Management measures for ancient settlements threatened by coastal hazards at Boca do Rio, Algarve, Portugal

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Introduction and background

Coastal areas are dynamic by nature, with physical changes occurring over various time scales. When these changes manifest themselves as a landward movement of the shoreline occurring on human time scales, the quantification of erosion rates becomes important (Moore and Griggs, 2002). The evolution of coastal retreat results from several relationships between external and local processes, with many variables potentially affecting the rate and manner of retreat. Currently, the Portuguese coastal zone is strongly affected by coastal erosion in association with an important sedimentary deficiency, which was initiated around the beginning of the 20th century, and became strongly enhanced after the 1930s-1940s (Dias and Neal, 1992). At present, shoreline retreat rates reach the order of a few meters per year in some parts of the Portuguese coastline (Dias and Neal, 1992). A decrease in fluvial sediment transport and a continuing rise in sea level are two of the main causes of coastal erosion not only in Portugal, but also in other parts of the world. Over shorter timescales, storms are also able to cause coastal retreat. Such retreat is only reversible on a human scale (years to decades) if sediment starvation is naturally or artificially stopped (*e.g.,* by beach nourishment or dune building) (Carter, 1988). Changes in storm patterns and incident wave climates may result in beach realignments and higher rates of foreshore change.

The style of coastal erosion (retreat) differs according to whether the shore is characterized by beaches or by cliffs. Beaches and their adjacent zones act as buffers to wave energy, and consequently they are sensitive to changes over timescales ranging from a few seconds to several years (Dias and Neal, 1992). Beach erosion takes place when sediment is removed from beaches at a rate that exceeds its replacement. Erosion is indicated by the removal (by waves) of sediment from an erosional bluff generally located near the back of the beach. Knowledge about forcing mechanisms and the related processes affecting shoreline displacement is essential to make decisions about effective coastal zone management.

In heavily developed coastal areas, such as the Portuguese coast, erosion threatens urbanization, tourism, and natural systems. Coastal engineering structures have historically been the most common response to shoreline erosion hazards both in Portugal and in many other parts of the world, but other choices include nourishment and retreat or abandonment. Most situations of coastal erosion hazard are concerned with developed, inhabited areas characterized by the presence of buildings, transport routes, infrastructural features, and residential dwellings in close proximity to the shoreline. However, coastal erosion can be also critically important when cultural and archaeological sites are located near the shoreline. The coastal stretch of Boca do Rio, western Algarve, Portugal, is an example of such a coast facing erosion (Figure 1). Settlements from ancient human occupation are located near this coastline, and the area has been designated a special protection zone (archaeological station).

Currently, however, only a very limited number of studies worldwide have been related to the management of coastal zones containing structures from ancient occupation. The objectives of this work are to quantify the shoreline evolution of the coastal stretch at Boca do Rio, and to evaluate preservation/conservation options for the ancient settlements.

Study area

The study area is located in the western Algarve, Portugal (Figure 1). Tides in the area are semi-diurnal, with average ranges of 2.8 m for spring tides and 1.3 m during neap tides, although ranges of 3.5 m can be attained. The regional littoral longshore drift is from W to E. The predominant wave direction in the region is from the W-SW, occurring 71% of the time, whilst waves come from the SE 23% of the time (Costa, 2001). Due to the particular coastal configuration, the study area is particularly exposed to the SE wave direction, which is responsible for inducing the major morphodynamic changes.

The Boca do Rio beach is the terminal part of a small infilled estuary located at the west of the Almádena cliff (Hindson and Andrade, 1999). The flat valley extends some 2 km upstream from the coastline and includes a supratidal flood plain (Andrade and Paulino, 1998). The sediment source to the beach is given by Budens Stream, with the mouth of the stream sifting the beach from the cliff stretches (Figure 2A). The stream discharge is very small, and sediments are deposited at the mouth.

