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# Analysing Short-Term Shoreline Changes Along the Ebro Delta (Spain) Using Aerial Photographs

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**ABSTRACT**

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The use of aerial photographs to estimate short-term shoreline changes, *i.e.* coastal changes at a monthly scale reflecting seasonal changes in the underlying hydrodynamics, is presented in this paper. To achieve this a data set of seven vertical aerial photographs with a time span of four months, taken at the Ebro delta (NE Spanish Mediterranean coast) has been used. The method was applied to the analysis of very flat areas, highly dynamic coastal features, storm impacts and to the entire deltaic coast. Although the study area is a microtidal environment, obtained results of the very flat areas analysis do not recommend its use at very short time scales due to meteorological tide influences. The formation, erosion and re-formation of a spit at the river mouth was easily monitored being controlled the evolution of its length, perimeter and subaerial surface. Aerial photos permitted to identify vulnerable zones to impacts of very energetic storms by characterising breaching events along the coast (location and magnitude). Finally, when the method was applied to the entire deltaic coast, a detailed seasonal and spatial distribution of shoreline changes was obtained. The comparison of shoreline rates of change obtained from photos with that obtained from beach profiles shows that the method is reasonably accurate at least for the Ebro delta coast.

**ADDITIONAL INDEX WORDS:** *Shoreline changes, aerial photography, Ebro delta, coastal erosion.*

## INTRODUCTION

The interest in studying coastal morphology has increased during recent decades, mainly due to coastal land loss problems, present in most of the world coastlines due to natural or man-induced agents (*e.g.* PILKEY *et al.,* 1989). As a result of this, the development of techniques to observe coastal processes with the required cost and accuracy has been a key issue in coastal morphology.

In this paper, one of the most frequently employed techniques to observe coastal processes, *i.e.* aerial photographs, is used to analyse coastal changes at the Ebro Delta (Spain). Although aerial photographs and photogrammetry have been extensively used to study many coastal morphology aspects—*viz.* coastal type identification, land uses, dune field evolution, *etc.* (see *e.g.* AMERICAN SOCIETY OF PHOTOGRAMMETRY, 1980), this work only deals with the application of this technique to study short-term (monthly) shoreline changes.

Coastal evolution can be considered as the global or integrated result of different processes acting at different time scales (*e.g.* DE VRIEND, 1991; FENSTER *et al.,* 1993). In fact, coastal changes are characterised by a broad spectrum of scales ranging from the very small ones (*e.g.* ripple formation) to the very large ones (*e.g.* secular changes due to sea level changes).

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The use of aerial photographs has been, so far, used mainly to observe coastal changes over relatively long time spans (*e.g.* DOLAN *et al.,* 1980; LEATHERMAN, 1983; ANDERS and BYRNES, 1991; MCBRIDE *et al.,* 1991). This technique has been seldom applied to quantify short-term coastal evolution (JIMENEZ *et al.,* 1995). Short-term coastal changes are here defined as those changes in coastal morphology occurring at a monthly scale, reflecting thus seasonal changes in the hydrodynamic regime (if any). In this case aerial photographs can be used to obtain a synoptic view of large coastal stretches, avoiding thus expensive and seasonal topographical beach surveys.

## STUDY AREA

The Ebro delta is located on the Spanish Mediterranean coast (Figure 1), about 200 km Southwest of Barcelona. The delta coastline has an approximate length of 45 km and its total subaerial area is about 320 km$^2$.

After several centuries of continuous growth, the deltaic trend of evolution changed a few decades ago (MALDONADO, 1986) in such a way that the present delta is no longer an intermediate river-wave dominated system as it was classified previously by *e.g.* WRIGHT and COLEMAN (1973), but it is now a wave dominated coast (JIMENEZ and SANCHEZ-ARCILLA, 1993). This change was mainly due to the nearly total reduction of sand river discharges induced by dam construction in the lower course of the Ebro river (VARELA *et al.,* 1986).

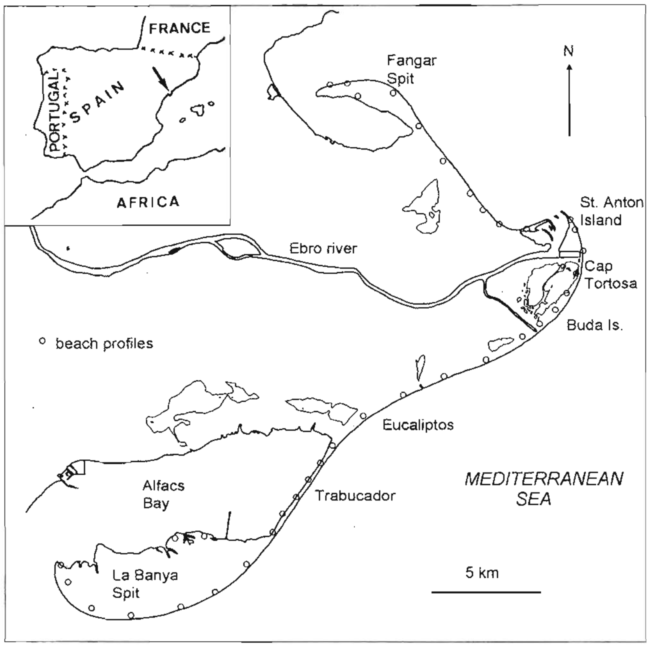


Figure 1. Map of the Ebro delta study area.

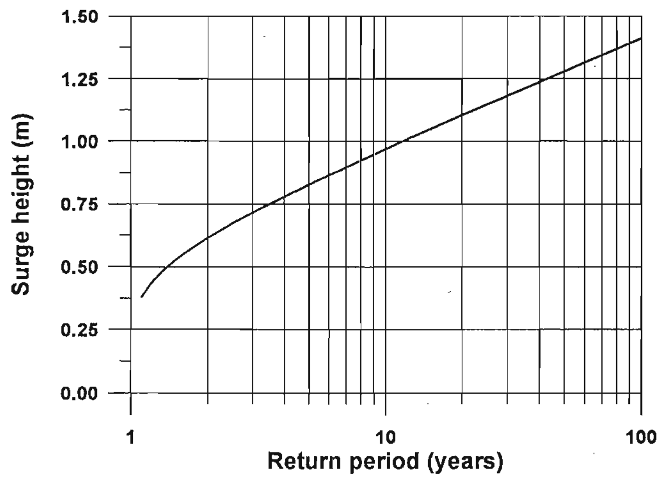


Figure 2. Storm surge climate at the Ebro delta coast (JIMÉNEZ *et al.* 1996).

