EFEITOS DA URBANIZAÇÃO E FUNCIONAMENTO TRÓFICO DE PRAIAS ARENOSAS

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EFEITOS DA URBANIZAÇÃO E FUNCIONAMENTO TRÓFICO DE PRAIAS ARENOSAS

"Dissertação apresentada ao Centro de Biociências e Biotecnologia da Universidade Estadual do Norte Fluminense Darcy Ribeiro, como parte das exigências para obtenção do título de mestre em Ecologia e Recursos Naturais."

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RESUMO

Os estudos em ecologia e manejo de praias arenosas têm se tornado cada vez mais importantes frente à pressão antrópica em nível global nesse ecossistema. Macroinvertebrados são potenciais presas de peixes da zona de surfe e constituem o grupo mais estudado e ameaçado pela urbanização de praias. A função de abrigo da zona de surfe para peixes juvenis e o funcionamento trófico de praias podem ser comprometidos pela pressão humana em praias urbanas, devido à redução na abundância de tais presas e predadores. O objetivo desse trabalho foi identificar os efeitos da pressão antrópica na estrutura de comunidade de peixes (capítulo 1), bem como no funcionamento trófico e fluxo de energia do ecossistema de praias (capítulo 2). Os resultados evidenciaram que os impactos antrópicos sobre os macroinvertebrados podem se propagar para potenciais predadores (p.ex. peixes comerciais). A redução na eficiência de ciclagem e fluxo de energia demonstrou a importância dos macroinvertebrados como componentes-chave no funcionamento do ecossistema de praias. Espécies de peixes de interesse comercial como a anchova (*Pomatomus saltatrix*) e aves marinhas (p. ex. *Sula* leucogaster) foram vulneráveis à pressão antrópica e podem ser usadas como espécies bandeira para aumentar o apelo conservacionista das praias arenosas.

ABSTRACT

The ecology and management studies in sandy beaches are becoming increasingly important because of the human pressure in this ecosystem around the world. Macroinvertebrates are potential preys of surf zone fish and they are the most studied and threated by human-induced changes in beach ecosystems. The nursery function of surf zones to juvenile fish besides the trophic functioning of sandy beaches may be negatively affected by human pressure in urban areas, due to the reduction in such prey's and predator's abundance. The aim of this study was to assess the effects of human pressure in the surf zone fish community structure (chapter 1), and in the trophic functioning and energy flow in beach ecosystem (chapter 2). The results indicated that the human impact on macroinvertebrates can affect their predator abundance (i.e. commercial fish). The lowest efficiency in energy transfer and nutrient cycling indicator pointed out the importance of macroinvertebrates as key-species in the beach ecosystem functioning. Commercial fish such as the bluefish *Pomatomus saltatrix* and seabirds (e.g. *Sula leucogaster*) were negatively affected by the human pressure and should be used as iconic species in the conservation and management programs for sandy beaches.

1. Introdução geral

O termo “praias arenosas” é frequentemente utilizado na definição de ecossistemas localizados na transição entre o ambiente terrestre e o ambiente aquático (oceano, estuários, lagos e/ou rios), formados pela deposição de sedimentos inconsolidados. Esse ecossistema está presente em mais de dois terços da costa mundial não congelada, uma vez que a sua ocorrência independe de fatores físicos, como a temperatura (McLachlan e Brown, 2006). Proteção da linha costeira, ciclagem de nutrientes, fornecimento de área para abrigo e desova da fauna marinha, exploração mineral, pesca, turismo e recreação são algumas das funções ecológicas e sócio-econômicas das praias arenosas(Defeo et al., 2009).

No seu limite oceânico, as praias arenosas se iniciam na zona de arrebentação, região de formação da crista e quebramento das ondas (Veloso e Cardoso, 2009). A energia de ondas se dissipa ao longo da zona de surfe até alcançar a zona entremarés, que se estende desde a linha d’água até o alcance máximo da maré alta de sizígia (Veloso e Cardoso, 2009). Toda a região localizada acima do limite de maré alta até o inicio da ocorrência de dunas ou vegetação de restinga caracteriza a zona supralitoral, que sofre influência somente do *spray* marinho ou é alcançada pelas marés em eventos de tempestades (Veloso e Cardoso, 2009).

A interação entre ondas, granulometria do sedimento e topografia resulta em diferentes tipos morfodinâmicos, que variam de praias refletivas, com zona de surfe estreita, sedimento grosseiro e inclinação abrupta, a praias dissipativas com extensa zona de surfe, sedimento fino e inclinação suave da face praial (Calliari et al., 2003). Entre os dois extremos morfodinâmicos, encontram-se as praias intermediárias (Calliari et al., 2003). Maior riqueza e abundância da biota e maior intensidade das interações biológicas são encontradas no extremo dissipativo, em razão da sua menor severidade física e maior produtividade primária, comparada às praias refletivas e intermediárias (Defeo and McLachlan, 2005).

A biota de praias arenosas varia de microorganismos a vertebrados, com representantes endêmicos, facultativos, marinhos e terrestres (McLachlan and Brown, 2006). A macrofauna bentônica (invertebrados maiores que 0,5 mm) e invertebrados intersticiais (meiofauna), incluindo crustáceos, moluscos e poliquetas são os principais animais endêmicos das praias (Harris et al. 2014). Vertebrados como peixes e aves marinhas e costeiras utilizam as praias ao menos temporariamente, como área de abrigo e alimentação (Lasiak, 1986; Hubbard e Dugan, 2003). Os principais representantes terrestres das praias arenosas são os insetos que habitam o supralitoral (Koop e Griffiths, 1982).

Em uma perspectiva histórica, os estudos em praias arenosas são subestimados (n≈ 3 mil), comparados a outros ecossistemas costeiros como manguezais (≈ 11 mil), recifes de coral (≈20 mil) e estuários (≈36 mil) (Nel et al., 2014). Apesar disso, o número de pesquisas científicas nesse ecossistema cresceu exponencialmente a partir da década de 80, quando as praias e a zona de surfe foram considerados ecossistemas marinhos funcionais (McLachlan & Brown, 1980). Desde então, a ecologia é o tema mais aplicado e a disciplina manejo e conservação tem sido uma das mais abordadas atualmente (Nel et al., 2014).

Há décadas, as regiões costeiras têm sido ocupadas para atividades humanas. As praias arenosas, como ambientes preferenciais para lazer e recreação têm se tornado amplamente urbanizadas para atender a demanda turística (Defeo et al., 2009). A urbanização tem causado prejuízos ambientais para o ecossistema de praias e ameaçado a sua integridade ecológica (Defeo et al., 2009; Harris et al., 2014). Em razão disso, ecólogos de praias arenosas em todo o mundo, incluindo o Brasil, tem tentado entender os efeitos negativos dos impactos humanos na saúde ambiental e na biodiversidade desse ecossistema e propor estratégias de manejo e conservação do ecossistema (Lucrezi et al., 2016).

Métricas de avaliação de impacto têm sido propostas, como estratégia para facilitar a elaboração de políticas voltadas para o manejo ecossistêmico de praias arenosas (Schlacher et al., 2014). Por exemplo, índices que quantificam a intensidade de urbanização, o potencial para conservação e ameaças cumulativas já foram criados como um guia para a tomada de decisão de gestores (McLachlan et al., 2013; Gonzales et al., 2014;Schlacher et al., 2014; Harris et al., 2015). O uso de espécies e comunidades de praias como bioindicadores de impactos humanos também têm sido amplamente sugerido para a avaliação rápida de tais impactos (Veloso et al., 2008; Schlacher et al., 2016).

A macrofauna e os peixes são os grupos mais estudados em praias arenosas (Nel et al., 2014). A sensibilidade da macrofauna aos impactos humanos, particularmente ao pisoteio, tráfego de veículos e limpeza de praia é bem conhecida (Veloso et al., 2006; Cardoso et al., 2016). Por outro lado, os estudos com peixes da zona de surfe são, na sua maioria, focados na dieta e nas variações sazonais das comunidades (Turra et al., 2015; Oliveira e Pessanha, 2014). Entretanto, a sensibilidade desse grupo à poluição, por exemplo, já foi destacada em praias estuarinas (Pereira et al., 2015; Franco et al., 2016). A resposta negativa à pressão humana também já foi registrada para outros grupos menos estudados no ecossistema de praias, como aves e insetos (Dugan et al., 2003; Gonzales et al., 2014). As consequências da redução da riqueza e abundância de diferentes espécies para o funcionamento trófico de praias urbanas são pouco conhecidas (Reyes-Martinez et al., 2014).

Em síntese, populações de praias arenosas têm sido negativamente afetadas pelos impactos oriundos da urbanização. Os macroinvertebrados, em sua maioria inconspícuos e com pouco apelo conservacionista, são os mais sensíveis à pressão humana em praias arenosas brasileiras (Veloso et al., 2006; Cardoso et al., 2016). Entretanto, existem lacunas de conhecimento na ecologia de praias arenosas, como estudos que avaliem a resposta de peixes a urbanização de praias arenosas oceânicas e as implicações da redução da biodiversidade para a rede trófica e funcionamento do ecossistema de praias. A escassez de estudos com tais enfoques e que incluem vertebrados de importância comercial (p. ex. peixes) dificulta a popularização das praias como ecossistemas marinhos de valor para a conservação (e não apenas uma área recreativa), tornando o manejo ecossistêmico uma missão árdua (Harris et al., 2014).

O presente estudo buscou preencher algumas dessas lacunas de conhecimento na ecologia de praias arenosas, de modo a incentivar a elaboração de políticas direcionadas para o manejo e conservação do ecossistema. Para isso, a dissertação foi dividida em dois capítulos. O primeiro capítulo tem o objetivo de determinar se a estrutura e a composição da comunidade de peixes da zona de surfe diferem em um gradiente de urbanização de praias arenosas. O segundo capítulo tem como objetivo determinar os efeitos da urbanização de praias arenosas na estrutura trófica e no fluxo de energia no ecossistema. O primeiro capítulo está publicado na revista *Continental Shelf Research* (vol. 132, 2016) e o segundo capítulo está submetido na revista *Ecological Indicators*. Ambos os capítulos trazem informações importantes sobre as implicações dos impactos humanos para comunidades que habitam praias arenosas e para o funcionamento do ecossistema, assim como bens e serviços ambientais que podem ser comprometidos. Tais informações contribuirão para a ampliação do banco de dados que será utilizado em parceria com a Rede de Monitoramento de Habitats Bentônicos Costeiros (REBENTOS), uma rede de âmbito nacional que busca avaliar efeitos de mudanças climáticas e impactos humanos nas comunidades bênticas de múltiplos ecossistemas costeiros.

CAPÍTULO I

DOES HUMAN PRESSURE AFFECT THE COMMUNITY STRUCTURE OF SURF ZONE FISH IN SANDY BEACHES?

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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 preywere collected during periods oflow 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, weobserved 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.

Keywords: Anthropogenic impact; Beach ecossystem; Fish community; Macroinvertebrates

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 & Ross, 1981; Lasiak, 1984a; Pessanha & Araujo, 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-Martinez et al., 2015).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 operations, 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; Reyes-Martinez et al., 2014).

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 withdifferent 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 & 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 & 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).

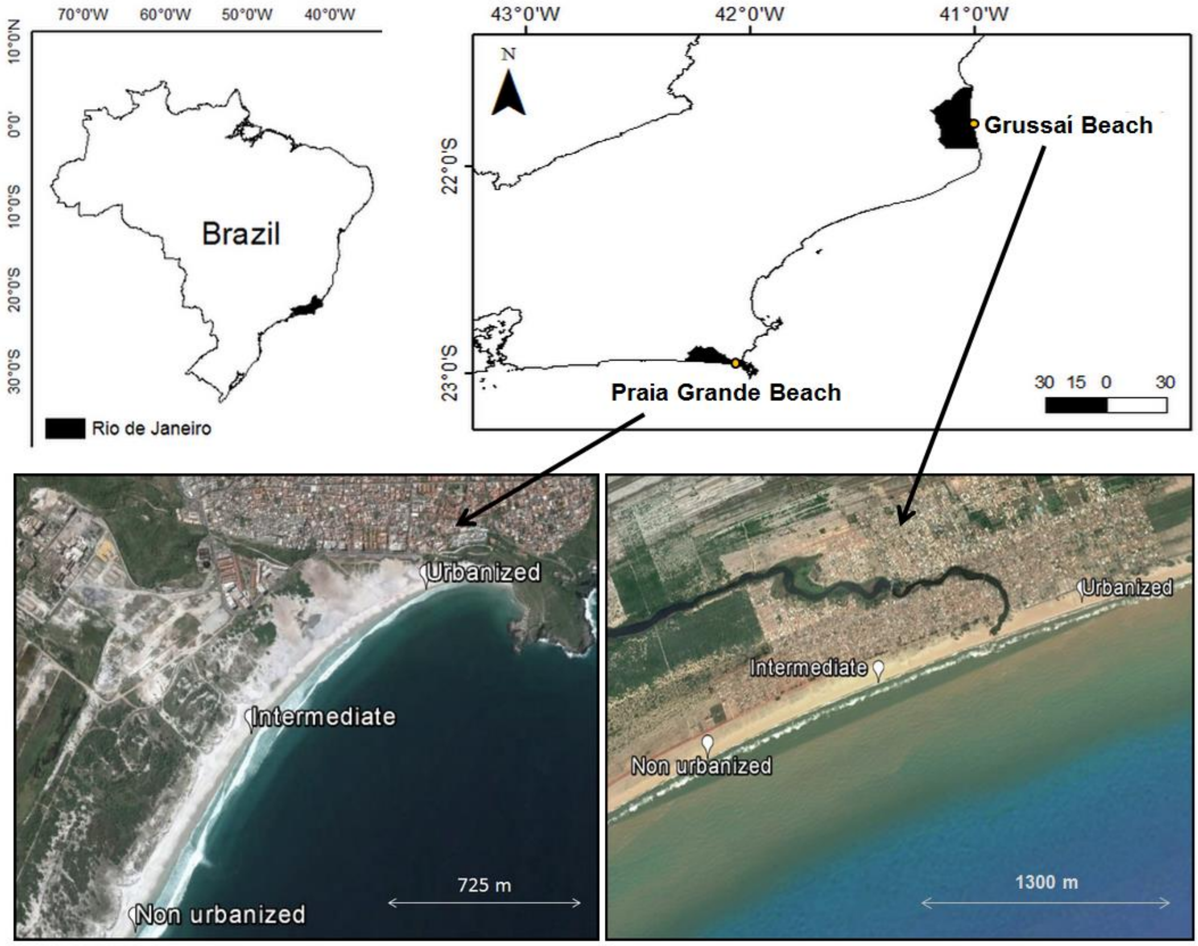

Figure 1. Study area maps showing the Grussaí and Praia Grande beaches, located respectively in the northern and southeastern Rio de Janeiro State. On Google Earth pictures the urbanized, intermediate, and non-urbanized sectors have been pointed out.

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 availability, 2) beach safety and health status and 3) carrying capacity (Tab. 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; Reyes-Martinez et al., 2014).

Human trampling of the intertidal zone was assessed in the winter (two counts) and summer (two counts) seasons by counting the visitors in the macrofauna sampling area between 09:00 AM and 15:00 PM every 30 minutes (Veloso et al., 2006). The counting was performed in sunny weather weekends nearest to macrofauna sampling dates or at the same days.

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

	Index of conservation value (CI)					
Category	**0**	**1**	**2**	**3**	**4**	**5**
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
Endangered and 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)					
Category	**0**	**1**	**2**	**3**	**4**	**5**
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		
Physical carrying capacity	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**					

2.3. Physical environment

The water temperature and salinity were measured in triplicates in each sampling campaign 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 (first author) 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 & Menezes, 1980; Menezes & 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 & 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-Martinez et al., 2015).

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). Under the BACI approach, the impact is indicated by statistically significant "beach x season" interaction (Bessa et al., 2014; Reyes-Martinez et al., 2015). When the interaction of interest was significant, the pair-wise PERMANOVA test was chosen to discriminate differences between the seasons (before and after impact) 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 usedsince 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.

3. Results

3.2 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) (Tab. 2). Urbanized sectors showed the highest number of visitors during the summer months (Tab. 2).

Table2. 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**		
Index of conservation value (CI)	Non-urbanized	Intermediate	Urbanized	Non-urbanized	Intermediate	Urbanized
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)	Non-urbanized	Intermediate	Urbanized	Non-urbanized	Intermediate	Urbanized
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**

3.3. Physical environment

In the non-urbanized sector of Praia Grande Beach, the wave heights were significantly higher (46 to 61 cm) than those in the intermediate (39 to 61 cm) and urbanized (29 to 46 cm) areas. In all sectors, the wave periods were significantly longer in the winter (Appendixes 1 and 2). 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 1 and 2).

