Recent Evolution of Culatra Island (Algarve – Portugal)

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Abstract

The evolution of Culatra Island between *circa* 1940 and 2001 was determined by analysis of vertical aerial photographs. The results obtained for shoreline variations, washovers evolution and island growth evidenced two different evolutionary periods. Before 1985, the shoreline was experiencing strong erosion in the west and the washovers were reduced by shoreline retreat. In the east the dominant process was island growth. After 1985, shoreline stabilisation was achieved both by natural and anthropic processes. Presently the vulnerability of the frontal dune is generally low, however, there are some places that demand recovery interventions.

1. INTRODUCTION

Culatra Island is a part of the Ria Formosa barrier island system located in the Algarve, southern Portugal (Figure 1). The system presently includes two peninsulas and five islands that vary significantly in their morphology and also in their exposure to incident waves. Culatra Island is exposed to a semi-diurnal mesotidal regime, with a maximum tidal range of about 3.9 m (Pilkey *et al.*,1989), and a low to moderate wave energy regime. Several authors have studied the longshore drift of the system agreeing that it is eastward directed, however, no consensus has been reached on the volume of sediment involved. The purposed range varies between $90 \times 10^3 m^3$/year (Andrade, 1990) and $250 \times 10^3 m^3$/year (Granja, 1984).

Two tidal inlets limit the island: the Faro/Olhão Inlet, at the western end and, on the opposite side, the Armona Inlet. The updrift Faro/Olhão Inlet is artificial, having been stabilised by jetties, and its permeability to longshore sediment transport is not clear. Andrade (1990) does not discount the possibility of a sediment transference process occurring, however, if there is transfer of sediment it would not involve the entire longshore drift volume.

Culatra Island is approximately 7 km long and can be divided in three different sectors according to morphodynamic characteristics. The west end of the island is partially artificial due to the presence of the Faro-Olhão Inlet jetties (built

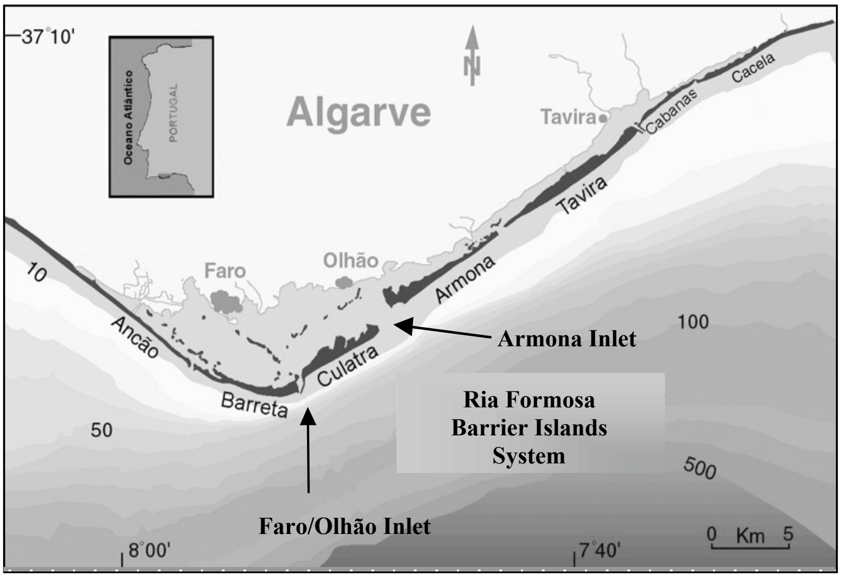

Figure 1: Ria Formosa Barrier Islands System

between 1927 and 1955) and a seawall/groyne system (built in the early 1980's) that was constructed to protect the human occupation. In this area the beach is relatively narrow and a dune bluff makes the transition to the dune system in the majority of the sector evidencing the lack of sediment supply. During the 1980's, occupation eastward of the seawall/groyne system increased rapidly over an ancient washover breach.

