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Macrofaunal patterns and animal–sediment relationships in Uruguayan estuaries and coastal lagoons (Atlantic coast of South America)☆,☆☆

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ABSTRACT

Estuaries vary considerably in geomorphology, hydrology and in the properties of sediments. Structure of benthic communities may respond to the interaction of these estuarine characteristics, resulting in between site differences. This work evaluated several hypothetical scenarios to explain variation in macrofaunal communities in permanently open estuaries and open/closed coastal lagoons of the coast of Uruguay, South America. Of particular relevance were three hypothetical scenarios: (1) that sediment characteristics, temperature or conductivity may explain variation in fauna between estuarine habitat types (estuaries vs. lagoons), (2) that fauna may not vary between habitat types, but may vary among sites in response to environmental variables and (3) that fauna differed between habitat types but patterns were not clearly being mediated by the measured environmental variables. Scenario 1 was discarded because none of the observed environmental variables showed a significant habitat effect. Patterns of species richness differed between lagoons and estuaries in accordance with scenario 3; richness was higher in open/closed lagoons than in estuaries. The abundance of three important infaunal species supported scenario 2: these species varied considerably among sites in response to the proportion of different sand fractions. Fine sands, common in all estuaries and in a lagoon, were characterised by polychaetes (*Laeonereis acuta* and *Alitta succinea*) whereas coarse sands, found in two lagoons were characterised by a bivalve, *Erodona mactroides*. Another three species responded to sediment but did not show clear site to site variation in abundance. Lagoons differ from estuaries in their higher site to site variation in sediment composition and in the diversity of community variants: lagoons may therefore increase regional diversity as compared to estuaries. We conclude that sediment type played a strong role in explaining variations in macrofaunal abundance among estuaries and lagoons.

1. Introduction

Estuaries are habitats characterised by strong environmental gradients in chemical and physical properties of the water column and the sea bottom. At present there is a considerable body of work documenting responses of estuarine benthic fauna to these properties. Benthic diversity responds to salinity (Attrill, 2002; Giberto et al., 2007; Holland et al., 1987; Remane and Schlieper, 1971) or to variation in salinity (Attrill, 2002). Fauna also responds to sediment type (Anderson et al., 2004; Giménez et al., 2006; Gray, 1974; Norkko et al., 2002; Ysebaert and Herman, 2002; Ysebaert et al., 2003), pollutants and organic enrichment (Essink, 2003; Gamito, 2008; Pearson and Rosenberg, 1978; Venturini et al., 2008), through direct and indirect mechanisms (Thrush et al., 2012). However, at the regional scale there is the question of whether these patterns are general or whether these vary in response to differences in the physical environment among estuaries.

Estuarine habitats are usually classified into different physiographic types (e.g. coastal lagoons, estuaries, fjords: Day et al., 2012; Kjerfve and Magill, 1989; Nichols and Biggs, 1985). They differ in their patterns of river runoff, tides, wind and coastal geology. For instance, tidal currents play a relevant role in patterns of water circulation in estuaries; by contrast, in lagoons, physical processes are dominated by wind Kjerfve and Magill, 1989. Since these processes also control mixing and transport of materials, they also affect the chemical and physical properties of the sediments and the water column. If we want to understand why abundance and community structure of estuarine fauna vary at a regional scale, then we may need to consider several hypotheses about how faunal abundance and community structure respond to the different types of estuarine habitat and to the environmental factors characterising these habitats.

We evaluated responses of macrofauna (multivariate community structure, species richness, and abundance of the most important

☆ Experiments comply with currents laws in Uruguay.
☆☆ The authors declare that there are no conflicts of interest.
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Table 1
Outcomes necessary for macrofaunal responses to be consistent with any of four hypothetical scenarios. The scenarios relate between-habitat and among-site variation of macrofauna with environmental variables (EV).

Scenarios	Fauna (F)	EV	F and E
1	Habitat effect	Habitat effect	
2	Habitat effect	No habitat effect	
3	Varies among sites; no habitat effect	Vary among sites	Covary
4	Varies among sites; no habitat effect		No covariation

species) to habitat type and key environmental variables (sediment fractions, salinity and temperature) in estuarine sites located in Uruguay (Atlantic coast of South America). The coastal landscape of Uruguay has a series of estuaries and open/closed lagoons connected to the Atlantic Ocean and characterised by a low number of species (Giménez et al., 2005, 2006; Jorcín, 1999; Muniz and Venturini, 2001). The main hypothesis concerning habitat effects was that macrofauna differ between lagoons and estuaries. Alternatively, macrofauna do not respond to habitat type (lagoon vs. estuary) but may vary among sites of similar physiographic type (= among estuaries or among lagoons). We also hypothesised that faunal variation between habitats or among sites reflect responses to sediment type, salinity or temperature because these variables characterise the most important environmental gradients in estuarine habitats. Differences between estuarine habitat types, associated with one or more of these environmental variables, have been found in South Africa: open/close estuaries support more abundant macrobenthic populations permanently open estuaries (Teske and Wooldridge, 2001), because of smoother gradients in sediments and salinity (Dye and Barros, 2005).