Grussaí Beach waves were higher in the winter, mainly in the intermediate and non-urbanized sectors (Appendixes 1 and 2). 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 1 and 2).

3.4. 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; Tab. 3). Additionally, Grussaí Beach showed lower macrofaunal abundance in the summer with no significant differences among the sectors (Fig. 2; Tab. 3).

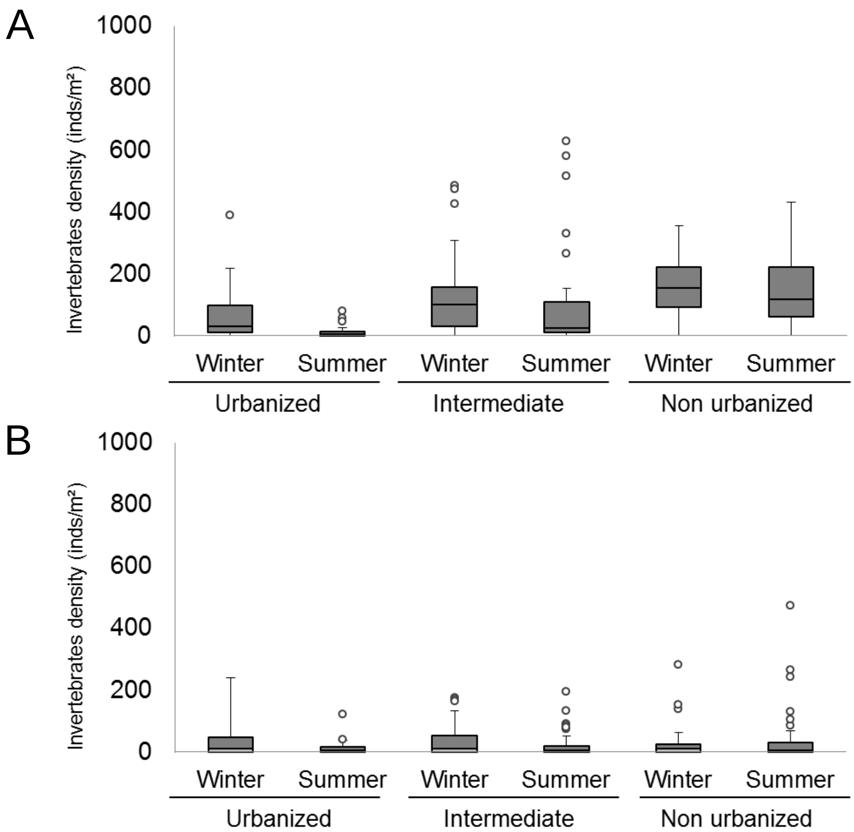

Figure2.Boxplot of intertidal macrofaunal density (inds/m²) at Praia Grande (A) and Grussaí (B) Beaches during the winter and summer campaigns. The black line and boxes represent the median values and interquartile range, respectively; the line bars are standard deviations; dots are outliers.

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. * $p < 0.05$

	Praia Grande beach			**Grussai beach**		
Source	perms	Pseudo-F	p (perm)	Perms	Pseudo-F	p
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
Non-urbanized	S x W	10.262	0.375	S x W	0.350	0.899
Intermediate	S x W	27.795	0.003*	S x W	12.286	0.204
Urbanized	S x W	46.283	0.001*	S x W	18.813	0.061

3.5. 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* (Sparidae) (9%) were the most abundant. *Dactyloscopus* sp., *D. argenteus*, *P. saltatrix* and *Umbrina coroides w*ere 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.

3.6. 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; Tab. 4). Grussaí Beach did not show significant differences in the descriptor values, either between the seasons or among the sectors (Fig. 3; Tab. 4).

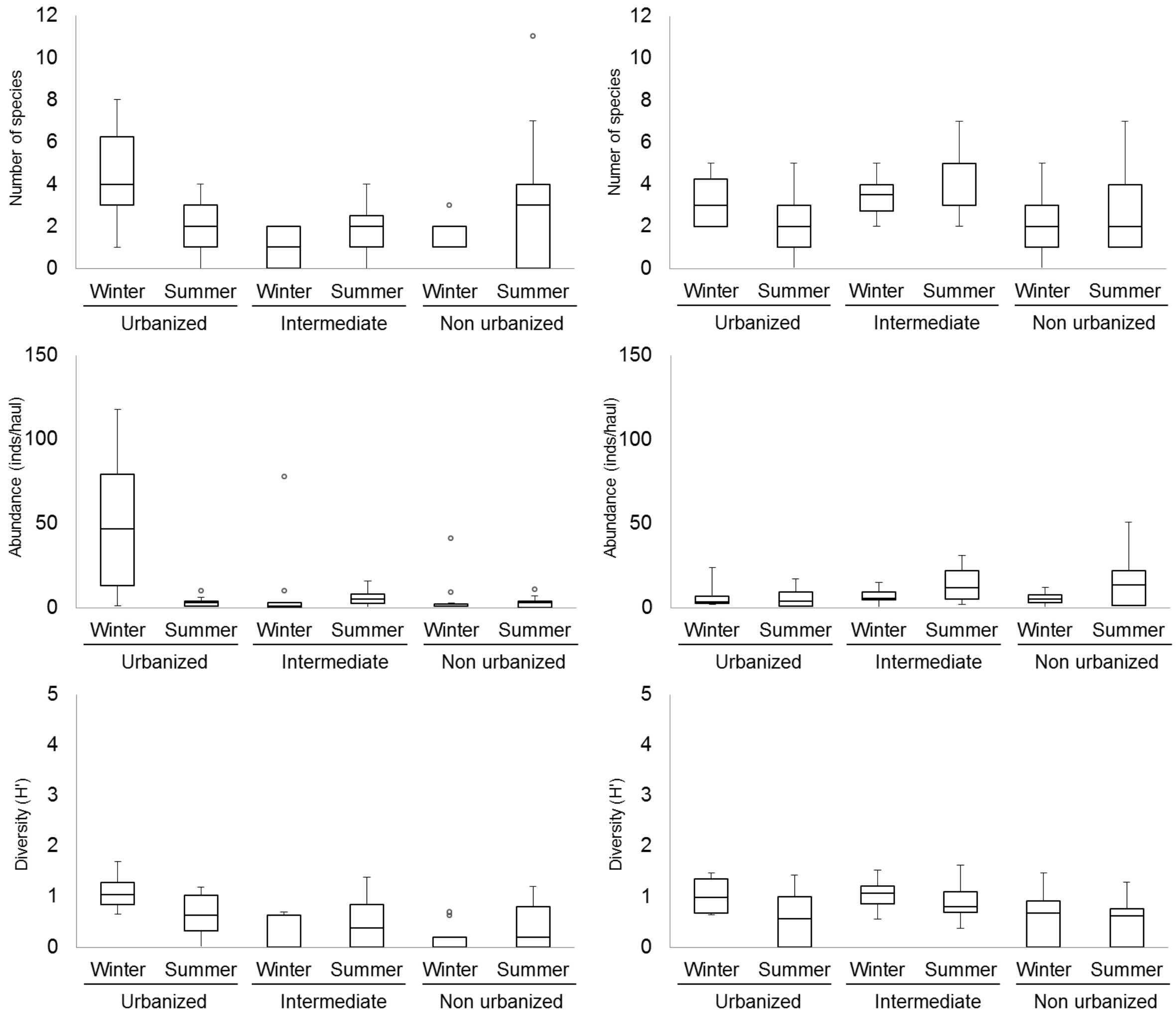

Figure 3. Boxplot of species richness, abundance and diversity index of surf zone fish communities on the urbanized, intermediate and non-urbanized sectors of Praia Grande(left) and Grussaí (right) beaches in the winter 2015 and summer 2016 surveys. Dots are outliers.

Table4.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. * p< 0.05

Praia Grande		**Richness**			**Abundance**			**Diversity**	
Source	perms	Pseudo-F	p	perms	Pseudo-F	p	perms	Pseudo-F	p
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 x season	999	6.099	0.008*	998	14.533	0.001*	999	1.867	0.002*
Pair-Wise test	Groups	t	p	Groups	T	p	Groups	t	p
Non-urbanized	S x W	0.402	0.694	S x W	0.3446	0.688	S x W	0.946	0.322
Intermediate	S x W	1.894	0.065	S x W	0.782	0.510	S x W	1.064	0.299
Urbanized	S x W	2.768	0.011*	S x W	5.116	0.001*	S x W	1.362	0.026*
Grussaí		**Richness**			**Abundance**			**Diversity**	
Source	perms	Pseudo-F	p	perms	Pseudo-F	p	perms	Pseudo-F	p
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 x season	999	0.708	0.119	999	1.764	0.186	999	1.738	0.183

The fish assemblage associations at Praia Grande Beach varied significantly among the sectors and between the seasons (Fig. 4; Tab. 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 (Tab. 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.

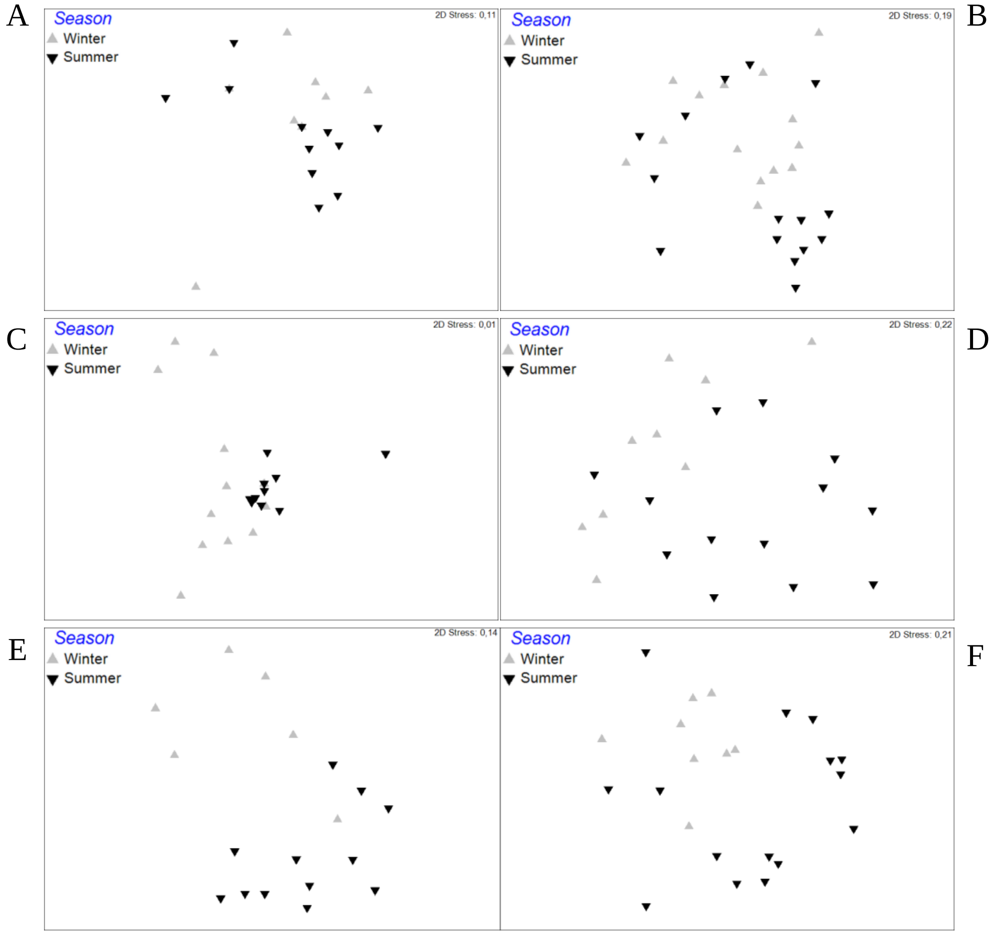

Figure 4.nMDS ordination from species abundance of the fish community in Praia Grande (left) and Grussaí (right) Beach sectors (non-urbanized, intermediate and urbanized). Gray triangles: before impact (winter) and black triangles: after impact (summer). A and B (non-urbanized); C and D (intermediate);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

Table5. 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. *p<0,05

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

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, 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= -0.51; R^2= 0.19; p= 0.07) and showed a positive correlation between the macrofaunal density and *P. virginicus*, *M. americanus* and *T. falcatus* (Fig. 6).

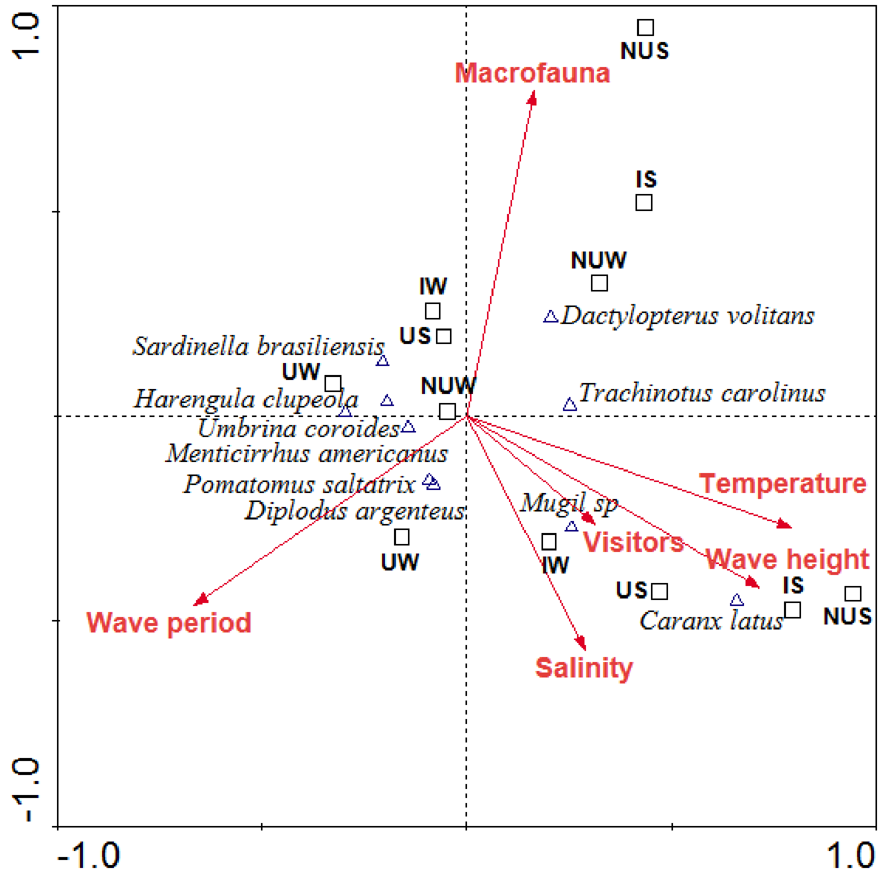

Figure 5. Factorial diagram of the canonical correspondence analysis, including the environmental variables wave period and height, water temperature and salinity, intertidal macrofaunal density, maximum number of visitors and most abundant fish species (triangles) during the summer and winter campaigns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

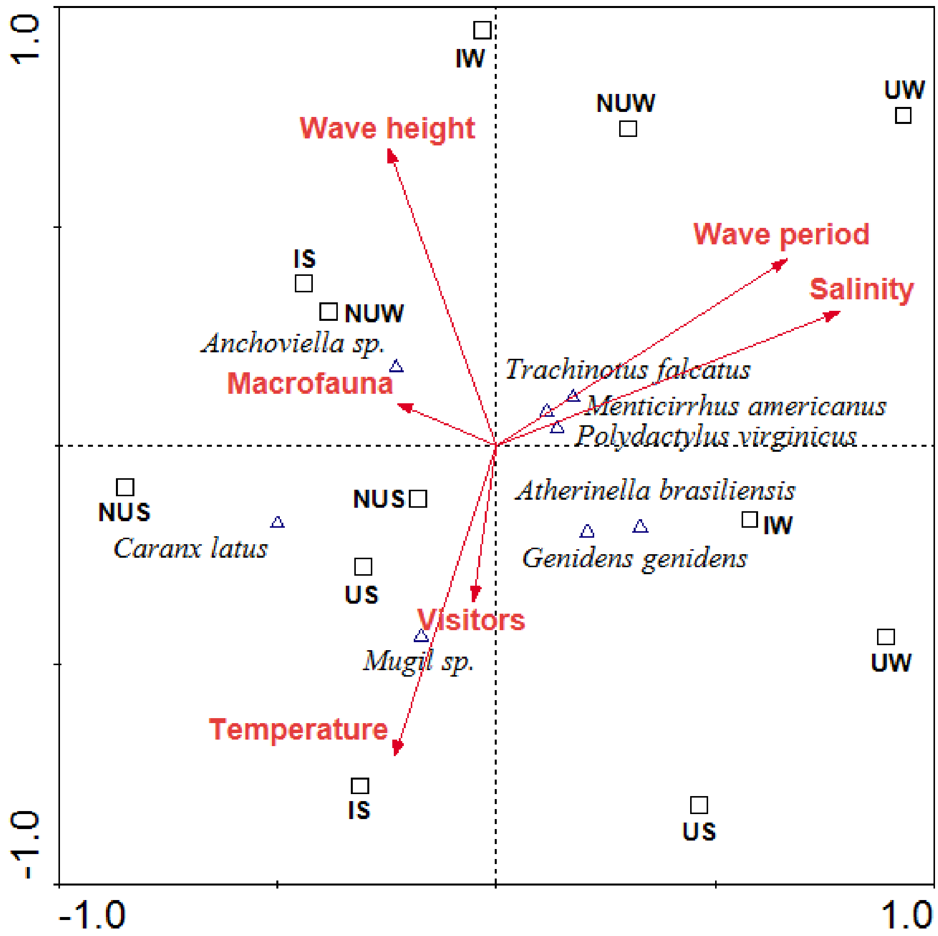

Figure 6. Factorial Diagram of the canonical correspondence analysis, including the environmental variables wave period and height, water temperature, most abundant fish species (triangles) and intertidal macrofauna of the intertidal zone found during the summer and winter campaigns (squares) in the 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, 1996; Gaelzer & 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 & 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 Rossi, 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 & 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 salinityvalues, 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 & 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 (Castilho-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 & Elliot, 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 (Grizzett 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-Martinez et al., 2015). 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.