The central sector was the historical location of an ancient inlet that, like other natural inlets of the system, used to migrate eastward. The inherited morphology in this sector reflects the diverse ages of the sand bodies alternating dune ridges with ancient tidal channels and washover breaches. In 1987, the Ria Formosa Natural Park installed sand fences on these breaches and a few years later the structures were infilled encouraging the installation of another set on top of the sediment trapped by the first. At present this last set is also infilled and *Elymus factus* and *Eryngimn martimum* are spreading along the surface. Permanent human occupation in this sector occurs exclusively on the inner margin of the island.

In the unoccupied eastern sector, an inlet dominated evolution occurs, with the development of curved sandy spits. The morphology is constituted by sand ridges separated by active tidal channels on the inner part, and by washover on the ocean side . In this sector, extensive overwash can occur under combined storm surge, spring tides and storm conditions.

The present study aims to quantify the recent evolution of Culatra Island with particular emphasis on shoreline changes and washover evolution.

2. METHODS

The evolution of Culatra Island was determined by analysis and comparison of vertical aerial photos taken between *circa* 1940 and 2001. Although it is not possible to specify the year in which the *circa* 1940 set was photographed it is presumed that it was after the first years of this decade. It is known that a major storm occurred in the region in 1940 or 1941. The 1940's photographs show large washover fans and evidences of strong erosion. Thus it is probable that the photo was taken after that event and so the year considered for calculations was 1945. The time periods considered for analysis were thus 1945 to 1958, 1958 to 1976, 1976 to 1985, 1985 to 1996 and 1996 to 2001.

Features such as vegetated areas, washover fans, human occupation and the shoreline were mapped and used to determine three parameters: shoreline changes, frontal dune ridge washover percentage and island growth.

Shoreline evolution was determined using 10 profiles by measuring the distance between the profile origin and the dune/beach limit, from aerial photographs from different years. Figure 2 shows the profile locations that are separated by 500m and are numbered eastwards, starting at the Faro-Olhão Inlet eastern jetty. The profiles used were located in three sectors; the Western Sector (P1 to P4), Central Sector (P5 to P7) and Eastern Sector (P8 to P10).

Due to the growth of the island the number of analysed profiles varies from 6 in *circa* 1940 to 10 after 1976. In the easternmost area further profiles were not considered since their analysis and comparison would only be possible after the 1970's due to the island growth. However, the location of the eastern tip of the island was included in the analysis of aerial photographs and considered for the measurement of the island growth.

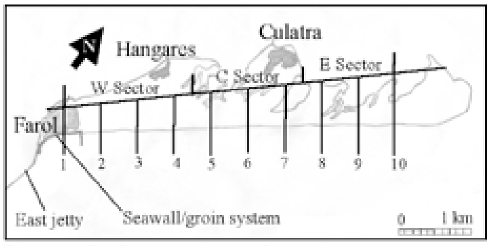

Figure 2: Profiles location on Culatra Island.

The washover breach percentage, in relation to the longshore extent of each sector dune front, was determined. This allowed the evaluation of the evolution of these vulnerable areas both by natural and artificial processes. It should be noted that the quality of the 1958 photograph did not allow its use for measuring this parameter.

Island growth due to the eastward progression of the eastern tip was also quantified by measuring the total length from the Faro-Olhão inlet eastern jetty attachment to the easternmost curved sandy ridge axis.

The estimated accuracy of the results presented varies from 4m to 13m, depending on the photograph scale. The resulting accuracy of the shoreline change rates has a minimum of 1.4m/year, between 1976-1985, and a maximum of 0.8m/year between 1996 and 2001. Values below these rates are under the estimated analysis accuracy.

