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An evaluation of climate change effects in estuarine salinity patterns: Application to Ria de Aveiro shallow water system

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ABSTRACT

It is of global interest, for the definition of effective adaptation strategies, to make an assessment of climate change impacts in coastal environments. In this study, the salinity patterns adjustments and the correspondent Venice System zonations adaptations are evaluated through numerical modelling for Ria de Aveiro, a mesotidal shallow water lagoon located in the Portuguese coast, for the end of the 21st century in a climate change context. A reference (equivalent to present conditions) and three future scenarios are defined and simulated, both for wet and dry conditions. The future scenarios are designed with the following changes to the reference: scenario 1) projected mean sea level (MSL) rise; scenario 2) projected river flow discharges; and scenario 3) projections for both MSL and river flow discharges. The projections imposed are: a MSL rise of 0.42 m; a freshwater flow reduction of ~22% for the wet season and a reduction of ~87% for the dry season. Modelling results are analyzed for different tidal ranges. Results indicate: a) a salinity upstream intrusion and a generalized salinity increase for sea level rise scenario, with higher significance in middle-to-upper lagoon zones; b) a maximum salinity increase of ~12 in scenario 3 and wet conditions for Espinheiro channel, the one with higher freshwater contribution; c) an upstream displacement of the saline fronts occurring in wet conditions for all future scenarios, with stronger expression for scenario 3, of ~2 km in Espinheiro channel; and d) a landward progression of the saltier physical zones established in the Venice System scheme. The adaptation of the ecosystem to the upstream relocation of physical zones may be blocked by human settlements and other artificial barriers surrounding the estuarine environment.

1. Introduction

Estuaries are some of the most productive sheltered ecosystems in the world (McLusky and Elliott, 2004) providing valuable resources for a multitude of human activities. The importance of defining and implementing effective long-term management strategies in transition environments, dependent on a reliable assessment of climate change impacts, is worldwide recognized. Pritchard (1967) defined estuary as “a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage”. As salinity distribution in estuarine systems depends on the equilibrium between spring/neap tidal cycle and freshwater flow, longitudinal salinity gradients are therefore generated in these systems.

Saltwater intrusion resulting from MSL rise is among the key concerns for coastal and estuarine environments as a consequence of climate change (Nicholls, 2010). Then, a decline in freshwater availability from surface runoff and coastal groundwater bodies is expected. It should have implications in municipal supply, industry and irrigation uses, compromising the communities' subsistence (Hilton et al., 2008; Rice et al., 2012). Fertile soils may become unfit for cultivation for a long period, due to their salinization by the saltwater landward expansion during high tide (Gornitz, 1991). Additionally, a long-term salinity increase may induce changes in species abundance, composition and distribution, due to their specific salt tolerance (Attrill and Rundle, 2002; Lirman and Cropper, 2003; Spalding and Hester, 2007), forcing them to displace upstream (Statham, 2012). This was observed by Génio et al. (2008) when studying the mortality of the gastropod *Nassarius reticulates* in Ria de Aveiro. However, human pressure in

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these environments boundaries may limit a displacement of species and habitats, and an irreversible damage in these ecosystems is expected (Hilton et al., 2008). If projected changes in precipitation are added up, river discharges will change as well as salinity in a seasonal time scale (Miller and Russell, 1992).

Despite the importance of this subject, the scientific community only recently begun making use of numerical modelling to study the climate change impacts in the salinity patterns of transitional environments. Numerical studies found in literature project a salinity increase and an upstream expansion of saltwater for MSL rise scenario, of which we cite several examples: i) Grabemann et al. (2001), in a study applied to the Weser estuary, Germany, projected an upstream displacement of the saltwater boundary of about 2 km, in average, for a MSL rise of 0.55 m; ii) Hong and Shen (2012), studying the impact of 1.00 m MSL rise in the Chesapeake Bay, USA, estimated an increase in saltwater intrusion length of about 11 km, in dry conditions, and of approximately 7 km, for wet conditions; iii) Rice et al. (2012), focusing on impacts at two Chesapeake Bay tributaries, found that, for MSL rises of 0.30–1.00 m, the increase of salinity is larger in the middle-to-upper zones than in lower and upper ones; iv) Liu and Liu (2014) concluded that a hypothetical MSL rise of 0.38 m in the Wu River estuary, Taiwan, for the end of the century, will push the limit of salt intrusion further upstream, raising the salt content throughout that environment.

