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Morphodynamic evolution of a sand extraction excavation offshore Vale do Lobo, Algarve, Portugal

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ABSTRACT

Offshore sand and gravel extraction for aggregates and beach nourishment is an important economic activity and has been a common practice in various countries worldwide for many years. The evolution of a sandpit, in particular its migration and rate of replenishment, depends strongly on the type of sediments involved, and on the physical and hydrodynamic characteristics of the surrounding area. In order to fully assess the associated impacts on local ecosystems and on the neighboring coastline morphology it is essential to make accurate predictions of the excavation recovery times. For this purpose it is fundamental to investigate areas where there is an adequate observational control of the evolution of the sandpit, prior and after the excavation, to properly calibrate existing numerical models with observations and fully evaluate their prediction adequacy. The present work investigates the evolution of an offshore sandpit located off Vale do Lobo, Algarve, Portugal, within a time span of four years (2006–2010), based on 4 bathymetric surveys, prior to and after the dredging operations, complemented with the analysis of wave data and numerical modeling simulations. The bathymetric data were used to evaluate the morpho-sedimentary evolution and to calculate the sediment volume changes. The results show an infill of approximately 17% of the initial exploration pit in the first 4 years, with an overall smoothing of the initial excavation bottom topography. Observations combined with modeling results demonstrate that the pit evolution depends mainly on storm events, since it is essentially during these periods that there is a significant sediment movement at the site water depth. Based on (1) the predicted number of stormy days for the forthcoming years, assuming that (2) the yearly average of such events in the past 57 years is representative, and considering (3) a decrease of the sandpit recovery rate in time, predicted by models and observations, it was possible to estimate that the Vale do Lobo sandpit recovery period is of ca. 38 years for its full, or near full, replenishment.

1. Introduction

The offshore extraction of sediments from coastal areas has been a common practice in many countries for many years, and it has become, in some places, the main source of aggregates for beach nourishment and for construction (Cooper et al., 2007; Kubicki et al., 2007). It has been shown to have several advantages compared with onshore exploitation, since extraction from rivers, estuaries and nearshore sand bars has proven in the past few years to have significant negative environmental and social impacts. Nevertheless, offshore sand extraction can also have negative impacts in the marine environment, not only in the morphodynamics of the region, but also in the local ecosystems, and this is often not restricted to the excavation area (Kubicki et al., 2007; van Rijn and Walstra, 2002; van Rijn et al., 2005).

The morphology and morphodynamics of the seabed are strongly affected by the creation of the local depression due to the excavation. The induced bottom morphology changes will in general influence the local flow and the wave field and consequently the sand transport rates (van Rijn and Walstra, 2002). Locally, the sediments from the surrounding areas tend to move inside the depression. Changes in the wave field, through refraction and, less significantly, also through diffraction, can modify the longshore sediment transport patterns and affect the shoreline morphology (Demir et al., 2004). Over longer time scales, the sandpit area can migrate towards the shore and may act as a sink for the sediments from the nearshore system (van Rijn and Walstra, 2002). The severity and persistence of such impacts depend, among others factors, on the hydrodynamic conditions, the nature of the substrate, the

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sandpit geometry and its distance to the shore, and the time-scale of the seabed perturbation (Cooper et al., 2007; Roos et al., 2008). In order to minimize these effects and nearshore coastal erosion, the mining areas need to be located offshore of the closure depth.

This work investigates the morpho-sedimentary evolution of an excavation area, located offshore Vale do Lobo in the Algarve, south of Portugal (Fig. 1), resulting from the sand exploitation for the nourishment of the Vale do Lobo beach (Gonçalves, 2009). The study is based on 4 bathymetric surveys, prior to and after the dredging operations and within a time span of four years (2006–2010), complemented with the analysis of wave data and numerical morphodynamic modeling simulations. The main aims of this paper are to understand the physical mechanisms responsible for the sandpit evolution and to estimate the sandpit recovery time from the observed and predicted filling rate.

2. Study area

The Vale do Lobo area is located in Loulé, on the southern Portuguese coast (Fig. 1). This coastal area is characterized by the existence of a medium height (10 to 15 m) active cliff and a narrow beach. The almost vertical cliff, that extends from Quarteira, in the west, to the Vale do Garrão area, in the east, is shaped in poorly consolidated red sandstones from the Plio-Pleistocene (Manupella, 1992). The cliffs in the Quarteira–Vale do Garrão coast are intercalated by sandy barriers that enclose the river mouths of the area (Teixeira, 2011).

The main sediment circulation cell offshore Vale do Lobo (Fig. 1) extends from Albufeira to Faro. The longshore transport is dominant and mainly wave induced, with a negligible aeolian transport. The cliffs are the main source of sand that feeds the longshore drift (Dias and Neal, 1992), with a small fluvial direct contribution (Rosa et al., 2013). The annual net transport rate is about 110 000 m^3/yr directed eastwards (Teixeira, 2011).

