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Influence of Hydrodynamics and Sedimentary Characteristics of Barqueiro Ria on Arealonga Beach Dynamics

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ABSTRACT

The Barqueiro Ria, located on the north coast of the Iberian Peninsula, is one of the Galician "Rías Altas", which includes Arealonga Beach, the longest beach in the Ria, located in the inner portion. During the 1990s strong erosion has been registered on the beach and associated dunes, while a wide intertidal spit has grown westward. This behaviour is related to the hydrodynamic and sedimentary characteristics of the Ría and Sor Estuary. Tide and wave influence are evaluated using numerical simulations for storm events. Seasonal topographic monitoring of beach and dune profiles and surface sediment samples allow to describe the variations in sedimentary volume and map sediment units. Furthermore, grain size parameters trends are used to determine the sediment transport patterns. Three different zones have been defined along beach and foredune according to their sedimentary dynamics behaviour: i) Eastern zone, with a clear erosive tendency generating the backshore and foredune destruction ii) Middle zone, with dune erosion but sediment accumulation in the intertidal zone, and iii) Western zone, where the beach presents an accumulative profile, with a well developed supratidal area and active dunes.

ADDITIONALINDEX WORDS: *Storms, erosion, grain size, geomorphology, foredune, beach*

INTRODUCTION

Erosion is the most important problem in many coastal areas. There are different causes, but the higher erosion rates are normally associated with stormy events (BIRKEMEIER, 1979). The more important parameters to be considered in order to characterise these events are significant wave height "Hs" and period "T" (KOMAR, 1976) as well as the duration and return period (CARTER, 1988). On the other hand, RUSSEL (1993) states that not only higher waves but also infragravitational waves generate erosion processes. Moreover, some other factors like low pressures, landward winds and tidal elevation intensify the effects of storms. Finally, incoming wave direction and boundary conditions must also be considered due to diffraction and refraction processes (ALONSO and VILAS, 1994).

Storm effects are reflected in beach profiles and therefore, in shoreline position of the beach. Cross-shore sediment transport from the shore face to submerged zones transforms the beach profile in order to acquire an equilibrium with the new hydrodynamic conditions (KOMAR, 1976). Principal mechanisms responsible for this process are the undertow and infragravitational cross-shore currents (RUSSEL, 1993). On the other hand, longshore sediment transport could generate tilting of the shoreline in embayed beaches. Frequently, stormy effects can also be detected inland, due to the supply of sediments from the dunes to the beach (CARTER, 1988) or impacting over coastal structures. Storm effects are normally evaluated in exposed beaches (FERREIRA and ALVEIRINHO-DIAS, 2000), while this study evaluates erosion processes in a beach located in the inner bay of a ria.

Monitoring beach profiles is one of the most effective techniques to characterise beach erosion, although numerical models are also useful (FERREIRA and ALVEIRINHO-DIAS, 2000). The main aims of this work are to quantify the variations of sediment volume along the dune and beach relating these to the geomorphologic and sedimentary characteristics of both the foredune and submerged environments of the inner part of Barqueiro Ria. These objectives are achieved using empirical measurement of several parameters and results from numerical models.

STUDYAREA

The north coast of the Iberian Peninsula can be included in the storm wave dominated region following INMAN and NORDSTROM (1971), but it can be also defined as a coast of Rias according to its morphology (SHEPARD, 1976). A Ria is the result of sea level rise inundating a fluvial paleo-valley, i.e., a long narrow, sometimes wedge-shaped arm of the sea whose depth and width diminishes landward.

The Barqueiro Ria is located in the northwestern limit of the Iberian Peninsula, between Estaca de Bares Cape at the west and Embarcadoiro Cape at the east, with its central axis describing a southwest-northwest orientation. It is one of the Galician Rías Altas, with less than 8 km length and 2.7 km wide, its bathymetry is very shallow, with a maximum depth of 25 m in the outer limit (Figure. 1). This geometry defines three segments of progressively smaller dimensions.

The tide is the main hydrodynamic driving force of the Ría, with a mesotidal range. Nevertheless, the ria is also subject to a strong oceanic wave influence (PÉREZ-VILLAR, 1999), since storms with Hs higher than 5 m and T bigger than 9 seconds are relatively frequent during the winter. Swell waves are more frequent from the west while sea waves approach from both west and northwest directions. Wind blowing inside the Ria cannot generate significant waves due its limited fetch (MONSÓ, 1995).