As a result of this decrease in the sand discharges, a very intense reshaping of the nearshore deltaic area began to take place. At the beginning of the 1960's, when the decrease of the sediment discharge started, the remodelling process was particularly intense and, at present, although the process still continues, the rates of change have significantly decreased (*e.g.* JIMENEZ and SANCHEZ-ARCILLA, 1993; JIMENEZ *et al.,* 1993). This reshaping determines the presence of rapidly eroding zones such as the area of the previous river mouth at Cap Tortosa-Buda Island, the Trabucador Bar, and most of the outer coast northwards of the river mouth, as well as accreting zones such as the end of both spits.

The trend of coastal changes has been successfully related with the existing net longshore sediment transport pattern (JIMENEZ and SANCHEZ-ARCILLA, 1993). This transport is driven mainly by the dominant eastern waves, which produce a net longshore sediment transport directed northwards in the northern hemidelta and, southwards in the southern one.

Wave characteristics along the Ebro delta coast can be roughly described by an average offshore significant wave height, $H_s$, of 0.75 m and an average mean wave period, $T_m$, of 3.9 sec (JIMENEZ *et al.,* 1996). Three main wave components can be distinguished from a "directional" standpoint: eastern (E and NE), southern and northwestern. Eastern components, characterised by higher and more energetic waves, are the predominant causes of morphological changes.

Like most of the Mediterranean coast the Ebro delta is a low microtidal environment with a maximum astronomical tidal range of about 0.25 m. However, meteorological tides associated to the offshore passage of low-pressure systems, are frequent. The storm surge climate for the Ebro delta coast can be seen in Figure 2.

## MATERIALS

The study here presented is based on the analysis of seven aerial photo campaigns, taken from October 1989 to October 1991, with an average time span of about four months. All the surveys were conducted using the same data acquisition technique. Vertical photographs were taken from an aircraft at a flight height of about 10,000 m equipped with a Wild Lens Cone RC10 camera and using a PAN 200 photo film. The focal length was 152.15 mm, resulting in a scale of 1: 70,000.

Each survey consisted of two flight lines with an orientation SW-NE (see Figure 3). The length of the longest one was about 40 km and it was usually covered by 14–17 photos. The shortest one, located towards the NW, was 30 km long, and it was covered by 11–13 photos. The average distance between the centre of the photos along the lines of the flight was about 3,000 m. This flight scheme produced an overlap of about 60 percent between stereoscopic pairs along the lines and a sidelap of about 30 percent.

At the same time, beach surveys were conducted along 38 control profiles covering the entire coastline of the delta. Most of the beach surveys were taken with a maximum time lag of about 20–30 days with respect of the date of the flight. Profiles were surveyed using standard topographical techniques for the emerged beach and with an echosounder mounted on a small boat for the submerged part of the profile. In both cases, each point was geographically referenced in the Universal Transverse Mercator (UTM) system.

These geomorphologic measurements were supplemented by water level, waves and wind data. Water level was measured using both analog and digital (part of the time) tide gauges, waves were recorded using an offshore directional waverider buoy and meteorological variables (wind characteristics and atmospheric pressure) were measured using offshore and onshore meteorological stations.

