Morphodynamics of an Embayed Beach in Majorca Island

Tiago Abreu, Benjamín Parreño-Mas, and José Pinto-Faria

Abstract

Cala Millor Beach is located in Mallorca Island and is a small sandy beach, embedded in a rocky bay. It remained generally in a state of equilibrium but, in the 60s, the urbanistic area began to develop towards the beach, interfering with the natural sediment transport of the bay. The seabed is covered by native vegetation known as Posidonia Oceanica, playing an important role in the morphodynamic system. This vegetation is responsible for the lamination of the waves through energy dissipation. To characterize the local dynamics, the SMC program (System of Coastal Modelling) is employed to study sediment transport trends and to evaluate morphological evolutions in the short term. The results seem to support the observed problem, resulting from an imbalance of sediment transport due to the drift from north to south. Moreover, the results support the idea that the morphological variations can be significantly attenuated in the presence of Posidonia Oceanica. This is of great importance for coastal management since the influence of the vegetation can be assessed, improving our knowledge on the coastal morphology and enabling to identify ways to protect the beach.

Keywords

Coastal management • Sediment transport • Hydrodynamic • Morphodynamics • Vegetation effects

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1 Introduction

Cala Millor Beach is an urban beach located in Majorca Island, which is one of the Balearic Islands of an archipelago placed in the western Mediterranean Sea. The beach presents a high occupation during the summer months. The economy of the area depends mostly on maintenance, in terms of comfort and quality, of both water and rest areas for this type of sandy beaches. The beach is embedded in a rocky bay and possesses a fine sandy layer, resting on a rocky substrate that continuously emerges and prevents recreational use of the beach for long periods. Sometimes that also takes place during the bathing season, which consequently causes damages to the tourism sector and business-related services.

In the past decades, the urbanistic area began to develop towards the beach, destroying practically the entire pre-existing dune system. This modified the natural equilibrium beach state, making the beach more reflective and vulnerable than before. Some solutions could be adopted to solve this problem, but it is important to bear in mind that, close to the shore, the sea bed is covered by native vegetation known as Posidonia Oceanica (Abadiea et al. 2018). It is recognized that this vegetation has an important role in the system, but few studies were done to evaluate its influence on the coastal morphology (Guillén et al. 2013). This kind of vegetation is responsible for the lamination of the waves through energy dissipation and different models that deal with this phenomenon can be found in the literature (e.g., Kobayashi et al. 1993; Lima et al. 2006; Sánchez-González et al. 2011).

In this work, it is intended to study the morphodynamic of the beach, considering representative wave regimes for that location. For the simulations, the SMC program (System of Coastal Modelling) was used, which integrates a series of numerical models and allows to model the study site. The results of this work enable a better understanding of Cala Millor beach morphology, taking into consideration the wave climate and, also, the roughness effects caused by

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Posidonia Oceanica. This is of great importance for coastal management since the influence of the vegetation could be assessed, improving the knowledge on the coastal morphology and enabling to identify forms of intervening on that beach.

2 Study Site

2.1 Cala Millor Beach

The municipality of Son Servera is located in the eastern part of the island of Mallorca, belonging to the largest island in the Balearic Islands (see Fig. 1). Son Servera's economy was based primarily on rich agriculture, livestock and fishing. However, nowadays, the tourism is the actual main source of income in this municipality and Son Servera has become one of the tourist centers of the island. Besides tourism, other different activities are rare in Son Servera.

The Cala Millor Beach is also called "Arenal de Son Servera" and it is located in the south bay area of Son Servera. The beach is embedded in 1600 m length and 35 m wide, being orientated NNE-SSW. The beach is composed of two distinct layers: a first sand stratum that lies on a second rock stratum. The sand essentially consists of bioclastic sand. The coarse fraction does not exist and the average of the particle size is uniform in all the studied samples, with a median grain size $d_{50} = 0.33 \pm 0.3$ mm (Gómez-Pujol et al. 2011).

2.2 Hydrodynamics

To characterize the hydrodynamics affecting Cala Millor it is necessary to know the local wave climate. For that purpose, the data obtained from the Capdepera buoy was analyzed. The buoy is located at a depth of 48 m (3.49° E, 39.65° N). Over the past decade, the buoy registered the beach is mainly affected by waves coming from the first and second quadrants, where swells from the first quadrant possess a higher frequency and present an average direction of 18° (N18E). The second quadrant presents lower frequencies with an average direction of approximately 117° (S63E).

