Contemporary subaqueous dune-field development off an abandoned river mouth in the Ebro Delta (NW Mediterranean)

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ABSTRACT: High-resolution multibeam bathymetry, bottom sediment samples and time series of turbidity and currents were collected over a dune-field on the Ebro Delta coastal area in the north-western Mediterranean. The acquired bathymetry images a 3.6 km^2 dune-field with dunes of 1 m of mean height and 240 m of mean wavelength. Comparison between historical charts and contemporary aerial photographs show that the dune-field lied over the same location where a river mouth sand bar emerged in 1880. Onset of the dune-field is suggested to happen when the former river mouth was abandoned and the shoreline underwent fast retreatment since the forties. Nowadays, strong currents induced by north-westerly winds produce a dynamic seabed over dunes, including ripple development suggesting that the dune-field would be currently active during the high-energetic events.

1. INTRODUCTION

Numerous examples of dynamic dune-fields on continental shelves are related to strong currents (i.e. Kubicki, 2008). On the Western Mediterranean tideless shelves, several dune-fields have been described, most of them interpreted to be formed in coastal areas during periods of lower sea level (Durán et al., 2013; Simarro et al., 2015). However, current examples of dunes development in shallow areas are scarce, probably because sea waves tend to wash out these features.

This study deals with a dune-field located on the shoreface of the Ebro Delta. Present-day sediment dynamics on the dune-field and the morphological evolution of the delta plain during the last century are analysed to unravel the formation mechanisms and present-day dynamics.

2. STUDY AREA

The Ebro Delta is ~325 km^2 and it is one of the most important wet coastal ecosystems in the Western Mediterranean (Fig. 1a). It is located in a micro-tidal wave-dominated coast (maximum tidal range of 0.25 m). Seasonal wave regime predominates with relatively high-energetic events between October and March when the most intense storms occur. These storms have an annual return period and a significant wave height (Hs) of 3.5 m (Bolaños et al., 2009). The area is subject to three main storm directions (E, NW, and S), with the most intense swell-dominated storms coming from the east. The wind regime is characterized by NW winds, which are extremely intense and persistent due to the orography, providing sea-dominated storms (García et al., 1993).

The deltaic plain evolution is essentially summarized in a progradational period of the Cape Tortosa mouth between 1880 and 1937; and an erosional period of this mouth from 1937 to present (Guillén and Palanques, 1997). The contemporary morphological changes of the present day deltaic lobe are primarily attributed to changes in the Ebro River mouth position and orientation. The opening of the current river mouth occurred in 1937, although it played a secondary role until the mid-twentieth century when it became the main river channel. (Fig. 1b).

3. DATA COLLECTION

High-resolution swath-bathymetry data of the Ebro Delta coast was acquired in summer 2004 with a Simrad EM3002d multibeam echosunder by the *Arraix* survey boat in the frame of the Spanish PRODELTA RTD project and during October of 2013 with an ELAC NautikSeaBeam 1050D by the B/O *García del Cid* in the frame of the FORMED project.

An instrumented benthic tripod was also deployed off Cape Tortosa over the dune-field at approximately 13 m depth from the 13th of October of 2012 to the 10th of January of 2013. The tripod was equipped with an Aanderaa current meter (RCM9) located at 1 mab, which recorded time series data of current intensities and directions and suspended particles concentrations every 30 minutes. The tripod was also equipped with a GOPRO camera that recorded sequences of 10 seconds every 4 hours. A sediment sample was recovered by a HAPS core at the tripod location.

Wave field measurements and statistics from the buoy offshore Tarragona were provided by the Spanish Ports Authority (Puertos del Estado) with hourly sampling. The wave data was propagated from the buoy, located at 688 m depth, to the tripod position considering only the shoaling effect.

Finally, an historical chart of 1880 from the Spanish Hydrographic Survey and aerial photographs obtained by the Cartographic and Geologic Institute of Catalonia (ICGC) were used to determine changes in the configuration of the river mouth.

4. RESULTS AND DISCUSSION

4.1. Dune-field characteristics

The dune-field extends over ~3.6 km^2 of the swath-mapped deltaic lobe in between the isobaths of 8 and 15 m, off the abandoned Cape Tortosa mouth (Fig. 1b). The bedforms are better-developed and slightly more symmetric in the north-western area than in the south-eastern one. The crests of these features are rather rectilinear and their orientation changes as they are arranged perpendicular to the bathymetric contours of the deltaic lobe. The dunes are composed of fine sand. Their height ranges from 0.5 to 2.2 m with a mean value of 1 m, while their wavelength ranges from 140 to 600 m with a mean value of 240 m. Small-scale bedforms (ripples) were observed during the deployment superimposed on the dunes (Fig. 2a).