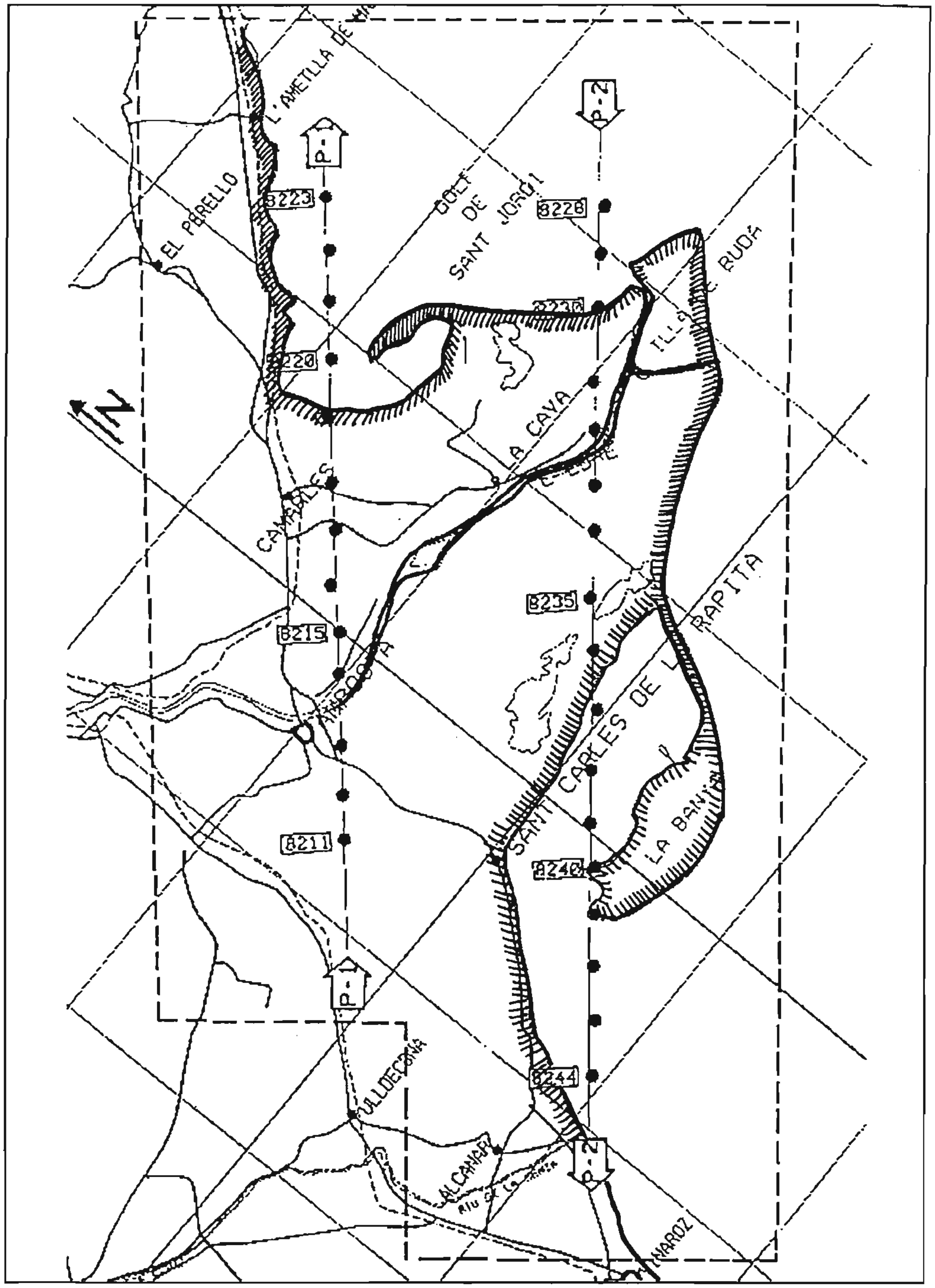


Figure 3. Flight sketch for photography surveys. Dots show photo centers.

## METHODS

### Shoreline Position

The extraction of shoreline positions from aerial photographs was done following standard photogrammetric techniques. THIELER and DANFORTH (1994a) describe the shoreline mapping process using six steps: establish a control network, digitise features on the photos, remove distortions, establish the absolute orientation, calculate the geographic shoreline position and compile obtained positions. The first four steps determine the accuracy to be obtained during the shoreline calculation, and the last one is a post-processing step.

To orient the obtained photos with respect to the ground, a control network established for the first campaign was used. It consisted in control or "ground" points obtained during a field campaign and which were subsequently referenced using neighbouring points obtained from the Spanish National Geodetic Network. These points were used for aereotriangulation which was done using a program developed at the Institut Cartogràfic de Catalunya (ICC). An averaged root mean square (*rms*) error of 1 m was estimated for horizontal positions (BOU, 1994).

Stereocompilation was performed using three different stereocompilers, two mechanical ones (Wild A8 and B8) with a zoom range of 5–20 × and an analytical one (Zeiss P3) with a maximum zoom of 24 ×.

The definition of shoreline positions from aerial photographs can in principle be obtained using different control lines: line of vegetation, the dune foot, the high water line, *etc.* (see *e.g.* CROWELL *et al.*, 1993, MORTON, 1991; FISHER and OVERTON, 1994). In this study, due to the existing coastal morphology—lack of generalised dune rows, coexistence of beach and deltaic plain, etc.—and tidal environment, the shoreline was defined as the mean water level, except when the survey was done during high tide (astronomical and/or meteorological) in which the water line at the time of the photo was used. Potential errors induced by the water level position will be discussed in the next section. Although the use of the wet/dry line to characterise the shoreline is quite extended, its application to the Ebro delta would not improve the obtained using the water line. This is due to the fact that the Ebro delta is a microtidal environment and any change in the water line, *e.g.* due to meteorological effects, will be also reflected in the same magnitude in the wet/dry line. Thus, similar horizontal translations for the water line and the wet/dry line would be expected.

The shoreline so defined was obtained by digitizing points along the control line from the aerial photo. Points defining shoreline were geographically referenced (in UTM) since the process is done after the obtention of the absolute orientation of the photos. An averaged *rms* error of 3.5 m and a maximum *rms* error of 5 m were estimated for shoreline positions (BOU, 1994).

Once all the shorelines were obtained, the following step was to prepare them to analyse shoreline displacements. In order to do this, a working or baseline was established landwards of all the extracted shorelines and parallel to the general shoreline trend (*e.g.* THIELER and DANFORTH, 1994b). Afterwards, 111 working profiles spaced 500 m apart were constructed orthogonal to this line. Profile orientations were selected to be locally perpendicular to the observed shoreline evolution. At last, the coordinates of the shoreline position corresponding to each control profile was determined by the intersection of each profile with the shoreline. By repeating this procedure with all the surveys, a database composed by shoreline distances from fixed points (corresponding to the working profiles) was obtained. This was done using MicroStation v4 (Intergraph) Geographic Information System software.

### Shoreline Rate of Change

Several different options exist to estimate the shoreline rate of change, depending on the time scale of the changes to be characterised and the nature of the available data (*e.g.* DOLAN *et al.*, 1991).

Since one of the main objectives of this paper is to analyse the suitability of aerial photography to characterise short-term coastal evolution (which is usually reflected by seasonal or cyclic changes with an alternating erosion-accretion pattern), the EPR method (end-point-rate) was selected for this purpose. EPR for each shoreline relative to the oldest shoreline was calculated. This method was selected to retain the seasonality of the changes (if any) and to avoid any treatment to filter or to smooth the data for the short-term analysis.

Additionally, the representative shoreline rate of change for the surveyed period (2 years) was also calculated using the LR method (linear regression) for both data sources (aerial photos and beach profiles). The use of this technique permit to characterise the net evolutive trend for the analysed period by filtering seasonal changes (DOLAN *et al.* 1991).

## RESULTS

The suitability of aerial photographs to characterise short-term coastal changes along the Ebro delta has been investigated for four different morphodynamic problems, related to four different environments within the delta.

### Very Flat Coastal Zones

Although the Ebro delta coast is a microtidal environment, meteorological tides occur frequently. Whereas the water-level-oscillation induced effect can be considered as negligible for the analysed photos—in general along the entire outer coast of the delta (swash zone slopes between 0.03 and 0.23)—,there exist some zones where a more detailed analysis becomes necessary. In the area of study three very flat areas exist: the inner coast of the two spits and a marsh zone at the river mouth, formed by sand banks and bars. These zones are characterised by a low-lying profile with very gentle slopes (less than 1/1,000) where small water level fluctuations produce large horizontal waterline migrations.

To illustrate this effect, a comparison of two photos of the northern spit appears in Figure 4a. The March 1990 photo shows a fully emerged spit with most of the sand above the mean water level. However, the October 1991 photo presents a submerged spit, with only the highest parts of the beach (dunes and berm of the outer coast) emerged.

