EXPERIENCES WITH BEACH NOURISHMENTS ON THE COAST OF ALICANTE, SPAIN

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Abstract – The historical evolution of sandy beaches on the coast of Alicante (Spain) has been analysed from aerial images from 1956 to 2019. The beach nourishments carried out in the 1990s to avoid coastal damages and to improve the touristic offer were studied. Shoreline evolution and beach surface has been obtained using GIS. The change of the sediment composition, from gravel to sand, due to the fills has caused a relevant imbalance. Beach nourishments failed its main aim of avoiding the shoreline erosion, causing environmental damages to the nearby *Posidonia oceanica* meadows.

Introduction

Coastal erosion is a worldwide problem. This issue is the result of multiple factors, such as the lack of sediment supply, climate change or anthropic actions that change the littoral morphodynamic [16]. Over the last few decades, there has been a gradual shift in coastal defence techniques, tending in recent years to soft actions such as the nourishment of sandy beaches as an erosion mitigation mechanism [7]. The placement of sand on the beach is considered the most acceptable form of coastal stabilization [5, 8]. However, it is important to be aware of the effects of the anthropic actions carried out in the past to project future coastal works [1, 2, 4, 17, 22, 23].

The analysis of the historical shoreline evolution has a key role in coastal studies [9]. Historically, the drawing of the coastline has been an arduous task with important methodological and technical limitations, but at present the use of Geographical Information Systems (GIS) has meant a great advance in this field, as it integrates various data sources (cartography, aerial or satellite images) that make it possible to obtain and compare the evolution of the shoreline over time [18, 19].

Another important aspect in the study of the evolution of the shoreline is to know the sediment characteristics. Changes in the typology of the sediment that conforms the beach can led to unsuccessful nourishment projects. Gravel beaches transformed into sandy ones caused permanent instability on the shoreline (originally stable) [4, 17, 23].

In this research, the historical evolution of 3 beaches on the coast of Alicante, (Spain) have been studied. The beaches of Guardamar del Segura, Calpe (Arenal beach) and Dénia (Marineta Cassiana beach) were selected due to its interest. These beaches were nourished in the 1990s, changing in the last two the sediment type from gravel to sand [23]. The aim of this research is to analyse the evolution of the nourishments, studying the shoreline movements and relating it with the sedimentary composition of the beaches.

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Materials and Methods

Our research has studied sandy beaches located on the Spanish Mediterranean coast, in the province of Alicante (Spain), whose main characteristics are described in Table 1. The location of these beaches along the coast is representative of the diverse environments in which they are situated: from long natural beaches with dune ridges to beaches in totally regenerated urban environments. In addition, these beaches have different exposures to incident waves, although most are oriented to the east, as is usual on the eastern Spanish Mediterranean coast. Their location is presented in Figure 1.

Table 1 - Characteristics of the studied beaches.

Beach	Municipality	Length (km)	D50 (mm)	Coast	Promenade
Marineta Cassiana	Dénia	1.20	0.370	Urban	Yes
Arenal	Calpe	1.37	0.260	Urban	Yes
Viveros	Guardamar del Segura	1.40	0.244	Dunes	No

