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COASTAL SUSTAINABILITY FOR UNCERTAIN FUTURES. A SPANISH MEDITERRANEAN CASE FROM THE RISES-AM- PROJECT

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ABSTRACT

This document presents the impacts of future climatic conditions as a function of coastal typology. The impact assessment is carried out at decadal and storm scales showing how such a combination produces the worst levels of damage. From here the implications at a “predictive” scale up to 10 years and at a projective scale up to 10 decades is considered. The resulting impact consequences, normalized by their respective probability of occurrence allow calculating risk levels. For the more clear vulnerability hotspots the proposal in the paper is to use natural accretion mechanisms where the natural power of meteorological and oceanographic events can be put to use to contribute sedimentary inputs to a starving coastal zone. In the same manner the natural adaptive capacity of coastal systems could be enhanced if natural accommodation space is provided or considered for present and future planning. The paper ends with some conclusions on the development of a pathway for efficient responses to climatic change.

Keywords: Coast, Climate, Impact, Sustainability and Natural Accretion.

1. IMPACTS AND TYPOLOGY

The impact of climatic pressures on a given coastal sector is conditioned by typology, resulting therefore in different vulnerabilities. To illustrate the case under present conditions the increase in coastal development and particularly for free transport coasts results in larger potential impacts of a more general nature (Figure 1). That results in a larger vulnerability and therefore smaller resilience.

Figure 1. Illustration of the larger vulnerability and smaller resilience for two cases from the Spanish Mediterranean coast showing how a rigidized coast (right panel) or coastal infrastructure very near to a dynamic shoreline (left panel) result in damages and therefore an actual realization of the potential vulnerability.

Conversely for an enhanced coastal adaptation, normally associated to the availability of space for such a process and for coasts where the transport only occurs for a more limited stretch (i.e. impounded transport coast) the impact potential is smaller and also whenever it verifies affects “only” a more limited or local sector of the coast. The result is that, provided there is enough space for adaptation under present conditions or even under future conditions (normally imposing a higher demand on space availability) the vulnerability is reduced and the natural resilience of the coast increases.

The impact of climatic factors is also conditioned by the geomorphological settings of the coast, been higher for low lying coasts (Figure 2). It is also higher for heavily rigidized urban coastal fringes as illustrated in Figure 2. In summary the vulnerability, as an integrated variable throughout a typical time interval, turns out to be higher for low-lying coasts, urban beaches or areas with a sediment scarcity for present coastal dynamics (Sánchez-Arcilla et al., 2008b; 2010; 2011; GECCC, 2010).

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Figure 2. Sample illustration of vulnerability hot spots along the Mediterranean Spanish coast, comprising low lying areas (Llobregat delta and Ebro Delta in the upper part of the figure) and urban rigidized coasts, illustrated by the Barcelona urban beaches (lower panel). The resulting vulnerability is a function of the socio-economic (Llobregat Delta) and natural (Ebro Delta) values of the considered coastal sector.

The assessment of impact and the associated vulnerability is therefore controlled by the features of the considered coastal sea domain. For semi-enclosed seas like the Mediterranean and in particular the Catalan coast, there is a general sediment starvation due to the diminishing erosion in river catchment basis. The limited amount of swell wave energy (Sánchez-Arcilla et al., 2008b; Bolaños et al., 2011) results in breaker bars that are nearly permanent and therefore a limited natural recovery of beach profiles after storms. These storms only affect the coast in about one fifth of the year duration as illustrated in Figure 3. Because of the limited energetic level of wave storms in these semi-enclosed seas other parameters such as storm duration (Figure 3) turn out to be as important as the storm intensity given by the wave height or the wave height squared (Sánchez-Arcilla et al., 2008a).

