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Agustín Sánchez-Arcilla

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BAR CHANGES DUE TO STORM EVENTS USING ARGUS: LIDO DI DANTE, ITALY

Clara Armaroli[1], Yann Balouin[2], Paolo Ciavola[1], Manuela Gardelli[1]

[1] Dipartimento di Scienze della Terra, Università di Ferrara, Via Saragat 1, 44100 Ferrara, Italia. clara.armaroli@unife.it
[2] BRGM, Service Géologique Régional, Languedoc-Roussillon (SGR/LRO), 1039 Rue de Pinville, 34000 Montpellier, France. y.balouin@brgm.fr

Abstract: In this study sand bars were analyzed using remote sensing techniques. An Argus system was installed at Lido di Dante, a small village near Ravenna, in northern Italy. The study period is between April 2003 and May 2004. Timex video images were used to analyze bar dynamics. Pixel luminosity intensity was sampled along 15 cross-shore profiles, 50m spaced. The system was perturbed by a storm event occurred in December 2003. Before this event the bars were undulated with 2 wide crescents, after the event the crescents became 5. Before and after this event the system was stable and it maintained a constant configuration. A preliminary conceptual model is presented: the system is self-organized, by redistribution of sand within a delimited longshore area, even under low energy conditions. When an energetic event occurs, the system changes, but it recovers its stable configuration within a short time (6 days).

INTRODUCTION

Nearshore sand bars are found on many sand-dominated coasts. These features are particularly important because they can contain a notable sand volume significant for nearshore sediment budgets. Moreover, they act as a form of natural protection against shoreline erosion by dissipating energy during erosive storm events. New monitoring techniques, such as the collection of video images, have shown to be very useful to study both quantitatively and qualitatively the dynamics of these landforms (Konicki and Holman 2000; Alexander and Holman 2004). Within the EU CoastView Project, an Argus video system was installed in February 2003 at Lido di Dante near Ravenna, in Italy. The Project aimed at defining Coastal State Indicators (CSIs), that are indicators of the state of the coast for management purposes (Albertazzi et al. 2003). The CSIs are defined as a series of parameters that are important to characterize the state of a beach and, if necessary, to plan interventions to avoid flooding, beach and dune erosion, etc. For the Lido di Dante site the most important CSIs were shoreline position, dune foot position, bar shape and position. The aim of this paper is to study the submerged part of the beach using video images, to create a conceptual model of the relationship between forcing signals and morphological response, and a morphodynamic classification (visually based) representative of the morphologies observed at the site.

FIELD SITE

The Lido di Dante beach is a 3 km-long 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 one (almost 2 km) is completely natural with dunes and a pine forest behind them (Figure 1). 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 (Armaroli et al. 2005).

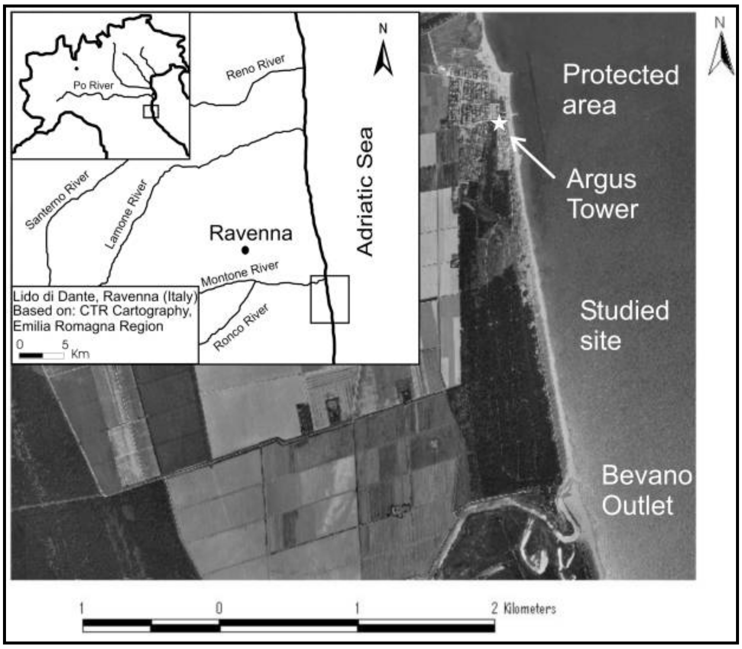


Fig. 1. Study site: Lido di Dante, Ravenna.

