Output 2 | Activity 2.1

Review and analysis of the state of the art of studies and management plans carried out in different coastal areas within the framework of coastal risk assessment.

English

REPORT 2.1 – 28 Dec 2018 - UNIDO/CTCN Rfx 7000002437

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Technologies for the design of a regional strategic plan for the coastal management and adaptation to Climate Change in the Province of Buenos Aires

Work team

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Summary

The threats (from the climate system) and the exposure and vulnerability (from the socioeconomic system) are the elements to take into account to advance on a coastal risk analysis. In the framework of Climate Change, it is necessary to focus on the study of the main threats of the system that for this case consist in waves and sea level.

Waves are the main agent for the transport of sediment on beaches and are largely responsible for the shape of the beach, while the average level of the sea results in the basic condition on which the storm events and wave weather develop. In a first approximation to these variables through data and global models, the projections of the same were analyzed.

The global atmosphere and ocean models (GCMs) used by the international scientific community to assess the effects of global climate change do not model the waves, the astronomical tide nor the meteorological tide (due to the different scales of these processes), so the latter should be studied separately based on the results obtained with the GCMs.

On a global scale, the projections for an increase in the mean sea level for 2081-2100 are in the order of 30 to 60 cm in the less pessimistic scenario and 50 to 100 cm in the most pessimistic scenario (in the Mar del Plata area the increase range is expected to be somewhat higher). Regarding the tides, in the case of the astronomical one, historical changes have been observed in the phase and amplitude of some of the main components, but whose impact on the extreme sea levels is not sufficiently understood yet. In the case of the meteorological one, changes that are not yet specified at the regional level are expected.

The situation with the projections of change in the swell is similar to the one described for the meteorological tide, but it could be affirmed that in the maritime coast of the province of Buenos Aires a slight increase in the average significant wave height could be expected, as well as a counter-clockwise rotation of waves in the southern section and a negligible one in the northern section, and a decrease and increase in the average period in the southern and northern sections, respectively.

A review was made of the different methodologies and/or tools that currently contribute to the risk analysis of coastal zones. In this review, the studies that were prioritized were the most recent ones, but also those that had different types of approaches and methodologies. Among the collected methodologies the ones that stand out are those that serve as support for decision making for the assessment of the impact of coastal climate change based on Geographic Information Systems (GIS) and allow the use of free access global data to be able to carry out preliminary analyzes quickly and at low cost; models with a high degree of detail in the representation of risk indicators, analyzis prepared from quantitative hazard and vulnerability indexes made up of different indicators, and improvements to existing tools that allow for the opinion of experts to be taken into account when the data involved are inconsistent or insufficient.

Numerical modeling has become an essential tool to quantify risks associated with different threats within coastal management, as well as to analyze the impact of infrastructure works and different future scenarios (especially associated with Climate Change). Depending on the physical problem they represent, these models can be hydrodynamic, sedimentological and/or morphological. They can be used independently or coupled together.

The importance of remote sensing applied to the analysis of marine and coastal phenomena that affect littoral dynamics was also highlighted, analyzing those methodologies that explore the Earth's crust from the atmosphere, using satellites or airborne sensors (aerial photography, LiDAR, satellite images, radar) as well as other techniques, that also apply indirect measurement, such as the analysis of video and photographs, or those used in terrestrial and marine geophysics (georadar).

Finally, different Coastal Management Plans (CMP) were revised, directing the search towards recent management tools and having different types of approach and methodologies: plans with a strong involvement of social actors, with lists of actions to be carried out in the short, medium and long term to reduce coastal risk, based on the principle of environments (or management units), with articulation of lines of action and management instruments under the analysis of impact indicators to assess efficiency. It is emphasized that most of the plans analyzed have an action horizon of between 5 and 10 years, enabling their review in the future.

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1 INTRODUCTION

1.1 Problem

The oceanic coast of the Province of Buenos Aires presents a great diversity of beaches along its 400 km, with different wave regimes, tides, and with variable morphological and granulometric compositions. Between San Clemente, in the NE, and Pehuén-Co, in the SW, there are more than 30 coastal cities that belong to 12 counties of the province (Figure 1.1). These cities have significant differences in terms of population and economic activities. The main activities are associated with tourism and commercial activities linked to the local ports.

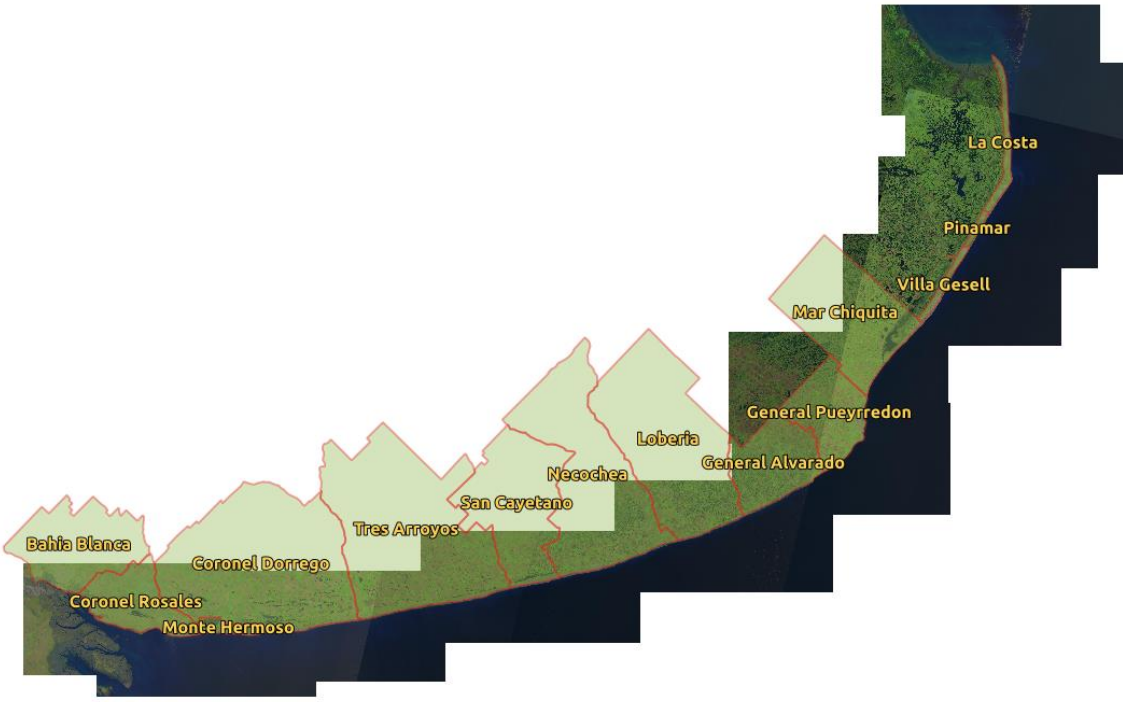


Figure 1.1. Counties of the maritime coast of the province of Buenos Aires.

This coastal region is affected by numerous environmental and climatic problems, mainly due to coastal erosion. Anthropic activities such as the construction of coastal defenses, urban growth on the dune zones, the extraction of sand and the exploitation of aquifers without proper management have aggravated erosion processes and increased vulnerability to climate change.

The constant action of the waves and the impact of the severe storm events (called “Sudestadas” in the region) are the main responsible for the erosive dynamics of the Buenos Aires coast. Studies related to specific works such as the installation of breakwaters to prevent erosion in the cliffs area in Mar del Plata, the execution of coastal defenses to protect roads, or plans to modify one of the breakwaters of the Port of Mar del Plata, reinforce the need to have comprehensive and planned coastal management. It is in this context that the concern of the province of Buenos Aires emerges regarding the vulnerability of the coast to the various threats that would affect its dynamics in the framework of climate change.

1.2 Technical assistance

The analysis of natural coastal processes (meteorology, climatology, hydrodynamics and morphology) in relation to changes in human activities and land use/coverage, is a necessary input for the study of risk of coastal erosion in a comprehensive manner and the generation of information needed for the concretion of a coastal management plan for Buenos Aires.

Within this framework, the Department of the Maritime Coast of the Province of Buenos Aires requested Technical Assistance from CTCN (Climate Technology Center & Network) that proposes two general objectives: i) to diagnose the current state of the dynamics in the oceanic coast of the province , and ii) implement a risk map against Climate Change and outline recommendations for coastal management, to be used as input in the implementation of a Strategic Management Plan for the whole of the Buenos Aires coast to be developed in the future.

Among the specific objectives to be reached by this Technical Assistance we can distinguish: i) to determine the changes that have occurred in the coastal dynamics during the last decades (sea level, waves, wind, morphological changes), ii) estimate from Climate Change projections the possible future coastal scenarios; and iii) to develop technological transferable tools, training and education associated with the project. Among the main products of this assistance stand out the enhancement of the numerical modelling tools of the applicant, the training and coaching in the utilization of these tools and the preparation of a manual of recommendations for coastal management of the oceanic coast of Buenos Aires.

This Technical Assistance is carried out by the professional teams of the Hydraulics Laboratory of the National Water Institute (INA, for its acronym in Spanish) of Argentina and the Institute of Fluid Mechanics and Environmental Engineering (IMFIA, also for its acronym in Spanish) of the Faculty of Engineering of the University of the Republic (UdelaR) of Uruguay.

1.3 Activity 2.1

Activity 2.1 of this Technical Assistance is part of the deliverable 2, in which a review and an analysis of the state of the art of the technological tools used to evaluate the coastal infrastructure alternatives is carried out. Specifically, this activity includes the compilation of international experiences in risk analysis and coastal management and its link with Climate Change and numerical modelling.

The report of Activity 2.1 focuses on the review of the state of the art in terms of the coastal risks associated with Climate Change, the analysis of their methodologies for analysis, the tools for modelling and observing these problems, and the analysis of coastal management plans. For this, a great amount of literature and experiences in this subject was reviewed from international, regional (Latin America) and local projects (Province of Buenos Aires, Argentina).

Specifically, results and projections on a global scale of the relevant threats such as waves and sea level were analysed, for the study of climatic risks in the coastal zone. Then, different methodologies and/or risk analysis tools were reviewed, prioritizing the most recent developments and having different types of approach and methodologies (based on Geographic Information Systems, use of global and low-cost data, modelling with a high degree of detail in the representation of the risk indicator, analysis with indicators, and consideration of the opinions of the experts when the data involved are inconsistent or insufficient). Numerical modelling (hydrodynamic, sedimentological and morphological models) was characterized as an essential tool to quantify risks associated with different threats in coastal management as well as to analyse the impact of infrastructure works and different future scenarios (especially associated with Climate Change).

The importance of remote sensing applied to the analysis of marine-coastal phenomena affecting coastal dynamics was also highlighted, analysing those methodologies that explore the Earth's crust from the atmosphere, using satellites or airborne sensors (aerial photography, LiDAR, satellite images, radar) as well as other techniques, that also apply indirect measurement, such as the analysis of video and photographs and those used in terrestrial and marine geophysics (georadar).

Different Coastal Management Plans (CMP) were reviewed, directing the search towards recent management tools that have different types of approach and methodologies: plans with a strong involvement of social actors, with lists of actions to be carried out in the short, medium and long term to reduce coastal risk, based on the principle of environments (or management units), with articulation of lines of action and management instruments under the analysis of impact indicators to assess efficiency. Finally, all the information reviewed was georeferenced and incorporated into a database (Figure 1.2).

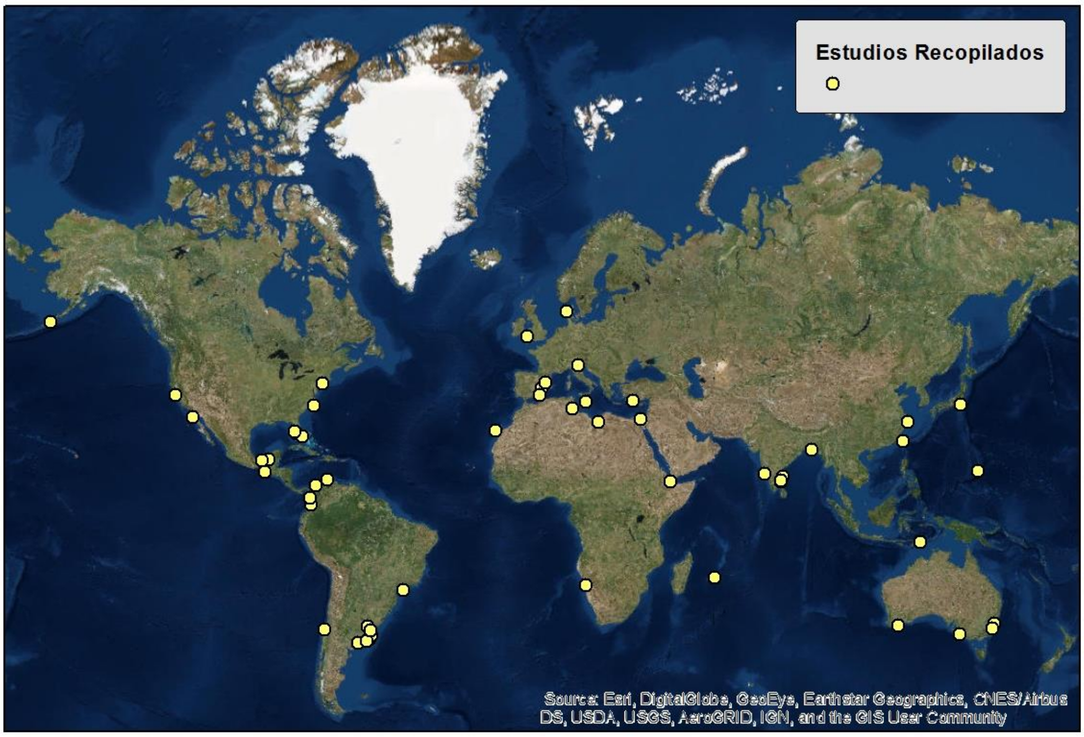


Figure 1.2. Location of the most relevant studies compiled for this report.

2 RISKS OF EROSION AND FLOODING OF COASTAL AREAS ASSOCIATED TO CLIMATE CHANGE

The conceptual reference framework for the definition of coastal risk used by the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2014), presented in Figure 2.1, raises the difference between threats (from the climate system) and exposure and vulnerability (from the socioeconomic system). In this framework, it is clear that any analysis of risks associated with Climate Change should quantify in a reasonable manner the main threats of the system.

This chapter summarizes the main existing studies and results in terms of the quantification of the relevant threats for the risk analysis in the coastal zone, which are: waves and sea level. It is important to mention that the results associated with the quantification of the threats presented below are the outcome of data and global models.

This chapter is broken down into three sections: first, the results included in the IPCC document (2013) are analysed, identifying the information available for the study area (maritime coast of the province of Buenos Aires); second, the main studies published from 2014 to date are summarized; and finally, the new results available for the study area are mentioned.

2.1 Threats

The main threats to the processes of erosion and flooding on the coast are of maritime origin, associated with extreme values of sea level and waves. In coastal sections influenced by the mouths of rivers or coastal lagoons, the processes associated with river discharges may also be relevant.

The total sea level on the coast is the sum of the average level, the astronomical tide and the meteorological tide (storm surge); on the beaches, where the processes associated with the break of waves are significant, the set-up and the ascent produced by the waves (run-up of the wave in the swash zone) is added to the above mentioned. Figure 2.2, taken from Melet et *al*. (2018) shows the superposition of levels described.

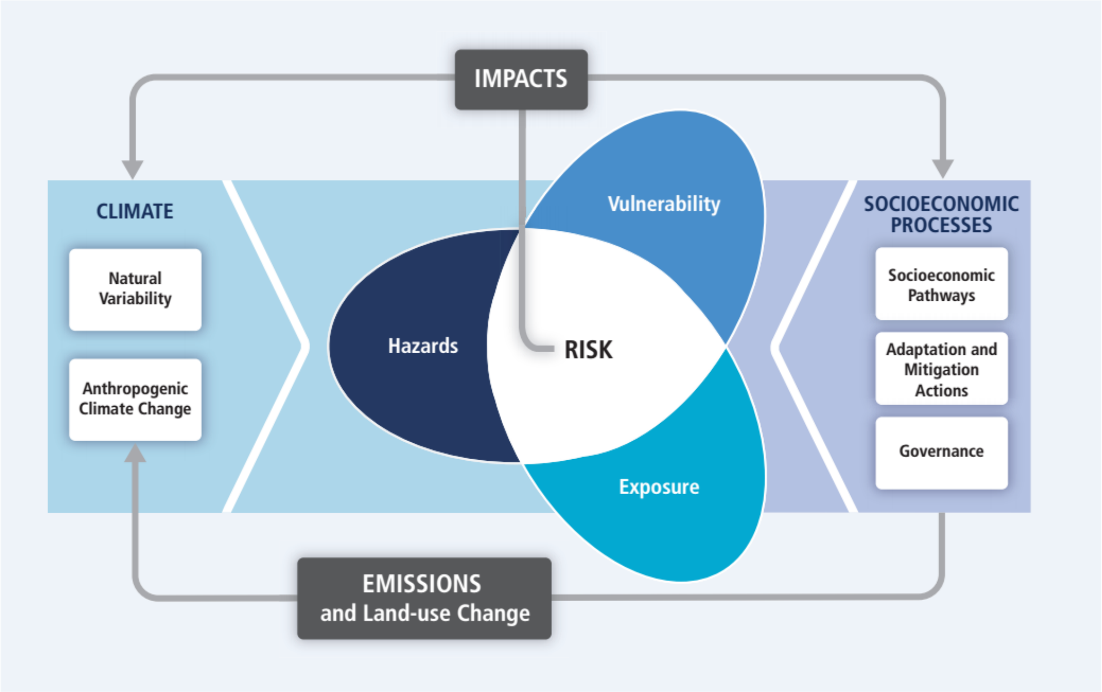


Figure 2.1. Figure TS.1 of the IPCC (2014) with the conceptual representation of the risk calculation.

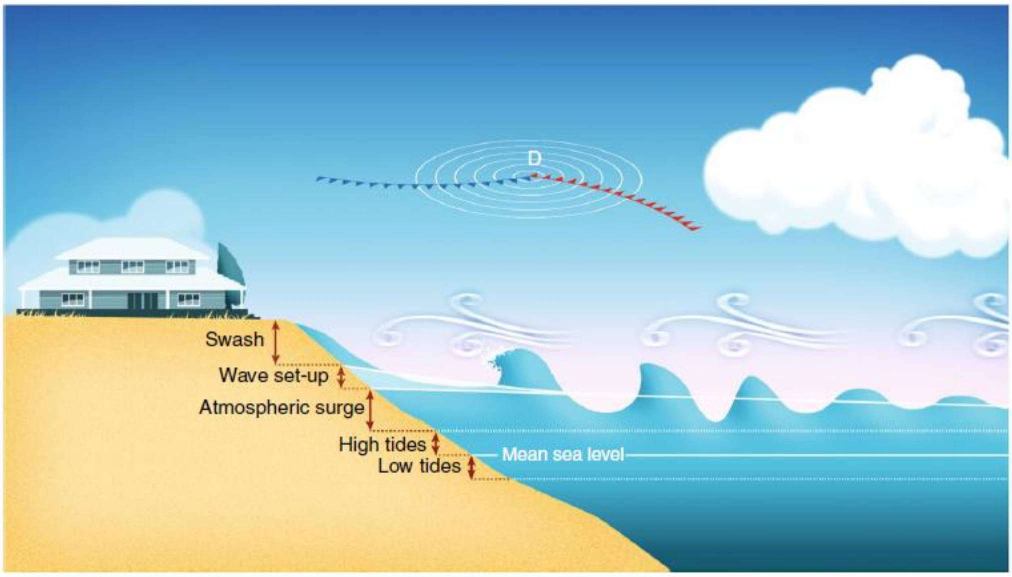


Figure 2.2. Scheme of the components of the total sea level in beaches, taken from Melet et *al*. (2018)

The waves are the main force for transport of sediment on beaches. Its characteristics, both in medium and extreme conditions, largely determine the layout and beach profile, as well as the response of it to storm events.

The changes in the level of threat caused by Climate Change therefore have a direct impact on the level of risk on the coast. However, the quantification of the expected changes in the level of threats in different climate change scenarios is not immediate. On the one hand, the global atmosphere and oceanic models (Atmosphere-Ocean Global Climate Models, AOGCM or GCM) used by the international scientific community to assess the effects of global climate change do not model the swell, the astronomical tide, nor the meteorological tide (storm surge), so these processes should be studied separately, based on the results obtained with the GCMs (see e.g. IPCC, 2013, chapter 13). On the other hand, these processes have different scales and origins, which requires different approaches to study each one of them, not being feasible from the technical and computational point of view the joint study of all of them in a single model (see e.g. Vousdoukas et *al*., 2018).

Next, the strategies used to estimate the change in waves and the sea level product of climate change are reviewed, as well as the results obtained in those studies that cover the area of interest (Atlantic coast of the province of Buenos Aires). Section 2.2 summarizes the information available in the 2013 IPCC report. Then, in section 2.3, the most relevant studies published in scientific journals from 2013 to date are briefly presented and discussed. Finally, section 2.4 summarizes the results obtained by the different works for the study area.

2.2 State of the art to the IPCC report (2013)

2.2.1 Mean sea level

Sections 13.5 to 13.7 of the IPCC (2013) discuss global and regional projections of mean sea level rise, as well as expected changes in extreme sea level and wave events.

Regarding the increase of the mean sea level, globally and regionally, the report discusses the results obtained through two approaches: by using semi-empirical methods and those obtained from the AOGCMs in the framework of the CMIP5 (Coupled Model Intercomparison Project Phase 5), indicating that the results obtained with the former are systematically higher but very unreliable, so the discussion of results focuses on those achieved with the latter.

Of the projections of increase in the mean sea level at a global level (GSLR), obtained from the AOGCMs of CMIP5 for different emission scenarios, it appears that it is very likely that by 2081-2100 the average sea level will increase between 32 cm and 63 cm in a RCP4.5 scenario and between 52 cm and 98 cm in a RCP8.5 scenario (values corresponding to the confidence range 5%-95%). Figure 2.3, taken from IPCC (2013), shows the evolution of the average level of the sea at a global level for the different scenarios of concentration of greenhouse gases (RCPs), indicating the contribution to the increase of the mean sea level generated by different factors.

Regarding the increase of the mean sea level in different regions, and in particular in the maritime coast of the province of Buenos Aires, the report summarizes the results obtained from the AOGCMs (see Figure 2.4) and presents the results corresponding to Mar del Plata (see Figure

2.5). It can be noted that the range of sea level rise in the study area would be somewhat higher than the increase in the mean global sea level.

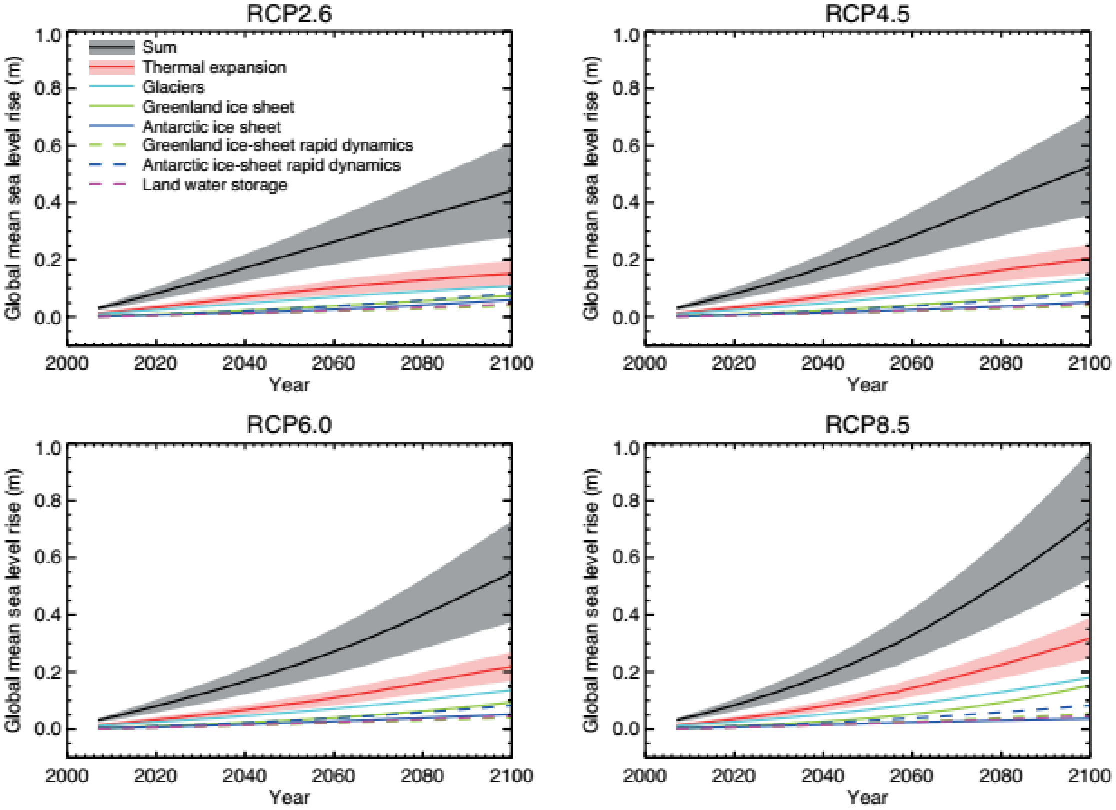


Figure 2.3. GSLR in different scenarios of concentration of greenhouse gases, obtained from the CMOG5 AOGCMs (figure 13.11 of IPCC, 2013).