If shorelines are extracted from both photographs (Figure 4b) and they are compared, a very large "erosion" of the spit would be obtained, resulting in a "maximum recession" of the inner coast of 1,200 m. However, this part of the deltaic coast shows a continuous accretion, due to the deposition of material eroded from the outer coast northwards of the river mouth (MALDONADO, 1986; JIMENEZ and SANCHEZ-ARCILLA, 1993). Moreover, the hydrodynamic regime of the inner bay is very low and only very small, locally generated waves are present, which are unable to produce any significant sediment transport and thus also unable to produce the apparently observed erosion.

This *erroneous* result, obtained from a direct comparison of photographs is due to the fact that the photo of October 1991 was taken with a water level 0.30 m higher than the March

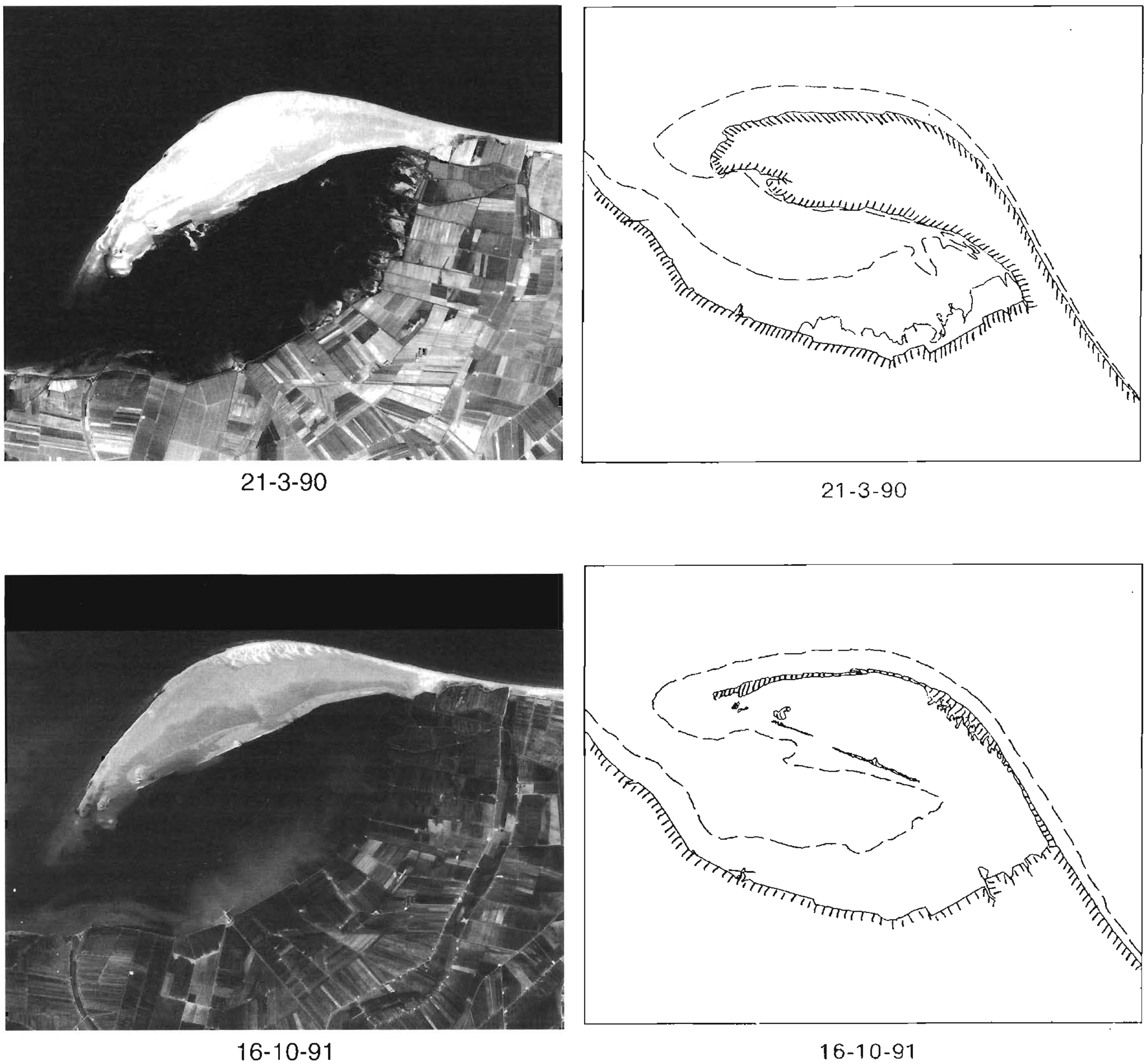


Figure 4. Northern spit. (a) aerial photos, (b) derived shorelines.

1990 one, due to meteorological effects. As it can be seen in Figure 4, the effect of such a meteorological tide on the shoreline position along the outer coast can be considered as negligible (compared with that observed for the inner coast) due to the existing beach face slope.

## Highly Dynamic Coastal Features

Figure 5 shows the formation and evolution of a spit at the Ebro river mouth. This coastal feature is typical of wave-dominated deltas (*e.g.* WRIGHT, 1978) and it can be used as an indicator of the net longshore transport direction (*e.g.* TAGGART and SCHWARTZ, 1988).

Along the outer coast of Sant Antoni Island, the net longshore sediment transport is directed towards the north from a point of zero net transport and divergence in longshore transport at Cap Tortosa (JIMENEZ and SANCHEZ-ARCILLA, 1993). The net transport rate along the outer coast has been estimated to be about 100,000 $m^3$/yr, most of which is deposited in the apex of the island as a spit due to wave refraction and diffraction processes together with the interaction with the discharge of the river flow. Part of the sediment is able to by-pass this zone and is deposited as sand banks and bars in the river mouth area.