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 return period have wave heights around 3 m and periods of 7.5 s (IDROSER 1996). On February 2003 an Argus system was installed at the site within the EU Project CoastView. The system consists of four cameras, three looking at the protected part of the beach and one looking at the natural one. The present paper will focus on results coming from the video monitoring of the natural area.

METHOD

Argus System

An Argus system (Holman et al. 1993; Aarninkhof and Holman 1999) consists of video cameras to acquire images, a computer at the site to pre-process the images, a dedicated space on a server to stock processed data and a software capable to extract information, such as shoreline evolution (Aarninkhof and Holman 1999; Aarninkhof et al. 2003), bar shape and position (Holman and Lippmann 1987; Lippmann and Holman 1989; Lippmann and Holman 1990). The video images are captured at the beginning of every hour, every day of the year, during daylight. The computer collects a ten-minutes film and processes it, generating three different kinds of images: snapshot, time average and variance of all pixels. The Argus software is capable of rectifying images using a series of Ground Control Points (GCPs) established in the field of view of the camera. The software converts the Real World Coordinates of the images into a Cartesian system with the origin centered on the tower. Submerged features are visible through timex video images as white areas. The white areas are regions where the waves preferentially break. Foam and bubbles associated with the breaking waves indicate the position of submerged features (Lippmann and Holman 1989). With the analysis of peaks in the luminosity intensity of pixels it is possible to find where the bars are. For the present study we used the AST tool (Argus Stack Tool), by sampling the luminosity intensity of the pixels along cross-shore arrays equally spaced alongshore (50 m). The studied area is between –1100 m and –1800 m from the Argus tower. The decision to study only the southern part of the area is supported by the need to understand the natural behavior of the subtidal beach, far from the structures and not influenced by diffraction/refraction of waves around the breakwater. The cross-shore camera resolution here is between 1 m and 4 m.

The days of the year on which the bars are visible were 79: 41 in Autumn/Winter and 38 in Spring/Summer. For the present study only 15 images were used (less than 20%). This last consideration will be discussed below (see “Video images and quantitative analysis”).

Wave and bathymetry datasets

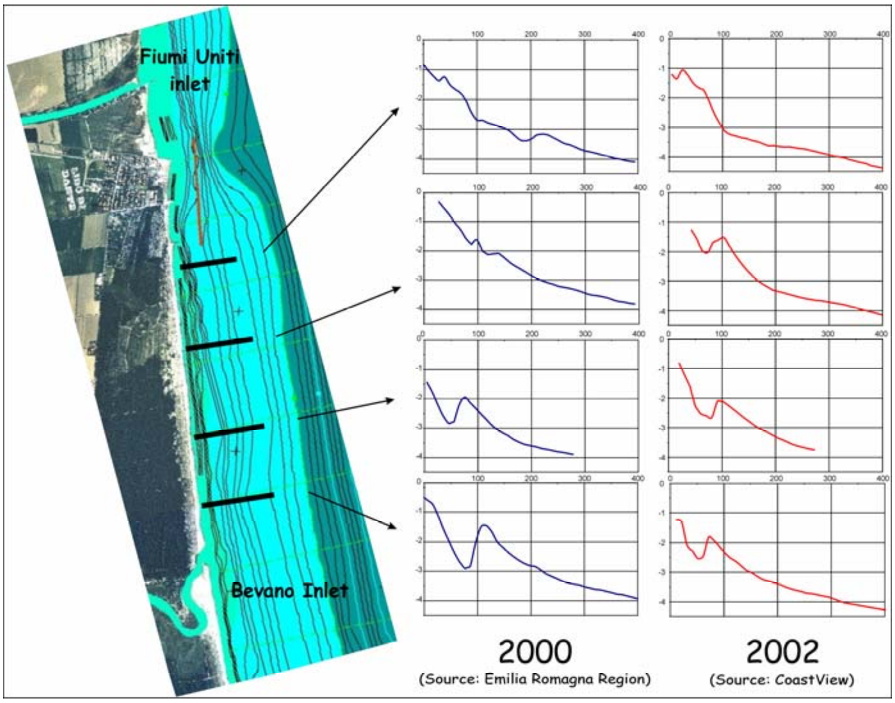
An analysis of wave data was done to characterize storm events occurred during the studied period. A storm was defined as an event where the wave height (Hs) reached at least 2 m, e.g. twice the most frequent wave in the Northern Adriatic. The duration of an extreme event was defined as the numbers of hours in which the waves exceeded the threshold defined above, starting immediately before and ending immediately after the storm peak. If there were several consecutive events they were considered as one single event, if the time gap between them was less or equal to 12 hours. Using video images it was possible to define a wave height threshold: if the waves are lower than 1.5-2 m the outer bar is not visible at this site. Wave data were measured by a buoy located in the northern Adriatic, in front of the Po Delta (Punta della Maestra), at almost 100 Km north of Lido di Dante, at a depth of 40 m below MSL. Wave height, direction and period are recorded at a frequency of one measure every half an hour. The buoy is part of a network of buoys installed along the Italian coast (RON). The records of wave data present several gaps due technical problems or because wave conditions are extremely strong during storms and the buoy stops data collection. Considering the period between March and December 2003 the percentage of missing data is 46%. This high value is due to the fact that in July (no data for the whole month), August and December there are many gaps. In the period between January and May 2004 the percentage of missing data is lower (28%).