The Boca do Rio beach has a collection of Roman ruins (Figure 2B), classified as public heritage within the Municipality Plan of Lagos City Council. According to Estácio da Veiga surveys *in* Santos (1971), the Roman ruins of Boca do Rio belong to a small fishery *villa*, comprising a collection of settlements with mosaics, balnearys, warehouses and a salting factory integrated in a small port (Figure 3). Two large, partially-recovered warehouses from the 18th century are also present at the site. Currently the ruins are directly exposed to wave action, with sea intrusion occurring each winter (Figure 2B). Blocs of limestone exist at the shoreface, which reduce the wave energy and limits the swash. The visible part of the ruins is exposed at the edge of an erosional bluff and extends about 25-30 meters along the shore.

Methods

In order to quantify coastal retreat in the area during the last 50 years, vertical aerial photographs from 1945, 1976, 1988, and 2001 were analyzed. Coastal retreat at Boca do Rio beach was quantified by measuring the distance between the shoreline and an imaginary line parallel to it (Figure 4). Seven transects (T1 to T7) normal to the shoreline were defined to constrain longshore variability. The area of the Roman ruins extends between T4 and T6. For the purposes of this study, the shoreline along the beach section was defined as the contact between the toe of the bluff and the beach. Taking into account the scales of the aerial photographs, spatial measurement accuracies of between 4.2 and 13.9 m were determined.

Several intervention scenarios were defined in order to improve methods of preservation/conservation of ruined settlements in the beach and cliff areas respectively. These scenarios fall into three general strategies: no intervention (type 1); execution of coastal protection works (type 2); and removal or relocation of the settlements (type 3). Each approach has its costs and benefits. For each possible scenario, a relative, semi-quantitative evaluation was made of five factors: costs; efficiency of preservation; difficulty of execution; environmental impacts; and patrimonial degradation (damage to or destruction of settlements). The aim of the analysis was to identify the most equilibrate and balanced intervention.

Results and discussion

Recent coastline evolution

Aerial photo analysis shows a general tendency of coastal retreat at Boca do Rio beach (Figure 5). Shoreline retreat clearly dominates at all observed periods and for all considered transepts (with exception to T1). Seaward shoreline displacement was observed only at T1 and only for the period 1976-2001. This was due to dune recovery next to the river mouth. Maximum shoreline retreats were observed during the 1976-1988 period. The coastline in front of the Roman ruins, which are located between T4 and T6, faced an average shoreline retreat between 0.15 and 0.33 m / year, between 1945 and 2001, and a maximum retreat of 0.8 m / year between 1976 and 1988.

In general, shoreline retreat was more pronounced in the central and western parts of the beach area (T3 to T7), probably due to spatial variation in exposure to waves. The eastern part is relatively re-entrant, while the western limit is more prominent (Figure 4). As a consequence, differences in the incident wave have led to different shoreline evolutions. In addition, the eastern area is under the direct influence of the stream mouth, being nourished by the discharged sediment. If coastal dynamic forcing mechanisms continue unaltered, and protective measurements are not implemented, this trend is expected to continue into the future. At medium to long-term it is expected to the Roman ruins sector a general shoreline retreat of about 0.25 m / year, and in special periods, a shoreline retreat up to 1 m / year.

The expressed rates of change can be amplified by human interventions at the Budens Stream drainage basin and by the anticipated acceleration of sea level rise. Also of importance is the possibility of extreme storm occurrences, which may provide punctuated accelerations in shoreline retreat. Although the sandy coast would in time recover from such storm events, the ancient ruins once destroyed by such storms will not be re--established. The higher magnitude and intensity of shoreline changes observed between 1976 and 1988 in the Boca do Rio beach can be explained by the relatively higher frequency of storm events during this period. Short-term storm events that last a few days and that have a recurrence of several years could Id represent a significant hazard additional to long-term shoreline trends (Esteves *et al*., 2002; Ferreira, 2005). Therefore, knowledge of long-term trends is only adequate to inform coastal management plans when maximum variations of short-term changes are properly incorporated (Esteves *et al*., 2002). This means that periods of higher retreat rates, as the case of the 1976-1988 period, should always be considered for management purposes, in addition to average conditions. Other factors with potential to vary and therefore affect erosion rates along the coast include a decrease in Budens Stream flow, an increase in exposure to the SE wave direction regime, and an increase in rainfall.

