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COASTAL EROSION AND ENVIRONMENTAL CHANGE IN THE CABANES-TORREBLANCA WETLAND (CASTELLÓ). DATA FOR SUSTAINABLE MANAGEMENT

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I. INTRODUCTION

The low-lying coastal geomorphology of Castelló is characterised by a succession of wetlands alternating with alluvial fans. The wetlands are separated from the sea by coastal barriers formed by wave action and N-S longshore drift. They are hydrated with water of continental or marine origin and thus present varied and valuable ecosystems with specific vegetal and fauna associations. Coastal barriers and lagoons in the Mediterranean low gradient microtidal coast were formed during maximum Holocene marine transgression, around 6000 years BP. When sea level stabilised, the lagoons were infilled with fluvial and lacustrine sediments. The *Cabanes-Torreblanca* lagoon is in an advanced stage of siltation and its coastal gravel barrier consists of different types of beach ridges, primary dunes, fossil dunes, washover fans and splays. On the other hand, it is an important lacustrine environment for migratory birds that shelter various ecosystems, being one of the less anthropised of the Spanish Mediterranean coast. In recent decades, rapid urbanisation of surrounding areas has contributed to its degradation and environmental improvement projects and dune regeneration are currently being carried out. In this context, the aim of this work is, first, to characterise the processes and recent and historical changes of this barrier-lagoon system and, second, to analyse the environmental improvement interventions in order to provide useful data for sustainable management of coastal environment.

II. GEOGRAPHICAL FEATURES

The study area is located in a coastal depression on the eastern branch of the Iberian Range between the Serra d'Irta in the North and the Desert de les Palmes-Serra d'Orpesa to the South. From the structural point of view, the coast is placed on a Maestrat sector tectonic depression, bounded by NE or ENE faults and staggered to the East. During the Pliocuaternary faulting episode, faults were reactivated that form the step from Torreblanca and the coastal plain. At the foot of these fault systems spread the Pleistocene and Holocene alluvial fans of the *Riu de les Coves* and *Riu Xinxilla*. The *Cabanes-Torreblanca* lagoon lies in the depression between both rivers.

III. METHODOLOGY

The methodology was based on GIS integration of geomorphological, geoarchaeological, biogeographical and LIDAR data. The geomorphological study was based on identification of forms and processes in the field, aerial photo interpretation and analysis of topographic profiles made with Global Mapper software and LIDAR data (1 metre resolution, www.terrasit.gva.es). Vegetation of various geomorphological units and environmental restoration interventions were analysed during the field work. Geoarchaeological records provided paleoenvironmental records and data on historical coastal tectonic subsidence. Changes in the barrier over the last 50 years were studied by georeferencing comparison of 1956 American Flight frames and 2005 orthophotos by the Cartographic Institute of Valencia. Manual soundings were conducted with an Eijkelkamp auger to determine wetland evolution. Sediments were analysed at the Department of Geography Geomorphology Laboratory (University of Valencia) and five 14C datings (peat and shells) were established in the Beta Analytic Laboratory (Florida USA). This database was used to lay out (on Microstation V8i CAD) geomorphological maps, gravel barrier processes and coastal change over a 1:1,000 scale digital vector map (municipality of Orpesa).

IV. WETLAND AND BARRIER GEOMORPHOLOGY

The coastal plain has a width between 1.5 and 3.5 km in a reach of more than 20 km between the towns of Orpesa and Alcossebre. The *Cabanes-Torreblanca* marsh forms a coastal barrier-lagoon system with permanently flooded areas in an almost flat space. It is bordered by alluvial fans of 1-3% average gradient. Only the *Xinxilla* and *Coves de Sant Miquel* rivers reach the sea. The latter is the main watercourse in the area, with a drainage basin of 500 km^2, and forms a wide alluvial fan prograding into the sea, which discharges gravels to the sea during floods. Towards the Southwest, the *Rambla de Manyes* alluvial fan divides the lagoon into two different environments. The wetland is bordered to the South by the alluvial fan assembly of the *Barranc de Miravet* and *Riu Xinxilla*.