Two single-beam bathymetric surveys were available before the Argus tower was installed: one done in March 2000 and another one in July 2002 (Figure 2). The one done in 2000 was part of a program of the Emilia-Romagna Regional authorities to monitor the evolution of its entire coast, to evaluate the loss of sediment due to subsidence, profile slope variations, as well as the presence of submerged features. The 2002 survey was done within the CoastView project in order to have a preliminary knowledge on the presence or absence of submerged features, their characteristics (distance from the shoreline, depth) and to have an idea of the elements to monitor with Argus (Albertazzi et al. 2003).

RESULTS AND DISCUSSION

Previous knowledge

The submerged part of the beach has been studied using cross-shore bathymetric profiles, 500 m spaced. The surveys reveal that the subtidal beach is changing considerably moving from the area close to the structures (N) to the one close to the Bevano River (S). As it is clearly visible in Figure 2, there are no permanent features along the profile close to the groin. The southern part of the beach is characterized by the presence of well-developed bars at a depth around –2 m below MSL, that are extremely stable within time and that show a slight cross shore dynamics, they are located between 80m and 100m from the shore. At this point of the study, these bars were thought to be parallel to the coast. A preliminary idea on the site was that there were no submerged features close to the structures and that the central area had a variable subtidal morphology. We supposed that in the southern part there was a stable bar, parallel to the coast, almost 1 Km long.



(Source: Emilia Romagna Region)

(Source: *CoastView*)

Fig. 2. Submerged features along four cross-shore bathymetric profiles, spaced almost 500 m. The first survey (blue) was done in 2000; the second one was done in 2002 (red). Depth is in meters below MSL.

Video images and qualitative considerations

A preliminary examination of the submerged features was done on rectified images on which the bars were visible (Figure 3). This study revealed that the area could be divided into two parts. The northern/central one is characterized by the presence of rapidly changing features. Here the foam patterns are complex. Regular submerged rhythmic features characterize the southern area. Two lines of bars are present: the inner bar, almost linear and attached to the shore, is seen first at a distance of –1100 m from the tower; the outer one is crescentic. The area that is immediately behind the groin is strongly influenced by the presence of structures and by the consequent diffraction and refraction of waves around the breakwater. Waves are also partially reflected by the rock groin.

Video images and quantitative analysis

A preliminary study was done on video images to find the effect of wave height and tidal level on the position of bar crest along the line as proposed by Alexander and Holman (2004). A comparison between direct surveys and video images was done using the bathymetric survey of 19 April 2003. The results showed that there is a very good correspondence between the location of submerged features found through direct measurements and the corresponding patterns of breaking waves on timex images at MSL (Figure 4). The luminosity intensity profiles for a day on which the bars are visible change their shape according to wave height and tidal level.