The different hypotheses to explain variation in fauna among habitats/sites and faunal response to environmental variables suggest four potential scenarios (Table 1). In scenario 1, faunal responses to sediment type, temperature, or conductivity explain macrofaunal differences between lagoons and estuaries, because fauna and environmental variables both vary among habitats. In this case, habitat should influence both the fauna and the environmental variables resulting in significant correlations. In scenario 2, faunal responses to sediment type, temperature, or conductivity explain between site differences in macrofauna, but macrofauna do not respond to habitat type per se. In this case the fauna should vary significantly among sites but not among habitats; in addition fauna and environmental variables should be correlated. There are two logical alternatives to these scenarios: in scenario 3 relationships between faunal and environmental variables do not explain faunal responses to habitat (i.e. macrofauna exhibit significant habitat effects but environmental variables do not). In scenario 4, habitat has no effect for fauna and environmental variables do not explain between site faunal differences. Although scenario 4 seems unlikely, a study in Australia (Dye and Barros, 2005) found patterns consistent with scenario 3 for macrofaunal diversity: in open/closed lakes the diversity of benthic assemblages was lower than in lakes open to the sea, supporting the hypothesis that habitat type affects macrofauna; however, this pattern was unrelated to variation in salinity or sediment composition. These authors hypothesised that low diversity resulted from a higher degree of isolation in closed lakes. The same explanation was proposed by Dye and Barros (2005) for the larger number of species found in permanently open estuaries of South Africa (Teske and Wooldridge, 2001). The degree of openness may affect the connectivity between estuaries and marine habitats or among estuaries. Estuarine species that export the larval stages may be less common in open/close systems due to recruitment limitation (Dye and Barros, 2005). Prolonged isolation can result in only species able to retain larvae persisting within an estuary (McKay et al., 2010). In addition, the closure of estuaries can strongly limit recruitment of estuarine-dependent fish fauna (Vivier et al., 2010), a fact that may affect trophic interactions.

In order to evaluate our scenarios we followed a series of sequential steps. The first step required evaluation of the responses of relevant environmental variables (temperature, conductivity and sediment characteristics) to habitat. This step was followed by evaluating the hypothesis that faunal distribution was driven by habitat type and varies among sites within the same habitat type. The third step required evaluation of responses of fauna to environmental variables. We also considered the possibility that faunal responses may differ across two zones within each estuarine site, the inlet (outer zone), connecting the site with the coastal waters, and the inner zone, more sheltered and characterised

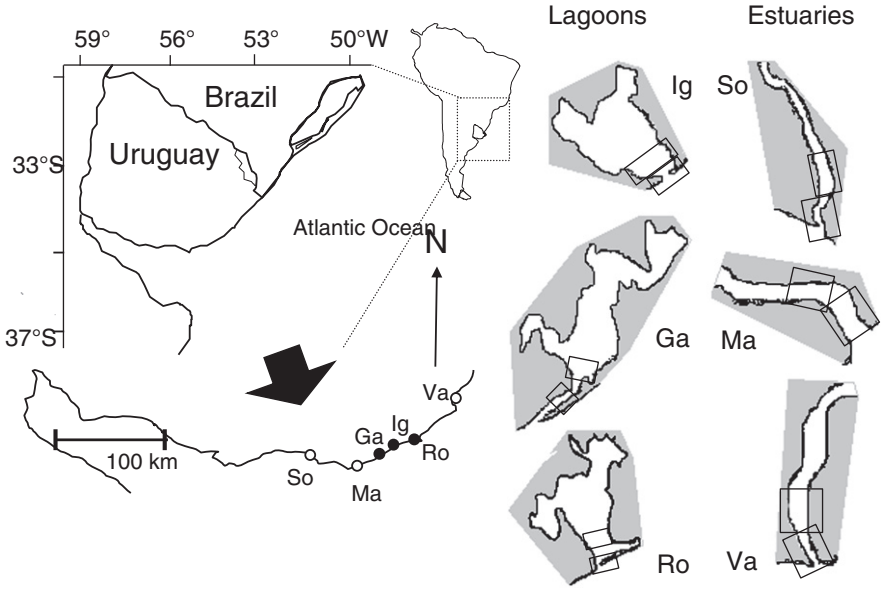

Fig. 1. Location of the different estuarine sites in the Uruguayan coast. Abbreviations of sites, are: Estuaries: So: Solís Grande, Ma: Maldonado, Va: Valizas; lagoons: Ig: José Ignacio, Ga: Garzón, R: Rocha, Open symbols are estuaries and black symbols are lagoons. The location of the zones is shown for each site separately (figures not on scale); the zones extended 1 km along the lagoon or estuarine shore.