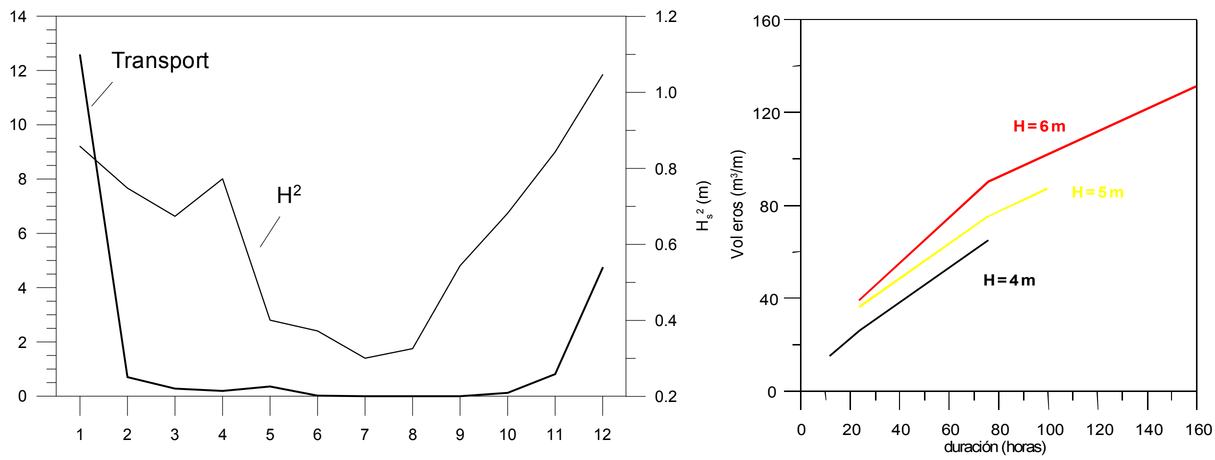

Figure 3. Schematization of the wave height distribution along the year (horizontal axis of the left panel image, with one representing January and twelve December) and how that affects the resulting longshore transport in the vertical axis in arbitrary units; the wave height squared is also expressed in the right vertical axis in square meters. The figure also shows the importance of parameters such as the storm duration (horizontal axis, right figure) where the eroded volume in square meters for a given beach profile appears to be controlled not only by the intensity of the wave height within the storm but also by the storm duration which may result in a factor three for the eroded volume.

2. DECADAL AND STORM SCALES

The assessment of climatic impacts and the associated sustainability of a coastal area require the simultaneous consideration of decadal scales (e.g. sea level rise at that scale) and the effect of storms under those future conditions. In this paper we have considered the global projections of high end scenarios from AR5 of IPCC (2013). The high end values and in particular the higher quantiles (e.g. 95% from Moore et al., 2013) show a level between 1.00m and 1.40m (Jevrejeva et al., 2014). The corresponding more likely range from IPCC covers a range between 0.6m and 1.0m, always for the year 2100.

However the physical impact will also be a function of the waves and storm surges acting on that given coastal stretch. For the Mediterranean case we are here considering the effect of mean sea level rise that has been introduced in terms of an average value for the Mediterranean which has been taken as 0.9 the global values, recognizing the slower adjustment in the Mediterranean Sea when compare to global oceans (Lionello et al., 2008; Sánchez-Arcilla et al., 2011). The available observations, although limited in time and space coverage, also support this behavior while, at the same time, illustrating the unequivocal increasing trend of temperature and mean sea level for the Mediterranean in general. Regarding storm waves there is still no downscaling from AR5. In this paper we have used some of the downscaling available from AR4 (Casas-Prat and Sierra, 2013; Casas-Prat et al., 2014). The main result is that although storm intensity remains reasonably steady the percentage frequency of southern waves increases. Regarding storm surges (Conte and Lionello, 2013) the available AR4 projections indicate an overall decrease, consistent with the same negative trend of storm intensity. Only for specific more resonant prone areas of the Mediterranean there may be an increase. However for the Catalan coast we have assumed there is no change in storm surges for the coming decades, consistently with the high end scenarios for sea level rise so as to combine the worst possible drivers for the assessment.