5. Acknowledgments

This work was funded by the Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro — FAPERJ (E-26/111.395/2012) and the Conselho Nacional de Desenvolvimento Científico e Tecnológico— CNPq (470142/2013-8). We acknowledge Davi Castro Tavares who cooperated with statistical analysis and the Laboratory of Environmental Sciences for logistic support.

6. Appendix

Appendix 1. 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**	
Praia Grande	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**
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	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**
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 2. 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. *p<0.05; ns: not significant.

	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 x 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 x S)	ns	ns	ns	ns	ns	ns	2.546	0.012*
I (W x S)	ns	ns	ns	ns	ns	ns	2.167	0.014*
U (W x 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

CAPÍTULO II

HUMAN-INDUCED CHANGES IN THE TROPHIC FUNCTIONING OF SANDY BEACHES

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Abstract

The increasing anthropogenic disturbance on coastal ecosystems has threatened ecological interactions and ecosystems functioning. To investigate if human pressure affects the trophic structure of sandy beaches, mass-balanced models were applied to a human impact gradient on two tropical sandy beaches. The food web models included detritus, phytoplankton, macroinvertebrates, fish and seabirds. Macroinvertebrates in non-urbanized sectors expressed the highest production fraction consumed by predators. The energy transfer and the cycling indicator were more efficient in the non-urbanized sectors than urbanized ones. The results indicate that macroinvertebrates sensitive to human impact such as trampling are essential to the trophic functioning of sandy beaches, and their biomass reduction may affect energy exportation to surrounding ecosystems. Despite the ecosystem functioning changes, we did not observe trophic cascades, and thus mitigating procedures are still possible.

Keywords: Beach ecosystem; Macrofauna; Modelling anthropogenic impact; Trophic interactions.

1. Introduction

The expansion of different human activities and their ecological effects on coastal ecosystems have accelerated with human population growth (Jackson et al., 2001). Exploitation, pollution and habitat destruction are usually considered the main drivers of biodiversity loss (Worm et al., 2006), which may affect individual species and communities, as well as ecological interactions, ecosystem functioning and the supply of goods and services (Thompson et al., 2012; Gilarranz et al., 2016). In addition, crucial ecological processes, such as production and nutrient cycling, have been severely altered by human activities in marine and coastal ecosystems (Yang et al., 2010).

A sandy beach and the adjacent surf zone characterize a physical interface between the sea and land (McLachlan et al., 1981). Abiotic factors, including grain size, beach slope and climatic variability are usually the main drivers regulating the abundance and distribution of beach biota (Defeo and McLachlan, 2005). However, trophic interactions play a central role in the energy flow, and knowledge of the food web structure can improve our understanding of the functional response of sandy beaches to environmental disturbance (Bergamino et al., 2016).

Exposed sandy beaches show lower in-situ primary productivity compared to other marine ecosystems (Schlacher et al., 2015). In general, food web supply depends on morphodynamics (McLachlan and Brown, 2006). Intermediate and dissipative beaches are usually fuelled by phytoplankton available in surf zone (i.e. diatoms), while reflective beaches rely mainly on stranded wrack and carrion from the sea (Maria et al., 2011, Bergamino et al., 2013). These energy sources support the macroscopic food chain of sandy beaches and includes suspension-feeders, scavengers and detritivorous macroinvertebrates (Inglis, 1989; Colombini et al., 2011). Intertidal macroinvertebrates are important prey to fish and shorebirds, playing an important role in energy transfer to higher trophic levels on sandy beaches (Nelson, 1986; Takahashi et al., 1999; Veloso et al., 2003; Petracco et al., 2012; Tomme et al., 2014)

Urbanization of sandy beaches has been intensified due to an increase in tourism and recreation activities (Schlacher and Thompson, 2012). As a result of coastal infrastructure, this ecosystem is threatened by stress from trampling, vehicle traffic, suppression of dune vegetation, armoring, nourishment and grooming (Reyes-Martinez et al., 2015; Machado et al., 2016). Intertidal macroinvertebrates have been considered the main bioindicators, because of their density reduction in urban sandy beaches (Veloso et al., 2008; Cardoso et al., 2016). However, only responses on community structure or individual species to human pressure has been identified in sandy beaches worldwide (e.g. Gonzales et al., 2014; Bessa et al., 2014; Reyes-Martinez et al., 2015; Cardoso et al., 2016), ignoring the species interaction and ecosystem functioning. In fact, food web research on sandy beaches is still scarce (see Lercari et al., 2010; Bergamino et al., 2013; Reyes-Martinez et al., 2014).

The removing of species in an ecosystem can change food web complexity and also induce a reduction in the efficiency of energy transfer (Pinn, 1980; Dunne et al., 2002). Moreover, the impact of these losses depends on the complexity of the ecosystem and function of species lost (Dunne et al., 2002). In a beach ecosystem, Dugan et al. (2003) provided evidences that reduction in macroinvertebrates availability negatively influence shorebirds abundance on exposed sandy beaches. In addition, Costa et al. (2017) showed that the lowest abundance of intertidal macroinvertebrates may be related to fish avoidance of surf zone in an urbanized sandy beach during the highest touristic season.

Mass-balance models are useful to describe trophic interactions among multiple species and quantify the energy flow in an ecosystem (Heymans et al., 2016). Most routines (e.g. trophic aggregation and mixed trophic impacts analysis) and indices (e.g. ascendency index, capacity index, system omnivory and Finn's cycling index) derived from Ecopath models have been used to evaluate human-induced changes in marine ecosystems (Patricio et al., 2004; Pratto et al., 2016). Highest values of the ascendency index were related to ecosystems under lower human impact (Baird and Ulanowicz,1993; Patricio et al., 2004), and highest Finn's cycling indices are found in less disturbed systems (Yang et al., 2010). Still, omnivory index may be positively associated to anthropogenic disturbance (Selleslagh et al., 2013).

Thus, the objectives of the present study were to (1) describe the ecosystems properties in sandy beaches with distinct human pressure; (2) determine possible human-induced changes on food web features (i.e. ascendency, connectance, system omnivory, overhead and capacity) and energy transfer efficiency across trophic levels; (3) determine the trophic role of macroinvertebrates in trophic functioning of sandy beaches. We tested the hypothesis that food web is less complex and the energy transfer between trophic levels is less efficient on beaches under higher human pressure, due to the lower richness and biomass of vulnerable prey species compared to lower pressure beaches.

2. Material and Methods

2.1. Study area

The study was conducted on two sandy beaches, Grussaí and Praia Grande, in the municipalities of São João da Barra (21°41'39.80"S41° 1'23.84"O) and Arraial do Cabo (22°58'23"S 42°1'57"O), respectively, in Rio de Janeiro State, Brazil (Fig. 1). Praia Grande beach is influenced by coastal upwelling, where cold (~18°C) and nutrient-rich water regularly influence the inner continental shelf, resulting in significantly higher biological productivity (Tavares et al., 2016). The southern limit of the state includes at least four seabird breeding islands, while the northern limit comprises a flyway route (Tavares et al., 2016).

Grussai and Praia Grande beaches have a wide coastal strip formed by areas under considerable human pressure (urbanized sectors) and others with low visitation rates (non-urbanized sectors) (Machado et al., 2016). Tourist visitation in the Arraial do Cabo municipality reaches up to 400,000 people, which is about three times higher than the municipality of São João da Barra (150,000). We used an urbanization index as a proxy for selecting the sectors with different degrees of human pressure (Appendix 1). Previous studies showed that macroinvertebrate abundance at Grussaí and Praia Grande beaches is lower in urbanized beaches than non-urbanized ones (see Machado et al., 2016 and Costa et al., 2017).

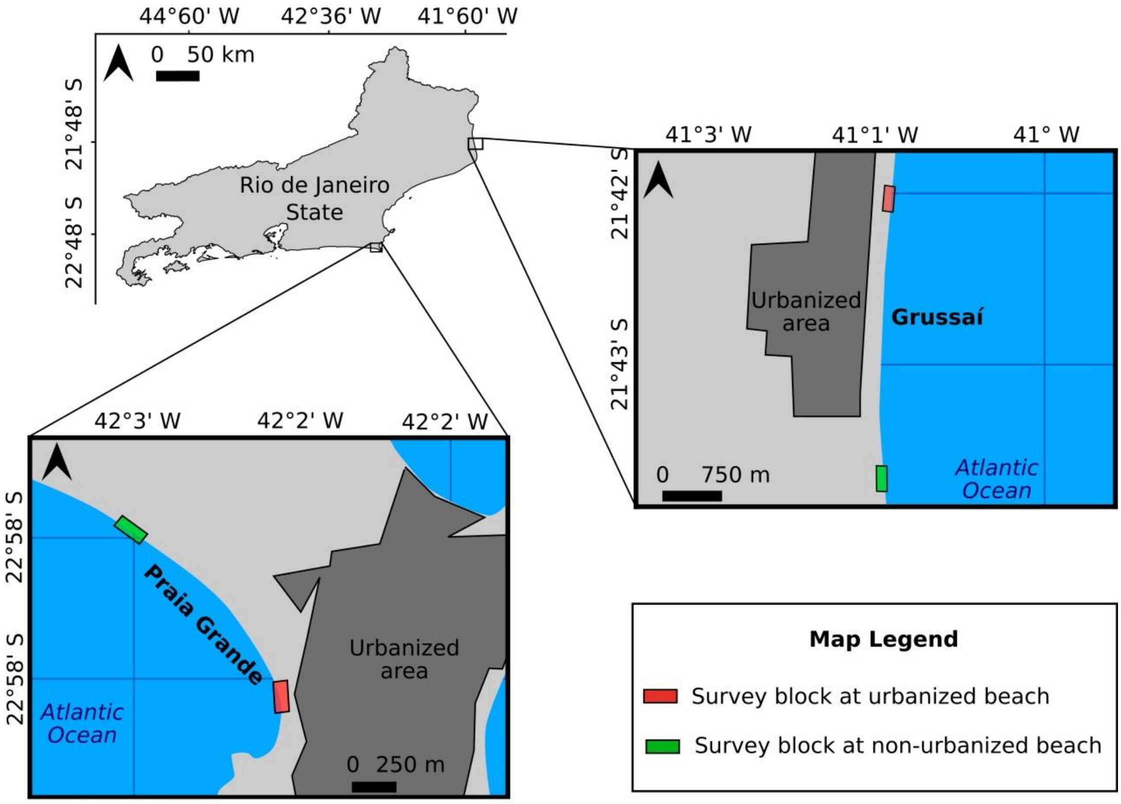

Figure 1. Map of the study area showing Grussaí beach and Praia Grande beach, in Rio de Janeiro State. The map was designed on Landsat 8 imagery obtained in January 2016.

2.2. Ecopath modeling approach

The software Ecopath with Ecosim was used to describe the trophic structure and energy flow of Grussaí and Praia Grande beaches. We included biomass and diet data of functional groups or species collected in sectors with distinct human pressure. Ecopath is a mass-balance model structured by a system of linear equations, one for each component of the ecosystem. The balance between production and consumption of each functional group or species is defined by the following equation:

$$B_i \cdot \left(\frac{P}{B}\right)_i \cdot EE_i - \sum_{j=1}^{n} Bj \cdot \left(\frac{Q}{B}\right)_j \cdot DC_{ij} - Y_i - E_i - BA_i = 0$$

where Bi and Bj represent the biomass of prey and predators; Q is the food consumption per year and P is the annual production; P/Bi is the production/biomass ratio equivalent to total taxa mortality; EEi is the ecotrophic efficiency, which is the proportion of the production consumed by the predators; Yi is the export from fishing catches (assuming Yi= 0); (Q/B)j is the food consumed per biomass unit of predator “j”; DCij is the proportion of prey “i” in the diet of predator “j”; Ei is the loss of biomass for other reasons (e.g., migration); and BAi is the biomass accumulation rate for “i” (Christensen et al., 2005). The software Ecopath with Ecosim requires additional information about the diet of the predators and the parameters B, P/B, Q/B and EE. If one parameter is unknown, Ecopath can estimate it based on the other parameters (Christensen et al., 2005).

The equation used to define the energy balance within each group or species in the ecosystem was:

Consumption (Q) = Production (P) + Respiration (R) + Unassimilated feed (U)

The information sources of each species or functional group input into the Ecopath software are summarized in Table 1. The models were constructed using biomass density in grams of dry weight per square meter (g DW/m^2), which was based on the average values of two sampling periods in the winter of 2015 (June to September) and two sampling periods in the summer of 2016 (January to March).

2.3. Basic input

2.3.1. Detritus and Phytoplankton

Phytoplankton and detritus biomass in the water were determined by the concentration of chlorophyll a and organic carbon particulate using images taken by the MODIS instrument on the satellite Aqua (NASA). The resolution of the images is approximately 4.5 km, which allowed the data to be obtained for all sectors and beaches.

The concentration of chlorophyll a converted to phytoplankton DW was 1mg of chlorophyll a = 100 mg DW (Reyes-Martinez et al. 2014). The P/B phytoplankton values followed Lercari et al. (2010). To determine the biomass of sediment detritus, nine aliquots of sediment were collected in each sector during each sampling period.

The organic matter content was determined based on the difference between the weight of the lyophilized and incinerated (350°C for 12 horas) sediment (Goldin, 1987). We included *Emerita brasiliensis* eggs as discrete trophic group, because it represented the main feeding resource to fish at Praia Grande Beach. The biomass of *E. brasiliensis* eggs, scraped from females, was determined after the eggs were dried at 60°C for 24 hours. It represented a proxy of the availability of this detritivore food resource to fish, as observed for Turra et al. (2015) with bivalves' siphons.

2.3.2. Macroinvertebrates

The macroinvertebrates were collected along three transects (50 m apart) perpendicular to the coastline. Each transect was divided into nine sampling points covering the entire intertidal zone (Machado et al., 2016). Sediment samples were collected using a 20 cm diameter/depth corer (0.188 m^2), sieved (1 mm mesh) in the field and fixed in 10% formalin. In the laboratory the organisms were separated, identified, counted, dried at 60°C for 24 hours, and weighed to determine the DW. The P/B ratio was calculated according to Brey (2001), which are related to the individual body mass of each species and to the annual average seawater temperature in the municipalities of São João da Barra (25°C) and Arraial do Cabo (24°C) (Reynolds et al. 2007). The Q/B ratio was calculated by the equation $\log(Q) = -0.420 + 0.742 . \log(DW)$ (Cammen, 1980), where DW is the individual dry weight.