Arealonga Beach is the longest beach of the Ria, with a length of 1300 m, which continue westward with a wide intertidal littoral spit. It is very exposed to incoming waves due to Ria orientation. The granite outcrop of Punta Castelos occupies the eastern limit of the beach, while the Sor Estuary is located in to the west. The quartz outcrop of Monte Furado is located in the centre of the study area, representing the limit between the exposed and the protected sectors of the beach (ALCÁNTARA-CARRIÓ *et al*., 2000). Aerial photographs of 1956, 1973, 1983, 1984 and 1990 help identify some erosive morphology in the foredune, without important modifications of the beach-dune limit. However, fieldwork has identified a 15-20 m shoreline retreat from 1990 to 2000 in the eastern limit of the beach (ALONSO *et al*.; 2000).

Human activities in the Ria, such as shellfish and fishing have been affected by these sedimentary changes. Collection of clams, cockles and razor shell have decreased during the last few years, and the Barqueiro fishing port is currently filling with sediments. Tourist development is not really important in this area.

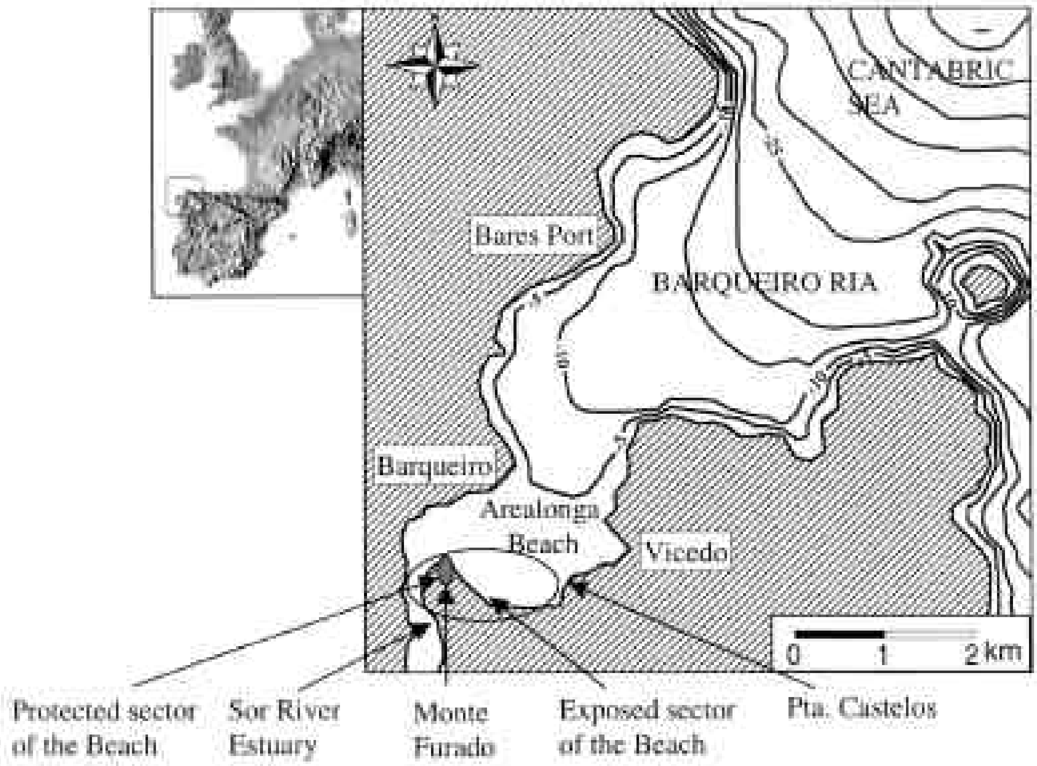

Figure 1. Location of the study area

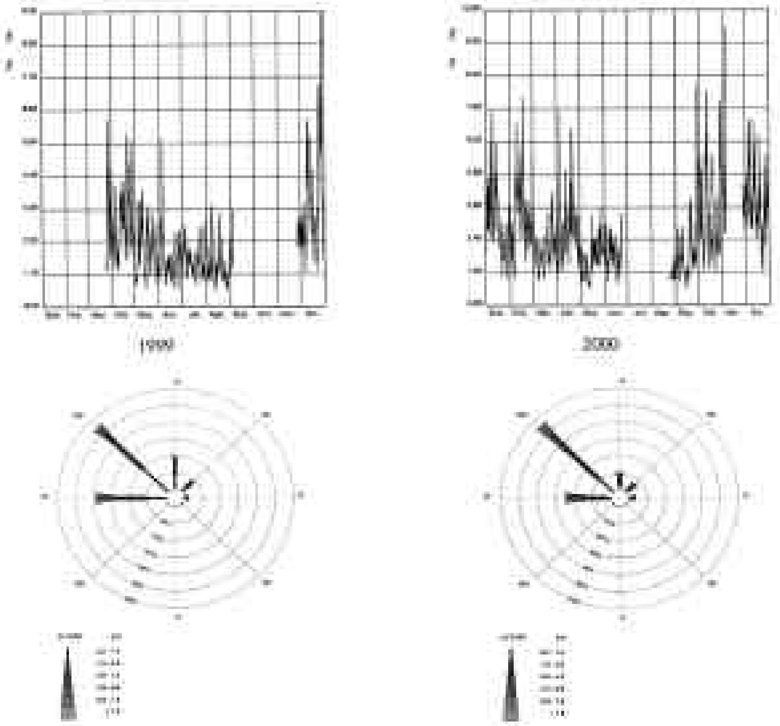

Figure 2. Significant wave height time series and wave roses for 1999 (A) and 2000 (B) after RAYO data (Puertos del Estado).

METHODOLOGY

Storm wave regime in the study area was characterised using data of RAYO directional wave recording network located opposite Estaca de Bares Cape (Figure 2). Wave simulation was carried out using the GHOST model (RIVERO *et al*. 1997), which considers different Hs, T and direction of waves, tidal elevation and local bathymetry. The model includes shoaling, refraction and diffraction of propagating waves, taken into account wave-current interaction, bottom friction, and wave breaking (CARCI and RIVERO, 1998).