Management scenarios

For the Roman ruins at Boca do Rio beach, five management scenarios were defined (Figure 6) and scores for the factors assigned to each of them. The first scenario is a type 1 strategy, the second and the third scenarios are strategies from type 2, and the fourth and fifth scenarios are a type 3 strategy. No intervention along the beach (first scenario) is characterized as being of low cost (since there is no investment in coastal defences/management) and as allowing the destruction of the ruins in the short or medium term by coastal erosion (patrimonial degradation).

The second scenario considered, beach nourishment, is an environmentally preferred method of shore protection that retains the beach as a very effective wave energy dissipater, but is useful only in the short-term. Beach nourishment can be found on coasts throughout Europe, where it stops or slows the retreat of the coastline (National Institute of Coastal and Marine management of Netherlands, 2004), being expensive to maintain but often justified in many cases where it is preferred to coastal damage or to "hard" defences (Carter, 1988). It is necessary to carefully select sources for nourishment so that the imported material will merge into the indigenous beach material. The introduced material should therefore exhibit the characteristics of the natural beach, while the sediment sources should be sought near to the area that requires nourishment (Carter, 1988). In some cases, the sediment source is the material dredged from a nearby river. For the present case the above is not a solution, since the Budens Stream already offers a small discharge and the sediments at the floodplain are not suitable for beach nourishment. Therefore, the second scenario implies a non-local sediment source and, consequently, increased costs.

The third scenario involves artificial cliff stabilization using a revetment or a seawall to directly protect the ruins. These structures are designed to withstand severe wave attack; nevertheless, the materials used often reveal poor longevities, leading to high maintenance costs (Carter, 1988). In addition, the protection is only local, and it carries high levels of environmental impact including the possibility of increasing the coastal erosion in surrounding areas (Pilkey and Wright, 1988).

The removal of the ruins to a museum, the fourth scenario, allows preservation of the structures of the settlement and a relatively low difficulty of execution. The environmental impacts expected are minimal, although high costs are associated with the removal works. An additional detriment is that once the ruins are removed, archaeological investigations in the original locale will be very limited.

The fifth scenario, beach nourishment and removal of the ruins, gives more time to prepare other studies concerning the preservation of the archaeological settlements, and allows the removal works to be conducted over a longer time frame. This mixed solution congregates all the advantages and disadvantages analyzed in the second and fourth scenarios, and assume a higher cost for the intervention.

According with the performed analysis, the removal of the Roman ruins to a museum seems to be the most profitable and balanced scenario of intervention. Taking into consideration the recent evolution of the beach section, any kind of intervention should be performed as soon as possible, particularly to avoid the impacts of winters during which storms are more frequent.

Summary and conclusion

The present study has examined the threat posed by shoreline erosion to a collection of Roman ruins located along the stretch of coast of Boca do Rio, Algarve, Portugal, considering the possible coastal management intervention options in order to protect or preserve the site.

Shoreline erosion data show that coastal retreat at Boca do Rio beach in the vicinity of the ruins has ranged between 0.15 and 0.33 m / year for the 1945-2001 period. Maximum shoreline erosion was recorded during the 1976-1988 period, probably related with more energetic and/or frequent storm events during that time. The retreat rates appear to be both temporally and spatially variable, suggesting that the processes involved are dependent largely on local shore dynamics. Therefore, the determined average rates should be regarded as a general trend, and subject to oscillations, which will likely continue in the future.

Based on the analysis of possible preservation measures, it is recommended to move the ruins to a museum, as urgent as possible, avoiding further destruction.

Studies focusing on the management of coastal zones that host ancient settlement sites are currently scarce. Considering the increasing rates of shoreline retreat in various parts of the world, there is an increased likelihood that more ancient settlements will be imperiled by coastal erosion. This study has examined possible management scenarios for such settlements by matching principles of coastal protection and conservation with measured shoreline erosion data. In the future, integration of coastal dynamics and historic heritage studies could be the key to provide improved analyses whereby the environmental, economic, and heritage values are considered together and used to inform a more complete management approach.