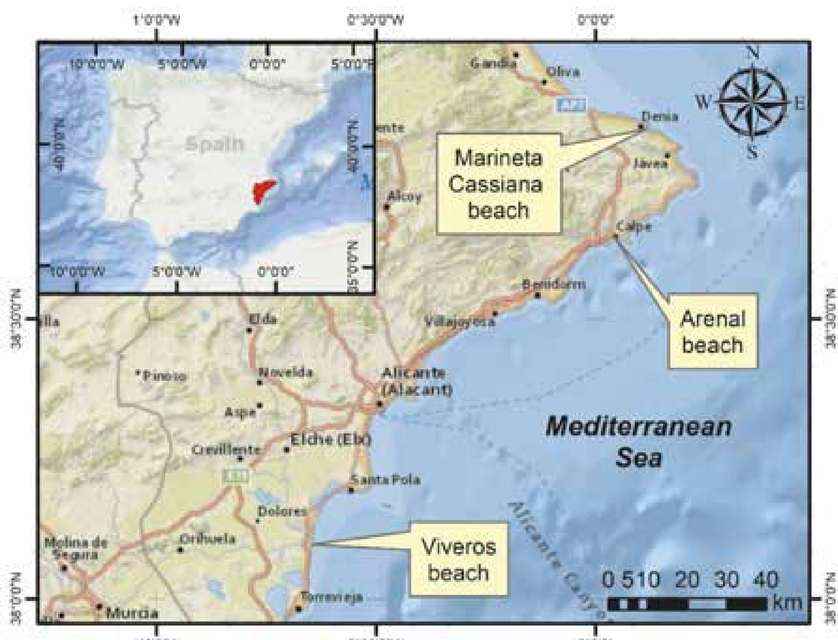

Figure 1 - Location of the beaches in the province of Alicante (Spain).

Aerial imagery covering a period from 1956 to 2019 were used to analyse the beach evolution. Data from 1956 and 2000 to 2019 were available in georeferenced orthomosaics in ECW format, in GCS UTM ETRS89 H30N. However, images from 1977 to 1998 were only in digital format, non-georeferenced. Thus, the first step was to georeference these images and create a GeoTIFF orthomosaic for each period. This task was performed using a Geographic Information System (GIS), in particular ArcGIS 10.5® software. Both non-georeferenced images and orthophotos were obtained from the PNOA website (National Plan for Aerial Orthophotography, https://pnoa.ign.es/). The spatial resolution of the datasets ranges from 1 m/pixel for the mosaics from 1956 to 1998, 50 cm/pixel for 2000 and 2005 images and 0.25 cm/pixel for the rest, from 2007 to 2019. This spatial resolution is high enough in all datasets to identify the shoreline.

The shoreline was vectorized for each period from the orthomosaics available. The vectorization process consists of the visual identification of the last wet mark on the beach, marking this line as the shoreline. All available images were taken in summer and with a relatively calm sea state, so the vectorized line is suitable for comparative study in time. The backshore surface was delimited by the polygon formed by the shoreline and the promenade or dune toe. Overlapping these layers from different periods, erosion or accretion areas were calculated, and thus the sediment budget was inferred. Perpendicular transects spatially separated 100 m were created to measure beach width changes. In addition, the bathymetry, sediment grain size distribution and seabed morphology have been studied by means of spatial analysis techniques in a GIS environment.

Results

Marineta Cassiana beach was nourished with sand in the 90s, reaching an average with of 27 from its initial width of 9 m. Since then, it has suffered erosion at rates of 1 m/year almost disappearing in some points of the beach. The nourishment changed the beach sediment typology, from gravel to sand.

The beach evolved from having an average width of 12 m in 1956 to a minimum of 7 m in 1984 (Figure 2a), with some sections of the beach with less than 2 m width. The contribution of material nourished the beach widths of the 1950s, and was especially important in the eastern part of the beach, where under the shelter of the new jetty the width of the beach increased from 6 m in 1986 to 52 m in 1992. However, in this area the beach suffers a relevant erosion losing practically all the surface gained, becoming its width non-existent since 2014.

This continuous erosion in time, with a negative trend of its surface (a loss of 60 %) is only reverted by the anthropic actions of beach nourishments (Figure 2b). Noteworthy were the fills with 67 000 and 25 500 m^3, which, when transformed into beach area, represents 25 830 and 12 750 m^2 respectively. However, from then until now the erosive trend of the beach has been maintained, having in 2018 a surface area of 11 500 m^2, similar to the minimum of 9 400 m^2 obtained in 1984, prior to the two consecutive nourishments. Moreover, *P. oceanica* meadow located close to the beach was flooded during the fills.