Fieldwork consisted on seasonal topographic monitoring of nine dune-beach profiles using a theodolite (Figure 3a). Six surveys were carry out from December 1999 to October 2001. Previous data from October 1998, was included from TOPONORT and was used to establish the initial topographic conditions. Bathymetry was measured in December 1999 using an echosounder and G.P.S. Topographic data was processed using kriging method and volume variations determined comparing successive surveys. Landward limits of the analysis area was defined for the foredune ridge while the hydrographic 0 (Ordnance Datum OD) was chosen as the seaward limit. Therefore, dune-beach monitoring permitted evaluation of both seasonal and annual time scale changes. Dune/beach interactions were obtained by surveys, photographs and field trip observations that enable establishment of different geomorphologic stages of foredunes along the study area according to models of HESP (1988, 1999), CARTER (1988) and ARENS (1994).

Surface sediment samples were collected during the surveys along each profile at the supratidal, high and low intertidal and subtidal zones, including the nearby dunes sediment samples when those were present. Submerged sediments samples were taken with a Van Veen drag in December 1999 (Figure 3b). Sediment samples were dry sieved using 0.5 f intervals from -3 to 4.5 f, and grain size parameters calculated using both graphic (FOLK and WARD, 1957) and moment measure (FRIEDMAN, 1961) methods.

Graphic grain size parameters obtained for samples of December 1999 were plotted to map the sedimentary units from the foredune to the submerged environments. Kriging algorithm was selected to interpolate from samples and Surfer software employed to draw the contour maps of mean size, sorting, skewness and kurtosis according to classical grain size criteria (FOLK and WORD, 1957; FRIEDMAN and SANDERS, 1978).

Grain size parameters trends of the December 1999 survey were used to determine the sediment transport patterns, applying the numerical model of GAO and COLLINS (1992).