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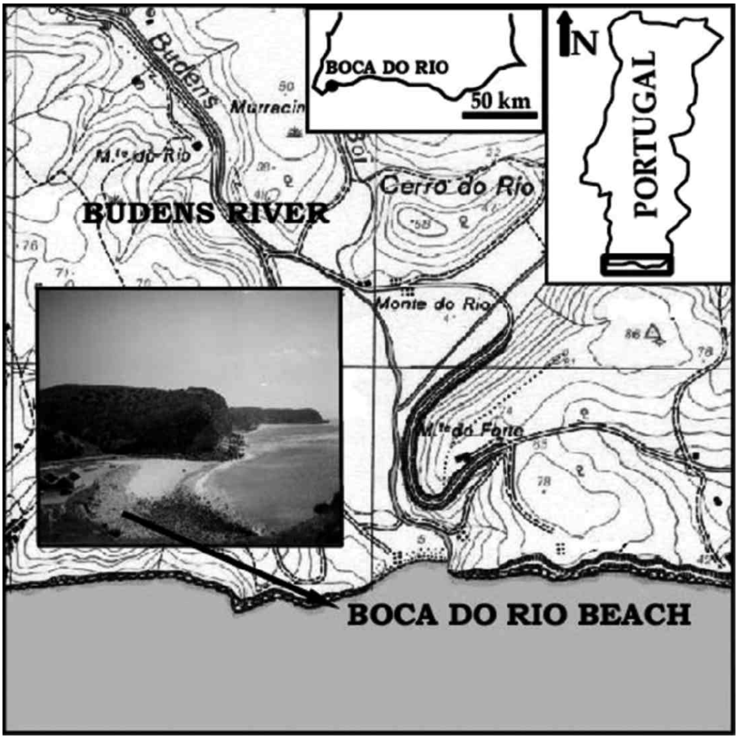

FIGURE 1. Location of the study area Boca do Rio beach, Algarve, Portugal.

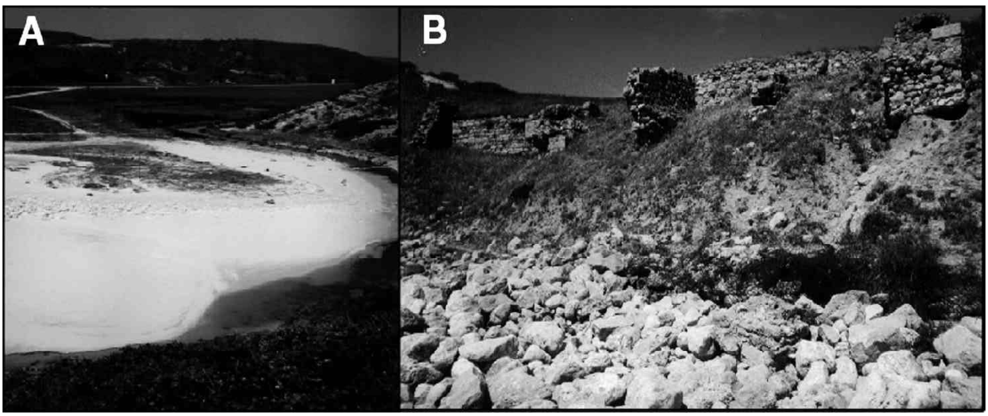

FIGURE 2. View of the Budens Stream, located to the East of the Roman Ruins (A). View of the Roman Ruins of Boca do Rio and their relative position to the cliff edge (B).

