Backbarrier evolution at a medium-term scale

A.R. Carrasco†, Ó. Ferreira†, A. Matias†, P. Freire‡ and J.A. Dias†

† CIMA
Universidade do Algarve, Campus de Gambelas
8005-139, Faro, Portugal
azarcos@ualg.pt; oferreir@ualg.pt; ammatias@ualg.pt; jdias@ualg.pt

‡ Laboratório Nacional de Engenharia Civil
Núcleo de Estuários e Zonas Costeiras
1700-066, Portugal
pfreire@lnec.pt

ABSTRACT


This study reports the medium-term evolution of a sandy backbarrier and its relation with prevailing wind conditions. Obtained results demonstrated that Ancão backbarrier does not behave as a scale-down version of higher energy fetch-limited or oceanic beaches, being considered as a low-energy beach with extremely low wind-induced wave conditions. Volumetric changes during the three years monitoring were small, and the analysis of low-scale changes was divided into four beach compartment: upper beach, beach face, tidal flat, sand bank. There was no significant correlation between prevailing wind conditions, volume and grain-size variation, neither a marked seasonal pattern. Some wind-induced beach changes were perceptive in the grain size variations, related mostly to aeolian offshore sediment transport. Morphological changes were similar in the upper part of the profile, including upper beach and beach face, with changes mostly related to wind and wind-waves energy. The lower part of the profile, which includes the tidal flat and the sand bank, frequently react independently from the upper part of the profile, although, sediment exchange between them was noticed during extreme conditions. The lower part of the profile had larger volumetric variability, without any evident wind dominance. The studied beach revealed high morphologic resilience, yet the overall quantities of sediment transported between 2005 and 2008 has particular relevance in the local coastal management context. Further research is needed to develop a broad-scale model of fetch-limited beaches, including the less energetic settings of the spectra such as backbarrier environments.

ADITIONAL INDEX WORDS: fetch-limited, small-scale, wind

INTRODUCTION

The magnitude of beach mobility is a function of the controls that increase or decrease susceptibility to erosion (Jackson and Nordstrom, 1992). Sand availability and wind conditions are important factors in fetch-limited beaches modulation (Anthony et al., 2006). In fact, wind and waves may be the principal source of energy for mobilizing and transport of estuarine beach sediments (Jackson, 1995; Nordstrom and Roman, 1996). Detailed research on beach morphology and dynamics revealed different response to changing wind and wave conditions (e.g. Hegge et al., 1996).

The relevance of these forcing processes for beach profile has been discussed by several authors, who demonstrate that the foreshore was the most active part of profile (e.g. Jackson, 1995). Besides the cyclic behavior (Nordstrom, 1980), changes in foreshore were mainly defined by sediment remove from the upper foreshore during high-energy events and farther deposition in the lower foreshore, whereas the tidal terrace is kept relatively stable (Jackson and Nordstrom, 1992). According to Nordstrom (1992) the depth of mobilization on the upper foreshore is small, and the active beach may be only a thin veneer of unconsolidated material. Rates of change are thus low, and survey profiles at fetch-limited beaches generally reveal little change in morphology, either alongshore or cross-shore (Nordstrom, 1980).

Whether this pattern of change may be conventional applied to other fetch-limited beaches is debatable, since there are still some gaps in the scientific knowledge of low energy beaches, particularly backbarrier systems. It is still needed to seek for a broad-scale characterization of fetch-limited beaches. This paper goal is to contribute to the understanding of very low energy fetch-limited beaches (under backbarrier settings) by reporting the results of medium-term monitoring of morphology and grain-size. The main objective is to identify the overall medium-term (months to years) evolution tendencies, and its integration within the context of other low-energy beaches.
FIELD SITE

The field site is located in the Ria Formosa, a multi-inlet barrier island system. The system extends over 56 km in length and includes two peninsulas, five islands and six tidal inlets that enclose a lagoon (Figure 1). Tides in the area are semi-diurnal; average ranges are 2.8 m for spring tides and 1.3 m for neap tides, but maximum ranges of 3.5 m can be reached during equinoctial spring tides. Average offshore significant wave height is 0.92 m (Costa et al., 2001). Behind Ancão Peninsula, the field site is sheltered from oceanic waves and therefore, exposed to a different wave and current regime. The main forcing mechanisms acting on the field site are tidal currents, wind and wind-induced waves. The backbarrier beach is limited by Ancão channel that connects to Ancão Inlet, located about 2250 m to SE. Ancão Inlet is a small ebb-dominated inlet with cyclic eastward migration pattern (e.g. Salles, 2001, Vila-Concejo et al., 2002). With the exception of waves generated by exceptionally strong winds, predominant waves are small, in the order of few centimetres in height (Carrasco et al., in press). The field site extends over ~100 m and is composed of three main morphologies: beach face, tidal flat and sand bank (Figure 1). Under low wave energy, the steep beach face (~40 m wide) presents a very narrow swash zone during high tide. In contact with the foreshore, a tidal flat with a gentle slope is present, ending in a small sand bank (30 m wide) parallel to Ancão channel. The tidal flat dissipates wave energy during the middle part of the tidal cycle. Both tidal flat and sand bank show no bedforms and are cut off by a small oblique secondary tidal channel. Human occupation includes a small number of dwellings in the backshore area and an alongshore elevated footpath.