The continuous accumulation of sand in this zone, in form

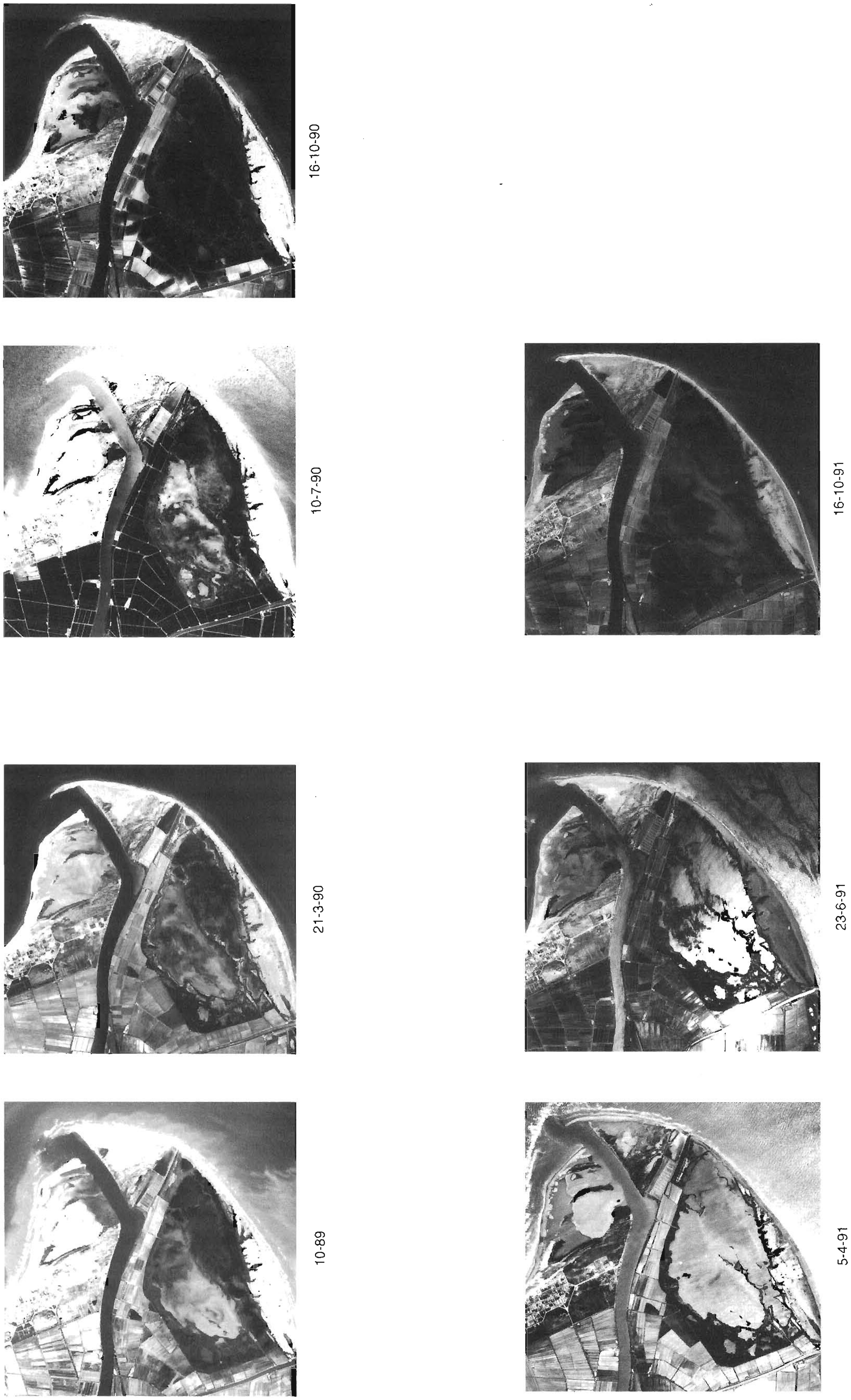


Figure 5. Spit development at the Ebro river mouth from October 89 to October 1991.

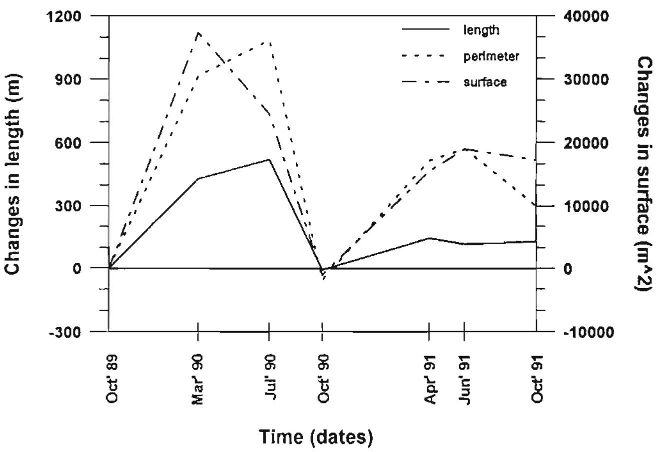


Figure 6. Time evolution of length, perimeter and subaerial surface of the spit at the river mouth.

a spit or as sand banks, is presently the main problem in the management of the river mouth area, at least for navigational purposes, since it produces siltation which requires periodic dredging to assure a minimum depth. An analysis of different alternatives to solve this problem can be seen in BOER *et al.,* 1994.

To analyse the spit evolution, three parameters were obtained from the aerial photographs: spit length, perimeter and emerged area. Figure 6 shows the time evolution of the three variables with respect to the configuration in October 1989.

In March 1990, the spit experienced the largest growth, with a length increase of about 425 m, a perimeter increase of about 900 m and an area increase of about 37,500 m$^2$. In July 1990, the spit had continued to grow, although with a small breach. This breach produces an increase in the perimeter and a decrease in the emerged spit area of about 12,500 m$^2$. In October 1990 a sudden disappearance of the spit was observed (the three studied parameters came back to nearly their initial values, when no significant spit was present). This was due to the action of a heavy storm during which high water levels (storm surge) and high waves coexisted (see SANCHEZ-ARCILLA and JIMENEZ, 1994).

After the storm passage the spit began to be slowly reconstructed by the deposition of sediment eroded from the outer coast. In April 1991 a small increase in length of about 100 m was detected. An important increase in surface and perimeter was also detected due to the spit widening. After April 1991 the spit appeared to be stable and no further growth was detected till October 1991. This "steady" behaviour is due to the fact that during May 1991 a river flood with a maximum liquid river discharge of about 1300 m$^3$/s occurred (present annual averaged river discharge is below 300 m$^3$/s). This flood produced an erosion of the river bed at the mouth generating a channel at the apex of the spit (RIERA, 1991). Under this new situation, the sediment transported along the outer coast needed a greater volume to "emerge" since the eroded channel had to be filled up. This means that, although no


Figure 7. Line drawing storm breach at Cap Tortosa connecting the inland pond with the sea based on air photos taken on October 1990.

emerged surface change was detected, this does not imply that there is no sediment transport. The set of available photographs has, thus, been successfully used to assess monthly-scale coastal changes in the river mouth area.