From the buoy data, it is also possible to analyze the fluctuations of the wave climate over the past three decades. Figure 2 shows the annual/seasonal variability in terms of significant wave height (H_s) and wave peak period (T_p). Some usual variability associated with the Mediterranean climate (defined by hot, dry summers and rainy winters). The figure presents the average values as well as their fluctuations regarding the standard deviation around the average. During summer months (Jun–Aug.), the wave height and the peak period are smaller in comparison to colder months (Dec.–Feb.). On average, we can adopt a value $H_s \approx 1.0$ m and $T_p \approx 6.2$ s.

3 Results

To model the study site regarding the hydrodynamics and sediment transport, the SMC program was used. This program was developed by the *Grupo de Ingeniería Oceanográfica y de Costas* (GIOC) of Cantabria University. The program includes a series of numerical models, allowing the hydro-morphodynamic modelling of the study site. BACO model is used to incorporate the local bathymetry.

In this model, it is possible to couple different conditions of sea waves and to simulate its spread on the bathymetry (OLUCA model). It is also possible to combine these results with MOPLA model, enabling morphodynamic computations.

For the simulation, one selected the data from Capdepera buoy mentioned in the previous section. Because it is recognized that the erosion is directly associated to the wave height, two situations were chosen for winter months where the biggest wave heights were recorded (Fig. 2—February). The monthly average value and such value aggravated by the standard deviation were considered. The corresponding peak period was also taken into account. Since the predominant propagation comes from NNE and SSE, both directions have been considered for the simulations.

Figure 3 shows sediment transport estimates obtained by the SMC program for a sandy bottom. The difference between the two panels lies on the wave direction related to the two dominant directions registered for the 1st and 2nd quadrants. It is noted that these results do not include effects associated with the vegetation seabed or tidal variations. The comparison reveals a clear imbalance of the sediment transport, reflecting the differences whenever the waves are originated in the first or second quadrant. This difference is evidenced by the magnitude of sediment transport in both situations, resulting in a pronounced transport to the south. This imbalance between north and south can lead to an annual net loss of sediments in the bay, resulting in the disappearance of the sand substrates of the southern dry beach area.

4 Discussion

To address the roughness effects associated to Posidonia Oceanica, other runs were performed with SMC. The area covered by the seagrass is extended from 5 to 30 m depth, reaching in some areas up to 35 m. The computational meshes were adapted to easily implement and meet the spatial arrangement of the seabed vegetation. Therefore, the

