Marine Geology 382 (2016) 1–16

Contents lists available at ScienceDirect

Marine Geology

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

Implications of delta retreat on wave propagation and longshore sediment transport - Guadalfeo case study (southern Spain)

Rafael J. Bergillos[a,*], Alejandro López-Ruiz[b], Miguel Ortega-Sánchez[a], Gerd Masselink[c], Miguel A. Losada[a]

[a]Andalusian Institute for Earth System Research, University of Granada, Avda. del Mediterráneo, s/n, 18006 Granada, Spain
[b]Department of Aerospace Engineering and Fluid Mechanics, University of Seville, Camino de los Descubrimientos, s/n, 41092 Seville, Spain
[c]School of Marine Science and Engineering, Plymouth University, PL4 8AA, Drake Circus, Plymouth, UK

ARTICLE INFO

Article history:
Received 29 April 2016
Received in revised form 11 September 2016
Accepted 21 September 2016
Available online 30 September 2016

Keywords:
Mediterranean delta
Erosion
Wave modelling
Longshore sediment transport
Downscaling

ABSTRACT

The influence of both natural and human-induced changes on the evolution of worldwide deltas has been widely addressed; however, the variations of the submerged morphology of the delta and their implications on coastal dynamics have received limited attention. This work details the spatial and temporal variability of the mouth of the Guadalfeo River (southern Spain) and focuses on the influence of submerged morphological changes, partly due to watershed regulation in 2004, on wave propagation and longshore sediment transport. Bathymetric measurements were carried out over a 15-year period (1999–2014), a wave propagation model was calibrated and applied, and an updated expression for longshore sediment transport was applied using downscaling techniques to obtain the complete littoral drift time series. The results show that the river damming led to coastline retreat and bed-level erosion up to 3 m along a 1-km section around the river mouth, with maximum erosion rates in excess of 760 m^3/m. These subtidal morphological changes reduced wave refraction and led to higher breaking wave energy. Variations in wave climate during the study period have also played a role in influencing the coastline dynamics. Although the erosion around the river mouth has decreased since 2008, partly due to a sediment pulse in 2010, eastward longshore sediment transport rates under westerly storm wave conditions have significantly increased since then. This has led to the propagation of the sediment deficit towards the east of the mouth, endangering urban developments at this location. This paper provides insights into the shift from wave-river dominated deltas towards deltaic coasts increasingly controlled by wave directionality and longshore sediment transport, and represents an advance on the understanding of the dynamics of many worldwide deltas where the river sediment supply has decreased due to human activities.

1. Introduction

Deltaic systems are located at the transition between fluvial and maritime environments; therefore, they respond rapidly to both human-driven and natural changes (Coleman and Wright, 1975; Orton and Reading, 1993), especially river damming and (relative) sea-level rise which are probably the most severe causes of the retreat of worldwide deltas (Syvitski et al., 2009). These systems are particularly vulnerable to coastline variations (Overeem, 2005; Syvitski and Saito, 2007), because numerous activities take place along deltaic shorelines and these all have high ecological, economic, and social importance. In recent centuries, anthropogenic activities have generated sediment supply issues, altered natural processes and changed the morphology of deltaic environments (IPCC, 2001; Hood, 2010;Anthony et al., 2014).

Numerous studies have focused on the influence of both natural and human-induced changes on the evolution of worldwide deltas, such as the Yangtze (Yang et al., 2011), Huanghe (Fan et al., 2006), Mekong (Le et al., 2007), Niger (Abam, 1999), Volta (Anthony et al., 2016), Nile (Frihy and Komar, 1993; Frihy et al., 2003), Rhône (Sabatier et al., 2006, 2009), Ebro (Jiménez et al., 1997; Jiménez and Sánchez-Arcilla, 1993), Po (Simeoni and Corbau, 2009; Simeoni et al., 2007), Danube (Vespremeanu-Stroe et al., 2007;Tatui et al., 2014), Arno (Pranzini, 2001), Ombrone (Pranzini, 1994) or Adra (Jabaloy-Sánchez et al., 2010). These studies generally analysed the dynamics of the subaerial part of the delta, including the coastline, attributing the observed coastal retreat to reductions in the fluvial (and sediment) inputs to the coastal system due to human interventions, such as water extraction for irrigation and dam building (Syvitski et al., 2009, 2005). However, the alterations in the

---

* Corresponding author.
E-mail address: rbergillos@ugr.es (R. Bergillos).

http://dx.doi.org/10.1016/j.margeo.2016.09.011
0025-3227/

submerged morphology due to these interventions, and the resulting modification of predominant coastal processes on a yearly-decadal scale have received very limited attention.

Wave refraction and longshore sediment transport (LST) are among the coastal processes affected by changes to the submerged bathymetry, whilst at the same time main drivers of coastal morphological changes (De Vriend et al., 1993; Almar et al., 2015). Their analysis over yearly-decadal temporal scales requires detailed wave climate analysis (Solari and Losada, 2011, 2012), application of advanced techniques to downscale wave variables (Camus et al., 2011, 2014), availability of high-quality bathymetric information and wave propagation towards the coast with an accurate numerical model (Ortega-Sánchez et al., 2014; López-Ruiz et al., 2015).

In 2004, the Guadalfeo River in southern Spain was dammed, regulating 85% of basin runoff (Nevot Pérez, 2004) and significantly reducing the sediment supply of the river (Bergillos et al., 2015a). As a consequence, the coastline has retreated by up to 87 m and the sediment of the delta wedge has been re-distributed mainly by wave processes (Bergillos et al., 2016a). Given its characteristics, recent history and similarities with many other worldwide deltas (Syvitski and Saito, 2007; Syvitski et al., 2009; Anthony et al., 2014; Anthony, 2015), the Guadalfeo delta represents a valuable example to study human-induced variations of the submerged morphology and their impact on coastal processes.

