ICCCM'05 Proceedings
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NEARSHORE BARS AS A NATURAL PROTECTION OF BEACHES, FIELD EVIDENCES FROM LIDO DI DANTE BEACH, ADRIATIC SEA

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1. INTRODUCTION

Nearshore sand bars are found on many sand-dominated coasts. These features are particularly important because they can contain a notable sand volume with significance for the nearshore sediment budget. Moreover, they act as a natural protection against shoreline erosion by dissipating energy (mainly of higher waves) during erosive storm events (Ferreira *et al.*, 1994). They are considered the most important morphological feature controlling beach equilibrium. Recently, to protect beaches against erosion, coastal managers are testing the efficacy of the reconstruction of subtidal bars and of shoreface nourishment. Results from the Dutch coast reveal that there is a good feedback effect on the beach (Hamm *et al.*, 2002).

2. FIELD SITE

The Lido di Dante beach is a 3 km stretch of coast, almost aligned in the N-S direction, divided in two parts: the one in front of the Lido di Dante village (almost 1 km) is protected by a breakwater and three groins, the other (almost 2 km) is completely natural with dunes and a pine forest behind them (Figure 1).

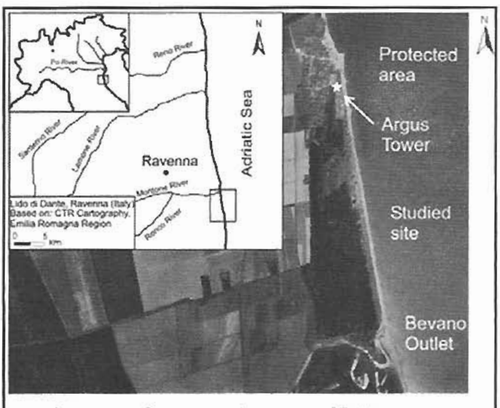

Figure 1. Study site: Lido di Dante, Ravenna.

The present study is about the unprotected part of the beach. Here the beach is composed of fine to medium sands. The dune system is very irregular, partially vegetated, and its elevation ranges from 2 m above MSL on the northern part of the beach to 4.5-5 m in the southern one. It is divided in two parts: dynamic foredunes and stable dunes at their back.

The tidal regime here, and in the whole Northern Adriatic, is strongly asymmetric, showing both diurnal and semi-diurnal components. The maximum tidal range is about 1.2 m during spring tides. The wave climate is usually of low energy, with significant wave heights less than 0.5 m, mainly from the East (65% of occurrences) (Gambolati *et al.*, 1998). Two different storm directions prevail in the Adriatic Sea: the Scirocco from SE, and the Bora from NE. Storms with one-year retur period, with direction NE-E-SE, have wave heihgts around 3 m and periods of 7.5 s (IDROSER, 1996).

3. METHODS

In this study, an interdisciplinary approach was used to characterise the beach state of Lido di Dante. Several indicators were used to define and characterise beach state indicators (Table 1), such as: vegetation associations, shoreline evolution (measured continuously using ARGUS video techniques within the EU Coastview Project, Albertazzi *et al.*, 2003), topography and bathymetry surveys, hydrodynamic measurements.

Nine surveys were done using a Total Station and an RTK DGPS, starting from December 2001 till February 2005. The beach and the dunes were monitored along cross-shore profiles regularly spaced (almost 150 m), starting from the dune crest down to a depth of -1/-1.5 m below MSL.

On February 2003 an Argus system was installed at the site within the European Project CoastView (Contract n°: EVK3-CT-2001-00054). The System consists of four cameras: three looking at the Lido di Dante protected beach, and one looking at the natural part of the beach. It is possible to extract information from video images such as shoreline position (Aarninkhof *et al.*, 2003), bar position and shape (Holman and Lippmann, 1987; Lippmann and Holman, 1989; Lippmann and Holman, 1990), beach width, dune vegetation cover, beach use (Jimenez *et al.*, 2005).

The bars were studied using a specific tool of Argus (Argus Stack Tool, AST), by sampling pixel luminosity intensity along cross-shore profiles regularly spaced (50 m). The bars are visible on Time Exposure Images (Timex). They are identified as white stripes generated by the foam of breaking waves on a ten-minutes time exposure (Holman and Lippmann, 1987).

Table 1. Different field investigations undertaken and main indicators analysed.