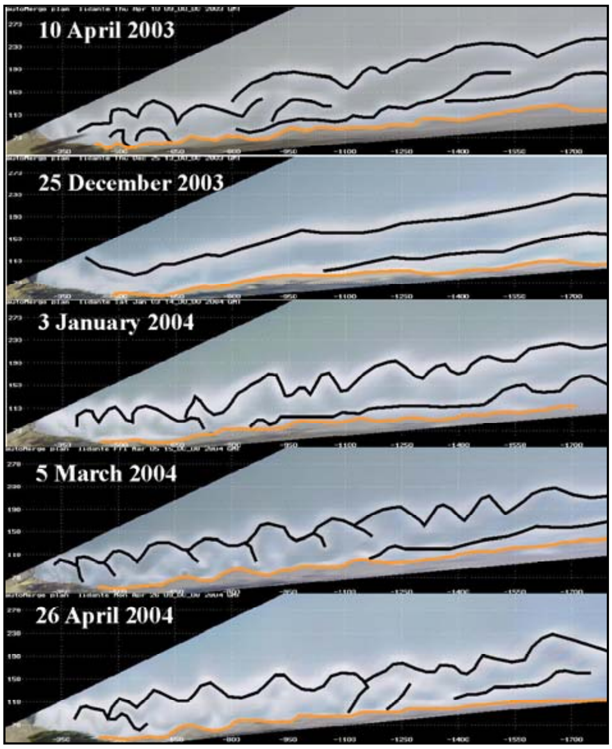


Fig. 3. Submerged bar evolution on rectified Argus images, between April 2003 and April 2004. The black lines are drawn manually on the images.

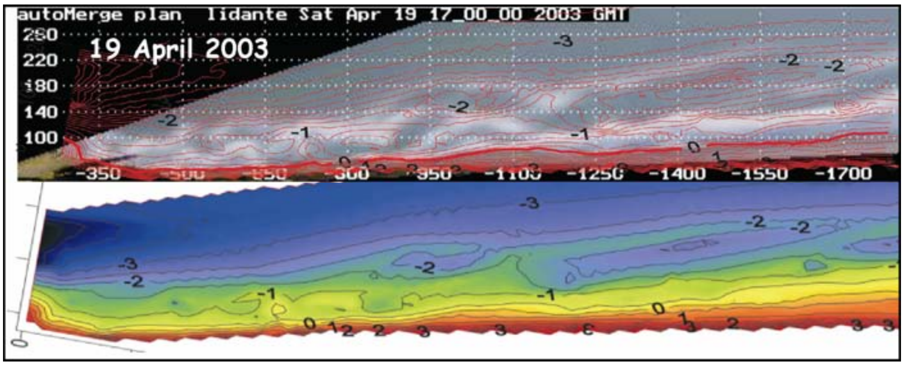


Fig. 4. Comparison between the bathymetric survey (red lines) and the Argus timex rectified image on 19 April 2003. The lower figure is the bathymetric survey.

A first sensitivity analysis was undertaken to: i) characterize the best environmental conditions (i.e. tide, waves, sun position) for detecting the bars; ii) estimate the errors in positioning, iii) identify the wave characteristics for which energy dissipation is a good indicator of bar position and shape. An example of the sensitivity of the methods to these parameters is illustrated in Figure 5 for 25 December 2003. The profiles show three peaks corresponding (from right to left) to the outer bar, the inner bar and the shoreline. If waves are too high, the surf zone appears white and the intensity profile is flat (Figure 5, lower graph). The same result is obtained if the tidal level is too low due to shallow water energy dissipation (below or equal to ± 20 cm below MSL). The error in positioning due to the tidal level variation is between 15 to 25 m for a variation of ±

15 cm (Figure 5, upper graph). Results of this analysis have evidenced that the best conditions were: a wave height (Hs) around 1.5 m and tidal level around –10 cm below MSL.