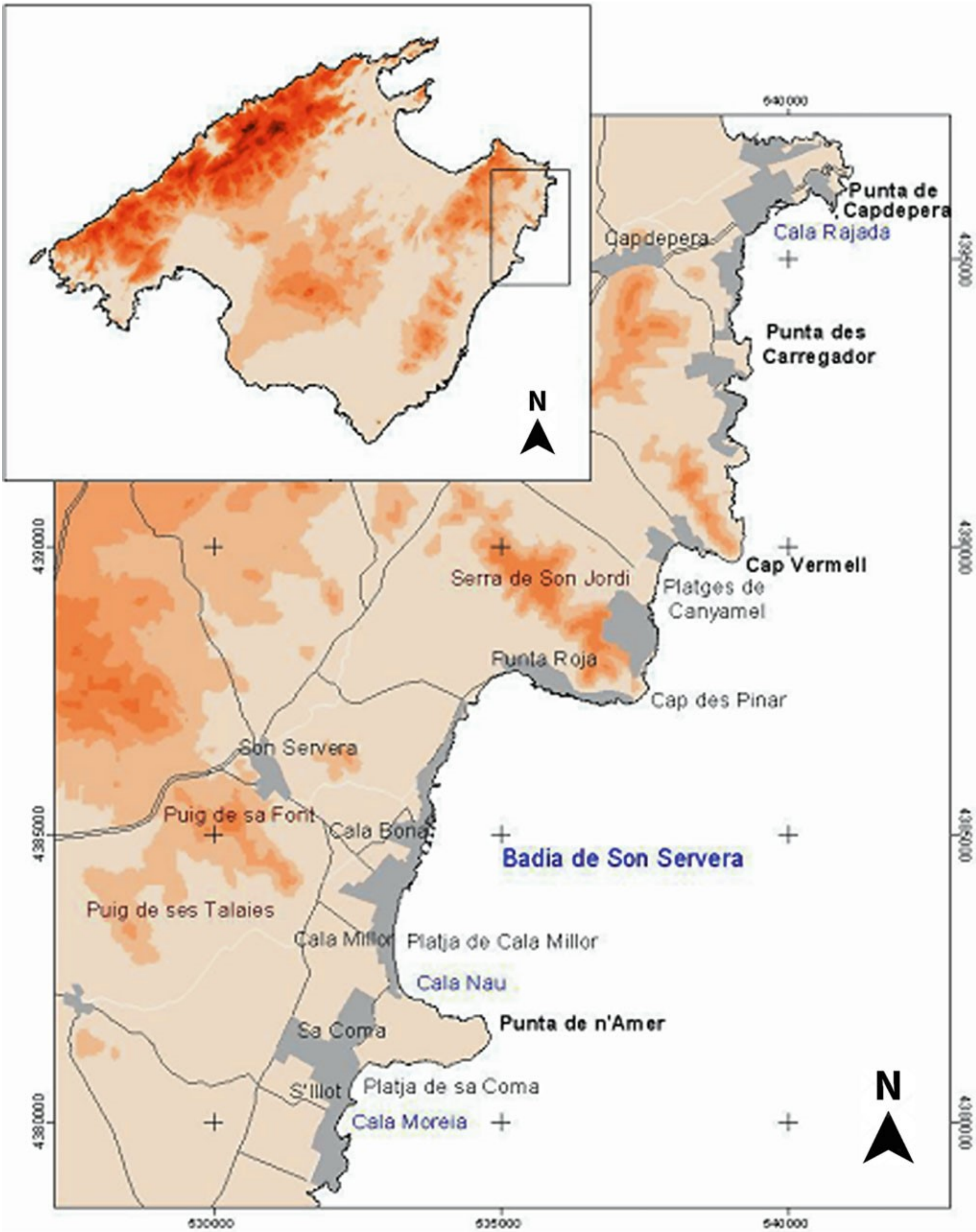

Fig. 1 Location of Son Servera's bay in Majorca Island

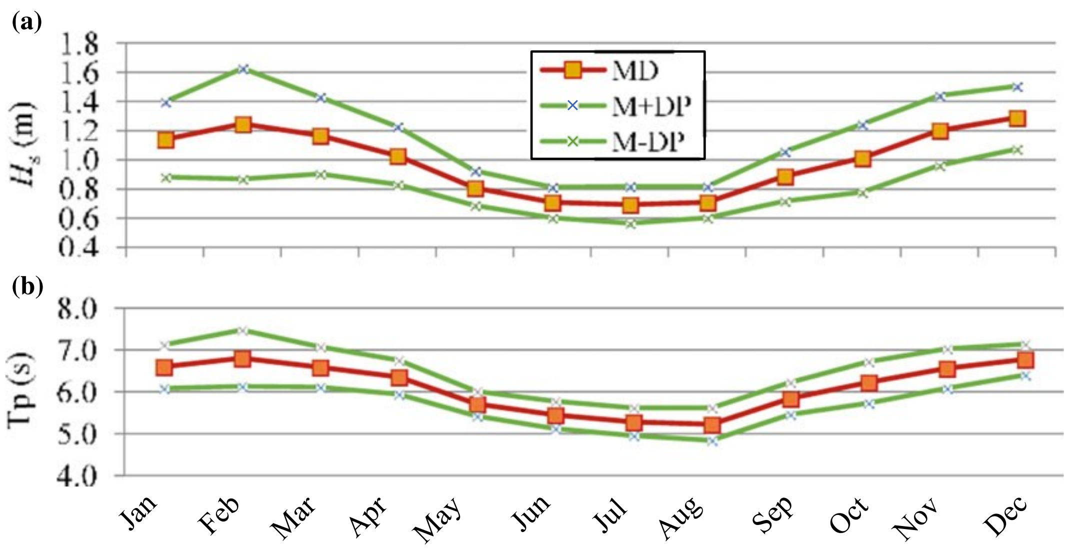

Fig. 2 Capdepera buoy: H_s and T_p over the past three decades. The red curves in the middle represent average values. The other lines add and subtract the standard deviation