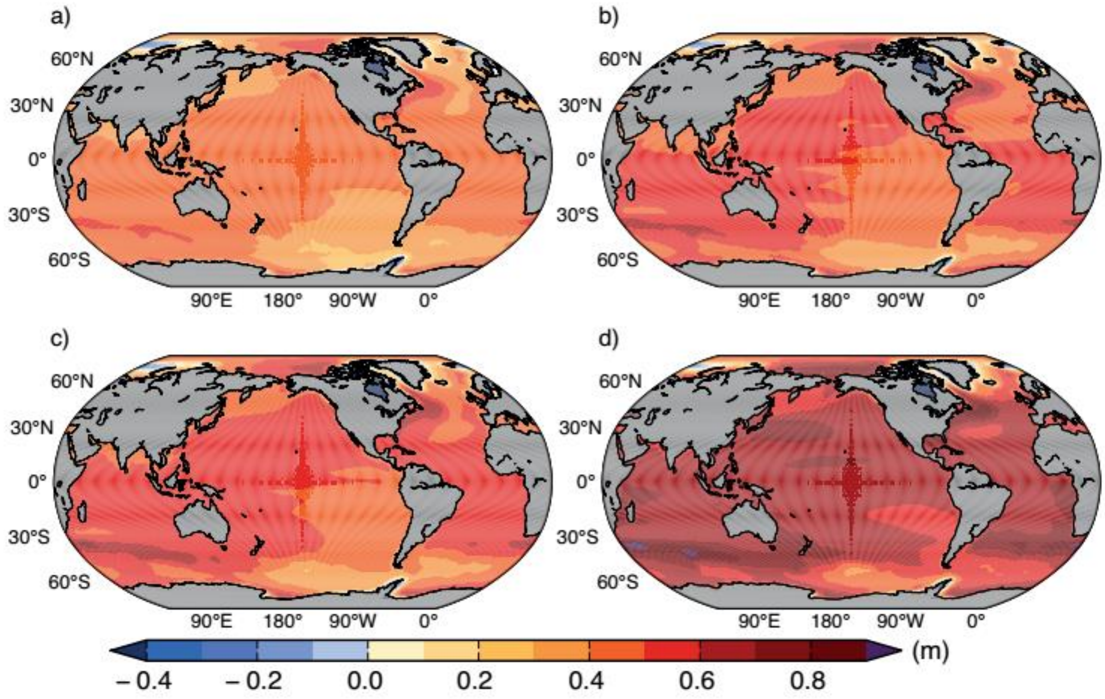


Figure 2.4. Increase in the regional average sea level by 2100 according to figure 13.20 of IPCC (2013): (a) RCP2.6, (b) RCP4.5, (c) RCP6.0 and (d) RCP8.5.

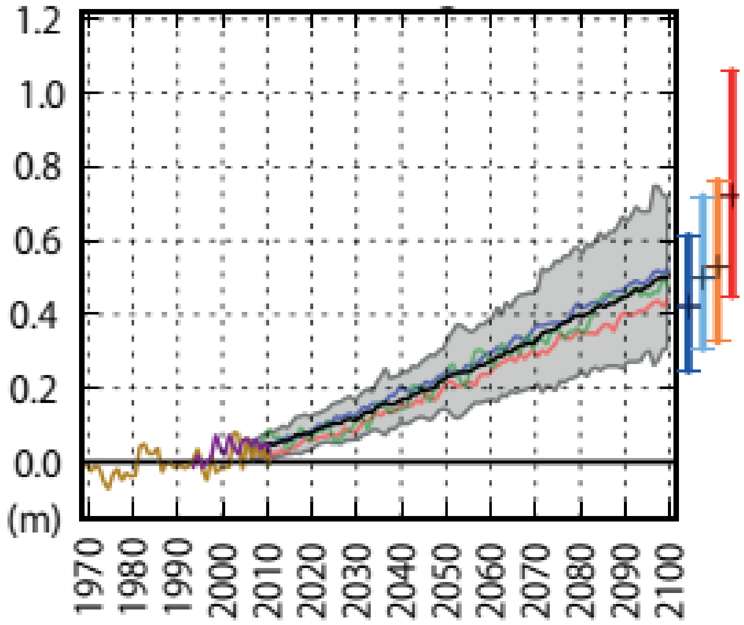


Figure 2.5. Increase in the average level of the regional sea for Mar del Plata according to figure 13.23 of the IPCC (2013). Curves in colours prior to 2010 correspond to observations; the black curve and gray shadow correspond to the average value and range 5% -95% in the RCP4.5 scenario. Colour curves after 2010 are the results of particular models in the RCP4.5 scenario. Colour bars on right vertical axis are ranges 5%-95% for RCP2.6, RCP4.5, RCP6.0 and RCP8.5.

2.2.2 *Total sea level*

The studies carried out to date from observed sea level data (Bindoff et *al*., 2007, Menéndez and Woodworth, 2010, see references in IPCC, 2013) show that there is an increase in the extreme values of the level of total sea worldwide, mainly due to an increase in the mean sea level.

For the 21st century, available studies indicate that it is likely that an increase in the occurrence of extreme sea level events will be observed in some regions, and this behaviour is very likely to be observed towards the end of the century. It is virtually certain that an increase in the mean sea level will produce an increase in sea level extremes, but there is not enough confidence in the projections of the storm events to make projections for specific places.

2.2.3 *Astronomical tide*

Reference is made to the studies by Jay (2009) and Muller et *al*. (2011) (see references in IPCC, 2013), where it is indicated that a historical change has been observed in the phase and amplitude of some of the main tidal components, but it is pointed out that the impact of this on extreme sea levels is not sufficiently studied yet.

2.2.4 *Meteorological tide (storm surge)*

Although it is expected that there will be changes in the meteorological tide in the different climate change scenarios, the report indicates that to date there is little confidence in specific results at a regional level. This is due, on the one hand, to the fact that few available studies have used GCMs outputs to force a meteorological tide model (Debernard and Roed 2008, Wang et *al*. 2008, Sterl et al. 2009, Colberg and MacInnes 2012, Harper et *al*. 2009, see references in IPCC, 2013) and, in addition, in all cases it has been done with results prior to CMIP5. On the other hand, there is little confidence in the ability of the GCMs to represent variations in the amount and intensity of storms for a specific point, which limits the possibility of evaluating changes in the meteorological tide at a local level.

2.2.5 *Waves*

In the IPCC report (2013), the situation with the projections of change in the waves is similar to that described for the meteorological tide. There is little confidence in the representation of the storms locally in the GCMs, which directly affects the confidence in the results obtained by forcing wave models with the winds obtained from them. In addition, to date the studies related to the change of waves due to climate change are very scarce and based mainly on outputs from the GCMs prior to the CMIP5.

The results presented are based mainly on the work of Hemer et *al*. (2013), and are also discussed the works of Mori et *al*. (2010), Fan et *al*. (2013), Semedo et *al*. (2013), Hemer et *al*. (2012a) and Wang and Swail (2006) (see references in IPCC, 2013), all based on results obtained with CMIP3. According to the results presented, on the maritime coast of the province of Buenos Aires, it would be expected a slight increase in mean annual significant wave height, a counter-clockwise rotation of the wave in the southern section and negligible in the northern section, and a decrease and increase of the average period in the south and north sections respectively (see Figure 2.6).

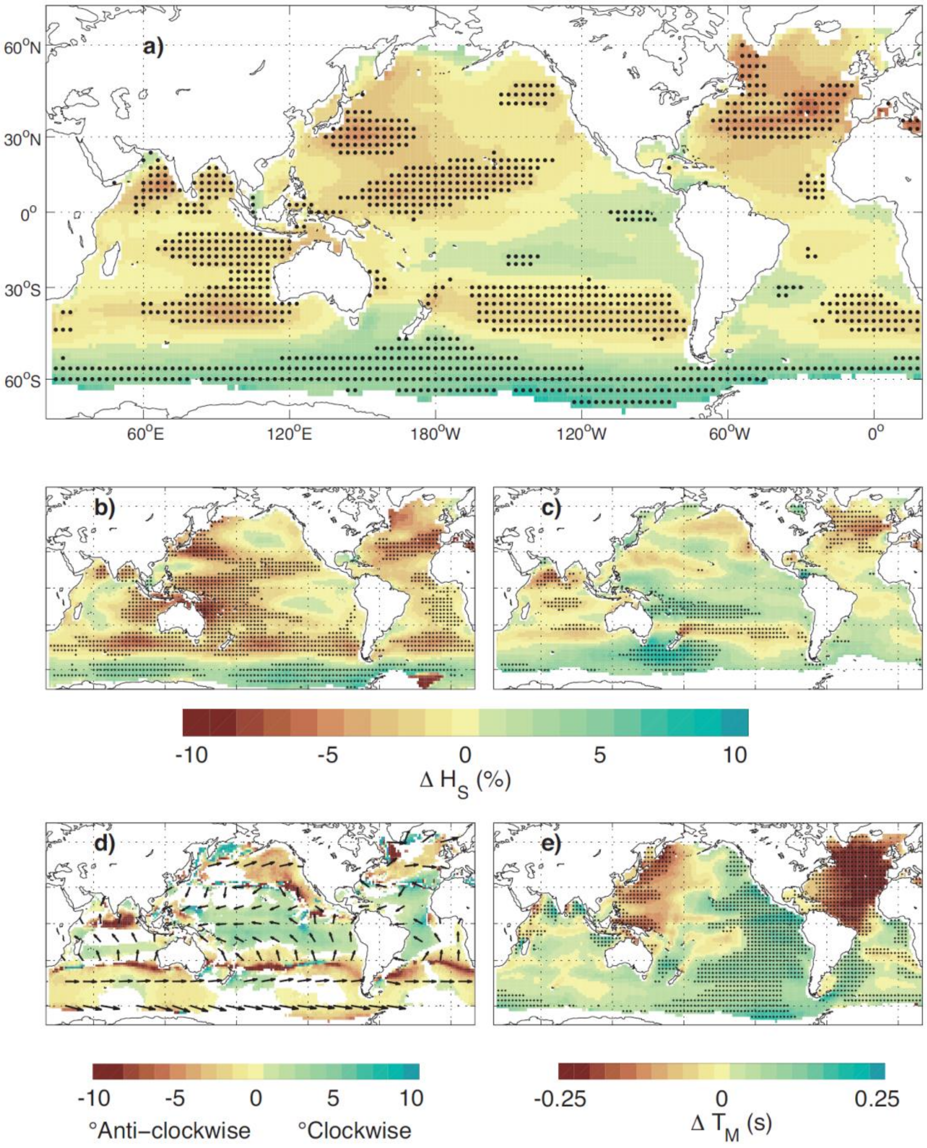


Figure 2.6. Figure 13.26 of the IPCC (2013). Above: change in height of significant mean annual wave (a), average of January, February and March (b) and average of July, August and September (c). Below: change in the annual average direction (left) and in the average annual period (right). Results corresponding to the study by Hemer et *al*. (2013).

2.3 Most relevant publications in the period 2014-2018

2.3.1 Mean sea level

Slangen et *al*. (2014) update the regional projections of increase of the mean sea level published in IPCC (2013), using the results of the CMIP5 climate models together with other sources of information that allow to quantify contributions to sea level rise not contemplated in these models. The work time horizon is 2100 and it manages the RCP 4.5 and RCP 8.5 scenarios. Carson et *al*. (2016) use the information generated by Slangen et *al*. (2014) to analyse the expected change in the mean sea level on the coast.

There are several studies that focus on specific contributions to the change of the mean sea level, either globally or regionally (e.g. Albrecht and Weisse, 2014, analyse the change in the mean sea level on the German North Sea coast by effect of changes in atmospheric pressures).

2.3.2 Total sea level

Recently, Melet et *al*. (2018) have pointed out the importance of considering the components coming from the waves in the analysis of the trends of the total sea level, particularly on beaches, where the set-up and the run-up produced by the swell can be significant. Some recent studies in this regard are Vousdoukas et *al*. (2017), focused on the coast of Europe, and Vousdoukas et *al*. (2018), where the analysis extends globally.

2.3.3 Astronomical tide

There are few studies focused on analysing how astronomical tides will be affected by climate change. Pickering et *al*. (2017) analyse the effect of sea level rise on the amplitude and phase of four astronomical tidal components at a global level. In their study, the authors do not refer to any standard projection scenario of climate change, but study the expected effect that would have different values of sea level rise, defined arbitrarily within the range of expected increases.

2.3.4 Meteorological tide (storm surge)

As with the astronomical tide, the number of studies focused on the analysis of the effects of climate change on the meteorological tide (or storm surge) is relatively small.

The usual approach for these studies is to use the winds and surface pressures obtained from climate models, either CMIP3 or CMIP5, to force a hydrodynamic model integrated vertically into global or regional domains. Yasuda et *al*. (2014) focus on the generation of storm surge by tropical cyclones in East Asia, focusing on the coast of Japan. In their simulations, they use results from CMIP3 climate models and focus on the 2015-2039 and 2075-2099 time horizons.

Vousdoukas et *al*. (2016) use results from eight CMIP5 climate models to force a two-dimensional hydrodynamic model in a domain that covers the entire European coast. The study analyses time horizons 2050 and 2100, and scenarios RCP4.5 and RCP8.5. Fortunato et *al*. (2018) uses a similar strategy, but focuses on a short-term time horizon (near future: 2024), for which it uses decadal predictions, and in a more limited spatial region, limited to the western Atlantic coast of Europe.

In Camus et *al*. (2017) use a different approach to estimate the expected global change in storm surge regime. In this case, the authors use a statistical methodology to make projections, both of storm surge and waves, using as a predictor the fields of surface pressures obtained from thirty climate models of the CMIP5. The results presented focus on the waves, not showing results related to storm surges.

2.3.5 Waves

Unlike what happens with the studies referring to the astronomical and meteorological tide, the bibliography published from 2014 to date regarding the effects of climate change on the waves is relatively abundant. The vast majority of studies use methodologies based on dynamic projections (i.e. the use of numerical wave generation and propagation models), although there are some works based on the use of statistical methodologies.

Wang et *al*. (2014) make wave projections using statistical methodologies, based on the pressure fields obtained with 20 climate models of CMIP5, with scenarios RCP 4.5 and RCP 8.5, for the time horizon 2080-2099. More recently, Camus et *al*. (2017) propose a new statistical methodology, which they apply to project waves and storm surges from the outputs of 30 CMIP5 models in the RCP 4.5 and RCP 8.5 scenarios. Perez et *al*. (2015) uses a methodology similar to that used by Camus et *al*. (2017), but limits its analysis to Europe.

There are several studies of dynamic wave projections on a global level. Hemer and Trenham, (2016) evaluate the results obtained from the outputs of ten climate models, eight from CMIP5 and two from CMIP3. Casas-Prat et *al*. (2018) uses results from five climate models to analyse wave projections at 2100 in the RCP8.5 scenario. Morim et *al*. (2018) compares global and regional studies of wave projections, including those obtained from CMIP3 climate models and CMIP5. As noted in this paper, although there are several regional studies (e.g. Wandres et *al*., 2017, in Australia, Shimura et *al*., 2017, in Japan), to date none have focused on the South Atlantic. Mentaschi et *al*. (2017), on the other hand, focuses on the projections of wave energy flow, calculated globally from the outputs of six climate models of the CMIP5.

Laugel et *al*. (2014) compare the wave projections obtained from outputs of CMIP3 climate models using dynamic and statistical methods, concluding that although dynamic methods are more accurate, statistical methods have the advantage of being much less computationally complex. This facilitates the quantification of uncertainty since it is possible to consider a large number of departures from climate models to evaluate the projections.

2.4 Results available for the maritime coast of the province of Buenos Aires.

2.4.1 Mean sea level

With regard to the mean sea level, the results obtained by Slangen et *al*. (2014), based in part on the outputs of CMIP5 climate models, indicate that for the maritime coast of the province of Buenos Aires there would be an expected increase for the 2081-2100 time horizon of about 60 cm in scenario A (assimilable to CPR 4.5) and about 80 cm in scenario B (similar to CPR 8.5) (see Figure 2.7). Carson et *al*. (2016) present these same results for Mar del Plata (see Figure 2.8).

With regard to possible variations of the astronomical tide, the results obtained by Pickering et *al*. (2017) show that in general the changes in the high tide levels will not be very important, even in extreme sea level rise scenarios (see Figure 2.9).

Finally, the results available for the Atlantic coast of Buenos Aires in terms of potential changes in the total sea level on beaches (Vousdoukas et *al*., 2018) show that the increase in the periodicity of extreme level events, with a period of current return of 100 years, will be important, being possible to experience a reduction of the return period to values of 10 years or less according to the time horizon and the Climate Change scenario considered (Figure 2.10).

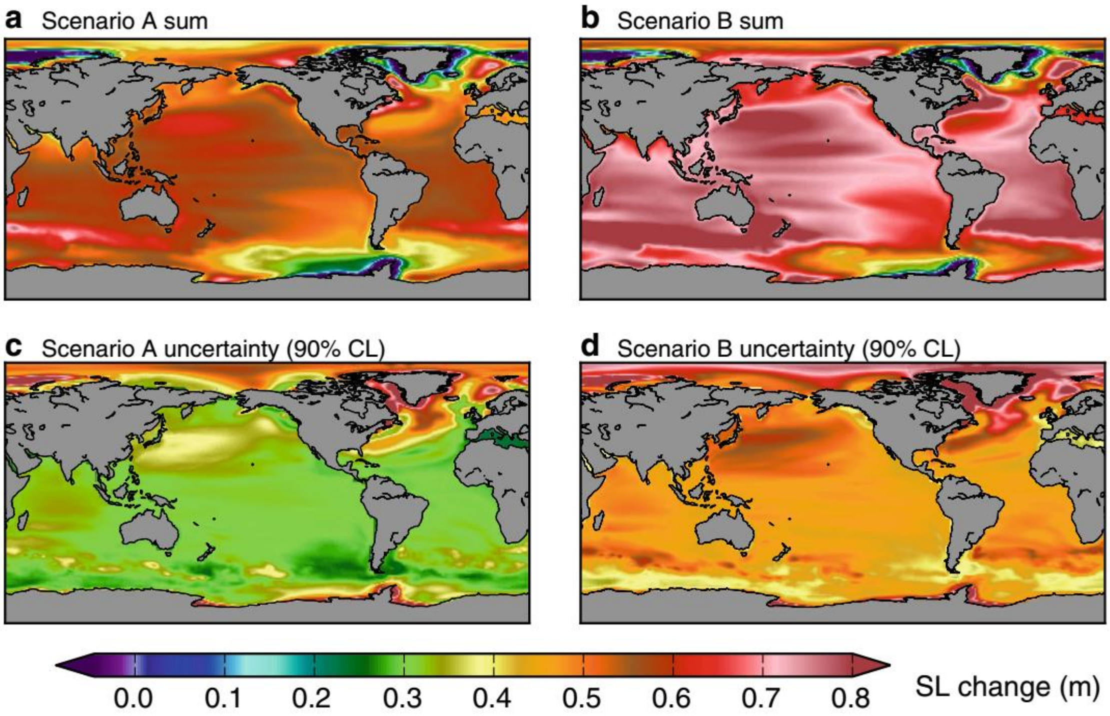


Figure 2.7. Results of SLC, changes in the mean sea level for 2081-2100 according to Slangen et *al*. (2014) (Fig.3). Scenario A assimilable to RCP 4.5 and scenario B assimilable to RCP 8.5.

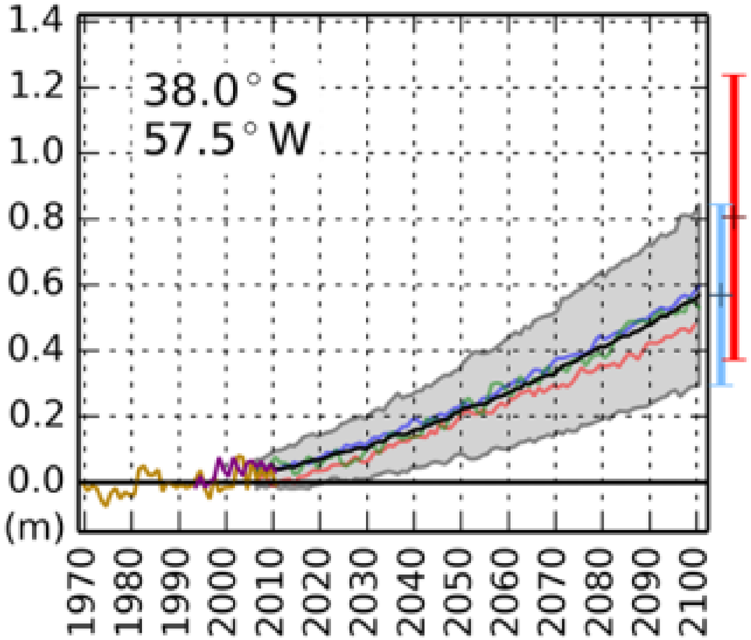


Figure 2.8. Increase of the mean sea level in Mar del Plata for CPR 4.5. Bars on the right axis are expected value and range 5% -95% for 2100 in scenarios RCP4.5 and RCP8.5 (Carson et *al*., 2016; Fig. 3).

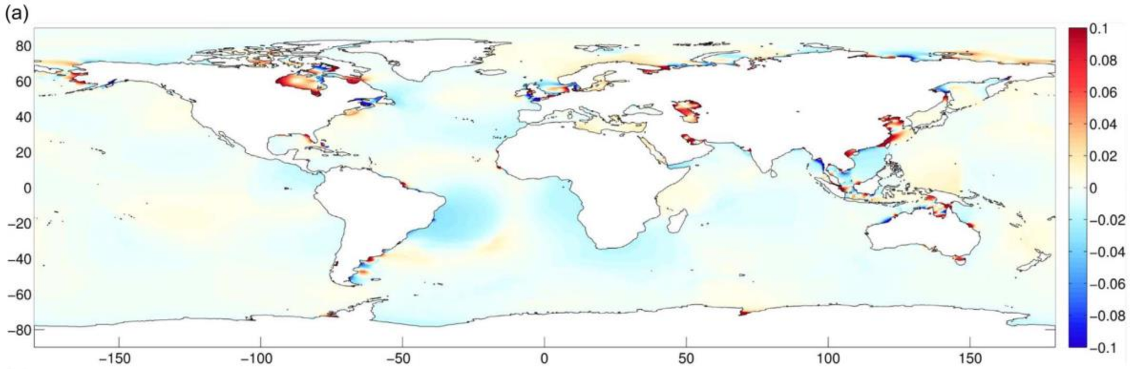


Figure 2.9. Change of the mean level of high tides at the global level assuming a rise of the mean sea level of 2 m (Pickering et *al*., 2017).

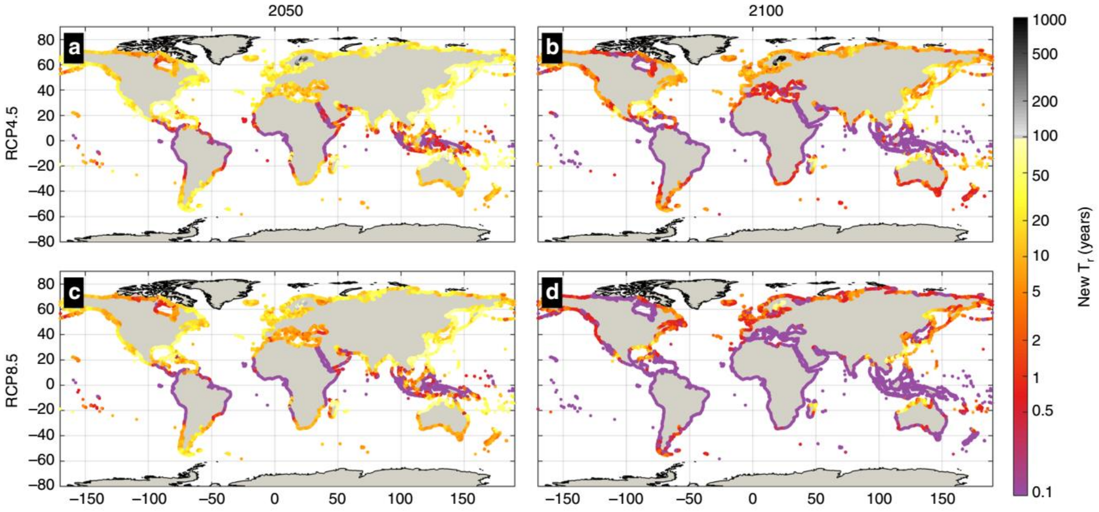


Fig. 8 Future frequency of the present day 100-year ESL. Colors show the return period of the present day 100-year ESL under RCP4.5 and RCP8.5 in 2050 (**a**, **c**) and 2100 (**b**, **d**), based on the median values. Note that the color scale is not linear

Figure 2.10. Change in the return period of the extreme sea level event with a current return period of 100 years, for different horizons and under different climate change scenarios (Vousdoukas et *al*., 2018).

