



## Sediment dynamics modulated by burrowing crab activities in contrasting SW Atlantic intertidal habitats

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### ABSTRACT

Biogenic bottom features, animal burrows and biological activities interact with the hydrodynamics of the sediment–water interface to produce altered patterns of sediment erosion, transport and deposition which have consequences for large-scale geomorphologic features. It has been suggested that depending on the hydrodynamic status of the habitat, the biological activity on the bottom may have a variety of effects. In some cases, different bioturbation activities by the same organism can result in different consequences. The burrowing crab *Neohelice granulata* is the most important bioturbator at SW Atlantic saltmarshes and tidal plains. Because of the great variety of habitats that this species may inhabit, it is possible to compare its bioturbation effects between zones dominated by different hydrodynamic conditions. Internal marsh microhabitats, tidal creeks bottoms and basins, and open mudflats were selected as contrasting zones for the comparison on a large saltmarsh at Bahía Blanca Estuary (Argentina). Crab burrows act as passive traps of sediment in all zones, because their entrances remain open during inundation periods at high tide. Mounds are generated when crabs remove sediments from the burrows to the surface and become distinctive features in all the zones. Two different mechanisms of sediment transport utilizing mounds as sediment sources were registered. In the first one, parts of fresh mound sediments were transported when exposed to water flow during flooding and ebbing tide, with higher mound erosion where currents were higher as compared to internal marsh habitats and open mudflats. In the second mechanism, mounds exposed to atmospheric influence during low tide became desiccated and cracked forming ellipsoidal blocks, which were then transported by currents in zones of intense water flow in the saltmarsh edge. Sedimentary dynamics varied between zones; crabs were promoting trapping of sediments in the internal saltmarsh ( $380 \text{ g m}^{-2} \text{ day}^{-1}$ ) and open mudflats ( $1.2 \text{ kg m}^{-2} \text{ day}^{-1}$ ), but were enhancing sediment removal in the saltmarsh edge (between 10 and  $500 \text{ g m}^{-2} \text{ day}^{-1}$  in summer). The implication is that biologically mediated sedimentological changes could be different among microhabitats, potentially leading to contrasting geomorphologic effects within a particular ecosystem.

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### 1. Introduction

Biological activity has important effects in terrestrial, marine and intertidal sediment structure, either stabilizing or destabilizing these bottom environments (Meysman et al., 2006). For example, in marine and intertidal systems, meiofaunal organisms secrete mucus while feeding (e.g., Riemann and Schrage, 1983;

Klause, 1986), and other organisms produce organic coating in the walls of burrows which enhance sediment cohesion (e.g., Aller, 1983; Watling, 1991). These biostabilization processes largely influence intertidal sediment strength by increasing cohesion mainly through secretion of polymers (Dade et al., 1991; Paterson, 1997). Extracellular polymeric substances (EPS) excreted by microphytobenthic organisms can also increase sediment stabilization (Decho, 2000) by formation of biofilms. However, destabilization of cohesive sediments may be promoted by macrofaunal bioturbation, which directly affects sediment porosity and permeability (Widdows et al., 1998). In addition, invertebrates may consume microphytobenthic organisms thus indirectly promoting sediment destabilization (Daborn et al.,

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1993). Thus, different biological activities can stabilize or destabilize intertidal sediments significantly affecting sediment transport (e.g., Nowell et al., 1981; Wood and Widdows, 2002) and geomorphology (Murray et al., 2002).

Within biological processes, burrowing activity can affect sediment erosion, transport, and sedimentation patterns (e.g., Cadée, 2001). A burrow can be a temporary excavation made by an organism while it slides through sediment or while it settling from the water column (e.g., Jones and Jago, 1993). In both cases, construction of burrows significantly affects the structure of the sediment since the cohesive nature of the sediment matrix is broken during this process (Jumars and Nowell, 1984). Active burrowing species can increase the rates of erosion and the mobility of the sediment, particularly when occurring at high densities (Posey, 1987; Talley et al., 2001; Perillo et al., 2005). While constructing burrows, these organisms bring sediments to the surface where it will be available for transport by currents (Murray et al., 2002) and waves. However, intertidal decapods often construct open burrows with funnel-shaped entrances that facilitate trapping of organic matter and sediment (e.g., Nowell et al., 1981; Suchanek, 1983; Botto and Iribarne, 2000; Botto et al., 2006). Furthermore, it is expected that burrowing activity will have different consequences depending on the hydrodynamic conditions where the activity occurs (see Murray et al., 2002). Thus, in habitats where flow energy has low values, it is expected that burrowing animals will produce trapping of sediments; whereas in habitats with high flow energies the removal rates of sediments could be increased by burrowing activity.

