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Advances in management tools for modeling artificial nourishments in mixed beaches

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ABSTRACT

This paper addresses the evolution of a mixed beach (Playa Granada, southern Spain) forced by an artificial nourishment project through the analysis of field observations and the modeling of hydro- and morphodynamics. The beach profile and coastline were periodically surveyed over a six-month period; a wave propagation model was calibrated by means of hydrodynamic measurements; four longshore sediment transport (LST) equations were tested through comparisons with bathymetric data; and the one-line model was applied between topographic surveys. The results indicate that severe coastline retreat (dry beach area loss > 208 m^2/day) occurred during the 45 days following the intervention. This is mainly attributable to the morphology of the nourished coastline, the different characteristics of the sediment used for replenishment compared to natural sizes, and the occurrence of an intense westerly storm. The dry beach extension increased afterwards influenced by the westward LST due to the dominance of easterly waves. The Van Rijn formulation was found to provide the best fits to the observed volumetric changes, obtaining modeled/measured ratios of 93.1% and 77.4% for the two study beach profiles. The outputs of the one-line model based on the Van Rijn approach were also the best, with root-mean-square errors decreasing during the study period and lower than 4.6 m over the last 3 months. These results show that the joint application of a calibrated wave propagation model, the LST equation proposed by Van Rijn and the one-line model constitutes a management tool for predicting the evolution of these complex coastal settings.

1. Introduction

Mixed beaches (MBs), which are composed of both sand and gravel fractions, are commonly found in coastlines with steep hinterlands (such as Mediterranean or New Zealand) and in previously para-glaciated areas (such as Ireland, UK or Canada) worldwide (Clemmensen et al., 2016; Shulmeister and Kirk, 1993). They are also found when nourishment projects use gravel to protect eroded sandy beaches (López-de-San-Román-Blanco, 2004; Mason and Coates, 2001). Although they have received increasing attention in recent years, numerous studies have highlighted the discrepancy between progress made in regards to sandy beaches and a lack of similar advances for gravel and MBs (Buscombe and Masselink, 2006; Horn and Walton, 2007; Jennings and Shulmeister, 2002; López-de-San-Román-Blanco et al., 2006; Mason et al., 1997; Masselink et al., 2014; Pontee et al., 2004).

In addition, deltaic systems, which are located in transitional areas between fluvial and maritime environments, respond rapidly to both natural and human-driven changes (Anthony et al., 2016; Coleman and Wright, 1975). In recent centuries, anthropogenic activities, such as river damming (Anthony et al., 2014; Syvitski et al., 2009), have generated sediment supply issues, altered natural processes and changed the morphologies of deltaic environments (Anthony, 2015; Hood, 2010). These systems are particularly vulnerable to coastline retreat (Overeem, 2005; Syvitski and Saito, 2007) because numerous activities occur along deltaic shorelines and they have high ecological, economic and social importance.

These coastal erosion problems demand low cost and environmentally friendly strategies (Brondizio et al., 2016; Van Slobbe et al., 2013). Among them, artificial nourishment approaches have been traditionally considered as unobtrusive and sustainable coastal interventions (Hamm et al., 2002; Hanson et al., 2002). Many previous works have studied the morphodynamics of nourishment methods applied to sandy beaches with a focus on detailed field measurements (Jackson and Nordstrom, 2011; Van der Wal, 2000b) and numerical models (De Schipper et al., 2016; Van den Berg et al., 2011). However, from marine and coastal points of view, there are significant gaps related to beach nourishment that motivate our

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work: (1) the amount of morphological measurements performed after replenishment projects remains limited for MBs, and (2) relatively few numerical models have been applied and compared with field data in reference to these beaches as a means of developing engineering tools for coastal managers.

These management tools must consider wave propagation patterns and longshore sediment transport (LST), as they are the main drivers of morphological changes along coasts. Modeling these processes requires accurate wave propagation towards the coast, the selection of the best formulation to estimate LST rates (Ashton and Murray, 2006; Mil-Homens et al., 2013) and the use of one-line type models to reproduce coastline evolution patterns (Antolínez et al., 2015; Payo et al., 2002). To our best knowledge, this three-step procedure has not been tested, based on comparisons with high quality field measurements, to model coastal evolution after a nourishment project on MBs.

The main objectives of this paper are to characterize and to model the morphodynamic response of a mixed deltaic coast (Playa Granada, southern Spain) forced by an artificial nourishment project. To meet these goals, the evolution of wave, wind and water level conditions is analyzed; a wave propagation model is calibrated and applied to address nearshore wave patterns; and morphological changes of the beach profile and the coastline are quantified and related to forcing agents. The propagation model is also used to apply different LST equations and the one-line model, selecting the formulation that best reproduces coastal evolution patterns through comparison with field observations to develop an integrated tool for the design of nourishments projects.

2. Study site

Playa Granada is a 3-km-long micro-tidal beach located on the Mediterranean coast of southern Spain (Fig. 1). It corresponds to the central stretch of the Guadalfeo deltaic coast (Bergillos et al., 2015a) and is bounded to the east by *Punta del Santo* (the former location of the river mouth) and to the west by the Guadalfeo River mouth (Fig. 1). The mouth exhibited a delta plain in the past, which is scarcely visible nowadays. The deltaic coast is bounded to the east by Motril Harbor, which is an artificial barrier that prevents eastward longshore sediment transport (Félix et al., 2012), and to the west by Salobreña Rock.

