Journal of Sea Research 128 (2017) 61–75

Contents lists available at ScienceDirect

Journal of Sea Research

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

Surf zone fish diet as an indicator of environmental and anthropogenic influences

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ARTICLE INFO

Keywords:
Feeding
Human pressure
Predation
Solid waste
Insect

ABSTRACT

Changes in species' abundance have been used as indicators of environmental and anthropogenic disturbances. However, sublethal, e.g., diet, changes should be detected before some alterations in the composition and structure of fish assemblages occur as a result of ecological negative impacts. The objective of the present study was to assess possible changes in surf zone fish diet in response to environmental and anthropogenic disturbances. Surf zone fish were sampled and their stomach contents were analyzed on two sandy beaches under different levels of human pressure in Southeastern Brazil. Habitat variables related to seasonality, food availability, anthropogenic disturbance, upwelling and river influence were measured as follows: (1) wave height; (2) water temperature; (3) intertidal macroinvertebrates abundance; (4) solid waste amount; (5) salinity; (6) particulate organic carbon (POC) and (7) chlorophyll *a* (Chl a). Our results showed the influence of seasonality, prey abundance and hydrodynamics in prey selection, and diet overlap between typical surf zone residents. A literature search was also performed and it shows that insects and *Emerita brasiliensis* eggs, which were the main food item consumed by some surf zone fish at urbanized Brazilian beaches, are unusual worldwide. Furthermore, solid waste was related to high consumption of insects by pompanos fish in urbanized areas, suggesting that this fish diet could be a sublethal indicator of human impact on sandy beaches.

1. Introduction

Sandy beaches and their surf zones are harsh environments distinguished from other marine ecosystems mainly by intense wave action and tide regulation (Beyst et al., 1999). Several species use them as their exclusive habitat or migratory path, but mainly as nursery areas (Jarrin and Miller, 2016). Juveniles and larva of fish species inhabit surf zones, where they gather abundant food resources (e.g. zooplankton and macroinvertebrates) and shelter from predators in the turbid waters (Benazza et al., 2015; Clark et al., 1996). A great diversity of surf zone fish feed opportunistically on large quantities of benthic prey, taking advantage of infauna resuspension by wave action (Lasiak and Mclachlan, 1987).

Food resources in marine environments may be partitioned among fish species, as a result of competition avoidance (Platell and Potter, 2001). Previous studies on fish diets along Brazilian sandy beaches described the feeding habits of either pairs or small groups of species with similar morphology and feeding behavior or belonging to the same family or genera (Andrades et al., 2014; Palmeira and Monteiro-neto, 2010; Rodrigues and Vieira, 2010; Zahorcsak et al., 2000). The results of the studies highlighted the influence of wave exposure, ontogenetic changes and seasonality on fish feeding and diet overlap (Beyst et al., 1999; Niang et al., 2010; Turra et al., 2015; Wheeler et al., 2002). The composition of nearshore invertebrates varies with wave activities and seasonality (Beyst et al., 1999; Schafer et al., 2002). In addition, surf zone fish usually avoid intraspecific competition (i.e. diet overlap) between juvenile and adults, consuming prey of different sizes at different life stages (Mendoza-carranza and Vieira, 2009).

Sandy beaches are currently one the most human-impacted of coastal ecosystems around the world (Defeo et al., 2009). The recreational and tourism values and urban occupation near the beaches are important factors in the loss of environmental quality (Munari et al., 2016). Solid waste and microplastic accumulation, metal pollution, dune suppression, trampling and vehicle traffic pose constant threats to the biodiversity and trophic functioning of this ecosystem (Cardoso et al., 2016; Costa et al., 2010; Hauser-davis and Cardoso, 2017; Munari et al., 2016). Benthic macroinvertebrates, which are potential prey of surf zone fish, have been negatively affected by human activities on beaches worldwide (Schlacher et al., 2016). However, the consequences of these anthropogenic disturbances on diets of benthic feeding fish are unknown.

The diets of surf zone fish have been characterized in impacted

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http://dx.doi.org/10.1016/j.seares.2017.08.003
Received 13 March 2017; Received in revised form 30 July 2017; Accepted 7 August 2017
Available online 09 August 2017

areas, but the studies often neglected control areas to evaluate the human-induced effects (Carlson et al., 1997; Hajisamae et al., 2004). Despite of the continuous and unstructured surf zone appearance and mobility of sandy beaches predators, juvenile and resident fish may display site fidelity in beach environments (Ross and Lancaster, 2002). Thus, fish diet comparison between impacted and control areas in the same beach-arc can indicate small-scale disturbances, since surf zone species are usually generalist and opportunistic feeders on the most locally abundant resources (Turra et al., 2015). Only Wilber et al. (2003) evaluated the effects of beach nourishment but they did not find evidences that this disturbance changes the feeding habitats of surf zone fish. In other ecosystems, fish diets have differed in environments under different levels of anthropogenic or natural disturbance (e.g. hypoxia) (Mcclelland and Valiela, 1998; Pihl et al., 1992). In addition, diet overlap among fish in highly impacted areas may be due to human pressures and food scarcity (Hajisamae et al., 2004).