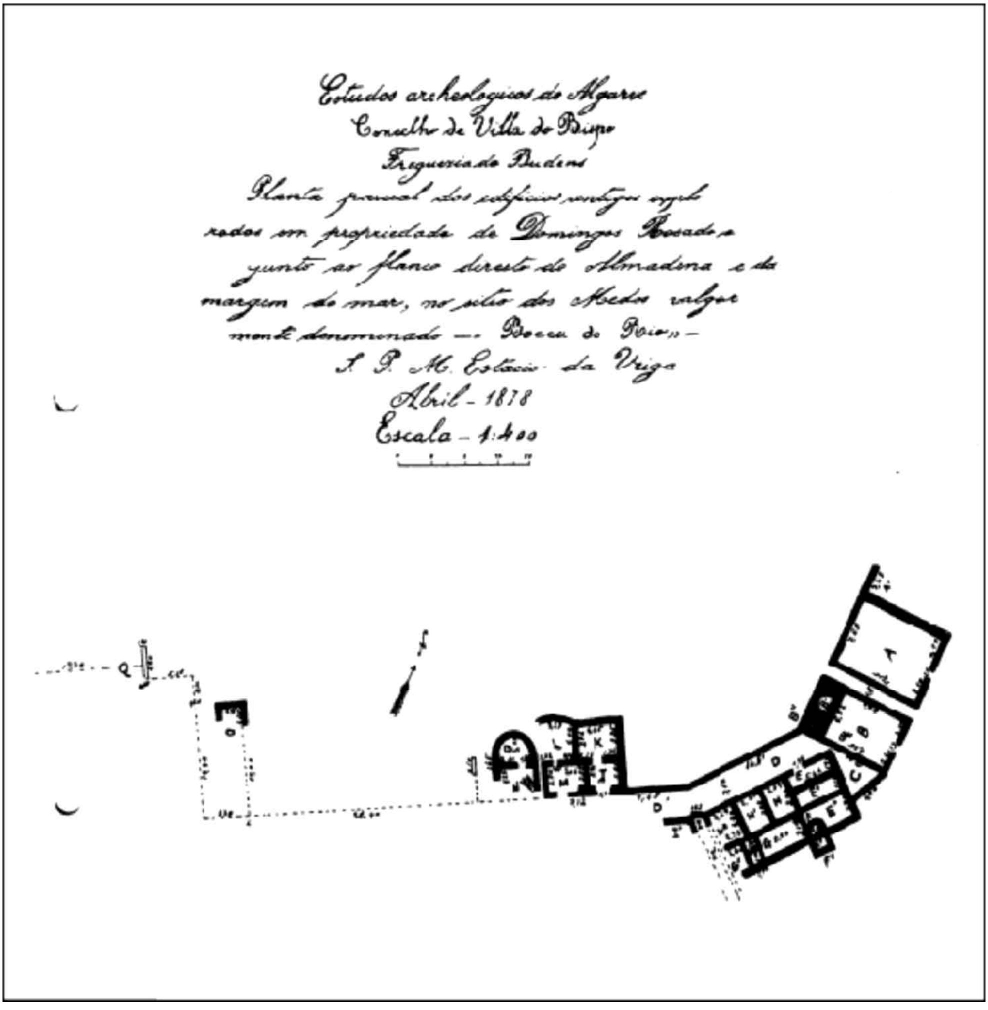

FIGURE 3. Partial plant of the ancient settlements of Boca do Rio, made by Estácio da Veiga (source: Santos, 1971).

FIGURE 4. Aerial photo from 2001 showing the seven control lines normal to the coast and the imaginary shore-parallel line used to measure changes in the bluff position at Boca do Rio beach.

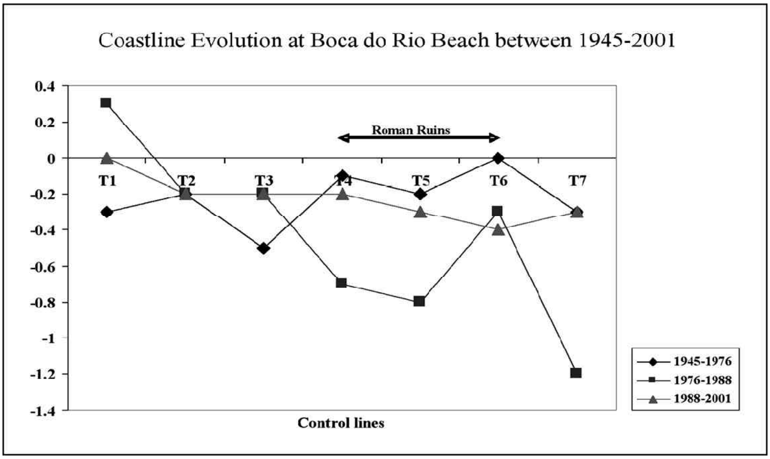

FIGURE 5. Shoreline evolution at Boca do Rio between 1945 and 2001. Negative values represent bluff or dune retreat and positive values dune recovery.