3. IMPLICATIONS

The effect of these projections on the Catalan coast has been calculated as predictions for a ten year scale and as projections for 50 to 100 years from now. The 10 year predictions, consistent with a recommendation from the DAVOS forum are based on the initial coastal state that corresponds to an average from the 1995 to the 2004 decade. This average has been derived from aerial photographs provided by the Institut Cartogràfic de Catalunya (ICC). The wave climate has been derived from the XIOM network of buoys along the Catalan coast. This has allowed to calculate beach width and longshore sediment transport. From here the beach width expected 10 years from now can be easily calculated, introducing in the analysis the inter annual variability of this transport process (Figure 4). The result is that most of the Catalan beaches, from the 700Km Northern most part of the Spanish Mediterranean coast, will have a width below 50m 10 years from now. That will enhance their vulnerability to storms and surges, resulting in increasing risk levels for the hinter land socio-economic and natural values.

The projections for 50 to 100 years from now, based on a comparison from the 1971-2000 time slices with respect to the 2071-2100 time slices and using five regional circulation models for the AR4 SRES projections indicate (Figure 5) that more than 50% of the beaches will be more vulnerable, due to the change in wave direction which would entail a reshaping of the coastal fringe, not acceptable under the present level of coastal squeezing for this part of the Mediterranean coast.

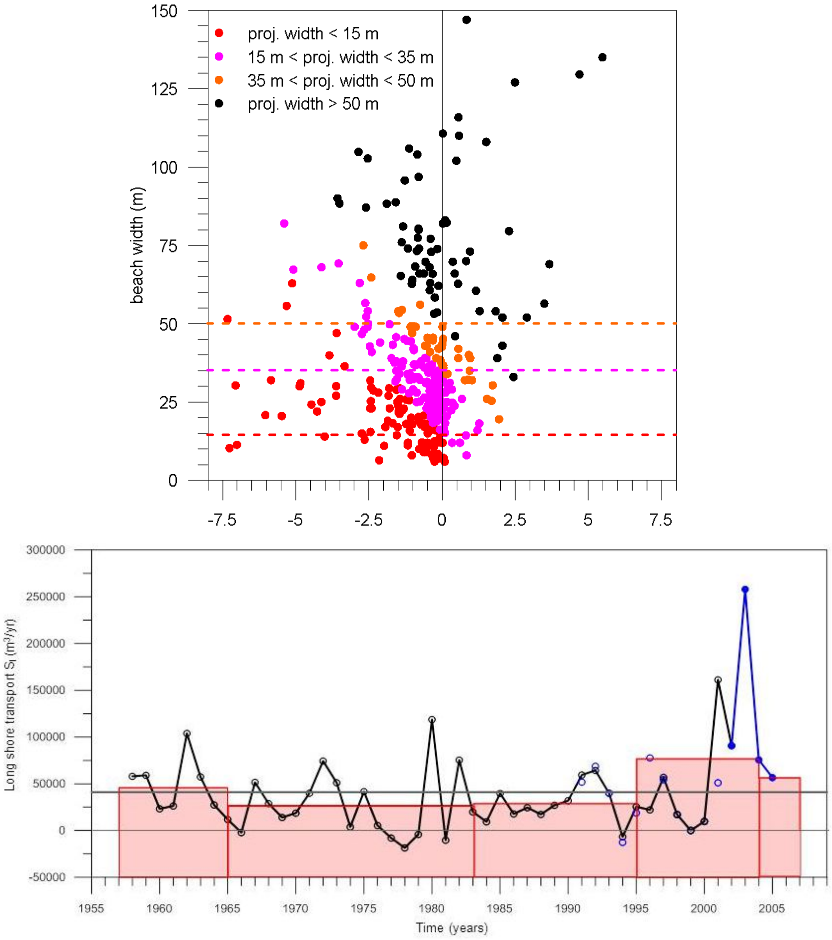

Figure 4. Prediction of the beach width 10 years from now using data from CIIRC (2010) and conventional geometric projections. The upper panel shows the resulting beach width with a color coding to distinguish those beaches with expected width larger than 50m (therefore less vulnerable) and those with expected width below that threshold. The lower panel indicates the time series of yearly averaged longshore transport to illustrate the inter annual variability, which is an important aspect to be considered for the "instantaneous" impact of a given wave storm, which may differ from this average prediction.

A similar analysis for the functional vulnerability due to the impact of mean sea level rise and changes in wave storminess on the overtopping rates for the harbors of the Catalan coast has shown that the impact will increase particularly for the harbor structures in the Northern part of this coast (Figure 5).