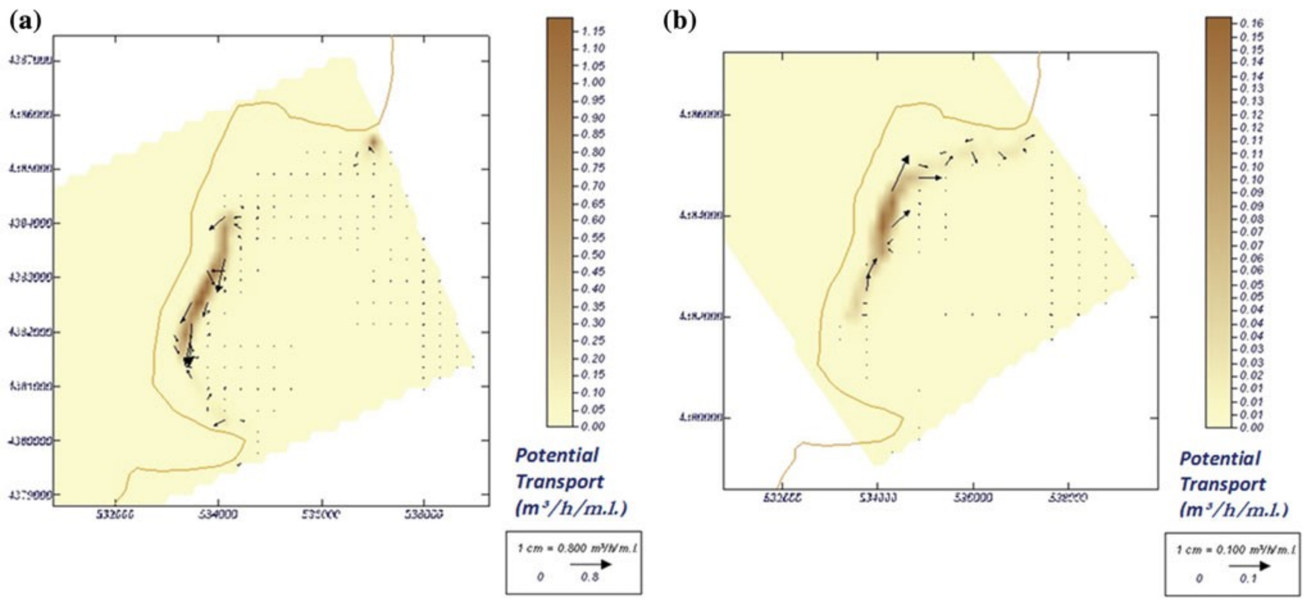

Fig. 3 Sediment transport values obtained for H_s = 1.6 m, T_p = 7.5 s with waves coming from the: **a** first quadrant (NNE); **b** second quadrant (SSE)

direction of propagation was changed, being placed parallel to the bathymetric lines. One recognizes these stirring characteristics are not dominant and, therefore, the results derived from this work are indicative in terms of the sediment budget. Nevertheless, the results enable to compare sediment transport trends in a qualitative sense and assess the importance of the bottom roughness.

In the literature, several models to evaluate the wave attenuation concerning vegetation effects on the seabed can be found (e.g., Dalrymple et al. 1984; Mendez and Losada 2004; Lima et al. 2006). In this study, the model proposed by Lima et al. (2006) was adopted since it incorporates vegetation movements and the interaction between the rods, which is the case for Posidonia Oceanica. The magnitude of the results leads to a significant decrease in sediment transport, in fact, more than halved. The sediment transport is mitigated because there is a reduction in the wave height induced by the vegetation. Therefore, the results support the idea that the morphological changes can be significantly attenuated in the presence of Posidonia Oceanica.

One stress that the model response is not taking into consideration, vertical dykes built on the beach in recent decades, as well as existing rock outcrops on the South Beach area. In addition, it is important to consider different scenarios with rising sea levels, incorporation of tides and storm surges. From a climate change perspective, Posidonia Oceanica can be severely affected and its effects should be addressed in the future (e.g., Pergent et al. 2016).

5 Concluding Remarks

Cala Millor Beach suffers a persistent loss of sediments since its natural balance was changed due to anthropic activities that took place on the Spanish coast in the 60s. The observed erosion turns out to be a serious problem for the development of this beach since the main incomes result from the tourist sector. It is necessary to correct the problem, or at least mitigate it, by means of sustainable and economic solutions.

In order to study the local dynamics of this beach the SMC program is employed. The model is used to study sediment transport trends and its evolution in the short term. The results seem to support an observed problem that results from an imbalance of sediment transport due to the drift from north to south during storm situations. Local conditions suggest a greater loss of sediments to the south, which can significantly affect the future use of the beach. For coastal management purposes, this kind of studies and tools are very important, essential for scenario-based planning and helping to propose alternatives to protect and mitigate sediment losses. The solutions require a deeper knowledge accounting for technical, functional, economic and environmental aspects.

In addition, it is recommended to undertake protective measures concerning the conservation of the Posidonia Oceanica meadow because it presents a clear positive effect on the mitigation of the energy reaching the beach.

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