2.4.2 Waves

The maritime coast of the province of Buenos Aires is included in the region called South Atlantic (SA) in the study by Morim et *al*. (2018). In this work it is indicated that there is no strong consensus between the results obtained with different models regarding the expected wave height trend in the region, but in general a tendency towards lower average and extreme wave height values is detected in the time horizon 2070-2100. However, it must be taken into account that the SA region covers from the coast of South America to the coast of Africa.

On the other hand, from the global study carried out by Casas-Prat et *al*. (2018), with time horizon 2081-2100, in which they use the outputs of five AOGCMs of CMIP5 with the climate change scenario RCP8.5, the following considerations for the study area are derived: (i) it is expected that the mean annual significant wave height increases up to 5% in the northern section and decreases up to 5% in the southern section, being statistically significant only the decreases in the wave height (see Figure 2.11); (ii) the maximum annual significant wave height could increase up to 10% throughout the area of interest, these increases being statistically significant (see Figure 2.12); (iii) the average annual spectral peak period would increase by up to 20% in the entire study area, this increase not being statistically significant (see Figure 2.13); (iv) the average annual mean spectral direction would have an anti-clockwise rotation of up to 10º in the northern section, statistically not significant, and between 10º and 20º in the south, statistically significant (see Figure 2.14).

Mentaschi et al. (2017) on the other hand analyses the expected changes in the wave energy flow of a 100 years return period, in the RCP 8.5 scenario. According to its results, an increase of up to 10% for 2100 is expected in the study area, while the expected changes for 2050 are not significant (see Figure 2.15). In what regards the direction of the energy flow, no significant changes are observed in the study area.

Camus et *al*. (2017) estimate the global change in the significant wave height, the average period and the meteorological tide in the RCP 4.5 and RCP 8.5 scenarios, using the outputs of thirty CMIP5 models. Unlike the works previously mentioned, Camus et *al*. (2017) use statistical techniques to perform wave and sea level projections. From the results shown in that paper it is clear that for the study area a decrease of up to 10% of the average annual significant wave height for the period 2070-2100 in the RCP 8.5 scenario would be expected (see Figure 2.16).

In Wang et al. (2014) probabilistic techniques are also used, but these reach contradictory results to those obtained by Camus et *al*. (2017) for the study area. The results obtained by Wang et *al*. (2014) show that for the study area it would be expected an increase in mean annual wave height in the northern section and a decrease in the southern part, as well as an increase in the entire area of the maximum annual wave height of up to 30 cm (Figure 2.17).

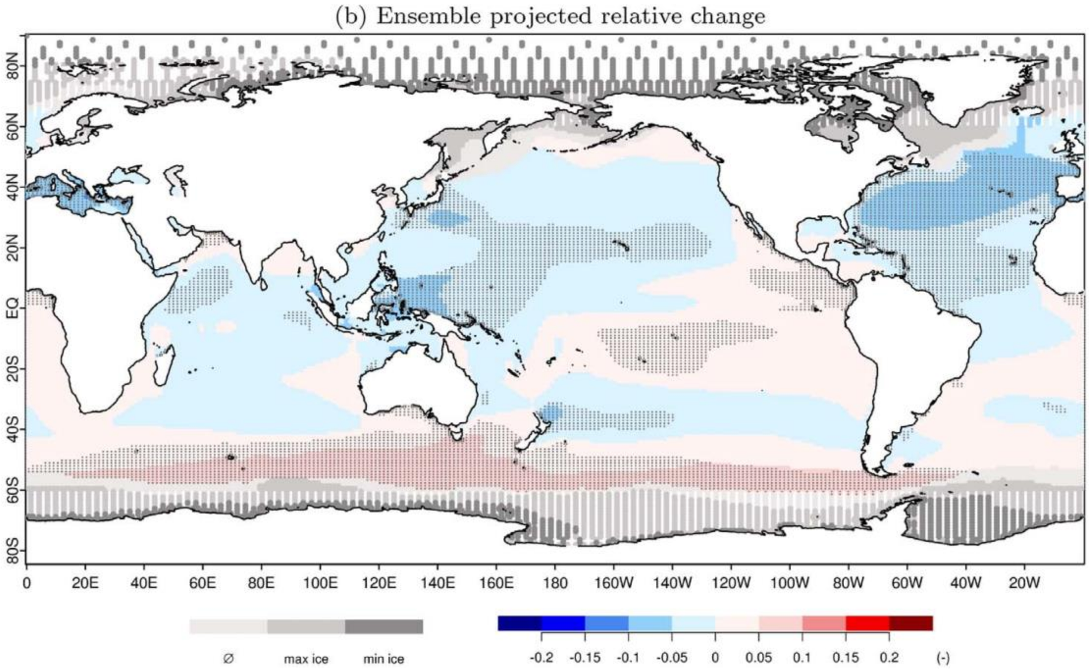


Figure 2.11. Assemble of the relative changes of annual mean Hs according to Fig. 8 of Casas-Prat et *al*. (2018).

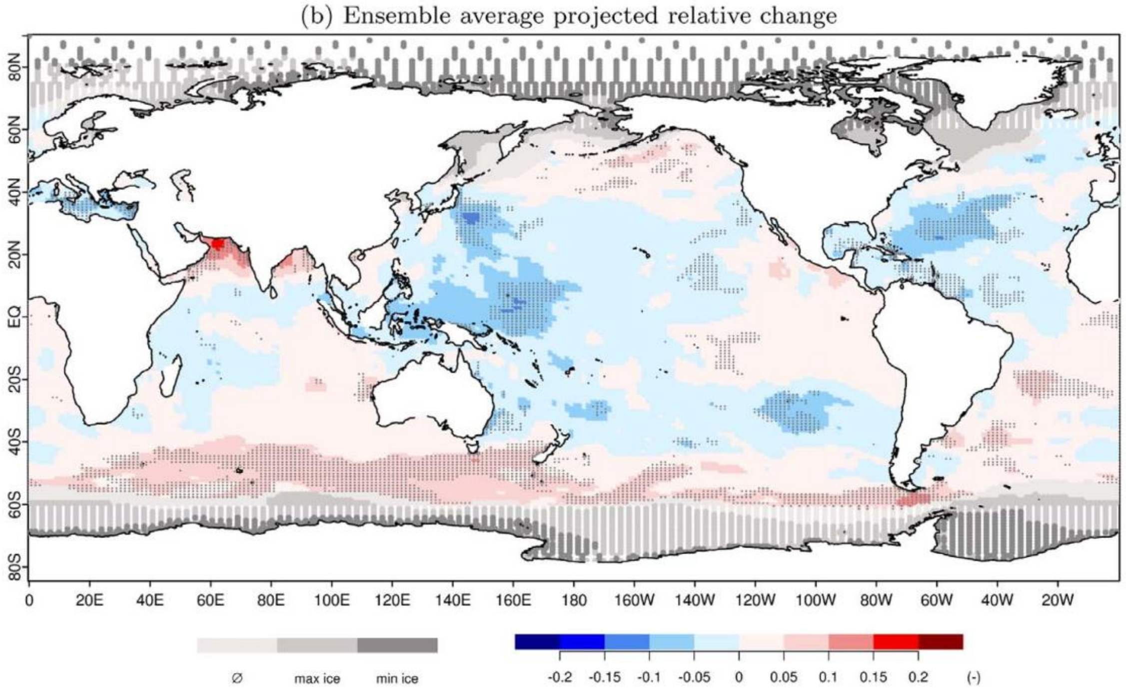


Figure 2.12. Assemble of the relative changes of annual maximum Hs according to Fig. 9 of Casas-Prat et *al*. (2018).

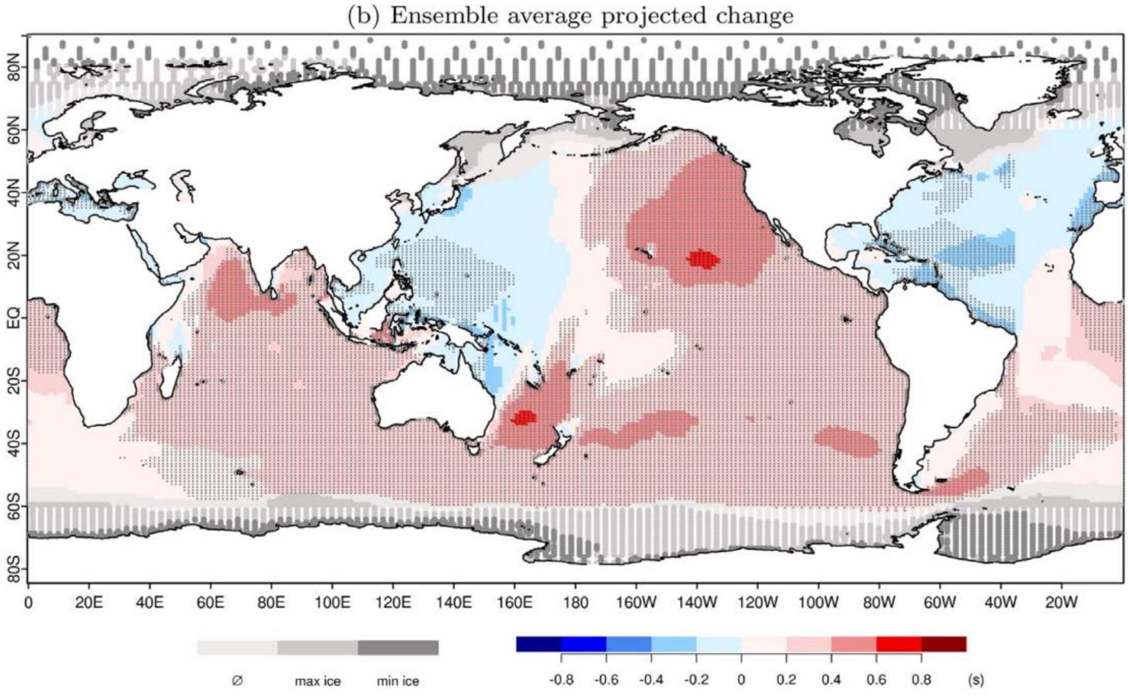


Figure 2.13. Assemble of the relative changes of mean annual Tp according to Fig. 10 of Casas-Prat et *al*. (2018).

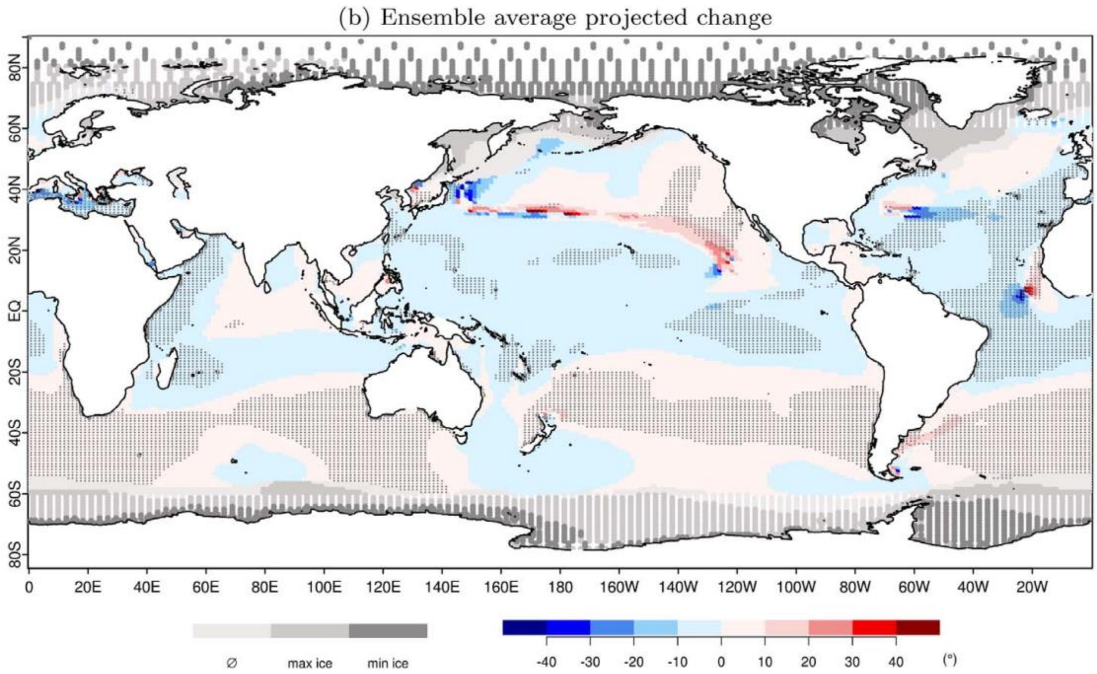


Figure 2.14. Assemble of the relative changes of the annual average direction according to Fig. 11 of Casas-Prat et *al*. (2018).

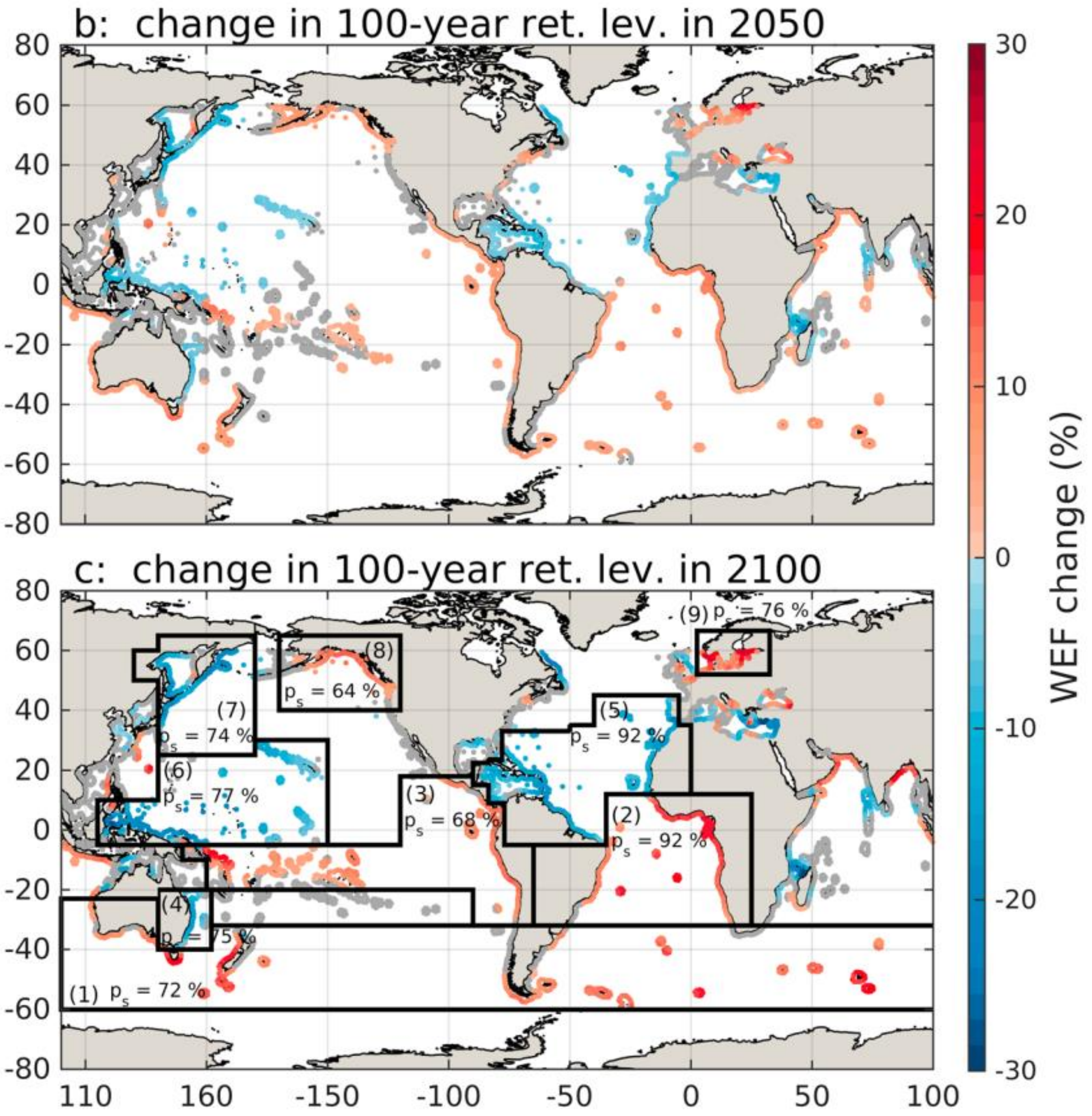


Figure 2.15. Expected changes in the wave energy flow of a 100 years return period according to Figure 1 of Mentaschi et *al*. (2017).

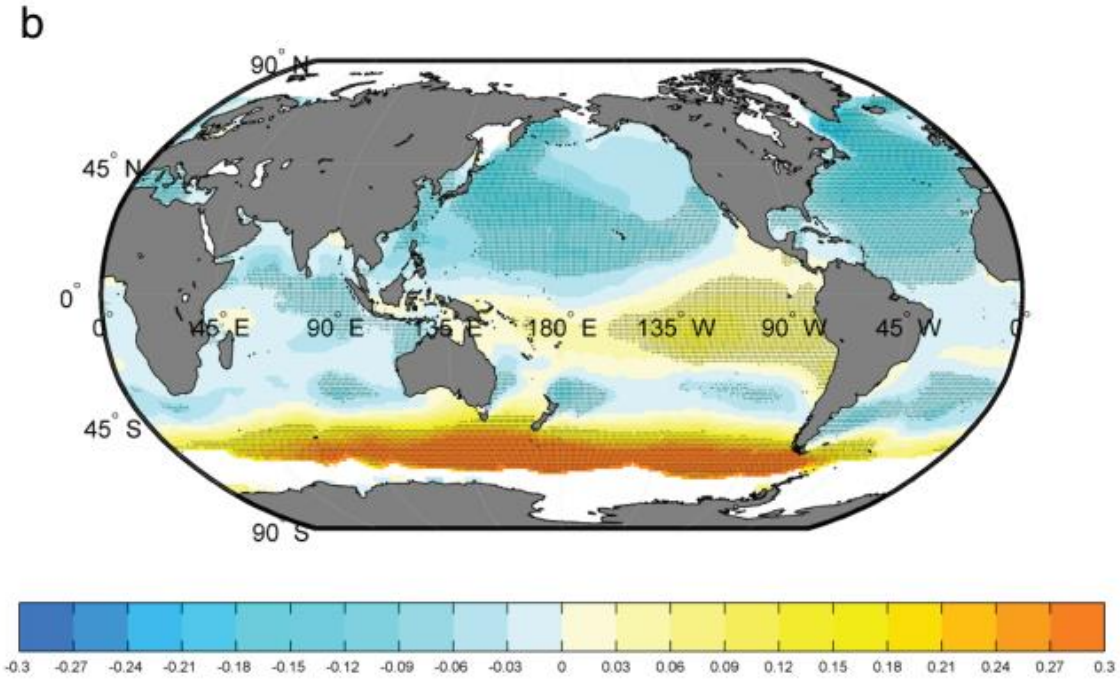


Figure 2.16. Change in mean annual Hs according to Figure 4 of Camus et *al*. (2017).

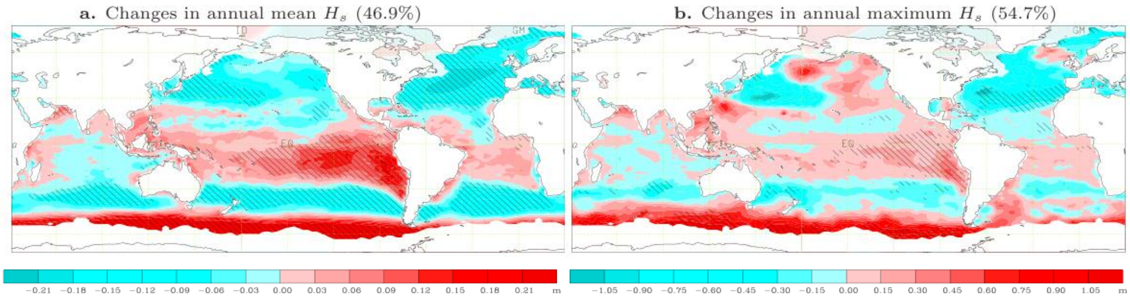


Figure 2.17. Result presented by Wang et *al*. (2014); Figure 2. Left: Assembly of change in average annual Hs. Right: Assembly of change in annual maximum Hs. RCP8.5; Changes for the time horizon 2080-2099.

3 MULTIPLE RISKS ANALYSIS

Risk Analysis is widely used in the management of coastal zones. They are used to quantify risks associated with different threats and give priority to intervention in the most exposed areas. This chapter provides a review of the different methodologies and/or tools currently using this type of analysis. In this review, the most recent developments including different types of approaches and methodologies were prioritized.

The methodologies collected include the DESYCO System and the CHW, which support decision-making for the assessment of the impact of coastal climate change, based on Geographic Information Systems (GIS) and allow the use of free access global data to make preliminary analysis quickly and at a low cost. It also details the National Coastal Property Model (NCPM) developed for the entire US coast with a very high degree of detail. A Risk Analysis is also presented in the study area (coastal zone of the Province of Buenos Aires) using vulnerability indexes, where the risk of coastal erosion is evaluated from the elaboration of quantitative indexes of danger and vulnerability composed of different indicators. Finally, a revision of the methodology of the Hierarchical Analytical Process (APH) is made, which is an improvement of existing tools (such as the Coastal Vulnerability Indexes) because it allows taking into consideration the opinion of experts when the data involved are inconsistent or insufficient (this is of immense importance, especially in the case of the mapping of coastal vulnerability, since the data are very heterogeneous in terms of scale, temporal resolution, etc.).

3.1 DESYCO system for the evaluation of climate change impacts

The DESYCO system (DEcision support SYstem for COastal climate change impact assessment) is a decision support system based on Geographic Information Systems (GIS) designed specifically for a better understanding of the risks posed by climate change at regional and/or local level (for example, the effect of sea level rise and coastal erosion on human assets and ecosystems) (Torresan et al., 2016). It has implemented a methodology of Regional Risk Assessment (RRA) that allows the spatial evaluation of multiple impacts of climate change in coastal areas and the classification of the most important elements at risk (beaches, wetlands, protected areas, urban and agricultural areas). The core of the DESYCO system is a multi-criteria decision analysis model (MCDA) (Figure 3.1) used to automate the steps of the Regional Risk Assessment (risk assessment, exposure, susceptibility, risks and damages) by integrating a combination of climate scenario information (global and/or regional climate projections and hydrodynamic/hydrological simulations) and non-climatic vulnerability factors (physical, environmental and socioeconomic characteristics of the analysed system). The interfaces of the system simplify the interaction with the computer system and provide a guide for the mapping of risks and the communication of results (see Figure 3.2).

DESYCO was applied in different coastal areas:

a) In the Northern Adriatic Sea it was used regionally in the Veneto and Friuli-Venezia Giulia regions comprising a study area of 20.218 km^2 (Rizzi, 2014, Rizzi et al., 2015b, Rousset et *al*., 2014, Santoro et *al*., 2013, Torresan et *al*., 2012, Unive Team, 2013) and locally in the municipality of Venice, being in this case the study area of 415 km^2 (Rousset et *al*., 2014, Torresan et *al*., 2013, Giannini et *al*., 2012). In both studies, the impacts of floods due to sea level rise, storm surge floods, stormwater floods, variations in seawater quality and coastal erosion problems were analysed. The risk metrics were provided by an assemblage of climatic, hydrodynamic and biogeochemical models (Figure 3.3). As described in Torresan et al. (2015), the model assembly begins with two GCMs (SINTEX G and CMCC-CM) forced by the IPCC SRES A1B1 scenario (Nakicenovic et *al*., 2000) for the period 2070-2100. The regional climate models (RCM) COSMO-CLM (Bucchignani et *al*., 2013) and EBU-POM (Djurdjevic and Rajkovic, 2008), respectively nested in the SINTEX G and CMCC-CM models, provided future projections of temperature, precipitation and wind variations on a Mediterranean scale that were successively used as input for a set of hydrodynamic, wave and biogeochemical models that run on the most detailed scales of the Adriatic and Northern Adriatic. In Figure 3.4 you can see maps of risks associated with the change in water quality due to climate change.