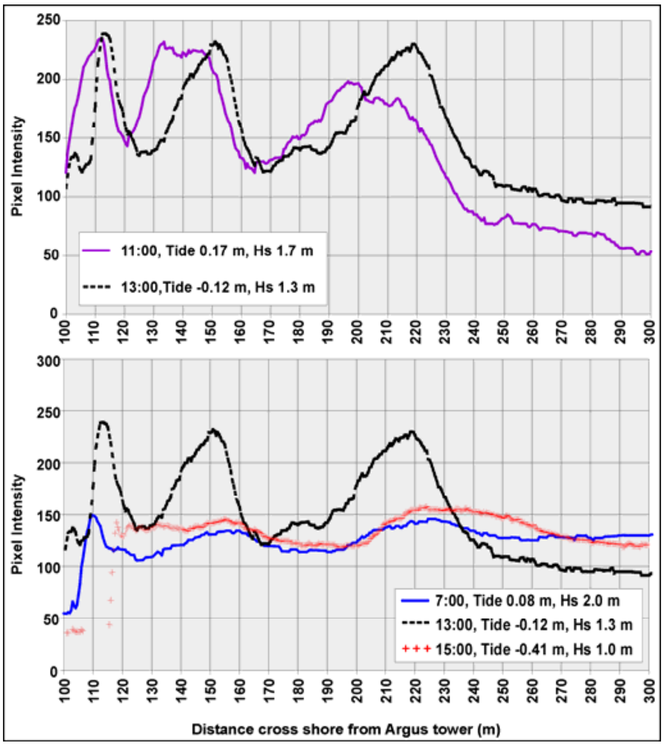


Fig. 5. Intensity peaks for a cross-shore array on 25 December 2003. On the upper graph, the effect of tidal level is clearly seen (more offshore dissipation at lower tide level, even if the wave height is slightly higher). The lower graph shows the difficulties to identify features when tide is very low (offshore dissipation of energy) or waves are too high (surf zone is too large to identify the features).

Spatial and temporal bar morphodynamics

After this sensitivity analysis, images considered to be good enough to reasonably identify the submarine morphology were selected. Analyzing the cross-shore profiles of pixel luminosity intensity it is possible to study the evolution of the outer bar, dividing the studied period in two parts: March-November 2003 and January-May 2004. In the first period the outer bar has a wavelength of 300-350 m (horizontal distance between two horns or crests) and wave amplitude of 20-30 m (vertical distance between horns and crests, mean value is 25 m). The bar system was very stable during the whole 2003. To notice that the storm of 3 April 2003 slightly modified the shape of the bar (Figure 7, upper graph) smoothing out the undulations. However, a strong event occurred between 23 and 26 December 2003 was able to straighten the bars. At the beginning of this event the buoy broke therefore no data is available for the peak of the storm. The data are available only for 25 and 26 December. On 25 December the maximum wave height was 3 m and direction from NE. After 6 days the bars became rhythmic again (Figure 6 and 7), increasing the numbers of crest oscillations, from 2 to 4/5 (oscillations increase of a factor of 2/2.5). Starting from January 2004 the outer bar became rhythmic with a wavelength of 150-200 m (almost half of the previous wavelength) and wave amplitude between 10 m and 40 m (mean value is 25 m, the same as in the previous period) (Figure 7). The inner bar remained linear and attached to the shore almost always at the same position. The cross-shore distance of both bars from the shoreline did not change; it remained between 60 m and 120 m from the shoreline. The changes were only in an alongshore direction and in the planar shape of the features.

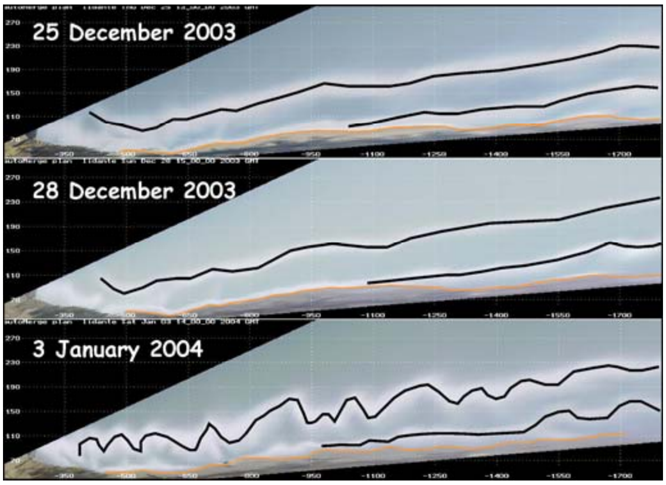


Fig. 6. Submerged bar evolution on rectified Argus images, between 25 December 2003 and 3 January 2004. The black lines are drawn manually on the images.