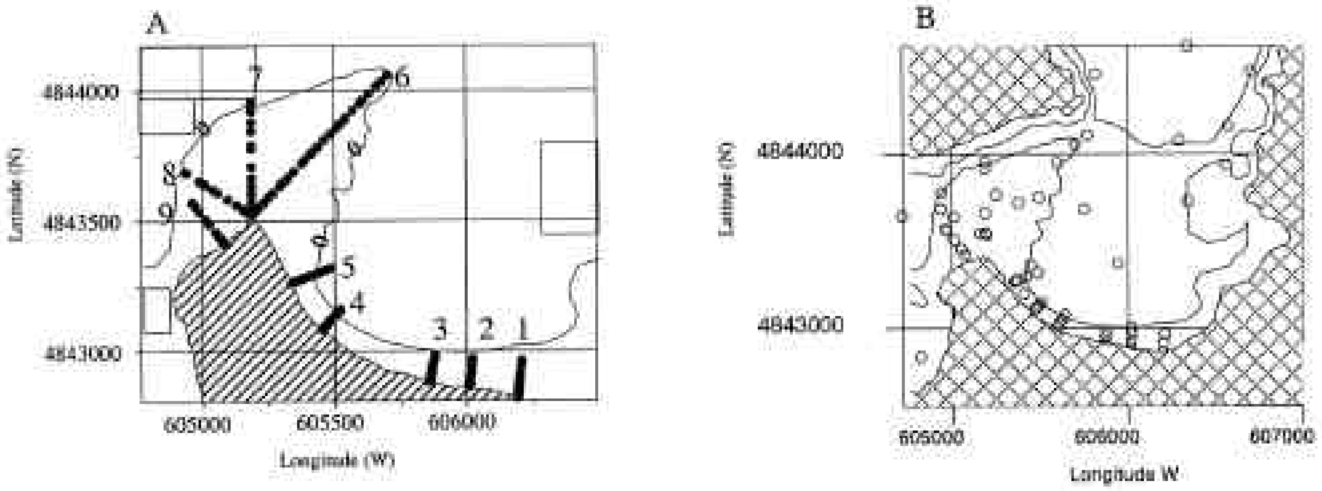

Figure 3. Beach profiles (A) and sediment samples (B) location.

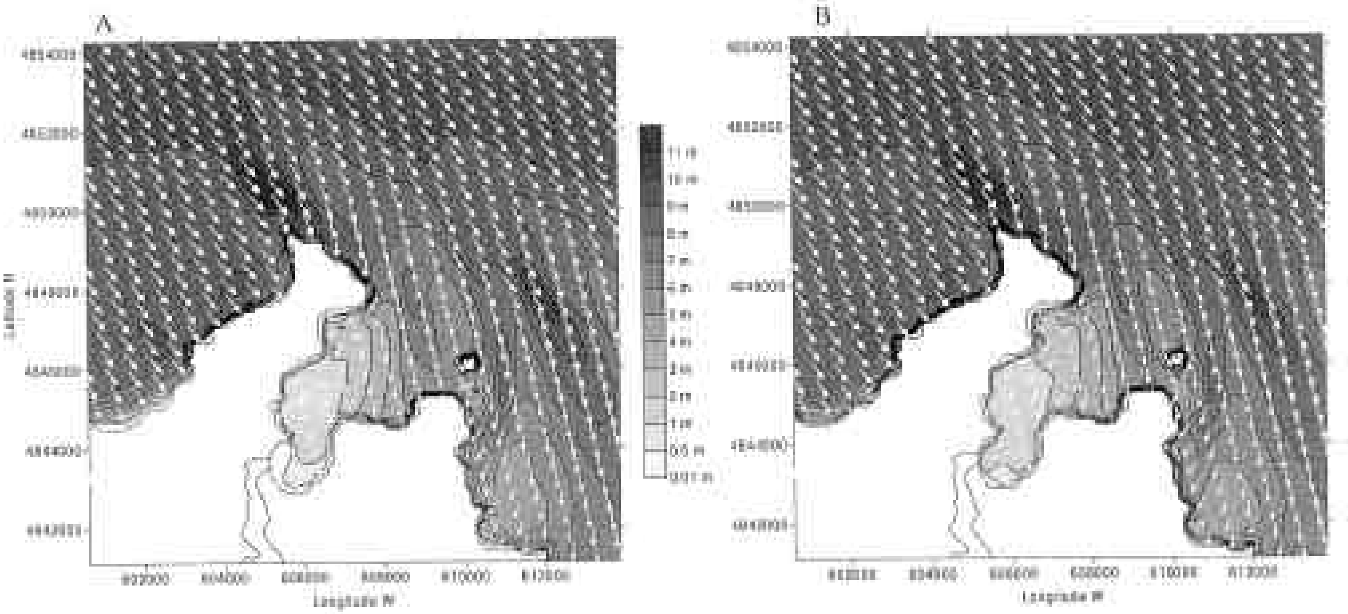

Figure 4. Storm wave simulation for l0w tide (A) and high tide (B) conditions.