## Vulnerable Zones Subject to Episodic Changes

Episodic changes are morphological changes induced by very energetic forcing agents with a long return period. These agents normally produce a significant modification of the coastal zone in a very short period of time. In the Ebro delta area, these agents are characterised by the simultaneous presence of storm surges and high waves (SANCHEZ-ARCILLA and JIMENEZ, 1994). These agents, although acting along the entire coast, will mainly affect to the most vulnerable coastal stretches. High vulnerability areas are barrier beaches, spits and very narrow beaches backed by isolated lagoons or ponds.

During the second week of October 1990, a severe storm hit the north-eastern Spanish coast. During the storm, high eastern waves (significant wave height, $H_s$, of 4.4 m and maximum wave height, $H_{max}$, of 8.8 m) and high sea level coexisted (storm surge of 0.40 m above mean water level). Although the impact of this storm was visible along the entire deltaic coast, several stretches experienced very large erosion (SANCHEZ-ARCILLA and JIMENEZ, 1994).

As mentioned above, the river mouth spit suffered such extensive erosion that the subaerial portion of the spit disappeared. At Cap Tortosa, a coastal stretch with a narrow subaerial beach, practically all the beach was eroded and a small breach was opened, connecting an artificial pond with the open sea (see Figure 7). However, the largest changes were detected at the Trabucador Bar (see Figure 8). The Tra-

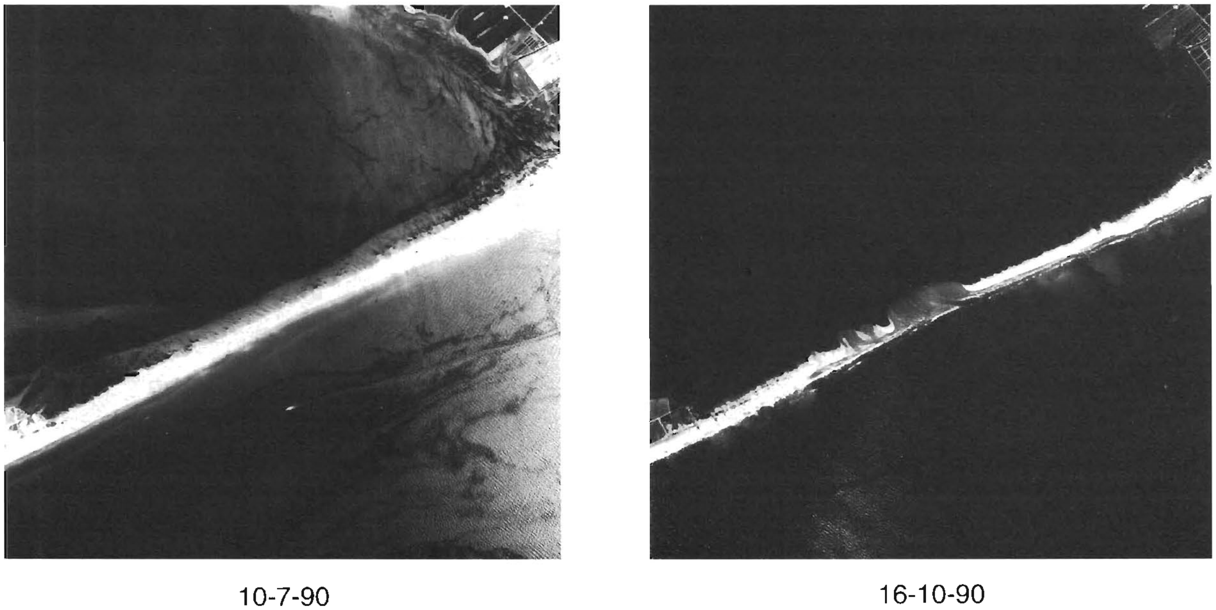


Figure 8. Breaching at the Trabucador Bar (left: before storm, right: after storm).

bucador is a barrier beach 5.5 km long linking the main body of the delta with the southern spit. The width of the barrier ranges from 100 m to 200 m and the maximum height above mean sea level is about 1.5 m. Due to these geomorphologic characteristics, the barrier is easily overwashed during periods of high waters.

During the storm, with high water levels and, at the same time, energetic waves acting on the coast, the intensity of overwash processes was so high that, a breach occurred (SANCHEZ-ARCILLA and JIMENEZ, 1994). The morphological effect can be seen in Figure 8, in which a breach of about 1 km length can be observed. Moreover, the morphology of the backbarrier beach that appears in the corresponding photograph indicates that overwash was the main erosive process during this event and that a large amount of sediment was transported towards the inner bay.

Using aerial photographs only the surface loss due to the storm impact can be calculated. Since the photograph corresponding to the breach event was taken under a surged water level, this surface does not correspond to the real surface loss above the normal mean water level. However, combining this information with field measurements of the breach topography, a volume loss of about 70,000 $m^3$ was estimated, with 80% of this material transported towards the inner bay (SANCHEZ-ARCILLA and JIMENEZ, 1994).

Therefore the aerial photographs cannot be used directly, in this case, to assess morphological changes. However, aerial photographs constitute an important supplement of information for the local topographic and bathymetric data, in the sense that they provide a synoptic view of the coastal response associated to the breach event. In that sense they can be used to obtain qualitative information to steer the field campaign.

## Regional Shoreline Change Analysis

As another illustration of the use of aerial photographs for short-term shoreline changes, the whole collection of aerial photos was used to assess the behaviour of the entire Ebro delta coast.

The estimated shoreline changes along the southern and northern hemideltas can be seen in Figure 9 and Figure 10, respectively. A clear pattern of spatial and temporal changes can be observed (the reference configuration was that obtained from the first campaign in October 1989).

South of the river mouth several different coastal stretches can be identified on the basis of morphological trends. Starting from the river mouth and moving towards the south the main stretches are (Figure 9): (1) Cap Tortosa, a highly erosive zone with a continuous and progressive shoreline recession; (2) Buda Island, an erosive zone, although with smaller erosion rates than the previous one; (3) Eucaliptos Beach, an accretive zone; (4) the Trabucador Bar, a barrier beach with a net erosive behaviour and (5) the southern spit, a highly accretive zone, with continuous shoreline progradation.

