Ecological Indicators 34 (2013) 268–276

Contents lists available at SciVerse ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original article

Tagus estuary salt marshes feedback to sea level rise over a 40-year period: Insights from the application of geochemical indices

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ARTICLE INFO

Article history:
Received 11 April 2013
Received in revised form 17 May 2013
Accepted 17 May 2013

Keywords:
Sea level rise
Salt marshes
Geochemical indices
^{137}Cs dating
Sediment accretion rates
Heavy metals
Elemental ratio-based indices

ABSTRACT

Sea level rise (SLR) has been evaluated using data acquired from two Tagus estuary salt marshes. Sediment accumulation rates over a 40-year study period were determined using ^{137}Cs along with an evaluation of several geochemical indices and ratios as proxies of the mechisms underlying these SAR variations. Correlating SLR data from 1963 to 2001 with the sediment accretion rates (SARs) an inverse pattern of interaction was observed, with lower SAR associated to periods of higher mean sea level (MSL) heights. This pointed out to an erosion effect of the salt marsh during higher tidal flooding. Although SLR apparently slows down SAR, it still presents a positive balance with SLR, similar to that identified in most mesotidal estuaries. The geochemical analysis of sediments and chemical alteration index (CAI) also suggest that the major processes inherent to the SAR vary inversely, being mostly based by physical disturbances. Geochemical ratio-based indices showed that both salt marshes presented enhanced high-energy transport driven inputs of sediments, although in Pancas salt marsh there is a slight evidence of chemical weathering of the sediments. Anthropogenic contamination of the sediments by heavy metals was identified and has been decreasing from 1963 to 2001, mostly linked to a marked reduction of industrial activities in some areas surrounding the Tagus estuary, rather than the sedimentary history of the estuary.

1. Introduction

Climate change is nowadays one major concern spanning across the environmental science community. It is widely accepted that increasing CO_2 levels may induce climate change through the greenhouse effect and holds the potential to affect most ecosystems to some degree. Some direct causes of CO_2 rising concentrations in the atmosphere are increasing temperature values and ocean acidification, but other may result from direct changes to the gas and particle contents within the atmosphere. The impact of an increased greenhouse effect has been widely studied (e.g. IPCC, 1990; Titus and Narayanan, 1995). The reports of the Intergovernmental Panel on Climate Change (IPCC, 1990), recently updated in 1995, specify that the global average air and sea surface temperatures are expected to rise by about 2.5 °C, within a range of 1.5–4.5 °C (Berner and Berner, 1996; Houghton, 1999; IPCC, 1999), although there is a degree of uncertainty about these estimations related to issues of geographical, diurnal and seasonal variability (Gates, 1993; Houghton, 1999). One of the major side-effects of global warming is sea level rise, due to polar ice meltdown and increasing ocean water supply, but also caused by the thermal expansion of this larger water mass. Inevitably, the most affected areas of the globe and highly vulnerable to sea level rise are located close to the seashore, including coastal lagoons, estuaries and the shoreline. Estuaries stand out as areas of special concern, since they include some of the most densely populated areas in our planet (Duarte and Caçador, 2012; Cohen et al., 2001). Estuarine ecosystems hold therefore great scientific potential in this context and will help us understanding climate change dynamics and their impacts upon these areas.

Salt marshes are often located along estuarine sides and they are particularly vulnerable to sea level rise (Dyer et al., 2002). Salt marshes are considered to be among the most productive ecosystems on the planet and they have an essential role as nursing areas for marine fish and invertebrates of great economic value. They are invaluable habitats and feeding sites to many migratory bird species, while sheltering great biodiversity (Reed, 1990; Van Dijkeman et al., 1990). The slope of the marsh in relation to the tidal amplitude, and the elevation of the shoreline offering better protection in conditions of increasing storminess (Dyer

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http://dx.doi.org/10.1016/j.ecolind.2013.05.015

et al., 2002) will be determining factors for the initial set-up and resilience of the salt marsh communities under increasing conditions of sea level rise (Simas et al., 2001). These areas are described as transitional water bodies in the Water Framework Directive of the European Union, and they are further recognized as ecologically sensible zones according to the Birds and Habitats directives. Locked between landmasses and ocean, rising seawater levels will play an important role in the future ecology of these regions. Sea level rise will also mean higher erosion rates in the outer boundary of the salt marsh (Reed, 1990). However, some mechanisms may counteract the influence of these climatic induced factors, as salt marshes also have the ability to keep their relative elevation above seawater throughout sedimentation (Salgueiro and Caçador, 2007). Salt marshes act as sinks for contaminants (Caçador et al., 2000; Duarte et al., 2010), carbon (Caçador et al., 2004) and nitrogen (Caçador et al., 2007). The major depositional process for these elements is through sedimentation of particulate matter during tidal flooding (Silva et al., 2009), when the halophytic vegetation acts as a baffle and sediment trap, leading to the settling of fine suspended particles transported on the water column that are deposited on the marsh (Silva et al., 2009). Furthermore, salt marsh growth is often associated to processes occurring in estuarine areas with high levels of sediment discharge, like mudflats (Simas et al., 2001). To counteract the effects of sea level rise, the marsh elevation must keep on at such a pace that is compatible with the rise. Otherwise flooding is inevitable and will be followed by subsequent marsh erosion. This has already been verified in the Nile and Mississippi rivers (Gornitz, 1991; Blum and Roberts, 2009). Another important factor to consider is the tidal range of the salt marsh. Stevenson et al. (1986) suggested that areas with high tidal range are associated with higher sediment transport rates, thus being less affected by sea level rise. In this case a negative feedback mechanism is observed, where a small increase in sea level leads to higher mineral deposition due to longer submersion periods. This is also associated with less sediment compaction due to reduced decomposition of organic matter in the sediment (Nyman et al., 1993; Allen, 1994). However, rapid sea levels rise, as predicted in some climate change scenarios (IPCC, 2007) increases salt-marsh loss caused by the increased submersion periods since salt marsh productivity (organogenic input) is suppressed (Nyman et al., 1993, 1994). Recently, an increasing number of numerical modelling studies have appeared aimed at identifying and simulate the main processes of marsh elevation dynamics in response to changing sea level (Allen, 1990, 1995, 1997; Callaway et al., 1996; Chmura et al., 1992; Day et al., 1999; French, 1993; Krone, 1987; Morris et al., 2002; Pont et al., 2002; Rybczyk and Cahoon, 2002; Rybczyk et al., 1998; Temmerman et al., 2003a; Van Wijnen and Bakker, 2001). However, as stated by Allen (2000), these models are at a rather embryonic stage of development. Important information can be obtained meanwhile from empirical studies of saltmarsh systems. By investigating sedimentary records in the context of the climate conditions that produced them it should be possible to understand how salt marsh geochemical characteristics and accretion rates have been responding to changes in sea level. This type of information will be very useful in practice, allowing for better adaptive management of human activities, and hopefully to guide our preparation and protective measures against future scenarios.