RESULTS AND DISCUSSION

Hydrodynamics

Storms from NW with 10 m of Hs and 15 s wave period are the most characteristics ones for the study area, while northern and northeastern waves are also important but less energetic. Numerical results of GHOST software show that eastern sector of the beach is the most intensely affected for the storm events (Figure 4).

Sedimentary volume variations

Seasonal volume variations across the foredune and beach show strong erosion in the eastern sector of the beach during the whole 2000, except in the summer. Littoral spit presents the most variable behaviour, although erosion rates are clearly lower (Figure 5). This seasonal pattern seems to be related to wave regime (Figure 2). The annual result is one of erosion of the eastern sector of the beach and accretion on the central sector and different areas of the littoral spit (Figure 6). When topography of October 1998 and October 2001 is compared, this tendency is clearly confirmed (Figure 6d). Consequently, continuous erosion of the beach and deposition across the spit generate a shoreline oscillation. Previous studies (MONSÓ, 1995) neglected the presence of longshore transport processes in the area, while ALONSO *et al*. (2000) proposed a westward longshore transport and even a clockwise littoral drift in the inner sector of the Ria. Seasonal and annual monitoring show that the littoral spit is nowadays growing. The depth of the mouth of the channel of the Sor River is progressively decreasing during the last decade, which has generated an important problem for the small port of Barqueiro.

Erosional processes have pushed the shoreline backward and consequently foredune destruction has occured, which acts as source of sediments for the beach. Preliminary data of December 1999 and March 2000 suggested three distinct zones according to beach-dune interactions (ALCÁNTARA-CARRIÓ *et al*., 2000): i) Eastern zone, with a clear erosive tendency, which has caused the backshore and foredune destruction, ii) Middle zone, with dune erosion but sediment accumulation in the intertidal zone, and iii) Western zone, where the beach presents an accumulative profile, with a well developed supratidal zone and incipient dunes. Detailed plot of dune-beach profiles confirms this differential behaviour along the whole the 2000 year (Figure 7).