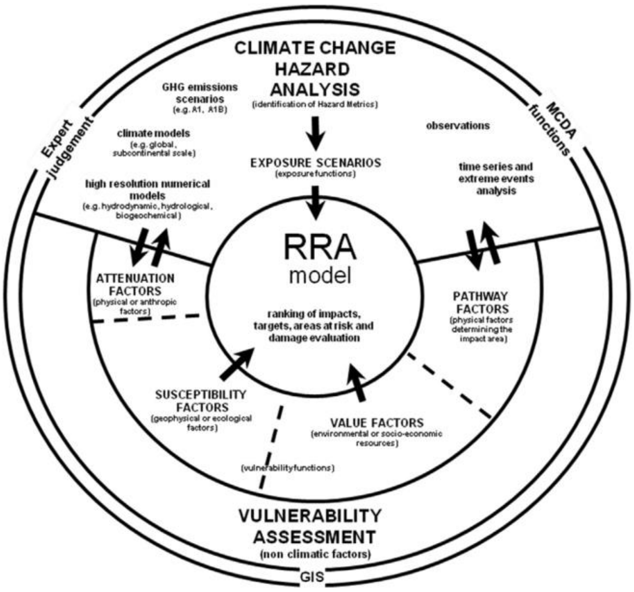
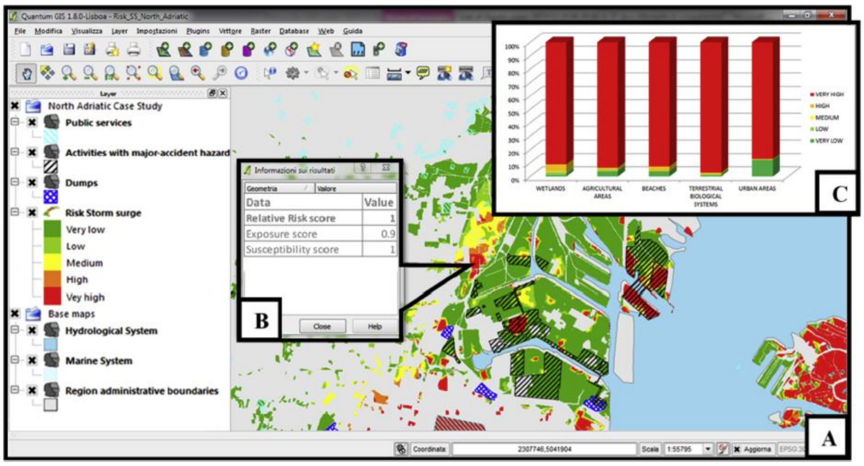


Figure 3.1. Conceptual framework for the Regional Risk Assessment (Torresan et *al*., 2016).



Data	Value
Relative Risk score	1
Exposure score	0.9
Susceptibility score	1

Figure 3.2. Risk maps produced by DESYCO. Interface integrated with QGIS (A), analysed layers (B) and graphs and statistics reported (C) (Torresan et *al*., 2016).

b) In the Gulf of Gabés (Tunisia), a regional scale study was carried out (with an area of interest of 74.373 km^2) where risks associated with floods due to rising sea levels, and floods due to the meteorological tide, were analysed (Lamon et *al*., 2013, Rizzi et *al*., 2015a). The trend for sea level used in the Gulf of Gabes was estimated from an assemblage of models created for the reanalysis of the Mediterranean sea level (Lamon et *al*., 2013), based on the high resolution system Nucleous for European Modelling of the Ocean (NEMO) (Tonani et *al*., 2008, Oddo et *al*., 2009). The assembly of models is based on the IPCC A1B climate projections (water temperature will increase from 18 °C to approximately 21 °C by the end of the 21st century, while salinity tends to be constant). The expected increase in sea level is 1,4 mm/year until the end of this century, that is, 14 cm in the year 2100.

c) In the Republic of Mauritius, a regional scale study was carried out (with a study area of 2.040 km^2) where risks associated with floods due to sea level rise and floods due to storm surge were analysed (Republic of Mauritius, 2012, Mysiak et *al*., 2013).

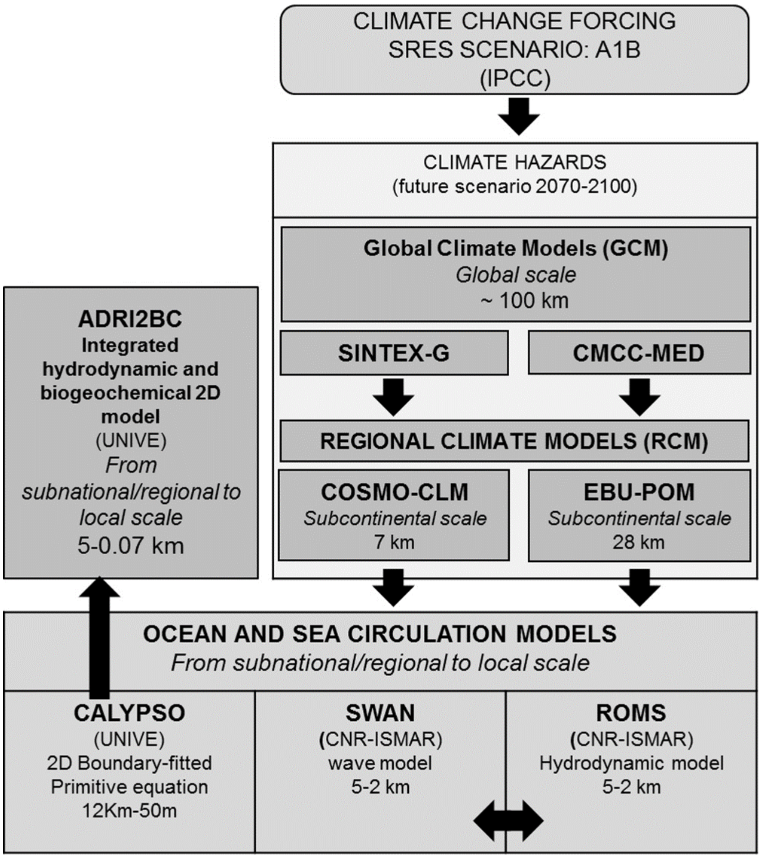


Figure 3.3. Model assembly and flow diagram used in the construction of hazard scenarios for the study of the North Adriatic Sea (adapted from Torresan et *al.*, 2015).

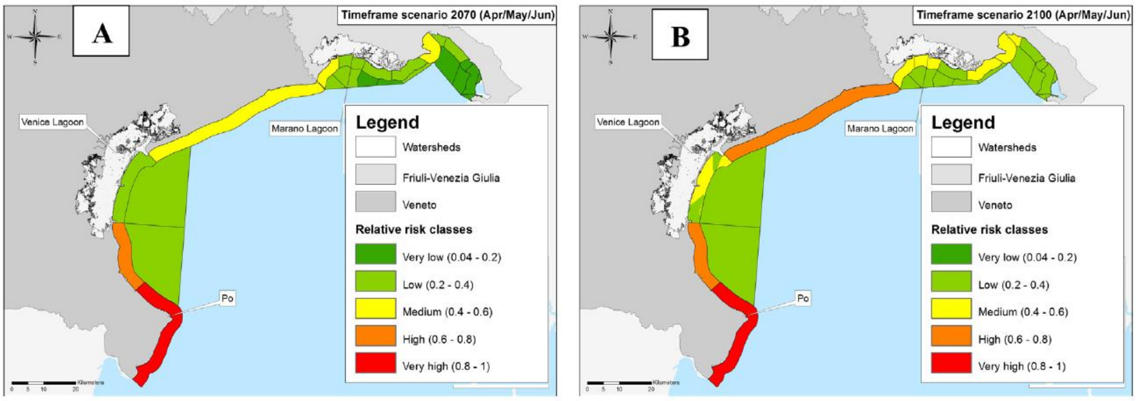


Figure 3.4. Map of relative risk of variations in water quality under climate change for the Northern Adriatic Sea (Rizzi et *al.*, 2015b).

3.2 CHW System (Coastal Hazard Wheel)

The Coastal Hazard Wheel (CHW) tool (coastalhazardwheel.org) is an information and support decision system for stakeholders in coastal areas around the world. This system is part of an initiative promoted by the United Nations Environment Program (UNEP) and is operated as a public-private partnership that involves a group of leading institutions (such as Deltares and the Danish Hydraulic Institute). Its three main functions are: i) conducting multiple risk assessments at the local, regional and national levels; ii) the identification of management options in a specific coastal area; and iii) the use of a uniform language to communicate information on coastal matters (Rosendahl Appelquist and Halsnæs, 2015, Rosendahl Appelquist et *al.*, 2016).

The CHW tool is based on a universal system of coastal classification that can be used in areas with limited data availability and, therefore, be used in both developed and developing countries. This system is a fundamental tool for classifying a specific coastal area, determining its risk profile, identifying the possible management options and communicate information about it.

The universal system of coastal classification has been especially designed to facilitate decision making and is based on the biogeophysical parameters that determine the characteristics of a coastal environment. These parameters include the geological arrangement, the exposure to waves, the variation of tides, the flora and fauna, the sedimentary balance and the storm regime. The system distinguishes between 131 generic coastal environments.

The CHW covers the risks of disturbance of the ecosystem, progressive flooding (due to the possibility of a gradual immersion of a coastal environment), intrusion of saline water, erosion and floods, and contains a total of 655 specific risk assessments, and a full profile risk for each generic coastal environment. The system incorporates the effects of climate change into profile risks and, therefore, is especially useful in terms of adapting to climate change.

It can be used for coastal management at local, regional and national levels, and is an ideal instrument to facilitate communication and exchange of information between the managers of the different management bodies, scientists and policymakers.
Figure 3.5 shows CHW 2.0, which is employed starting at the center of the wheel and moving outwards, ending with the evaluation of hazards in the outermost circles.

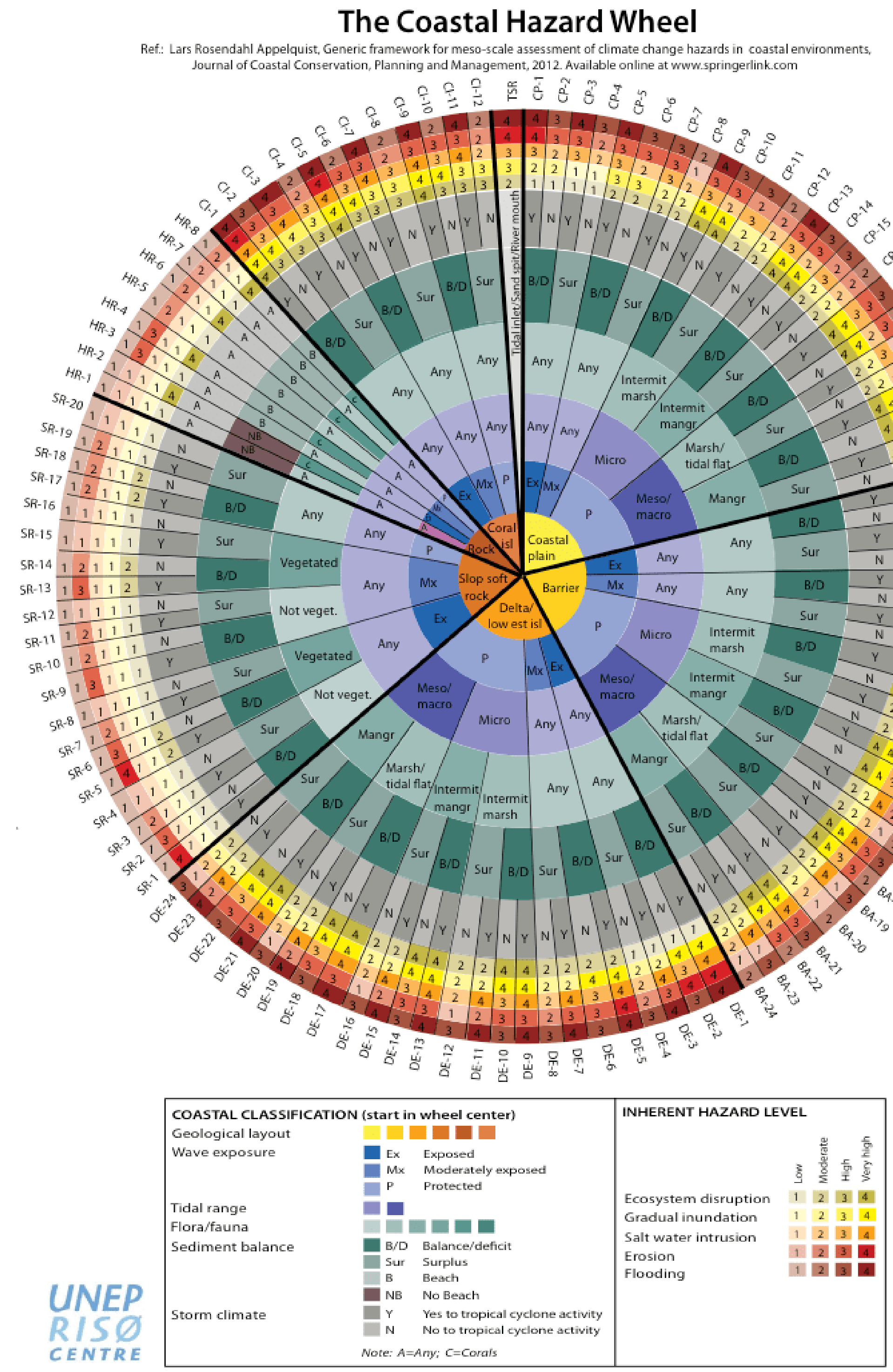


Figure 3.5. Coastal Hazard Wheel (CHW) version 2.0 (Appelquist, 2014).

This methodology was used in different places. Here are some of the applications implemented:

a) Djibouti: In partnership with the International Fund for Agricultural Development (IFAD), a national multi-hazard assessment was implemented for Djibouti. The evaluation was carried out as part of the pilot activities for the CWH system. The evaluation resulted in a variety of hazard maps that have been used by IFAD for national hazard management and the prioritization of project activities (Rosendahl Appelquist and Balstrøm, 2014). The assessment showed that the coast of Djibouti is characterized by extensive stretches with high or very high dangers of alteration of the ecosystem, mainly related to coral reefs and mangrove forests. The danger of saltwater intrusion is moderate in most of the Djibouti coast. High or very high erosion hazards are associated with the sedimentary plains, estuaries and river mouths of Djibouti, while the risks of very high flooding are associated with the mouths of rivers (Figure 3.6).

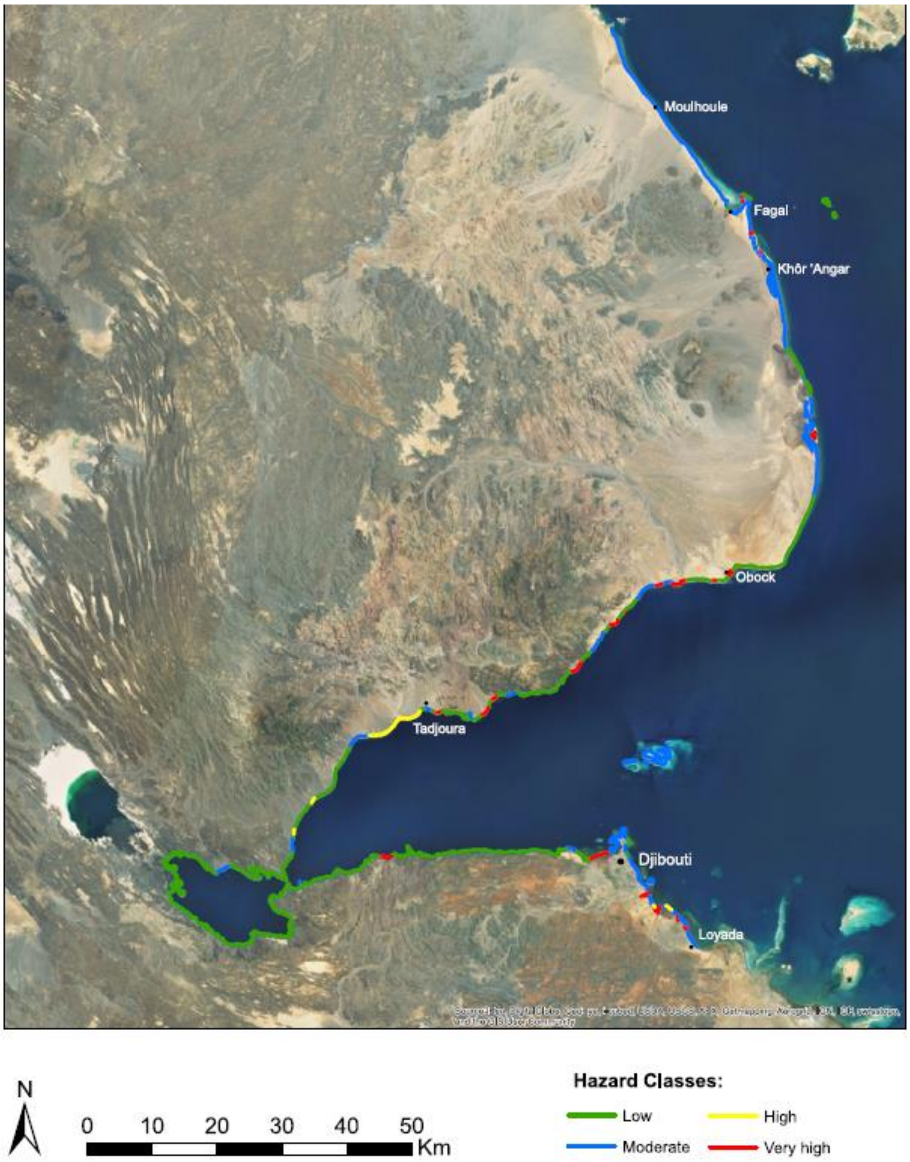


Figure 3.6. Flood risk map in Djibouti (Rosendahl Appelquist y Balstrøm, 2014).

b) Malta: The study carried out in Malta provided information on the erosion hazards along its coastline and also on other climate-related hazards. The evaluation was carried out by researchers from the University of Malta and generated maps for the management that describe the coastal susceptibility to climate change. The study provides a description of the entire Maltese coastline in terms of ten different coastal configurations that infer management considerations for five types of danger. The results of the study are presented as a contribution to more effective management and decision-making by civil protection and planning agencies and as a key first step in the risk analysis process. The details of the evaluation can be seen in Micallef et *al*., 2018.

c) Coasts of Tapachula, Mexico: In this study, a preliminary analysis was made of the coastal risk level of the beaches of the municipality of Tapachula (Chiapas, Mexico), based on future estimates of the increase in ambient temperature and the rise of mean sea level, as well as the extreme events. There was also a documentary analysis of the extreme events and damages caused during the last five years (CastroCastro , 2018).

d) Colombia: As part of the activities for the development of a coastal Master Plan for Colombia, the CHW methodology has been used for a national assessment in coastal erosion. The project aimed to test the use of open access global data for regional coastal assessments and to test the automation processes of the application. The main results were a high to very high risk of erosion in 47% of the Caribbean coast and 23% of the Pacific coast. More data in Stronkhorst et *al*. (2018).

e) State of Karnataka, India: As part of the pilot activities of the CHW methodology, a regional assessment was carried out for the state of Karnataka (India). The evaluation was implemented with the substantial support of the Indian Institute of Administration of Ahmedabad. The application made use of public geophysical data and remote sensing information and shows how the CHW system can be applied at a scale relevant to regional planning purposes. Maps of regional and subregional hazards were developed (Figure 3.8). The hazard assessment shows that 61% of the Karnataka coastline has an inherent risk of high or very high erosion, which makes erosion the most frequent coastal hazard. The dangers of flooding and intrusion of saline water are also relatively widespreaded, since 39% of the Karnataka coastline has an inherent high or very high risk for both types of hazard (Rosendahl Appelquist and Balstrøm, 2015).

f) Denmark: The CHW methodology has been employed for a large number of small pilot assessments on the various Danish coasts. The evaluations have been used to develop and test the procedure and identify the challenges for applications on a very diverse coastline. The evaluation data for the Danish coast are currently only used for internal development purposes of the CHW methodology developers.

g) Bangladesh: In this project, several procedures of the CHW methodology were automated to use publicly available geographic data. In this work, different sources of data are being evaluated and the potential of the model to replace human interpretation in coastal decision making is being critically reviewed. The potential of the tool is investigated both in risk assessment and for planning/management, and a comparison is made with the 2100 Plan of the Delta of Bangladesh, which is currently in its final formulation stage.

h) Timor Leste: This evaluation addressed the key challenges of climate change for the coastal zones of Timor Leste and was carried out by the United Nations Development Program (UNDP). It involved a national vulnerability assessment (Figure 3.7) and the development of adaptation strategies for the country as a whole (UNDP, 2018).

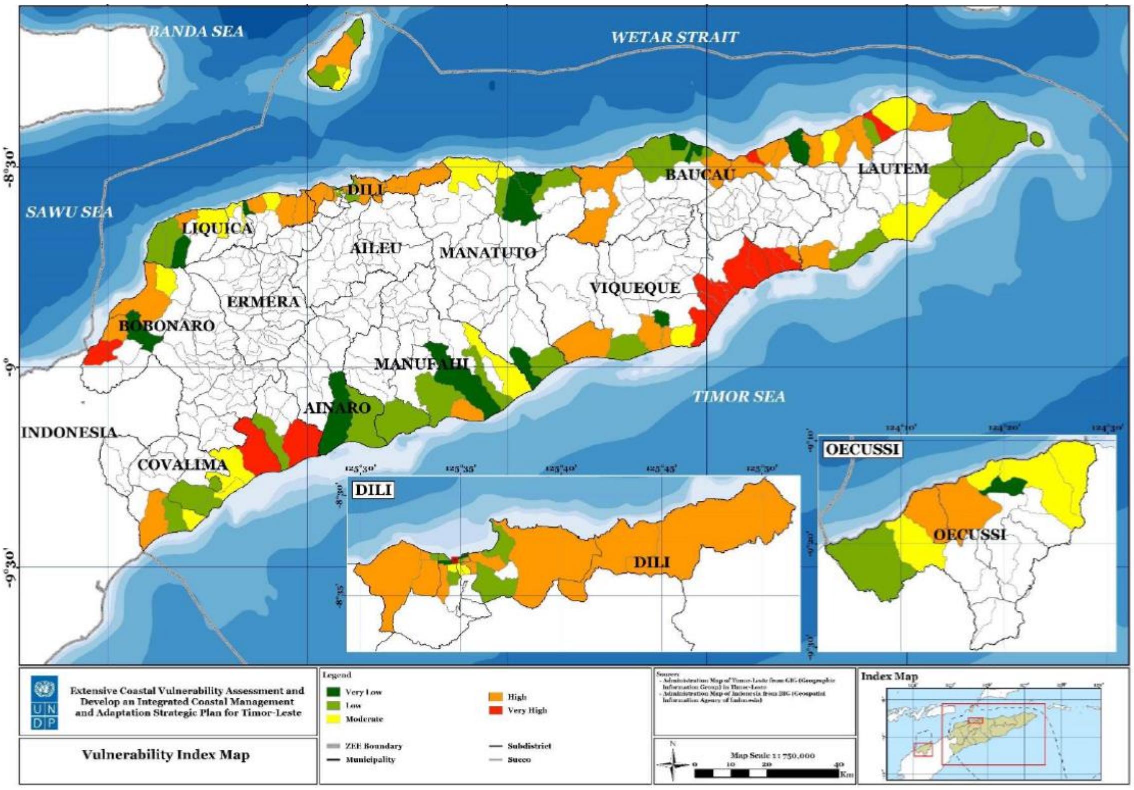


Figure 3.7. Map of the Vulnerability Index for Timor Leste (PNUD, 2018).

i) Island of Saipan (Northern Mariana Islands): The CHW tool has been used in this case as part of a broader assessment of climate change vulnerability for Saipan Island by the Commonwealth of the Northern Mariana Islands. The objective of the evaluation was to select and prioritize different projects to adapt to climate change on the island, as well as to provide the basis for additional studies (Greene and Skeele, 2014).

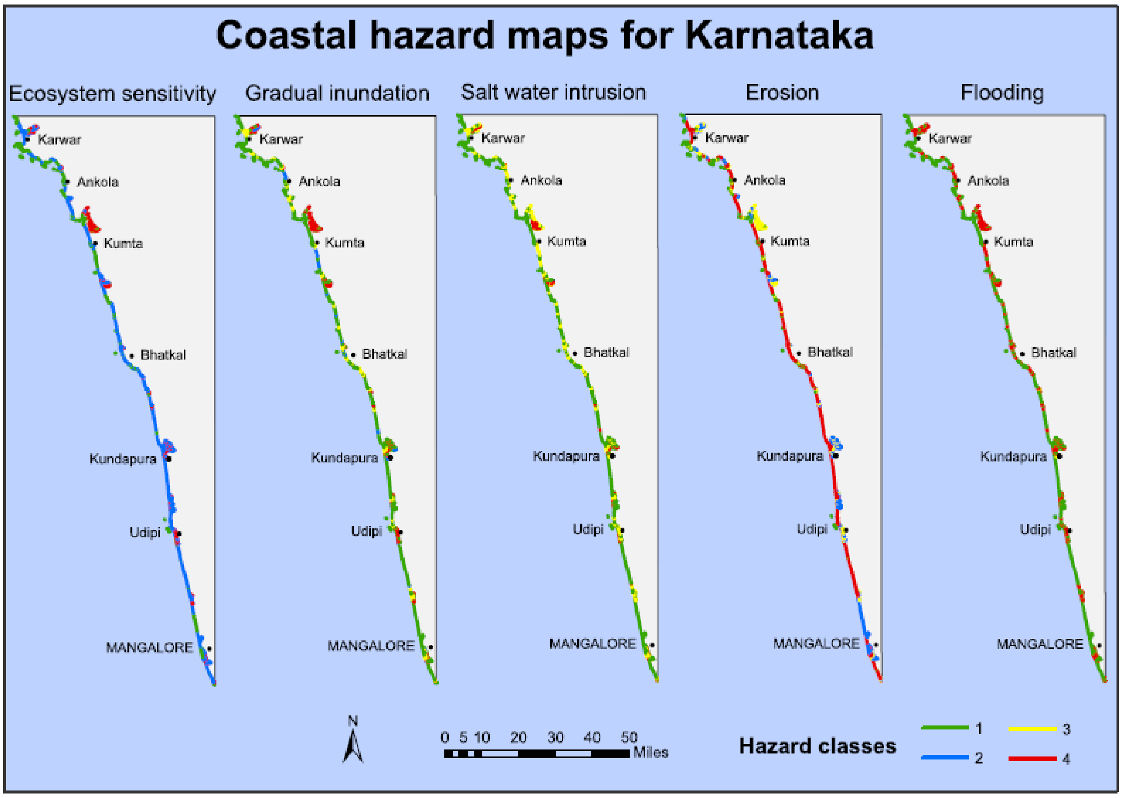


Figure 3.8. Coastal threat maps for the State of Karnataka, India (Rosendahl Appelquist y Balstrøm, 2015).