The impact of the October 1990 storm can be seen identified easily in the shoreline change data. Most of the experienced shoreline erosion can be attributed to this storm (it can be seen that the Trabucador Bar experienced the largest erosion, due to the barrier breaching). In accretive stretches, a decrease in the net accretion rates can be also observed during the storm influenced period.

Northwards of the river mouth (Figure 10) a simpler pattern is detected, in which only two different stretches are identified: (1) most of the outer coast of the hemidelta, showing a slight erosive behaviour and (2) the northern spit, which has experienced continuous accretion.

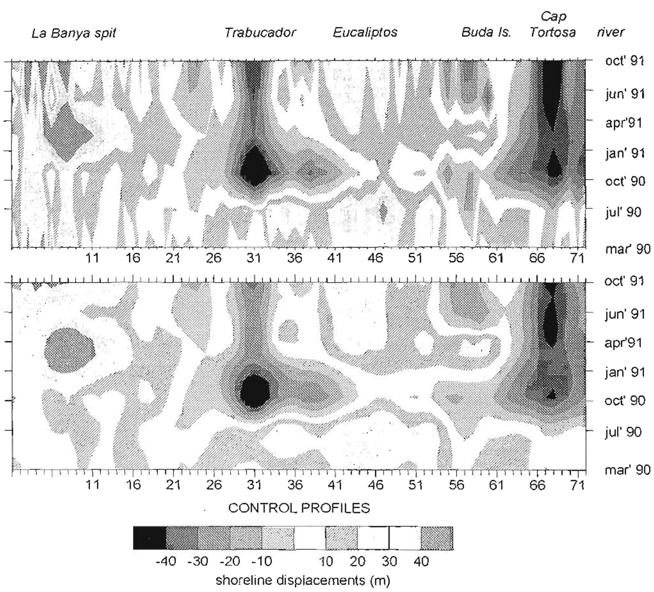


Figure 9. Shoreline changes at the southern hemidelta with respect to the first campaign—October '89—(upper: measured changes from aerial photographs, lower: after smoothing with a three-point running average).

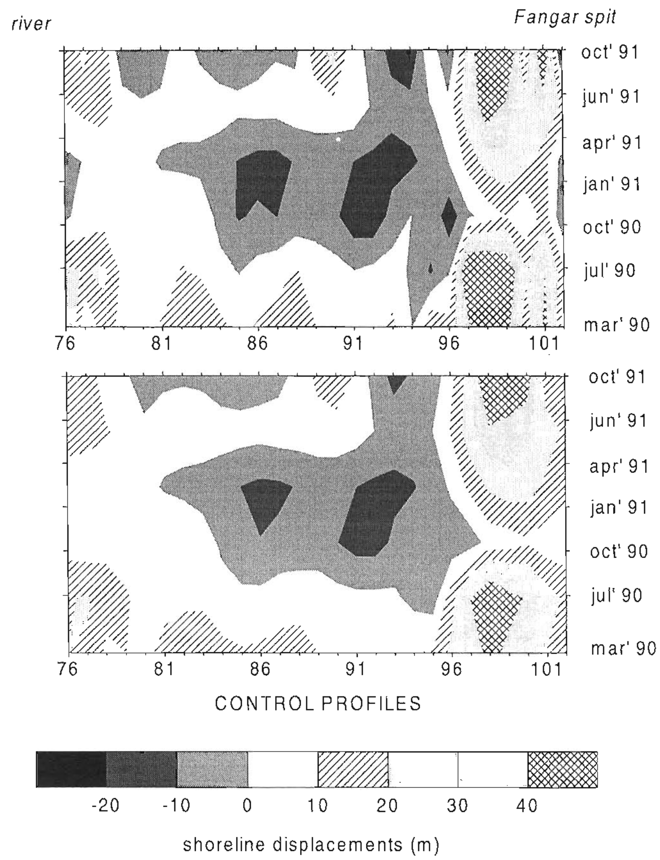


Figure 10. Shoreline changes at the northern hemidelta with respect to the first campaign—October '89—(upper: measured changes from aerial photographs, lower: after smoothed with a three-point running average).

Finally, the net evolutive trend of the shoreline for the period of study was calculated using the LR method. This was done with data obtained from aerial photographs (using the shoreline displacements presented in Figures 9 and 10) and with shoreline data from field topographic measurements. To do this, shoreline rates of change obtained by JIMENEZ and SANCHEZ-ARCILLA (1993) using beach profiles were recalculated for the time period covered by aerial surveys. Figure 11 shows the longshore distribution of the shoreline rates of change calculated using both data sources along the Ebro delta coast. It can be seen that from the qualitative point of view (type of evolution) the agreement is perfect, *i.e.* eroding and accreting zones are coincident. When the obtained rates of change are quantitatively compared, only small differences are found. In fact, a linear relationship given by *rate of change from photos = 0.98 rate of change from profiles* with a determination coefficient of $r^2 = 0.97$ was obtained in the comparison analysis (see Figure 12).

This analysis of the regional behaviour of the Ebro delta coast illustrates the suitability of aerial photographs for the short-term evolution of reasonably large physiographic units.

## DISCUSSION

The use of aerial photographs to estimate short-term shoreline changes has been presented for various field examples. Although, in overall terms, it can be considered as a good and useful tool, some points have to be further discussed for a proper use in short-term coastal morphodynamics.

Although the study area is a microtidal environment, there exist some zones characterised by a very gentle profile, in which small water level changes, can produce very large shoreline migrations. These zones cannot be studied at this

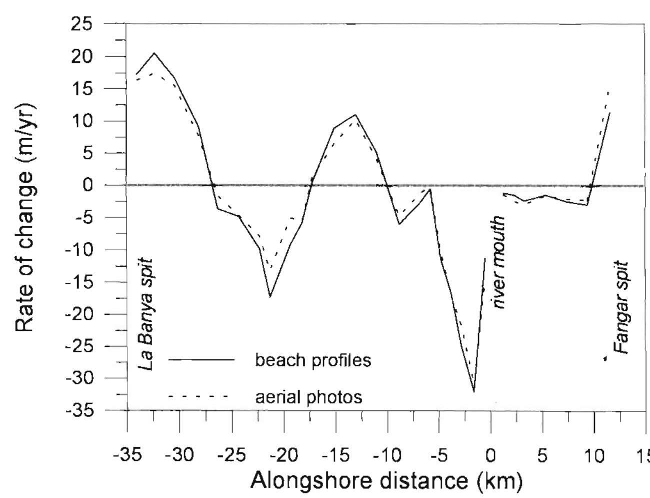


Figure 11. Alongshore distribution of shoreline rates of change (using LR) obtained from aerial photos and beach profiles.