The beach of Arenal (Calpe) has suffered a series of anthropic actions that have modified its morphology, from being historically a gravel beach to become a beach of medium sands today. In 1993, it was nourished with 228 400 m^3 of sand. In addition, to support and guarantee the beach stability, two breakwaters were built. Both breakwaters point slightly into the interior of the beach, and they are semi-submerged in their outermost half to cause less visual impact and to facilitate the renewal of water. In 2007, the beach was nourished with 31 500 m^3 of sand of the same median size as the existing one.

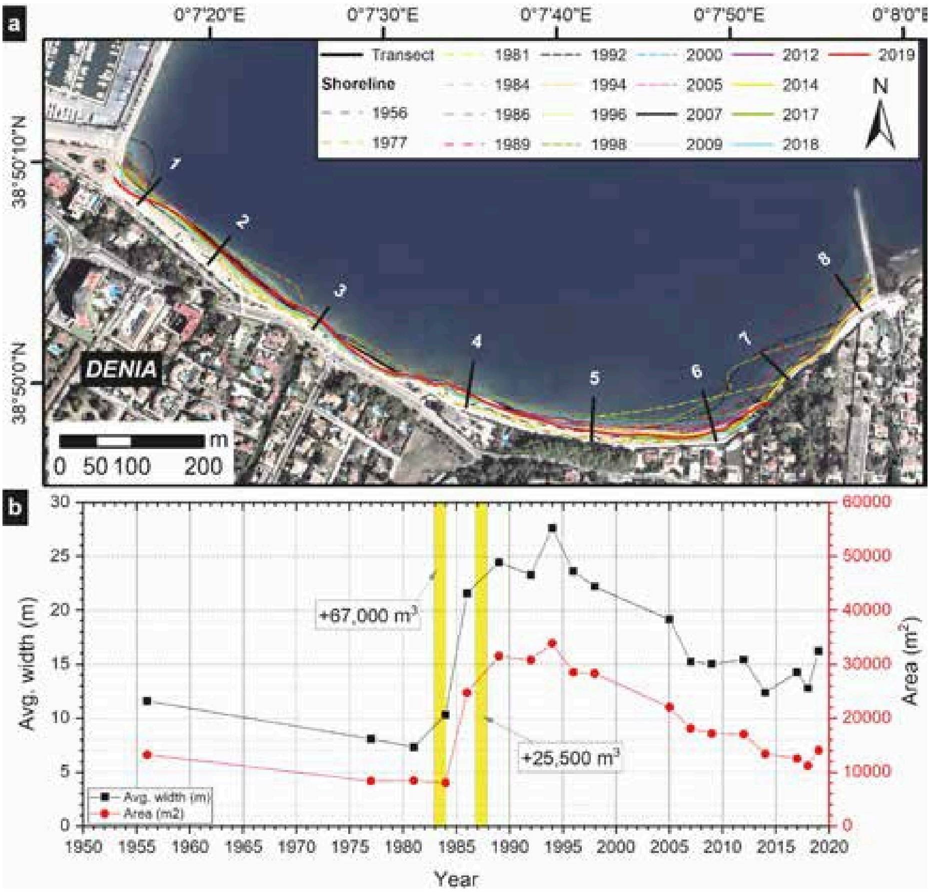

Figure 2 - (a) Shoreline evolution from 1956 to 2019 for Marineta Cassiana beach (Dénia), with location of transects. (b) Beach area and average width, with nourishments noted.

A surface increase immediately after the nourishments is detected, but the erosion trend continues afterwards. In 1992 the width of the beach was zero in a stretch of 500 meters long, in its central position. The 1993 nourishment meant an increase in the average width of 50 m. However, from that moment until 2005 the erosion rates of -1.3 m/year make the beach continue in regression. Since the second contribution in 2007, the beach has shown a stable trend, except in its western part where erosion is detected next to the breakwater. The beach area passed from a minimum of 20 000 m^2 to its maximum after the nourishment of 1993, when it reached 70 000 m^2. Since 2007 the beach surface is stabilized in 53 000 m^2.

