Bol. Inst. Esp. Oceanogr. 15 (1-4). 1999: 283-288 **BOLETÍN** INSTITUTO ESPAÑOL DE OCEANOGRAFÍA
ISSN: 0074-0195

Preliminary results of the Cacela Peninsula (southern Portugal) replenishment

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Received October 1997. Accepted April 1998.

ABSTRACT

Cacela Peninsula, located on the eastern edge of the Ria Formosa barrier island system (southern Portugal), had a very low-breached and poorly-vegetated dune field. During the winter of 1995/1996, several overwashes occurred, which led to the opening of a new inlet. After this event, a major dune replenishment of 325 000 m³ of sediment was begun. To evaluate the replenishment's effect on beach behaviour, a monitoring program was established consisting of monthly profile surveys at sites located both in the replenished area (5 sites) and eastwards of this area (3 sites). Two topographic maps made immediately pre- and post-replenishment, were used for volume comparisons between sites, together with profile surveys. The Levante erosive event that occurred in March 1997 was responsible for erosion of about 10 % of the total replenishment. This erosion was more pronounced at sites 2 and 3, the most prominent places of the replenished area. After this event, no major volume changes were observed in the replenished area's subaerial beach during the period studied (February 1997-August 1997). Eastwards of this area some accretion occurred, which was not necessarily related to the replenished sediments' erosion. The replenished area's beach profiles showed relatively slow evolution from a generally dissipative profile (winter 1997) to a berm-type profile (summer 1997). For non-replenished areas of the peninsula, this evolutionary trend was less evident. In light of the present data, a readjustment of the profile is expected, including probable new bluff retreat on the prominent sites.

Key words: Replenishment, dune, beach dynamic.

RESUMEN

Resultados preliminares de la operación de realimentación de la península de Cacela (sur de Portugal)

La península de Cacela, localizada en el límite oeste del sistema de islas barrera de Ria Formosa (sur de Portugal), tiene un campo de dunas poco desarrollado y escasamente vegetado. En el invierno de 1995/1996 una serie de inundaciones dieron lugar a su rotura, con la formación de un nuevo inlet. *Después de este evento tiene lugar una importante operación de realimentación de las dunas utilizando 325 000 m³ de sedimento. Para evaluar el efecto de esta realimentación en las características de las playas anexas, se estableció un programa de monitorización, consistente en una serie de levantamientos topográficos mensuales, en el área de realimentación (5 perfiles), así como al este de ésta (3 perfiles). Se utilizaron dos mapas topográficos, obtenidos antes y después del evento, para la comparacion volumétrica entre perfiles conjuntamente con los levantamientos topográficos. Los eventos erosivos de marzo de 1997 fueron responsables de la erosión de cerca del 10 % del total de realimentación. La erosión fue más pronunciada en los perfiles 2 y 3, correspondientes a los sectores más prominentes del área de realimentación. Después de este evento no se observaron grandes cambios en la playa emergida, situada en este sector, en el periodo de estudio (febrero-agosto de 1997). Hacia el este del sector realimentado se produjo un proceso de acreción, no necesariamente debido a* *la erosión de los materiales de realimentación. Los perfiles de playa localizados en el área de realimentación mostraron un grado relativo de evolución lento, desde perfiles generalmente disipativos (invierno de 1997) a perfiles tipo berma (verano de 1997). Para los sectores no reconstituidos de la península la evolución de los perfiles fue menos evidente. A la vista de estos datos, un reajuste de los perfiles es todavía previsible, incluido un probable nuevo retroceso en las áreas más prominentes.*

Palabras clave: *Realimentación, duna, dinámica de playa, península de Cacela (sur de Portugal).*

INTRODUCTION

The study area is located on Cacela Peninsula (southern Portugal), which constitutes the eastern limit of the Ria Formosa barrier island (Pilkey *et al.*, 1989) (figure 1). The Lacém inlet (or Cacela inlet) separates this peninsula from the adjacent western island.

According to Andrade (1990), the peninsula has a length of approximately 4 500 m and an average width of 200 m. The average dune height of the sand ridge top is about 4.5 m Z.H. (above hydrographic datum) with a maximum height of 7.3 m Z.H., at the eastern part. The dune field was intensely breached by large washovers, showing its high vulnerability to storm action. Accordingly to Pilkey *et al.* (1989), overwash processes may ultimately close the narrow lagoon and shorten the length of the barrier island system by moving the existing eastward mainland attachment westwards.

