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Lagoon water-level oscillations driven by rainfall and wave climate

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ABSTRACT

Barrier breaching and subsequent inlet formation represent critical processes that ensure the temporary or permanent connection and transference of water, nutrients, or living organisms between a lagoon and the open sea. Here, we investigate the conditions inducing natural barrier breaching through a 34 months monitoring program of water-level oscillations within a shallow lagoon and the adjacent nearshore, at the Northern coast of the Iberian Peninsula, Louro lagoon. Seven natural openings were identified to have occurred during the three monitored wet seasons, from the 2009 to 2012, (Wet1, Wet2 and Wet3); four in the Wet1, two in the Wet2 and one in the Wet3. The openings were grouped in three types depending on the observed relation between the lagoon water-level (L_{wl}), the estimated berm height (B_h) and the water-level at the beach (B_{wl}): (i) openings by lagoon outflow, which include those characterized by L_{wl} higher than B_h and lower B_{wl}; (ii) openings by wave inundation, including those induced by B_{wl} higher than B_h, and (iii) mixed openings, which result from a combination of the two previous conditions. We observed that L_{wl} is modulated by the rainfall regime (R_f) and can be explained by the accumulated precipitation. We estimated applying runup equations to obtain B_h and B_{wl} which depend on the wave climate and tidal level. The inlet lifespan was found to be regulated by the wave climate and rainfall regime; in particular barrier sealing was associated with a sudden increase in wave period and a reduction in precipitation. This work proves that the natural openings could be predicted successfully with support to medium term water-level monitoring programs, which in turn may significantly contribute to strategic decision making for management and conservation purposes.

1. Introduction

Coastal barrier breaching (inlet formation) is a complex morphodynamic process that enables free water exchange between the lagoon and the open sea. Processes performing at both the seaward and the bay side of a barrier may induce barrier breaching (Boothroyd, 1985; Fagherazzi and Priestas, 2012; Gordon, 1990; Hayes, 1979; Kraus et al., 2002; Pierce, 1970). The consequences of such processes are not restricted to lagoon and barrier morphology (Bird, 1993; FitzGerald et al., 2000; Gordon, 1990; Kraus et al., 2002; Morris and Turner, 2010; Pacheco et al., 2011), but they also have a significant impact over the biogeochemical fluxes by promoting water, sediments, nutrients and pollutants exchange, with the sea (Dussaillant et al., 2009; Dye and Barros, 2005; Gale et al., 2006; Moreno et al., 2010; Schallenberg et al., 2010). Once open, inlets can remain active or close after a period of time depending on their hydraulic efficiency, which in turn depends on the rainfall regime, the tidal prism and the long-shore and/or cross-shore sediment transport by local waves (Castelle et al., 2007; Cayocca, 2001; Cruces et al., 2009; Fitzgerald et al., 1984; Fortunato et al., 2014; Green et al., 2013; Ranasinghe and Pattiaratchi, 2003; Ranasinghe et al., 1999; Rich and Keller, 2013). Yet, inlets can intermittently open and close, imposing a temporary character to the connection between lagoons and the ocean.

Depending on the timing of their opening through the year, inlets can be regular, i.e. the connection with open sea occurs seasonally or cyclically, or they can be irregular, if the opening timing does not occur periodically. Regular openings are related to seasonal favorable conditions such as (i) high water-levels and large storm waves impacting the sea side of coastal barriers, or (ii) lagoon high water-levels induced by strong river discharges and heavy rainfalls (Bird, 1993; Dussaillant et al., 2009; Gale et al., 2006; Gordon, 1990; Weidman and Ebert, 2013). Alternatively, irregular openings usually occur at sites where the seasonal contrasts are not significant, preventing periodic timing in their opening-closing behavior (Gale et al., 2006; Gordon, 1990; Morris and Turner, 2010). Yet, it is worth noticing that many of the examples described in

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the literature refer to manually opened inlets (with the support of bulldozers) for flood-abatement and flushing purposes (Fortunato et al., 2014; Kraus and Wamsley, 2003; Roy et al., 2001; Wainwright and Baldock, 2015).

Establishing the frequency and the thresholds of natural barrier breaching and closure is crucial for vulnerability assessment and to prevent the damage to infrastructures in populated coastal areas and/or damage to ecosystem services. Despite this, understanding barrier breaching and closure is constrained by limitations related to the apparently unpredictable character of natural openings and closures, and the often lack of data regarding barrier breaching and inlet development fronting a coastal lagoon. Indeed, there are very few examples that include a complete monitoring to understand all the processes involved and provide the required information for management purposes.

To our knowledge, so far only a few studies have been made in small coastal lagoons -pocket lagoons- (Figueiredo et al., 2007; Gordon, 1981; Rijkenberg, 2015), and are non-existent in coastal lagoons located along rocky coasts. In this regard, the present work aims at resolving the mechanisms behind barrier breaching and closure of intermittently connected lagoons by monitoring water-levels in a coastal lagoon. The study site is located at the NW Iberian coast, with a relatively small surface and catchment area. The aim is to improve our understanding on natural breaching and closure processes with particular attention to those openings induced by extremely high water lagoon levels. To understand the mechanisms behind the opening and closure of the ephemeral inlet at Louro lagoon we have examined the water-level changes in the lagoon and explored the most likely forcing processes. This was undertaken through the analysis of different data sets of water-level monitoring (sea and lagoon), topographic, wave climate and metereological data.