The *Cabanes-Torreblanca* lagoon is characterised by extensive peat deposits with abundant aquatic vegetation and significant freshwater springs in the contact zone with the *Riu de les Coves* alluvial fan. Historical human activity transformed the ecological conditions, draining the marsh since at least the seventeenth century. A narrow coastal gravel barrier with discontinuous Pleistocene sandstone outcrops isolates the lagoon from direct marine influence. The gravel beach ridge is up to 3 m tall and narrow width, sloping steeply towards the sea and gently landward. The gravels are coarse (average diameter of 15-18 cm inland and 10-15 cm towards the beach), moderately homometric, well rounded and slightly flattened. Towards the mainland they have a dark coating and usually lack sand matrix. The barrier is retreating or transgressive, as evidenced by the existence of recent peats on the beach. Its morphological features, with washover fans in the adjacent wetland, are related to sedimentary deficit.

V. HOLOCENE WETLAND EVOLUTION. COASTAL SUBSIDENCE

Archaeological excavations in *Torre la Sal* (*Riu Xinxilla* distal fan) facilitate analysis of the geomorphological evolution. Geoarchaeological and sedimentological data and radiocarbon dates from a sedimentary record (SM7) covering the entire Holocene sequence provide clues about the coastal evolution and neotectonic background (Ruiz and Carmona, 2009).

5.1. Record of the SM7 core in the Prat de Cabanes marsh

This core (4 m depth) is located 350 metres from the coastline in the southern sector of the wetland. Five horizons can be distinguished from bottom to top.

1) Gray-green clays and silts with nodules of distal alluvial fan appear at the base of the core.
2) 3,75 to 3 m depth, a horizon of light gray silty clay, with gray nodules and plant debris, interpreted as freshwater wetlands (7530-7320 cal years BC) appears.
3) 3 to 1.5 m depth, a level composed of gray to dark gray silty clay with a progressive increase in organic matter content, carbonates and gastropods appears.
4) From 1.58 to 1 m appear abundant shells of *Cerastoderma glaucum* (approximately 3 cm in diameter).
5) Finally, the top level (0-1 m depth) consists of gray-brown silty clays with appreciable organic matter content and a large number and diversity of gastropods and a few small-sized shells of *C. glaucum*.

Sedimentological data and radiocarbon dates show that there was a freshwater lagoon during most of the Holocene and historical period (from 7530-7320 cal years BC). Towards the top of the record, the lagoon undergoes a progressive increase in salinity which peaks at 1,25 m depth (level of *Cerastoderma* shells) dated in the Modern Age. Accretion rates along the Holocene ranging between 0,25 and 0,50 m / millennium produced a gradual infilling of the lagoon that would be well advanced between the imperial Roman period (1820 ± 40 years BP at 1.25 m depth) and the Late Middle Ages (740 ± 40 years BP at 0.8 m depth).

5.2. Geoarchaeological record

Recent excavations carried out near Torre la Sal, in the Pleistocene alluvial fan of *Riu Xinxilla,* detected 683 negative structures with types of buckets, silos, holes, wells, treadmills, ponds, ditches, etc., of which more than 500 corresponded to the Neolithic period (VI-V millennium BC) (Flors, 2009). On the other hand, dozens of silos from the Neolithic period (III millennium BC) were excavated in the coastal sandstone (Guillem *et al.*, 2005). The rest of the structures correspond to the Iberian, Roman and Andalusian periods. Islamic wells are deep (> 3 m) and reached the water table after breaking Pleistocene conglomerates and calcareous crusts. In addition, the remains of a large port city with marine anchorage of the Iberian period (VI-I centuries BC) were excavated on the Pleistocene fan surface close to Torre la Sal (XVI century AD) (Wagner, 1978; Fernández, 1980, 1988, 1990; Flors, 2009).