3.3 *National Coastal Property Model (NCPM).*

The National Coastal Property Model (NCPM) was developed by the United States Environmental Protection Agency (USEPA) and thoroughly examines the US coast at a high level of detail (with square cells of 150 m side) incorporating elevation data, land sinking and property values for each site. It also estimates the cost and effectiveness of different responses to the flood threat and provides economic impact results for three response categories: total protection or coastal shielding, beach feeding and abandonment of properties (Neumann et *al*., 2010).

The local application of this model was carried out in two US cities: Tampa, Florida and the city of New York (Neumann, et *al*., 2015). In these applications, for the projections of future climate, the Community Atmospheric Model coupled with the Integrated Global Systems Model (IGSM-CAM), presented in Monier et *al*., 2013 was used. The scenarios employed in the application of this model reflect the IGSM-CAM results in reference to sea level rise for the year 2100 (Paltsev et *al*., 2013).

The results obtained reflect the capacity of the NCPM to analyse flood threats due to a progressive rise in sea level and its combined effect with the meteorological tide on coastal properties, which may be of critical importance, as shown in Figure 3.9 (Tebaldi et *al*., 2012, Lin et *al*., 2012).

3.4 Analysis by Multiple Criteria Decisions

Multiple Criteria Decision Analysis (MCDA) has historically been useful to support complex decision making in the areas of infrastructure development, climate change and public policy formulation (Linkov and Bridges, 2011, Linkov et *al*., 2006a, 2007, 2008, Keeney and McDaniels, 2001).

In coastal areas it was applied in Alaska, whose coasts are especially vulnerable to erosion and other changes that have caused significant damage and threats to infrastructure, human health and safety and economic prosperity (Karvetski et *al*., 2011). This study evaluated and compared the vulnerability and needs of 22 communities, using criteria focused on the vulnerability of critical infrastructures, human health and emergency services, and economic and cultural activities with the objective of prioritizing, among other actions, the development of the protection of infrastructure. The criteria adopted for the MCDA were: i) critical infrastructure, ii) human health and safety, iii) limited use of coasts, iv) community environment / geographical location, v) housing and population, vi) environmental danger, vii) cultural importance and viii) commercial and/or non-residential areas. The US Army Corps of Engineers (USACE) has applied this criterion seeking to incorporate the uncertainty associated with the direct and indirect effects of projected climate change on the management and planning of infrastructure projects (US Army Corps of Engineers, 2009b; Knuuti, 2002).

3.5 Vulnerability indexes

Vulnerability as part of risk has gained great importance in recent years, especially in the sciences that study the environment and in relation to sustainability. Currently, vulnerability is considered a key factor to understanding risk comprehensively and managing it (Hegde and Reju, 2007), and is defined as the characteristics of a person or group based on their ability to anticipate, survive, resist and recover from the impact of a natural threat (Blaikie et *al*., 1996).

Risk assessments analyse its two components, hazard and vulnerability. On the one hand, the physical characteristics and particularities of the threat or danger are studied and on the other hand, those of the population and infrastructure exposed to it (Birkmann, 2007, Del Río and Gracia, 2009). From the combination of both, the risk of the area is determined in relation to a certain event and, by mapping the spatial distribution of the risk, the risk scenario is obtained (Cardona, 1993). The most widely used method for risk assessment is the development of quantitative hazard and vulnerability indexes composed of indicators (Birkmann, 2007, Hegde and Reju, 2007, Szlafsztein and Sterr, 2007, Del Río and Gracia, 2009, Furlan et *al*., 2011, Martins et *al*., 2012). These indicators should be representative of the physical and socioeconomic characteristics of the area to be studied and of each unit of analysis. At the same time, they should not be too numerous since, if they are related, they can reflect similar processes (interactions). The analysis and evaluation of coastal risks are very complex tasks due to the number of natural and socioeconomic factors that interact in the coastal environment (Del Río and Gracia, 2009).

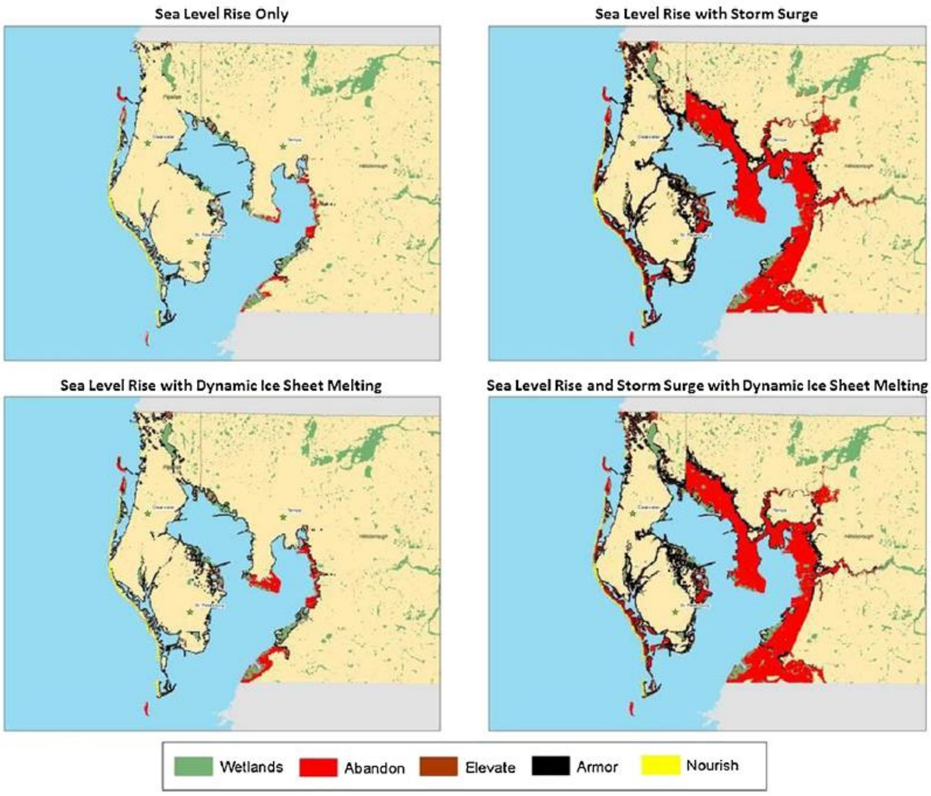


Figure 3.9. Effect of incorporating the weather tide into the economic impact estimates for Tampa, Florida York (Neumann, et *al*., 2015).

An example of this methodology can be found in Merlotto et *al*. (2016) and Merlotto et *al*. (2017). In these works several studies were developed to analyse the coastal erosion risk in the Province of Buenos Aires (Argentina) (from the party of La Costa to the party of Coronel Rosales) with indicators to assess the danger and vulnerability, and the zoning of risk and its components was carried out in order to contribute to the formulation of strategies for a coastal management plan. The hazard index is made up of nine indicators: coastal geomorphology, beach width, front beach slope, granulometry of the front beach sediments, maximum tidal range, mean wave height in surf, type of surf, orientation of the coast against Sudestadas, and rate of erosion or accretion. The vulnerability index is made up of three indicators: demographic indicator, living conditions indicator and work and human consumption indicator. These are variables that cover demographic, educational, health, sanitary, economic, productive and labor aspects, as well as exposure of the population. The danger of coastal erosion varies from very low to high in the province of Buenos Aires (Figure 3.10). Mainly, the type of predominant coastal geoform and the orientation of the coast against the Sudestadas, have been the determining indicators. The spatial distribution of hazard of coastal erosion reflects areas with different levels along the coast. The greatest danger manifests itself in the southeast of the province with high values and decreases towards the north and towards the west (Figure 3.10). In the coastal strip of the province of Buenos Aires, a very low to low vulnerability predominates, with small sectors with a moderate vulnerability. In general, the most favoured socio-economic sectors of the population are those that are located and inhabit the maritime front. This is reflected in the vulnerability found since it depends on the social, economic, educational and cultural characteristics of the population exposed to the erosive phenomenon. The assessment of hazard and vulnerability has resulted in coastal erosion risk for the province of Buenos Aires predominantly very low, with only one sector of high risk, small sectors of moderate risk, and sectors of low risk more widespread than the latter (Figure 3.10). The southeast of the province of Buenos Aires is the sector that presents the highest levels of risk of coastal erosion (Figure 3.10) determined mainly by high hazard.

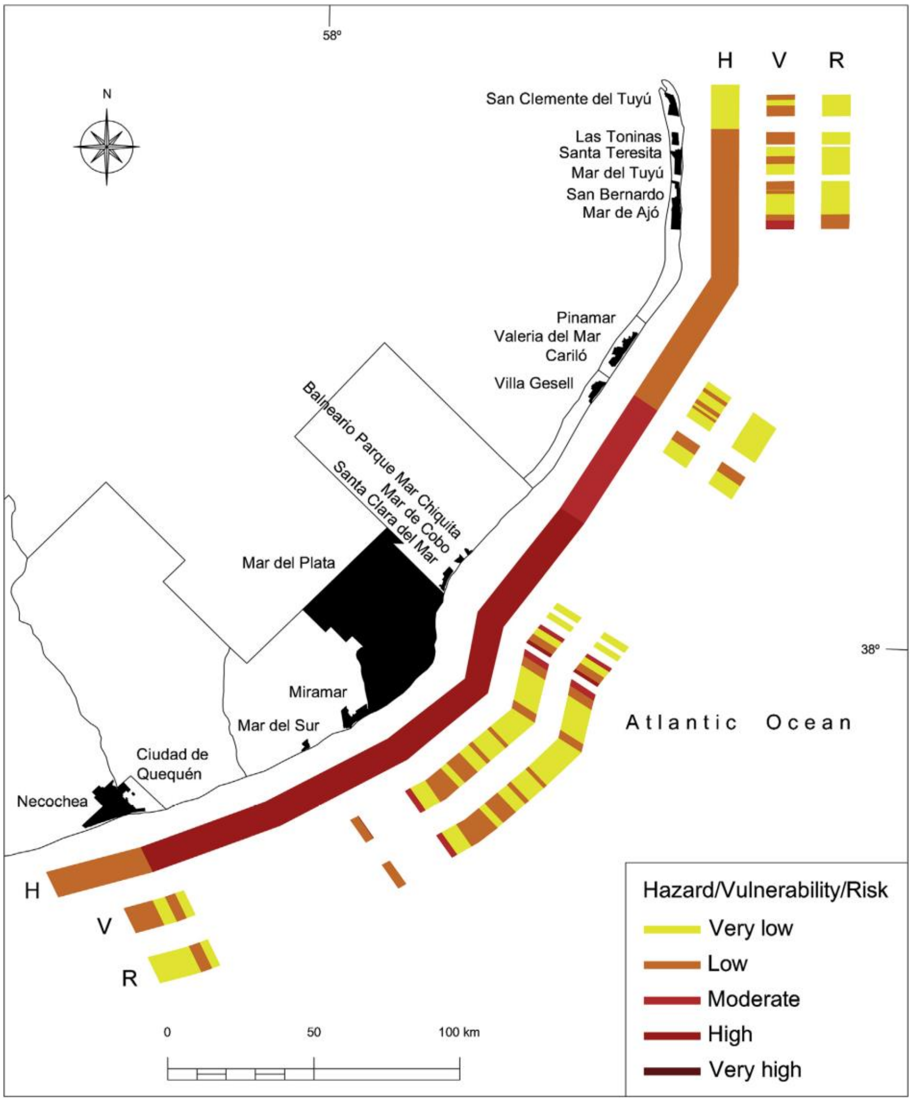


Figure 3.10. Hazard (P), vulnerability (V) and risk (R) of coastal erosion in the Province of Buenos Aires (Merlotto et *al*., 2017).

3.6 Analytical Hierarchical Process

The methodology of the Analytical Hierarchical Process (AHP) is presented as an improvement of existing tools (Coastal Vulnerability Indexes) for the assessment of vulnerability. AHP has several advantages over these traditional methodologies: First, it takes into consideration the opinions of experts when the data involved are inconsistent or insufficient. This is of immense importance, especially in the case of the mapping of coastal vulnerability, since the data are very heterogeneous in terms of their scale, temporal resolution, etc. AHP's ability to integrate expert opinion, as well as to convert qualitative information into quantitative weights, makes it very useful for coastal vulnerability studies. Secondly, the comparison in pairs allows the prioritization of several parameters among themselves. This is important in the case of regional studies, where one parameter may be more dominant in one region than in other.

The AHP has been used as a decision-making tool in several studies related to the zoning of landslide hazards, flood mapping and mapping of soil erosion risks (Phukon et *al*., 2012, Bhatt et *al*., 2010, Sinha et *al*., 2008, Rahman et *al*., 2009). However, its use for coastal vulnerability has been very limited.

Chang et al. (2012) used AHP to prioritize protection of the coast of Miaoli, Taiwan. Yin et *al*. (2012) (Figure 3.11) and Ozyurt et *al*. (2011) have assessed coastal vulnerability due to sea level rise for the Chinese coast and the Turkish coast, respectively. A recent study by Le Cozannet et *al*. (2013) that deals with AHP and coastal vulnerability, broadly analyses the nuances (advantages, disadvantages and uncertainties) of this approach.

A final application of this methodology was carried out in the region of Puducherry (India), where the December 2004 tsunami and the 2011 Thane cyclone caused great human and economic losses (Mani Murali et *al*., 2013). The devastation caused by these events highlighted the need for a vulnerability assessment to ensure a better understanding of the elements that cause different hazards and, therefore, minimize the side effects of future events. In this study, socioeconomic parameters were included along with the physical parameters to calculate the coastal vulnerability index using weights derived from AHP.

Seven physical-geological parameters (slope, geomorphology, elevation, coastal line change, sea level rise, significant wave height and tidal range) and four socioeconomic factors (population, land use / land cover, roads and location of tourist areas) are considered to measure the physical vulnerability index (PVI) (Figure 3.12), as well as the socio-economic vulnerability index (SVI) of the Puducherry coast. Based on the weights and the scores obtained with AHP, vulnerability maps were generated to demarcate areas with low, medium and high vulnerability. Then, through the combination of the PVI and SVI values, the coastal vulnerability index (CVI) is obtained (Figure 3.12). Finally, the various coastal segments are grouped into the 3 vulnerability classes to obtain the coastal vulnerability map. The results obtained allow the identification and prioritization of the most vulnerable areas of the region to further help the government and the resident coastal communities to improve the management and conservation of the coasts.

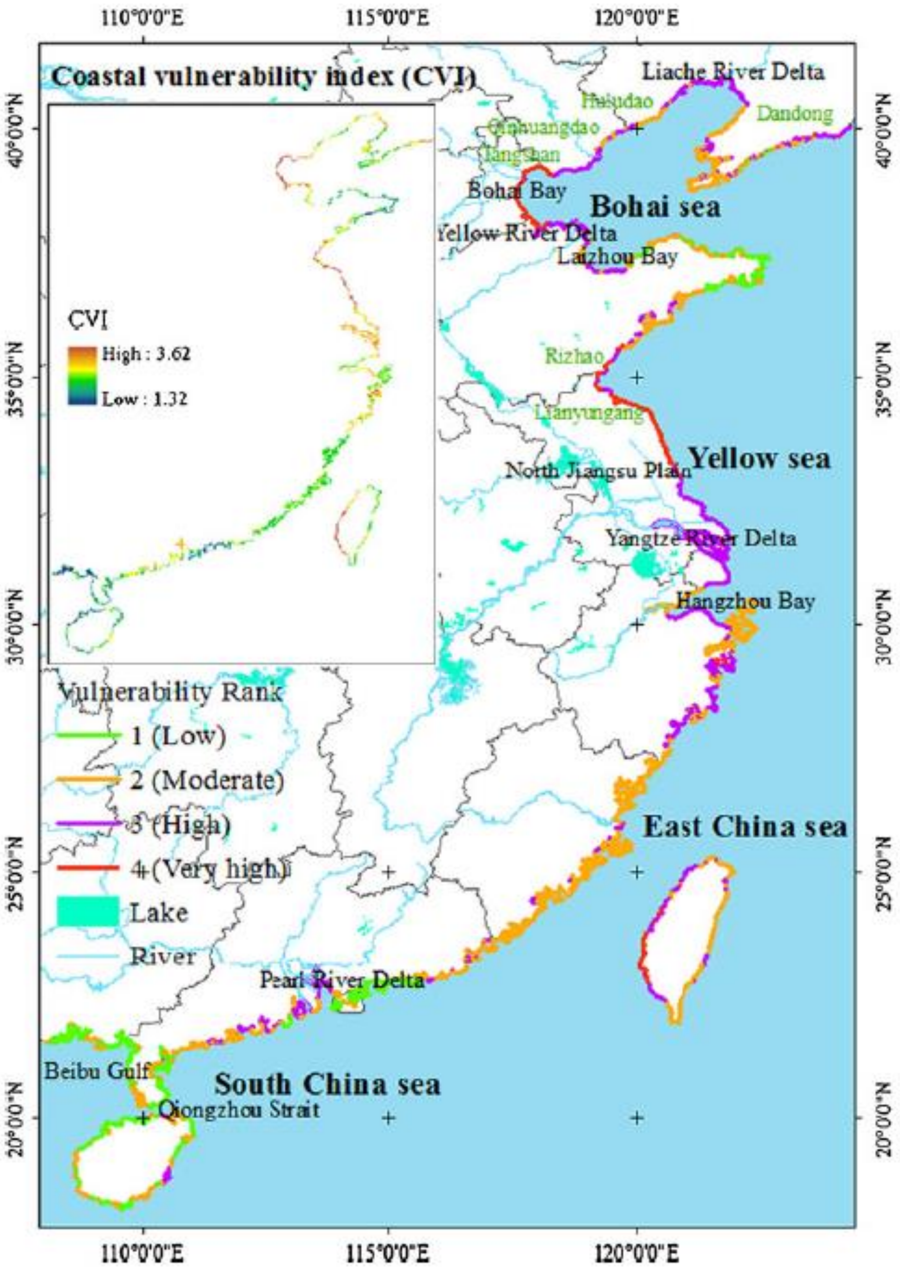


Figure 3.11. Coastal Vulnerability Index for different segments of the Chinese coast (Yin et *al.*, 2012).

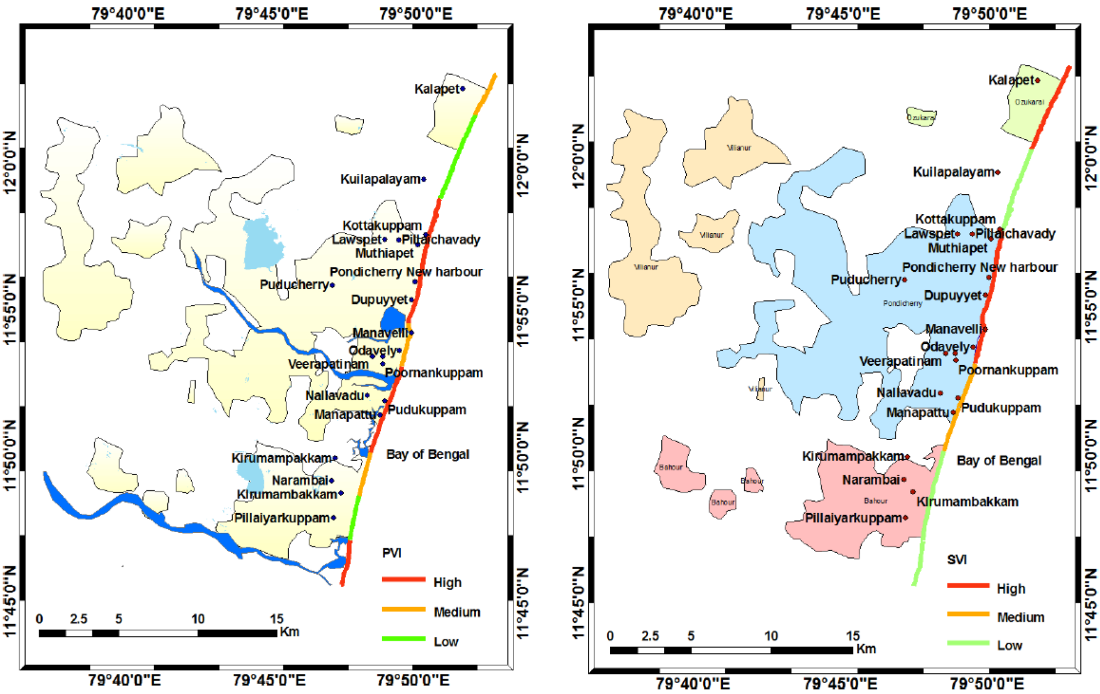


Figure 3.12. Maps of the physical vulnerability index (PVI) (left) and coastal vulnerability index (CVI) (right) for the coasts of Puducherry, India.

4 HYDRODYNAMIC, SEDIMENTOLOGICAL AND MORPHOLOGICAL MODELLING

Numerical modelling has become an essential tool to quantify risks associated with different threats in coastal management as well as to analyse the impact of infrastructure works and different future scenarios (especially associated with Climate Change). Depending on the physical problem they represent (and the resulting equations that they solve) the models can be classified into: i) Hydrodynamic Models, ii) Sedimentological Models and iii) Morphological Models. These models can be used independently or coupled together. Morphological models are commonly coupled to sedimentological models. In turn, the latter two are usually coupled to a hydrodynamic model that serves as a forcing for the processes that are to be studied.

In this chapter, a review of these models is made, focusing on applications made in the region.

4.1 Hydrodynamic Models

The Hydrodynamic Models can be used independently or coupled to other models to simulate a wide range of coastal processes, such as the simulation of meteorological tides and coastal flooding; waves and wave transformations including their breake. In turn, they are often used as forcers to study problems of erosion, transport and deposition of sediments, erosion of dunes, variations in the coastline and water quality.

There are numerous jobs where this tool is used. Kumar et *al*. (2008) present simulations of the impact of the storm surge on the coasts of the Indian Ocean using a two-dimensional hydrodynamic model such as MIKE 21 of the Danish Hydraulic Institute (DHI, 2002). In Madsen and Jakobsen (2004) a modelation that reproduced the meteorological tide that in 1991 left 140.000 dead in Bangladesh is presented. In Samaras et *al*. (2016) various hydrodynamic models are presented in the south of Italy with the TELEMAC models (Brière et *al*., 2007) and MIKE21 (DHI, 2002) with the aim of having operational applications for coastal planning, decision making and evaluation of coastal risk. In addition, several modelling jobs were used in coastal planning activities. In Reikard (2009) and Bozzi et *al*. (2014), for example, potential wave kinetic energy sites were identified. In the works of Stockdon et *al*. (2012), Idier et *al*. (2013) and Archetti et *al*. (2016) different hydrodynamic models are presented to assess vulnerability and/or coastal risk.

In the region several modelling works detailed below were carried out.

In Re (2005) flood risk maps are determined in the coastal area of the Río de la Plata in the province of Buenos Aires for current conditions and for possible future scenarios, by the numerical modelling of the hydrodynamics of the Río de la Plata. For that, a hydrodynamic model was implemented, called RPP-2D (Re, 2005, Jaime and Menéndez, 1999), using the HIDROBID II software (Menéndez, 1990). The objective of the model is to simulate the generation of storm waves in the Río de la Plata and its Maritime Front. This model was calibrated to adjust to the predicted astronomical tide, the seasonal average levels and the frequency of occurrence of levels in Buenos Aires for the decade of 2000, and the large storm waves. The verification of the model was made comparing the seasonal average levels, and the frequency of occurrence of levels in Buenos Aires for each year of the present decade, sea level data obtained by the satellite TOPEX/Poseidon (D'Onofrio, 2003), and measured current speeds. The proposed future scenarios represent average and maximum conditions foreseen for the 2030 and 2070 decades. As a result of the simulations, the seasonal mean levels were obtained throughout the domain of the model and the response of the system to storm events with different return periods. Flood risk maps were drawn from the information of levels along the entire Argentine coast of the Río de la Plata (Figure 4.1). As a result of this study, it is concluded that the areas permanently flooded on the Argentinean coast of the Río de la Plata due to the effects of climate change will be relatively small. This means that the threat of flooding will continue to be eventual, and linked to storm waves. The three coastal zones most vulnerable to flooding are: the Paraná Delta Front, the coastal strip that goes from Berisso - Ensenada to Berazategui - Quilmes and a strip to the South of Samborombón Bay. For future scenarios, the risk of flooding in the lower basin of the Matanza - Riachuelo and Reconquista rivers is increasing.