METHODS

Wind data were obtained from a nearby wind station, Faro airport (Figure 1: Weather Underground, 2008). Prevailing directions and daily average maximum speeds (data recorded every 30 min) were determined for the period of data collection. Topographic data were gathered from April 2005 to March 2008 (survey 1 till survey 26). Ten cross-shore profiles (\(a\), at east, to \(j\), at west) with 10-m spacing were undertaken at each survey. Profiles were analyzed to ascribed cross-shore morphometric variability, and alongshore heterogeneity over the overall survey area. A mean profile was determined and standard deviation of elevation for each cross-shore position was computed. Regions of the profile with higher morphological variability (i.e. peaks in standard deviation) were considered separate individual morphological compartments (see example in Figure 2B). Four main morphological compartments were distinguished: upper beach, beach face, tidal flat and sand bank. The same compartments were identified through the overall surveyed area (between profile \(a\) and profile \(j\)). Beach volume was determined in relation to Mean Sea Level (MSL). Grids were interpolated assuming the topographic profiles intersection. Kriging was used as the grid-fitting method with 0.5 m spacing. Volume computation errors include equipment error (maximum vertical error of \(+0.003\) m, quoted by the manufacturer), fieldwork operational errors (mean horizontal error of \(0.01\pm0.07\) m, and mean vertical error of \(0.00\pm0.002\) m, based on test surveys) and surface interpolation method errors (maximum difference between interpolations with different methods of 0.39%). Volume calculations were also undertaken for each morphological compartment.

Superficial sediment samples were collected during fieldwork at the main compartments along profiles \(d\) and \(i\). Traditional laboratory dry sieving procedures for unconsolidated clastic sediments were used for the coarse fraction. The pipette method was used for the fine fraction. Grain-size parameters were obtained following Folk and Ward (1957) method, using GRADISTAT (Blott and Pye, 2001). Values of \(d_{50}\) (median diameter) were computed.

RESULTS

Morphological and Sedimentological Analysis

The overall area is relatively homogenous, with no major changes in the volume (Table 1, Figures 3 and 4a). Mean volumetric variability between 2005 and 2008 was generally low, about -0.001 m\(^3\) m\(^{-2}\) (Figure 3). Higher magnitude changes took place in the last two years of analysis (end of 2007 and beginning of 2008; Figure 3); periods of beach volume depletion were more common during 2007 (Figure 4a). There is no noticeable seasonality: mean summer volume was about 11,920 m\(^3\), and mean winter volume was of 11,823 m\(^3\). Moreover, there is no tendency for erosion/accretion between neap and spring equinoctial tides (Figure 4a).

Areas of larger morphological variability were constrained to the berm location, between the upper beach and the beach face, and to the transition between the beach face and tidal flat (Figure 2). Erosive episodes were frequent in locations closer to Ancão channel (Figure 1), in the lower part of the profile. Despite higher volumetric variations of the lower part of the profile, \(d_{50}\) variability was usually greater at the upper beach and beach face (Figure 4c). Finer sediments dominate the upper tidal flat and the sand bank (Table 1). November 2005 and March 2008 demarked

Figure 1. Field site location, showing Ancão Peninsula backbarrier, and (inset) a vertical aerial photograph (taken in 2007) with the main beach compartments.
enrichment of finer sediment (associated with lower energy), whilst January 2006 and January 2007 demarked the deposition of coarse sand (associated with high energy events, Figure 4c).

Wind driving conditions
It was observed an overall prevalence of W-NW winds (Figure 5) with a few episodes of easterly winds (mostly at the end of 2007 and beginning of 2008). Maximum month intensities occurred associated to S-SE winds (Figures 4b and 5). Wind intensity was generally moderate with average wind velocity of ~4 m s\(^{-1}\). With the exception of February 2008 (maximum West wind of about 17 m s\(^{-1}\)), no major high energy episodes occurred between 2005 and 2008. Mean and maximum wind intensities during summer were 4 m s\(^{-1}\) and 15 m s\(^{-1}\), respectively; and mean wind direction was of 210º. Mean and maximum wind intensities during winter were 4 m s\(^{-1}\) and 17 m s\(^{-1}\), respectively; and mean wind direction was of 181º (higher percentage of NE winds).

Evolutionary Patterns
There is low correlation between the prevailing wind conditions and grain-size (Table 1). Only the upper beach had significant negative correlation with mean wind intensity. Wind direction had negative relationship with \(d_{50}\) at the four compartments. The eastern part of the surveyed area was, generally, more reactive to wind (higher correlations, profile d).