If one analyses wave data from the two periods (Table 1), they are not different in number of events, directions of main storms and duration of each event. The analysis was done between April and November 2003 and between January and May 2004. The storm in December was not included in this analysis, because it was an exceptional event, because of its effect on submerged features. It lasted for almost 3 days, the longest storm in the study period, with maximum wave height on 25 December of 3 m and direction from NE. To notice that probably we are underestimating the maximum wave height reached during the storm because on 23 and 24 December data are missing. This event was able to straighten the bars and to move them slightly offshore. In the year 2003 there were events that had a maximum wave height around 3 m and maximum duration of 28 hours (Table 2). During the year 2004 there were events that were even stronger with maximum wave height of 3.5 m and maximum duration of 35 hours (Table 3) and that had no significant impact on the morphologies. In 2003 the ratio between events from NE and SE (number of events from NE / number of events from SE) is 3, but the longest in number of hours are from SE (Table 2). In 2004 the ratio between events from NE and SE is 0.5, and again the events from NE are of low duration. If we consider the whole wave dataset, including also wave heights that are between calm conditions and 2 m, the ratio between NE and SE directions in both periods is 0.5. We can conclude that the critical forcing that influences the morphological system is mainly the duration of an event (meaning also the clustering of successive events) rather that its energy or direction. This hypothesis is supported by the low impact of the event of 3 April 2003, which lasted for 12 hours.

Table 1. Wave Climate in the study period, April 2003-May2004*[*]

Time Period	Wave height (Hs), below 1.5 m, %	Number of extreme events	Duration of extreme events, hours	Max wave height (Hs), m
April 2003-November 2003	93%	8	2 - 28	2.8 m
January 2004-May 2004	88%	8	5 - 35	3.5 m

* December 2003 is not included.

Table 2. Strong events with a duration > of 10 hours in the period between March and November 2003

Time Period	Max wave height (Hs), m	Duration of extreme events, hours	Direction	Number of crescentic features
3 April 2003	3	12	SE	2
31 October and 1 November 2003	2.5	19	SE	3
7 and 8 November 2003	3	28	SE	3

Table 3. Strong events with a duration > of 10 hours in the period between January and May 2004

Time Period	Max wave height (Hs), m	Duration of extreme events, hours	Direction	Number of crescentic features
18 and 19 January 2004	3.5	16	NE	4
19 and 20 February 2004	3	35	19/02 from SE; 20/02 from NE	4
22 February 2004	2.2	13	SE	4
7 and 8 March 2004	3	25	SE	5
11 March 2004	2.5	13	SE	5
04 May 2004	2.5	10	SE	4