Mean tidal range in this area is 2.5 m, reaching up to 3.6 m during spring tides. The offshore wave climate is dominated by the southwest waves, with 51.5 % of occurrences (Costa, 1994); southeast conditions (known as the *Levante*) are also frequent (25 %). The mean annual value for significant wave height is 0.92 m (medium energy), with the southeast wave conditions having a higher mean value (1.2 m) than the southwest waves (0.8 m) (Costa, 1994). The southeast-facing orientation of Cacela Peninsula provides a sheltered situation with regard to longer-fetched southwest waves. However, it is directly exposed to the *Levante*, normally associated with sea waves (smaller fetch).

The prevailing longshore current direction is dominantly west to east.

According to the above tidal and wave conditions, the barrier islands fall into the mixed energy zone of Hayes's (1979) classification.

During the winter of 1995/1996, several overwashes occurred, that ledd to the opening of a new inlet, in front of Fábrica, approximately in the middle of the peninsula. This inlet had a width of about 35 m at low tide and a minimum channel level of 1.3 m Z.H., therefore only active during mean-to-high tides.

In order to protect the Fábrica location, to maintain clam and oyster cultures and to avoid overwashes, a major dune replenishment operation was undertaken, between October 1996 and February 1997. This operation affected the western 2 000 m of the peninsula, closing the new inlet and re-es-

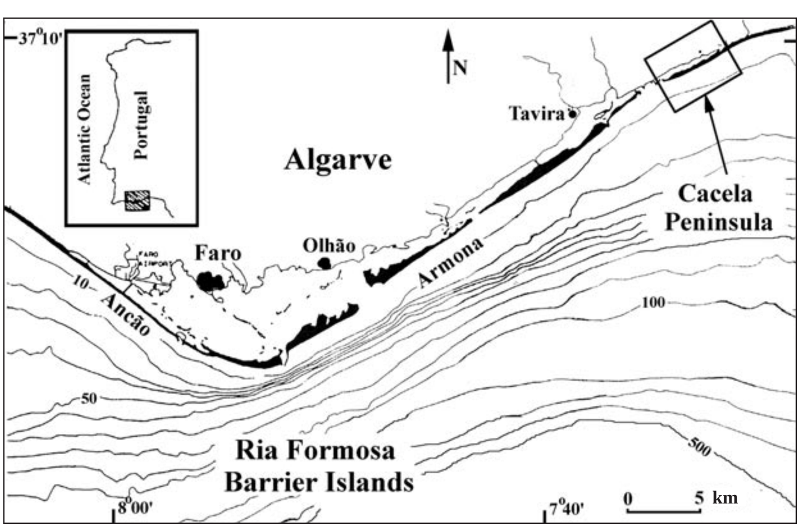


Figure 1. Location of Cacela Peninsula in the barrier island system

tablishing the beach conditions there. It involved dredging the inner channel to the −2.0 m Z.H. depth, i.e. 4 m below mean sea level, in order to try to recreate the 1970s situation. The dredged sediments were heterogeneous both in composition and in granulometry, including a fine fraction that was partially lost to the sea by superficial drainage.

Soon after the replenishment project, some pioneer dune vegetation started to naturally colonise the upper beach and recovered dune. However, it was not very efficient in trapping aeolic sediment.

A set of fences was placed on the top of the replenished area in April 1997 to trap sediment and avoid disturbance by trampling. Although this peninsula does not have permanent human occupation, two elevated foot-bridges have been built to enable people to cross replenished areas, en route to the beach, mainly during the summer.

The objective of the present study was to evaluate the dune replenishment effect over the beach behaviour, together with the beach-dune interactions, during the first six months post-nourishment.

MATERIALS AND METHODS

Topographic maps

Two 1:2 000 scale topographic maps of the western peninsula were obtained, immediately before and after the replenishment operation. These maps were digitised using the AUTOCAD computer program and SURFER grids were made by interpolation of the original irregularly-spaced raw data.

The methods used for grids generation were 'kriging', 'inverse distance' and 'triangulation', for grids with regular nodes at 2 m × 2 m, 5 m × 5 m, and 10 m × 10 m. These grids were used to compute the total amount of the replenished dune.

A first approach was made using the topographic surface after replenishment and a base level. The computed base level was 3.5 m Z.H., corresponding to the obtained mean level for the top of the previous topographic surface. Secondly, the two topographic surfaces were compared solely for the replenished area.