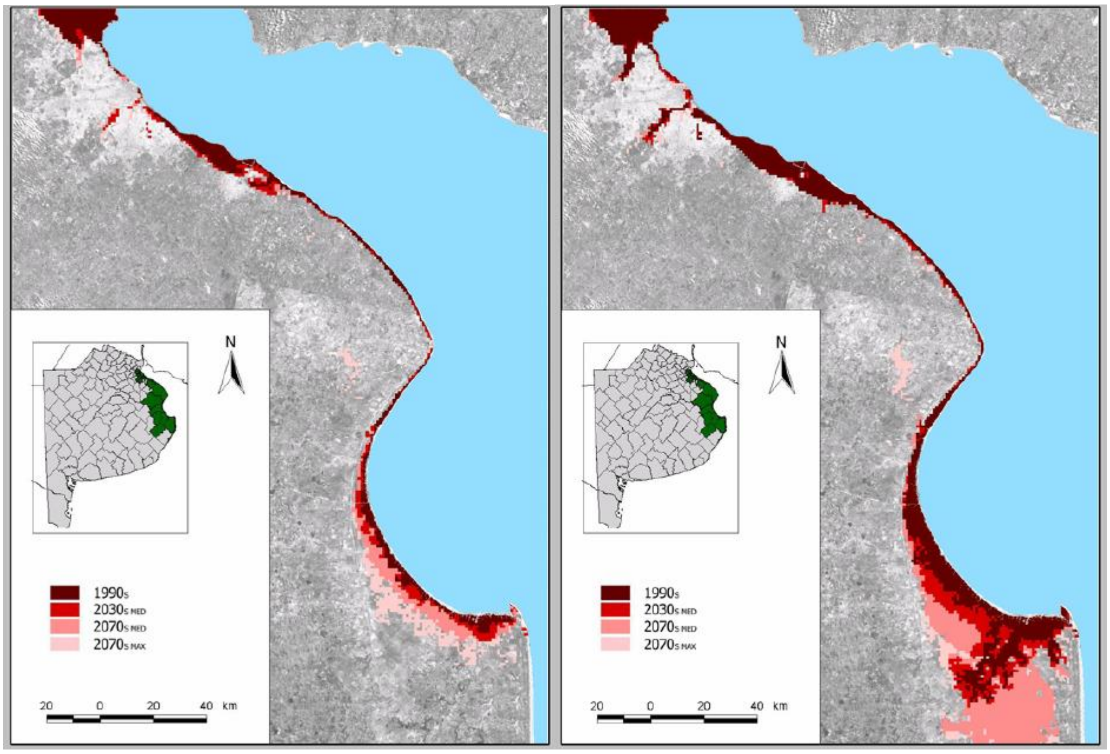


Figure 4.1. Flood risk maps for return periods of 5 years (left) and 100 years (right) (Re, 2005).

In Lecertua (2010) an analysis of flood duration risk is carried out in the coastal areas of the Río de la Plata considering Climate Change, but focusing on the Metropolitan Region of Buenos Aires, the most densely populated area of Argentina, where an extensive area of this region is considered vulnerable to flooding during the passage of storm waves usually known as "Sudestadas". To this end, a methodology for the construction of flood risk maps on the Argentinean coast of the Río de la Plata is presented. These maps are constructed for a baseline scenario (decade of 1990) and two future scenarios of Climate Change (decades of 2030 and 2070), allowing the floods to be assessed for different return periods. To carry out the flood risk maps, a hydrodynamic model called RPP-2D (Re, 2005), previously calibrated and verified, was used to represent the dynamics of the Río de la Plata. With the model, river levels have been obtained in control stations, which allow generating different statistical analysis. On the one hand, the frequency of occurrence of events for the case of intraannual recurrences was studied and, on the other, a bivariate endpoint analysis was performed for the case of interannual recurrences. With the statistical information and the digital terrain model, the respective flood risk maps were constructed (Figure 4.2).

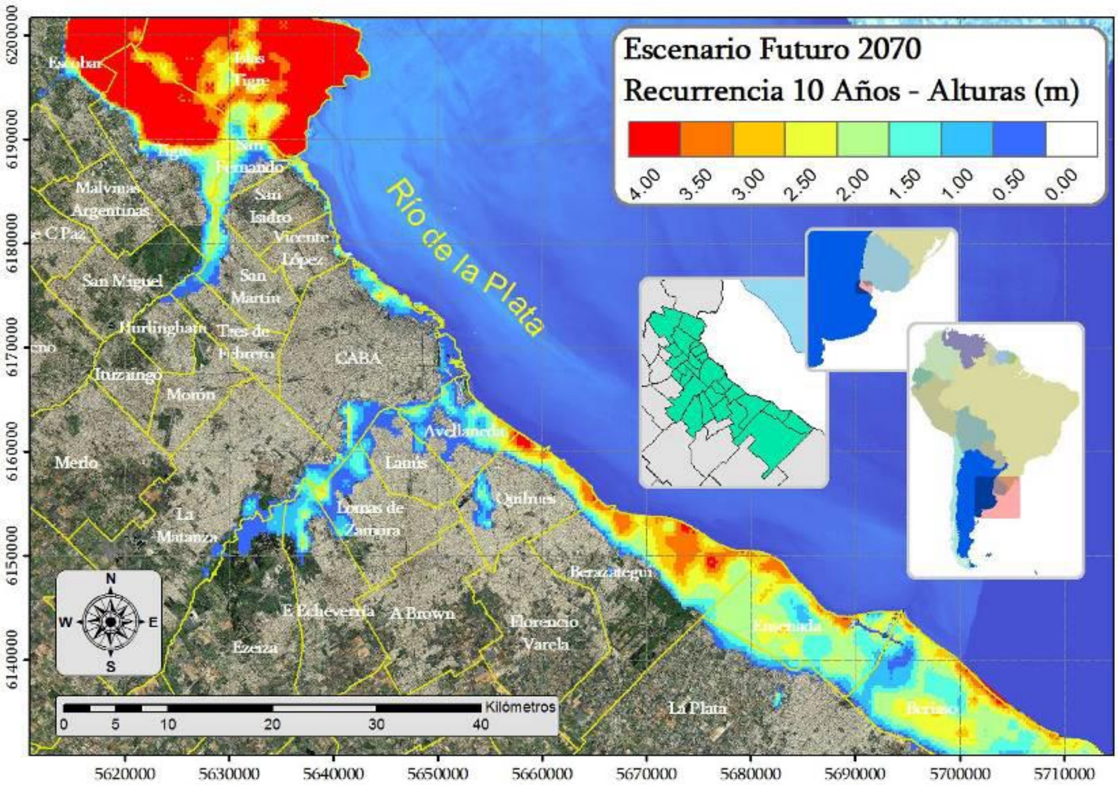


Figure 4.2. Flood Risk Maps - Future Scenario 2070 - Heights (m) (Lecertua, 2010).

Another use of the hydrodynamic models is the characterization of the wave conditions to which certain infrastructure will be exposed under different scenarios. Alfredini et *al*. (2014) presents a study of the wave climate for extreme conditions expected under different climate change scenarios for the metropolitan area of the port of Santos on the coast of São Paulo (Brazil). This port is the most important freight transfer terminal in the southern hemisphere. In previous studies, the authors showed how this area is subject to climatic changes that determine, in the long term, an increase in sea level. In this research, an additional analysis of a long-term wave database (1957-2002) was performed. The database was generated from a comparison between wave data modelled in a deep-water model (ERA-40 Wave model - ECMWF) and wave data measured by a coastal buoy during the years 1982-1984 on the coast of the Port. The calibration coefficients, according to the angular sectors of the wave direction, were obtained by comparing the measured data with the modelled data and applying them to the original scenarios using a hydrodynamic model in the port environment (MIKE 21 SW).

The analysis performed shows an increase in the significant height of the wave (Hs) (Figure 4.3), in the peak wave period (Tp) and in the frequency of storms in the last decades. Taking into account the increase in marine risks and the high values of facilities and infrastructure in the Port of Santos, it is of vital importance to minimize the risks by adopting adaptation policies linked to climate changes that determine an impact both in the port area and in the coastal environment of São Paulo.

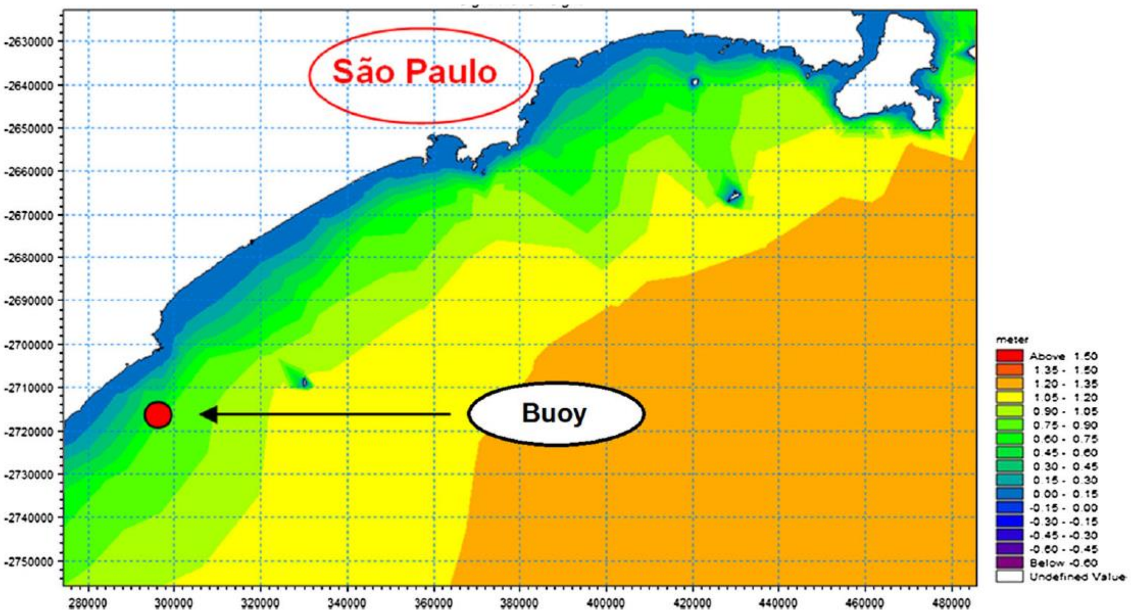


Figure 4.3. Simulation of significant wave height (Hs) performed with the MIKE 21 SW (Alfredini et *al.*, 2014)

4.2 *Sedimentological Models*

The study of sediment dynamics is very important to understand morphological processes in coastal areas. Among the multiple applications of sedimentological models, the study of the increase in sedimentation in the Guayas estuary (Becker, 2017) carried out with the Delft3D FM software is highlighted. In Hesse (2017) a sedimentation study is presented in the Weser estuary

(Germany), including its impact on the dredging tasks in the area. The dynamics of dredged sediments in the North Sea are studied in Schuurman et *al*. (2017) using Delft3D and DELWAQ.

In the region, the work of Peixoto et *al*. (2018) is highlighted, where the results of the implementation of the numerical code SisBaHiA (Rosman, 2017) are presented to study, through the eulerian treatment of the transport of silts and sands, the consequences of the occurrence of extreme events in the estuary of the Quequén Grande River (Buenos Aires, Argentina). Three scenarios are analysed: one of them represents the most frequent condition found with constant minimum flow and exclusive supply of fine material in suspension. The other two scenarios represent situations after the fall of important rainfall in the basin with transport of sands that follow flow hydrographs of floods. It is found that, under conditions of normal river discharge, only fine sediments are transported while the sands remain deposited on the bed of the estuary. The transport of the sands takes place only during floods, generating erosion in the middle and upper estuarine sections and sedimentation in the lower section (Figure 4.4). The work carried out constitutes a significant advance in the validation of a tool whose application is expected to provide answers to problems that have been installed for some time now. These are related to the behaviour of suspended sediments, their incidence in erosive mechanisms (upstream of the step) and sedimentary (downstream of step), the predictability of their transport in different situations of river discharge (i.e. very low discharge, fluvial or sporadic and sudden floods), extraordinary variations of the tide and eventual changes in the morphology or bathymetry. In particular, the results confirm the favourable conditions for selective sedimentation in the port area where periodic dredging is necessary to maintain the navigability of large grain cargo vessels.

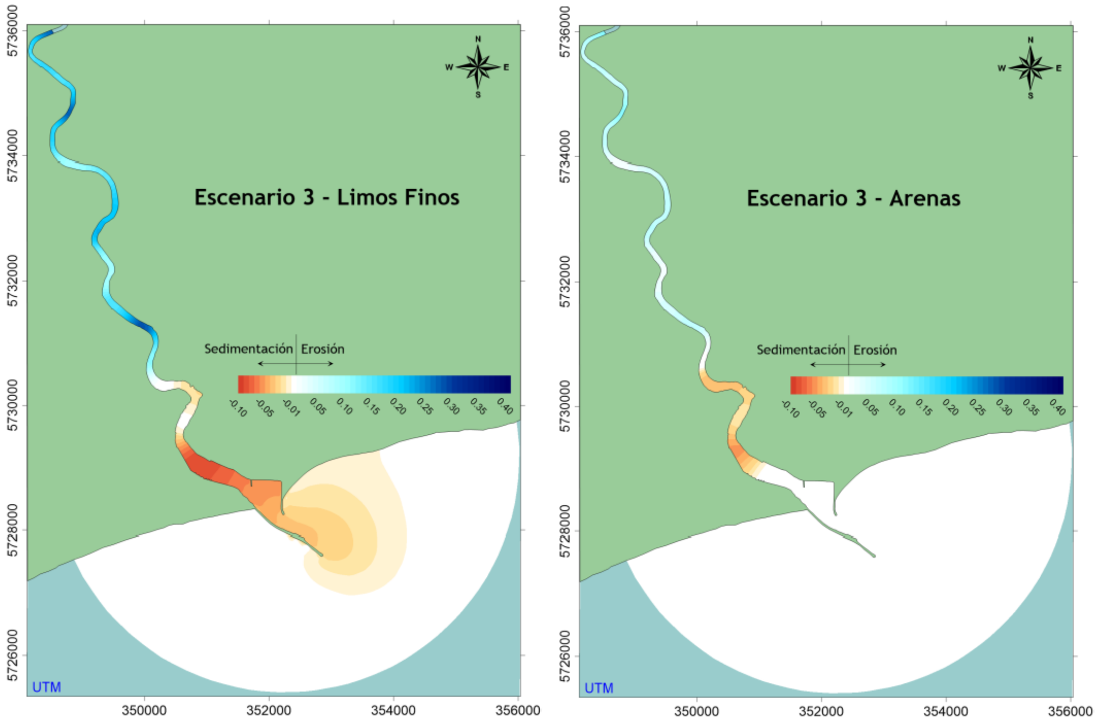


Figure 4.4. Erosion and sedimentation rates of fine silts and sands (Peixoto et al., 2018).

4.3 Morphological Models

The morphological models can be used with different objectives, such as the morphodynamic study of beaches facing different hydrodynamic forcing or the analysis and impact of different infrastructure works. In general, morphological models are usually coupled with a sedimentological model. Sierra et *al*. (2009) presents the morphological response of a beach to submerged permeable coastal structures using the LIMORPH software (González Marco, 2005, Alsina, 2005). Caichac et *al*. (2017) presents the application of a morphological model coupled with a hydrodynamic model (XBeach with Delft3D FM) to study the evolution of the coastal area of Anmok (South Korea). In the works of van Duin et *al*. (2004), Burcharth et *al*. (2014), Karambas (2014) and Karambas and Samaras (2014), the application of morphological models for the design of coastal protection infrastructure is presented.

Already in the region, within the group of morphodynamic studies is the work of Cueto Fonseca and Otero Díaz (2018). The main objective of this study is to describe the morphodynamic response of the beaches of the Colombian Caribbean to extreme wave events. In this specific case, such events were the passage of the cold front of March 2009 and Hurricane Matthew on the beaches of Bocagrande (Cartagena, Bolívar) and Costa Verde (Ciénaga, Magdalena), using the XBeach model as a modelling tool (Roelvink, 2009). XBeach is an open source numerical model originally developed by the University of Delft to simulate hydrodynamic and morphodynamic processes on sandy beaches with a domain of about a few kilometers and within storm time scales (Roelvink, 2009). This model solves hydrodynamic processes associated with gravitational waves (refraction, asomeration and breakage), infragravitational waves, set-up induced by waves and currents; and morphodynamic processes, such as dune erosion and sediment transport. The wave propagation from the virtual buoys of reanalysis in deep water to shallow waters was executed with the SWAN (Simulating WAves Nearshore) model (Booji and Holthuijsen, 1987). The starting point of the beach profiles of Bocagrande and Costa Verde is just where the wave propagation in shallow waters begins with XBeach. Once the characterization of the study beaches and the collection of hydro-morphodynamic variables was carried out, the XBeach model was calibrated and validated with the experimental data. In total, 160 sea states were modelled for the study beaches, 40 states per season (dry and wet) in Bocagrande and in Costa Verde. Subsequently, with the parameters calibrated in each beach and the results thrown by SWAN, the extreme events selected for the study area were modelled with XBeach to perform the morphological evolution analysis (Figure 4.5). The recoil of the Bocagrande profile can become critical in both extreme events, going back between 100 and 150 meters. Under these conditions, severe effects on the population living near the sea can be materialized, generating floods by disappearing the natural barrier that make up the dunes of the beach. On the other hand, in Costa Verde the regression observed in the results is less pronounced, remaining stable between 20 and 30 meters. This minor affectation obeys to the very nature of the profile of the beach, which presents a clearly reflecting section in the area where the breaking of the waves is generated, reflecting a great amount of energy. The morphological change on the beach profile and the advance in the Costa Verde coastline is not dangerous for the community that lives close to the sea and does not show significant changes in its original structure before the passage of Hurricane Matthew or the cold front of March 2009.

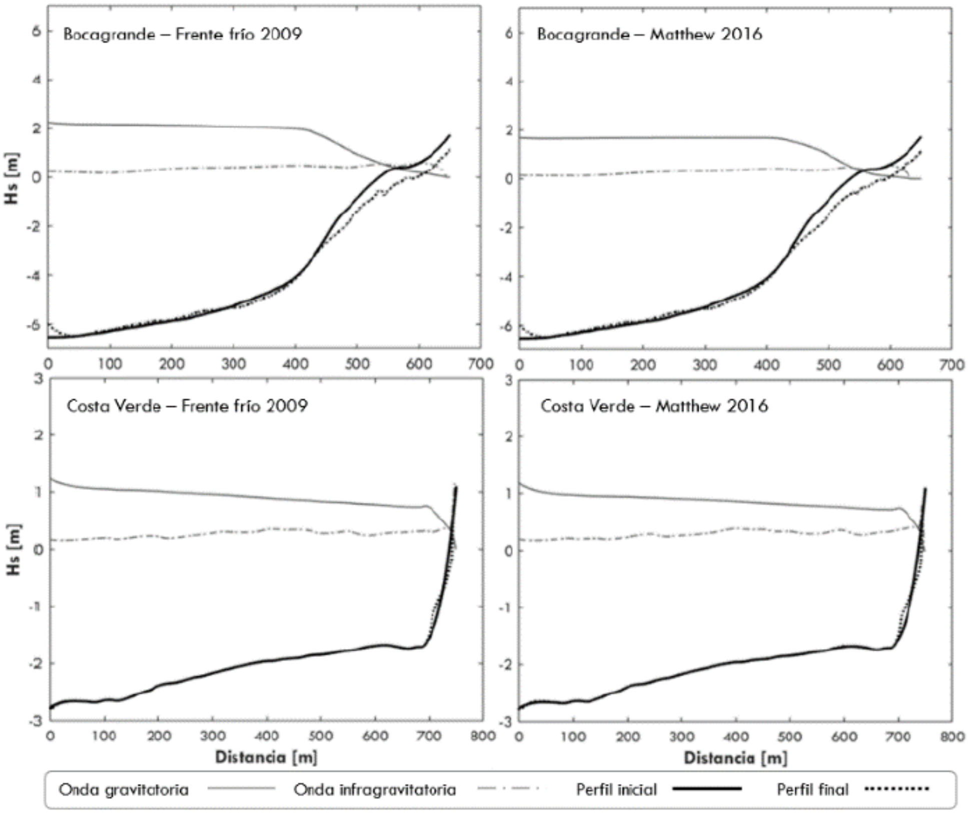


Figure 4.5. Morphological evolution of the beaches of Bocagrande (above) and Costa Verde (below) modelling the passage of the cold front in 2009 and Hurricane Matthew in XBeach (Cueto Fonseca and Otero Díaz, 2018).

In the same direction as the previous work is that of Kuc Castilla (2018). It focuses on the detection and analysis of the historical changes of the coast as well as on the hydrodynamic characterization of the beach of Sabancuy (Mexico). Changes in the coastline along this beach were studied through the use of satellite images, determining the areas of accretion and erosion of the beach over a period of 11 years (2004 - 2015). The results show that the East breakwater that protects the access channel has a growth area of 70.933 m^2, while the beach at the West breakwater shows a loss of area of 15.766 m^2. For the hydrodynamic characterization, XBEACH software (Roelvink et *al*., 2009) was used to estimate wave propagation, speed and direction of currents as well as changes in morphology as a result of different simulation scenarios. This paper analyses the problem and offers a proposal as an alternative to minimize erosion of the beach.

To determine the area of erosion/accretion between images of different dates, the method of reference areas was used. This method consists in drawing a polygon that covers the intertidal zone in the oldest image, serving as a reference baseline. The vertices of this polygon are taken as the limits to obtain the corresponding polygon in each image. The area produced by the intersection of polygons between subsequent images corresponds to the displacement of the coastline, from which the areas of erosion and accretion were calculated by means of the difference of continental areas between images (Figure 4.6). Negative displacement values are considered as erosion and positive values denote accretion (Torres Rodríguez et *al*., 2010). The data used for the analysis and characterization of the waves were obtained from the reanalysis module of the WAVEWATCH III model (2018), having the significant wave height (Hs), peak period (Tp) and direction of the waves with intervals every 3 hours in the period 2005 - 2017. The wave data were extracted from the element of the calculation grid located at coordinates 19°20'14" N and 91°19'59.94" W, 40 km from the coast.

The ODIN software (ODIN, 2015), developed by the Institute of Environmental Hydraulics of the University of Cantabria (IH-Cantabria) was used to obtain the probability of occurrence of significant wave height in medium regime, the significant wave height threshold for extreme regime, as well as the annual wave and storms roses. The mean regime was defined by adjusting the data to distributions of Normal, Log-Normal, Weibull of Minimums and Gumbel of Maximums, observing which had the best adjustment for the correlation coefficient.

It was considered as an alternative for the recovery of the beach, that a sand bypass was implemented given the characteristics of the area and the problem previously established, in such a way that existing sediment in the estuary could be used to contributing to the recovery of the width of the beach.

Figure 4.6. Detail of the areas of accretion and erosion in the area of the access channel (Kuc Castilla, 2018).

Among the works that focus on analysing the impact of infrastructure works, those of Cáceres et *al*. (2012, 2016) stand out. In these studies, an analysis of the littoral dynamics in the surroundings of the South breakwater of the Port of Mar del Plata (Argentina) is carried out through numerical modelling. This study is relevant because the Port of Mar del Plata is an important center for the fishing industry in Argentina. Due to the partial obstruction of the sediment transport caused by the South breakwater of the port, the coastal area is characterized by the advance of the upstream coastline, the development of a sand bank through the access channel and significant processes of erosion on beaches located north of the port. The mechanisms responsible for these processes were evaluated using the flexible mesh MIKE 21/3 Morphological Modelling System developed by the Danish Hydraulics Institute (DHI). This system is composed of a hydrodynamic model (MIKE 21 HD) that calculates the variations of the water level and flow in response to extreme forces. This module allows to simulate effects of flood and drying, dispersion of quantity of movements due to turbulent fluctuations, bed shear stress and potential flows of seas. This model is based on the shallow water equations, integrated in the vertical, and with the Reynolds approximation based on the decomposition of the flow variables in their mean value plus the fluctuation (known as the RANS equations: Reynolds Average Navier-Stokes), with the application of the Boussinesq hypothesis for the resolution of the system (DHI, 2011a). The wave spectral model (MIKE 21 SW) is based on unstructured meshes, which simulates the growth, decay and transformation of local waves generated by wind and ocean waves (DHI, 2011b). MIKE 21 SW is particularly applicable for the prediction of wave climate in large areas, as well as for studies located in coastal areas. The model takes into account wave growth due to wind action, wave-wave non-linear interactions, dissipation due to white-capping, dissipation due to bed friction, dissipation due to wave breakage by the beds influence, refraction and shoal due to depth changes and wave-current interaction. The sand transport model (MIKE 21 ST Q3D) calculates the sediment transport rate and changes in sea level due to the combined action of waves and currents (DHI, 2011c). MIKE 21 ST Q3D solves the spatial and temporal variation of the shear stress, flow velocity and sediment concentration using Fredsøe's model (1984). The model determines the transport of sediments with a quasi-3D approximation, that is to say in each position where the transport is evaluated, the vertical structure of the horizontal flow is calculated based on the average speed in the vertical computed by the model MIKE 21 HD and the vertical distribution of shear stresses.