5.3. Changes in the coastline. The subsidence process

It is important to note that the groundwater currently emerges at the bottom of the Neolithic silos, excavated in the distal part of the fan (2-3 m asl). Clearly these Neolithic structures, at the time they were being used, were out of reach of the water table fluctuations. On the other hand, the silos (III millennium BC) excavated in the coastal sandstone (currently positioned in the swash zone of the beach) and some Iberian walls that are below current sea level, had a coastline away from their present position. Thus, subsidence related to extensional tectonics processes has located them within the reach of groundwater and has caused the retreat of the coastline to the mainland, submerging the archaeological structures under seawater.

VI. RECENT PROCESSES IN BARRIER AND SHORELINE

Recent processes in the barrier were studied by analysing fourteen transverse profiles along the barrier (LIDAR data), comparison of aerial photographs from the years 1956 (American Flight) and 2005 (ICV orthophotos) and field work (geomorphological, textural and natural vegetation data). These data will help assess the sustainability and functionality of the recently completed environmental restoration. The barrier has been divided into six sections showing different morphology, vegetation and beach processes

Reach 1. Covering the urban reach of the barrier close to *Riu de les Coves* alluvial fan, where artificial supplies of sand and attempts at dune regeneration were carried out. Four breakwaters constructed in 1970 caused a retreat to the South up to 70 metres at some points.

Reach 2. A highly recessive stretch of coast, where the beach ridges had fully moved toward wetland (landward rollover process) between 55 to 65 metres. The barrier has lost width, from about 40-50 metres in 1956 to 20-25 metres in 2005, so that organic clays of the wetland are currently exposed on the beach shore. On the other hand, during storms washover fans were formed with numerous tongues of gravel thrown over the barrier by the waves, eroding or breaking it.

Reach 3. This is the central part of the barrier and it is in equilibrium or with minor changes in width since 1956. The barrier width reaches up to 165 metres at some points. Three environments can be distinguished from the wetland to the sea. The first, nearest to the backbarrier, is an extensive area of very thick gravel splays; the second is formed by several prograding longitudinal gravel ridges, without sandy matrix, while the third is a high and narrow ridge parallel to the coast formed by gravels with vertical imbrication. This is the best preserved section of the study area and presents a high degree of naturalness. Vegetation has a zonal gradient from the wetland to the sea, related to the geomorphological environments described, with typical Mediterranean scrub near the wetland, smaller species towards the sea, specimens of *Salicornia* and *Limonium* colonising salt accumulations and herbaceous marsh species near the sea.

Reach 4. Near the Quarter Vell, the barrier loses height and width and becomes a single flattened gravel ridge, with a wide sandy beach. At the barrier grow psammophile species typical of more or less stabilised dunes. The retreat of the coastline in this area is clear, as evidenced by the fact that the waves are currently dismantling the eastern walls of Carabinieri barracks built in the early 20th century away from the coastline.

Reach 5. A stretch of retreating coast (15-25 m) with a single narrow ridge of gravel, which has moved into the wetland (landward rollover process). Washover fan deposits can be seen (see Google Earth image of 2009). In the 1956 aerial photograph, at the southern part splays of very coarse gravel and sand and smaller ridges prograding towards the sea can be seen. Morphological and vegetational characteristics are very similar to those described in section 3. The dune ridge reaches maximum width to the south, where it is supplied with sand from small beaches formed between extensive outcrops of sandstone at the coastline. Conservation and environmental improvement interventions have recently taken place; actions undertaken included trail construction and excavation of an «artificial wetland».

Reach 6. In the vicinity of Torre la Sal, next to the *Riu Xinxilla* fan, the coastline has eroded 20-40 m over the last 50 years. Next to the tower, at the beachfront, alluvial fan red clays and silts with archaeological remains are distinguished. Improvement interventions include the supply of sand to the beach, dune regeneration and building promenades with footbridges.

