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A retrospective assessment of the hydrological conditions of the Samborombón coastland (Argentina)

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ABSTRACT

Coastal wetlands are transitional zones that play an important role as buffers between the land and sea in several ways, such as protecting the land from storm surge and reducing the input of nutrients from surrounding watersheds to the sea. Understanding the influence of human activities on the hydrological conditions of coastal wetlands is of paramount importance for preserving the ecological function and biodiversity of these unique ecosystems. In the last century, the Samborombón coastland (Argentina), which is an extensive intertidal wetland, has been affected by hydraulic projects and human activities. In this study, through a retrospective assessment of the hydrologic conditions, we show the impacts of channelization, embankments and mining on the surficial and groundwater hydrology of the Samborombón wetlands. The results indicate that channelization has promoted tidal flooding and seawater encroachment along the channels. The embankments have separated large areas from the estuary tides; during heavy rainfalls, they act as obstacles and cause the inundation of inland regions while allowing the accumulation of sodium chloride by saltwater evaporation after tidal overtopping events. The freshwater resources in the aquifer of the paleo-coastlines have been seriously damaged by mining of the shell ridges. The halophyl vegetation in the marshlands and the native forest of the shell ridges, which depend on tidal flow and fresh water, respectively, have been threatened. Nevertheless, although the hydrology of the Samborombón coastland has undergone changes, the engineering projects did not permanently modify or damage the surrounding ecosystems. The outcomes of this study will be useful for remediating ecosystems that have been impacted by human activities by following the fundamentals of ecological engineering.

1. Introduction

Coastal wetlands are highly dynamic environments that act as transitional areas between the land and the sea and are governed by continental and marine processes. Estuarine wetlands are exposed to frequent natural fluctuations and alterations. They are periodically inundated by high tides and storm surges as well as being flooded during intense rainfall. In coastal wetlands, marine and continental waters are exchanged and surface water and groundwater are mixed to form complex spatially and temporally variable systems (e.g., Tóth, 1963; Werner and Lockington, 2006; Robinson et al., 2007; Wolanski, 2007; Cao et al., 2012; Werner et al., 2013). Groundwater seeps from the land to the sea and seawater intrudes into coastal aquifers. In estuarine wetlands, the mixing of seawater and groundwater depends on the regional geo-morphologic characteristics of the coast, including ground elevation, soil texture, subsoil heterogeneity and climatic conditions (e.g., Sophocleous, 2002; Rizzetto et al., 2003; Pousa et al., 2007; Teatini et al., 2011; Braga et al., 2013a,b; Day et al., 2013). Hydrological processes in such areas are often highly influenced by human activities, such as the overexploitation of natural resources, land reclamation, hydraulic projects and urbanization. These processes hasten salt contamination, land degradation, pollution and subsidence, which cause serious damage to soils and freshwater resources and threaten the ecological system. For example, urbanization, industry and port activities have greatly affected the environmental quality of Santos Bay (Brazil), resulting in severe sediment contamination and water pollution (Zanardi Lamardo et al., 2000; Abessa et al., 2005; Magalhães et al., 2012). In the Yangtze River Estuary (China), engineering projects, such as the construction of a

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dam and a deep-water navigation canal, have caused many hydrodynamic modifications (Yang et al., 2005; Tang et al., 2011; Zhang et al., 2013), while urban development and industrial growth have caused the deterioration of surface water quality (Ren et al., 2003). The Han River Estuary (South Korea) has undergone changes in water dynamics and chemistry due to engineering projects, such as the construction of submerged dams (e.g., the Singok and Han River dams), which have significantly decreased freshwater outflow to the open sea (Park, 2004; Yoon and Woo, 2013). In the northern Adriatic coast of Italy, the overexploitation of subsurface fluids during the 20th century, especially during the 1960s and 1970s, was responsible for regional subsidence. The decrease of ground elevation produced a significant retreat of the coastline, erosion of salt marshes and tidal flats, increased the frequency of flooding in lowlands and historical cities such as Venice and Ravenna (Carbognin and Tosi, 2002; Amos et al., 2010 and references therein) and worsened the saltwater contamination of shallow aquifers and farmlands (e.g., Carbognin et al., 2009; Viezzoli et al., 2010).

Understanding the influence of humans on the hydrologic conditions of transitional coastal environments is of paramount importance because of the widely recognized buffering functions of these unique transitional ecosystems for biodiversity and valuable economical resources such as agriculture and fisheries. This issue is also essential for planning the correct restoration of ecosystems that have been substantially disturbed by human activities and for guiding environmental adaptation in a changing climate. In this sense, ecological engineering, which is defined as the design of sustainable ecosystems that integrate human society with the natural environment for the benefit of both, has to be developed (Mitsch, 2012; Cheong et al., 2013).