2.3.3. Fish

The fish were collected in the surf zone using a beach seine net that was 25 m long and 2.5 m tall, with 10 mm mesh (Gaelzer and Zalmon, 2003). The net was hauled parallel to the shore at 1.5 m deep, covering a total area of approximately 500 m^2. Each sampling period included 10 hauls of five minutes. The fish were fixed in 10% formaldehyde, weighed, identified, and their stomachs dissected to analyze the food items with a stereomicroscope. Conversion from WW to DW and the Q/B and P/B ratios were obtained using Fish Base (http://www.fishbase.org). The biomass values included in the models reflect the average annual catch per unit effort (CPUE) of the four sampling periods.

The invertivorous and piscivorous fish diet was determined from the stomach content analysis. The proportion of each prey was based on the index of relative importance (Hyslop, 1980), which is calculated using frequency of occurrence (F%), abundance (N%) and wet weight (W%) data of each food item: IRI = (N% + W%). F%.

Table 1. Model compartments and data sources of the Ecopath basic input for Grussai beach and Praia Grande beach.Biomass (B); Production/Biomass (P/B); Consumption/Biomass (Q/B), Ecotrophic efficiency (EE).

Groups	**Grussaí Components**	**Praia Grande Components**	B	P/B	Q/B	EE	Diet
Seabirds	-	*Phalacrocorax brasilianus,Sula leucogaster, Fregata magnificens, Larus dominicanus, Sterna hirundinacea*	1	5	10-14	5	15
Piscivorous fishes	Ariidae	*Pomatomus saltatrix*	1	2	2	5	1
Invertivorous fishes	*Menticirrhus americanus, Polydactylus virginicus, Trachinotus spp.*	*Diplodus argenteus, Dactylopterus volitans, Menticirrhus americanus., Trachinotus carolinus., Umbrina coroides*	1	2	2	5	1
Small pelagic fishes	*Anchoviella sp., Atherinella brasiliensis*	*Harengula clupeola,Sardinella brasiliensis*	1	2	2	5	2
Macrofauna	*Atlantorchestoidea brasiliensis, Emerita brasiliensis, Excirolana armata, Excirolana braziliensis, Hemipodia californiensis, Mysida sp.*	*Atlantorchestoidea brasiliensis, Emerita brasiliensis, Excirolana armata, Excirolana braziliensis, Hemipodia californiensis,Olivancillaria vesica,* Lumbrineridae, Unidentified Amphipod	1	3	4	5	7-9
Primary producer	Phytoplankton	Phytoplankton	6	8			
Detritus	Water detritos	Water detritus	6				
	Sediment detritos	Sediment detritus	1				
		Emerita brasiliensis eggs	1				

(1) Present study,(2) Frouse & Pauly, 2012 (3) Brey, 2001, (4) Cammen, 1980, (5) Estimated by Ecopath, (6) Satellite imagery, (7) Reyes-Martinez et al. 2014, (8) Lercari et al. 2010, (9) Carrasco and Oyarzún 1988, (10) Naves et al. 2013, (11) McLachlan et al. 1980, (12) Gil-Weir et al. 2011, (13) Danckwerts et al. 2014, (14) Nagy et al. 1999, (15) Schreiber and Burger, 2001

2.3.4. Seabirds

We estimated the abundance of seabirds using point counts at fixed distances of 50 meters in both urbanized and non-urbanized sectors (Bibby et al., 2000). All seabirds foraging within quadrants with a 100-meter radius in the surf zone were recorded. Bird counting events lasted 3 min maximum to prevent overestimating individuals (Tavares et al., 2015). Birds were identified at the species level by the same observer to prevent inter-observer differences (Bibby et al., 2000).

The abundance data was converted into wet weight (WW) by multiplying the total number of individuals by the average individual weight of each species (Schreiber and Burger, 2001) and converted to dry weight (DW) using the conversion factor WW= 3.18 DW (Marcström and Mascher, 1979). Annual food consumption (Q) was obtained from published data (Tab. 1). EE was considered zero, because seabirds are top predators on beaches, and P/B was estimated using the software Ecopath.

2.3.5. Model parameterization

The models are balanced when the input data into each compartment is equivalent to the sum of the outputs. To create mass-balanced models we manually modified the diet matrix or input data (B, P/B or Q/B) until the EE of all groups was less than or equal to "1," which was necessary to validate the models (Lercari et al., 2010; Reymans et al., 2016). Manual adjustments were made mainly in diet matrix from published data.

The pedigree routine in the Ecopath allows assigning scores for each input data (B, P/B, Q/B and diet) using categories according to data origin (e.g. sampling locally and high precision; approximate or indirect method; estimated by Ecopath). The inputs from locally sampled data have the best confidence level and it should have the highest scores in the scale, which were chosen following Christensen and Walters (2004). The average pedigree indices for all the models were ≥0.5, indicating their good quality (Lassalle et al., 2014).

2.3.6. Food web and energy flow

The ecosystem properties of sandy beaches under distinct human pressures were described using the total values of consumption, exportation, respiration, total system throughput (sum of previous parameters), production (secondary and primary production), net primary production and biomass excluding detritus.

The food web features was compared among the sectors through: 1) connectance index, which indicates the connection of the ecosystem components and is calculated by the ratio between the actual and possible number of interactions; 2) system omnivory index, which indicates the distribution of the trophic interactions of the ecosystem. It represents an average of omnivory index of all consumers, weighted by the logarithm of each consumer's food intake ; 3) ascendency index, which indicates the level of development and organization of the ecosystem (Ulanowicz, 1986); and 4) overhead index, which reflects the resilience of the ecosystem. Finn's Cycling Index was determined to indicate the fraction of the ecosystem's throughput that is recycled. A trophic aggregation analysis was performed to provide the transfer efficiencies estimated between successive trophic levels. This analysis was represented by the Lindeman Spine (Figs. 4 and 5), which is also available in the Network Analysis of the Ecopath software.

The mixed trophic impact (MTI) routine was applied to quantify the trophic impacts of each functional group biomass on all others (Ulanowicz and Puccia, 1990). Therefore this tool can be useful to determine de trophic role of the models compartments in the food web.

3. Results

On both beaches, the detritus in the sediment represented a primary source of energy in the ecosystem (752 to 847 g/m²), compared to the detritus in the water (0.27 to 0.43 g/m²) and phytoplankton (0.43 to 0.68 g/m²) (Tab. 2). At Grussaí Beach, catfish (Ariidae) were the main top predators and the crustaceans *Emerita brasiliensis* and *Excirolana braziliensis* were the main primary consumers in both urbanized and non-urbanized sectors (Tab. 2). At Praia Grande Beach, the brown booby *Sula leucogaster*, which was most abundant in the non-urbanized sector

(BNU= 1.7 and BU= 0.6 g/m²), and the kelp gull *Larus dominicanus*, which was most abundant in the urbanized sector (BNU= 0.1 and BU= 0.2 g/m²), were the top predators. The sand drum *Umbrina coroides* and the bluefish *Pomatomus saltatrix* were found exclusively in the urbanized sector of Praia Grande beach. *E. brasiliensis* was the main primary consumer in both sectors (BNU= 8.5 and BU= 2.0 g/m²), followed by *Atlantorchestoidea brasiliensis* in the non-urbanized sector (BNU= 1.7 g/m² and BU<0.001). Both of the species had less biomass in the urbanized sector of Praia Grande beach (Tab. 3).

The highest values of ecotrophic efficiency of the intertidal macroinvertebrates were generally found in areas with less human pressure. At Grussaí Beach, *A. brasiliensis* (EENU= 0.98 and EEU= 0.32), *E. braziliensis* (EENU= 0.17 and EEU= 0.01) and *E. brasiliensis* (EENU= 0.95 and EEU= 0.54) were the most preyed macroinvertebrates in the non-urbanized sector (Tab.2). At Praia Grande Beach, *A. brasiliensis* (EENU= 0.19 and EEU= 0.02), *E. brasiliensis* (EENU= 0.82 and EEU= 0.43) and an unidentified amphipod (EENU= 0.69 and EEU= 0.26) were most preyed in the non-urbanized sector (Tab. 3).

The ecosystem proprieties did not differ in areas under different human pressure (Fig. 2 and 3; Tab. 4). At Grussaí each, the majority of the total system throughput flowed to detritus (NU= 43% and U= 41%) or was exported (NU= 42% and U= 39%) (Tab. 4). At Praia Grande Beach, the sum of all consumption was greater in the non-urbanized sector (NU= 46% and U= 31%), as well as the sum of all respiratory flow (NU= 34% and U= 22%), total biomass excluding detritus (NU= 12.2 and U= 4.2) and the Finn's cycling index (NU= 0.22 and U= 0.02) (Tab. 4).

Table 2. Basic output of the mass-balanced models in the non-urbanized (NU) and urbanized (U) sectors of Grussaí beach.Trophic level (TL); Biomass (B); Production/Biomass (P/B); Consumption/Biomass (Q/B), Ecotrophic efficiency (EE).Parameters estimated by Ecopath are in bold.

	TL		**B (g/m²)**		**P/B**		**Q/B**		**EE**	
Models compartments	**NU**	**U**	**NU**	**U**	**NU**	**U**	**NU**	**U**	**NU**	**U**
Ariidae	3.24	3.21	0.049	0.050	0.47	0.47	13.20	13.20	**0.00**	**0.00**
Menticirrhus americanus	3.00	2.96	0.016	0.013	1.18	1.18	9.50	9.50	**0.00**	**0.00**
Polydactylus virginicus	2.67	2.81	0.006	0.010	1.23	1.23	10.20	10.20	**0.00**	**0.00**
Trachinotus spp.	3.02	2.09	0.016	0.018	0.63	0.63	7.20	7.20	**0.00**	**0.00**
Small pelagic fishes	2.25	2.25	0.048	0.020	2.68	2.68	32.20	32.20	0.95	0.95
Atlantorchestoidea brasiliensis	2.00	2.00	0.010	0.010	4.50	3.70	238.87	205.49	**0.98**	**0,32**
Emerita brasiliensis	2.00	2.00	0.064	0.329	0.80	0.79	59.82	59.47	**0.95**	**0.54**
Excirolana armata	2.00	2.00	0.001	0.001	32.56	33.19	523.40	519.79	**0.59**	**0.85**
Excirolana brasiliensis	2.00	2.00	0.029	0.020	3.31	13.80	180.89	202.83	**0.17**	**0.01**
Hemipodia californiensis	2.27	2.18	0.004	0.005	5.56	4.61	268.37	232.62	**0.03**	**0.02**
Lepidopa richimondi	2.00	2.00	0.004	0.004	2.23	2.00	123.54	120.62	**0.09**	**0.17**
Mysida spp.	2.00	2.00	0.001	0.010	81.74	7.53	455.61	202.93	**0.96**	**0.94**
Phytoplankton	1.00	1.00	0.428	0.422	509.50	509.50			**0.14**	**0.21**
Sediment detritus	1.00	1.00	847.872	833.550						
Water detritus	1.00	1.00	0.419	0.429						

Table 3. Basic output of the mass-balanced models in the non-urbanized (NU) and urbanized (U) sectors of Praia Grande beach.Trophic level (TL); Biomass (B); Production/Biomass (P/B); Consumption/Biomass (Q/B), Ecotrophic efficiency (EE).Parameters estimated by Ecopath are in bold.

	TL		B (g/m²)		P/B		Q/B		EE	
Models compartments	**NU**	**U**	**NU**	**U**	**NU**	**U**	**NU**	**U**	**NU**	**U**
Sula leucogaster	3.50	3.73	1.700	0.600	**4.75**	**4.75**	94.90	94.90	0.00	0.00
Larus dominicanus	3.50	3.73	0.100	0.200	**11.27**	**11.27**	225.44	225.40	0.00	0.00
Sterna hirundinacea	3.50	-	0.004	-	**4.65**	-	92.90	-	0.00	-
Fregata magnificens	3.50	3.73	0.004	0.007	**3.01**	**3.01**	60.12	60.12	0.00	0.00
Phalacrocorax brasilianus	3.50	3.73	0.007	0.004	**3.16**	**3.16**	63.17	63.17	0.00	0.00
Pomatomus saltatrix	-	3.53	-	0.013	-	**0.27**	-	5.40	-	**0.34**
Dactylopterus volitans	3.00	3.00	0.427	0.116	0.94	0.94	6.50	6.50	**0.02**	**0.02**
Diplodus argenteus	2.04	2.93	0.001	0.009	0.47	0.47	19.20	19.20	**0.39**	**0.03**
Menticirrhus americanus	2.06	2.03	0.003	0.012	1.16	1.16	9.10	9.10	**0.06**	**0.01**
Trachinotus spp.	3.00	2.99	0.010	0.021	0.56	0.56	8.50	8.50	**0.03**	**0.01**
Umbrina coroides	-	2.02	-	0.025	-	3.80	-	10.30	**-**	**0.00**
Small pelagic fishes	2.50	2.50	0.0003	0.027	1.61	1.61	14.10	14.10	**0.95**	**0.01**
Atlantorchestoidea brasiliensis	2.00	2.00	0.172	0.000	2.01	5.12	135.23	279.99	**0.19**	**0.02**
Emerita brasiliensis	2.00	2.00	8.500	2.040	0.59	0.91	49.07	68.65	**0.82**	**0.43**
Excirolana armata	2.00	2.00	0.008	0.002	32.40	38.74	231.26	279.99	**0.84**	**0.96**
Excirolana braziliensis	2.00	2.00	0.010	0.005	3.49	16.24	198.98	68.65	**0.17**	**0.12**
Unidentified Amphipod	2.00	2.00	0.018	0.006	3.20	4.13	185.87	658.41	**0.69**	**0.26**
Hemipodia californiensis	2.14	2.00	0.018	0.002	1.46	1.75	101.02	252.51	**0.01**	**0.00**
Lumbrineridae	2.14	2.10	0.010	-	23.13	-	390.87	-	**0.00**	-
Olivancillaria vesica	2.14	2.10	0.308	0.009	2.37	2.40	90.70	91.67	**0.00**	**0.19**
Phytoplankton	1.00	1.00	0.680	0.590	650.00	650.00			**0.97**	**0.48**
Water detritus	1.00	1.00	0.266	0.317						
Sediment detritus	1.00	1.00	752.496	809.592						
Emerita brasiliensis eggs	1.00	1.00	0.161	0.060						

Table 4. Ecosystem attributes estimated by Ecopath for the non-urbanized and urbanized sectors of Grussaí and Praia Grande beaches.

	Grussaí		**Praia Grande**		
	Non urbanized	**Urbanized**	**Non urbanized**	**Urbanized**	**Units**
Sum of all consumption	41.3	56.5	680.9	343.4	g/m²/year
Sum of all exports	198.3	178.2	121.3	242.8	g/m²/year
Sum of all respiratory flows	25.2	37.1	505.2	243.4	g/m²/year
Sum of all flows into detritus	203.2	187.4	183.2	289.0	g/m²/year
Total system throughput	468.0	459.1	1490.7	1118.6	g/m²/year
Sum of all production	225.9	222.8	481.2	414.9	g/m²/year
Calculated total net primary production	218.1	214.7	441.7	383.5	g/m²/year
Total biomass (excluding detritus)	0.95	1.2	12.2	4.2	g/m²
Connectance Index	0.2	0.2	0.2	0.2	
System Omnivory Index	0.03	0.03	0.02	0.03	
Ascendency	578.4 (57.9)	700.5 (62.1)	2765.4 (53,1)	1986.7 (48.2)	flowbits (%)
Overhead	421.3 (42.1)	427 (37.9)	1916.7 (36.8)	1873.8 (45.5)	flowbits (%)
Capacity	999.7 (100)	1127 (100)	5207.9 (100)	4118.7 (100)	flowbits (%)
Finn's cycling index	0.23	0.25	0.22	0.02	% TST

The food web complexity and features (conectance, omnivory system, ascendency, overhead and capacity) did not differ between urbanized and non-urbanized sectors. However, higher predation intensity by invertivorous fish (e.g., Trachinotus spp.) on intertidal macrofauna was observed in the non-urbanized sectors (Fig. 2 and 3). In the urbanized area of Grussaí Beach, water detritus was the main food resource of Trachinotus spp., which resulted in a lower trophic level (TL= 2.1) compared to the non-urbanized area (TL= 3). At Praia Grande Beach, *E. brasiliensis* was an important food resource for fish, especially *D. volitans* (Fig. 3). In addition, *E. brasiliensis* eggs were the main food of *Menticirrhus americanus* in both sectors, *Diplodus argenteus* in the non-urbanized sector and *U. coroides* in the urbanized sector (Fig. 3). In the non-urbanized sector, *A. brasiliensis* was the main prey of *T. carolinus* (Fig. 3).