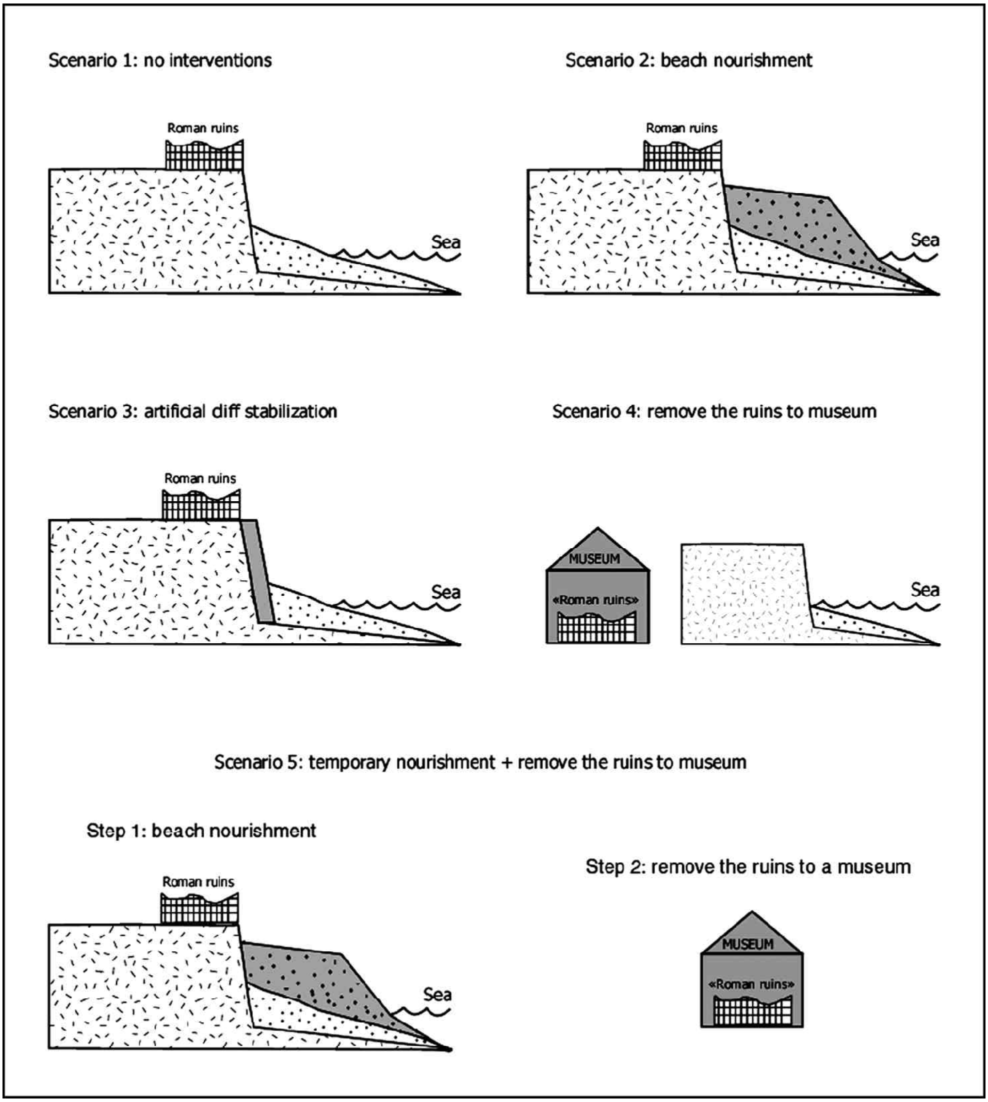

FIGURE 6. Management scenarios proposed to the Roman ruins of Boca do Rio.