The main objective of this paper is to study the spatial and temporal variability of the mouth of a highly altered deltaic system. This work describes the changes on the submerged morphology and quantifies their impact on wave propagation and longshore sediment transport near the coast. Firstly, multibeam bathymetric measurements over a period of 15 years (1999–2014) are analysed and a wave propagation model is calibrated and applied to the study site. Secondly, an updated LST formulation (López-Ruiz et al., 2012a, 2014) was applied to help explain the coastal changes. Finally, advanced wave climate downscaling techniques are used to further explore the feedbacks between nearshore morphology, wave directionality and LST.

2. Study site

The Guadalfeo River mouth is located on the southern coast of the Iberian Peninsula that faces the Mediterranean Sea, between *Punta del Santo* (location of the river mouth before 1943) and the Salobreña Rock (Fig. 1). The lower course of the river is channelized through two parallel river jetties of 8 km-long and separated 55 m. The deltaic coast is bounded to the west by Salobreña Rock and to the east by Motril Port (Félix et al., 2012), which represents a barrier to longshore sediment transport (Maldonado, 2009).

The Andalusian littoral of the Mediterranean Sea is characterised by the presence of high mountainous relief and short fluvial streams, and the main contributor of sediments to the beach in the study area is the Guadalfeo River. Its basin has an area of $1252 \cdot 10^6$ m^2 and includes the highest peaks on the Iberian Peninsula (~3400 m.a.s.l.). Consequently, the river is associated with one of the most high-energy drainage systems along the Spanish Mediterranean coast. The relatively steep topographic gradients lead to large contributions from a wide range of sediment sizes (Millares et al., 2014a). As a result, the particle size distribution on the coast is particularly complex with varying proportions of sand and gravel (Bergillos et al., 2015b).

The pre-regulation hydrological regime of the Guadalfeo River had peak discharges that exceeded 1000 m^3/s (Capel-Molina, 1974). However, the construction of Rules' Reservoir in 2004, at a distance of 19 km from the mouth and with a capacity of $117 \cdot 10^6$ m^3, modified the natural flow regime and altered the behaviour of the system downstream. In particular, the reduction in sediment supply to the

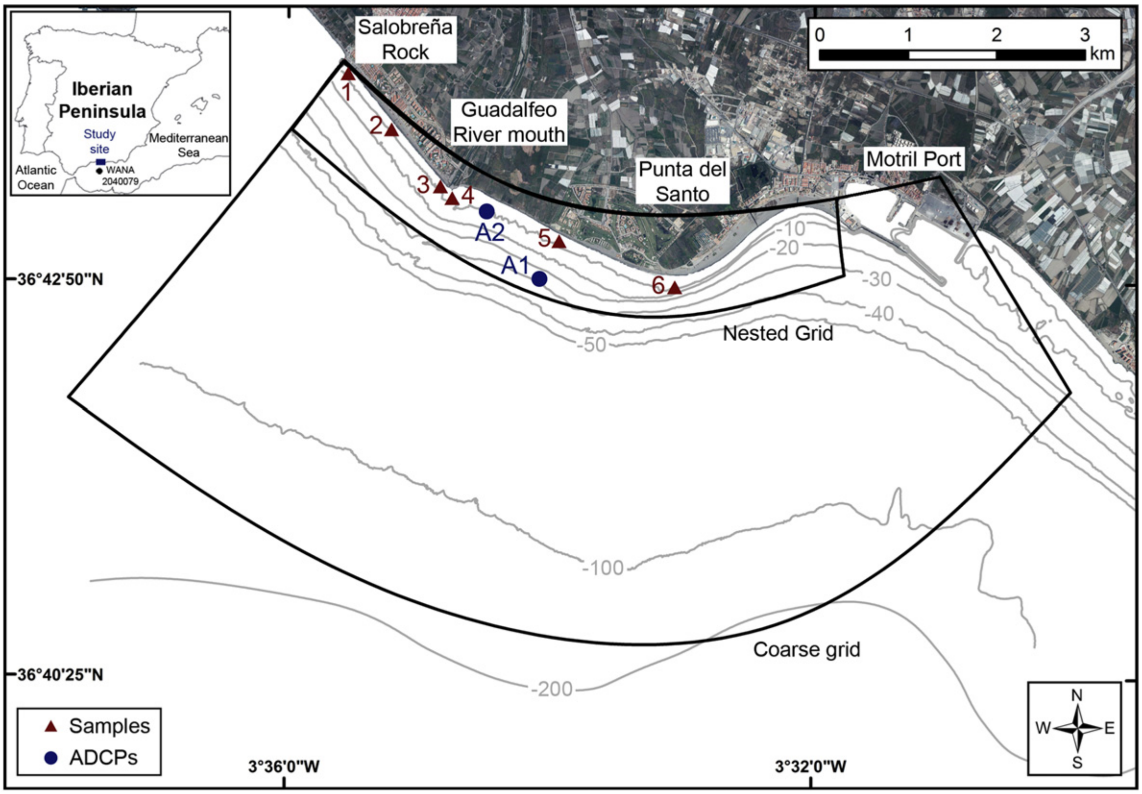

Fig. 1. Location and bathymetry of the study site, indicating the profiles where the sediment samples were taken (red numbered triangles), the ADCPs (blue circles A1 and A2) and the grids used in the numerical model. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)