In what concerns modelling the impact of different river discharges or projected discharges, combined or not with MSL rise projections, the following results are found: i) Chua and Xu (2014) predicted, for San Francisco Bay, an intrusion of salt water further upstream along this century in response to MSL rise projections and observed a compression of salinity fronts for increasing freshwater inflows; ii) Robins et al. (2014), predicting the combined impact of MSL rise and seasonal freshwater flows projected for the end of the century (reduced summer flows and increased winter flows) in the Conwy estuary, UK, observed a generalized salinity increase during summer but a largely unchanged salinity during winter; iii) Chen et al. (2015) predicted an increase in average salt content and in salt intrusion in Tamsui River estuary, Taiwan, for 2100, due to MSL rise projections; this increase was intensified for freshwater discharge decrease conditions; iv) Huang et al. (2015), studying the impact of salinity variations for oyster growth at two important oyster reefs in Apalachicola Bay, Florida, estimated an average salinity increase due to sea level rise and a salinity decrease under higher river discharges; v) Yang et al. (2015), determining Snohomish River estuary (USA) response to sea level rise, estimated a shifting of salinity intrusion points further upstream, while under higher flow projections, the same authors found a downstream displacement of intrusion points.

This study is applied to the Ria de Aveiro located on the north Portuguese coast (Fig. 1). This environment has a typical estuarine behavior in wet conditions (Vaz and Dias, 2008), when well-

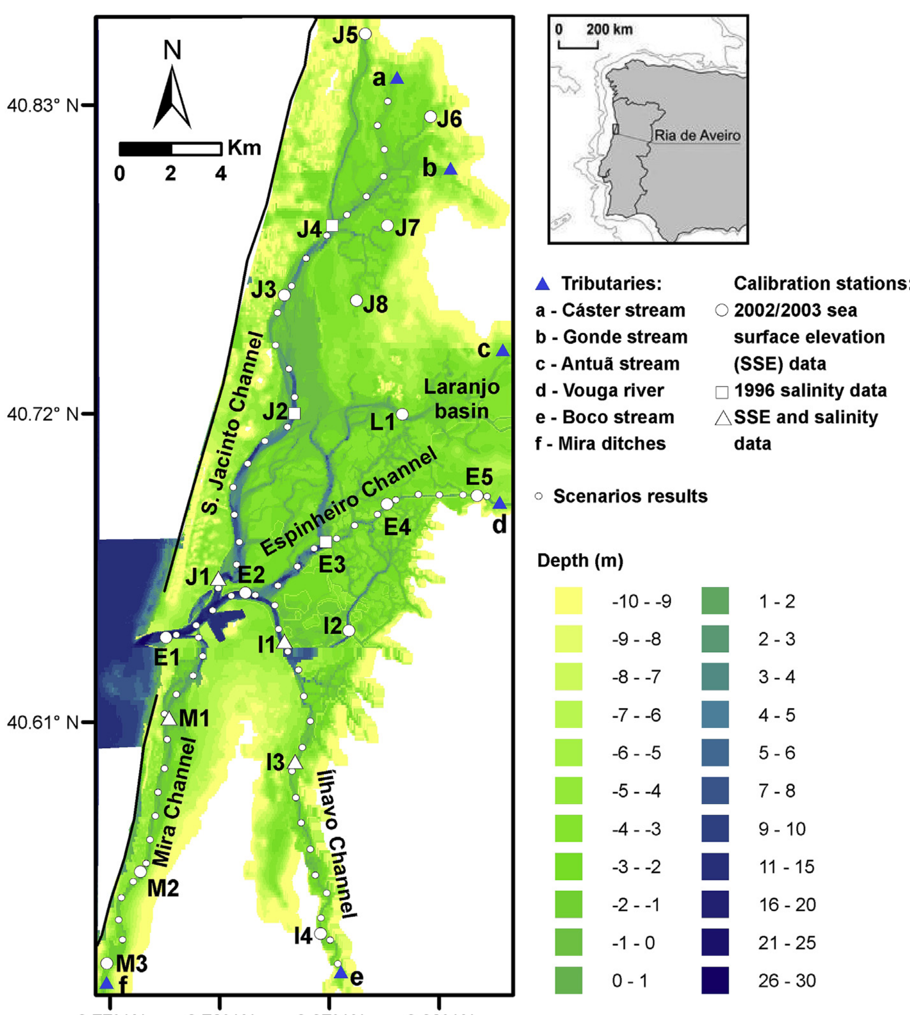

Fig. 1. Ria de Aveiro bathymetry and marginal topography, with depth relative to chart datum. Location of tributaries' outfalls, calibration stations and points of salinity results extraction along channels for each scenario.