The study area is mainly constituted by lithoclastic coarse sand (CS-1 in Fig. 1). Nearer the shore, the sediments consist in general of lithoclastic medium sand (grain size between 0.25 and 0.5 mm and identified as MS-1 in Fig. 1); further offshore lithoclastic gravelly sand (grain size higher than 2 mm; gS-1 in Fig. 1) predominates (IH, 1985). The lithoclastic coarse sand identified in the excavation area (black box in Fig. 1) presents a dominant grain size between 0.5 and 2 mm, with a fraction of sediments with a grain size higher than 2 mm that is lower than 15%, and it is essentially quartzitic with a low percentage (<10%) of carbonates (Teixeira, 2011). Based on side scan sonar data and in situ observations through scuba diving, Teixeira (2011) mapped the rocky outcrops offshore Vale do Lobo shown in Fig. 1 (R — gray polygons).

This coastal area has suffered serious erosion problems in the recent past. The construction of several groins in the Vilamoura area in the 70s (west of Quarteira; Fig. 1), to attenuate the coastal erosion, has interrupted the downdrift littoral transport and induced significant erosional problems eastwards, increasing the natural coastline retreat trend for that costal sector. According to Marques (1997), the coastline mean retreat rate for the Vale do Lobo area has evolved from ~0.55 m/yr, in the 1974 to 1980 period, to ~1 m/yr between 1983 and 1992.

In order to mitigate the intense coastal erosion felt in this zone, an artificial beach nourishment was carried out. The Vale do Lobo beach nourishment undertaken between October 1998 and January 1999 was the first case of an offshore sand extraction in the Algarve, and a total of approximately 700 000 m^3 of sand were extracted (Teixeira,

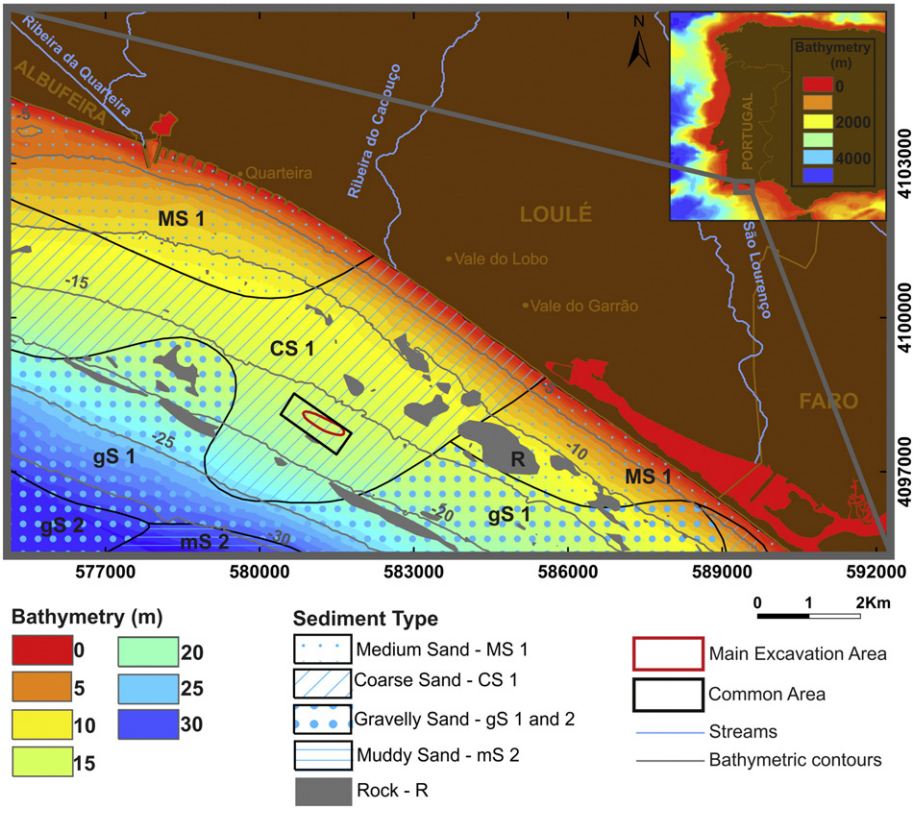

Fig. 1. Bathymetry and superficial sediments in the study area offshore Vale do Lobo, Algarve, Portugal. The red ellipse shows the location of the main excavation area and the black polygon indicates the area common to all available bathymetric surveys. The bathymetry shown is from the Portuguese Hydrographic Institute (2001 survey, courtesy of the Administration of the Hydrographic Region of the Algarve — ARH Algarve). The inset in upper right corner shows the location of the study area in mainland Portugal; bathymetry from the GEBCO 2008 (2 miles spacing) digital bathymetric grid. On top of the bathymetry are represented the superficial sediments in the study area, based on the Hydrographic Institute Map of Superficial Sediments (IH, 1985), side scan sonar data, in situ observations and manual sampling (60 cm deep) through scuba diving (Teixeira, 2011). The numbers 1 and 2 after the sediment type indicate if it corresponds to a lithoclastic or lithobioclastic sediment, respectively. Coordinate system in UTM Zone 29N, datum WGS84 and bathymetry referred to the Hydrographic Zero datum (ZH).