4.2. Sediment dynamics

The time series measurements indicate that strong currents and waves are able to mobilize the bottom sediment (Fig. 2). The maximum near-bottom current intensities were approximately 0.6 m/s flowing towards the SSE (Fig. 2b). These strong currents were mainly driven by NW winds (Mistral) and displayed 30-40 degrees angle with respect to the crestline of the dunes, at the tripod location. On the one hand, current intensities and wave-height increases were associated with increments in the water turbidity (Fig. 2). On the other hand, ripple formation, migration or decay were observed during these higher-energetic periods. Ripples morphologies varied depending on the hydrodynamic conditions from wave-dominated to wave- and current-dominated conditions (Fig. 2). Formation and evolution of the dunes, particularly considering the dunes crestline orientation, can therefore be reasonable related to the strong wind-induced SSE-directed currents. The observations suggest that interaction between dunes and the subordinated bedforms (ripples) is probably key to the evolution of the dunes; however it have to be further studied.

4.3. Dune-field development

The Ebro River mouth prograded from 1880 to 1937 when a new mouth opened to the north. This northern mouth progressively became the main Ebro River channel. Thereafter, the former Cape Tortosa river mouth was progressively abandoned leading to a severe shoreline retreatment of ca. 2,300 m from 1947 to 2014 (Fig. 1b). The sediment eroded from the Cape Tortosa mouth was transported by waves and currents and redistributed along the delta plain. The location of the current dune-field coincides with that of a partially emerged mouth sand bar in 1880 and it is very close to the shoreline of Cape Tortosa during the forties (Fig. 1a and b, respectively). Therefore, the dune-field onset presumably began in the forties favoured by the availability of large amounts of sand on the shoreface supplied from the eroded delta plain. Strong near-bottom currents induced by NW winds generated the dune-field in this erosional shoreface.

5. CONCLUSIONS

High-resolution seafloor mapping allowed identifying a dune-field located over the former Cape Tortosa river mouth in the Ebro Delta. The dune-field is ~3.6 km^2 of the swath-mapped area. Dunes display a maximum wave height and wavelength of 2.2 and 600 m, respectively. The dunes are composed of fine sand and are better-developed in the north-western area. They are mostly symmetric with crestlines oriented perpendicular to the bathymetric contours.

The dune-field presumably developed because of the abandonment of the former Cape Tortosa river mouth since the forties. The measured currents, wave-field and turbidity time series data suggest that the studied dune-field can currently be active. Moreover, observations showing continuous formation, migration and decay of ripples during storm periods evidence a dynamic area of sediment remobilization.

Analysis of the contemporary development of this dune-field in an erosional coastal deltaic system can provide new insights for better understanding bedforms genesis during transgressive episodes at geological time-scales. Despite most Mediterranean continental shelves are occupied by relict, waning or low-dynamic bedforms, examples of present-day formation are very scarce. Finally, the time-scale over which the dune-field has evolved (several decades) may provide a useful example to predict the morphodynamic shoreface evolution in a future sea level rise scenario.

6. ACKNOWLEDGMENT

Q. Guerrero was supported by the Spanish Government by FPI grant (Ref. BES-2013-066261). This research was supported by the project FORMED (CGL2012-33989). We appreciate the captain and the crew of the R/V *García del Cid* and the *Arraix* for their kind assistance. R. Durán is supported by a CSIC JAE-Doc contract co-funded by the FSE.

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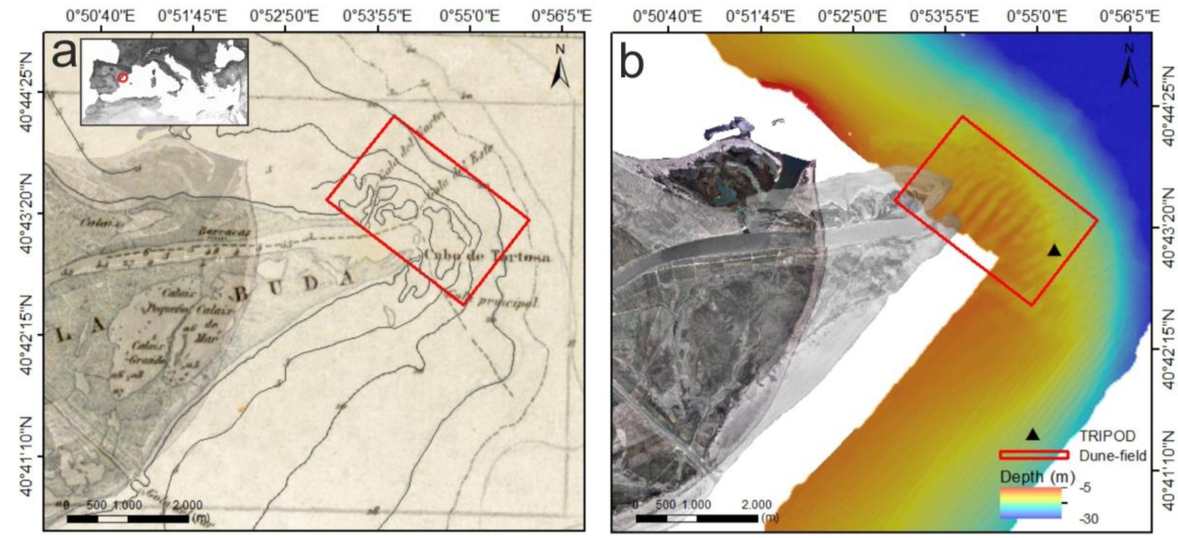

