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Pima Adapta Costas, a Characterisation of Flooding and Erosion Under Different Climate Change Scenarios Along the Catalan Coast †

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Abstract: Climate change, with sea level rise as one of its main consequences, will heavily change the dynamics of the coast in the next years. The assessment of the impacts that could cause is a key issue to anticipate measures and reduce risks, mainly flooding and erosion. PIMA Adapta Costas is a national project financed by "Ministerio de Transicion Ecológica y el Reto Demográfico" which aims to answer these unknowns along the Spanish coast. This work presents the evaluation of such impacts in 54 Catalan beaches located in 8 littoral cells. Erosion has been characterized by tracking the retreat of different datums whereas flooding has been defined as the sum of all inundated areas during more than 4 hours. The obtained results are integrated in a specific viewer developed by the ICGC. A complete description of the impacts will help identifying common response patterns that can be used to select optimal management strategies to reduce risks.

Keywords: climate change; XBeach; flooding; erosion; sandy coast

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1. Introduction

About the 60% of the world's population lives within the first 100km of the coast [1]. At present, the coastal fringe is supporting important socio-economic activities which in many cases, especially in the Mediterranean, are at risk due to the lag of sediment that generates the necessary protection. Such situation will be exacerbated under the expected new climate scenarios. As it can be seen, the protection of these areas is crucial and a key problem to be solved in future coastal plans. In the last years, the European Union has dedicated huge efforts to better know the functioning of the coast under new climate conditions. An example of this is the EU projects MARLIT [2] and REST-COAST [3], among many others. It is also widely accepted that sea level rise will be the main culprit for unprecedented coastal flooding as well as accelerating erosion. Climate change will not only produce a rise of the sea level but also a change in the current wave extreme regime and meteorological events [4], altering the present coastal risk landscape.

The Ministerio para la Transición Ecológica y el Reto Demográfico (MITECO), jointly with the Generalitat de Catalunya as one of the Spanish autonomous regions with coast, have launched the project PIMA Adapta Costas whose main objectives are the characterisation of coastal flooding and erosion due to the effects of climate change. This study presents the results of this project at 54 beaches along the Catalan coast (NW Mediterranean). The selected beaches cover a wide range of coastal archetypes, from low-lying to high coasts, and, from urban to semi-natural environments and can be considered as representative of that coastal stretch [5]. The analysis has been performed by means of the numerical hydro-morphodynamic model XBeach [6].

The purpose of this work is to evaluate the impacts for a combination of different sea levels and storm events representative of different return periods to help on the identification of common responses and from them selection of optimal mitigation strategies.

2. Methods

Coastal flood and erosion hazards have been studied in 5 major steps: Step I — Selection of beaches, Step II — Physical parameters definition; Step III — Modelling, Step IV — Post-process of results and Step V — Visualisation.

The selection of the study cases (Step I) was carried out following the sedimentary littoral cell concept defined in [7]. All coastal provinces of Catalonia were selected: Tarragona (5 beaches), Barcelona (40 beaches) and Girona (9 beaches), covering main coastal archetypes. The criterium of most inhabited beaches was added to help in the final selection (Figure 1).

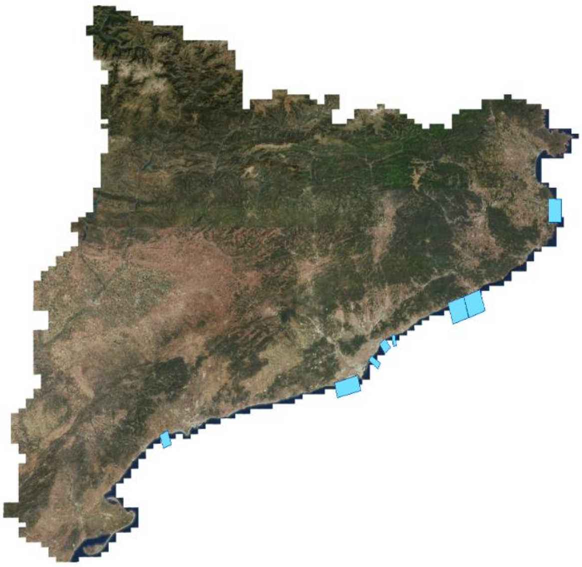

Figure 1. Coastal stretches (blue rectangles) analysed in this study (orthophoto provided by ICGC).

