Monitoring the implementation of a dredging plan in the Óbidos Lagoon (Portugal)

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Abstract: The Óbidos lagoon (central west coast of Portugal) is a small coastal system exposed to intense wave action. Because its inlet is highly dynamic and closes occasionally, frequent interventions have been carried out by local and national authorities. However, their results have been ephemeral, and the interventions' efficiency needs to be assessed. A monitoring program was applied to understand the morphodynamics of the lagoon during the implementation of a dredging plan in its downstream sector. Topo-hydrographic surveys, airborne and satellite images, wave parameters and water levels data acquired between March 2015 and March 2016 are analysed. Results show that the objectives of the dredging plan were reached regarding the increase of the sandy barrier crest height and the tidal channels deepening. The tidal range inside the lagoon increased significantly as a result of the inlet enlargement and the channels deepening, and the flood dominance decreased leading to a significantly more stable inlet mouth.

Key words: Tidal inlet, Morphologic evolution, Hydrodynamics, Monitoring, Dredging

1. INTRODUCTION

Coastal lagoons are water bodies limited by a sand barrier that are periodically connected to the ocean by restricted inlets (Woodroffe, 2003). Their characteristics, influenced by the relative balance between wave energy, tide and river inflow, make these systems among the most productive in the world and very attractive for touristic development and leisure activities (Chapman, 2012; Conde *et al.*, 2015; Lillebø *et al.*, 2017).

The Óbidos Lagoon, located in the central west coast of Portugal, presents a highly dynamic inlet. Frequent inlet closure episodes or its migration along the sand barrier, leading to margins erosion, have led the authorities to take mitigation measures often with ephemeral results.

This paper presents and discusses the results of a monitoring program implemented to understand the morphodynamics of the lagoon during the execution of a dredging plan in its downstream sector.

2. STUDY AREA

The Óbidos lagoon, located between the Nazaré and Peniche headlands, presents an elongated shape perpendicular to the coast with NW-SE general orientation (Fig. 1). The lagoon is a small system with a surface between 4.4 km^2 (mid-tide) and 8 km^2 (high tide) and an average depth of 3 m (Bruneau, *et al.*, 2011). The lagoon is separated from the sea by a 1.6 km sand barrier and presents two main sectors. The upstream sector is characterised by high sedimentation rates from the watershed inflows. These correspond mainly to the Real, Arnóia and Cal rivers, and are only significant in winter (Maretec, 2004). The majority of the water lines are dry in the summer months.

The downstream sector is controlled by the complex dynamics of the inlet and the flood-tide delta sand bars. The tidal range in the nearby ocean varies between 1 and 4 m, in neap and spring tide, respectively, and the lagoon is exposed to severe wave climate (off-shore significant wave height > 2.5 m during 20% of the time) promoting a very dynamic inlet. During maritime winter the wave action promotes the inlet infilling, reducing the tidal range inside of the lagoon; the situation is reversed in the maritime summer when the tidal currents contribute to enlarge the inlet increasing the tidal range inside the lagoon (Oliveira *et al.*, 2006).

This complex natural dynamics of the lagoon often requires management measures to prevent and/or mitigate consequences in the ecosystem quality (during inlet closure episodes) and in the margins stability (when the inlet approaches the margins during a migration episode).

A dredging plan was proposed (General Plan of Interventions of the Óbidos Lagoon, Fortunato and Oliveira, 2007). The plan consists of dredging the two main tidal channels and several transverse channels. The dredged material is used to reinforce the sand barrier, by increasing its height, and to protect the south margin. The original plan also proposed a partially submerged guiding wall to prevent the southward migration of the inlet mouth. However, the actual intervention was restricted to the dredging of the two main channels, and two of the transverse channels.

Fig. 1. Location of the the Óbidos Lagoon. The target area for the monitoring plan is represented in dash. Image: ESRI Basemap.