Monitoring programme

The monitoring programme consisted of monthly field surveys, performed at low spring tide. Eight profiles were selected, with a distance of about 400-500 m between consecutive sites, leading to a total survey length of 3 300 m. Five of the sites (P1 to P5) were located on the 2 000 m replenished part of Cacela Peninsula; the other three sites (P6 to P8) were located eastwards of the replenished area (figure 2). The selection criteria comprised both areas, to permit an evaluation of both direct and indirect effects of the dune intervention. Data presented in this study covers the surveys from March to August 97.

The obtained data were used for morphological and volumetric comparisons. Profiles P1 to P5 were also obtained for conditions immediately before and after dune replenishment.

RESULTS

Computed volumes for the replenished sediment ranged from 313 000-337 000 m³, as a result

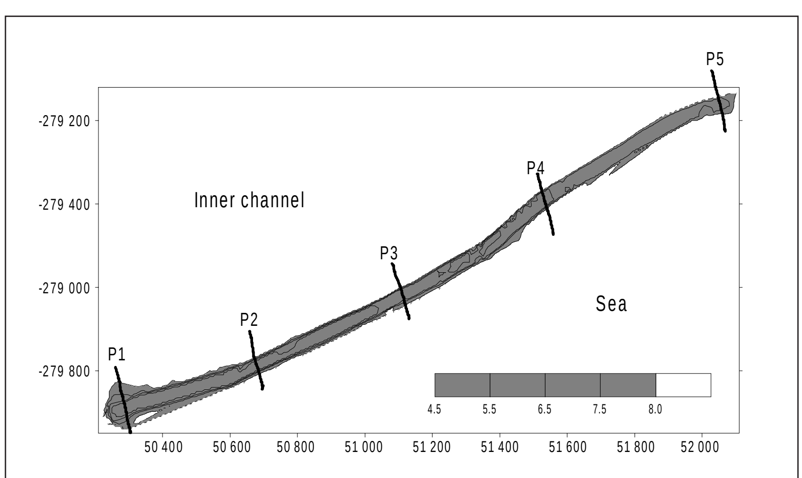


Figure 2. Location of Cacela profiles 1-5, in the replenished area (all values in metres, with elevations referred to the hydrographic data)

of the different interpolation methods and grids. A mean volume of about 325 000 m^3 can be used as a reliable estimate of the actual replenished volume. This volume was spread over the dunes, thus producing a dune crest rise of about 3.5 m for sites 1 to 4, and a 1 m rise for site 5 (figure 2). Replenished sediment volumes for each site are presented in table I. The smaller deposited volume at site 5 was due to the shorter dune crest rise.

The first erosive events occurred a few days after the dredging and replenishment operation, as a result of southeast waves (*Levante*). A beach-and-dune volume balance was computed for each site, under pre-storm and post-storm conditions (table I). The considered base level was the mean sea level (2.0 m Z.H.). The greatest volume losses occurred at sites 1 and 4, with 77.5 m^3/m and 72.7 m^3/m erosion volumes, respectively.

Table I. Replenished volumes and post-storm volume changes at each site

Site	Replenished sediment volume (m^3/m)	Volume balance between February and March (m^3/m)	Eroded volume from the dune replenishment (m^3/m)
1	349.1	–77.5	77.5
2	149.1	–2.8	8.9
3	195.9	–49.6	16.7
4	266.6	–72.7	0
5	140.6	–9.1	2.3

Volumes eroded directly from the replenished dune, excluding the beach changes, were also estimated. In this case, volume calculations at each site were made using as a base level the base elevation of the replenished seaward front. Significant sediment losses from the artificial dune occurred in profiles 2 and 3. The highest volume loss at site 1 occurred in a very restricted area, and was also related to the adjustment of Lacém inlet to the new conditions. Differences between eroded volumes from site to site resulted from the different exposures of the artificial dune, since the replenishment had prominent places (e.g. P3) and re-entrant places (e.g. P4) (figure 2).

Computed volumes point to an estimated erosion of about 10 % of the total replenished volume, during the March *Levante* event. This led to the formation of a new bluff on the seaward front of the replenished area, ranging from 1.6 m to 3.1 m in height.

