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Behavioural responses of talitrid amphipods to recreational pressures on oceanic tropical beaches with contrasting extension

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ABSTRACT

Ocean sandy beaches are prime sites for human recreation. The integrity of these ecosystems may suffer greatly from tourism-related pressures. Behavioural adaptations of fauna are key traits as responses to environmental pressures and short time changes. In particular, orientation performance of talitrid amphipods to recover the optimal zone on the beach has been proposed as bioindicator of shoreline stability, mainly related to sedimentary dynamics and geomorphological changes. The question focused here was whether recreational activities and urbanisation may influence orientation performance of talitrids on oceanic tropical beaches with contrasting extension (beach length).

Field orientation experiments were performed during Spring 2014 testing populations of the talitrid *Atlantorchestoidea brasiliensis* on four tropical beaches at Rio de Janeiro (Brazil), selected according to their human access (two with and two without public access) and length (two pocket and two extended beaches). The influence of landscape cues on the orientation of talitrids was experimentally tested in two etho-assay conditions: with and without the landscape vision. Talitrids used landscape cues and sun compass to orient seawards and the highest precision of orientation was recorded in the pocket beach without human access. A more scattered response was observed in the urbanised pocket beach under conditions of screened landscape and when the sun was veiled or covered by clouds, showing the importance of the local landscape features in these conditions. The populations from the extended beaches showed a similar and more scattered orientation, which may be interpreted as behavioural plasticity to cope with beach natural changes, disregarding human pressure on the beaches. The behavioural performances of talitrids on the four tropical beaches varied according to different human pressure conditions and beach extension, confirming the reliability of the use of talitrid orientation as bioindicator of beach changeability.

1. Introduction

Sandy beaches are the most extended ecological interface systems between land and sea and are characterised by variable morphological and ecological conditions, resulting in highly dynamic habitats (McLachlan and Brown, 2006). The society greatly values these naturally occurring assets, which, when left intact, may support both ecological processes and sustainable use (McLachlan and Brown, 2006; Schlacher et al., 2007, 2015). Coastal urbanisation and recreational activities may create direct pressures on beach ecosystems, which may compromise their ecological integrity and in consequence economic value and even public appeal (Brown and McLachlan, 2002; Defeo et al., 2009; Harris et al., 2015).

The general paradigm of beach ecology holds that beaches are resilient to human uses and recognizes that resident fauna have specific adaptations to inhabit this dynamic environment (McLachlan and Brown, 2006). Beach macrofauna have developed key behavioural adaptations in order to successfully establish on sandy beaches such as mobility, burrowing ability, rhythmicity and orientation, characterised by plasticity to face natural changes (Defeo and Gomez, 2005; Scapini, 2006, 2014). Intensive human use of beaches has been recognised to negatively affect beach fauna and specific impacts of recreational activities are well documented, such as pedestrian trampling (Weslawski et al., 2000; Veloso et al., 2006, 2008; Ugolini et al., 2008; Schlacher and Thompson, 2012; Bessa et al., 2013a, 2014) and damages caused by off-road vehicles (Schlacher et al., 2008), as well as disturbances to behaviour profiles of birds (Schlacher et al., 2013). In this regard, macroinvertebrates have been considered good bioindicators of beach ecological condition, including their taxonomic diversity and

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abundance, range of physiological tolerance to stress, behavioural plasticity and life-history strategies (e.g. Scapini and Ottaviano, 2010; Veloso et al., 2008; Bessa et al., 2013a, 2013b, 2014; Nourisson et al., 2014; Schlacher et al., 2014; Scapini et al., 2015). These traits allow macrofauna to respond to a wide range of potential beach modifications, including possible coastline retreat due to climate global change.

One particular well-studied trait is the orientation behaviour expressed by talitrid amphipods, key species in temperate and tropical sandy beaches, which are able to return to the optimal beach zone (zonal orientation) from a distant point, not directly linked with the goal, using the sun compass and additional cues, e.g., landscape vision, beach slope and wind (reviewed in Scapini, 2006, 2014 and references therein). The sun compass is genetically fixed in populations where the shoreline has not changed in time (long term, allowing several generations, Scapini et al., 1985), while on highly dynamic (eroded, accreting or changing orientation) shorelines talitrids tend to scatter or orient using local landscape features (Ugolini et al., 1986; Scapini et al., 1995). A learning capacity, based on a calibration of sun compass to local landscape cues was observed in populations of the talitrid *Talitrus saltator* from dynamic beaches (Ugolini and Macchi, 1988; Scapini, 2006). There are a considerable number of studies that demonstrate that sandhoppers calibrate the sun compass by adjusting their orientation with respect to local cues, when naturally or accidentally displaced from their optimal zone on the beach (e.g., Fanini et al., 2007; Bessa et al., 2013a, 2013b; Scapini et al., 2015). Accordingly, the orientation of talitrids may represent an immediate response to environmental changes and play a major role in ecosystem resilience under disturbance conditions (Scapini, 2014). This capability have been considered a good estimator of beach perturbations, namely those related with sedimentary modifications, such as the construction of seawalls, beach nourishment and artificial dunes (Fanini et al., 2007, 2009; Scapini et al., 2005; Nourisson et al., 2014; Bessa et al., 2014). Scapini et al. (2015) proposed the sun orientation of talitrid amphipods as a bioindicator of beach stability in terms of shoreline changes due to modified or interrupted sedimentary transport, as observed in extended versus pocket beaches.