Caesium-dating techniques are widely applied to SLR and SAR studies in coastal environments. Although its undeniable efficiency providing good insights on SAR, they only tell half the story. This way, the present work not only aims to assess sediment accumulation rates in the Tagus salt marsh over the last 40 years using ^{137}Cs dating, but also the possible application of geochemical and elemental-based indices in order to provide insights on the processes behind the temporal oscillations and spatial variations in the SAR. In a time of major concern in which respects to global changes, this analysis will be integrated in the context of rising sea level conditions. This way is intended not only to evaluate the possible use of this geochemical indices but also to use them as storytellers of the recent past of Tagus estuary.

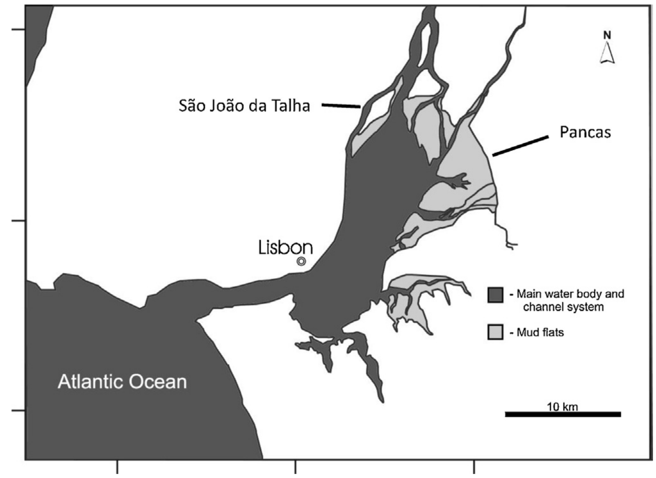

Fig. 1. Map of the Tagus estuary showing Pancas and S. João da Talha salt marsh sampling stations.

2. Material and methods

2.1. Study area description

The Tagus estuary is the largest estuary on the west coast of Europe (38°44′ N, 9°08′ W), located in the most populated area of Portugal (Fig. 1). It is a shallow estuary and its circulation is mainly driven by tides. The Tagus River drains a total area of 86,629 km^2, representing the second most important hydrological basin in the Iberian Peninsula. The river is the main source of freshwater into the estuary. Inflow fluctuates seasonally with an average monthly value varying from 120 m^{-3} s^{-1} in summer to 653 m^{-3} s^{-1} in winter (last 30 years of Water National Institute public database, INAG). Estimated water residence time ranges from 6 to <65 days for winter and summer average river discharge, respectively (Martins et al., 1984). It is a mesotidal estuary according to the NOAA classification, with semi-diurnal tides ranging from 0.4 m at neap tide to 4.1 m at spring tide. Seawater enters the estuary through a deep narrow inlet channel. The tidal influence reaches 80 km inland from Lisbon.

Coring took place at Pancas (PAN) salt marsh, located in the southern side of the Tagus estuary within the Natural Reserve of Tagus Estuary and in S. João da Talha (SJT) salt marsh, located in the northern side in Lisbon metropolitan zone. Three sediment cores were taken using a tubular probe (6.7 cm diameter) in 2001. The cores were taken along the salt marsh in an area vegetated by *Sarcocornia perennis*. Appropriate measures were taken to avoid compaction during the coring. The position of the cores and vertical level of the coring sites was attained by GPS.

2.2. Laboratory analysis

The cores obtained at the sampling stations were brought back to the laboratory in refrigerated chambers and sliced. The samples were dried to constant weight at 60 °C. Organic matter content was determined by loss on ignition (LOI) after slowly ashing subsamples at 600 °C for 3 h.

The sediment accumulation rate was calculated on the basis of the two pronounced ^{137}Cs-peaks, which were present in all the cores. The lower peak corresponds to the 1963 maximum in testing of nuclear weapons in the atmosphere and the upper peak is