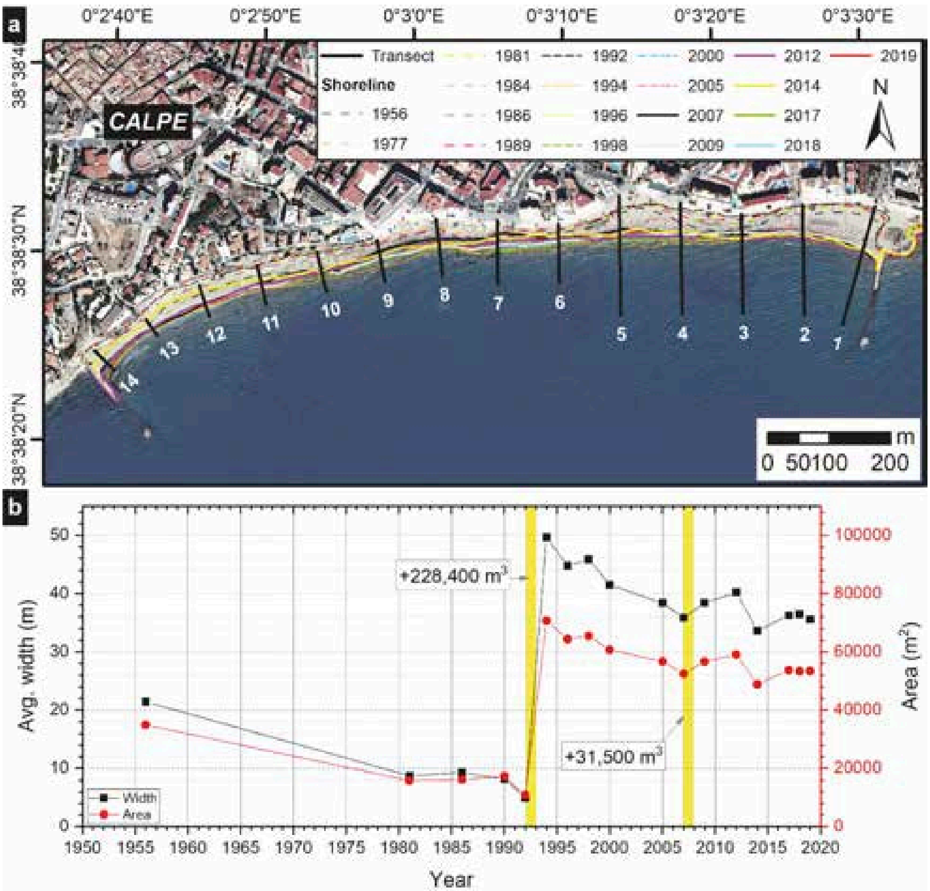

Figure 3 - (a) Shoreline evolution from 1956 to 2019 for Arenal beach (Calpe), with location of transects. (b) Beach area and average width, with nourishments noted.

Arenal beach maintains its profile once the equilibrium beach profile was reached after the nourishment of 1993. The depth of closure is located at 330 m from the coast and 7.75 m depth. The *P. oceanica* meadow was located at 6 meters depth, so is in the active onshore zone. This caused that the sediment filled the *P. oceanica.* The disappearance of this high-environmental asset and natural reef is an undesired effect of the nourishment.

Viveros beach (Guardamar del Segura) was historically stable due to longitudinal north-south transport, with a surface of ~240 000 m^2 and average width of 65 m. This trend continued until 1986, when groynes were built to prevent the river mouth from silting. In 1990 the shoreline retreated 20 m, recovering 50 m (+14 000 m^2) in the following period (1990-1992) due to the fill using the sediment dredged from the river channel. The sand dumped at this point was a silty/clayey sand, so it was quickly displaced by the waves, losing in the period 1992-1994 about 30 m of beach width. In 1998 a marina was also built and the dredge material was verted to form an artificial dune. From that moment, erosion has been increased, reaching values of 3 m/year and thus causing that during the storms the waves reach the dune ridge, eroding it. The relation between dune and beach erosion rates was 2.3. The slight increase in surface detected in 2017 is at the expense of the erosion of the artificial dune ridge, which has lost 20 m width since it was created in 1998. At present (2019) beach width is at minimum values in almost all transects.