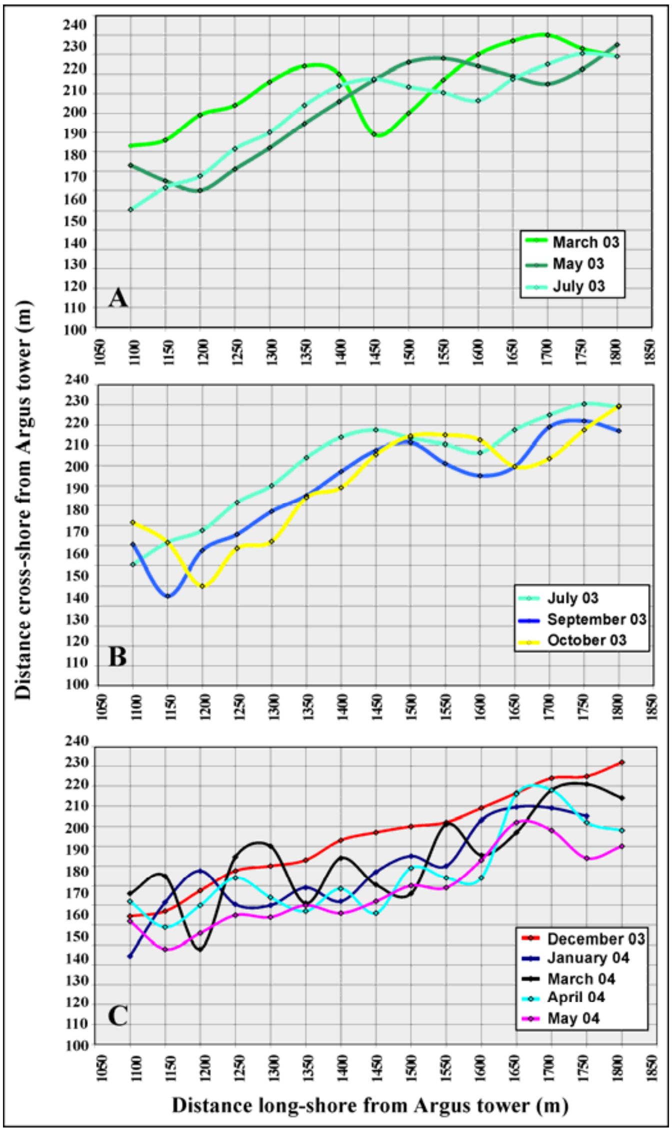


Fig. 7. Submerged bar evolution along cross-shore profiles, between April 2003 and May 2004. The position of the bar crest was identified by sampling pixel luminosity intensity.

Conceptual model: forcing signals and morphodynamic state

An element to take into account for bar morphodynamics is the relaxation time of the morphological system (Winjberg and Kroon 2002; van Enckevort et al. 2004). The relaxation time is "the time-span between the onset of morphological change and attainment of equilibrium corresponding to the new process conditions" (De Boer 1992). This definition implies that there is a correlation between the forcing event and the morphological variations. Clearly the effect of waves on the submerged features is controlled by wave height, by the volume of sand transported, by the grain size and the water depth on the bar crest and in the trough (van Enckevort et al. 2004). If the volume of transported sand is large, particularly strong waves (with different heights for different sites) are the only capable of redistributing the sediment and create a new morphological equilibrium state. In such conditions it is important to know the rate of sediment transport on the bar crest and in the trough, as well as the wave characteristics at the study site. According to Wijnberg and Kroon (2002), it is possible to define if there is a relaxation time effect on each specific morphological system. The relaxation time effect occurs if it is possible to find a correlation between a sequence of forcing events and the consequent morphological variations. This means that during a storm bars changed and after the event a new equilibrium state is reached (Figure 8). To understand if this is the case, a long time series of bar observations is needed (position, planar shape, crest and trough depth), as well as an analysis of the wave climate for the period of observations.

At the Lido di Dante site, using Argus, it was possible to have several information on the effect of storms on the bar system. Along the two studied periods the planar shape of the submerged feature did not change as well as their cross-shore position. Between April and November 2003 the morphodynamic state of the bars remained the same. In the second period, between January and May 2004 the system had the same morphodynamic state as previously observed with an increase in the number of rhythmic elements. In between there was a perturbation event, occurred in December 2003, capable of straighten the bars. The persistence of this 2-d configuration was 6 days only, extremely shorter in comparison with the two states previously and successively observed (5-8 months persistence). Probably the events occurred within the two periods were not strong and long enough to generate evident variations in the morphological state of the bars. However longer time series of bars shape and position measurements are necessary to understand which is the equilibrium configuration of the seabed, meaning which is the number of rhythmic elements that are in equilibrium with the mean wave climate at the site. A future study will focus on the analysis storms comparable to the perturbation event observed in December 2003. It is clear that if a storm is strong (wave height around 3 m) but it does not last for a certain number of hours (i.e. 72 hours) it is not able to redistribute the sand and to change the morphodynamic state of the bar system.

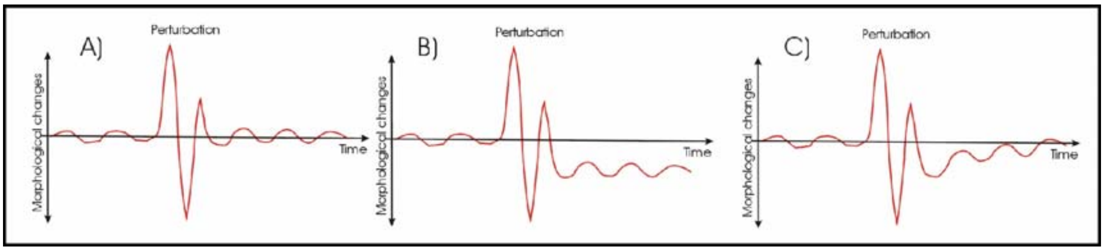


Fig. 8. Possible effects of a storm perturbation: A) the dynamic equilibrium is perturbed, but after a relaxation time, the system get back to the initial situation; B) after the perturbation, the system reaches a new dynamic equilibrium different from the initial one; C) the system reaches a quasi-steady equilibrium state, but tends to recover the initial state. This last scheme could be considered as the A with a longer relaxation time. However, in such a case, the relaxation time is much longer, and the return to the initial position is very difficult (as a new perturbation can occur).

