sob diferentes condições de maré e descarga fluvial. Atlântica 25 (1), 27–33.
Lacerda, C.H.F., Barletta, M., Dantas, D.V., 2014. Temporal patterns in the intertidal faunal community at the mouth of a tropical estuary. J. Fish. Biol. 85 (5), 1571–1602.
Lasiak, T.A., 1981. Nursery grounds of juvenile teleosts: evidence from the surf zone of King's beach, port Elizabeth. South Afr. J. Sci. 77 (9), 388–390.
Lasiak, T.A., 1984. Structural aspects of the surf-zone fish assemblage at King's beach, Algoa Bay, South Africa: long-term fluctuations. Estuar. Coast. Shelf Sci. 18 (4), 459–483.
Lasiak, T.A., 1986. Juveniles, food and the surf zone habitat: implications for teleost nursery areas. South Afr. J. Zool. 21 (1), 51–56.
Machado, P.M., Costa, L.L., Suciu, M.C., Tavares, D.C., Zalmon, I.R., 2016. Extreme storm wave influence on sandy beach macrofauna with distinct human pressures. Mar. Pollut. Bull. 107 (1), 125–135.
Manfrin, A., Bombi, P., Traversetti, L., Larsen, S., Scalici, M., 2016. A landscape-based predictive approach for running water quality assessment: a Mediterranean case study. J. Nat. Conserv. 30, 27–31.
Marengo, J.A., Alves, L.M., 2005. Tendências hidrológicas da bacia do rio Paraíba do Sul. Rev. Bras. Meteorol. 20 (2), 215–226.
McLachlan, A., Defeo, O., Jaramillo, E., Short, A.D., 2013. Sandy beach conservation and recreation: guidelines for optimising management strategies for multi-purpose use. Ocean Coast. Manag. 71, 256–268.
Menezes, N. A, Figueiredo, J. L., 1985. Manual de peixes marinhos do sudeste do Brasil. II Teleostei (4). São Paulo, Museu de Zoologia da Universidade de São Paulo, pp. 105
Modde, T., Ross, S.T., 1981. Seasonality of fishes occupying a surf zone habitat in the northern Gulf of Mexico. Fish. Bull. 78 (4), 911–922.
Nelson, W.G., 1986. Predation and prey population variation in a high energy sand beach macrofaunal community. Ophelia 26 (1), 305–316.
Niang, T.M.S., Pessanha, A.L.M., Araújo, F.G., 2010. Diet of juvenile *Trachinotus carolinus* (Actinopterygii, Carangidae) in sandy beaches on coast of Rio de Janeiro, Brazil. Iheringia Série Zool. 100 (1), 35–42.
Oliveira, R.E., Pessanha, A.L., 2014. Fish assemblages along a morphodynamic continuum on three tropical beaches. Neotrop. Ichthyol. 12 (1), 165–175.
Pereira, H.H., Neves, L.M., Costa, M.R., Araújo, F.G., 2015. Fish assemblage structure on sandy beaches with different anthropogenic influences and proximity of spawning grounds. Mar. Ecol. 36 (1), 16–27.
Pessanha, A.L.M., Araújo, F.G., 2003. Spatial, temporal and diel variations of fish assemblages at two sandy beaches in the Sepetiba Bay, Rio de Janeiro, Brazil. Estuar. Coast. Shelf Sci. 57 (5), 817–828.
Reyes-Martínez, M.J., Lercari, D., Ruíz-Delgado, M.C., Sánchez-Moyano, J.E., Jiménez-Rodríguez, A., Pérez-Hurtado, A., García-García, F.J., 2015a. Human Pressure on Sandy Beaches: Implications for Trophic Functioning. Estuar. Coasts 38 (5), 1782–1796.
Reyes-Martínez, M.J., Ruíz-Delgado, M.C., Sánchez-Moyano, J.E., García-García, F.J., 2015b. Response of intertidal sandy-beach macrofauna to human trampling: an urban vs. natural beach system approach. Mar. Environ. Res. 103, 36–45.
Robertson, A.I., Lenanton, R.C.J., 1984. Fish community structure and food chain dynamics in the surf-zone of sandy beaches: the role of detached macrophyte detritus. J. Exp. Mar. Biol. Ecol. 84 (3), 265–283.
Ross, S.T., McMichael, R.H., Ruple, D.L., 1987. Seasonal and diel variation in the standing crop of fishes and macroinvertebrates from a Gulf of Mexico surf zone. Estuar., Coast. Shelf Sci. 25 (4), 391–412.
Ross, S.W., Lancaster, J.E., 2002. Movements and site fidelity of two juvenile fish species using surf zone nursery habitats along the southeastern North Carolina coast. Environ. Biol. Fishes 63 (2), 161–172.
Serejo, 2004. C.S. Talitridae (Amphipoda, Gammaridea) from the Brazilian coastline. Zootaxa 646, 1–29.
Small, C., Nicholls, R.J., 2003. A global analysis of human settlement in coastal zones. J. Coast. Res., 584–599.
Stelling-Wood, T.P., Clark, G.F., Poore, A.G., 2016. Responses of ghost crabs to habitat modification of urban sandy beaches. Mar. Environ. Res. 116, 32–40.
Turra, A., Santos, F.B., Bessa, E., Fernandez, W.S., Bernadochi, L.C., Denadai, M.R., 2012. Population biology and diet of the southern kingcroaker Menticirrhus americanus (Linnaeus, 1758)(Perciformes: Sciaenidae) in Caraguatatuba Bay, southeastern Brazil. Braz. J. Oceanogr. 60 (3), 343–352.
Turra, A., Fernandez, W.S., Bessa, E., Santos, F.B., Denadai, M.R., 2015. Multi-species generalist predation on the stochastic harvested clam Tivela mactroides (Mollusca, Bivalvia). Estuar., Coast. Shelf Sci. 166, 115–123.
Underwood, A.J., 1992. Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world. J. Exp. Mar. Biol. Ecol. 161 (2), 145–178.
Valentin, J.L., Monteiro-Ribas, W.M., 1993. Zooplankton community structure on the east-southeast Brazilian continental shelf (18–23 S latitude). Cont. Shelf Res. 13 (4), 407–424.
Veloso, V.G., Silva, E.S., Caetano, C.H., Cardoso, R.S., 2006. Comparison between the macroinfauna of urbanized and protected beaches in Rio de Janeiro State, Brazil. Biol. Conserv. 127 (4), 510–515.
Veloso, V.G., Neves, G., Lozano, M., Perez-Hurtado, A., Gago, C.G., Hortas, F., Garcia Garcia, F., 2008. Responses of talitrid amphipods to a gradient of recreational pressure caused by beach urbanization. Mar. Ecol. 29 (s1), 126–133.
Whitfield, A.K., Elliott, M., 2002. Fishes as indicators of environmental and ecological changes within estuaries: a review of progress and some suggestions for the future. J. Fish. Biol. 61 (sA), 229–250.
Wilber, D.H., Clarke, D.G., Burlas, M.H., Ruben, H., Will, R.J., 2003. Spatial and temporal variability in surf zone fish assemblages on the coast of northern New Jersey. Estuar. Coast. Shelf Sci. 56 (2), 291–304.
Zahorcsak, P., Silvano, R.A.M., Sazima, I., 2000. Feeding biology of a guild of benthivorous fishes in a sandy shore on south-eastern Brazilian coast. Rev. Bras. Biol. 60 (3), 511–518.