Beach volumes above mean sea level were computed for all profiles obtained from late March to early August (figures 3 and 4). No major volume changes occurred during this period, for profiles located in the nourished area (figure 3). On profiles 6 to 8, at the non-replenished part, some accretion was noticed, ranging from 9.1 m^3/m to 19.2 m^3/m (figure 4).

Qualitative analysis was used to highlight the morphological feature evolution of the subaerial beach. Both the replenished areas (see figure 5 for an example of a replenished site) and non-replenished areas (see figure 6 for an example of a non-replenished site) were considered.

DISCUSSION

Cacela Peninsula was an extremely vulnerable system, densely breached, with a very low, poorly vegetated, single-crest dune field. As a consequence of the major dune nourishment operation, during the winter of 1996/1997, the sand-dune ridge top was raised from an average height of ap-

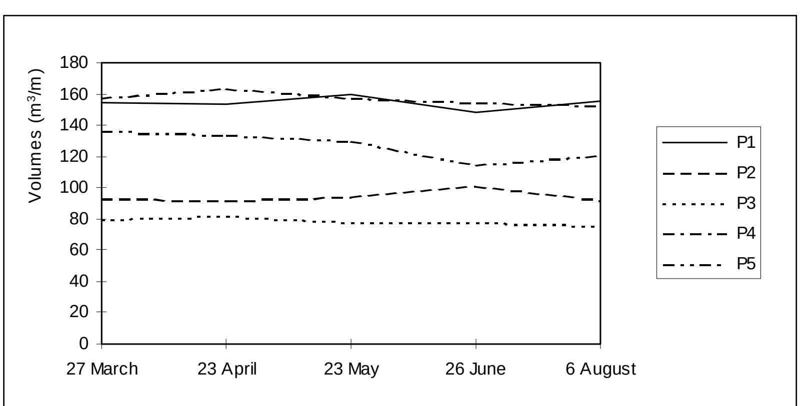
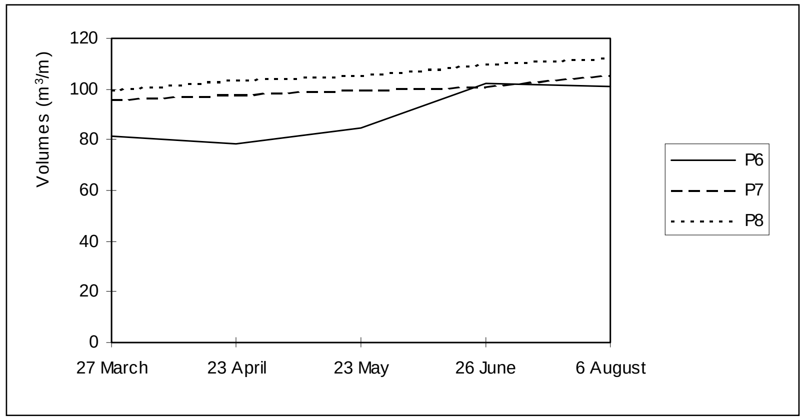


Figure 3. Subaerial beach volumes for P1 to P5, from March to August 1997 (note that profile volumes between sites are not directly comparable, since they have different origins)

Figure 4. Subaerial beach volumes for P6 to P8, from March to August 1997



proximately 4.5 m Z.H., to 5.5-7.5 m Z.H., by dumping approximately 325 000 m³ of dredged sediments.

This operation enabled the system to react to erosive events differently. Prior to replenishment, overwashes were frequent, being responsible for a great deal of dune destruction and silting the internal channel. Due to the dune-crest rise, overwashes are no longer expected in the western replenished area. However, relatively strong erosion occurred after *Levante* events, with the loss of replenished sediments and backshore sediments. This erosion was more pronounced in places where the seaward front was prominent, inducing bluff retreat and making the replenished area narrower (table I).

In the specific case of site 1, the readjustment of the Lacém inlet was one of the processes contributing to the high erosion values observed (table I).

Volumetric analysis, however, revealed that a dynamic equilibrium situation was reached after the erosive events, since approximately the same beach volumes were maintained from late March until August of 1997 (figure 3).

At non-replenished sites, the low level of accretion can be explained either by longshore transport of the updrift eroded sediments, or natural seasonal changes in the beach profile.

Profile analysis data revealed that post-replenishment beach behaviour at Cacela Peninsula during erosive events was to form a generally dissipative profile, with a poorly-defined berm, as is expected for non-interventioned areas. This post-storm beach profile was developed over a relatively short timescale (hours to a few days), but it was observed that recovery to a complete berm-type profile (figure 5) was a relatively slow process, taking several weeks.