3. RESULTS AND DISCUSSION

3.1 Island growth

The eastward expansion of Culatra Island has been outlined as the principal process responsible for the narrowing of the Armona Inlet. This highly dynamic processhas been studied by several authors (Esaguy, 1984, Dias 1988, Pilkey *et al.* 1989, Andrade 1990, Vila-Concejo *et al.* 2002) and benefited from the extension of the Faro/Olhão Inlet jetties (concluded in 1955). Indeed, the island growth was higher, with an average rate of 62 m/year, between 1958 and 1976 (Figure 5) than in the rest of the time period considered for the present study. Before that, between 1945 and 1958, the eastern tip of Culatra was growing 32 meters each year on average.

After 1976 a reduction in the average rates of the island growth was observed, from 44m/year (1976-1985) to 13 m/year (1985-1996). In the last period (1996-2001) a reduction in the area occupied by the sandy spits responsible for the island growth was observed. During this same period the process accelerated to 43 m/year. This however may not represent an intensification of the island growth, in terms of volume, considering that the sediment was being deposited over a narrower area. These results are generally consistent with others previously published and small differences might be related with differing methods.

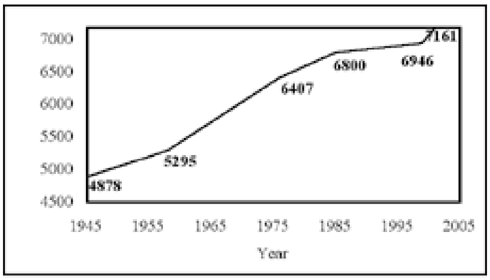

Figure 3: Island length evolution.

3.2 Shoreline evolution

The analysis allowed the quantification of the shoreline changes that occurred over the past five decades (Figure 4). Erosion rates in the Western Sector during the first period considered (1945-1958) were lower at the first two profiles and significantly higher at P3 and P4. This was possibly a consequence of the presence of the jetties, which constitute an obstacle to littoral drift and also created a shadow zone on the downdrift beach. Further east, on P5 (Central Sector), accretion took place with small embrionary dune vegetation being developed on the washover throat. Simultaneously, in some places (*e.g.*, P6) the shoreline retreated where overwash processes occurred.

Between 1958 and 1976 the island experienced major erosion and consequently the former frontal dune ridge was lost in some areas, especially in the west. Erosion was expanded eastwards, reaching P6.

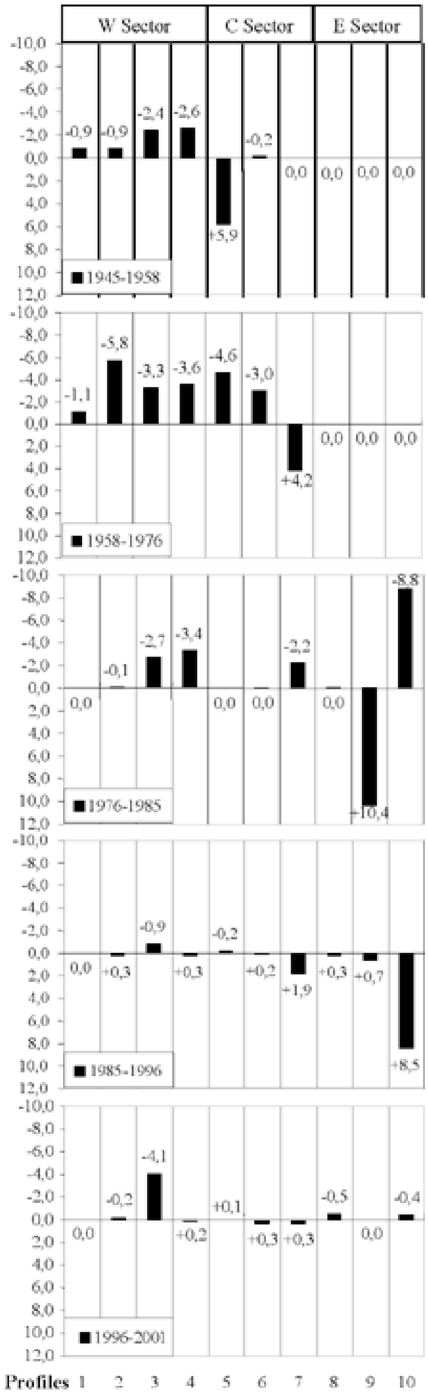

Figure 4: Shoreline variations rates.