The definition of all necessary physical parameters was performed in Step II. This includes the morphological characteristics of beaches, bathymetry and sediment grain size, and the characterisation of the wave climate and mean water level. The selected beaches are sandy and their granulometry was obtained from [7]. A digital elevation model with 5x5 meters resolution was used from the open access database of ICGC. The bathymetry was obtained from existing nautical charts. All geospatial information was processed using a geographical information system maximizing the resolution and precision of the shallower parts near the shoreline. The maximum depth, where the hydrodynamic conditions were launched, varies between 50m and 80m. The wave climate has been based on the climatic projections of RCP4.5 and RCP8.5 developed by IH Cantabria [8]. The data is organized in nodes every 0.08º along the Spanish coast in which a time series of wave height, period and associated direction is presented. The selected beaches have been characterised by 8 nodes of this dataset. Two timespans have been considered for the analysis: the period 1985-2005 representing the current sea wave climate and the period 2081-2100 which represents the long-term projection on which the RCP4.5 and RCP8.5 climate scenarios have been studied. In all cases, the storm regime has been calculated by means of the peak over threshold method and by fitting the best non-exceedance probability distribution function. Once the best function has been found, the corresponding storm events with associated return periods of 50, 100 and 500 years are used to assess their impact on the coast. The storms have a duration of 12 hours in which conditions remain constant at their maximum intensity, this is in coherence with other storm events in the area [9]. The mean water level for the RCP4.5 and RCP8.5 climate change scenarios corresponds to the projections given by the "Oficina Catalana del Canvi Climàtic (OCCC) and the "Intergovernmental Panel on Climate Change" (IPCC) [10] [11]. The present conditions were represented by mean water level of 0m.

The modelling, that is, the preparation and execution of XBeach is done in Step III. It is needed, for each case scenario defined in Step I, a grid represented in three different files for x, y coordinates (in this study, defined in ETRS89) and the depth reference. A combination of the topography and bathymetry created in Step II was generated resulting in final grids of 10x10 homogeneous meters resolution which were converted into the specific files using different programming languages. The values also obtained from Step II were used to configurate the hydrodynamic and morphodynamic parameters. To reduce computational time, the MPI (message passing interface) module of XBeach was applied, using 4 simultaneous processors instead of 1 and reducing the average simulation time from 10 hours to 1 hour.

Step IV corresponds to the post-processing of the results. Coastal flooding is geospatially defined with a polygon from the computational grid. Inundation is considered when a node in the domain is wet, with a water height of centimetres, during more than 4 hours over all the simulation. The delimitation of the polygon is finally generated by comparing the output results of the model and the orthoimage of the area, using previous knowledge. This approach reduces possible errors increasing the confidence of the results, which could be lowered by the resolution of the grid. The erosion/sedimentation hazard has been described through the shoreline position. It has to be noticed that present conditions are represented by the coastline located at level 0m whereas for the RCP4.5 and RCP8.5 scenarios it is located a level 0.85m and level 1.14 respectively. In all cases, it has been assumed that the simulated storms have associated a storm surge of 0.3m.

Finally, in Step V, results are integrated in a viewer based in GIS environment which is accessible at https://visors.icgc.cat/PIMA-AdaptaCostas/. The developed platform allows the user to select the climate change scenarios within a combination of the described different storm events for both studied variables. An example of polygons from a storm condition of a return period of 500 years for present conditions and under the RCP8.5 scenario is shown in Figure 2. Besides, the figure also shows as an example the shoreline positions for present conditions, RCP4.5 and RCP8.5.

Figure 2. Result of a littoral cell situated in Tarragona. a) Flooding polygons where blue is obtained from present MWL conditions with storm of 500 years of return period and violet represents MWL conditions of RCP8.5 with 500 years return period storm; b) Close-up of the area with coastline

represented as color lines. The red line shows present MWL and 500 years return period conditions, the blue line has MWL conditions for RCP4.5 and 500 years return period and the pink line shows the retreat for MWL of RCP8.5 under storm conditions of 500 years return period.

3. Results and Discussion

The Barceloneta beach (Figure 3) is an example of low-lying urban coast. The backshore position in the area is about 3m in the lowest point being most of the urban area at about 2.5 m. As it can be also seen from Figure 3, at present, the area suffers flooding during very severe conditions. This is a situation that has been reported in extreme events such as the Gloria storm (year 2020). When SLR is considered (RCP8.5 scenario), the resulting flood is much higher due to the fact that rigid bottom (the urban area) is reached and less sediment is available to generate a submerged bar. This behaviour has been observed on other beaches with similar characteristics. In general, as expected, the increase of the storm intensity results in an increase of the inundated area, being completely flooded for the return period of 500 years. For the climate change scenarios, the associated SLR allows storm to reach the urban non erodible bottom inducing a much more inundated surface which can extend up to 200 m inland. When analysing the flood within the storm it can be seen that sea water is entering, as expected, through the lowest points of the emerged beach and backshore finally resulting in a complete homogeneous inundated area.

Figure 4 illustrates the case of a relatively narrow emerged beach with streams and channels connecting lagoons. It has to be said that for those cases, the model setup considers these areas as dry. For present and SLR scenarios, extremely severe storm conditions use these points as preferred paths for inundation. The low slopes jointly with the existence of levees at both sides of the streams or lagoon entrances channel the water, being able to reach up to 500 meters inland. This behaviour has been also observed by [12] when studying the Ebro Delta river mouth under different SLR scenarios. Although the hypothesis of a dry condition might not seem according to reality, it can become more realistic under climate change conditions in which is expected an important reduction of rainfall rates.