In the SW Atlantic estuaries and embayments, both tidal flats and salt marshes vegetated by species of *Spartina* and *Sarcocornia* are dominated by the burrowing crab *Neohelice granulata* (e.g., Spivak et al., 1994; Iribarne et al., 1997; Bortolus and Iribarne, 1999; Iribarne et al., 2005). This crab species construct vertical burrows of up to 10 cm in diameter (Iribarne et al., 1997; Botto and Iribarne, 2000) that can reach up to 1 m depth in vegetated marshes (Iribarne et al., 1997) where crabs are herbivorous in contrast to tidal flats where crabs are mainly deposit feeders. The burrows remain open during high tide periods and generally remain full of water during low tide (Iribarne et al., 1997; Botto and Iribarne, 2000). Furthermore, these burrows act as passive traps of sediment and detritus in open mud flats (Botto and Iribarne, 2000; Botto et al., 2006). Depending on their plastic morphology (i.e., funnel-shaped entrances or tubular-shaped entrances), these burrows trap both suspended particles and bedload material respectively (Botto et al., 2006). The funnel-shaped entrances and the bed roughness generated by crabs are largely responsible for this effect (Botto et al., 2006). Crabs also remove a large quantity of sediment (up to 5 kg day<sup>-1</sup> m<sup>-2</sup>, Iribarne et al., 1997) while constructing and maintaining burrows and the excavated sediment is deposited in the surface often forming mounds near burrow entrances (Botto and Iribarne, 2000). Recent studies showed that *Neohelice granulata* may facilitate tidal creek formation and further growth at SW Atlantic salt marshes (Perillo and Iribarne, 2003a; Perillo et al., 2005; Minkoff et al., 2006; Escapa et al., 2007), thus enhancing marsh erosion (Perillo and Iribarne, 2003b).

Thus, to compare the effects that burrowing activities by *Neohelice granulata* has on sediment dynamics in contrasting intertidal habitats (i.e., with different hydrological status) is the main goal of this study. With this purpose we (1) evaluate the distribution, architecture and density of crab burrows in different intertidal habitats inhabited by crabs, (2) quantify the trapping of sediments by burrows in the different habitats, (3) quantify the amount of sediment which is transported due to crab activities, and (4) estimate the balance between sediment trapped and transported due to crab activity in the different habitats.

## 2. Materials and methods

### 2.1. Study area

The study was performed at the Bahía Blanca Estuary, a large embayment habitat (2300 km<sup>2</sup>) affected by up to 4 m semidiurnal tides (Perillo and Piccolo, 1991) and characterized by a series of major NW–SE tidal channels separated by extensive tidal flats, saltmarshes, and islands constituting a mesotidal coastal plain system (Perillo and Piccolo, 1999; Perillo et al., 2005; Fig. 1). Salt marshes are mostly dominated by species of *Spartina* (mainly *Spartina densiflora* and *Spartina alterniflora*) and by *Sarcocornia perennis* (formerly known as *Salicornia ambigua*) as in the majority of the SW Atlantic estuaries (Isacch et al., 2006). Open mudflats, streamside (i.e., creeks ends that dissect the marsh surface) and banks of tidal creeks and most of the inner marsh area are dominated by the burrowing crab *Neohelice granulata* (Iribarne et al., 1997; Bortolus and Iribarne, 1999; Botto et al., 2006). To contrast the effect of crab activities on the sedimentary dynamics in microhabitats subject to different hydrodynamic conditions, four types of habitats were characterized in terms of current velocity using a hand current meter (the current meter was located 10 cm above the bottom level, precision 0.5 cm s<sup>-1</sup>), 20 independent readings were carried out during the first hour of the ebbing phase of neap tides in each habitat. Thus, the habitats selected were: open mudflats (current velocity during neap tides:  $\bar{x} = 10$  cm s<sup>-1</sup>, SD (standard deviation) = 3 cm s<sup>-1</sup>,  $n = 20$ ; thereafter called “mudflat”), inner saltmarsh ( $\bar{x} = 8$  cm s<sup>-1</sup>, SD = 3.5 cm s<sup>-1</sup>,  $n = 20$ ; thereafter called “saltmarsh”), tidal creek bottoms (between one and three meters downstream from the creek head;  $\bar{x} = 40$  cm s<sup>-1</sup>, SD = 8 cm s<sup>-1</sup>,  $n = 20$ ; thereafter called “creek”), and creek tidal basins (unvegetated areas of the saltmarsh surface that drains toward creeks;  $\bar{x} = 34$  cm s<sup>-1</sup>, SD = 15 cm s<sup>-1</sup>,  $n = 20$ ; thereafter called “basin”).

### 2.2. Density and distribution of crab burrows in the intertidal

Field surveys were performed with the purpose of determining the spatial distribution of crab burrows in the different hydrodynamically-defined habitats described above (i.e. “mudflat”, “saltmarsh”, “creek”, “basin”). Burrow densities and size distribution were surveyed using quadrats (0.5 × 0.5 m side) which were randomly allocated in all sites ( $n = 20$  samples in each site), counting burrows inside the squares and measuring their diameters. Active burrows were also identified (i.e. burrows with recently removed sediment, prints, or presence of crabs) and recorded. We conducted this sampling during January 2003 (southern hemisphere summer) and repeated in August 2003 (winter), January 2004, and August 2004. These sampling dates were selected to contrast the summer when crabs are very active versus the winter when crabs are mainly inactive (see Section 3), although the burrows often persist during the winter season. The null hypothesis of no differences in burrow density between habitats and seasons was evaluated with Two-way ANOVA, taking habitat and season as fixed factors (Zar, 1999). Main effects were not considered and reported for the two-way ANOVAs when significant interaction between factors was detected, since it indicates that the factors are not independent (see Underwood, 1997), we carried out an *a posteriori* planned comparisons between means in the case of significant interaction effect (Underwood, 1997). For all statistical analyses, monotonic transformations were used when assumptions were not satisfied (following Underwood, 1997; Zar, 1999). The requirements of data normality and homoscedasticity required by ANOVA were tested with the Shapiro–Wilk (test for normality) and Bartlett’s test (test for homoscedasticity) before and after transforming data. We corrected all *p*-values of all Tukey tests for Type I

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