The morphological model was calibrated and validated by bathymetric surveys carried out in the vicinity of the port’s access (Figure 4.7). The model was applied with a simulation in the medium term (three years), with special interest in the evaluation of the efficiency that a dredging work would have to restore the design depth of the channel. This morphological modelling allowed a better understanding of the main hydrodynamic and sedimentological processes that occur around the entrance of the port, as well as obtaining potentially useful information for the design of structures and the planning of maintenance dredging. It was determined that for the present hydrosedimentological conditions the sand bank moves towards the access channel with high sedimentation rates (Figure 4.8), for which it requires regular maintenance, or the construction of complementary works such as sediment traps, breakwaters, the extension of the South breakwater, etc. From the point of view of the reduction of sedimentation, the effectiveness of any intervention must be verified before its application. In all cases, the transport of sediments will always be blocked, for which an artificial bypass of sand should be considered in order to protect the beaches located north of the port.

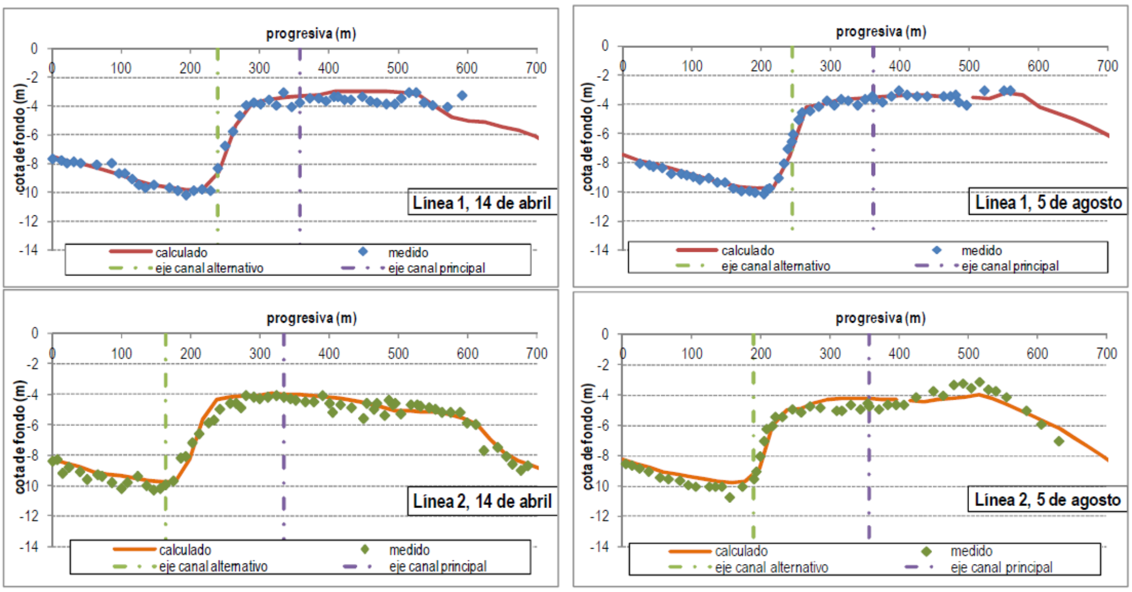


Figure 4.7. Profiles of the sandbank calculated with the numerical model and values measured in the surveys of 04/14/2009 and of 05/08/2009.

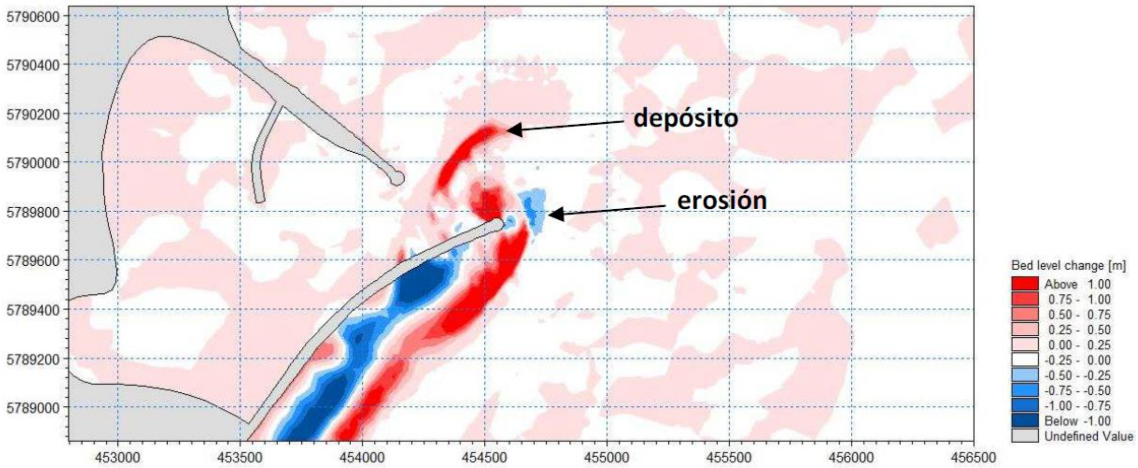


Figure 4.8. Relative changes in the bed level as of 08/01/2009 in the South breakwater of the port of Mar del Plata (Cáceres and Castellano, 2012).

5 REMOTE SENSING APPLIED TO PREVENTION, MONITORING AND EVALUATION OF NATURAL RISKS ON COASTAL ZONES

Given that the marine-coastal phenomena that affect coastal dynamics cover large spatio-temporal scales, traditional monitoring systems present enormous limitations in the collection of information due to their high costs and associated logistical limitations. In recent years, numerous instruments have been developed associated with remote sensing (understanding by remote sensing as the technology that allows obtaining information from bodies located on the earth's surface without making contact with them; Chuvieco, 1990) that serve to monitor and evaluate situations of risk in coastal areas. This chapter gives an account of the different tools used for this purpose and the different applications of them.

Remote sensing or remote sensing systems reviewed in this chapter include those that explore the Earth's crust from the atmosphere, using satellites or airborne sensors (aerial photography, LiDAR, satellite images, radar), as well as other techniques, also applying indirect measurement, used in terrestrial and marine geophysics (georadar). Also included in this review are several video and photograph systems, which are often of collaborative use, low cost and with a strong growth in recent times.

5.1 LiDAR

Several studies conclude that to carry out an effective coastal management, planners require quantitative information and a high resolution on the elevation of the terrain to be able to perform resource management, planning, navigation and research (Brock and Purkis, 2009).

The use of airborne LiDAR (Light Detection and Ranging) platforms provides information on the elevation of the land, the evolution of the coastline and the vulnerability of coastal zones to the different natural hazards, through monitoring, mapping and modelling changes in those areas. Analogous to radar, LiDAR uses an airborne laser scanner that emits millions of fast pulses over a certain area, and uses the time interval between the emission of those pulses and their detection (reflected signal) to calculate the distance to the measuring point (Chang, 2010); The faster the instrument detects the reflected signal, the closer the reflected surface will be to the instrument, and therefore the higher the elevation.

Typically, a LiDAR database can be used as a topographic basis for flood maps produced by a GIS, identifying areas that may be below the level of the highest tides, or that could be flooded during a tsunami. This type of study has been carried out in Chennai (Usha et al., 2011) and

Cuddalore, in the south-east of India (Murthy et *al*., 2011), where several historical tsunamis were simulated in a hydrodynamic model to provide the stakeholders with a map of vulnerability according to the risks.

Another use of this methodology has a history in California. The risk of erosion of the coasts of California is well known and many large-scale photogrammetry studies have been carried out in several sectors (Moore and Griggs, 2002, Hapke et *al*., 2009). Some of these studies have used historical aerial photographs, combined with a cliff line derived from the use of LiDAR for a more recent period of time (Hapke and Reid, 2007), and estimates of the volume of sediment eroded in some specific areas have also been made. For example, between 1998 and 2004, a strip of 43 km of cliffs in southern California contributed more than 150.000 m^3 of material per year (Young and Ashford, 2006) to the coastal zone. There are several LiDAR databases available for free, for this part of the coastline (www.opentopography.org).

The Oceanographic and Hydrographic Research Center of the Pacific, in Colombia, located in the city of Tumaco, has recently produced tsunami flood maps of the cities of Tumaco and Buenaventura, both located on that coast. The flood maps have been derived from LiDAR data combined with cartographic bases of digital aerial photographs (CCCP, 2009) and have allowed to identify the most exposed areas and therefore the population at risk, as well as the areas that could be used as safe areas of relocation of the population or eviction in case of tsunamis.

The work of Zhang et *al*. (2011) presents a series of predictive models to estimate the area of southern Florida that could potentially be flooded under scenarios of sea level rise (SLR) of 0.5-1.5 m (Figure 5.1), concluding that the Keys of the Florida, to the south of the peninsula, are particularly vulnerable to the SLR since many islands, of this chain of 1.700 islands, are below 2 m of elevation. The LiDAR has been used to create flood polygons in this area, where they have been combined with other databases derived from GIS to create a SLR scenario that would flood 91% of the area (> 310 km^2), displace more than 56.000 people and would cause almost US$ 27 trillion in property losses.

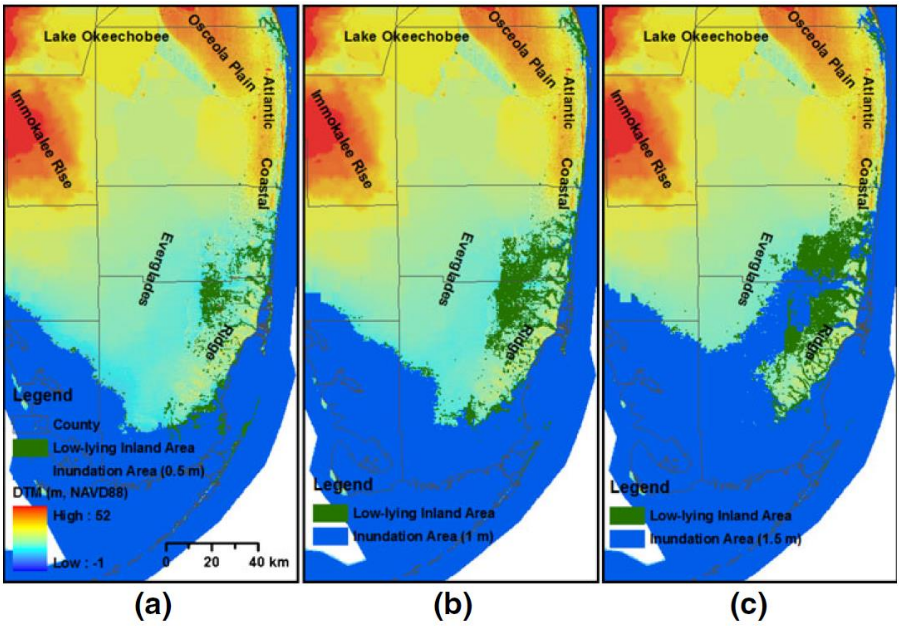


Figure 5.1. Flood maps for South Florida with increases of 0.5 m (a), 1 m (b) and 1.5 m (m) of sea level. The sea level is referenced to NAVD88. The flood area represents land areas flooded directly by the projected sea level rise, while the Low-lying Inland Area delimits the areas that are below the projected sea level, but they are separated from the flood area by barriers of elevation.

5.2 Radar

5.2.1 Radar applications to dune barriers

In recent years, the combination of photographs obtained from airplanes and satellites, as well as satellite images have been repeatedly used for the mapping of dune barriers (Isla et *al*., 2001, Paskoff and Manríquez, 2004, Bértola and Merlotto, 2010, Cortizo, 2010). Some of these methods combine processings using infrared bands and the NDVI vegetation difference standardized index (Rodríguez et *al*., 2009). Using conventional satellite images with different positions of the Sun (inclination and orientation), better cross-sectional and linear dune heights have been obtained than those obtained with digital terrain models with better resolution (Levin et *al*., 2004).

Combinations of images ASTER and Radarsat managed to identify fields of active and fixed dunes in Peninsula Valdés (Blanco et *al*., 2007). The L band of the PALSAR sensor (ALOS satellite) has recently been used to confirm the distribution of oases in the Libyan Desert (Paillou et *al*., 2009).

5.2.2 Radar applications to submerged forms

SAR images have been repeatedly used to detect portions of the sea with different surface tension. Thus they have been required to follow pollution plumes or oil spills (slicks). In addition, from the first images obtained from Seasat, oceanographers identified submerged forms that had been mapped with underwater methods (Achuchman et *al*., 1985).

South of the mouth of the San Matías Gulf in Argentina, there is a sand wave field with a significant gravel content. Through the C band of the ERS radar it was possible to map these sand and gravel waves that extend to depths of 60 m (Gagliardini et al., 2005). These shapes have heights of 10 m and wavelengths of 600 m, and can be recognized in SAR images when:

- The height of the irregularities is significant with respect to the depth,

- The speed of the current is between 0.4 and 0.5 m/s, and

- The wind speed is between 3 and 12 m/s (Schuchman et *al*., 1985, Gagliardini et *al*., 2005).

Radars acting as altimeters have been implemented on the French Atlantic macromareal coast to analyse the variations of the tide. Radars arranged in PVC or stainless steel tubes have been installed in ports with ranges between 5 and 12 m, with systematic errors (square root of squares) of between 0.6 and 2.3 cm (Martín Míguez et *al*., 2008).

5.3 *Satellite images*

Coastal erosion and floods due to the rise in mean sea level represent geological risks that occur continuously, and at different time scales. In order to study these changes, it is essential to carry out a detailed temporal analysis of the different positions occupied by the coastline during the study period. Defining the position of the coastline is not simple because given its constantly changing nature, it allows to establish different arguments for its definition, which are collected in Boak and Turner (2005). Remote sensing offers a series of tools based on the different spectral behaviour of the selected areas, so that the extraction of the shoreline is done automatically, precisely based on these characteristics, and not on the experience and expertise of the operator in charge of the restitution and digitalization of the water line (Rodríguez, 1999b).

On the other hand, different methods that allow to increase the precision in the determination of the coastline at a subpixel level are being developed. The algorithm developed by Ruiz et *al*. (2007) and Pardo et *al*. (2007, 2008, 2012), starts with the initial extraction of an approximated coastline at pixel level and, in a second phase, on this first line, the position search is made at a subpixel level. The developed program is based on the previous resampling of the image to work on smaller pixels. On a given neighbourhood of the new resampled image and located on the preliminary coast line, a polynomial function of 5th degree is adjusted and, once this mathematical function is defined analytically, the point at which the curvature is null and the gradient is maximum is deduced. This analysis is repeated successively along the preliminary coastline, so that in the end it is possible to deduce the position of the shore with a very low average error (Pardo et *al*., 2008).

In this sense, the work of Di et *al*. (2003a) is also interesting because it proposes an algorithm to automatically extract the coastline from IKONOS images. They also propose other procedures using Digital Elevation Models (DEM), reaching acceptable errors in their definition (Di et *al*., 2003b, Li et *al*., 2003).

Finally, the work of Boak and Turner (2005) presents a clear definition of the coastline, and a vast review of possible ways to identify it. It also shows a review of the data sources, and the different techniques used to delimit the coastal edge, based both on manual procedures of digitization on aerial photography, as well as on more sophisticated ones such as classification by neural networks.

Another application of satellite images is the measurement of the topography of the ocean surface and the observation of the variations of the global average level of the sea and its relationship with global climate change. In this regard, the information provided by the TOPEX/Poseidón[1] (1992-2001), Jason-1[2] (2001-2008), Jason-2[3] (2009-2016) and Jason-3[4] (2016-present) satellites stands out.

5.4 Video and photograph systems

Within remote sensing methodologies we can also highlight those that use video systems. An example of this is presented in Osorio et *al*. (2010). This paper presents the HORUS monitoring system, jointly developed by the National University of Colombia and the University of Cantabria. HORUS is a system capable of continuously quantify changes in various natural areas, with the aim of helping scientists understand the processes involved and the managers to make decisions about them. HORUS is composed of a data collection system based on video cameras, an information processing software and a system for displaying results online. The entire scheme of operation of the system is presented in Figure 5.2. One of the applications of this system is the determination of the coastline with respect to a reference line, which serves to define zones of erosion and zones of accretion (Figure 5.3).

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[1] https://nssdc.gsfc.nasa.gov/nmc/spacecraft/display.action?id=1992-052A

[2] https://web.archive.org/web/20080513070927/http://topex-www.jpl.nasa.gov/mission/jason-1.html

[3] https://sealevel.jpl.nasa.gov/missions/ostmjason2/

[4] http://www.wmo-sat.info/oscar/satellites/view/206

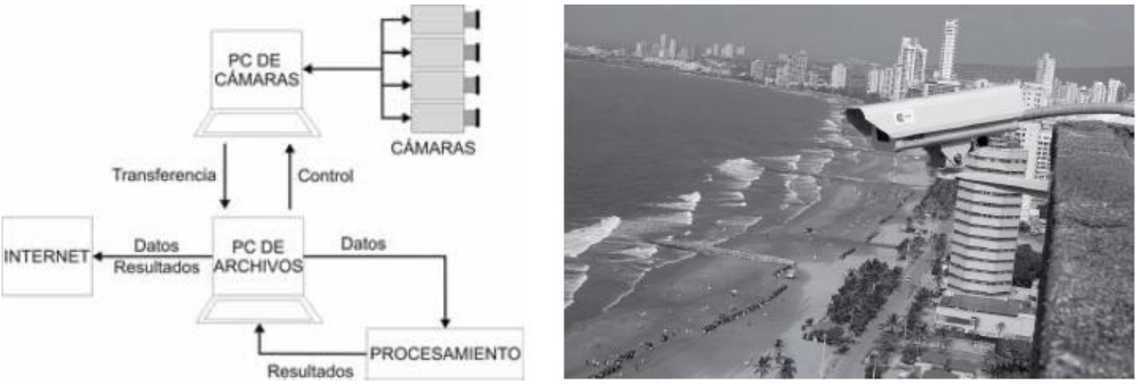


Figure 5.2. Outline of the HORUS system hardware (left) and sample of the monitoring cameras on the beaches of Bocagrande - Cartagena (right).

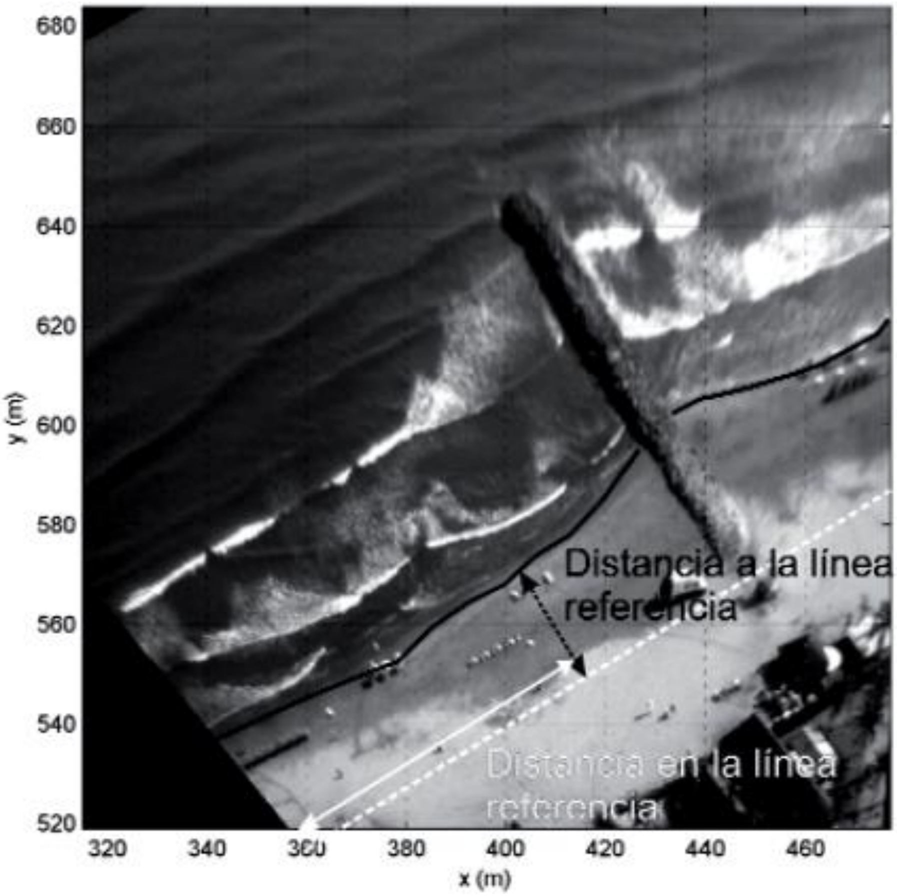


Figure 5.3. Determination of the coastline and location of the reference line on the beaches of Bocagrande (Cartagena, Colombia).

Another methodology is the one presented in Splinter et al. (2018). It shows the collaborative coastal monitoring system called CoastSnap developed by the UNSW (Sydney). CoastSnap is a beach monitoring program that allows users to contribute to their monitoring. This proposal is operational in Australia, the United Kingdom and Brazil. To contribute to the database, a cell phone must be placed in the cradle located on certain beaches (Figure 5.4) and then share the image via social networks (Facebook, Instagram or Twitter) or sending it by email. By controlling the position and angle of the camera using these cradles, images can be obtained to analyse the changes that may occur on the beaches (width and shape, movements of the coastline, etc.).

Figure 5.4. CoastSnap monitoring system.

5.5 Georadar

The Georadar geophysical technique or GPR (Ground Penetrating Radar) is a very useful tool for shallow geophysical prospecting, providing information on the stratigraphy of the terrain in the first meters of depth. Its main advantages are the high resolution and speed in the acquisition of data. It began to be used on a regular basis as of the 1930s (Daniels, 2004), its first applications being the estimation of ice thickness in glaciers. Rapidly, its scope of application became more and more extensive, ranging from the location of fresh water to the study of salt deposits, passing through different stratigraphic and geotechnical applications, applied to the environment or geological risks. The study of coastal dynamics in dune environments is another field of application of georadar that is currently developing (Bristow et *al*., 2005, Bristow and Pucillo, 2006, Pedersen and Clemmensen, 2005, Costas et *al*., 2006). Since the 1970s, it has undergone considerable expansion, and is currently one of the most used and continuously developing geophysical prospecting methods.

In recent years there have been several studies on the application of this technique to sedimentary materials in coastal areas, standing out the sedimentary history of materials and processes based on the identification and interpretation of radar facies. Good example is the recently published study on the dynamics of the active dune field of the Fangar arrow, in the

Ebro Delta (Spain). In Gómez-Ortiz et *al*. (2009a) and Rodríguez-Santalla et *al*. (2009) the internal structure of Barjanoid dunes of the Ebro river delta is established from the data obtained with georadar.

The deposits and erosive structures resulting from the effects of storms on the coast are some of the materials in which this technique has been applied with more success. In this sense, it is worth mentioning the good results obtained in sandy barriers in different areas. On coast of the United States, georadar has revealed the existence of several scarps caused by severe stormy events, currently buried under the current escarpment (Buynevich et *al*., 2004). The sedimentological record in this area has recorded the occurrence of successive episodes of major storms in the North Atlantic during the last 3000 years. These catastrophic events have left their mark as coastal flooding sequences, truncated wind deposits, and also with the deposition of sedimentary levels with high concentrations of heavy minerals mobilized and transported there by these storms. The greater electromagnetic contrast of this type of levels enriched in heavy minerals is visible in the radargrams in the form of perfectly delineated continuous reflectors. Also in this type of material, but in this case on the coast of Australia, Switzer et *al*. (2006) manage to establish the structure and sedimentary evolution of sandy Holocene barrier-lagoon systems. An evolution clearly marked by flood deposits on a large scale caused by the action of storms and, in some cases, tsunamis preceded by the corresponding erosive episodes.

Regarding variations in sea level position, works such as the one of Tamura et *al*. (2010) highlight the benefits of the georadar method. The authors identify significant variations in sea level, and significant elevations in beach deposits from the Holocene on the northeast Pacific coast of Japan from georadar profiles. It is important to mention the application of georadar in this case due to the absence of terrace levels of this age that could be used as a reference.

6 COASTAL MANAGEMENT PLANS

In this chapter a revision of different Coastal Management Plans (CMP) is made. In the search, the most recent Plans that had different types of approach and methodologies were prioritized.

Among the most current and complete Plans are those developed in the different States and Counties of Australia (country that has CMP's for most of its coastline, which exceeds 25.000 km). The CMP of the Shire of Jerramungup (Aurora Environmental, 2018) and the coastal area of Shoalhaven (Shoalhaven, 2018) are detailed below. The first one was developed with a strong participation of the different social actors involved in the problem. The second CMP highlights the list of actions to be carried out in the short, medium and long term to reduce coastal risk.

