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Response of intertidal sandy-beach macrofauna to human trampling: An urban vs. natural beach system approach

Mª José Reyes-Martínez [a, *], Mª Carmen Ruíz-Delgado [a], Juan Emilio Sánchez-Moyano [b], Francisco José García-García [a]

[a] Departamento de Sistemas Físicos, Químicos y Naturales, Universidad Pablo de Olavide, Ctra. Utrera Km 1, 41013 Sevilla, Spain
[b] Departamento de Zoología, Universidad de Sevilla, Av. Reina Mercedes 6, 41012 Sevilla, Spain

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ABSTRACT

Sandy beaches are subjected to intense stressors, which are mainly derived from the increasing pattern of beach urbanization. These ecosystems are also a magnet for tourists, who prefer these locations as leisure and holiday destinations, and such activity further increases the factors that have an adverse effect on beaches. In the study reported here the effect of human trampling on macrofauna assemblages that inhabit intertidal areas of sandy beaches was assessed using a BACI design. For this purpose, three contrasting sectors of the same beach were investigated: an urban area with a high level of visitors, a protected sector with a low density of users, and a transitional area with a high level of human occupancy. The physical variables were constant over time in each sector, whereas differences were found in the intensity of human use between sectors. Density variations and changes in the taxonomic structure of the macrofauna with time were shown by PERMANOVA analysis in the urban and transitional locations whereas the protected sector remained constant throughout the study period. The amphipod *Bathyporeia pelagica* appears sensitive to human trampling pressure and the use of this species as a bioindicator for these types of impact is recommended.

1. Introduction

Ecosystems across the world are being damaged due to the rapid expansion of the human population (Defeo et al., 2009). Coastal areas are particularly vulnerable to this phenomenon, especially given that 41% of the global population lives within the coastal limits (Martínez et al., 2007).

In addition to residential uses, coastal areas – and sandy beaches in particular – have long been a magnet for tourists (Jennings, 2004), who prefer these locations for recreational activities and holiday destinations. Beach ecosystems are therefore subjected to intense stressors as a result of increasing coastal infrastructure, the development of shoreline armoring, beach nourishment, resource exploitation, pollution, and grooming (Schlacher et al., 2007). These activities are mainly the result of the increasing pattern of urbanization of beaches and the improvements of tourist facilities. This trend, in which economic sustainability is preferred over biological sustainability, leads to substantial environmental costs (Davenport and Davenport, 2006) that threaten the ecological integrity of coastal systems (Lucrezi et al., 2009).

Tourism warrants particular attention since it is the economic engine of many countries (Davenport and Davenport, 2006) and involves large numbers of visitors to beaches, especially in the summer season. The high level of human occupation can disrupt coastal ecosystems through a wide range of activities, such as camping (Hockings and Twyford, 1997), the use of off-road vehicles (Schlacher and Thompson, 2008), and other recreational pursuits (Fanini et al., 2014). These actions can modify the natural physical characteristics of beaches and have a direct effect on macrofauna communities and their distribution patterns, which can in turn result in a significant loss of biodiversity (Defeo et al., 2009). A direct effect of the various activities carried out on beaches is human trampling. The effect of trampling on faunal communities is an important topic that has been addressed for different ecosystems, such as rocky shores (Ferreira and Rosso, 2009), coral reefs (Rodgers and Cox, 2003), and mudflats (Rossi et al., 2007). On sandy beaches this issue has been considered from different perspectives; for example, at the population level the effect of human trampling has been well analyzed for supralittoral species of talitrid amphipods (Ugolini et al., 2008; Veloso et al., 2008, 2009; Weslawski et al.,

* Corresponding author.
E-mail address: mjreymar@upo.es (M.J. Reyes-Martínez).

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2000) or ocypodid decapods (Barros, 2001; Lucrezi et al., 2009). On the other hand, at the community level the impact of human trampling has been addressed both in controlled experiments (Moffet et al., 1998) and by field observations involving comparison of highly trampled areas with control zones (Jaramillo et al., 1996; Veloso et al., 2006). The results of these studies have shown a decrease in the abundance of macrofauna within the trampled area. However, this pattern cannot normally be directly attributed to trampling itself, since the highly trampled areas correspond to highly urbanized zones and the response of species may thus be due to a set of influential factors inherent to coastal development or 'compound threats' (Schlacher et al., 2014) rather than to the isolated effect of trampling. To our knowledge, only Schlacher and Thompson (2012) have evaluated the isolated effect of trampling by comparing trampled (access point) and control areas on a beach unmodified by human action. However, the temporal scale was not considered in that study.

When the effect of an impact is analyzed, it is recommended that the experimental designs consider samplings on different time-scales, both before and after a proposed development that may have an impact, and on different spatial-scales (Underwood, 1994). The information obtained in this way can be used to distinguish between natural changes and those that are attributable to impacts, and it also allows the magnitude of the impact to be measured (Underwood, 1992).

Before/After/Control/Impact (BACI) design enables the exploration of a wide range of responses, such as changes in abundance, diversity, richness, biomass, or body condition (Torres et al., 2011). BACI is therefore a robust design to detect human impacts (Aguado-Giménez et al., 2012).