Samborombón Bay, which is an extensive intertidal wetland that was declared a RAMSAR site in 1997, is located on the Argentinean side of the outer estuary of the Rio de la Plata (Fig. 1). The bay extends for 180 km (224,000 ha) and receives the Samborombón River from the northwest, the Salado River from the west and the Ajo River from the south. Lowlands and marshlands are present behind extensive salt marshes and muddy tidal flats. They are frequently flooded by tides and storm surges from the Atlantic Ocean, but the most significant damage to socio-economic development often results from heavy rain on the coastal plain. For this reason, several natural and artificial canals have been constructed to drain the bay's low hinterland.

The world's major estuarine wetlands are subject to economic development and social transformations that exert great pressure to exploit natural ecosystems and trigger changes in the hydrodynamics and hydrochemistry of the water resources. Unlike many of the world's estuaries that are heavily populated and industrialized, Samborombón Bay contains only small urban and built-up areas. The socio-economic development is mainly associated with livestock farming and mining. Nevertheless, several engineering and hydraulic projects have been constructed over the last century without assessing the anthropogenic impact on the hydrology of the coastal wetlands. The hydrological studies that have been carried out in the area have focused on the aquatic communities of the Río Salado basin (e.g., Conzonno et al., 2001; Gabellone et al., 2008; Rosso, 2008), estuary dynamics (e.g., Guerrero et al., 1997; Simionato et al., 2004; Acha et al., 2008), the hydrodynamics and hydrochemistry of the surface and groundwater (e.g., Carol et al., 2009, 2011, 2012; Carol and Kruse, 2012) and the present and expected hydro-morphologic setting in relation to relative sea level rise (Tosi et al., 2013). To date, no studies have integrated the previous natural surface and subsurface hydrology and analyzed the effect of human interventions at both regional and local scales. The retrospective assessment of hydrologic conditions is a methodology that conceptualizes the surficial water and groundwater interactions that are driven by natural conditions and human-induced processes. The results of studies of site-specific processes can successfully be extended to a larger scale to characterize the hydrological setting of the entire coastland. The retrospective assessment of hydrologic conditions requires the identification, compilation and analysis of relevant existing data sets. Remotely sensed data provide a synoptic view of the terrestrial landscape and can be especially useful for assessing and monitoring natural resources (e.g., surface water, vegetation, wetlands) over large areas with frequent regular observations (Jiang et al., 2008, 2013; Sleeter et al., 2013). Satellite images represent a unique means of evaluating long-term changes in climate and hydrology over wide and inaccessible areas that lack in situ measurements. Images provide support to regional hydrological studies because they reveal patterns, land cover and land use modifications (Campbell, 1996). Moreover, they can provide reliable information about the extent and spatial distribution of "hot spot" events (i.e., floods due to rivers, storm surges or intense rainfall). The systematic archiving of Landsat data makes this information valuable for retrospective analyses of environmental characteristics that are applicable to regional studies (Wulder et al., 2012).

The overall aim of this work is to develop a conceptual model of the hydrologic setting of the Samborombón coastland under natural conditions, such as those at the beginning of the last century, and modified by anthropogenic interventions. The model was developed by a retrospective assessment of the hydrological conditions that was aided by the interpretation of satellite images that were integrated with the results of previous studies and observations from exploratory field investigations.

2. Materials and methods

2.1. Study site description

The coastland of Samborombón Bay (Fig. 1) is part of the Río de la Plata estuary and is influenced by the estuary's semidiurnal microtidal regime (Acha et al., 2008). The tidal wedge penetrates from the Atlantic Ocean into the upstream portion of the estuary with salinities that vary from 20 to 1 g/L at the outer and upper limits, respectively (Guerrero et al., 1997).

The climate is humid temperate with an average annual rainfall of 940 mm and evapotranspiration rates reach 770 mm/yr (Pousa et al., 2011). Several studies and historical records describe significant climatic oscillations that are evidenced by alternating periods of droughts and floods (Olivier, 1959). Moncaut (1957a) reported that during the "gran seca de Darwin" (1827–1832), the Samborombón and Salado Rivers dried and were filled with dead animals, while Moncaut (1957b) described a boat that arrived at the Chascomús lagoon from the estuary (100 km inland) because the entire coast was flooded.

In the last 40 years, precipitation has increased to more than 1000 mm/yr (Kruse and Laurencena, 2005) and the frequency of severe flood events has increased (Scarpati et al., 2011). During the rainy periods, the low slope of the terrain favors the retention of water on the floodplain for long periods, forming shallow lakes and marshes, and the region undergoes prolonged flooding events that can affect part or all of the bay. When this occurs, small towns are isolated, roads are covered with water and crops are damaged.

The fluvial network that flows into Samborombón Bay comprises the Samborombón River (Río Samborombón), the Salado River (Río Salado) and the Ajó River (Río Ajó) (Fig. 1). The Samborombón River and the Salado River flow through an extensive flat floodplain with numerous meanders, most of which are abandoned, and are partially connected to permanent and seasonal