3. MONITORING PLAN

The monitoring program was designed to: (1) characterize the morphology and the hydrodynamics of the lagoon downstream sector in the reference situation (pre-intervention); (2) monitor the evolution of the water level inside the lagoon, the morphological evolution of the emerged zones, channels, and the inlet position in the sandy barrier; (3) define possible actions to be taken in order to anticipate or mitigate any negative impacts of the intervention. Data were acquired between March 2015 (reference situation) and March 2016 (after the intervention) (see Figure 1 for locations).

3.1. Remote sensing

In order to assess the evolution of the emerged zones, two ortophotos were obtained, one before and another after the intervention. Also, a satellite image (Deimos 2) was acquired on June 2015. The water index (McFeeters, 1996) was calculated in the reference image, allowing the extraction of the water mask (polygon that corresponds to the submerged zone). This mask was validated with the bathymetric line extracted from the digital terrain model (DTM) of the reference situation corresponding to the water level measured at the local tide gauge at the time of the image acquisition. For each image, the water mask was applied along with the terrain mask, that corresponds to the area above the highest astronomical tide line (LMPMAV, Rilo *et al.*, 2014) made available by the Portuguese Environment Agency (APA), and the outer coastal zone mask defined by the surf line. These masks allowed the exclusion of these regions from the images and the clustering algorithm K-means was applied. The classification obtained was used in ArcGIS to map the morfosedimentary units. Despite the lower resolution, the high acquisition frequency of the LANDSAT8 satellite images (extracted from https://landsat.usgs.gov/) allowed a qualitative analysis of the inlet evolution.

3.2. Topo-hydrography

Two topo-hydrographic surveys were performed before and after the intervention, in order to assess the bottom evolution in the downstream sector. A previous survey, dated from 2004, was also available. The surveys were compared using the software Surfer (version 8.04) using kriging as gridding method. The topo-hydrographic evolution between the different dates was assessed and the spatial distribution of the volumetric variations analysed.

3.3. Hydrodynamic data

Wave climate in the Óbidos Lagoon area were determined through the data in the wave buoy of the Hydrographic Institute (IH), located near Nazaré. Predictions of LNEC's operational model (Fortunato et al., 2017), available at http://ariel.lnec.pt, were used to fill in data gaps.

Similarly, sea levels in vicinity of the lagoon were determined at the nearest tide station located in Peniche (http://www.emodnet.eu/) and the results of the operational model of LNEC for the same location were used to fill the data gaps.

Water levels inside the lagoon were acquired through a tide gauge installed by the Hydrographic Institute at the Foz do Arelho pier. Based on these data several parameters were calculated: tidal range; ratio between the tidal range in the lagoon and at the sea; tidal asymmetry, as a proxy of the inlet infilling.

3.4. River discharges

River discharges into the lagoon can contribute positively to the evolution of the inlet, decreasing the flood dominance. In the absence of river discharges information, two alternative sources were considered for a qualitative analysis: precipitation forecasts for Foz do Arelho extracted from http://www.windguru.cz; and water height data measured in Real river, provided by APA.

4. MORPHOLOGIC EVOLUTION

4.1 Morfosedimentary units mapping

In the reference situation, the inlet channel was poorly developed and the south channel was very silted (Fig. 2). The areas above Chart Datum (CD) clearly dominated (96.5%) compared to those below CD (3.5%). The main differences in the surface of the lagoon after the intervention are: (1) a significant change of the inlet, with its enlargement; (2) the volume of the main bar of the flood delta (a preferential sedimentation area) is significantly reduced; (3) the absence of the emerging zone from the ebb delta in the post-dredging situation; (4) increment in the area of the flood delta bars, mainly along the south margin resulting from the dredged material deposition for protection this margin.

Fig. 2. Morfosedimentary units, before (above) and after (below) the intervention.

4.2 *Topo-hydrography*

The comparison of the surveys before and after the intervention (Fig. 3) shows that the mean elevation was practically unchanged. The deposition and excavation volumes are 600 000 m^3 and 523 000 m^3, respectively. The dredging of the channels promoted the reduction of the main flood delta bar, which has a tendency for silting. The maximum elevation of the sandy barrier crest, which was between +7 and +8 m CD, shows after the intervention values between +9 and +10 m CD, as foreseen in the project. The slope of the sand barrier also increased significantly.