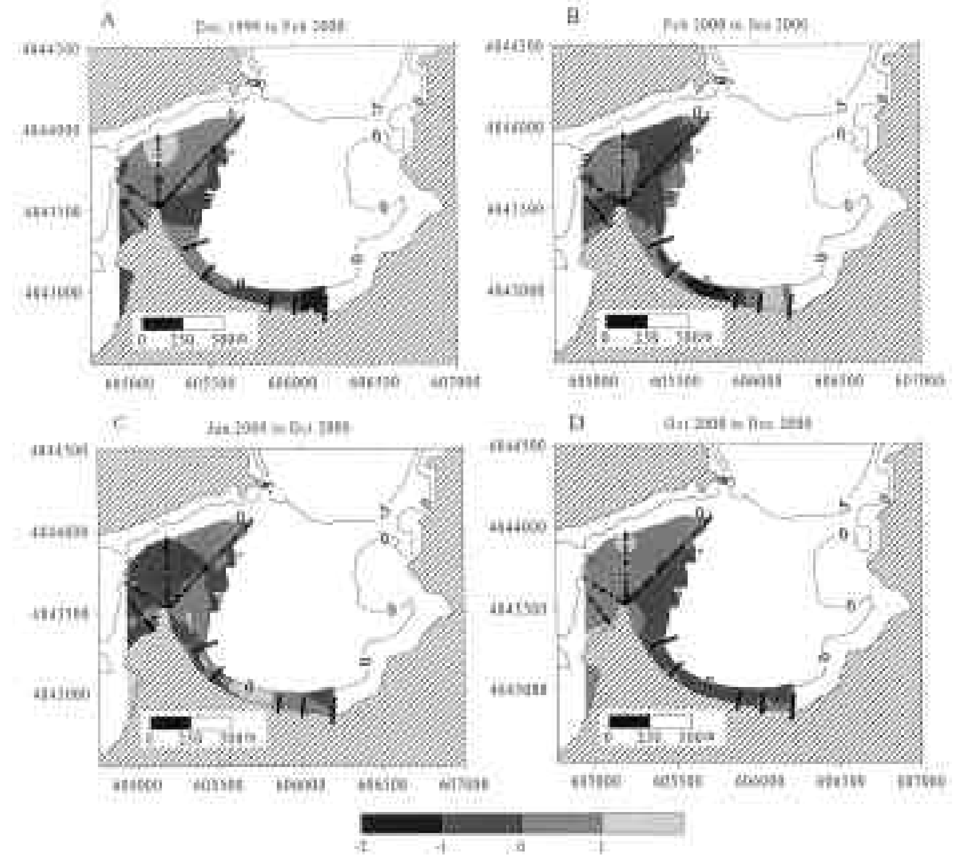

Figure 5. Seasonal variation of sedimentary volume (m^3/m^2). Negative values means erosion, while positives represent accretion.

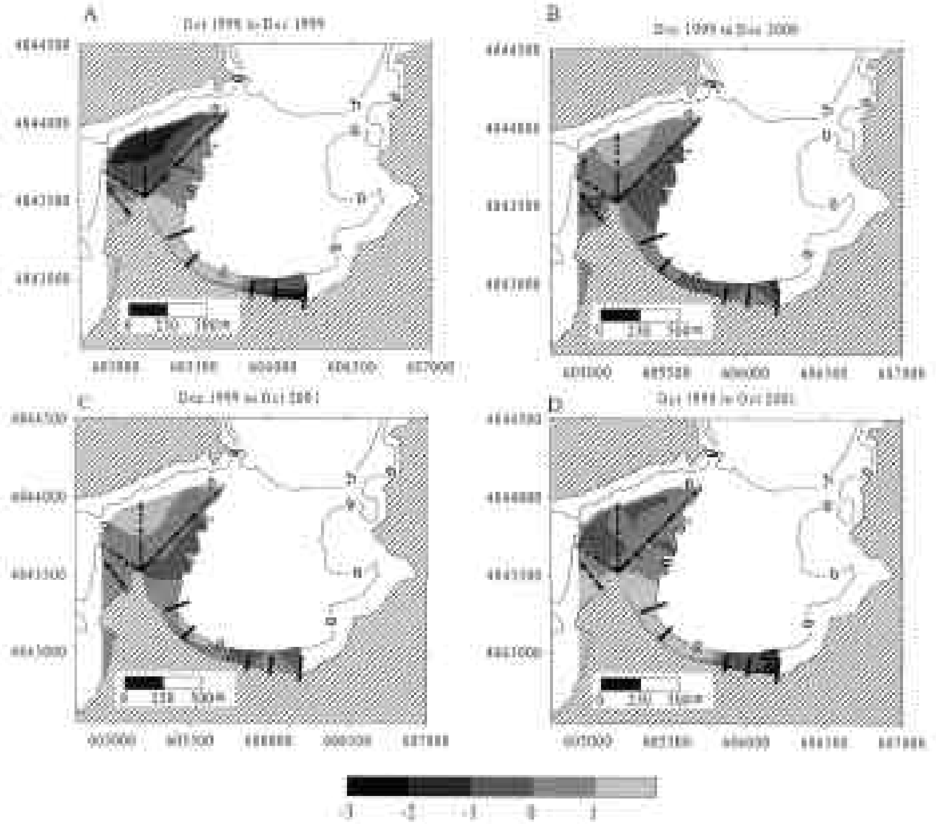

Figure 6. Annual variation of sedimentary volume (m^3/m^2).