The energy flow on both beaches is represented in Figures 4 and 5. The Lindeman spine showed that herbivory was higher than detritivory in all sectors. At Grussaí Beach, most of the primary production flowed to detritus in the both sectors (NU= 86% and U= 79%). At Praia Grande Beach, the consumption of detritus (NU= 25% and U= 14%) and phytoplankton (NU= 98% and U= 48%) was higher in the non-urbanized sector (Fig. 5). There was a higher efficiency in energy transfer from TL2 to TL3 in both non-urbanized sectors (Figs. 4 and 5).

Phytoplankton, sediment and water detritus showed a positive effect on most trophic groups, especially on intermediate trophic levels (i.e. macroinvertebrates) in all the sectors (Figs. 6 and 7). Fish species such as *M. americanus* and *Trachinotus* spp. showed a negative impact on most macroinvertebrates mainly in the non-urbanized sector of both Grussaí and Praia Grande beaches (Figs. 6 and 7). The fish *P. virgninicus* acted in a similar way in all sectors of Grussaí beach (Fig. 6). At Praia Grande Beach, *E. brasiliensis* eggs showed a positive impact on the fish *D. argenteus*, *M. americanus* (in both sectors) and *U. coroides* (urbanized sector) (Fig. 7). The negative impact effect of *S. leucogaster* on all fish species was greatest in the non-urbanized sector on Praia Grande Beach, except on *P. saltatrix*, which was exclusive species of the urbanized sector (Fig.7). *L. dominicanus* had a negative impact on fish in the urbanized sector, but it was less important than *S. leucogaster* impact in the non-urbanized area (Fig.7).

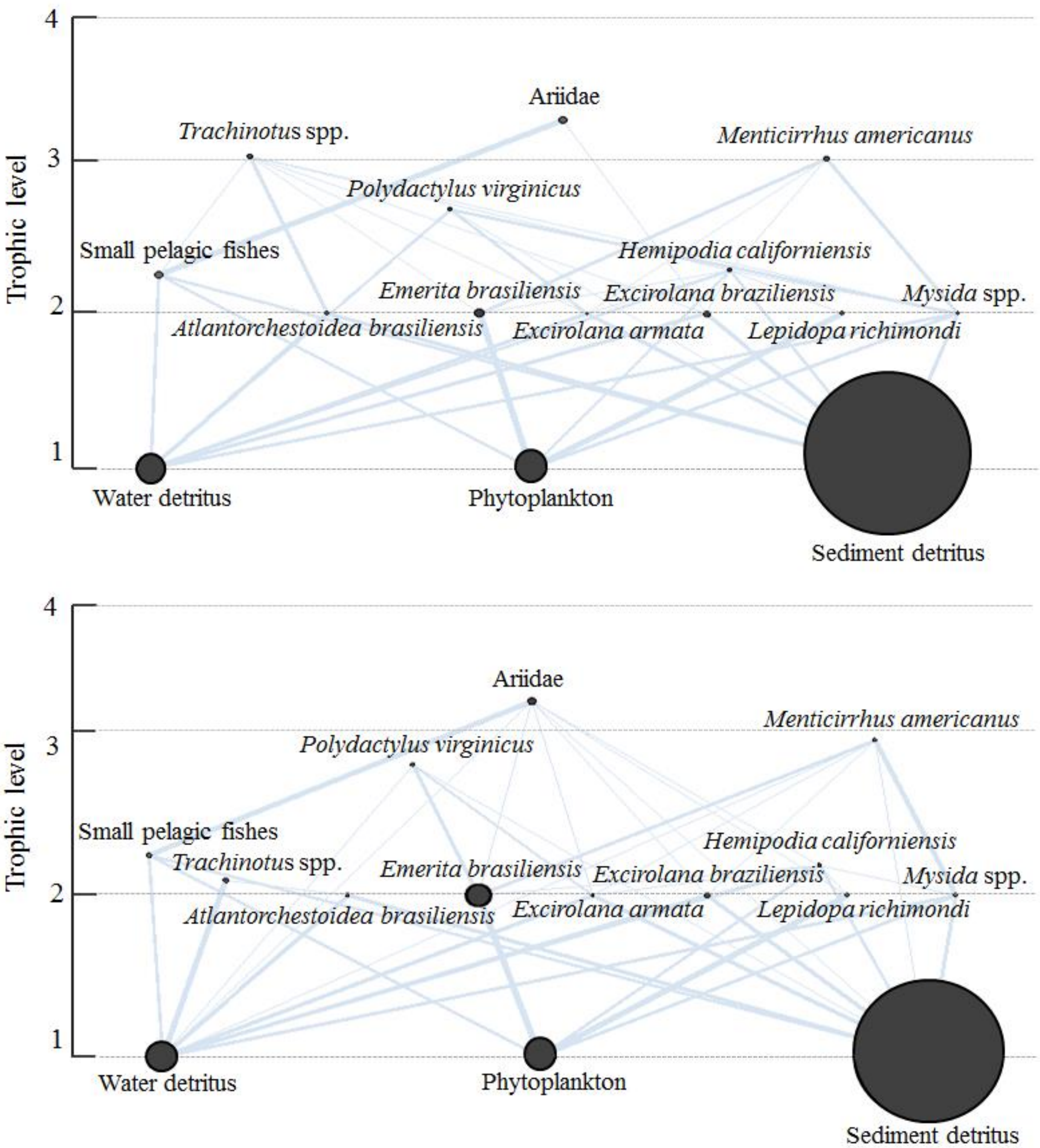

Figure 2. Food web in the non-urbanized (A) and urbanized (B) sectors of Grussaí beach.

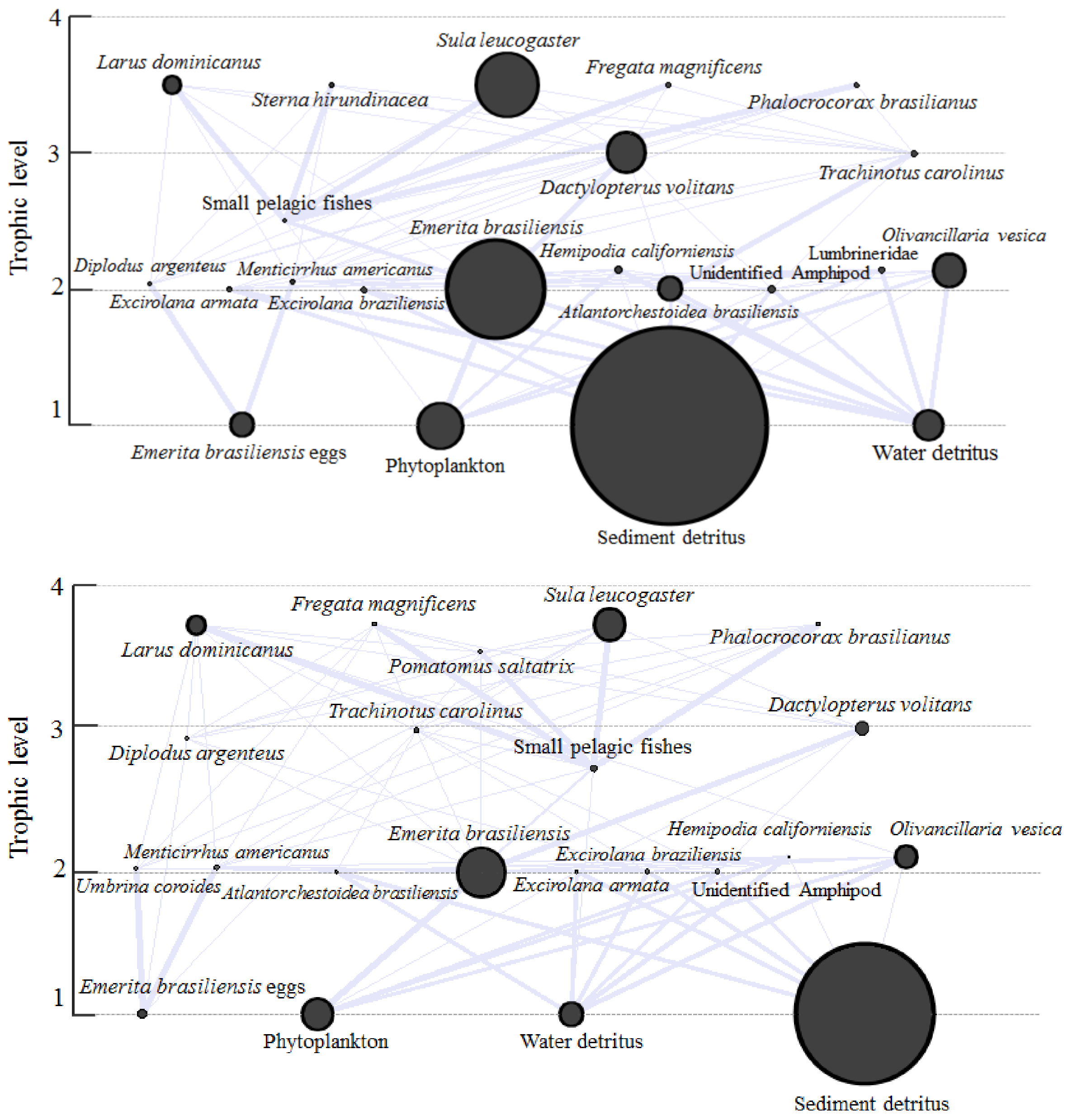

Figure 3. Food web in the non-urbanized (A) and urbanized (B) sectors of Praia Grande beach.

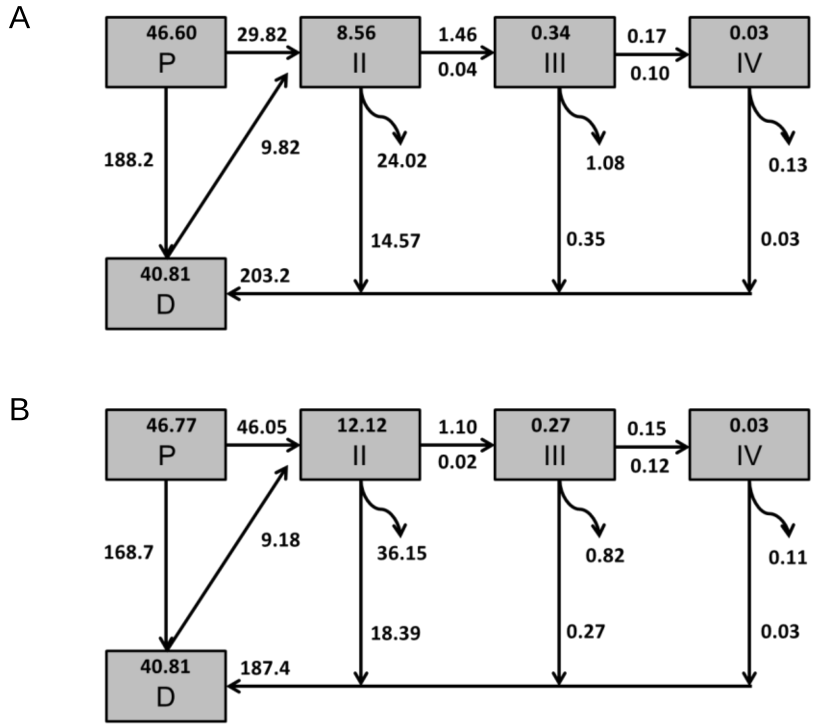

Figure 4. Energy flow through the trophic levels (P: Producers; I, II, III and IV) in the non-urbanized (A) and urbanized (B) sectors of Grussaí beach. The values inside the boxes denote trophic level biomass. Horizontal arrows denote energy flows from one level to the following, whereas down arrows denote energy flows to detritus and curved arrows indicate respiration. All flows are expressed in g/m2/year.

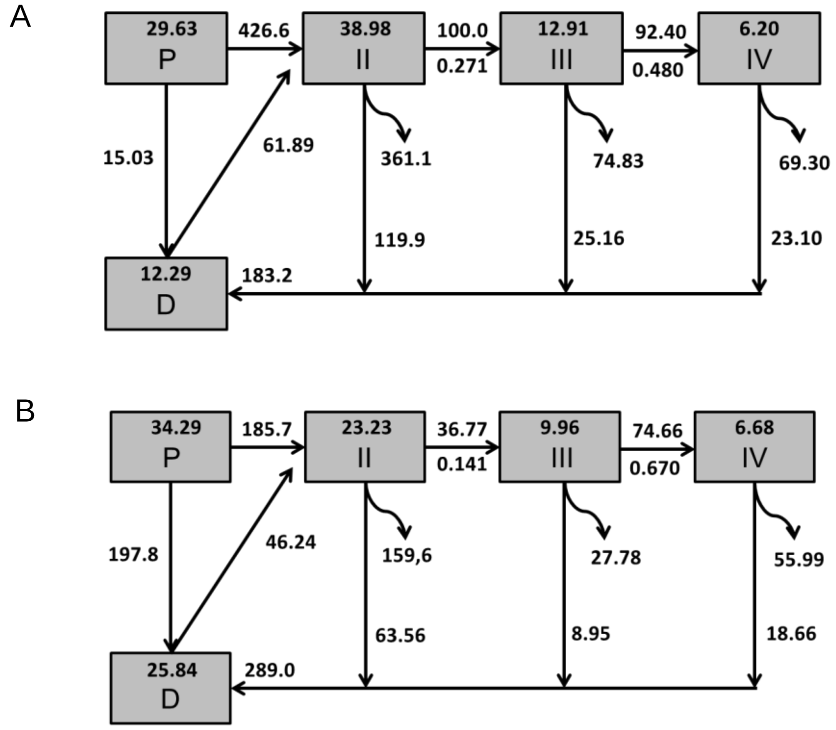

Figure 5. Energy flow through the trophic levels (P: Producers; I, II, III and IV) in the non-urbanized (A) and urbanized (B) sectors of Praia Grande beach. The values inside the boxes denote trophic level biomass. Horizontal arrows denote energy flows from one level to the following, whereas down arrows denote energy flows to detritus and curved arrows indicate respiration. All flows are expressed in g/m2/year.

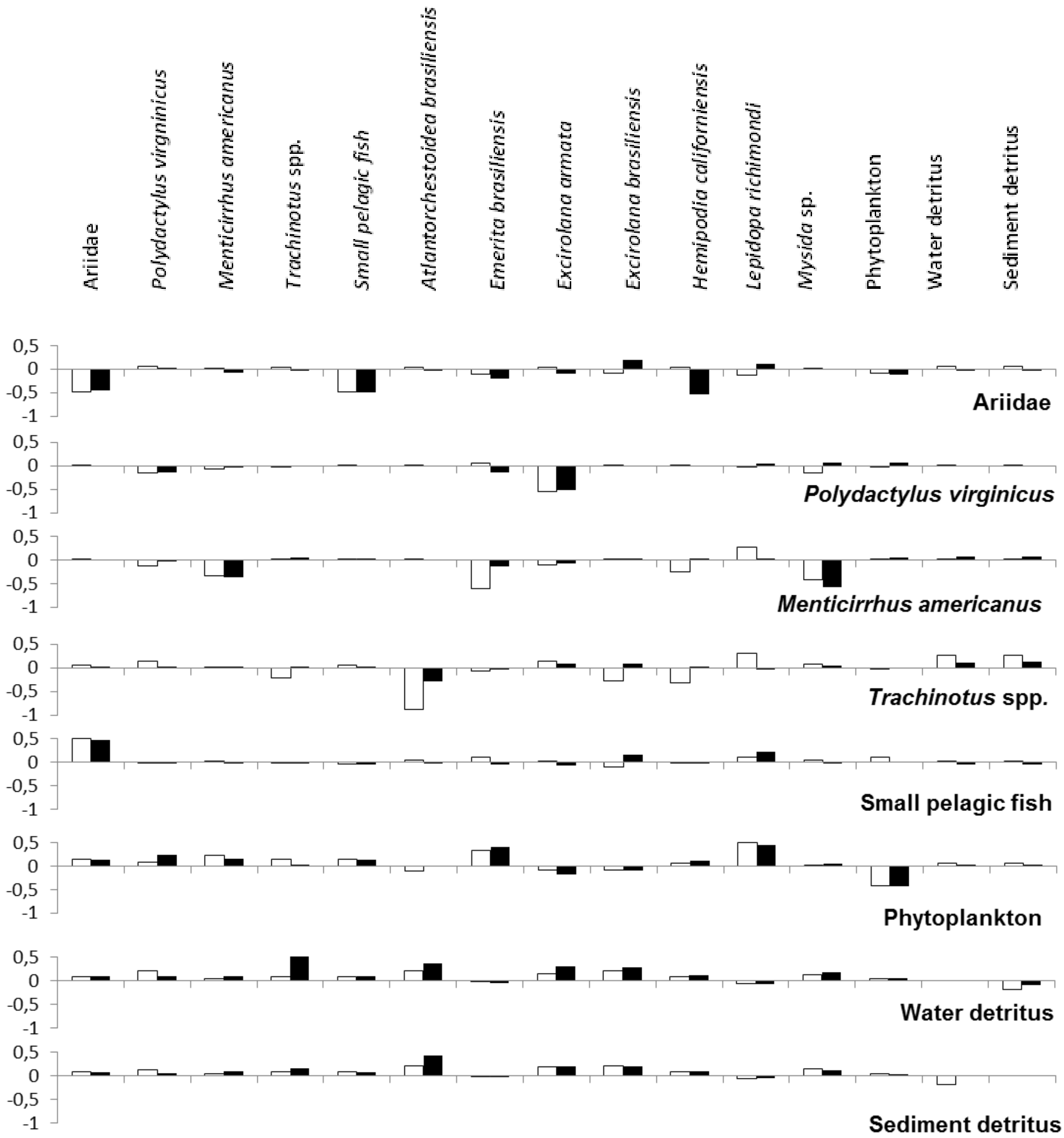

Figure 6. Mixed trophic impact of the compartments in the urbanized (black bars) and non-urbanized sector (white bars) of Grussaí beach. Black bars correspond with urbanized sector. Positive interactions are represented by upwards bars negative interactions by downwards bars.