Previous studies on the western limit of the barrier island system, Ancão Peninsula, revealed an opposite behaviour, with rapid beach recovery after storm events, including the shoreward displacement of 20 m³/m to form a new berm, in just one tidal cycle (Martins *et al.*, 1996). This contrasted with Cacela beach behaviour, considering that both belong to the same physiographic unit (the Ria Formosa barrier island system). These differences can be related to the different morphodynamic behaviours of the two beaches, since Faro beach is a

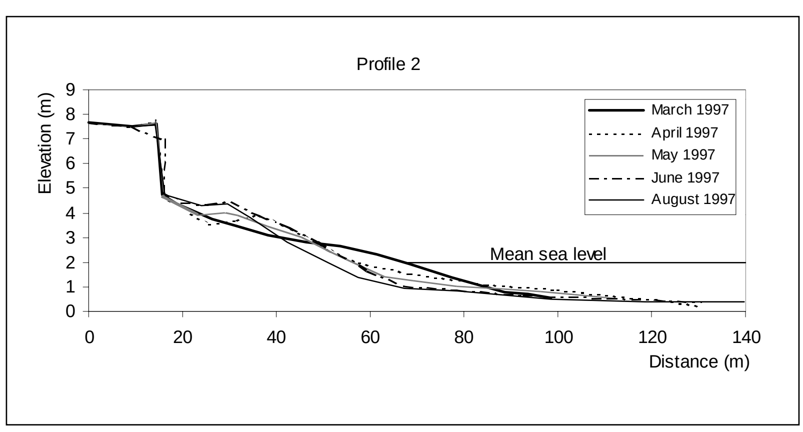


Figure 5. Subaerial beach profiles for site 2 from March to August 1997

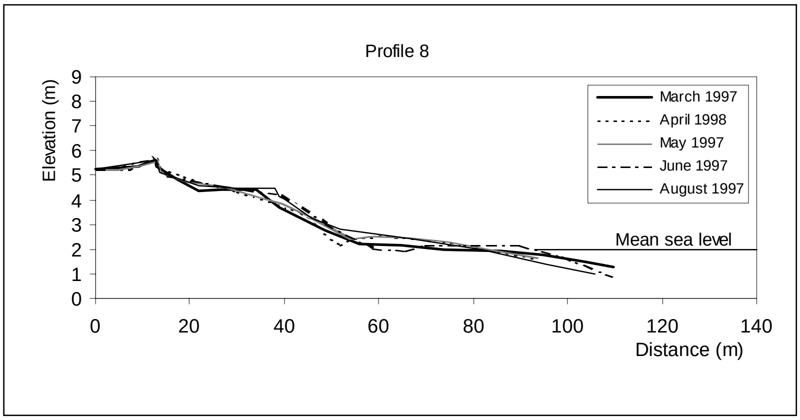


Figure 6. Subaerial beach profiles for site 8, from March to August 1997

reflective one (Reyes *et al.*, this volume) exposed to dominant southwest waves, whereas Cacela beach is intermediate-to-dissipative and protected from the dominant waves.

At non-replenished areas of Cacela Peninsula, the beach profile transition from winter to summer conditions was less evident (figure 6), due to an almost constant presence of a beach berm at the backshore.

In light of the present data, and since part of the replenishment is still prominent relative to the general alignment, readjustment is still expected, with further erosion of those prominent zones. Also, beach-dune profile readjustments were expected at the replenished area, at least until a new dynamic equilibrium is reached.

It is noteworthy that aeolic sand accumulation on the upper beach and the recovered dune was relatively small, and that a higher amount would be expected if vegetation had been planted and/or fences had been installed on the dunes immediately after nourishment operations. To improve this situation, new fences and vegetation are being placed in the replenished area. Therefore, some dune recovery is expected in future observations, and the monitoring programme will continue.

ACKNOWLEDGEMENTS

The authors would like to thank the Ria Formosa Natural Park for its support and co-operation in our fieldwork, especially the rangers Armando and Silvério. Thanks also to A. R. Ramírez for his help on the Spanish abstract.

This research is part of the European Union ELOISE Programme (ELOISE 027) within the framework of the DUNES project, carried out under contract ENV4-CT96-0215.

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