FIELD TECHNIQUE	INDICATORS
Topography, bathymetry	*Long term evolution* *Beach width* *River mouth migration*
RTK GPS	*Erosion hot spots – overwash areas* *Dune front steepness*
Video system	*Beach width* *Beach occupation* *Impact of storm events* *Bar location and shape*
Hydrodynamics	*Energetical context*
Vegetation	*Dune state*

For this study the dune vegetation was studied using one aerial photograph (2002 flight over the whole area) at very high resolution (less than 1 m) and using direct measurements to characterise different species present on the area. An estimation of the percentage of coverage of each species was evaluated coupling the aerial photo with direct measurements. The dune crest elevation was obtained from direct surveys by walking on the foredune ridge with an RTK DGPS. Particular attention was put on measuring the extension of overwash areas and on measuring the presence and elevation of trampling-induced paths ("corridors" that cut the dune ridge in several parts).

4. Results and Discussion

The site was monitored for almost 3 years, with both direct measurements and remote sensing techniques. The beach can be subdivided into two main areas: the northern part, close to the groin, which shows evident coastline retreat (more than 10 m/year), and the southern part which seems to be relatively stable (Table 2).

A preliminary qualitative study of the submerged features was done on rectified images on which the bars were visible. This study revealed that the submerged beach could be divided into two parts. The northern/central one is characterised by the presence of not-well defined features, changing rapidly. Here the foam patterns are extremely complex. The southern area is characterised by regular submerged rhythmic features. The decision to study the southern area (from -1100 m up to -1800 m from the tower) is supported by the need to identify the natural behaviour of the submerged beach, far from the structures and not influenced by diffraction/refraction of waves around the breakwater (Figure 2).

A quantitative analysis was done on images captured between April 2003 and May 2004 (Armaroli *et al.*, 2005). The submerged morphology is characterised by two lines of bars: the inner bar almost linear and attached to the shore at a distance of -1100 m from the tower; the outer one is crescentic, with a wave length of 300-350 m and a wave amplitude of 20-30 m. The bar system was very stable during the whole 2003 year.

A strong event, occurred on 25 December 2003, was able to straighten the bars. After 6 days the bars became rhythmic again with a wave length of 150-200 m and a wave amplitude (between horns and crests) between 10 m and 40 m. The inner bar remained linear and attached to the shore almost always at the same position. It is possible to divide the study period into two intervals: 2003 and 2004, not considering the strong event in December 2003. Results show that the cross-shore distance from the shoreline of both bars did not change significantly (between 40 m and 100 m).

Table 2. Beach state indicators results in both unprotected (North) and bar-protected (South) areas.

Indicators	Northern part	Southern part
Beach width	10-20 m	40-50 m
Dune retreat	0.85 m/month	0.2 m/month
Dune height	1.6-3.5 m /MSL	3.5-4.5 m/MSL
Dune front steepness	66%	16%
Dune vegetation	sparse *Ammophila*	stable associations
Bar location	No outer bars	100-200 m/shoreline
Storm breakers	Shore breakers	Bar breakers
Overwash areas	3 large areas	1 located area
River mouth migration		80 m /year

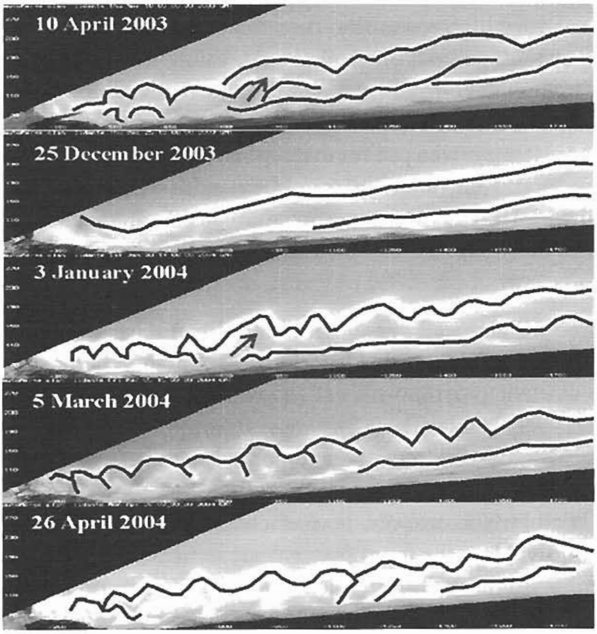

Figure 2. Position and shape of subtidal bars on Argus Timex rectified images. Period between April 2003 and April 2004. Black lines drawn manually on the images identify the bar crest. The arrows represent rip currents. For further details on coordinate system, image processing tools, etc., see Albertazzi *et al.*, 2003.