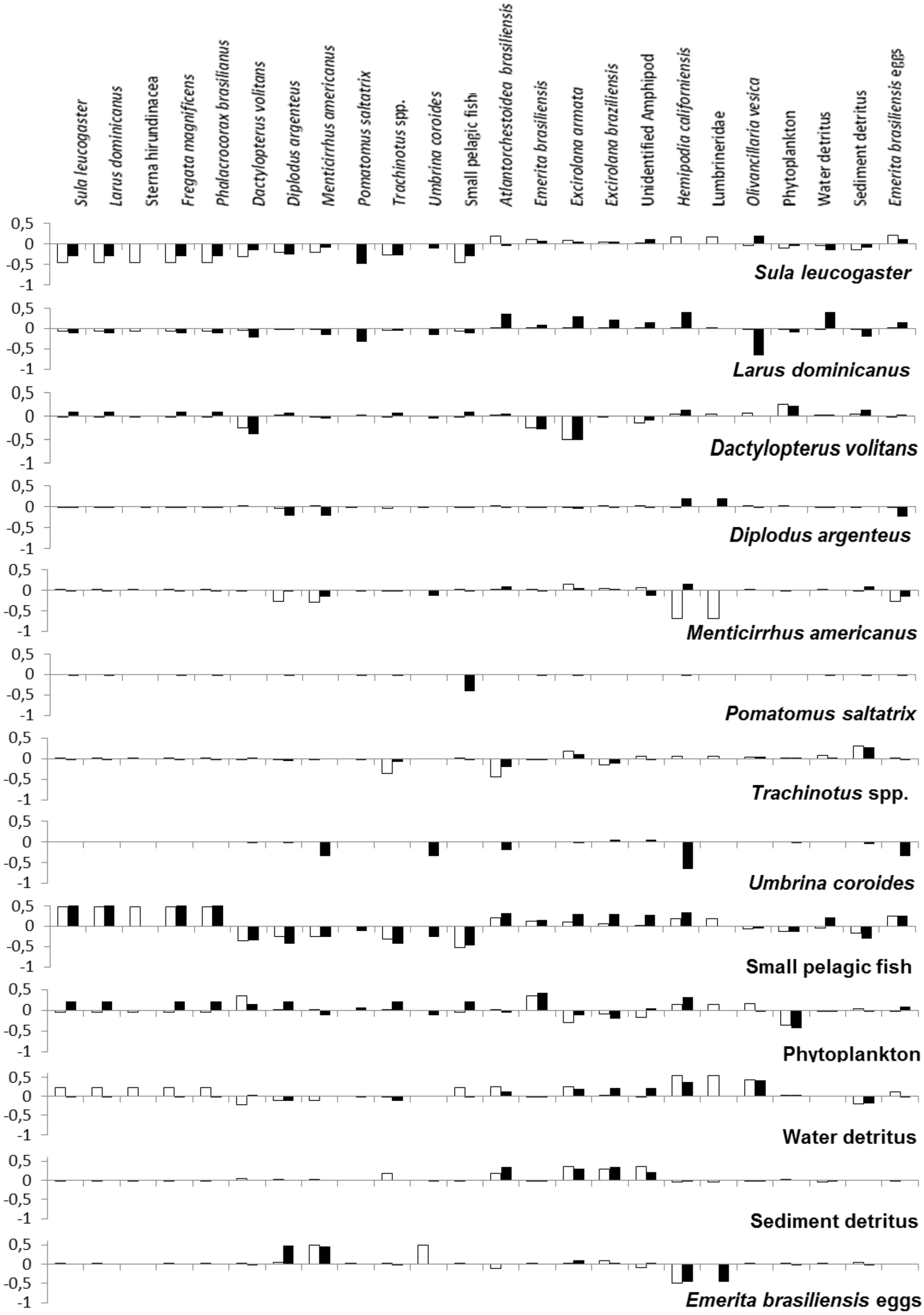

Figure 7. Mixed trophic impact of the compartments in the urbanized (black bars) and non-urbanized sector (white bars) of Praia Grande beach. Black bars correspond with urbanized sector. Positive interactions are represented by upwards bars negative interactions by downwards bars.

4. Discussion

This study investigated the urbanization effects on the food web and energy flow properties of tropical sandy beaches. Severe human pressure showed negative effects on the biomass of intertidal macroinvertebrates, mainly the detritivorous ones. Basic functions of the beaches, such as TST cycling and energy flow were also negatively affected, which indicates that macroinvertebrates are important trophic resources in the ecosystem functioning.

Species richness is an important food web attribute and is related to the number of interactions and complexity of an ecosystem (Thompson et al., 2012). Beach sectors under different human pressures were similar for the number of species and several properties of the ecosystem (e.g., omnivory, conectance, ascendency and overhead), reflecting the same food web size and complexity. Nevertheless, the biomass and ecological role of seabirds (i.e. top-level predator) and macroinvertebrates (i.e. fish prey) were affected mainly in the urbanized sector of Praia Grande Beach, which is a national tourist region.

The piscivorous seabird *S. leucogaster* avoids the urbanized sector of Praia Grande beach, where there are also pets and kleptoparasitism by gulls that take advantage of human detritus (Tavares et al., 2013). This contradicts the optimal foraging of *S. leucogaster*, since the urbanized sector provides higher food availability (i.e. surf zone fish) than the non-urbanized site, at least in the low tourist season (Costa et al., 2017). Thus, it is supposed that *S. leucogaster* spends more time and energy searching for prey (i.e. fish) on non-urbanized sector. Despite of human pressure, two potential preys of *S. leucogaster* (e.g. the fish species *P. saltatrix* and *U.coroides*) were found exclusively on urbanized sector, where the negative trophic impact (i.e. predation) by *S. leucogaster* on other fish species biomass is lowest, as observed in the MTI analysis. These results suggest a human-induced loss on the ecological role of top-level predators and a top-down control effect in the food web. However, other authors pointed out a bottom-up effect on shorebirds abundance as a result of lower availability of macroinvertebrates in disturbed sandy beaches (Dugan et al., 2003; Reyes-Martinez et al., 2014). It is unlike that *L. dominicanus*, which was more abundant on urbanized sector has a relevant trophic impact on *P. saltatrix*, *U. coroides* and other fish species, since this gulls have a large diet breadth compared to *S. leucogaster* and they also feed on other prey, such as intertidal macroinvertebrates (McLachlan et al., 1980; Yorio et al., 1998).

The vulnerability of macroinvertebrates to human activities, such as beach trampling and vehicle traffic, has been widely recorded (Reyes Martinez et al., 2015; Cardoso et al., 2016). Also, harvesting macroinvertebrates (e.g., *E. brasiliensis*) for human consumption and fishing bait is a common practice on the studied beaches, but this is usually underestimated (Brazeiro and Defeo, 1999; Defeo, 2003). The ecological role of macroinvertebrates seems to be well-performed in the non-urbanized sectors on both beaches, since their biomass was more negatively impacted by fish species in the MTI analysis and their ecotrophic efficiency was higher compared to urbanized areas. In a similar way, Reyes-Martinez et al. (2014) showed the stronger influence that shorebirds generated on the amphipod *Talitrus saltator* in a non-urbanized beach, compared to a disturbed area. As a result, energy transfer between TL 2 and TL 3 was most efficient in non-urbanized sectors, suggesting a human-induced change in the ecosystem energy flow (Reyes-Martinez et al., 2014).

At Grussaí beach the preferential consumption of insects from human waste (i.e. water detritus) by *Trachinotus* spp. and it trophic level reduction in the urbanized sector also suggest the human influence in the beach trophic functioning. In general, intertidal crustaceans are the most important feeding resources to surf zone fish, including *Trachinotus* (Nelson, 1986; Takahashi et al., 1999; Tomme et al., 2014), as observed on the non-urbanized beaches. Under natural conditions, terrestrial insects washed away represent a minor detritivore input to sandy beach predators (McLachlan et al., 1981). However, this higher resource availability should influence the foraging behavior and trophic level (TL) of *Trachinotus*, a typical mobile beach consumer (Spiller et al., 2010; Twefik et al., 2016). Most TL-based indicators have been used to track anthropogenic changes in marine ecosystems, such as the removing organisms from the food web by selective fishing (Pauly et al., 1998; Reed et al., 2016). Yet, this is the first evidence of human-induced change in trophic level of a predator in sandy beaches.

In general, sandy beaches have low species diversity and fewer biological interactions compared to other marine ecosystems, such as coral reefs and rocky shores (McDermott et al., 1983; McLachlan and Brown, 2010). Also, the majority of beach predators are generalists (Turra et al., 2015), which are relatively less sensitive to cascading extinctions caused by breakdown of trophic interactions (Carboni et al., 2010; Tylianakis et al., 2010). However, predators as birds and commercial fish sometimes avoid this environment, due to severe human pressure (as observed for *S. leucogaster* on Praia Grande beach) or impacted areas that have less food availability (Dugan et al., 2003; Tavares et al., 2013; Costa et al., 2017). We did not find differences in the food web complexity among areas under distinct levels of human pressure, but the beach avoidance by generalist predators could reduce the diversity of interactions over the long term, compromising sandy beaches as foraging areas.

Some macroinvertebrates played a central role in the energy transfer and trophic functioning of beach ecosystem. The lower biomass of the detritivores *A. brasiliensis* and *E. braziliensis* in the urbanized sector of Praia Grande beach induced the lower consumption of detritus showed by the Lindeman Spine and cycling index reduced in this area under intense human pressure. In fact, cycling tends to be less efficient in urban beaches and other disturbed environments (Yang et al., 2010) and Finn's cycling index is an indicator of anthropogenic disturbance in ecosystems (Reyes-Martinez et al., 2014). According to Veloso et al. (2008), the contribution of decomposer organisms, such as talitrid amphipods and cirolanid isopods, has been valued about $62 billion per year, including the decomposition of organic waste produced by humans. In addition, the primary production of microphytobenthos and phytoplankton in the surf zone depends directly on the nutrient cycle of the benthic macrofauna and meiofauna (McLachlan et al., 1981; McLachlan and Brown, 2010).

Sediment detritus represented the food web component with highest biomass on both beaches. However, phytoplankton consuming was higher than detritivory, emphasizing the dependence on herbivory on the beach trophic functioning, as found in other studies (Lercari et al., 2010; Reyes-Martinez et al., 2014). Otherwise, most of primary productivity was not consumed, but it was converted to detritus. Furthermore, the majority of the total system throughput on Grussaí beach also flowed to detritus or was exported (≥ 80%). These results elucidates the usual low diversity of consumers and the role of beaches, at least with intermediate/reflective morphodynamics, as energy exporters to adjacent coastal systems (Lercari et al., 2010). This characteristic differs from other more productive costal environments, such as coral reefs, bays and coastal lagoons, as well as the non-urbanized sector of Praia Grande beach (80% of the total system throughput was consumed), which has dissipative morphodynamics and is directly influenced by the upwelling phenomenon (Linn et al., 1999; Arias-Gonzáles et al., 2004; Okey et al., 2004; Ullah et al., 2012). Indeed, only in the non-urbanized sector of Praia Grande beach, most of the primary productivity was consumed. This was result of the higher biomass of *E. brasiliensis*, which is a typical herbivorous on Brazilian sandy beaches (Veloso et al., 1997). This specie is one of the most utilized for human consumption and fishing bait (Defeo, 2003) and it was also negatively affected in the urbanized sector.

In summary, we showed that modifications in the biomass of several macroinvertebrates and consequently on their predator diet were responsible for reducing the energy transfer efficiency among distinct trophic levels in the beach ecosystem. In addition, basic ecological functions, such as cycling, appear to be negatively affected by the decreasing biomass of these intertidal organisms (Reyes-Martinez et al., 2014). Despite the changes in ecosystem functioning, we did not observe human-induced trophic cascades, indicating it is still possible to mitigate the impact. Intense beach trampling of certain areas is considered the main human pressure on macroinvertebrates. Minimizing this impact is challenging because the beaches are recreational areas (Schlacher et al., 2014). The ecological functions of the macroinvertebrates were well-performed in the non-urbanized sectors. Thus, the expansion of infrastructure facilities should be based on urban zoning plans that prioritize the conservation of macroinvertebrates, which seem to be key species for the functioning of coastal ecosystems. Management should start in urban areas of the beaches, by reduction the emission of solid waste and amount of macroinvertebrate harvesting, in addition to dispersing crowds and recreational activities.

5. Acknowledgements

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6. Appendix

Appendix 1. Estimation of urbanization index values of Praia Grande beach and Grussaí beach (modified from Gonzales et al., 2014). Gover’s method, $X' = ((\sum X - X\ min) / (\sum X\ max - X\ min))$, was used to calculate the index, where X is the value assigned to each of the six variables and Xmin–Xmax corresponds to the extreme values of the range (0–5 in this case). The index ranges from “0” to “1,” where values close to 1 indicate beaches with the highest human pressure.

	Praia Grande beach		**Grussaí beach**	
	Non-urbanized	Urbanized	Non-urbanized	Urbanized
Urbanization index				
Proximity to urban centers (0 - 5)	1	5	1	5
Building on the sand (0 - 5)	0	3	0	3
Beach cleaning (0 - 5)	0	1	0	1
Solid waste on the sand (0 - 5)	2	5	2	5
Vehicle traffic on the sand (0 - 5)	2	3	2	3
Frequency of visitors (0 - 5)	0	5	0	5
Total score	**0.2**	**0.7**	**0.2**	**0.7**

Appendix 2. Diet matrix that resulted in unbalanced models on non-urbanized sector of Grussaí Beach

	Prey \ predator	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	Ariidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	*Polydactylus virginicus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	*Menticirrhus americanus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	*Trachinotus* spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Small pelagic fishes	0.93	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Atlantorchestoidea brasiliensis	0.00	0.00	0.00	0.74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	*Emerita brasiliensis*	0.00	0.00	0.56	0.01	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00
8	*Excirolana armata*	0.00	0.22	0.01	0.004	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00
9	*Excirolana braziliensis*	0.07	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00
10	*Hemipodia californiensis*	0.00	0.00	0.002	0.003	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00
11	*Lepidopa richimondi*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00
12	*Mysida* spp.	0.00	0.78	0.43	0.11	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00
14	Phytoplankton	0.00	0.00	0.00	0.00	0.33	0.00	1.00	0.00	0.00	0.08	1.00	0.33
15	Water detritus	0.00	0.00	0.00	0.00	0.33	0.50	0.00	0.50	0.50	0.10	0.00	0.33
16	Sediment detritus	0.00	0.00	0.00	0.00	0.33	0.50	0.00	0.50	0.50	0.10	0.00	0.33
17	**Sum**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Appendix 3.Diet matrix that resulted in balanced models on non-urbanized sector of Grussaí Beach.

