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Coastal erosion and loss of wetlands in the middle Río de la Plata estuary (Argentina)

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ABSTRACT

Many worldwide coastal wetlands are facing erosion, severely putting at risk their noteworthy ecological functions. The Punta Indio coast, which bounds the Argentinean side of the middle Rio de la Plata Estuary, is experiencing noticeable shoreline retreat, as clearly shown by the occurrence of erosive features and wetland loss. The first step in understanding the causes of the coastal erosion is estimating the long-term historic evolution of the coastal changes. In order to overcome the unavailability of historical topographic data, we have used remotely sensed imagery (aerial photos and satellite images) to retrieve the multiple shoreline positions over the period 1943–2013. The rates-of-change and net shoreline movements have been computed by a statistical approach based on the Digital Shoreline Analysis System. Results point out that severe shoreline retreats (up to −7.4 m/yr) affect wide wetland sectors, especially where the natural intertidal vegetation is absent. In these areas, the native vegetation has been cut in the last century, and human activities such as tourism and settlements building experienced a strong development over the last decade. The simulated evolution of the coastline changes for the next 50 years shows that shoreline retreatments will take place very fast, about 4 m/yr. A general warning concerning possible consequences of severe degradation of the wetlands is given, while a remediation strategy, in conjunction with a coastal protection plan, are discussed.

1. Introduction

Many coasts of the world are suffering from severe erosion due to global and regional changes related to natural processes –sea-level rise, land subsidence, loss of sediment supply– and anthropogenic pressure –construction of coastal infrastructures and defenses, urbanization and other anthropogenic activities– (Ford, 2013; Mimura, 1999; Morris, Sundareshwar, Nietch, Kjerfve, & Cahoon, 2002; Nicholls et al., 2007; Zhang, Douglas, & Leatherman, 2004). Consequently, the hydrogeological hazard in the coastlands is increasing, as the natural protection provided by the beaches is vanishing.

The main role of coastal wetlands is their function as ecosystem-based coastal defenses; as such, they provide many important ecological and physical services, like the protection and mitigation of flood and surge events, pollution filtering, groundwater recharge, habitat for fish and wildlife (Odum, 1978, pp. 1–25). The most important natural function in stabilizing shorelines is played by wetland vegetation, which favors the sedimentation processes and reduces coastal erosion driven by storm surges (Anderson & Smith, 2014; Perillo, Wolanski, Cahoon, & Brinson, 2009; Feagin et al., 2011). However, coastal wetlands are fragile ecosystems, and shoreline erosion, as well as relative sea level rise, severe storm events, hydraulic reclamation, nutrient inputs and pollution, lead to their irreversible loss and degradation (Bird, Chua, Fifield, Teh, & Lai, 2004; Brinson & Malvárez, 2002; Kaiser, 2009; Michener, Blood, Bildstein, Brinson, & Gardner, 1997; Zedler & Kercher, 2005). Therefore, considering the valuable ecosystem services provided by coastal wetlands and their importance in driving local economies, e.g., fishing and tourism (Adamus et al., 1991, p. 297; Barbier, Acreman, & Knowler, 1997, pp. 1–27; Le Page, 2011, pp. 3–25), shoreline erosion and other causes of wetland degradation should be promptly monitored and studied.

Recently, the paradigm that wetlands provide shoreline protection was called into question (Feagin et al., 2011). In order to

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support the paradigm, Gedan, Kirwan, Wolanski, Barbier, and Silliman (2011) conducted a literature review and a small meta-analysis of wave attenuation data, finding that, in many instances, wetland plants reduce erosion, storm surge, and even small tsunami wave impacts. The Authors conclude that despite that the shoreline protection paradigm still stands, some gaps remain in the knowledge of the mechanistic and context dependent aspects of shoreline protection.

In Argentina, many coastland sectors are characterized by the presence of wetlands and most of them are included in protected areas, i.e. natural reserves sites of the world *heritage* network of the RAMSAR (Isacch, Escapa, Fanjul, & Iribarne, 2010). Despite these valuable ecosystems are protected, they undergo high ecological and physical pressures due to anthropogenic activity (e.g., Bértola, Cortizo, & Isla, 2009; Carol, Braga, Kruse, & Tosi, 2014; Codignotto, 2009; Isla, Cortizo, & Turno Arellano, 2011) and climate changes (e.g., Codignotto et al., 2011), which have led to significant coastal erosion (e.g., Pousa et al., 2007).

The Punta Indio District is located in the east margin of the middle estuary of the Río de la Plata, on the northeastern sector of Buenos Aires Province (Fig. 1). It is characterized by a humid and swampy region that comprises pampas grasslands and coastal wetlands, which are part of the biosphere reserves of the Buenos Aires province, recognized under the UNESCO's Man and the Biosphere Programme (MAB) (www.unesco.org/mab/). The importance of this area lays on its biodiversity. Within a limited area there are a large number of plant communities: *Vigna Luteola, Zizaniopsis bonariensis* (Espadaña), *Echinochloa helodes*, sedges, *Scirpus americanus* (totora), *Erythrina crista-galli* forest (Cagnoni, Faggi, & Ribichich, 1996; Vervoorst, 1967).