The concept of beach stability involves a complex combination of interactions of geologic, oceanographic, meteorological and, to a lesser extent, biological processes and may occur across a broad range of spatial and temporal scales (McLachlan and Brown, 2006). High levels of urbanisation and human activities may also influence beach stability altering their profiles, sedimentary dynamics and consequently may affect beach fauna, but the effects of these impacts are difficult to discern from naturally occurring changes of such dynamic environments (Defeo et al., 2009; McLachlan et al., 2013) and need to be estimated.

Beach ecologists have considered beach length as an important element on beach morphodynamics and surf-zone circulation having consequences for local macrofauna populations (Brazeiro, 1999; McLachlan and Brown, 2006; Cardoso et al., 2012). However, much of the scientific knowledge on beach ecology concerns exposed extended beaches and there is still significant scope for gaining further insights into the way the morphodynamics of smaller (pocket) beaches may influence beach communities and their capacity to withstand potential environmental changes, either natural or human-induced (Deidun and Schembri, 2008; Cardoso et al., 2012; Scapini et al., 2015). Most work on pocked beaches was done in the Mediterranean Basin, where tide and swash regimen are limited in extension, experiments on oceanic tropical beaches were interesting to verify the hypothesis illustrated above of the dependence of macrofauna behavioural adaptations on beach morphodynamics.

The talitrid *Atlantorchestoidea brasiliensis* (Dana, 1853) is one of the most important species structuring the macrofaunal assemblages of exposed sandy beaches of Rio de Janeiro in Brazil (Cardoso and Veloso, 1996, 2001; Cardoso, 2002). Still there was no information regarding their behavioural adaptations, namely orientation strategies to maintain/recover the optimal zone on the beach when displaced under different environmental conditions. A sizeable body of literature has evidenced the intensive human use and habitat changes that occurs on beaches from Rio de Janeiro (e.g. Veloso et al., 2006, 2008; Cardoso et al., 2016) offering the opportunity to test the behavioural skills of the talitrid *Atlantorchestoidea brasiliensis* for the first time on oceanic tropical beaches.

The goal of this study was to provide an assessment of the behavioural adaptations of the talitrid amphipod *Atlantorchestoidea brasiliensis* on tropical beaches, and to analyse the effects of recreational human use and urbanisation of beaches, as well as beach extension on the orientation performances of this species. In particular, the question was open to whether the orientation with landscape cues (high buildings backing the beach) would allow orientation seawards under covered sky. The hypotheses tested were: 1) urbanisation and recreational activities negatively affect talitrid orientation behaviour; 2) populations on pocket beaches show better adapted (more precise seawards) orientation than populations on extended exposed beaches, likely subject to changing sedimentary transport; 3) populations on urbanised beaches use human constructions as landscape cues.

2. Materials and methods

2.1. Study sites and urbanisation level

Four tropical ocean beaches located along 60 km of the coast of Rio de Janeiro (Brazil) were selected to test the behavioural adaptation (i.e. orientation performance) of the talitrid *Atlantorchestoidea brasiliensis* (Fig. 1). Beaches were selected according to their extension: two pocket beaches < 1000 m in length, limited by natural headlands (representing each a cell for sediment transportation and currents) and two extended beaches with a length of several kilometres, exposed to dominant winds and currents. Additionally, these beaches were selected taking into account their recreational uses: i.e. two with free public access and highly urbanised beaches (sensu Veloso et al., 2006) versus two protected beaches where human access is limited (Fig. 1).

For this purpose, the extended (13 km) beach Restinga da Marambaia (23°03′S, 43°30′W) was selected (Fig. 1). This beach has fine sand and is classified as very exposed (according to the classification of McLachlan, 1980), of intermediate morphodynamics type and with a wide surf zone (Caetano et al., 2006; Cardoso et al., 2016). Restinga da Marambaia beach is located in a Brazilian Military area where public human access is not permitted. To assess the effect of beach extension a similarly protected beach with fine sand was selected, but with lower extension (500 m) - the pocket beach Fora (22°57′S, 43°11′W), which is a reflective beach nested in between rocky headlands and is also located in a military area with restricted public visitation (Veloso and Cardoso, 1999).

Additionally, two urbanised beaches with contrasting extension were selected: the extended beach “Barra da Tijuca” and the pocket beach “Prainha” (Fig. 1). Barra da Tijuca (35°15′S, 11°2′W) is an exposed beach 16.5 km long (Fig. 1). The most urbanised section was selected which measures about 8 km (Alvorada) and is interrupted by a protected sector (about 4 km, Reserva), with the remaining 4.5 km also urbanised. This area has free access for public, crowded neighbourhoods and many recreational amenities (restaurants, bars, hotels and boardwalks among others), which provide the ideal conditions for the access of visitors all year-round. In terms of morphodynamics, Barra da Tijuca is an intermediate beach with medium grain size (Veloso et al., 2008). The secluded 800 m long Prainha beach (23°25′S, 43°25′W), which is one of the best-known surfing beaches in Rio de Janeiro; for this reason it is highly frequented all year-round. Cardoso and Veloso (1996) characterised this pocket beach as reflective and exposed with medium sand. Detailed information regarding the sediment properties and classification of beaches (Beach Index and exposure) are available in Cardoso et al. (2016).