Bioindicators have been suggested as rapid assessment tools for evaluating human impacts on sandy beaches (Neves and Benvenutti, 2006; Ugolini et al., 2008; Veloso et al., 2011). The indicators should respond predictably to human stressors, since declines in abundance are a result of lethality (Schlacher et al., 2016, 2016). However, other sublethal responses, such as changes in feeding habitats and behavior, may be applied to environmental assessment and detection of negative ecological impacts, before lethal effects are manifested (Schlacher and Lucrezi, 2010; Tewfik et al., 2016). Food provides the resources required for maintenance, growth and reproduction, and therefore it is of central importance to ecological studies of fish and their conservation (Gonzales et al., 1996). Besides, diet studies are fundamental to understand the trophic organization of ecosystems and ecological role of fish species (Palmeira and Monteiro-neto, 2010).

The aim of this study was to compare the surf zone benthivorous fish diet in sectors under distinct human pressure on two Brazilian sandy beaches. Similarly to other beaches on the southeast Brazilian Coast, tourism associated with recreational activities and trampling are the main source of disturbance in the urbanized areas, making intertidal macroinvertebrates (i.e. fish food) scarce (Amaral et al., 2016; Costa et al., 2017; Machado et al., 2016). Therefore, we test the hypothesis that surf zone fish of the urban sectors of two Brazilian beaches consume less intertidal macroinvertebrates and show higher diet overlap compared to non-urbanized areas.

2. Materials and methods

2.1. Study area

The study was performed in Grussaí Beach (21°41′39.80″S; 41° 1′23.84″O) and Praia Grande Beach (22°58′23.96″S; 42° 1′57.45″O), located, respectively, in the northern and southeastern regions of the Rio de Janeiro State, Brazil (Fig. 1). The beaches are physically distinct. Grussaí Beach has intermediate morphodynamic (e.g. medium sand size and intense wave action) and it is influenced by the Paraiba do Sul River plume, mainly during the rainy season between October and April (Machado et al., 2016; Marengo and Alves, 2005). Praia Grande Beach is dissipative/intermediate, with a prevalence of fine and medium sand sizes and a gentle slope (Gaelzer and Zalmon, 2008; Machado et al., 2016). It is directly influenced by an upwelling, which is usually more intense in the summer season, rendering the water colder, and richer in nutrient (Valentin and Wanda, 1993). In addition, Grussaí and Praia Grande beaches have a wide coastal strip, including areas under different levels of human pressure (Costa et al., 2017). Therefore, these beaches provide an encouraging environment in which to study the natural and human-induced changes in surf zone fish diet.

We selected three areas in each beach. The first types of areas were urbanized sectors that had a higher number of tourists because of better infrastructure, paved beach access, bars and vendors. These sectors received up to two visitors/m^2 during the high tourist season (December to March), with increasing recreational solid waste density, i.e., food-related items, cigarettes, other plastics, which was higher than that at other beaches worldwide (see Suciu et al., 2017) and decreasing abundance of several macrofaunal species (e.g. *Atlantorchestoidea brasiliensis*, *Hemipodia californiensis*, *Ocypode quadrata* and *Emerita brasiliensis*) and the abundance of other vertebrates (Costa et al., 2017; Machado et al., 2016; Suciu et al., 2017). The second types of areas were non-urbanized sectors that did not have good infrastructure, i.e., paved roads, bars and vendors, to receive tourists and were located in protected areas. Thus, these sectors had low visitation rates, well-preserved dune vegetation and better environmental quality compared to urbanized beaches, i.e., highest macroinvertebrates and lowest solid waste density. The third types of areas were intermediate sectors that shared characteristics with both of the other categories and acted as a transition sector. We used an urbanization index (González et al., 2014) as a proxy for selecting the sectors with different degrees of human pressure (Appendix A).

2.2. Sampling and laboratory procedures

2.2.1. Fish survey

Fish, environmental and human pressure data 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). In each sampling campaign, surf zone fish were collected at flood tide with a beach seine net, 25 m long, 2.5 m high and a stretched mesh size of 10 mm. The fish specimens were fixed in 10% formaldehyde for identification, length measurement and dissection for stomach content analysis (Holden and Raitt, 1974). The food items were identified to the lowest taxonomic level possible or divided into arbitrary prey categories using specific identification guides (Amaral et al., 2006; Serejo, 2004), counted and weighted.

2.2.2. Environmental variables

Water temperature and salinity were monitored during each survey with a Horiba U50 portable multi-parametric probe. Wave height was determined by visual assessment (Machado et al., 2016), because wave exposure may affect fish prey abundance (Garrido et al., 2008; Niang et al., 2010). Particulate organic carbon (POC) and Chlorophyll a (Chl a) were determined in each survey campaign using images taken by the MODIS instrument on the satellite Aqua (NASA), as a proxy of Paraíba do Sul River and upwelling influence at Grussaí and Praia Grande beach, respectively.

2.2.3. Human pressure

Solid waste larger than 1 cm (e.g. food packaging, straws and soda cans) was quantified along five transects perpendicular to the coastline, from the water line to the beginning of the dune vegetation, as an indicator of human impact.

2.2.4. Intertidal prey abundance

Intertidal 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) and fixed in 10% formalin. In the laboratory the organisms were identified and counted (Serejo, 2004; Amaral et al., 2006).