4. RISK LEVELS

An objective approach to rank coastal impacts and vulnerability and therefore to support decisions is to calculate the risk level for each of the studied coastal sectors and coastal functions, beach based or harbor based. The situation for the Catalan coast shows highly transient pressures (short duration storms acting only during part of the year) and a transient population pressure, due to the increase of users in the summer season which may be larger than one order of magnitude with respect to the population using the territory in the winter season. This, combined with a squeezed territory due to the mountain chain backing the Catalan coastal fringe and the presence of several small to medium rivers occupying part of the coastal territory result in a high level of risk even under present conditions that will likely get more acute in the future under climatic change.

This can be illustrated by the higher vulnerability hot spots which, as mentioned before, are low lying coasts and rigidized sectors. The existence of a railway line and a motorway running parallel to the coastal fringe and within access of the strong storms illustrate the need for a dynamic management based on the calculated risk levels. The present economic situation which limits the capability for intervention and even more the adaptation or planning for future conditions, will aggravate this problem, precluding a proactive coastal management approach and leading to a poorly reactive policy, always more expensive in the long term.

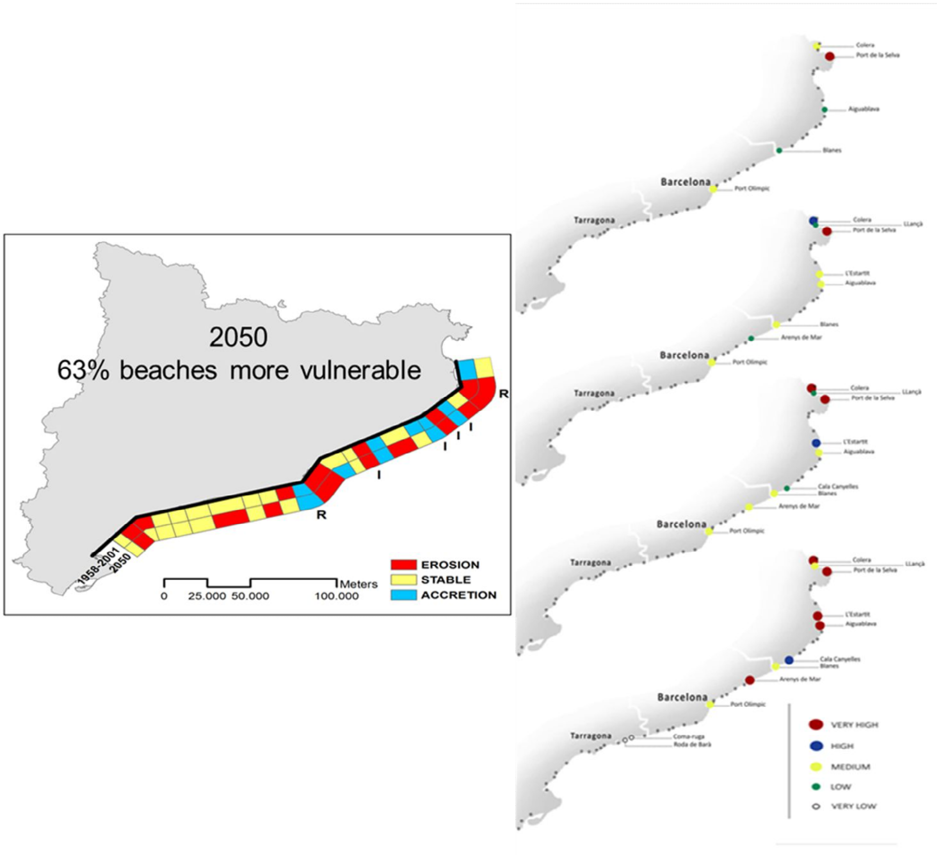

Figure 5. Summary of the implications of climatic change on the Catalan coast for beach vulnerability (left panel) and harbor functional vulnerability due to overtopping (right hand panel). The figures are based on information from Casas-Prat and Sierra (2014) and Casanovas (2014).

5. SUSTAINABILITY

Under these conditions it is imperative to look for more sustainable solutions at local, regional and global scales.

