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Variations in macrobenthic community structure in relation to changing environmental conditions in sandy beaches of Argentina

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ABSTRACT

This study describes for the first time the intertidal macrobenthic community of exposed sandy beaches located near the Bahía Blanca Estuary (38°S) and reports the physical characterization of this coastal fringe. The main objective of the study was to link environmental variables to biotic information, analyzing the results in the context of the *Swash Exclusion Hypothesis (SEH)* and possible estuarine influence. Four beaches were sampled seasonally at different distances from the mouth of the Bahía Blanca Estuary. To characterize the morphodynamic state of the beaches, the Dean parameter (Ω) was calculated. Multivariate analyses were used to assess benthic community structures and their relationships with physical variables. The two beaches located closest to the Bahía Blanca Estuary were classified as intermediate and those located further from the estuary as dissipative. Richness, diversity and biomass of intertidal macrobenthic communities varied with the *SEH*, increasing towards the dissipative beaches. However, total density was higher on intermediate beaches, possibly because of nutrient-rich silt-clay sediment input from the estuary, enabling them to maintain a higher density of organisms than dissipative beaches. The estuary acts as a moderator of habitat hardness, which together with the morphodynamic state of the beaches is an important factor in the structuring of the macrobenthic community along this coastal fringe.

1. Introduction

Sandy beaches are the most common environments on coastal zones and these dynamic ecosystems are defined by three factors: tidal regime, wave climate and sediment type. The interactions between these factors determine the morphodynamic state of beaches, which span a continuum from harsh reflective beaches (narrow and steep, under conditions of small tides, low energy waves and coarse sand) to benign dissipative systems (wide and flat, under conditions of large tides, high wave energy and fine sand) with intermediate states between the above extremes (see Short, 1996).

The benthic fauna of sandy beaches includes representatives of most invertebrate groups and is generally dominated by mollusks, crustaceans and polychaetes (Bertness, 1999). The relationships between the intertidal benthic macrofauna and beach morphodynamics have been critical in beach ecology studies and focused on elucidating spatial and temporal patterns along a gradient of contrasting morphodynamic types (McLachlan et al., 1981; McLachlan, 1990; Defeo et al., 1992; Jaramillo et al., 1995; Rodil and Lastra, 2004). These studies showed that the richness, diversity, density and biomass of the macroinvertebrate community generally increase towards the more dissipative morphodynamic beach type. This is called *Swash Exclusion Hypothesis* (*SHE*: McLachlan et al., 1993) and constitutes the fundamental principles of beach ecology, which are integrated into a coherent framework (Defeo and McLachlan, 2005; McLachlan and Dorvlo, 2005).

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Furthermore, sandy beaches are closely linked to their adjacent ecosystems such as estuaries, rivers, streams and coastal lagoons in terms of sediment, freshwater, exchange of organic matter and nutrients (Lercari and Defeo, 1999, 2003, 2006; Lercari et al., 2002). These environments are generally responsible for changes in salinity, temperature, grain size and nutrient load and can also affect the biological organization of the macroinfauna on sandy beaches. In this context, the concurrent effects of beach morphodynamics and the influence of adjacent environments should be considered when modeling large-scale variations in macrofaunal biological descriptors of benthic communities (Lercari and Defeo, 2006). Despite the ecological importance of these interactions, considerable gaps exist in our understanding of the processes involved in the ecological coupling between exposed sandy shores and adjacent ecosystems.

The coastline closest to the Bahía Blanca Estuary in Argentina is characterized by extensive exposed sandy beaches that vary slightly in their morphodynamic state. In contrast to other estuarine areas, the salinity in the external zone of the Bahía Blanca estuary is similar to that of the adjacent continental shelf (Martos and Piccolo, 1988; Piccolo and Perillo, 1990) and the estuary therefore does not generate a strong salinity gradient along the coast. However, it does contribute with high loads of suspended sediment to the adjacent coast (Perillo et al., 2000) and consequently, it appears to be a significant source of nutrients and organic matter. This work describes the intertidal macrobenthic community and the physical features of sandy beaches adjacent to the Bahía Blanca Estuary, to interrogate the relationships between environmental variables and changes in community structure.