Punta Indio is a little town in the homonymous district, partly located in the wetland. Its socioeconomic development depends on the tourist activities carried out in the coastal zone where a serious shoreline retreat has been recently observed (Codignotto et al., 2011).

Due to the lack of previous studies and in-situ measurements, it is not fully understood when did coastal erosion begin and which is the main cause driving the shoreline retreat.

In order to overcome the lack of data, remote sensing archive images could provide an effective tool for the assessment of coastal changes (Kuenzer, van Beijma, Gessner, & Dech, 2014). Remotely sensed images are extensively used to calculate retreatment and progradation rates of shorelines by comparing multi-temporal images. However, the detection of the coastline position is affected by uncertainties, especially those related to the unknown time and meteo-climate conditions at the time of the image acquisitions, and to the proxy shoreline chosen by the operator. Many studies on the shoreline changes have utilized a uniform vertical level as a proxy shoreline, such as low or high water marks (Anders & Byrnes, 1991; Romine et al., 2009, 2013, pp. 149–57). Others, especially in micro-tidal environments, directly defined the shoreline position as the water line at the time of the photograph, taking into account the necessary corrections and uncertainties related to this value (Aiello, Canora, Pasquariello, & Spilotro, 2013). Moreover, errors related to digitizing and processing affect the detection of the shoreline position. Several studies have considered the errors and uncertainties related to mapping techniques, digitizing of the shoreline and imagery acquisition and processing. Considering these errors and uncertainties, it is important to produce reliable and statistically significant results (Anders & Byrnes, 1991; Crowell and Latherman, 1991; Moore, 2000; Morton, Miller, & Moore, 2004; Thieler & Danforth, 1994). When shoreline change is large, the error in shoreline positioning is relatively small; therefore, the erosion rates are reliable. Conversely, when shoreline change is smaller, the erosion rates become less reliable (Crowell, Leatherman, & Buckley, 1993).

This study is aimed at understanding past and expected morphological evolution of the Punta Indio littoral and factors responsible for shoreline erosion that are leading to significant wetlands loss.

We detect coastal changes using aerial photographs and satellite images acquired in the 1943–2013 period. Starting from the multiple shoreline positions, rates-of-change are computed and analyzed by a statistical approach based on spatial explicit methodology. Focusing on the sectors where coastal morphology resulted more dynamic, we discuss the cause-effect process, i.e. the relationship between past and expected long- and short-term shoreline changes, coastal erosion, loss of wetlands and development of built-up areas and coastal facilities for touristic needs. Concluding, a remediation plan is proposed.

2. Study area

This study focuses on the Punta Indio littoral, which is located at the right side of the Río de la Plata estuary, northeast sector of Buenos Aires Province, Argentina (Fig. 1).

The littoral of Punta Indio is formed by the Holocene depositional sequence, consisting of ancient tidal flats, a beach ridge plain, and recent marsh deposits (Cavallotto, Violante, & Parker, 2004; Fucks, Schnack, & Aguirre, 2010; Violante & Parker, 2004). The ancient tidal flat sector is represented by silt to clay sediments on surface, becoming sandier in depth; the beach ridge plain is represented by parallel systems composed of sandy and shelly deposits with finer textures between them. The present marshland is a narrow fringe parallel to the coast and it is composed of clay sediments. It constitutes an intertidal wetland where the hydrological and sedimentological processes are mainly regulated by tide action. Pleistocene loess-like deposits are exposed in the mainland while in the littoral they lay beneath the Holocene sequence. The geomorphological setting of the Holocene coastal plain is characterized by flat morphologies gently sloping toward the estuary, where ancient sandy beach ridges occur (Fig. 1). From the hydrogeological point of view, the ancient beach ridges allow the rainwater storage in shallow lenses, the only source of fresh groundwater, as the regional shallow aquifer is saline. The use of groundwater is generally limited because the risk of saltwater upcoming.

The Río de la Plata plays the main role in the sedimentary processes in the area under study. It discharges an average of about 22,000 m^3/s (Jaime, Menéndez, Uriburu Quirno, & Torchio, 2002), principally controlled by its two main tributaries, the Uruguay and the Paraná rivers, which are also the major sources of sediments, while the contribution of small creeks is negligible. The study area coincides with the maximum turbidity zone of the estuary, reaching sediment concentrations ranging from approximately 150 mg/L to 250 mg/L (Bazán & Janiot, 1991, pp. 65–91). The Río de la Plata estuary has a mixed semi-diurnal micro tidal regime characterized by a mean range of 0.71 m (Balay, 1961, p. 153). Tide flow direction alternates at intervals of 5–7 h and acts subsequently in the same and in the opposite direction to the river tributaries discharge. In some parts of the estuary this phenomenon pauses the flow and facilitates the decanting of transported sediments (Balay, 1961, p. 153).

However, because of the shallowness and increasing width of the Río de la Plata estuary, water level variations are strongly influenced by heavy SE-SSE winds, which can occasionally reach 75–88 km/h (D'Onofrio, Fiore, & Pousa, 2008). During storm surge events, locally known as “sudestadas” (southeasterlies), the water level of the estuary can raise more than 3 m, encroaching inland for several kilometers and producing a severe impact on the coast.