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Monitoring the evolution of nearshore nourishments along Barra-Vagueira coastal stretch, Portugal

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ABSTRACT

Maintenance of existing harbors implies regular dredging activities. Where the combined use of dredging and disposal of dredged material on nearby sediment-starved beaches can induce major changes in the beach morphology and generate unexpected impacts in the environment, monitoring becomes a concern. This paper was designed to analyze, interpret and evaluate a set of monitoring data collected along a regular-nourished coastal stretch with dredged sand (Barra-Vagueira coastal stretch, northwest coast of Portugal), surrounded by an energetic hydrodynamic environment with a scarce natural sediment input. Based on a field data set, collected between 2009 and 2015, the present study brings together a set of correlated analyses, intended to assess the morphodynamic evolution of the fills as well as their impact to the adjacent coast. The available data set encompasses topo-hydrographic surveys collected for 12 cross-sections (with 1 km spacing) distributed along the coastal stretch and bathymetric measurements collected for the dumping areas. Considering the concurrent offshore wave forcing, dominant temporal and spatial patterns, morphological changes, evolution trends, sediment budgets, and short- and medium-term responses of the fills are investigated by the use of ArcGIS tools and application of a multivariate statistical method based on Empirical Orthogonal Functions (EOFs). Overall, during the monitoring period, almost 2.8 Mm^3 of sand was dumped in different locations and periods to control the erosion observed downdrift of the inlet. However, bathymetric surveys and profile indicators still point out the erosional longshore pattern diagnosed decades ago as a result of a negative longshore sediment balance. Observations also revealed that short-term changes arising from the seasonal cycles of cross-shore material exchange are mainly linked to the largest variations in the beach profile shape, also affecting the sediment budget. Profiling indicated cross-shore volume variations ranging from ± 250 m^3/m and ± 1500 m^3/m in the subaerial and subaqueous portion of the profile, respectively, along the monitored period. After the first completed seasonal cycle the sand bar, artificially created by the nourishments, could not be visually detected in the profiles, suggesting a cross-shore redistribution of the fill material. All the analyses developed in this paper stress the importance of establishing proper monitoring programs based on adequate surveying instruments and data collection strategies, in order to ensure high-density data that could be used in support to the decision-markers.

1. Introduction

Dredging operations are regularly undertaken for maintenance of existing harbors. In order to maximize the benefit taken from maintaining depths or deepening activities of navigation channels, the dredged material is typically reintroduced into the littoral system through direct placement at downdrift areas, where beaches have become depleted of material. In this respect, monitoring becomes a concern since the combined use of dredging and disposal of dredged material may induce major changes in the beach morphology and generate unanticipated impacts in the environment, especially in a long-term perspective (Monge-Ganuzas et al., 2013; Mateus et al., 2016; Rehitha et al., 2017). Although the potential use of dredged material for sediment replacement of eroding beaches is widely recognized, there is little comprehensive guidance available for engineers or planners regarding an adequate monitoring plan.

Monitoring is particularly valuable since it serves to objectively document and assess the performance of the project, determining how well it fulfills the requirements for which it was designed, and evaluate related impacts on adjacent shorelines (Capobianco et al., 2002; Gravens et al., 2003; Vacchi et al., 2012). Analysis of monitoring data can also shed light on an adequate frequency of surveying, or even on

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the natural conditions that prompt the need for improving the project performance or developing potential design alternatives (Capobianco et al., 2002; Castelle et al., 2009; Vacchi et al., 2012). Particular data of interest include topo-bathymetric surveys, waves and water levels, and characteristics of native and placed sediments. Beach profile surveys are essential for estimation and documentation of fill volumes and changes in the beach cross-section, allowing the prescribed sectional fill volume to be verified in compliance with the design specifications. Wave and water level data also provide valuable information for understanding project behavior and formulating solutions by establishing cause-and-effect relationships between the forcing conditions and the measured beach response. Beach sediment sampling is needed to determine sediment properties, for example, the grain-size distribution. This is of particular importance when the nourished and the native sand have very different properties, which can directly affect the beach profile shape and influence the fill evolution (Creed et al., 2000; Gravens et al., 2003).

The dynamic behavior of nourished beaches as well as dredged areas together with the need to ensure project functionality over the design life requires a systematic monitoring plan to be established. However, in many cases they are not well planned or carried out in a comprehensive manner. A weak point of many monitoring schemes is that the surveys only cover a limited area (such as the dumping areas) and are not properly extended in the cross- and longshore directions. Consequently, a confident assessment of the impact of the project and the design efficiency may be compromised (Hamm et al., 2002). Overall in Europe, the best monitoring practices are still those adopted in Dutch and German projects, which support regular monitoring activities (Hanson et al., 2002; Schipper et al., 2016; Blossier et al., 2017). Apart from that, although the monitoring may be obligatory, beach nourishments in Europe are usually monitored during their early development, commonly one complete seasonal cycle, corresponding to the time that beach profile needs to reach a new equilibrium state (Larson et al., 1999), and then once or twice a year (Hanson et al., 2002; Yates et al., 2009; Utizi et al., 2016). Dean (2002) suggested a time interval between surveys of 1/2 year to 2 years, unless unusual behavior is expected. In USA, monitoring programs established to track the evolution of nourishment projects are typically undertaken over a few years, but on an annual to biannual basis, with few reports of monthly or seasonal variability (Bodge et al., 1993; Browder and Dean, 2000; Yates et al., 2009). Compared to Europe and USA, the estimated number of nourishment projects including monitoring programs in Australia is much smaller (Cooke et al., 2012).