Figure 1. (a) Location of the study area on the 1880 hydrographic chart superposed on the 2014 aerial photograph. (b) 1947 and 2014 aerial photographs; bathymetric map; and location of the dune-field and the tripod (red square and black triangle, respectively).

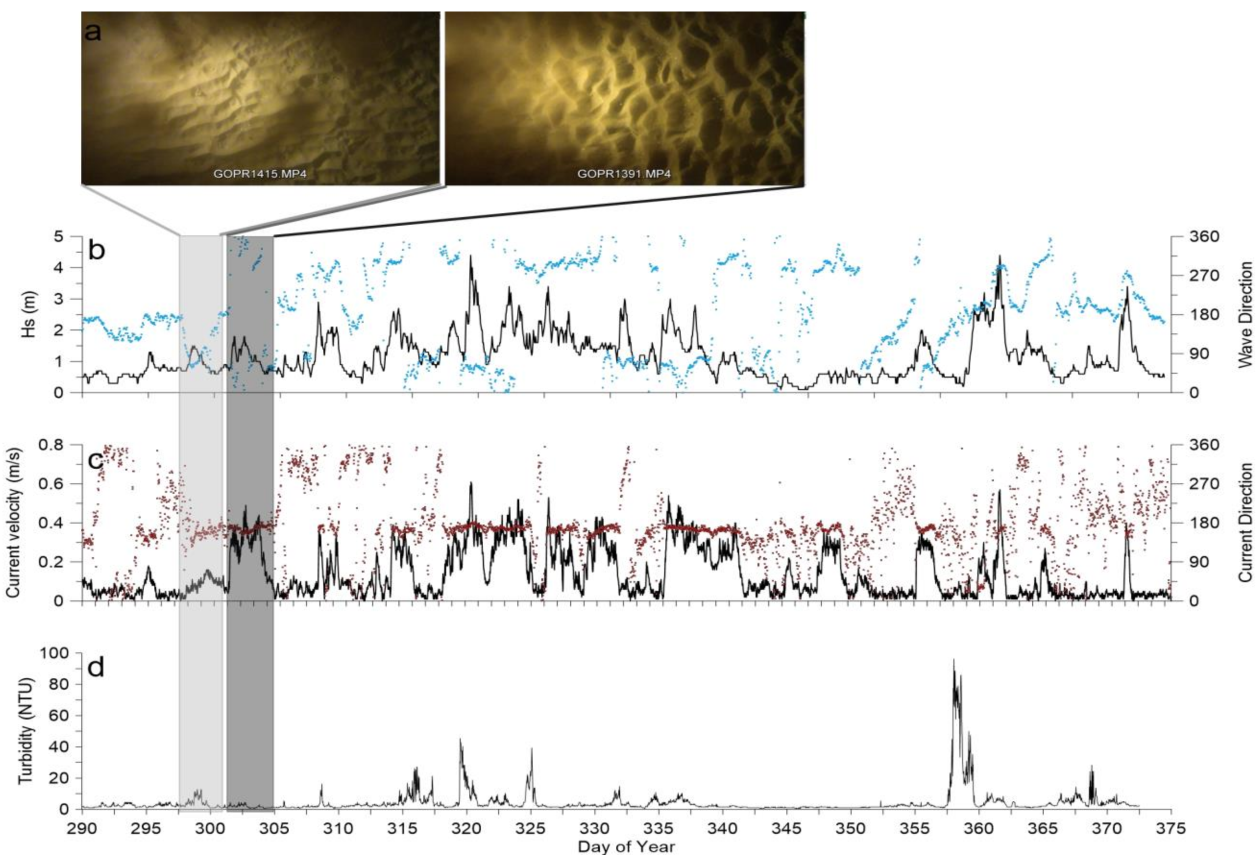

Figure 2. (a) Examples of the two rippled morphologies observed as a result of wave-dominated (to the left marked with lighter polygon) or wave and current-dominated hydrodynamic conditions (to the right marked with dark polygon). Time series data from 18th October of 2013 (day 291) to 10th of January of 2014 (day 375) of: (b) Significant wave height (black line) and wave direction (blue dots); (c) Current velocities (black line) and current directions (red dots); (d) Turbidity time series data.