2. Materials and methods

2.1. Study area

This study was conducted into a continuous coastal fringe of exposed sandy beaches within the Provincial Nature Reserve Pehuen-Có – Monte Hermoso (39°S; 61°W). The area has a mesotidal regime with semidiurnal tides, low slope and is backed by extensive sand dunes. The mean amplitude ranges between 2.32 and 3.35 m for neap and spring conditions, respectively, with a mean value of 3.10 m (Servicio de Hidrografía Naval, 2009). The area has a temperate climate; the average temperatures oscillate between 14 and 20 °C and the mean annual precipitation is 650 mm (Carbone, 2003; Campo de Ferreras et al., 2004). The prevailing wind directions are from N, NW and NE, whereas the strongest winds come from the S, SE and SW, especially in spring and summer (Servicio Meteorológico Nacional, 1992).

The Bahía Blanca Estuary (38°S; 62°W) has an elongated shape, the inner reach of the estuary is narrow and the mouth is wide and opens to the southwestern Atlantic Ocean. It is a mesotidal estuary, formed by a system of interconnected channels separated by islands and wide tidal flats. The Sauce Chico River and the Naposta Grande creek provide most of the freshwater inflow. However, based on the salinity distribution, only the inner reach behaves as a partially mixed estuary, while the outer one is homogeneous with mean salinities similar to those of the adjacent continental shelf (Martos and Piccolo, 1988; Piccolo and Perillo, 1990).

2.2. Sampling design

Sampling was conducted seasonally during 2010 at four beaches along this continuous coastal fringe, at 25, 27, 50 and 54 km from the external zone of the Bahía Blanca Estuary (Base Baterías), designated as beach 1, 2, 3 and 4 respectively (Fig. 1). At each sampling site, five transects were established equidistant from each other (5 m) and perpendicular to the tide line, from the upper to the lower intertidal zone (swash zone), during daytime and low tide. Each transect was divided into levels, located every 10 m in the middle and upper intertidal, and every 5 m in the lower intertidal. At each level, one sample was taken per transect, with a plastic core of 16 cm diameter and 40 cm depth (area = 201 cm^2) and sieved through a 1 mm mesh. Organisms retained were fixed in 10% formalin and identified to the highest taxonomic separation possible. The wet weight was determined for each species at all sites.

2.3. Environmental characterization

In order to detect environmental variation along the coast studied; the physical variables were measured at the same coastal sites as the biology. Sand samples (six) were taken along a transect perpendicular to the tide line, from the upper to the lower intertidal zone (swash zone), with a plastic cylinder of 10 cm diameter and 10 cm depth (area = 78.5 cm^2). Sand samples were washed, dried, homogenized and weighted before mechanically sieving through the traditional sieves column. Mean grain size, sorting, skewness and kurtosis were computed according to Folk and Ward (1957) and results were expressed as φ values ($\varphi = -\log_2$ diameter in mm). The pelitic fraction (gr), defined as the silt-clay fraction (<63 μm) was also calculated for each sand sample. Wave height (m) was determined by measuring breaking waves with graduated poles against the horizon (Emery, 1961). Wave period (s) was estimated as the time interval between consecutive breaking waves, measured with a stop-watch. Temperature (°C), turbidity (UNT) and salinity were obtained with a digital multisensor Horiba U-10. Salinity was measured using the Practical Salinity Scale. To characterize the seasonal morphodynamic state of the beaches, the Dean parameter (Ω) was employed. This index allows to define how reflective or dissipative a beach is, and is defined as:

$$\Omega = \mathrm{Hb}/\mathrm{Ws.T},$$

where Hb is the wave height of the surf (m), Ws is sand fall velocity (m s^{-1}) and T is the wave period (s). The values of $\Omega < 2$ represent reflective beaches, whereas $\Omega > 6$ defines dissipative ones and $2 < \Omega < 6$ characterizes intermediate beach states (Short, 1996).

The physical variables measured (temperature, salinity, wave height, wave period, turbidity) and the variables calculated (mean grain size and pelitic fraction of the sediments) were compared between beaches by one-way ANOVA. Environmental variables were also analyzed by non-metric multidimensional scaling analysis (nMDS), from a similarity matrix calculated by the Euclidean distance index (with normalized data). The differences between groups was evaluated by one-way analysis of similarities (ANOSIM method, global test and pairwise tests), at a significance level of $p < 0.05$ and R statistic > 0.5.

2.4. Biological characterization

Species abundance (*IST*, individuals m^{-1}) and biomass (*BST*, g m^{-1}) per strip are given by averaging the density or biomass q (individuals m^{-2} or g m^{-2}) in each sampling station i of all m samples pertaining to transect r (q_m) and multiplying by the corresponding width of the surveyed area (w) (Defeo, 1996):

$$IST, BST = \left[\sum_{i=1}^{m}(qi)/n\right]w$$

Both measures were employed in order to avoid biased results as a consequence of changing beach profile during rough and calm