The changes were only in the long-shore direction and in shape. Analysing wave data both periods are comparable in number of events (7 events with wave height around 3 m), directions of main storms (NE and SE), duration of each event (between 2 and 18 hours), as well as relaxation time of the morphological system (Wijnberg and Kroon, 2002) that was between 1 and 4 months. In between these two similar periods there was a significant event in December 2003 that was not particularly strong (Hs=3 m, direction from NE) but it lasted for a long time (24 hours, the longest event in the considered period). This major perturbation of the system, able to completely change the shape of the bars. A successive qualitative analysis was done on the images between May 2004 and January 2005. The results revealed that the bars are rhythmic with the same number of rhythmic features as Spring 2004. The effect of storms occurred in winter 2004/2005 was to straighten the bars and to move them slightly offshore.

This analysis evidences a strong seasonal pattern in the hydrodynamics and a consequent cyclical behaviour of nearshore bars. However it is interesting to notice that, whatever is the shape of the outer bar, its position remains quite stable, and an inner bar is always observed in the southern part of the site.

Long term monitoring of beach profiles reveals that there is a strong shoreline retreat of the northern area, the one close to the structures. The central and southern parts are oscillating or stable. Here the beach shows a dynamic equilibrium around its mean profile, depending on the position of the internal bar. The intertidal morphologies move in the long-shore direction and become attached or detached from the shore according to the wave climate.

The shoreline evolution was assessed comparing video images of the study area at spring tides under calm conditions, images of the area immediately before the storm, immediately after the event and at spring tides after the storm. This analysis was undertaken to study the erosion caused by the storm and whether or not the beach recovers its equilibrium state. The results show again that the area is divided into two parts: the one close to the structures is dramatically eroding, the central and southern areas are oscillating or stable. Even if they were not particularly strong, the storms occurred in winter 2004/2005 generated beach loss mainly in the area close to the structures (up to 500 m from the Argus tower). Here the time sequence of the storms played an important role. The erosive effect was enhanced by the joint occurrence of storms in a short time. This lead to the incapacity of the system to recover an equilibrium state between two "waves attacks". The dunes were touched by run-up and overtopped by waves.

Regarding the central and southern parts of the beach, the analysis done on the images revealed that there are rhythmic features moving in an along-shore direction, according to the direction of the waves. The rhythmic features are strictly related to the presence of intertidal bars that move along-shore and that, as underlined before, become attached or detached to the shore. The analysis done on the shoreline position revealed that the southern part of the beach is wide and "safe".

The dune system height is changing moving southwards. The dune height is around 2 m close to the structures while it is of 4-5 m in the area close to the Bevano river mouth. Dune vegetation cover is an indicator of where the dunes are healthy and where there is a constant influence of destabilising factors on the vegetation itself growing on the dune crest and at its foot. The vegetation distribution identifies three areas: the one to the south is characterised by the presence of wide areas covered by *Ammophila*, that is an indicator of dune stability. The area presents a vegetation association sequence (from the beach to the back dunes) composed by *Cakile maritimum/ Ammophila arenaria/ Tortula ruralis*. Moving northwards the density of *Ammophila* decreases constantly and dramatically, with a prevalence of shrubs, and *Cakile maritimum* and *Tortula ruralis* disappear. The northern area has almost no *Ammophila*.

Regarding the dune foot, on the long term period (from December 2001 till February 2005) there was retreat in the central area, while in the area close to the structures the dunes have almost disappeared. This was caused by overwash and overtopping events occurred during storms in winter 2004/2005. A comparison between the dune foot position measured in the surveys before and after a storm occurred in September 2004 reveals a variable behaviour of the area up to about 1 km from the tower, where it was actually achieved a peak in retreat (14 m). There is localised sediment input due to dune erosion during the storm, as testified by many points of overwashing observed in the field. It is striking how the dune undercutting rate drops passed the 1 km boundary from the Argus tower, which also corresponds to a general stability of the intertidal beach from the video profiles. The area receives consistent sediment input from lateral erosion of dunes at the Bevano river mouth, due to northward migration of the inlet and subsequent sand removal from the mouth by long-shore drift directed northwards (Balouin *et al*, 2004, Ciavola *et al*, 2005).