The analysis of the erosion/accumulation hazard through the position of the shoreline (Figure 2 and Figure 5) shows recession rates with ranges between 10m and 30m when sea level rise and storminess are considered. Although, the location of the coastline does not necessary represent a good proxy. During storms, is expected a coastline retreat due to the induced erosion in the shore, especially, in dissipative beaches where the sediment is mainly deposited in a submerged bar. However, for high water levels, the most emerged parts of the beach come into play, being able to feed the base and consequently not produce a significant variation of the shore since the erosions are mainly concentrated in the upper part. As expected, the higher the water level, the greater the shoreline retreat respect to the present situation will be. Nevertheless, as it has been said, this behaviour not necessarily has to happen and mainly depends on the sediment availability at the emerged bar. The results also show that gentle beach slopes, that corresponds to fine sand fractions, are more sensitive to climate change resulting in greater shoreline retreats.

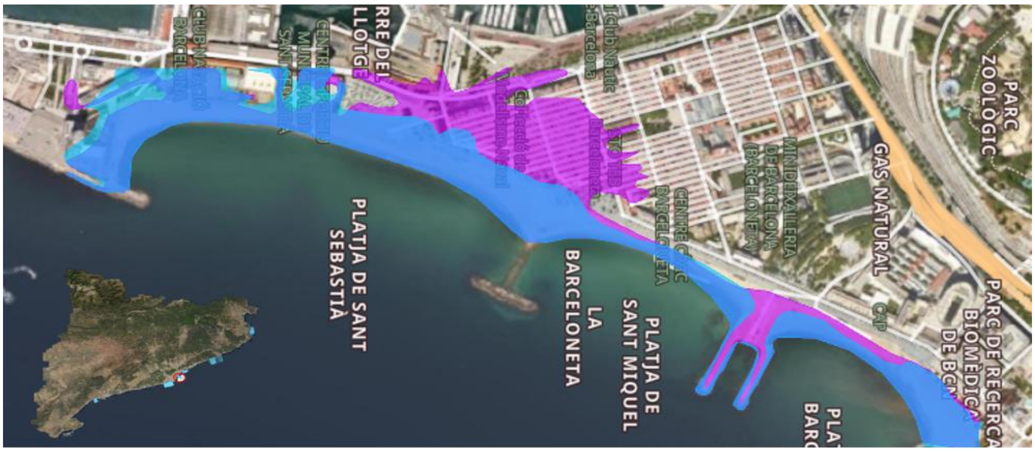

Figure 3. Results of one of the most damaged studied beaches, situated in Barcelona. The blue polygon is obtained from present MWL conditions with storm of 500 years of return period and the violet represents MWL conditions of RCP8.5 with 500 years return period storm. The parts with lighter blue polygon represent areas where for present conditions are flooded but for RCP8.5 conditions will be dry under the studied conditions.

Figure 4. Result for a beach situated in Gavà (Barcelona). The blue polygon is obtained from present MWL conditions with storm of 500 years of return period and the violet represents MWL conditions of RCP8.5 with 500 years return period storm. It can be observed how the water enters to the streams.

Figure 5. Close-up of Gavà (Barcelona) with coastline represented as color lines. The red line has present MWL and 500 years return period conditions, the blue line has MWL conditions for RCP4.5 and 500 years return period and the pink line shows the retreat for MWL of RCP8.5 under storm conditions of 500 years return period.

4. Conclusions

The characterisation of some parts of the Catalan coast using morphodynamical models has resulted an interesting tool to predict the possible consequences that could be seen in the future for the suggested predictions. The observed behaviour for the different analysed scenarios shows how low-lying coastal stretches are the most vulnerable to flooding. Furthermore, on low urban coasts, the beach configuration is not enough to stop the incident waves and once the non-erodible surface is reached, the waves can penetrate more than 200m inland. From this, it can be seen that the maintenance of an enough emerged beach width or the generation of a backshore coastal room are necessary strategies to cope such scenarios. Besides, coastline retreat as an erosion/accumulation indicator does not seem to be the best proxy since it does not get affected so much by storm conditions and the increase of sea level rise has a direct impact on it.

On the other hand, the mouths of rivers and streams, due to their low nature, channel coastal flooding. In these cases, the channels show an inverse behaviour whereby sea water, depending on the orographic characteristics of the area, can penetrate more than 500m.

The methodology used in this study presents how the high-resolution results of hazards are useful when defining management policies on a larger scale. This study opens the door to implement even higher resolution topobathymetries to improve the erosion processes at the beach and to better determine the dynamics that will follow the storm passing. The shown work also allows to define common patterns that could be used to reduce the risks associated to the most populated and important beaches of Catalonia. Also, the definition of the flooding impacts as polygons and the retreat as lines would help the administration to understand and situate the problem, which will facilitate their decision about the mitigation actions.

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