2. Study site

The explored pocket coastal lagoon (*Louro*) is located in a small embayment at the northern margin of the *Ría de Muros* entrance, at the Atlantic coast of Galicia, NW Iberia (Fig. 1). Louro lagoon is a pocket lagoon and is influenced by both fresh and saline waters (Cobelo-García et al., 2012). It is an important habitat for numerous plant and animal species, and is included in the Natura 2000 network of the European Union (EU).

The lagoon is a very shallow water body with a flat bottom bed (Fig. 1). It has a surface area about 0.25 km^2, nearly 0.62 km-long and around 0.34 km wide. Reed beds characterize the marginal areas of the lagoon, where the sediment is mostly sand and silt. Sandy sediments characterize the central area, while muddy sediments dominate the

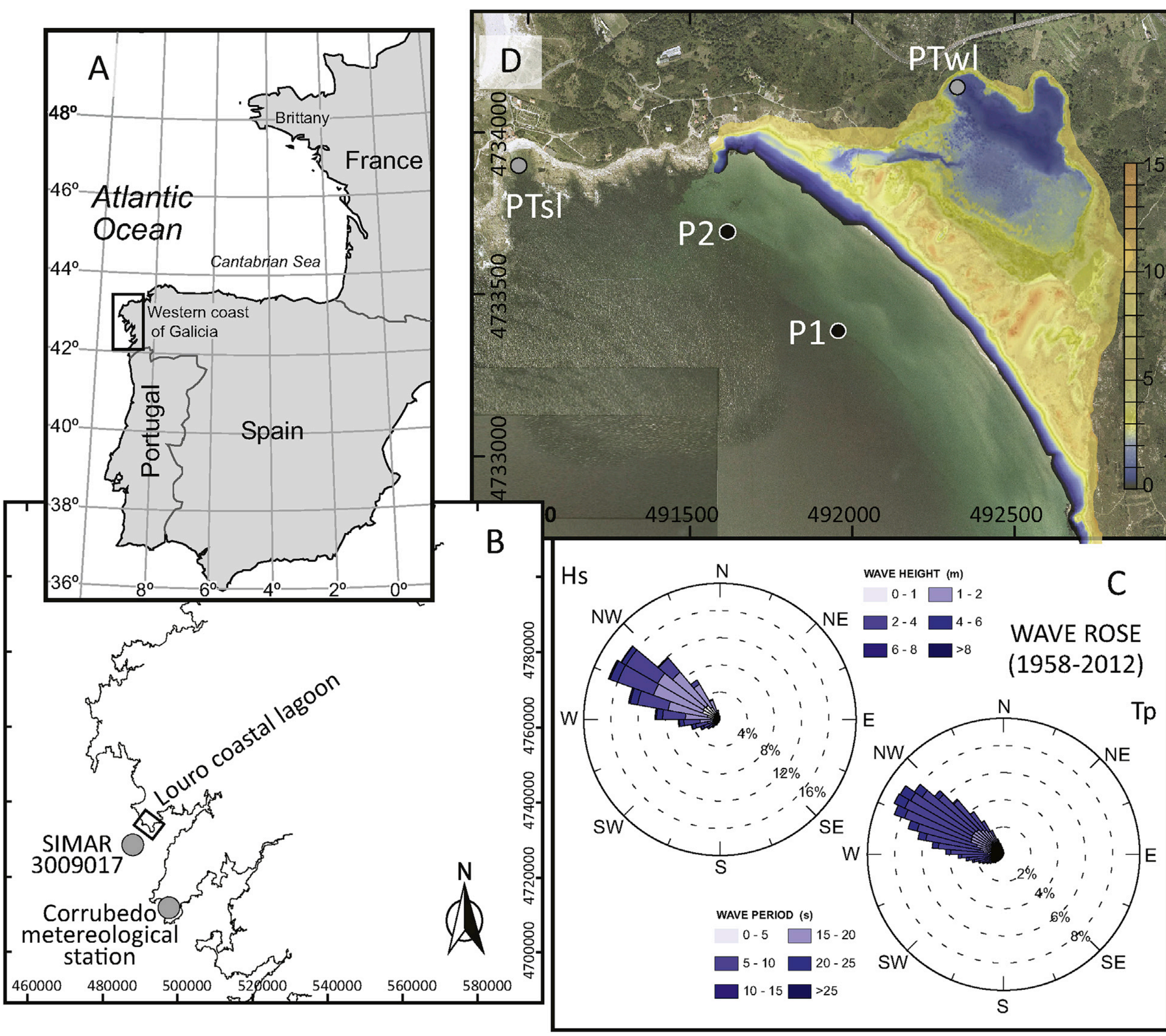

Fig. 1. Location of field site. (**A**): Location in the framework of the Iberian Peninsula. (**B**): Position of Louro coastal lagoon, SIMAR node and meteorological station. (**C**): Significant wave height (Hs) and period (Tp) at SIMAR 3009017 point. (**D**): Aerial imagery of Louro coastal barrier lagoon (2004), with MDT of the barrier and lagoon derived from LiDAR data (2009). The grey dots indicate the location of the water-level loggers. PTsl: sea-level record; PTwl: lagoon record; P1 and P2 are the locations for the points used to extract wave characteristics from SWAN propagation model.