Within the RISES-AM- project we are considering the enhancement of accreting mechanisms along the coast, so as to use the hydraulic power of riverine and marine flooding to supply volumes of sediment that will offset the present scarcity. Such natural accretion mechanisms have been well-known four areas like coastal wetlands (Sierra at al., 2003; Ibáñez et al., 2010) where the control flooding and presence of vegetation has resulted in enhanced accretion, therefore increasing resilience in a natural manner.

The over wash of low-lying narrow beaches such as for instance barrier beaches in deltaic areas, also results in accretion for the lee side of the barrier. This goes however accompanied by breaching which may decrease the resilience of such narrow barriers. This can be illustrated by the Trabucador bar in the Ebro Delta, 200Km south of Barcelona, where modest relative sea level rise increases of 0.3m (two thirds assigned to relative sea level rise and one third assigned to subsidence) will result in a severe decrease of natural resilience in 100 years (Figure 6).

The sustainability paradox facing such semi-enclosed coasts in areas like the Mediterranean is that when trying to preserve the territorial extent in front of any alongshore barrier the beach width will steadily decrease while if an adaptation is allowed the beach width will maintain although a fraction of the territory will be lost. Therefore for coasts where there is accommodation space the option of allowing realignment of the shoreline will allow the maintenance of beach width. Oppositely the shore line rigidization will cause the disappearance of the sandy belt.

The availability of accommodation space will determine which of the two approaches is to be preferred or if it is feasible at all. As an illustration, for the central part of the Catalan coast more than half of the coastal sectors do not allow or provide accommodation space mainly due to human uses and infrastructures (Figure 7).

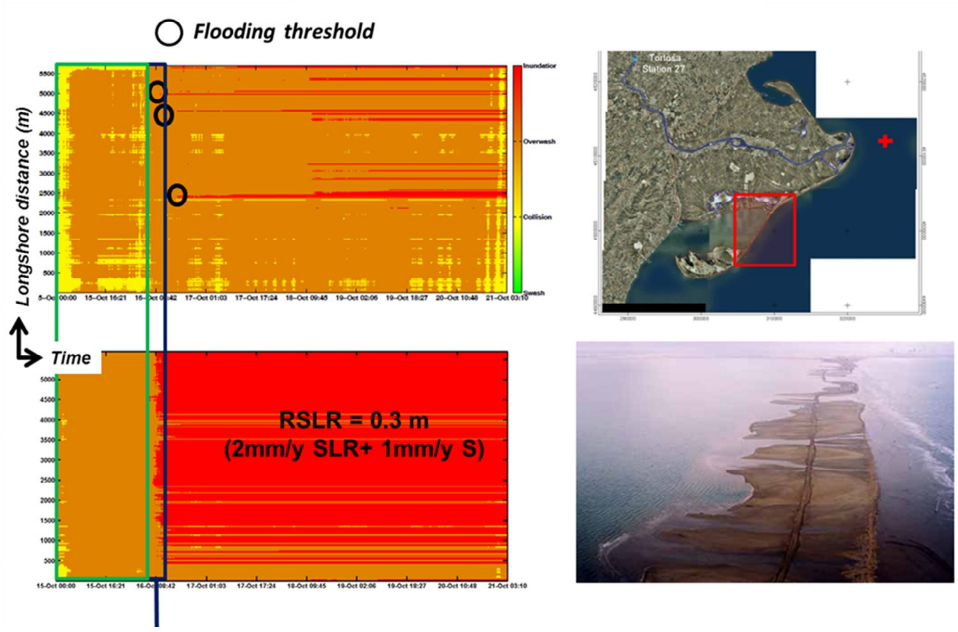

Figure 6. Illustration of the decrease of natural resilience in a narrow barrier beach in the Ebro Delta within the Spanish Mediterranean coast for a present climate storm (which actually occurred in October 2005 and corresponds approximately to a return period of 5 years).

The morphodynamic projection shows how the flooding threshold that produces breaching occurs only in three main locations along the barrier under present conditions but will be generalized (red color) for future conditions corresponding to a relative sea level rise of 0.3m (2mm per year due to sea level rise and 1mm per year due to subsidence) for the year 2100. Morphodynamic simulations may lead to a trustworthy option to test the feasibility of these natural processes at local scales, then filling the missing gap between climate projections and coastal fringe observations (Gràcia et al., 2013).