	Prey \ predator	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	Ariidae	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2	*Polydactylus virginicus*	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
3	*Menticirrhus americanus*	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
4	*Trachinotus spp.*	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
5	Small pelagic fishes	0,99	0,00	0,00	0,05	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6	*Atlantorchestoidea brasiliensis*	0,00	0,00	0,00	0,74	0,00	0,00	0,00	0,00	0,00	0,10	0,00	0,00
7	*Emerita brasiliensis*	0,00	0,00	0,56	0,01	0,00	0,00	0,00	0,00	0,00	0,10	0,00	0,00
8	*Excirolana armata*	0,00	0,22	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,00	0,00
9	*Excirolana braziliensis*	0,01	0,00	0,00	0,08	0,00	0,00	0,00	0,00	0,00	0,10	0,00	0,00
10	*Hemipodia californiensis*	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
11	*Lepidopa richimondi*	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,10	0,00	0,00
12	*Mysida* spp.	0,00	0,78	0,43	0,11	0,00	0,00	0,00	0,00	0,00	0,10	0,00	0,00
14	Phytoplankton	0,00	0,00	0,00	0,00	0,25	0,00	1,00	0,00	0,00	0,10	1,00	0,33
15	Water detritus	0,00	0,00	0,00	0,00	0,25	0,50	0,00	0,50	0,50	0,10	0,00	0,33
16	Sediment detritus	0,00	0,00	0,00	0,00	0,25	0,50	0,00	0,50	0,50	0,10	0,00	0,33
17	**Sum**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**

Appendix 4.Diet matrix that resulted in unbalanced models on urbanized sector of Grussaí Beach.

	Prey \ predator	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	Ariidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	*Polydactylus virginicus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	*Menticirrhus americanus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	*Trachinotus* spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Small pelagic fishes	0.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	*Atlantorchestoidea brasiliensis*	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
7	*Emerita brasiliensis*	0.07	0.51	0.18	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00
8	*Excirolana armata*	0.06	0.32	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00
9	*Excirolana braziliensis*	0.001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
10	*Hemipodia californiensis*	0.001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	*Lepidopa richimondi*	0.007	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
12	*Mysida* spp.	0.00	0.00	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
14	Phytoplankton	0.00	0.00	0.00	0.00	0.33	0.00	1.00	0.00	0.00	0.00	1.00	0.00
15	Water detritus	0.00	0.08	0.00	0.91	0.33	0.50	0.00	0.50	0.50	0.27	0.00	0.50
16	Sediment detritus	0.00	0.08	0.02	0.00	0.33	0.50	0.00	0.50	0.50	0.27	0.00	0.50
17	**Sum**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Appendix 5. Diet matrix that resulted in balanced models on urbanized sector of Grussaí Beach

	Prey \ predator	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	Ariidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	*Polydactylus virginicus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	*Menticirrhus americanus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	*Trachinotus* spp.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Small pelagic fishes	0.90	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	*Atlantorchestoidea brasiliensis*	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
7	*Emerita brasiliensis*	0.07	0.42	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00
8	*Excirolana armata*	0.01	0.27	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.00	0.00
9	*Excirolana braziliensis*	0.001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
10	*Hemipodia californiensis*	0.001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	*Lepidopa richimondi*	0.001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
12	*Mysida* spp.	0.00	0.00	0.57	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
14	Phytoplankton	0.00	0.00	0.00	0.00	0.33	0.00	1.00	0.00	0.00	0.00	1.00	0.00
15	Water detritus	0.01	0.15	0.00	0.91	0.33	0.50	0.00	0.50	0.50	0.27	0.00	0.50
16	Sediment detritus	0.01	0.16	0.04	0.00	0.33	0.50	0.00	0.50	0.50	0.27	0.00	0.50
17	**Sum**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Appendix 6. Diet matrix that resulted in unbalanced models on non-urbanized sector of Praia Grande Beach

	Prey \ predator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	*Sula leucogaster*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	*Larus dominicanus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	*Sterna hirundinacea*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	*Fregata magnificens*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	*Phalacrocorax brasilianus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	*Dactylopterus volitans*	0.20	0.16	0.20	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	*Diplodus argenteus*	0.20	0.16	0.20	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	*Menticirrhus americanus*	0.20	0.16	0.20	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	*Trachinotus* spp.	0.20	0.16	0.20	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Small pelagic fishes	0.20	0.16	0.20	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	*Atlantorchestoidea brasiliensis*	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	*Emerita brasiliensis*	0.00	0.02	0.00	0.00	0.00	0.07	0.01	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.18	0.00	0.00
13	*Excirolana armata*	0.00	0.00	0.00	0.00	0.00	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.18	0.00	0.00
14	*Excirolana braziliensis*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.18	0.00	0.00
15	Unidentified Amphipod	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.18	0.00	0.00
16	*Hemipodia californiensis*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	Lumbrineridae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	*Olivancillaria vesica*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	Phytoplankton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	1.00	0.00	0.00	0.30	0.00	0.00	0.00	0.00	1.00
20	*Emerita brasiliensis* eggs	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.90	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.09	0.00	0.00
21	Water detritus	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00	0.00	0.33	0.50	0.00	0.50	0.50	0.30	0.20	0.20	0.09	0.00	0.00
22	Sediment detritus	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.50	0.00	0.50	0.50	0.40	0.20	0.20	0.09	1.00	0.00
23	**Sum**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**0.10**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Appendix 7.Diet matrix that resulted in balanced models on non-urbanized sector of Praia Grande Beach.

	Prey \ predator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	*Sula leucogaster*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	*Larus dominicanus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	*Fregata magnificens*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	*Phalocrocorax brasilianus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	*Dactylopterus volitans*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	*Diplodus argenteus*	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	*Mentricirrhus americanus*	0.005	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	*Pomatomus saltatrix*	0.005	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	*Trachinotus* spp.	0.008	0.01	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	*Umbrina coroides*	0.97	0.96	0.97	0.97	0.97	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Small pelagic fishes	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	*Atlantorchestoidea brasiliensis*	0.00	0.01	0.00	0.00	0.00	0.92	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.10
13	*Emerita brasiliensis*	0.00	0.00	0.00	0.00	0.00	0.05	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01
14	*Excirolana armata*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.04
15	*Excirolana braziliensis*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Unidentified Amphipod	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	*Hemipodia californiensis*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	*Olivancillaria vesica*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	Phytoplankton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	1.00	0.00	0.00	0.33	0.28	0.28	0.28
20	Water detritus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.50	0.00	0.50	0.50	0.33	0.57	0.57	0.57
21	Sediment detritus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.50	0.00	0.50	0.50	0.33	0.00	0.00	0.00
22	*Emerita brasiliensis* eggs	0.00	0.00	0.00	0.00	0.00	0.00	0.97	0.95	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	**Sum**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Appendix 8.Diet matrix that resulted in unbalanced models on urbanized sector of Praia Grande Beach.

	Prey \ predator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	*Sula leucogaster*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	*Larus dominicanus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	*Fregata magnificens*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	*Phalocrocorax brasilianus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	*Dactylopterus volitans*	0.005	0.005	0.005	0.005	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	*Diplodus argenteus*	0.005	0.005	0.005	0.005	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	*Mentricirrhus americanus*	0.005	0.004	0.005	0.005	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	*Pomatomus saltatrix*	0.005	0.005	0.005	0.005	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	*Trachinotus* spp.	0.005	0.005	0.005	0.005	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	*Umbrina coroides*	0.005	0.004	0.005	0.005	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Small pelagic fishes	0.97	0.97	0.97	0.97	0.00	0.00	0.00	0.97	0.1	0.0001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	*Atlantorchestoidea brasiliensis*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	*Emerita brasiliensis*	0.00	0.003	0.00	0.00	0.90	0.3	0.003	0.01	0.001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10
14	*Excirolana armata*	0.00	0.00	0.00	0.00	0.098	0.5	0.05	0.00	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
15	*Excirolana braziliensis*	0.00	0.00	0.00	0.00	0.00	0.0	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04
16	Unidentified Amphipod	0.00	0.00	0.00	0.00	0.003	0.2	0.2	0.00	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.001	0.001
17	*Hemipodia californiensis*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	*Olivancillaria vesica*	0.00	0.003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	Phytoplankton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	1.00	0.33	0.00	0.33	0.00	0.00
20	Water detritus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.33	0.50	0.00	0.33	0.50	0.33	0.28	0.28
21	Sediment detritus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.50	0.00	0.33	0.50	0.33	0.57	0.57
22	*Emerita brasiliensis* eggs	0.00	0.00	0.00	0.00	0.00	0.99	0.73	0.00	0.20	0.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	**Sum**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

Appendix 9. Diet matrix that resulted in balanced models on urbanized sector of Praia Grande Beach.

	Prey \ predator	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1	*Sula leucogaster*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	*Larus dominicanus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	*Fregata magnificens*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	*Phalocrocorax brasilianus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	*Dactylopterus volitans*	0.005	0.005	0.005	0.005	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	*Diplodus argenteus*	0.005	0.005	0.005	0.005	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	*Mentricirrhus americanus*	0.005	0.004	0.005	0.005	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	*Pomatomus saltatrix*	0.005	0.005	0.005	0.005	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	*Trachinotus* spp.	0.005	0.005	0.005	0.005	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	*Umbrina coroides*	0.005	0.004	0.005	0.005	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Small pelagic fishes	0.97	0.97	0.97	0.97	0.00	0.00	0.00	0.97	0.1	0.0001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	*Atlantorchestoidea brasiliensis*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	*Emerita brasiliensis*	0.00	0.003	0.00	0.00	0.90	0.0001	0.004	0.01	0.001	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10
14	*Excirolana armata*	0.00	0.00	0.00	0.00	0.098	0.00	0.001	0.00	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01
15	*Excirolana braziliensis*	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04
16	Unidentified Amphipod	0.00	0.00	0.00	0.00	0.003	0.00	0.01	0.00	0.10	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.001	0.001
17	*Hemipodia californiensis*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	*Olivancillaria vesica*	0.00	0.003	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	Phytoplankton	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	1.00	0.33	0.00	0.33	0.00	0.00
20	Water detritus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.00	0.33	0.50	0.00	0.33	0.50	0.33	0.28	0.28
21	Sediment detritus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.50	0.00	0.33	0.50	0.33	0.57	0.57
22	*Emerita brasiliensis* eggs	0.00	0.00	0.00	0.00	0.00	0.99	0.98	0.00	0.20	0.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	**Sum**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**

2. Discussão geral

A ecologia de praias arenosas tem tido avanços significativos nas últimas décadas (Nel et al., 2014). A consolidação de teorias ecológicas e a melhoria em técnicas de amostragem têm contribuído na aplicação de pesquisas básicas no manejo e conservação desse ecossistema ameaçado pelas atividades antrópicas (Defeo et al., 2009; Nel et al., 2014). Por outro lado, o estudo ecológico em praias arenosas ainda lida com inúmeras limitações, principalmente devido à natureza dinâmica do ecossistema (Modde e Ross, 1981; Schlacher et al., 2015). Tais limitações incluem: 1. Dificuldade em separar alterações naturais e induzidas pela ação antrópica nas populações e comunidades (Defeo et al., 2009); 2. Constante troca de espécies entre os limites oceânicos e terrestres (Schlacher et al., 2015); 3. Intenso hidrodinamismo e risco de subamostragem de organismos (p.ex. peixes) (Rome, 1990).

O número de espécies de macroinvertebrados e peixes coletado na praia de Grussaí não ultrapassou 9 e 11, respectivamente (Apêndices 1A e 2A). Na Praia Grande foram coletados no máximo 16 espécies de macroinvertebrados e 5 espécies de peixes em uma campanha de amostragem (Apêndices 1B e 2B). Praias arenosas se caracterizam pela elevada dominância de poucas espécies comparadas a outros ecossistemas costeiros, em razão do intenso hidrodinamismo (Lasiak et al., 1984; McLachlan e Brown, 2006). A eficiência na captura de peixes por arrasto na zona de surfe, por exemplo, pode ser reduzida com o aumento da ação de ondas em praias (Romer, 1990). A amostragem pode ainda ser ineficiente, devido ao hábito demersal ou capacidade de algumas espécies de perceber visualmente a presença das redes (p. ex. *Pomatomus saltatrix*) (Romer, 1990). A água mais turva da Praia de Grussaí comparada a Praia Grande, por exemplo, pode explicar a captura de mais espécies nessa praia. Entretanto, é improvável que tais limitações tenham comprometido os resultados obtidos no presente estudo. Espécies da família Mugilidae, *Pomatomus saltatrix* e peixes demersais como *Menticirrhus americanus, Dactylopterus volitans* e Ariidae foram frequentes nos arrastos (>10%), mesmos em campanhas com maior ação de ondas (ver capítulo 1). Em adição, a estabilização das curvas de rarefação da maioria das campanhas de coleta indica que o número de espécies de macroinvertebrados e peixes não foi subestimado em razão do esforço amostral (Apêndices 2 e 3). O número máximo de espécies aves marinhas registrado em uma campanha de coleta foi 3, dada a elevada dominância de *Sula leucogaster* que nidifica em ilha localizada a 500 m da Praia Grande (Tavares et al., 2016).

Estudos em praias estuarinas lidaram com a dificuldade em separar modificações antrópicas e naturais na estrutura de comunidades de peixes, mas também verificaram a influência humana nesse ambiente dinâmico (Pereira et al., 2015; Franco et al., 2016). Os resultados do presente estudo também evidenciaram a forte influência de fatores naturais, particularmente na salinidade, na comunidade de peixes da Praia de Grussaí, em razão da maior influência da vazão do Rio Paraíba do Sul no verão. As coletas dos parâmetros abióticos foram pontuais (duas campanhas por temporada), mas seguiram um padrão para a região, de maiores temperaturas e precipitação no verão (Apêndice 4). Da mesma forma, na Praia Grande a forte influência hidrodinâmica na comunidade de peixes pôde ser constatada, com base em dados de altura e período de ondas coletados em todas as campanhas de amostragem, que corroboram aos estudos anteriores na mesma praia (Gaelzer e Zalmon, 2003). Portanto, as coletas pontuais dos dados abióticos refletem os padrões de ambas as praias e podem ser considerados fortes estruturadores da comunidade de peixes da zona de surfe. Por outro lado, na Praia Grande a interação da influência do hidrodinamismo com a pressão humana foi clara, de modo que somente na área urbanizada, verificou-se menor riqueza, abundância e diversidade de peixes no verão, período de alta temporada turística e escassez de presas nesse setor. Assim, apesar das dificuldades em separar alterações naturais daquelas induzidas pela ação antrópica em ecossistemas dinâmicos como praias arenosas, o uso de áreas controle permitiu inferir que peixes, particularmente residentes e que se alimentam de macroinvertebrados de praias sensíveis à pressão humana, evitam o setor urbanizado da Praia Grande durante o período de alta temporada turística.

Modificações induzidas pelo homem na biomassa de macroinvertebrados e na dieta de peixes nas praias estudadas tiveram influência também no funcionamento trófico do ecossistema. Com base em modelos tróficos construídos no programa ECOPATH, verificou-se menor eficiência na transferência de energia entre níveis tróficos e no indicador de ciclagem do ecossistema em praias urbanas, comparadas as áreas de pouca visitação humana. Tais resultados corroboram ao encontrado por Reyes-Martinez et al. (2014) em praias na Espanha e elucidam que macroinvertebrados são componentes-chave em praias arenosas. A ausência de padrões sazonais nas métricas de rede trófica pode ser considerada uma das principais limitações aplicação dos modelos. Entretanto, a biomassa e o número reduzido de algumas espécies considerando os diferentes períodos de amostragem separadamente (verão e inverno) impediram a parametrização dos modelos, descrição adequada da dieta de peixes e a interpretação dos padrões em nível ecossistêmico. Entretanto, outros estudos também construíram modelos tróficos em praias com base em médias anuais de biomassa das espécies, mas com a maior parte dos dados obtidos na literatura (Lercari et al., 2010; Reyes-Martinez et al., 2014). Os modelos tróficos do presente estudo foram construídos considerando principalmente dados coletados em campo e forneceram informações importantes que poderão ser úteis na elaboração de estratégia de mitigação de impactos em praias arenosas.

As principais limitações do uso do ECOPATH resultam da premissa de sistema estável em que se baseiam os modelos (Christensen e Waters, 2004). As praias arenosas são ecossistemas dinâmicos, de modo que variações temporais tem influência direta na biomassa das espécies (McLachlan e Brown, 2006). Isso significa que a aplicação dos modelos considerando médias de dados pontuais constitui um risco, no que diz respeito à confiabilidade dos modelos gerados. De fato, a construção de modelos tróficos com base em médias obtidas a partir de séries temporais de longo prazo fornecem dados mais confiáveis. Entretanto, pesquisas de longa duração em praias arenosas são escassos no Brasil. Além disso, os estudos em praias arenosas são frequentemente compartimentalizados, isto é, consideram zonas (p. ex zona de surfe e entremarés) ou grandes grupos (macroinvertebrados e peixes) separadamente (Nel et al., 2014). A abordagem compartimentalizada em praias, embora seja fundamental para a identificação da resposta individual das espécies à pressão humana, não permite a visão holística obtida por modelos ecossistêmicos, necessária para a elaboração de medidas de gestão visando à manutenção do funcionamento do ecossistema e de bens e serviços ambientais.