The Andalusian littoral of the Mediterranean Sea presents commonly short fluvial streams and high mountainous relief angles. The Guadalfeo River, which is associated with one of the most high-energy drainage systems along the Spanish Mediterranean coast, contributes most sediment to the beach. Its basin covers an area of 1252 km^2 and includes the highest peaks on the Iberian Peninsula (~ 3400 m.a.s.l.). The steep topographic gradients lead to large contributions from a broad range of sediment sizes (Millares et al., 2014). As a result, the particle size distribution on the studied coastal area presents varying proportions of sand and gravel (Bergillos et al., 2015b), with three predominant fractions: sand (~0.35 mm), fine gravel (~5 mm) and coarse gravel (~20 mm).

The river was dammed 19 km upstream from the mouth in 2004, regulating 85% of the basin run-off (Losada et al., 2011). As a consequence of river damming, the delta currently experiences coastline retreat and severe erosion problems (Bergillos et al., 2016b). The studied stretch of beach, which is occupied by an exclusive leisure resort, golf courses, restaurants and summer homes (Félix et al., 2012), has been particularly affected (Bergillos et al., 2015c). Consequently, artificial nourishment projects have been frequent since the entry into operation of the dam (Bergillos et al., 2016a), with an average annual cost of 125,045.5 euros/year.

Climatic patterns change considerably between the summer and winter. The region is subjected to the passage of extra-tropical Atlantic cyclones and Mediterranean storms, with average wind

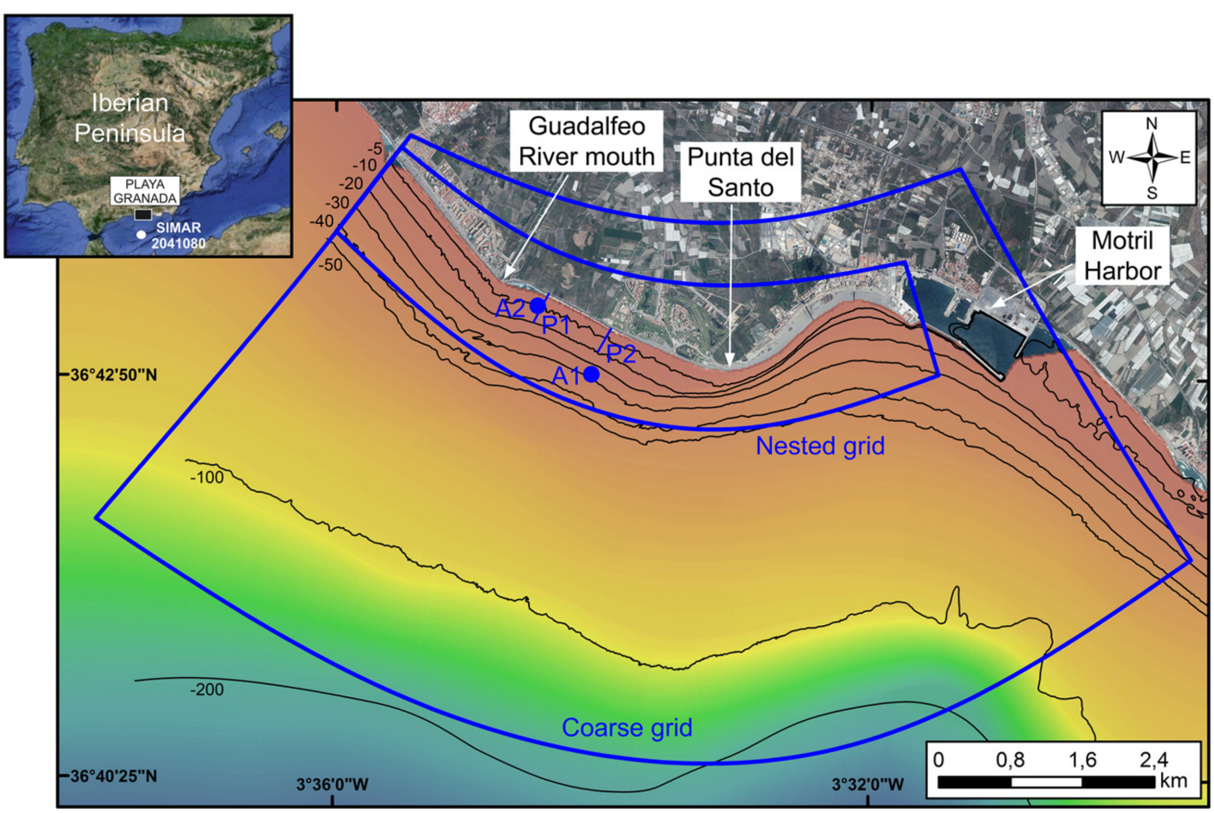

Fig. 1. Location of the study site, indicating the bathymetric contours (in meters), the positions of the ADCPs (blue circles A1 and A2), the measured profiles (blue lines P1 and P2) and the grids used in the numerical model.