The shoreline definition also introduces a number of complexities and uncertainties that, unless properly solved, will preclude an objective application of any approach related to future coastal management under climate change. This complexity is illustrated in Figure 8 where the present, administratively accepted, shoreline appears with a continuous line for the area near the Barcelona harbor North-Eastern limit. The projection for the year 2100 shows how this shoreline will affect part of the urban area and even the harbor facilities. Therefore this introduces a dilemma on how to define the shoreline, the corresponding setback lines under future climates and even the possibility of allowing under future conditions (with an increased sea level rise) the overtopping of given coastal sectors for energetic storm events. The short term impact would probably be smaller than the cost of fully rigidizing all such coastal areas.

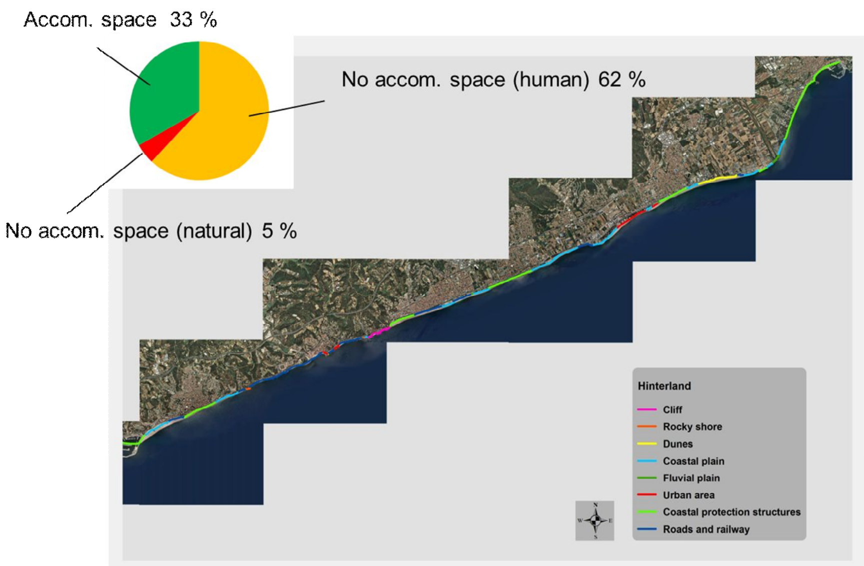

Figure 7. Summary of the accommodation space available in the central part of the Catalan coast showing that for more than 50% of coastal sectors there is no accommodation space due to human uses or infrastructure. Only in one third of the considered sectors there is enough accommodation space to allow for a managed realignment and therefore a more natural beach maintenance.

Figure 8. Present shoreline definition and projection by 2100 for the North-East side of the Barcelona harbor showing the difficulty of establishing and even defining a shoreline and the need to consider shoreline rigidization and even future *overtopping* under future climate particularly when considering a combination of accelerated sea level rise with energetic storm events.

6. CONCLUSIONS

The efficient response to coastal impacts under present and mainly future climate conditions must consider the present situation and the projected evolution. Actual economic conditions will determine the feasibility of the selected approach and even the convenience to implement some of the short term measures which may imply higher future costs so that the mid to long term sustainability is ensured.

The efficient response to mitigate coastal climate change impact must therefore consider the main points described in previous sections:

- The combination of storm and decadal scales so as to capture the full extent of evolving climates.
- The particular vulnerability of areas such as low lying deltaic coasts and urban beaches that will require earlier "maintenance".
- The full cost of any coastal intervention that should cover the initial and maintenance dimensions plus also the expected impact at short and long term scales, so as to avoid present decisions that may lead to undesirable future states of the coastal area.
- The combination of conventional interventions with novel approaches that enhance natural accretion. The selection of measures that work with Nature will result in a more sustainable coastal area under any type of climate.
- The performance of the various coastal sectors and interventions according to some objective set of criteria as, for example, the objective evaluation of risk levels as a function of climate and coastal functions.

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