VII. DISCUSSION. TECTONIC SUBSIDENCE AND SHORELINE RETREAT. COASTAL MANAGEMENT

7.1. Evolution of the lagoon: from freshwater to brackish. Subsidence rates

Comparing the 14^{C} dating of the wetland, it is noted that the Holocene southern sector sequence (SM7 core) is shallower and longer than the northern sector and accretion rates in the northern sector are higher and variable (0,20-0,83 m / Millennium). On the other hand, the gradual evolution of freshwater lagoon to brackish throughout the Holocene period reflected in the SM7 core is in line with foraminifera studies carried out in the Albufera of Torreblanca (northern sector), where there were living species in waters of low salinity around 6000 years BP. The neotectonic background would explain the high subsidence rates measured in this lagoon.

7.2. Morphology of the barrier. Coastline erosion: processes during the last 50 years

A strong shoreline retreat can be corroborated in some places of the barrier on a 50-year timescale. In addition, in the cross sections we can see that these processes are associated with a major loss of the barrier width. This type of barrier is well characterised as recessive in the scientific literature and its processes have been linked to a sedimentary deficit and/or a relative rise in sea level (Carter *et al.,* 1989; Carter and Orford, 1993; Orford *et al.,* 1995; Forbes *et al.,* 1991; 1995), although part of the erosion may be due to anthropogenic causes, such as the breakwaters of Torrenostra. We think that the local tectonic subsidence is a major factor in the retreat of the coast. From the dynamic perspective, this causes horizontal changes of the shoreline position, migration landward and saltwater intrusion. Finally, it is important to note that not all the barrier is recessive; there is a stable stretch of considerable width (sections 3 and 4) formed by large splays and progradating ridges. The existence of these prograding sectors (currently undergoing erosion) indicates that changes have to be analysed with a longer time scale

7.3. Keys for a sustainable environmental management

From the above, it follows that an essential objective of environmental management should be to control coastal erosion by maintaining a sedimentary balance. This should be a key factor in the sustainability of the interventions on beaches and gravel barrier. First, the five breakwaters built in Torre Nostra (section 1) hinder the transport of sediment and cause a strong retreat of shoreline located at the southern barrier. Sediment retention at these breakwaters should also have influenced in the narrowing of the barrier at section 2. Second, some of the interventions carried out by managers of the Cabanes Natural Park could be harmful to maintaining the barrier. Sediment removal during excavation of several artificial ponds for birds has significantly narrowed the width of the barrier, to the extent that it can easily break during ordinary storms. Southward there is an embryonic sand dune area, fed by the sandstone outcrops in the beach that would be an appropriate space for dune regeneration. However, the barrier is crossed by a number of guided environmental trails that impede the establishment of vegetation and sand. Finally, south of the fishing village of Torre la Sal, the Coastal Service of the Ministry of Environment has developed a «draft of coastal path and recovery of the public domain». The actions taken are dune regeneration and installation of over-raised footbridges. This regeneration, however, has had unsatisfactory results, since the minor nature of the dunes and the natural processes of shoreline retreat hinder a prolonged stay of the sediment, periodically eroded by frequent winter storms.

VIII. CONCLUSIONS

A progressive increase in salinity and marine influence associated with local tectonic subsidence characterise the evolutionary model of this lagoon. The relative rise in sea level caused the landward migration of the shoreline and facilitated saline intrusion, as seen from geoarchaeological data. This evolutionary model is different from those established in the international literature on microtidal, low gradient coasts for Mediterranean lagoons like the nearby Albufera of Valencia, characterised by an evolution towards continentalisation. Its gravel barrier presents a peculiar morphology, texture, sedimentology and vegetation without human alteration in many sectors and is possibly unique in the Spanish

Mediterranean area. Recent processes denote an important sedimentary deficit that may lead to very rapid and irreversible changes, since the barrier breaks in catastrophic sea-storms. Knowledge of the morphodynamic and vegetation evolution is essential in the assessment and sustainable management of this natural area.