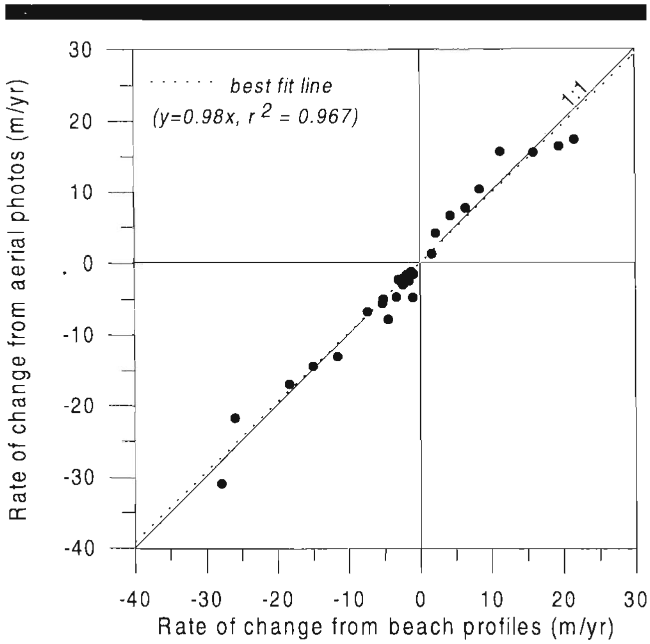


Figure 12. LR shoreline rates of change obtained from aerial photos *versus* obtained from beach profiles.

seasonal scale using aerial photographs, even in microtidal conditions, unless detailed water level records and beach profiles exist. In this case, the local shoreline obtained from the photos has to be corrected taking into account the topography of the flooded coast. To do this efficiently, a very detailed topography is required and, when this is available, it is no longer necessary to use aerial photographs. This implies that the estimation of coastal changes in very flat areas from aerial photos should be considered mainly at the long term scale (*e.g.* DOWNS *et al.* 1994).

In some cases, the use of aerial photos to estimate the intensity of some coastal processes must be complemented with additional field observations. In this study, whilst aerial photographs seem to indicate the growth of a spit in the Ebro river mouth and the reduction in growth speed after a storm passage, this was not really true. In fact, longshore transport rates after the storm were similar to the situation before the storm, but more sediment was necessary to produce the same emerged spit because a submerged trench was eroded by a small river flood at the tip of the spit. This fact could not be detected using only aerial photographs.

When aerial photos have been used to estimate short-term shoreline changes along the entire outer coast of the delta, good results have been obtained. Thus, seasonal changes characterised by alternating periods of erosion and accretion have been well described as well as different alongshore patterns in shoreline behaviour.

To assess the quality of the results obtained from photos, they have been compared with those calculated through the analysis of beach profile data. This was done by comparing the net shoreline evolution trend for the analysed period obtained using the LR method for both data sources. Considering the estimated type of evolution, *i.e.* eroding and accreting zones, a total agreement between both methods was observed. As for shoreline rates of change regards, although small differences have been found, both methods give similar magnitudes. The ratio between rates from photos and profiles has been calculated in 0.98, which indicates that both type of measurements quantitatively agree over the time span studied.

## CONCLUSIONS

The analysis of seven sets of aerial photographs covering the Ebro delta coast, with an average time span of four months, has shown that they can be used to evaluate short-term coastal changes.

Although the Ebro delta is a microtidal environment, meteorological tides produce water level oscillations larger enough to mask or to produce fictitious shoreline changes in topographically flat zones. To analyse aerial photos in these zones, detailed water level records and beach profiles must be used, unless very large "fictitious" shoreline displacements were accepted. Due to this problem, the quantitative analysis (from aerial photos) of changes in the inner coast of the two spits and in the north part of the river mouth is not recommended when only aerial photographs are available.

The analysis of aerial photos is, on the other hand, a very convenient technique to evaluate coastal changes of highly dynamic coastal features in a very detailed manner. Thus, the used data set permitted to evaluate the development of a spit at the river mouth as well as its complete removal due to a storm action and the post-storm recovery. This was done characterising the time evolution of its length, perimeter and surface. The action of a small river flood produced a trench at the river mouth which induced that more sediment was necessary to produce the same surface of subaerial spit. This fact could induce a wrong interpretation of the spit behaviour during the latter monitored period since if only photos were used a nearly steady situation after March 1991 would be identified.

At the same time, the analysis of aerial photos has been successfully used to evaluate coastal changes due to energetic events, and to identify coastal stretches sensitive to such events. During the monitored period, the impact of a severe storm on the Ebro delta was detailed characterised along the entire coast. Although a generalised coastal erosion was observed, the impact of such storm permitted to characterise highly vulnerable zones to episodic events by identifying the location and extension of breaching events along the coast.

When aerial photos were used to characterise regional shoreline changes for the entire Ebro delta coast a well defined seasonal alternance of erosion and accretion behaviour was observed. Moreover, besides this temporal pattern, a well defined spatial pattern of shoreline evolution was also characterised, identifying coastal stretches showing a systematic kind of evolution, *viz.* accretion zones as both spits, erosion zones as Cap Tortosa, the Trabucador Bar and the northern hemidelta.

To assess the quality of the results obtained from aerial photos, the shoreline evolution trend for the monitored period (using LR) were compared to that estimated from beach profile data. Using the two methods, eroding and accreting zones were predicted in the same coastal stretches with similar calculated shoreline rates of change (a linear relationship of 0.98 between calculated rates using both data sources was obtained).

As a final point, the use of aerial photographs to estimate and quantify short-term shoreline changes along the Ebro delta coast has been proven as a good technique given similar results to that obtained from beach profile data.

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