Self-organization models (Caballeria et al. 2002) consider that there is no direct correlation between the forcing signals and the “final” equilibrium state of the submerged features. A perturbation on the seabed starts a sequence of events capable to generate a rhythmic configuration. The exact nature of the perturbation event is unclear: van Enckevort et al. (2004) identify in edge wave formation one of the many causes of morphodynamic instability. There is a feedback mechanism that generates rhythmic features, not directly related with the forcing sequence but with the spatial distribution of perturbations: in this sense, even if edge waves can be the cause of perturbation, the final morphology at equilibrium does not necessarily reflects the characteristics of the edges waves (van Enckevort et al 2004). If a self-organization tendency is believed to exist for a given site, this implies that the final configuration is largely dependent on the pre-existing morphology rather than on the forcing sequence. At Lido di Dante we did not know the initial configuration that had generated the rhythmic configuration observed during the year 2003. The Argus station was installed in February 2003 and the system immediately appeared rhythmic. The sequence of morphodynamic states was evident after the storm in December 2003: straight 2-d bar with a short persistence, 3-d bars with a long persistence. At Lido di Dante site, an eventual perturbation able to initiate self-organization of the bars was not analyzed. However, it is clear that the groin generates considerable perturbation on the hydrodynamics, forming edge waves. This could be the mechanism initiating the formation of a rhythmic pattern. It will be interesting to study if this is a peculiar sequence and if the number of rhythmic elements will remain 4/5 or it will decrease to the same number that was present during 2003 (2/3). The presence of the river at the southern boundary of the study site is an element that must be taken into account for the morphodynamics study. The Bevano River brings sediment to the sea that is available for the submerged part of the beach (Balouin et al. 2004). It will be interesting to study if there was a variation in the sediment input between 2003 and 2004 that was able to influence the submerged features configuration.

Conceptual model: morphodynamic classification

The present study focuses on the outer bar behavior without considering the inner bar and the emerged part of the beach. The inner bar remained stable for the entire study period. The subaerial beach is wide and the dunes are never reached by up-rush even during storms.

Using the information presented it is possible to create a conceptual model of the area by a visual classification of the submerged part of the beach. Using the morphodynamic classification of Wright and Short (1984), only for the outer bar configuration, it is possible to classify it as an intermediate type C. According to the classification of Lippmann and Holman (1990) the outer bar is classified as “bar type E” - offshore rhythmic bar (longshore rhythmic forms; continuous trough; infragravity scaling). The classification remains the same in both considered periods passing through an intermediate type B (Wright and Short 1984) or “bar type G” - infragravity scaled 2-d bar (no longshore variability; infragravity scaling) (Lippmann and Holman 1990). From these classifications, the expected equilibrium state for the outer bar is a 3-d rhythmic morphology. This would confirm either the hypothesis of the new equilibrium state with a shorter rhythmic pattern, or the hypothesis of a very long relaxation time that could bring back the system to its initial state

CONCLUSIONS

The study focused on a period of one year (April 2003-May 2004) and it revealed that the bars that were observed at the beginning of the project increased the number of rhythmic features of a factor of 2/2.5 (wavelength from 300-350 m to 150-200 m), while the mean wave amplitude remained the same (25 m). This is a behavior often observed at different sites around the world (van Enckevort et al. 2003), where the rhythmic forms are present and develop under low to medium wave energy conditions. Data obtained seem to suggest an important role of the duration of high magnitude events in a complete re-arrangement of the system from 3-d to linear forms. An important influence of the initial morphology on the final equilibrium configuration is also supposed, as 3-d morphologies are created again within a short period after major storm events.

The morphodynamic classification identified the outer bar as “intermediate type C” (Wright and Short 1984) or “bar type E” (Lippmann and Holman 1990). Future studies will focus on the interaction between the outer and the inner bar, considering also the effect of the river sediment input on the double bar system.

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