5. Erosion Risk Assessment

The long term direct surveys clearly identify two areas that have a different behaviour (Table 2). The northern one is affected by the presence of defence structures and is constantly eroding. Between December 2001 and March 2003 the retreat was of 10 m (more than 0.6 m/month, Figure 3). The dune crest elevation is ranging between 1.5 m and 5 m.

As it is clearly visible in Figure 4, the dune crest is not continuous and it is cut by trampling-induced paths in several parts. These "corridors" are affected by wind scouring, because the vegetation has been destroyed, and salt water, because they become preferential paths for the sea when it reaches the dune foot during storms, generating wide overwash areas.

According to the classification of Short and Hesp (1982), the foredunes could be divided in two parts: the northern one is classified as percentage of vegetation cover between 20% and 45%, small blowouts and lee side avalanching. Here the vegetation has almost disappeared due to the effect of storms occurred in winter 2004/2005. In this area the stable dune at the back is reached by the sea during strong events.

The southernmost foredune ridge could be classified as percentage of vegetation cover between 75% and 90%, incipient blowouts, discontinuous ridge and lee side accumulation. The southern area is characterised by a fragmented topography but the elevation of the dune crest and of trampling-induced paths is higher. The stable dune at the back is characterised by a dense vegetation cover and is never reached by uprush, even during bad weather conditions.

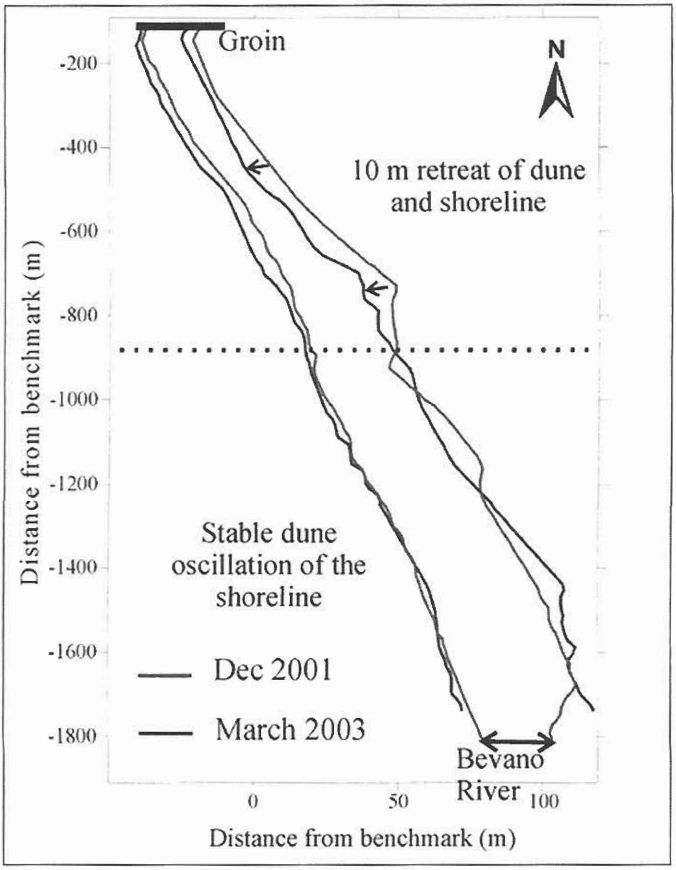

Figure 3. Retreat of dune foot and shoreline between December 2001 and March 2003. Dune foot as +2 m above MSL contour line, shoreline as MSL (0.00 m below MSL) contour line.

It is possible to calculate the maximum water elevation (encompassing storm surge, wave set-up, run-up, tide) for the study area, considering the worst scenario, to create a dune risk map. The mean beach slope was calculated as 5% (mean slope along four reference profiles along the whole area). The highest tidal level during spring tides used here is of 0.5-0.6 m above MSL. The maximum run-up was evaluated using the formula of Holman (1986), in Kroon and Masselink 2002, for the return period wave of 1, 10, 100 years. Storm surge and wave set up effects, calculated for the study area by Yu *et al.* (1998), were added to the highest tidal level. The results are shown in Figure 4, in which the foredune elevation is represented together with the maximum elevation reached by waves during storm events at the three considered return periods. It is evident from the Figure 4 that the northern area is at risk even from overwash with a return period wave of 1 year, while the southern one is not at risk even with a return period wave of 100 years. Using the results presented here a dune risk map was created, dividing the risk in overwash-risk and overtopping-risk (Figure 5).