Beach fauna plays a major role in the functioning of beach ecosystems (McLachlan and Brown, 2006). Benthos are involved in nutrient regeneration (Cisneros et al., 2011), they are trophic links between marine and terrestrial systems (Dugan, 1999; Lercari et al., 2010) and are stranded material decomposers (Dugan et al., 2003; Lastra et al., 2008). The identification of factors that cause disturbance is therefore a crucial task in maintaining the continuity of sandy beach ecosystems. If one primarily considers human trampling, supralittoral species have traditionally been viewed as highly vulnerable (McLachlan and Brown, 2006) although the swash beach area, which is inhabited by the greatest diversity of macrofauna, is most commonly used by people (Schlacher and Thompson, 2012). Studies aimed at determining the effects of pedestrian activity with an emphasis on intertidal species are scarce, despite their potential as a tool in the design of management plans and conservation policies in these ecosystems (Jaramillo et al., 1996). The objective of the study reported here was to quantify and evaluate the effect of human trampling on macrofauna assemblages that inhabit the intertidal area of sandy beaches in a gradient of human pressure. The study was carried out using a BACI design. In this context, the trajectory of density, richness, diversity index, and community taxonomic structure were evaluated before and after an episode of high tourist occupancy. In addition, the most vulnerable species that can be considered as indicators of these types of impact were explored.

2. Material and methods

2.1. Study area

The study was carried out in three sectors of a sandy beach with an anthropogenic pressure gradient. The beach is located in Cádiz Bay in the southwestern region of the Iberian Peninsula (Fig. 1). Cádiz Bay is a shallow (maximum depth of 20 m) mesotidal basin (maximum tide 3.7 m) with a mean wave height of 1 m (Benavente et al., 2002). This coastal area has a subtropical climate with a mean annual temperature of 19 °C and the prevailing winds blow from the West and East (Del Río et al., 2013).

The urban sector of Valdelagrana (36°34′13″N; 6°13′29″W) has a high level of urban development (housing and hotels) and high human occupancy during the summer season. The backshore is occupied by constructions and tourism infrastructure (e.g., parking spaces, streets, boardwalks), which have destroyed the vegetation cover and the dunes system (personal observation). Moreover, this sector is subject to daily mechanical grooming of beach sand to remove debris. In contrast, Levante (36°32′53″N; 6°13′34″W) is a pristine sector that belongs to a protected area (Los Toruños Metropolitan Park). In this area the salt-marsh system in the backshore area is preserved (Veloso et al., 2008) and there is a well-developed dune system that reaches 2 m in height and 50 m in width, with natural vegetation cover that is a key area for nesting and shelter for marine birds species (Buitrago and Anfuso, 2011). This area can only be reached on foot. The intermediate sector (36°33′38″N; 6°13′26″W) is located in the transitional area between Valdelagrana and Levante. This area is not urbanized and is located within Los Toruños Metropolitan Park. The backshore includes a dune system with vegetation cover interrupted by an access path. Visitors also have other facilities and a tourist train transports people from the park entrance to this sector. The protected and intermediate sectors are manually groomed (daily) to remove human debris selectively.

2.2. Sampling procedures

The largest tourist influx in Spain occurs during the summer months (June to August). As a consequence, six sampling campaigns were conducted in each sector (urban, intermediate, and protected) during spring tides; three in each sector before the tourist season (March, April, May 2011) and three in each sector after (September, October, November 2011).

At each site six equidistant and across-shore transects were placed in a 100 m long-shore area. Each transect comprised 10 equidistant points, from the high tide water mark to the swash zone to cover the entire intertidal area. At each sampling level, fauna samples were collected with a 25-cm diameter plastic core to a depth of 20 cm. Samples were sieved on site through a 1-mm mesh sieve, preserved in 70% ethanol, and stained with Rose Bengal. Sediment samples were also collected at each sampling level with a plastic tube (3.5-cm diameter) buried at a depth of 20 cm. The beach-face slope was estimated by the height difference according to Emery (1961).

The macrofauna were quantified and identified in the laboratory and the sediment characteristics (mean grain size, sorting coefficient, sand moisture, and organic matter content) were determined. The mean grain size was determined by sieving dry sediment through a graded series of sieves (5, 2, 1, 0.5, 0.25, 0.125, and 0.063 mm) according to the method described by Guitian and Carballas (1976). Sand moisture was measured by the weight loss after drying the sediment at 90 °C. The organic matter content was estimated as the difference between dry sediment weight and sediment weight after calcination at 500 °C.

The number of users observed at each sector was used as a proxy to quantify the human trampling intensity. A total of six human censuses were conducted; three censuses were performed (1 census per month at each sector) at the spring tide during the period of the greatest inflow of visitors (June, July and August, 2011); and three censuses were conducted before impact. The counts were performed every 30 min for a 6 h period (until high tide) and were conducted in the same zone as the macrofauna sampling in an area of 50 m along the shore × beach width. In