Relationship analysis between beach volume variation, slope and wind, was not conclusive (Figure 6). The overall volumetric changes vs. wind do not follow an obvious pattern, and there is no apparent tendency in wind-induced changes (Figure 6); rather there was a cloud distribution, with no statistical relation (with correlation coefficients \(r<0.3\)). Beach slope had poor, but a better, than volume, linear relation with wind direction (Figure 6d).

DISCUSSION AND CONCLUSIONS
During the three years monitoring the backbarrier did not report an evident volumetric seasonally neither any cyclic pattern (contrary to observations by Nordstrom, 1980). Volumetric changes were generally small, corroborating the natural beach reluctance to change (Carrasco et al., 2009). Indeed, the low magnitude of recorded changes when compared with other low-energy beaches (e.g. Jackson and Nordstrom, 1992) suggests that backbarriers lapped by narrow tidal channels should be classified as low-energy beaches with extremely low wind-induced wave influence. The down-scale approach from oceanic beaches cannot be used. The studied beach reacts to winds and waves differently than oceanic beaches, which includes a strong longshore tidal component that may dominate morphological changes (Carrasco et al., in press). The small amount of change observed at this backbarrier may be due to the availability of sediments in the longshore transport system or to the low breaking waves energy because of limited fetch provided by the narrow Ancão channel. These small morphological changes prove that techniques and analysis employed at oceanic and higher energy fetch limited beaches are not suitable for the beaches on the lower energy part of the spectrum.
Cleary, two patterns of responsiveness were observed for the upper and lower parts of the profile, where site specific controls revealed different local domains, as observed by Jackson and Nordstrom (1992) for fetch-limited beaches. Volumetric changes at the beach face and at the upper beach had the same signal, and the same way changes at the sand bank and at the tidal flat (Figure 4c) also had the same signal. Volumetric variability had the lower part of the profile was independent from wind (Table 1): changes at this location are mostly governed by tidal current velocities (Ancão channel, Figure 1; Carrasco et al., in press). At the upper part of the profile, wind had a more important role, and wind (wave)-induced changes influenced the seasonal grain size variation (Figure 4b and c). The upper beach was the morphology that had a higher correlation between volumetric changes and wind mean intensity (Table 1). This compartment is barely reached by swash, and therefore sediment displacements are mostly related to aeolian transport (westerly winds, blowing from the dune to the beach; Figure 1), and to human-induced changes.

The maximum wind velocities reached between 2007 and 2008 may be responsible for destructive beach episodes (Figures 3 and 4) during winter, by an increase in maximum wind intensity from SW. The surveyed area is relatively homogeneous in the alongshore direction (Figure 2A), without significant slope or volume changes. However, it encloses two different types of response to wind. Because of the natural physiographic configuration, the eastern part of the surveyed area was more reactive to wind, showing better correlation between mean wind intensity and $d_{50}$ (profile d, Figure 4c and Table 1).

During a few episodes, the beach face had opposite volumetric change to the tidal flat/sand bank (Figure 4c), suggesting that cross-shore transference had occur (mainly between the lower beach face and the upper tidal flat, Figure 3). Despite these small scale landward exchanges, sediment displacements were generally limited and restricted to extreme events (e.g. wind intensities above 12 m s$^{-1}$, Figure 4a and b). The present analysis did not confirm any sediment exchange between the upper and lower foreshore, as portrayed in Jackson (1995), and Nordstrom (1992). Future research should now be focused in the definition of hydrodynamic thresholds driving medium-term beach volume variation, including wind direction and intensity as well as tidal currents, and to the cumulative beach inheritance role in beach mobility.

Despite sediment transport has small magnitude it influences local human activities. Shellfish farming is highly dependent upon bed sediment properties especially the ratio sand/mud. Therefore, studies transport in this area is relevant for coastal management issues.

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![Figure 4](image_url)

**Table 1** Sediment median diameter ($d_{50}$) and correlation coefficients between $d_{50}$ and prevailing wind conditions ($p=0.05$, $r>0.55$).

<table>
<thead>
<tr>
<th>Compartment</th>
<th>Correlation coefficient</th>
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<tbody>
<tr>
<td>lower</td>
<td>$d_{50}$ ($mm$)</td>
</tr>
<tr>
<td>upper beach</td>
<td>$d$</td>
</tr>
<tr>
<td>beach i</td>
<td>$i$</td>
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<td>beach d</td>
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<tr>
<td>face i</td>
<td>$i$</td>
</tr>
<tr>
<td>tidal flat</td>
<td>$d$</td>
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<tr>
<td>flat i</td>
<td>$i$</td>
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<tr>
<td>sand i</td>
<td>$d$</td>
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<tr>
<td>bank i</td>
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Figure 4. (a) Beach volume variation, (b) wind direction and intensity, and (c) grain size distribution ($d_{50}$).
LITERATURE CITED