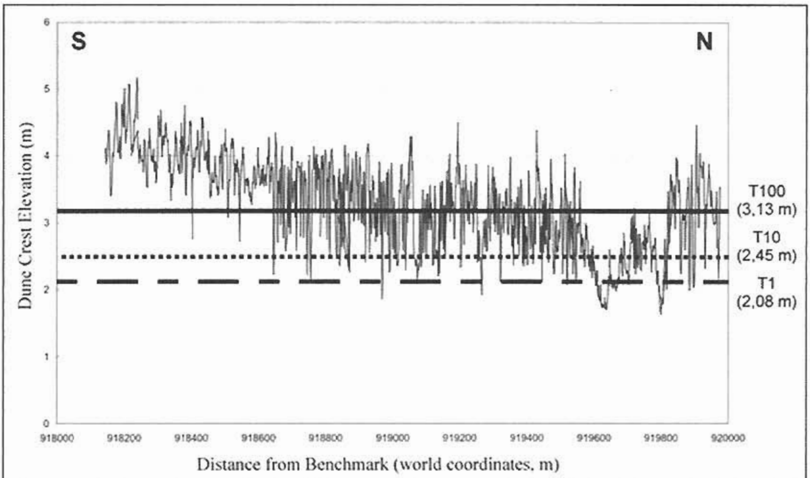

Figure 4. Dune crest elevation and maximum wave run-up for return period wave of 1, 10 and 100 year, considering the worst scenario (high tide + storm surge +wave set up). The dune crest was surveyed on February 2004.

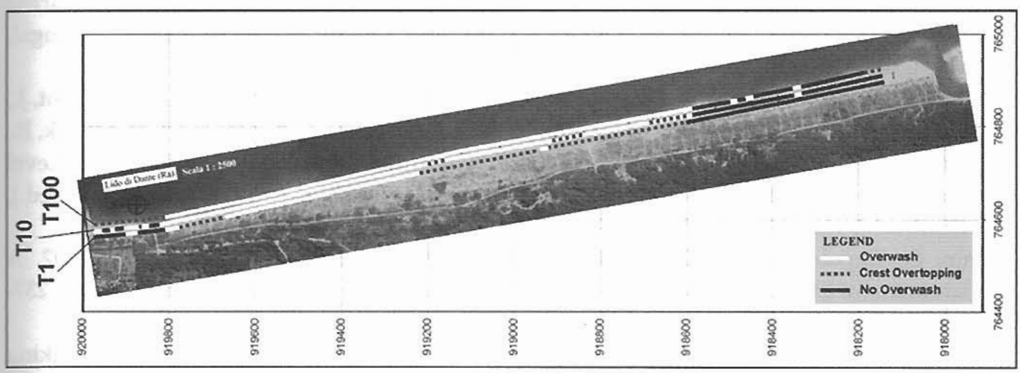

Figure 5. Dune risk map considering the worst scenario, for a return period wave of 1, 10, 100 years.

6. Concluding remarks

All indicators point towards a pessimistic scenario for the future evolution of this beach, particularly on the northern part that is already in a critical situation following the overwash events that took place in the winter 2003-2004 and again in winter 2004-2005. This evidence from the medium term monitoring outlines the protective role of the subtidal bars in maintaining a dynamic stability on the southern part of the beach. Despite the quantification of wave energy dissipation by these subtidal bars not being presented here, breaking of waves during energetic events is clearly seen on video images (see Figure 2, and Armaroli *et al.*, 2005). Such a role of a natural bar system should consequently be taken into account in beach management, and nourishment projects should be planned in order to maintain these "natural" forms of wave dissipation.

Acknowledgments

This paper is a contribution to the EU project COASTVIEW (contract EVK3-CT-2001-00054). Y. Balouin also acknowledges the financial support of the Commission of the European Communities through a Marie Curie Fellowship (contract EKV3-CT-2002-50014).

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