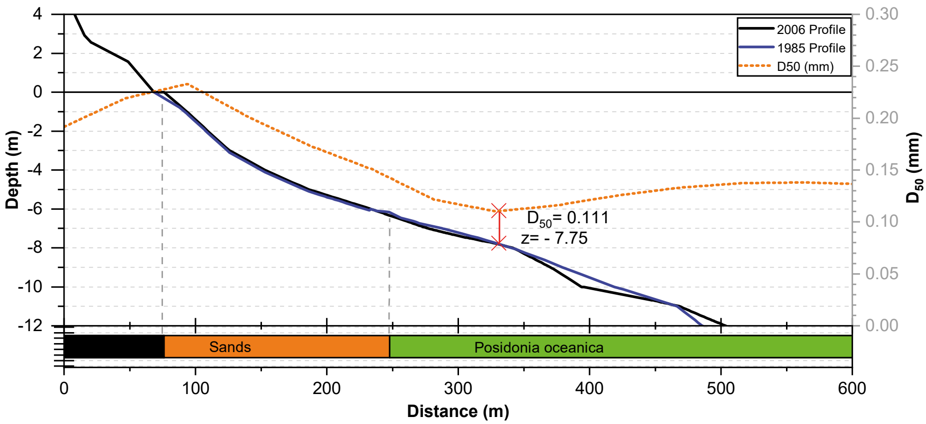

Figure 4 - Beach profile prior and after nourishment of Arenal beach (Calpe) and median sediment size distribution, with depth of closure marked.

Discussion

The urban growth due to the mass tourism [21], the continuous construction of marinas and commercial ports, promenades and groynes had an extraordinary impact on the Mediterranean coasts [2, 11, 20]. Therefore, governments should provide solutions, such as beach nourishment for protection against erosion [13].

This research has studied three nourished beaches in the south east of Spain in the 1990s. Its interest relies on the time passed since the fills were carried out (30 years) and the fact that two beaches (Marineta Cassiana and Arenal beaches) changed its natural sediment type from gravel to sands with the aim of increase its tourist attraction [17].

Establishing the sedimentary budget of a beach is fundamental. The availability of photogrammetric surveys allows the analysis of the shoreline evolution using GIS techniques [1]. For this research, aerial images from the last 63 years were used to monitor the shoreline evolution of the selected beaches, successfully obtaining the shoreline evolution (Figure 2, 3 and 5) and enabling the measurement of the evolution of the anthropic actions carried out.

The results have shown that: i) There is a continuous loss of sand on the beaches analysed, with erosion rates after anthropic actions even worse than previous ones. (ii) The coastal defence system based on fills do not contain the projected beach width in the long term, and (iii) The nourishment design must be improved to avoid affecting the nearby marine flora and fauna.