Críticas aos modelos tróficos normalmente giram em torno da agregação dos dados de componentes funcionalmente similares ou espécies de um ecossistema em uma “caixa preta”, resultando na descrição tendenciosa e incompleta das interpelações no sistema e gerando falhas na interpretação dos resultados (Angelini, 1999). O presente estudo agrupou poucas espécies em grupos funcionais, particularmente pequenos peixes pelágicos, uma vez que a biomassa dessas espécies foi reduzida e inviabilizou o ajuste dos modelos e interpretação dos padrões gerais (ver capítulo 2). Entretanto, é importante ressaltar que a inserção dos dados, bem como os ajustes necessários para a construção dos modelos seguiram criteriosamente as recomendações e manuais disponíveis na literatura (Lassale et al., 2014; Heymans et al., 2016), permitindo qualidade e interpretações confiáveis dos modelos construídos. Portanto, apesar das limitações dos modelos, o presente estudo forneceu resultados satisfatórios de possíveis mudanças induzidas pela ação antrópica no funcionamento das praias arenosas como um ecossistema funcional e não somente dos efeitos da pressão humana em compartimentos isolados.

A proporção de presas na dieta de predadores é uma das informações básicas necessárias para a construção dos modelos tróficos no ECOPATH. A determinação da dieta de peixes, principais predadores em praias, lida com a possível subestimação/superestimação de presas por meio das análises de conteúdo estomacal (Hyslop, 1980; Roñones et al., 2002). Tais limitações incluem: 1. Exatidão na contagem do número de indivíduos muito digeridos; 2. Pesagem de partes de presas que não representam a importância das mesmas na dieta do predador; 3. Digestibilidade diferencial de diferentes presas (Hyslop, 1980; Roñomes et al., 2002). O uso de marcadores químicos, como isótopos estáveis, supera tais limitações, entretanto não substituem a análise de conteúdo estomacal, já que tais marcadores não têm resolução taxonômica necessária para inferir sobre relações tróficas específicas (Hobson e Clark, 1992). Variações ontogenéticas também podem ter influência direta na dieta dos peixes em praias (Monteiro-Neto e Cunha, 1990), entretanto o comprimento padrão das espécies de peixes não variou significativamente na comparação entre setores (Apêndice 5). Apesar das limitações inerentes às análises de conteúdo estomacal, o objetivo do presente estudo não foi descrever minuciosamente a dieta das espécies de peixes, que por sua vez, exige um número de indivíduos elevado, séries temporais amplas e técnicas matemáticas para estimar o peso real de presas recuperadas (Bittar e Di Beneditto, 2008). Em adição, tais limitações foram possivelmente minimizadas, considerando a baixa diversidade e biomassa reduzida de presas em praias arenosas.

O manejo de praias arenosas é voltado tradicionalmente para a manutenção e restauração de características geomorfológicas importantes na proteção da linha costeira (Schlacher et al., 2008). Os aspectos ecológicos raramente são considerados (Micallef e Williams, 2002). A ausência de interação entre ecólogos e gestores e o baixo apelo conservacionista de praias arenosas são citadas como possíveis razões para a ineficiência no manejo ecológico do ecossistema (Schlacher et al., 2008). A vulnerabilidade de macroinvertebrados à pressão humana em praias brasileiras é amplamente divulgada na comunidade científica (Neves e Benvenutti, 2006; Veloso et al., 2006; Veloso et al., 2008; Cardoso et al., 2016; Machado et al., 2016). Os resultados do presente estudo também ressaltaram a importância ecológica de macroinvertebrados e as consequências ecossistêmicas da redução da sua biomassa em praias urbanas. Entretanto, macroinvertebrados são organismos inconspícuos e de baixo interesse conservacionista.

O termo "espécie-bandeira" é usado frequentemente para caracterizar espécies promotoras da conservação em maior escala, já que a sua proteção resulta na conservação de inúmeras outras espécies e no funcionamento de sistemas naturais (Dietz et al., 1994). A reintrodução do mico-leão-dourado, espécie ameaçada de extinção, na mata atlântica é um exemplo de sucesso no uso de espécies-bandeira em programas de preservação e recuperação de habitats degradados (Kierulff e Oliveira, 1994; Ruiz-Miranda et al., 2006). A Praia Grande é uma praia de apelo turístico nacional e abriga inúmeras espécies que tem potencial para serem utilizadas como espécies-bandeira, como a ave marinha *Sula leucogaster* e a anchova *Pomatomus saltatrix*, que tem elevado valor comercial. Ambas as espécies foram negativamente afetadas pela intensa pressão humana em área urbana e são popularmente conhecidas. A Praia de Grussaí, praia de apelo turístico regional, também abriga espécies de relevância comercial, como *Mugil* sp., como destacado no capítulo 1, embora os efeitos da urbanização nessa espécie não tenham sido evidentes. Portanto, a Praia Grande parece ter maior potencial para o uso de espécies-bandeira. A educação ambiental é uma estratégia de médio a longo prazo para a disseminação do conhecimento acerca de tais espécies e o seu uso efetivo nos programas de conservação ambiental (Dietz et al., 1994).

Medidas de curto prazo para a conservação de praias arenosas e da sua biodiversidade, como a redução da emissão de resíduos sólidos e do pisoteio (aglomeração de pessoas) também foram sugeridas no presente estudo. O aumento do número de lixeiras é uma medida simples e viável economicamente e pode ser aplicada em ambas as praias para reduzir a quantidade de lixo nas praias. Da mesma forma, o aumento das opções de lazer ao longo da praia pode proporcionar maior dispersão das pessoas e redução do impacto do pisoteio. Entretanto, o sucesso da aplicação de tais medidas, possivelmente depende de estudos socioeconômicos *a priori* (Santos et al., 2005). Santos et al., 2005 destacou que a quantidade de lixo na praia pode ter relação direta com o grau e escolaridade dos visitantes e não necessariamente com a quantidade de lixeiras, por exemplo. Dependendo do perfil dos visitantes, a educação ambiental, assim como proposto para disseminação do conhecimento acerca das espécies-bandeira em potencial, também deve acompanhar as medidas de curto prazo aqui propostas.

Em resumo, o presente estudo forneceu inúmeras informações importantes para a ecologia de praias arenosas. A maior parte dos estudos é compartimentalizado, limitando o entendimento das consequências da urbanização para as praias como ecossistemas funcionais. As principais imitações logísticas e de amostragem inerentes ao estudo de praias parecem ter sido minimizadas. Os resultados obtidos tem potencial de aplicação no manejo e conservação desse ecossistema ameaçado pela ocupação urbana das regiões costeiras. Estudos futuros devem priorizar a identificação detalhada dos requerimentos de habitat, bem como possíveis mecanismos e impactos subletais responsáveis pela redução na abundância de espécies-bandeira em potencial em praias (p.ex. aves costeiras e caranguejo-fantasma *Ocypode quadrata*), acompanhados do entendimento do perfil socioeconômico dos visitantes das praias.Tais informações podem ressaltar a importância da manutenção de características naturais de habitat e ampliar a divulgação de praias arenosas como ecossistemas ameaçados e de elevado valor ecológico, facilitando o manejo voltado para a conservação.

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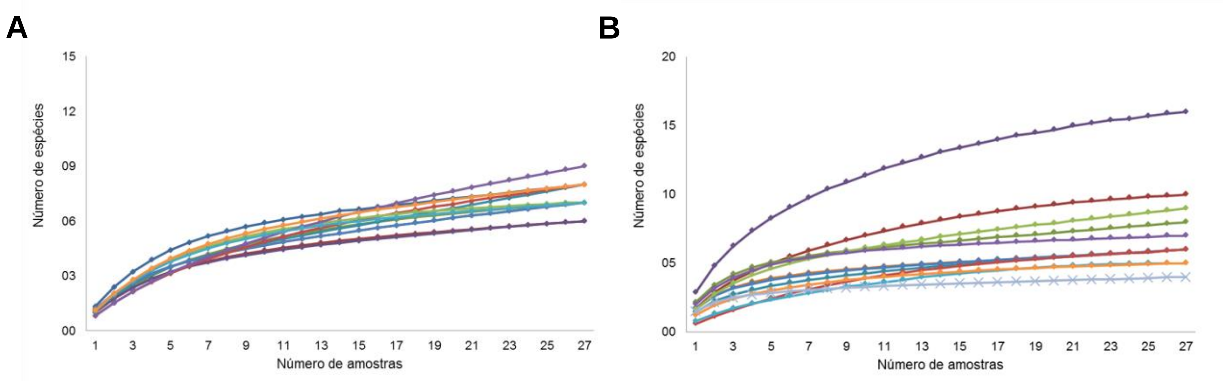
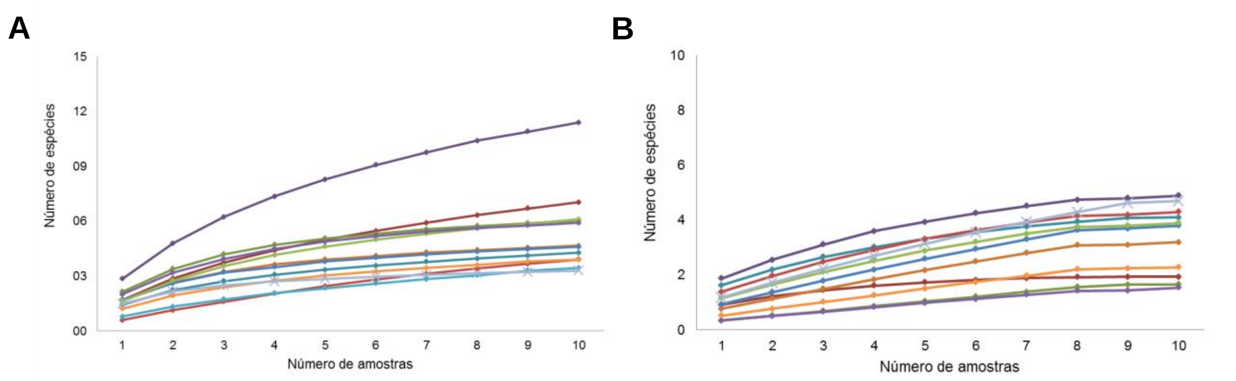
4. Appendices

Apêndice 1. Lista e contribuição de todos os coautores para a submissão e publicação dos artigos científicos que compõem a dissertação.

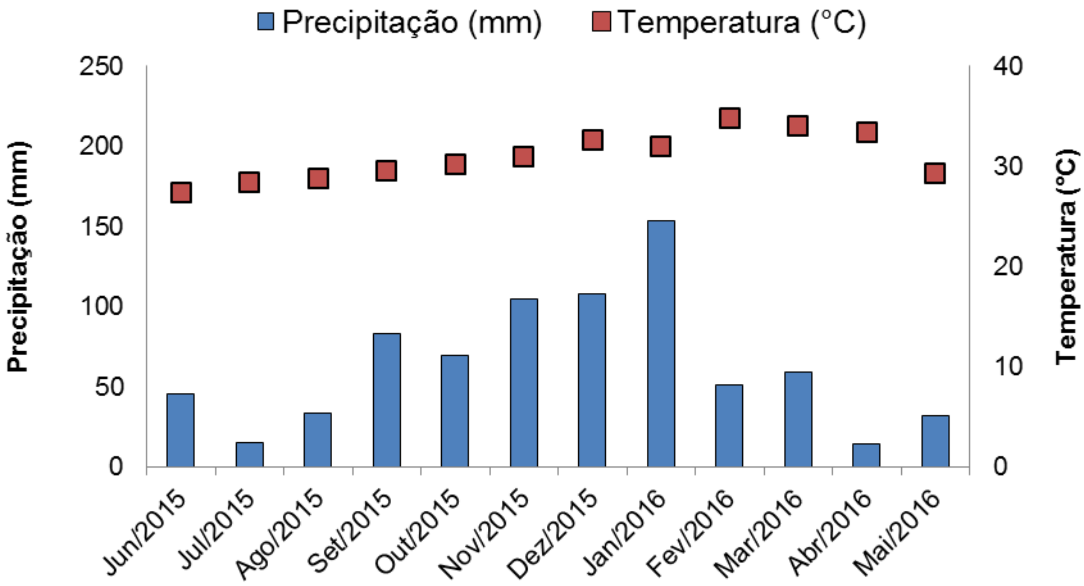
Coautor	Capítulos	Contribuições
Davi Castro Tavares	2	Coleta de dados no campo Coleta e processamento de imagens de satélite Mapa da área e estudo Interpretação e discussão dos resultados Revisão do manuscrito
Danilo Freitas Rangel	2	Coleta de dados no campo Levantamento de informações das aves marinhas inseridas nos modelos tróficos Interpretação e discussão dos resultados Revisão do manuscrito
Júlia Gomes Landmann	1	Coleta de dados no campo Levantamento bibliográfico sobre peixes da zona de surfe Interpretação e discussão dos resultados Revisão do manuscrito
Luiz Ricardo Gaelzer	1	Coleta de dados no campo Análise e interpretação dos dados Revisão do manuscrito
Marjorie Cremonez Suciu	2	Coleta de dados no campo Levantamento de informações dos macroinvertebrados inseridas nos modelos tróficos Interpretação e discussão dos resultados Revisão do manuscrito
Ilana Rosental Zalmon	1 e 2	Orientação oficial Coleta de dados no campo Interpretação e discussão dos resultados Revisão do manuscrito



Apêndice 2.Curva de rarefação do número de espécies de macroinvertebrados em relação ao número de amostras coletadas na Praia de Grussaí (A) e Praia Grande (B). As linhas representam as 12 campanhas de amostragem (duas campanhas de verão, duas campanhas de inverno e três setores).



Apêndice 3. Curva de rarefação do número de espécies de peixes em relação ao número de amostras coletadas na Praia de Grussaí (A) e Praia Grande (B). As linhas representam as 12 campanhas de amostragem (duas campanhas de verão, duas campanhas de inverno e três setores).



Apêndice 4. Valores mensais de temperatura máxima média e precipitação total de junho de 2015 á maio de 2016. Fonte: Instituto Nacional de Meteorologia (INMET).

Apêndice 5. Comprimento padrão (CP) médio (mínimo-máximo) e número de indivíduos que tiveram seus estômagos analisados (n) das espécies de peixes coletadas nos setores urbanizado e não-urbanizado das praias de Grussaí e Praia Grande.

	Urbanizado		**Não-urbanizado**
Praia de Grussaí	CP (min-max) (cm)	n	CP (min-max) (cm)
Ariidae	9,6 (7,4 -15,5)	17	10,7 (7,5 -13,4)
Menticirrhus americanus	8,8 (6,0 -10,4)	11	8,5 (6,8 -12,7)
Polydactylus virginicus	5,9 (4,1 - 8,7)	16	7,1 (6,1- 8,7)
Trachinotus sp.	5,4 (4,3 - 7,4)	26	4,9 (2,8 - 6,7)
Praia Grande	CP (min-max) (cm)	n	CP (min-max) (cm)
Dactylopterus volitans	14,2 (5,1 - 19,2)	11	14,9 (5,0 - 20,8)
Diplodus argenteus	3,1 (2,4 - 3,9)	36	2,9 (2,9 - 2,9)
Menticirrhus americanus	4,6 (1,6 - 8,4)	53	6,2 (4,6 - 8,7)
Pomatomus saltatrix	4,6 (3,8 - 6,7)	42	-
Trachinotus carolinus	2,5 (1,7 - 4,3)	40	3,1 (2,2 - 5,7)
Umbrina coroides	5,4 (2,9 - 8,0)	54	-

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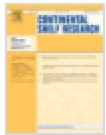

Does human pressure affect the community structure of surf zone fish in sandy beaches?

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

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Highlights

- We investigated whether urbanized beaches affect surf zone fish community.
- Fish richness and abundance was significantly lower in high tourist pressure areas.
- Visitors' abundance and macrofaunal prey density show a negative association.
- Dispersion of recreational activities is an important mitigation action.
- Commercial surf zone fish should be used as iconic species in management programs.