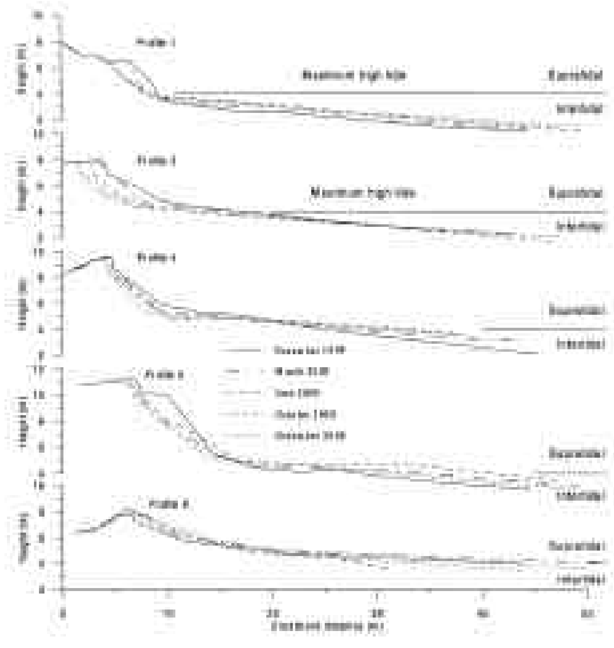

Figure 7. Crosshore detailed profiles of foredune and beach.

Sedimentary characterisation

Mean size, sorting and skewness are the most useful parameters to describ the sediments, while the kurtosis is normally not useful (FRIEDMAN, 1961). Sedimentary maps of these parameters reflect the presence of different environments in the study area (Figure 8). The eastern sector of the beach is composed of fine, poorly sorted and negatively skewed sand. In opposite, the littoral spit and the western sector of the beach are mainly composed of medium sand, although coarse sand is also present due to river channel; sand is middle sorted and not skewed or symmetrical. Finally, the submerged area is basically composed of fine, well or very well and positively skewed or symmetrical sand, but seaward of this it changes to very fine poorly sorted and not skewed sand.

This sedimentary pattern is due to the presence of the erosion/accretion processes. Grain size distributions of the sediments covering the exposed sector present a wide size range of coarse sediments, while the fine fractions are transported westward. The littoral spit presents the coarser sediments due to the fluvial dynamics and tidal currents, forming megaripples structures. The submerged zone is composed of finest and best sorted sediments.