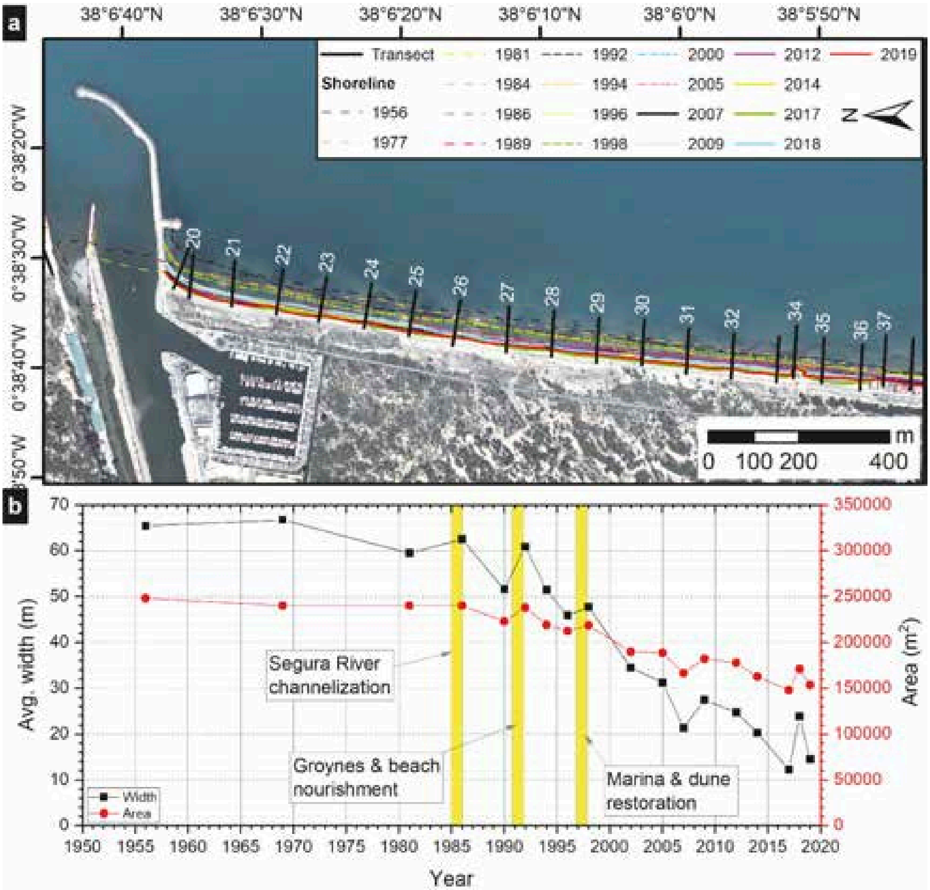

Figure 5 - (a) Shoreline evolution from 1956 to 2019 for Viveros beach (Guardamar del Segura), with location of transects. (b) Beach area and average width, with anthropic actions noted.

A nourishment might cause alarm on public opinion, among other things, because of the initial width in the first years, or the possible environmental damage that the turbidity of the water might cause due to the new material used for the beach nourishment [4]. In Marineta Cassiana beach, *P. oceanica* meadow located close to the beach was flooded during the fills, causing its loss and probably incrementing the erosion rates detected.

Many works can be found where the essential aspects for the design of beach nourishment are described [3, 6, 10, 12]. However, a very important factor, such as the used sediment to feed the beach has been less studied, although there are studies on nourishments that indicate that for example the density of sediment influences much more than size in the longevity of a beach nourishment [24]. The use of inappropriate sediment to execute the nourishments may be the reason of its poor results. It is essential for a coastal engineer to have mineralogical and morphologic studies before taking any decision before any beach nourishment, since any change in its typology or its characteristics may produce an unsuccessful nourishment, such as the examples shown in this research. The study of the mechanisms of weathering by accelerated laboratory tests [14, 15] could be the solution to stablish the relationship between sediment wear and erosion of the shoreline in future beach nourishments designs.

Conclusion

The change of the sediment composition, from gravel to sand, due to the nourishments has caused a relevant imbalance in two of the studied beaches. The fills implemented have not contained the projected beach width. The nourished area has almost disappeared, increasing the previous erosion rates. Thus, nourishment design must be improved to avoid affecting the marine flora and fauna. The cut-off of the longshore transport due to the construction of groynes for the channelization of Segura river has also caused that the erosion increases in Guardamar del Segura.

In order to make the appropriate decisions for the conservation and/or actuation within the coastal system, it is necessary a complete an historical knowledge of all those factors. This knowledge, as well as an adequate communication between the decision-makers and the coastal engineers, are key elements to achieve positive results in the medium and long term.

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