Recalling that the Faro/Olhão Inlet jetties were completed in 1955 it is presumed that the increase in the shoreline retreat was a response of the beach to this human intervention. Accretion was restricted to the eastern tip (P7), associated with island growth.

The construction of the groyne at Farol beach (Western Sector) and the extension of the seawall occurred during the period 1976-1985, stabilising the shoreline on P1. The Western and Central sectors showed smaller retreat rates. However erosion was extended once again further to the east, reaching P8. The effect of the groyne construction on the shoreline evolution is not obvious, since there was no major beach accretion updrift, nor shoreline retreat increase downdrift. This could be due to its placement within the "shadow area" of the east jetty of the Faro/Olhão Inlet.

The significant erosion that occurred on P7 (Central Sector) was associated with overwash processes. The behaviour of the younger eastern areas was conditioned by its characteristic curved structures, with dune ridge development and overwashes occurring and inducing extreme shoreline changes at nearby sites.

Between 1985 and 1996, the shoreline changes on the entire island were small. In some parts, a wide berm was colonised by pioneer vegetation. On the large washovers in the Eastern Sector this colonisation helped dune formation, diminishing the possibility of further overwashes.

During this period there were few areas undergoing erosion and these were usually associated with small overwashes (*e.g.*, P3). At P5 (Central Sector) a bluff was cut in the high dunes, thus undergoing an erosive process. P10 showed strong accretion induced by dune ridge development associated with island growth.

During the last period analysed (1996-2001), the Western Sector underwent a small shoreline retreat, except at P3 where overwash processes were once again responsible for strong retreat. However the dune field was strongly degraded by trampling and aeolian deflation. The seawall/groyne system was also severe damaged during storms. In the Central and Eastern Sectors small shoreline changes were dominant, while the island was continuously growing through sandy spits. However this growth is not expressed in the profiles since it mainly occurred eastwards of P10.

3.3 Washovers evolution

In the study area it is possible to distinguish two types of washover structures. The first type occurs predominantly in the eastern half of the island and is characterised by large breaches separated by small dune ridges. Coalescence of adjacent washover fans is frequent and usually it is associated with the attachment to tidal channels. The second type consists of small intrusion washover fans usually individualised, that are common in the Western Sector.

Figure 5 presents the results obtained for the evolution of the washover percentage of the frontal dune. Previous to 1985 overwashed areas diminished continuously on the entire shoreline, with similar rates but due to different processes. Since the Western Sector was experiencing strong erosion the shoreline retreated to the back of the existing breaches. As a consequence, the washover percentage of the frontal ridge reduced from 39 % to 15% from 1945 to 1985. On the rest of the island, especially in the Eastern Sector, the natural recovery of the breaches produced a similar result. Between 1976 and 1985 the washover percentage was reduced from 55% to 41% in the Central Sector and from 71% to 58% in the Eastern Sector.

The sand fences placed in 1987 were effective in washovers reduction (in the Central Sector they diminished from 41% to 17% from 1985 to 1996), through strong sand accumulation at these structures. The efficient sediment trap was probably due to the combined effect of berm development (dry sand fetch increase) and well-designed fences. In the Eastern Sector a similar process was occurring but without anthropic influence. The berm was being colonised by pioneer vegetation and, in 1996, the washover portion of the frontal dune was less than 4%.

In 2001, there were few active washover breaches in the analysed area. In fact, between 1996 and 2001, the dune percentage affected by overwash processes decreased to 5% in the Western Sector, 1% in the Central Sector and 3% in the Eastern Sector. These results are clear evidence of the ongoing dune recovery process along the shoreline.