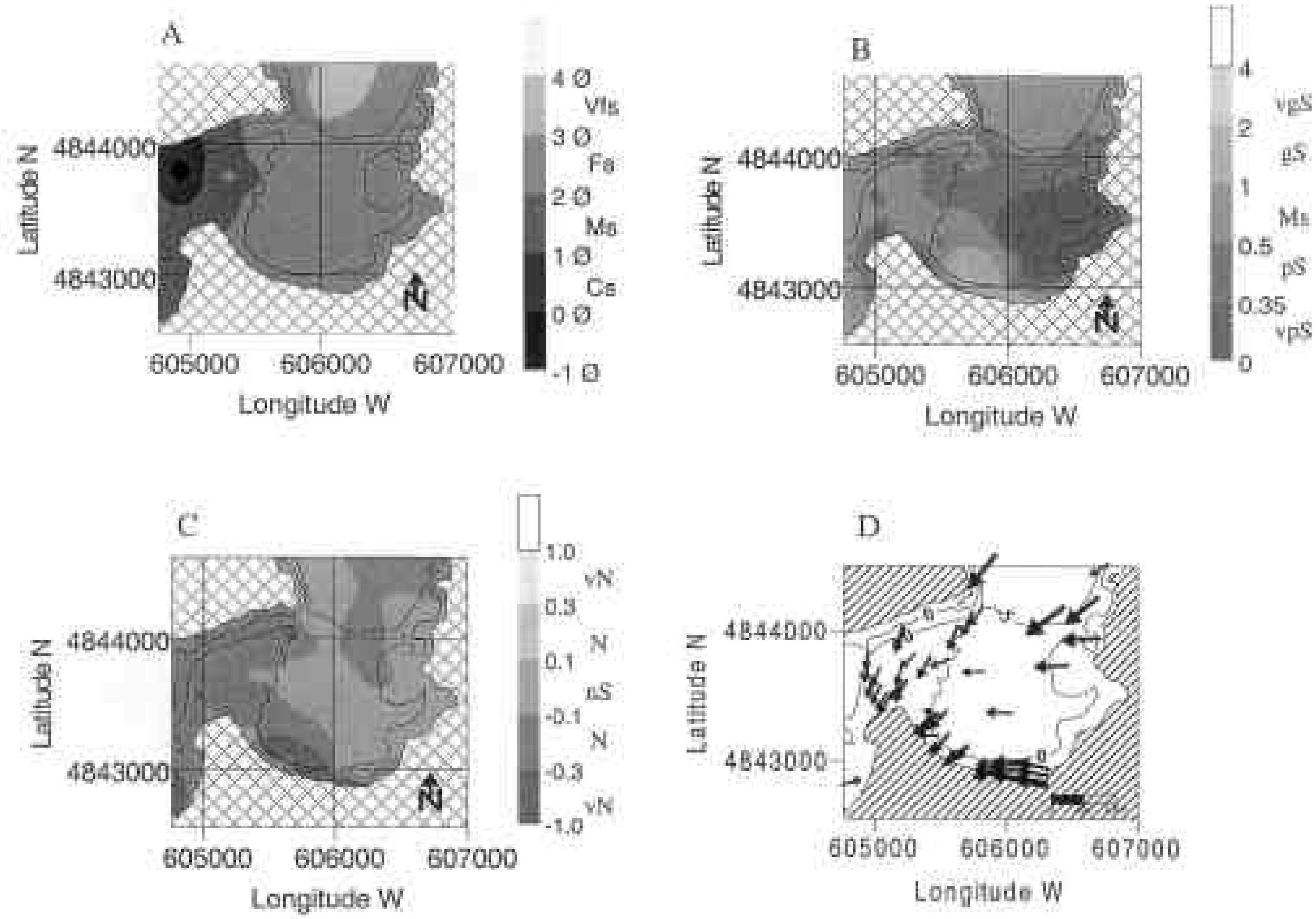

Figure 8. A Mean grain size distribution Cs: Coarse sand; Ms: medium sand; Fs: fine sand; vFs: very fine sand. B) Sorting distribution vgS: very good sorted; gS: good Sorted; mS: moderately sorted; pS: poorly sorted; vpS: very poorly sorted. C) Skewness distribution vN: very negative; N: negative; nS: nearly symetrical; P: positive; vP: very positive. D) Sediment transport pattern

Spatial variations of mean size, sorting and skewness parameters were used for MCLAREN and BOWLES (1985) to identify the sediment transport patterns. The numerical model of GAO and COLLINS (1992) has been applied to predict the sediment transport pattern in December 1999. Vector maps show a westward longshore transport in the eastern sector of the beach, where higher beach and dune erosion rates have been measured, while the central sector and littoral spit act as sink areas, according to their accumulative tendency (Figure 8D).

Geomorphologic evolution tendency

Beach morphology is also related to hydrodynamics and sedimentary processes. Echo sounder profiles show that the bottom of the Ria is very smooth, without submerged bars, but a little gradient can be identified on the beach, with the lower slopes in the eastern zone. However, morphologic differences are most evident in the foredune. Therefore, three stages can be identified in the Arealonga foredune according to model of HESP (1988). At Eastern Monte Furado the beach is very exposed to storms. Therefore, it shows a clear erosive tendency, which has caused the backshore and foredune destruction during the last decade. The eastern sector nowadays shows complete erosion, with an active scarp, while the central sector presents also an erosive morphology, but scarp is filled of vegetation and a lower accretion is detected in the base.

In opposite, western Monte Furado the beach presents a well developed supratidal zone with incipient dunes, while the active foredune is partially vegetated with Ammophila arenaria L. and Elymus farctus Viv., the second foredune is fully stabilised with grass and finally the third foredune is occupied by a forest of Pinus pinaster Aiton.

CONCLUSIONS

Arealonga Beach is located in the inner sector of a ria, but it is clearly affected by the storms events, especially during high tide moments. Numerical simulations show that the eastern sector of the beach is the most exposed to wave action. Consequently, it presents a clear erosive process. Monitoring of dune-beach crosshore profiles indicates that erosion is not only seasonal, but also a continuous on a supra annual trend. On the contrary, the central and western sectors of the beach and the littoral spit show low accumulative rates. Therefore, a westward longshore transport can be defined to explain the tilt of the beach.

Sedimentary maps of mean size, sorting and skewness show textural differences between the submerged area, three sectors of the beach and the littoral spit, related to sediment dynamics. Morphology of the beach and foredune also varies along the study area, which permit to define in conclusion three different morphodynamic stages: i) Eastern zone, with a clear erosive tendency generating the backshore and foredune destruction ii) Middle zone, with dune erosion but sediment accumulation in the intertidal zone, and iii) Western zone, where the beach presents an accumulative profile, with a well developed supratidal area and active dunes.

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