An interesting development is the formation of a sand spit, in the northern sand barrier, directed to the interior of the lagoon, observed in early 2016. Later monitoring showed that this sand spit, about 200 m long, had no major impact on the stability of the inlet.

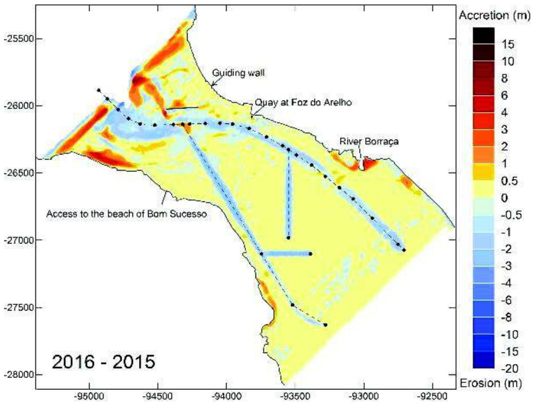

Fig. 3. Comparison of 2016-2015 surveys. The project guidelines are marked in dashed line.

5. HYDRODYNAMICS

5.1 *Forcings evolution*

The analysis of the forcings evolution during the intervention showed that the conditions of the levels (tides and surges) were favorable to the maintenance of the inlet open. The occurrence of two storms, with significant wave heights of about 6 m, before the intervention (beginning of March 2015), may have contributed to the inlet closure and the difficulty in reopening it. During the intervention, several storms with significant wave heights of about 5 m occurred without noticeable consequences. The fluvial inflows to the lagoon were very variable without a relevant effect on the inlet evolution.

5.2 *Water level evolution*

As a result of the extensive opening of the inlet and the deepening of the channels, the tidal range in the lagoon increased significantly compared to the reference situation. Also, a progressive decrease in the flood dominance during the maritime summer occurred (Fig. 4). Both conditions contribute to the inlet stability. Thus, the monthly average of the difference between the ebb and flood duration decreases from June to October 2015, typically increasing after that time (Table I).

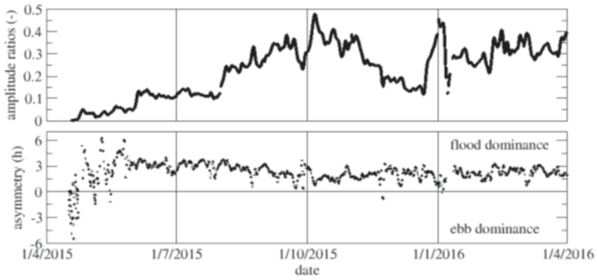

Fig. 4. Tide characteristics inside the lagoon (Foz do Arelho) during the intervention: rate of tidal range in the lagoon and at the sea; tidal asymmetry.

Table I. Evolution of the tide asymmetry in the Óbidos Lagoon during the intervention. Monthly average of the difference between the flood and the ebb durations in the Foz do Arelho pier (in minutes)

2015							
May	June	July	August	Sept.	October	November	December
150	185	185	164	123	106	115	122
2016							
January	February	March					
111	141	133					

6. CONCLUSIONS

During the monitoring period the morphological evolution of the downstream sector of the Óbidos Lagoon was determined by the natural hydrodynamic conditions and those resulting from the dredging intervention that mobilized important volumes of material (about 717 000 m^3).

The objectives of the dredging plan were reached regarding the inlet enlargement and the channels deepening and the increase of the height of the sandy barrier crest by material deposition. The tidal range inside the lagoon increased significantly and the flood dominance decreased leading to a significantly more stable inlet. Also the protection of the residential area of Bom Sucesso (Fig. 1) in the south margin was strengthened by the deposition of dredged material.

During the intervention period, the inlet channel shifted southward and became more meandered. This behaviour could potentially have been avoided with the construction of the proposed guiding wall.

Due to the natural morphological variability of the downstream sector of the Óbidos Lagoon, it is expected that the conditions observed after the intervention will change. The post-intervention monitoring will enable the evaluation of its long term efficiency and the definition of possible corrective measures.

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