In Portugal, coastal waters and beaches are considered maritime public domain and are state-owned. The actual policy for safety assessment and erosion control is established by the Ministry of the Sea , which follows the Portuguese Environment Agency (APA) recommendations. The general practice is that there is no funding from private organizations for coastal protection. Thus, all costs are borne by the national government. The APA is responsible for issuing permits (designated through the Environment Impact Statements (DIA) - valid for two years) for coastal protection and other structures in the coastal zones, requiring anticipated studies of possible environmental related-impacts to the project proposal. Although a monitoring scheme is built into this legal structure and described in the DIA, due to the limited public financial resources generally devoted to coastal defense protection, regular monitoring of the coastline is usually neglected. Despite the coastal management strategies still focus on a remedial rather than preventive policies, an overall long-term strategy for coastal management along the coast has been developed, anticipating follow-up programs. In accordance with many countries in Europe (Roberts and Wang, 2012; Burcharth et al., 2015), a general transfer from hard to soft coastal erosion mitigation strategies is emerging, where beach nourishment assumes a central role (RGTL, 2014).

The primary objective of this study was to examine the suitability of a dataset established by DIA in connection to a monitoring program developed for a Portuguese coastal stretch, regularly nourished with dredged material from maintenance activities of the Aveiro Harbor navigation channel, northwestern of Portugal. Attention is given to the beach morphology variability and sediment transport processes by examining temporal and spatial patterns of the nourished beaches and how they change (with focus on cross-shore profile and dumping area evolution). Time series of field measurements collected in connection to underwater nourishment operations performed along Barra-Vagueira coastal stretch were used and analyzed to investigate fill responses in medium-to long-term periods. This dataset encompasses topo-hydrographic surveys collected for 12 cross-sections (1 km spacing) located along the study area (between Sep-2009 and Feb-2015), as well as hydrographic surveys collected within the dumping areas (between Sep-2009 and Apr-2015). Geographic Information System (GIS) techniques and Empirical orthogonal functions (EOFs) were employed as the main tools to relate morphological changes, evolution trends, sediment budgets, sediment transport gradients, and short- and medium-term responses of the fills to the incoming wave conditions. The results from the present paper encourage more frequent monitoring work, especially in cases of beaches with strong seasonal cycles.

2. Field site

Barra-Vagueira is a 10 km long coastal stretch, located on the northwest coast of Portugal, just south of the Aveiro Harbor (see Fig. 1). This stretch, approximately centered on the sandy coast between Espinho and Cabo-Mondego, is currently facing serious erosion problems. The proximity to the Aveiro lagoon and urban areas, the low-lying sandy topography, and the fragile dune system, susceptible to overtopping and flooding during energetic wave conditions and large tidal amplitudes, make this coastal stretch a vulnerable and exposed area to erosion (Coelho et al., 2011; Pereira et al., 2013). As a result, there is an imminent risk of breaching of the dune system that separates the Aveiro lagoon from the sea.

The serious erosion recorded is mainly related to sediment supply deficit, which is resulting from the progressive weakening of the alluvial sources and the sediment blockage by manmade structures (Coelho, 2005; Coelho et al., 2009a; Pereira et al., 2013). The 1.8 million m^3/year of sediment that under normal conditions would come from Douro River (near Porto) and feed the littoral drift towards south (estimated to be 1.5–2.0 million m^3/year), has been decreased to about 0.25 million m^3/year mainly due to the construction of hydro-power dams (Veloso-Gomes, 1991; Bettencourt, 1997; Andrade and Freitas, 2002; Coelho et al., 2009a, 2009b; Costa and Coelho, 2013).

In terms of sediment dynamics, since the longshore sediment transport is interrupted by the Aveiro Harbor breakwaters, strong accumulation of sand is occurring on the updrift (north) side, while a significant retreat of the shoreline occurs at the southern beaches (Barra, Costa Nova and Vagueira). This retreat is controlled by a groin field and a seawall along Costa Nova beach, and a seawall and a groin along Vagueira beach (Fig. 1). According to the long-term shoreline evolution study developed by Veloso-Gomes et al. (2006), for a period of 10 years (1980–1990), the shoreline retreat rate in Costa Nova beach and Vagueira beach is estimated to be 3.7 and 3.9 m/year, respectively. The erosion rates vary over time: for the period 1996–2001, EUROSION (2006) indicates an erosion rate north of Costa Nova and Vagueira of around 6.6 m/year, while the Vagueira waterfront experienced a rate about 7.1 m/year; going back further in time, EUROSION (2006) refers an erosion rate at Aveiro of about 8.2 m/year when analyzing the shoreline movement between 1947 and 1958.

The beach profiles possess dominant seasonal variations and present intermediate to dissipative general morphodynamic behavior north of Aveiro Harbor and intermediate morphodynamic behavior south (SNIRL, 2015). Mean sediment grain sizes along Barra-Vagueira coastal stretch range from medium to coarse sand in the subaerial part of the profile and medium to fine sand in the subaqueous portion. A study