During the entire analysed period the area where overwashes created large washover structures migrated to the east in association with the island growth.

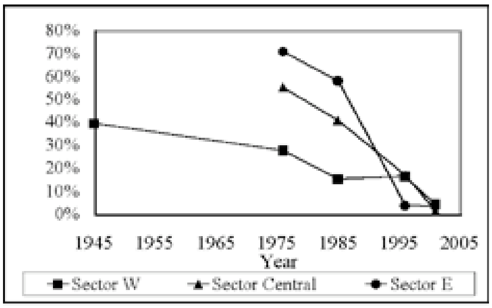

Figure 5: Washover percentage of the dune frontal ridge evolution.

3.4 Integrated analysis

By comparing island growth (Figure 3) and shoreline evolution (Figure 4) it can be noted that the erosion area and an accretion peak migrated to the east as the island expanded. The profile that separated the erosion and accretion areas migrated from P5 between 1945-1958 to P10 between 1985-1996. This gives an eastward displacement of about 62.5m/year during these periods, which is similar to the observed island growth rates.

Erosion dominated the west of Culatra as the accretion area moved to the east associated with the island elongation. Whenever a new spit was projected into the mouth of the Armona Inlet it was immediately incorporated into the island main body by formation of vegetated dune ridges. However, these new structures were almost perpendicular to the shoreline allowing overwashes to occur in the low areas between ridges. Although there are no results for the evolution that occurred further east than P10, this overwash process is now occurring in the youngest areas of the island, near the present location of the Armona Inlet, as shown in the latest aerial photographs. The large majority of current washover areas is therefore located to the east of P10.

During the period analysed, the occurrence of washovers tended to reduce over time in all analysed sectors. In the Western Sector this was due to the strong shoreline retreat experienced by this part of the island up until 1985. In the Central Sector the preservation of the dunes was ensured by human intervention.

At present the evolution rates of the shoreline position of Culatra, except at its eastern tip, are relatively small. There are however some isolated instances of shoreline change, especially in the Western Sector. During the entire analysed period the island growth rates varied in the same way as the shoreline change rates, including erosion rates in the Western Sector.

4. CONCLUSIONS

The results presented in this study reveal the importance of island growth as an indicator of the variations noticed on Culatra Island during the last five decades. Between 1945 and 1985 the island had two distinct behaviour areas: one in erosion, the west; and the other in accretion, the east. The boundary between these areas followed the eastward development of the island and migrated along the shoreline to the east during this period. Also during this period shoreline retreat was important for the reduction of washovers in the Western and Central Sectors. This indicates the dominance of the shoreline retreat over overwash processes.

The washovers of the Central Sector and part of the Eastern Sector were recovered by the Ria Formosa Natural Park with the installation of sand fences. The positive results obtained were a consequence of the presence of a wide berm that supplied the necessary dry sand aeolian fetch. The area of non-intervention (the Eastern Sector) also reduced its washovers but, in this case, naturally. Indeed, the accretion conditions that dominate the eastern tip of Culatra after 1985 were decisive for the recovery of the areas previously overwashed.

During the 1990's there were no significant changes in the island. The low evolution rates were maintained generally over all the shoreline and the island's eastward growth also continued with moderate annual rates. During this decade the correspondence between island growth and island changes was once again evident. As the elongation of the island decreased its shoreline changes tended to also decrease.

Although the results do not in general demand any recovery interventions there are some places where the dunes have a high vulnerability to overwashes. The area downdrift of the Farol beach groyne (Western Sector) reflects the combined action of lack of sediment, trampling and aeolian depletion. Considering the results obtained for the fence placement in other parts of the island, it is recommendable to apply similar recovery efforts in this area. However, the dry beach width is not enough to provide sufficient aeolian fetch. Therefore, any recovery program aiming at effective and environmentally acceptable results should consider artificial nourishment as a means to supply the lack of sediment induced by the engineering structures located on the western end of Culatra Island.

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