Other Plans included in the present review are those made in the United Kingdom (Williams et *al*., 2018). They have the peculiarity of being based on the principle of environments (or management units), which is very useful for the integrated management of coastal areas, but often these environments do not coincide with the limits of the different jurisdictions.

Finally, two CMP's within a regional scale are presented. One for the coastal area of the department of La Guajira (Colombia, INVEMAR-CORPOGUAJIRA, 2012), which exposes the risks and threats of the study area in detail, shows the articulation of the lines of action and management instruments and creates impact indicators to evaluate the effectiveness or impact of the CMP. The other Plan in the region was developed for the town of Pehuén Co (which belongs to the study area of this project) (Bustos, 2017) and is a methodological guide for comprehensive coastal management with strong social participation.

6.1 Coastal Management Plan 2017 – 2027 for the Shire of Jerramungup (Australia)

The coast of the Shire of Jerramungup (Australia) (Figure 6.1) is under growing pressure, due to an increase in users, particularly in summer. This has led to an increase in the use of infrastructure, access roads and beaches, including sensitive or vulnerable areas. The analysed plan (Aurora Environmental, 2018) includes advice for the management of coastal areas, with practical ideas for its management. It is highlighted in this Management Plan, that the information provided by users and managers of the area has allowed to give priority to certain work plans and complementary projects.

As a peculiarity, the region has native people who claim ownership over certain sectors. It is from this situation that the development of this management plan is proposed to be made in conjunction with these populations, expanding the capacity of coastal management action.

Figure 6.1. Location of the Shire of Jerramungup.

The Management Plan was made following the nine steps mentioned below:

1. Definition of the Baseline
2. Definition of the Planning Framework
3. Review of the current state of the coastal zone
4. Preliminary advice on Coastal Hazards
5. Community and stakeholder participation
6. Problems and recommendations of coastal management
7. Advice and recommendations for Coastal Nodes
8. Implementation
9. Monitoring, evaluation and review of the Management Plan

6.1.1 Objectives

The Management Plan seeks to achieve the following objectives:

- Promote a sustainable use of coastal natural resources, maintain high levels of biodiversity and facilitate community leisure in coastal areas.
- Establish budget categories for coastal management, maintenance and monitoring projects.
- Strengthen the South Coast Management Group of Australia (existing partnership that includes the Shire of Jerramungup, other local governments of the South Coast, other landowners, community members and stakeholders).
- Form a Coastal Action Group that allows the Shire to work together with stakeholders to plan and implement coastal projects.
- Relate to the community and key stakeholders to raise awareness about the main objective of this management plan.

6.1.2 Risks and threats

The Plan identified the main risks and threats, among which the main are:

- Increase in tourism and recreation (camping, fishing, vehicle circulation)
- Climate change (sea level rise, storm waves, fires, impacts on vulnerable species)
- Difficulties related to planning for coastal development that ensure a reduction in key impacts, such as habitat loss, pollution, etc.
- Wild animals.
- Lack of infrastructure and lack of maintenance of services
- Lack of formal effluent systems and waste treatment
- Fire and post-fire impacts, such as erosion and weed growth
- Weeds and pests
- Diseases
- Poor handling and poor maintenance due to access difficulties in remote areas
- Lack of funding
- Vandalism
- Use of closed roads and creation of new roads
- Lack of knowledge
- Ownership of land (private, fiscal, native property, etc.)
- Coastal risk (example: cliffs)
- Management of community expectations
- Informal camping in sensitive areas.
- Large camping groups that result in environmental degradation due to lack of adequate infrastructure

6.1.3 Existing management tools at the time of elaboration of the coastal management plan

The National Research Service of Adaptation to Climate Change (NCCARF) developed an online tool called CoastAdapt (Department of Environment and Energy, 2017).

The Shire also made a study (MP Rogers y asociados, 2017) in which, from the information available, areas of the coastline or areas of value within the Shire that could be at risk due to the impact of coastal hazards in the next 100 years were identified. The modelling of the area made it possible to identify the areas likely to be at risk and where a management and risk adaptation plan should be applied. The necessary information to be able to make future models was also identified. This study identifies areas of the coastline that could be stroked by coastal hazards in the following time periods: Imminent (0-5 years), Expected (5-25 years) and Projected (25-100) and produced a map of coastal hazards that show areas of potential impact in different time frames. The options presented in the report are:

- To avoid new developments within the area stroked by coastal hazards
- To remove or re-locate objects and infrastructure of interest within the area identified as likely to be subject to intolerable risk for damage caused by coastal hazards
- To adapt measures of action to certain risks
- To protect natural reserves, public access, infrastructure, etc.

Figure 6.2. Coastal hazard lines for different temporal scenarios (Aurora Environmental, 2018).

6.1.4 Implementation of the coastal management plan

The implementation of this Management Plan is not mandatory. An effective implementation will depend on the availability of resources, both human and financial.

The Management Plan recommends that its implementation is audited annually by the different parties involved. In turn, it should be reviewed in 10 years and updated if necessary.

6.2 Coastal Management Plan for the Shoalhaven area (Australia)

The coastal landscape of Shoalhaven (165 km along the southeastern coast of Australia) (Figure 6.3) forms a natural, social and economic treasure. The Council of Shoalhaven, together with other government agencies, manages 40 open beaches and 11 coastal lakes and estuaries. This Coastal Zone Management Plan (CZMP) establishes the coastal management plan within the government area corresponding to the city of Shoalhaven for the next 5 years. During that time, the Council will develop a new Coastal Management Program (Shoalhaven, 2018).

The key strategies and action plans within the CZMP include:

- Regulate the urban development in the coastal zone to ensure minimizing the environmental impact and long-term safety of the residents.
- Guarantee a balance between beach stability and user comfort.
- Provide mechanisms for the management and mitigation of risk for public and private spaces.
- Guarantee that the Shoalhaven coastline continues to be a space of natural value for the community.

This plan focuses on two types of coastal danger: i) erosion of beaches, run-up of waves and long-term retreat of coasts and ii) instability of coastal cliffs.

The management plan also provides guidelines on important natural and community values such as:

- The ecological health of beaches and coastal dunes.
- The social health of coastal communities.
- Appropriate locations and services to support and encourage coastal use by the community.

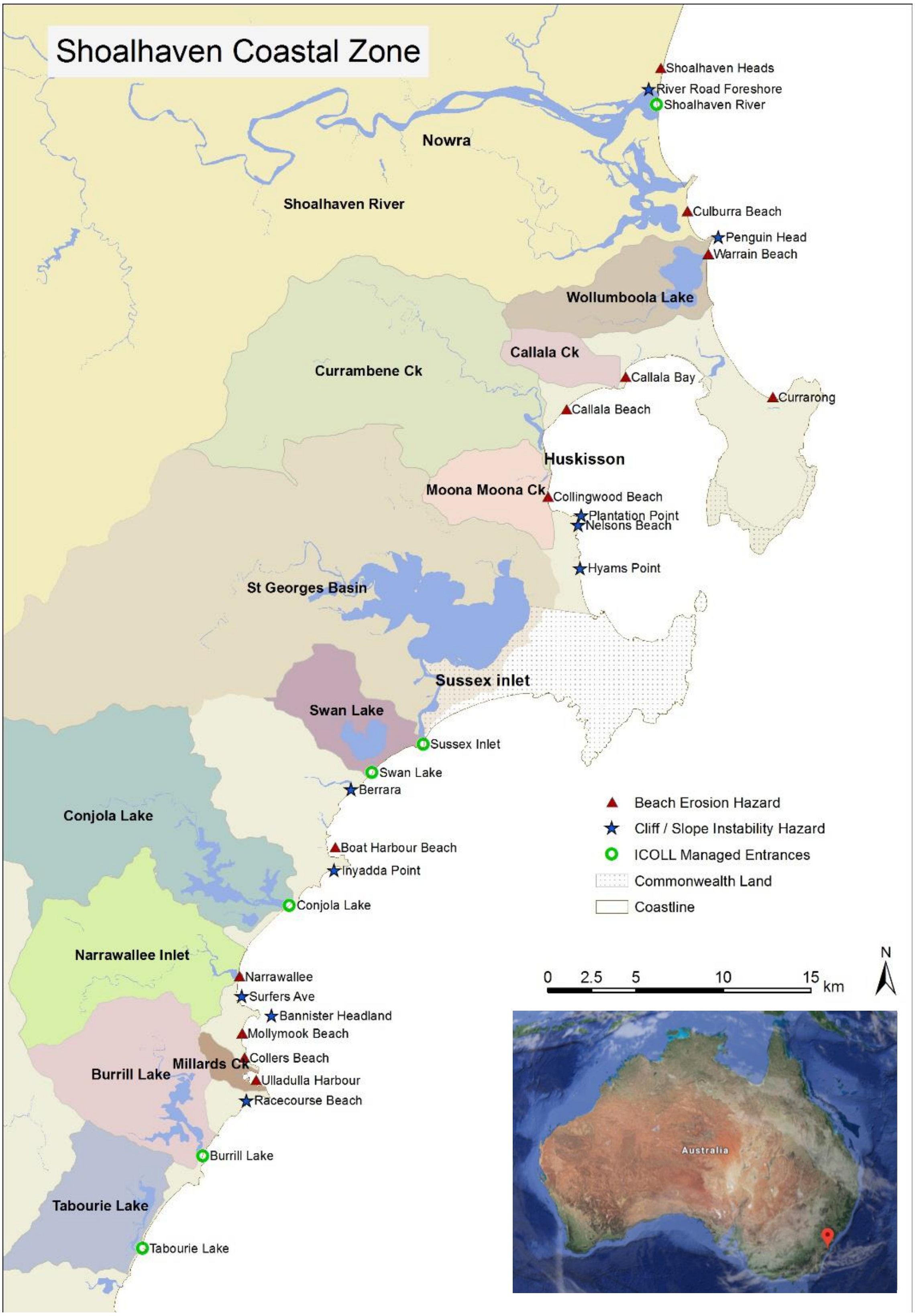


Figure 6.3. Location of the Shoalhaven coastal area (Australia).

6.2.1 *Principles and objectives*

- Give effect to all legislation and relevant policy in NSW that applies to the coastal areas of Shoalhaven.
- Manage all coastal systems comprehensively.
- Align the Coastal Zone Management Plan with the management plans for estuaries, the environment and Council control.
- Relate to the community in the processes of review and preparation of coastal management programs.
- Keep the community informed about coastal processes and response actions.
- Manage the coastal zone in an adaptable way, with clear processes to modify the procedures when new knowledge is acquired.
- Invest in effective and efficient strategies to achieve positive natural, social, cultural and economic results within the responsibilities of the Council.
- Incorporate coastal hazards into the land use planning of the Council.
- Maintain natural systems and processes to improve their health and diversity.
- Support the economic and social well-being of local communities by maintaining safe access to beaches and encouraging recreational activities.

6.2.2 *Strategic approach*

The CZMP has four main sections (Figure 6.4) that are contained and interact with an adaptive management framework. Adaptive management is a process to manage uncertainty, incomplete information and changing coastal systems, to improve and refine management over time (Figure 6.5).

Figure 6.4. Framework for adaptive management of coastal risks and the four areas of interaction (Shoalhaven, 2018).

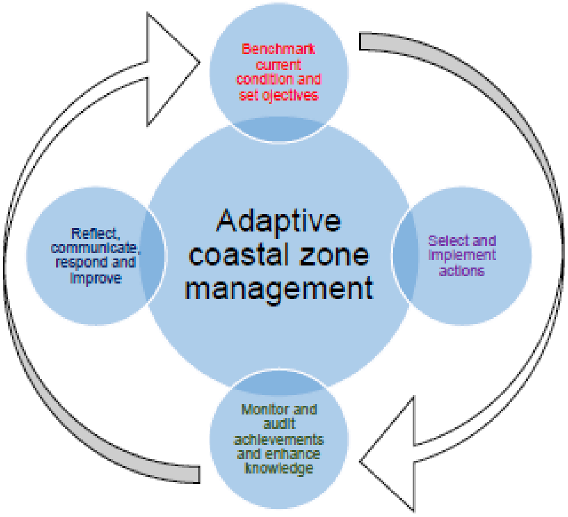


Figure 6.5. Key considerations for adaptive management of coastal zones (Shoalhaven, 2018)

6.2.3 Evaluation process

The Management Plan consists of 6 steps that are mentioned below:

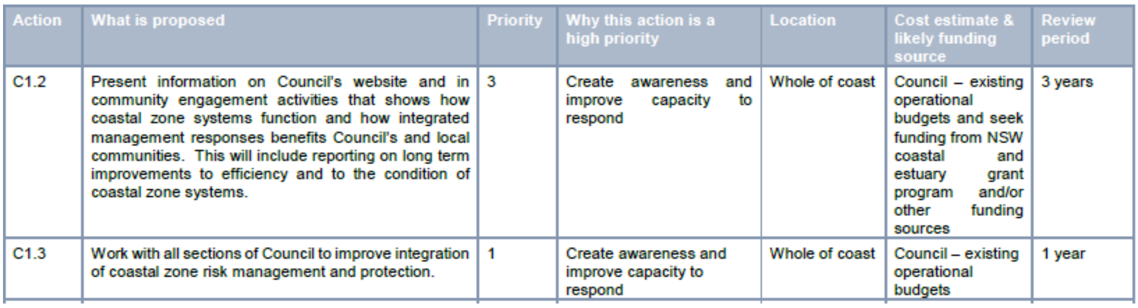
1) Understand the coastal process for present time and for the years 2030, 2050 and 2100.
2) Evaluate coastal hazards for the present time and for the years 2030, 2050 and 2100.
3) Evaluate the use of the community and the natural and built values.
4) Evaluate coastal risks and probable consequences for the present time and for the years 2030, 2050 and 2100.
5) Select and implement coastal risk management strategies.
6) Monitor, evaluate and review.

6.2.4 Implementation priorities

High priority actions are those that respond to extreme or very high risks. These are actions that:

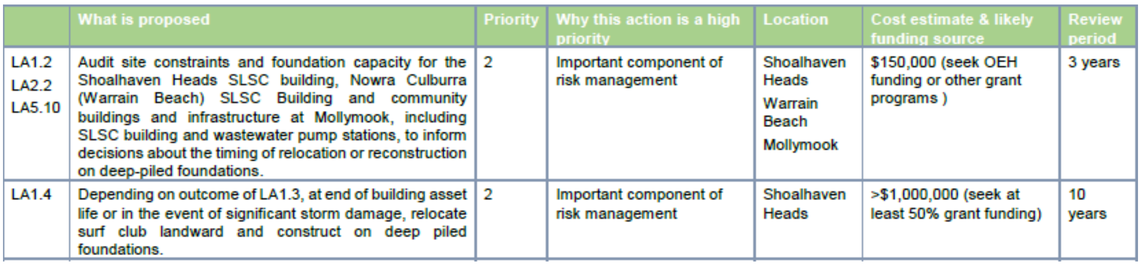
- Preventively reduce risk.
- They protect or improve biodiversity and ecology values of the area and increase the resilience of natural systems.
- Build awareness and knowledge in the community.
- Establish adaptive management frameworks.
- They reach more than one of the previous points at the same time.

All the actions considered in this plan were classified into three groups, according to the implementation period. In turn, each of them was assigned a priority category (from 1 to 3) as shown in Figure 6.6, in Figure 6.7 and in Figure 6.8.



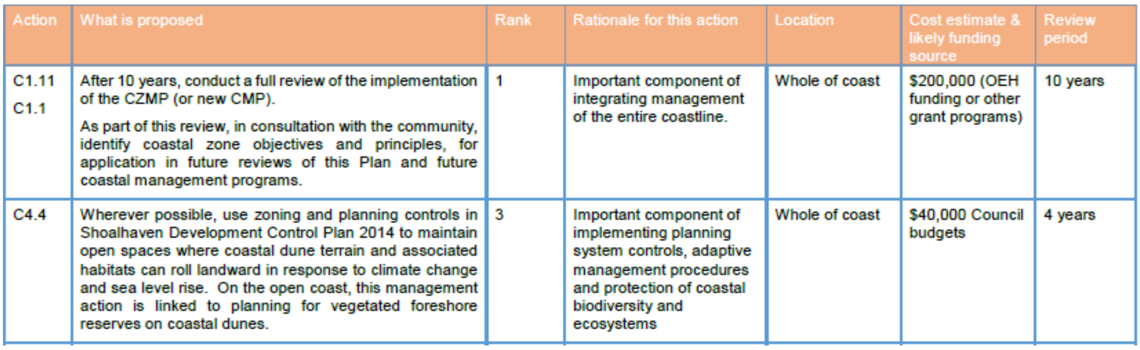
Action	What is proposed	Priority	Why this action is a high priority	Location	Cost estimate & likely funding source	Review period
C1.2	Present information on Council's website and in community engagement activities that shows how coastal zone systems function and how integrated management responses benefits Council's and local communities. This will include reporting on long term improvements to efficiency and to the condition of coastal zone systems.	3	Create awareness and improve capacity to respond	Whole of coast	Council – existing operational budgets and seek funding from NSW coastal and estuary grant program and/or other funding sources	3 years
C1.3	Work with all sections of Council to improve integration of coastal zone risk management and protection.	1	Create awareness and improve capacity to respond	Whole of coast	Council – existing operational budgets	1 year

Figure 6.6. Example of actions in the short term (0 to 2 years) (Shoalhaven, 2018).



	What is proposed	Priority	Why this action is a high priority	Location	Cost estimate & likely funding source	Review period
LA1.2 LA2.2 LA5.10	Audit site constraints and foundation capacity for the Shoalhaven Heads SLSC building, Nowra Culburra (Warrain Beach) SLSC Building and community buildings and infrastructure at Mollymook, including SLSC building and wastewater pump stations, to inform decisions about the timing of relocation or reconstruction on deep-piled foundations.	2	Important component of risk management	Shoalhaven Heads Warrain Beach Mollymook	$150,000 (seek OEH funding or other grant programs)	3 years
LA1.4	Depending on outcome of LA1.3, at end of building asset life or in the event of significant storm damage, relocate surf club landward and construct on deep piled foundations.	2	Important component of risk management	Shoalhaven Heads	>$1,000,000 (seek at least 50% grant funding)	10 years

Figure 6.7. Example of actions in the medium term (3 to 5 years) (Shoalhaven, 2018).



Action	What is proposed	Rank	Rationale for this action	Location	Cost estimate & likely funding source	Review period
C1.11 C1.1	After 10 years, conduct a full review of the implementation of the CZMP (or new CMP). As part of this review, in consultation with the community, identify coastal zone objectives and principles, for application in future reviews of this Plan and future coastal management programs.	1	Important component of integrating management of the entire coastline.	Whole of coast	$200,000 (OEH funding or other grant programs)	10 years
C4.4	Wherever possible, use zoning and planning controls in Shoalhaven Development Control Plan 2014 to maintain open spaces where coastal dune terrain and associated habitats can roll landward in response to climate change and sea level rise. On the open coast, this management action is linked to planning for vegetated foreshore reserves on coastal dunes.	3	Important component of implementing planning system controls, adaptive management procedures and protection of coastal biodiversity and ecosystems	Whole of coast	$40,000 Council budgets	4 years

Figure 6.8. Example of long-term actions (more than 5 years) (Shoalhaven, 2018).

6.3 *Coastal Management Plans due to erosion problems for the United Kingdom*

Williams et *al*. (2018) present a summary of coastal management plans due to erosion problems in the United Kingdom (SMP: Shoreline Management Plans)[5]. The usual responses to combat

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[5] https://www.gov.uk/government/publications/shoreline-management-plans-smps/shoreline-management-plans-smps

erosion problems include protection measures of hard and/or soft types (to maintain or advance on the coastline), adaptation, relocation of inhabitants, and sacrificed areas. Relocation and sacrificed areas are increasingly used as a response to coastal erosion.

The three alternatives of action mentioned (Defense, Adaptation and Relocation - DAR) (Figure 6.9.a and Figure 6.9.b) are usually applied in an exclusionary manner, whereas they should be able to be implemented as a mixed strategy, adapted in turn according to a fourth variable, which is the cause of erosion (Figure 6.9.c). In this way, depending on the weight of each measure, different solutions can be applied against coastal erosion or sea level rise. The weights assigned to each variable can be modified during the implementation phase depending on the results obtained through constantly changing scenarios.

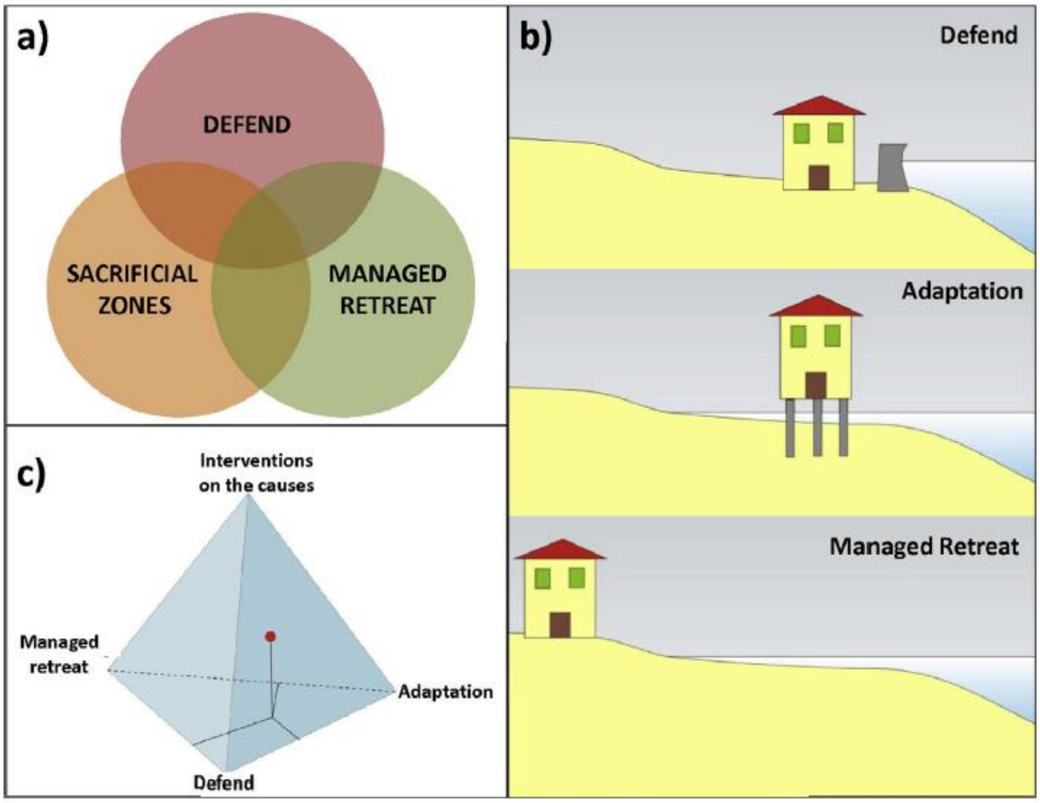


Figure 6.9. Strategies against coastal erosion (Williams et *al*., 2018)

The SMPs of the United Kingdom are based on the principle of environments (or management units); this is very useful for the integrated management of coastal zones, but often these environments do not coincide with the limits of the different jurisdictions. In the United Kingdom, SMPs are non-legal high-level documents that represent large-scale risk assessments associated with coastal developments in cultural and natural environments. They are planning documents for planning processes that identify the limitations of coastal dynamics and identify areas of potential risk along with the associated consequences that can bring about decisions under different future scenarios.

The first SMP had five-year review cycles. In 2000, the Ministry of Agriculture, Food and Fisheries of the United Kingdom (MAFF, 2000) recommended that the future SMPs have a horizon of 100 years and involve all stakeholders in their preparation. These recommendations were further refined in 2003 and finally implemented in 2006 (DEFRA, 2006). These second generation plans considered longer-term implications, that is, 50-100 years in view of climate change and had the participation of the concerned parties. The United Kingdom currently has twenty-two SMPs covering the entire coast of England and foresee three scenarios: from 0 to 20 years, from 20 to 50 years and from 50 to 100 years. The stretches of coastline are divided into "management units" and have an associated type of action to be taken to face erosion problems, shown in (Figure 6.10):

- Areas where an attempt is made to maintain the coastline, for which different types of defences are proposed.
- Non-intervention areas, where there are no planned investments in the defence against floods or erosions, regardless of whether there are previously artificial defences.
- Relocation areas: These areas are usually coupled with other planning and regulation techniques, such as the identification of risk areas, regulating the type of structures so that it is easy to relocate them if necessary or create buffer zones (or withdrawal zones) on which it is not allowed to build. This last measure is a very effective method to minimize damage to property due to flooding and erosion, by removing the structures from the danger zones. It is also a low cost alternative. One of the main problems that this type of solution has is that on the one hand it must be a rigid measure that involves national, regional and municipal regulations, while on the other, it must be flexible enough to adapt to future changes. If the measure is not adopted with extreme care, continuous reviews of sea level rise can make adaptation plans obsolete and trigger endless litigations.

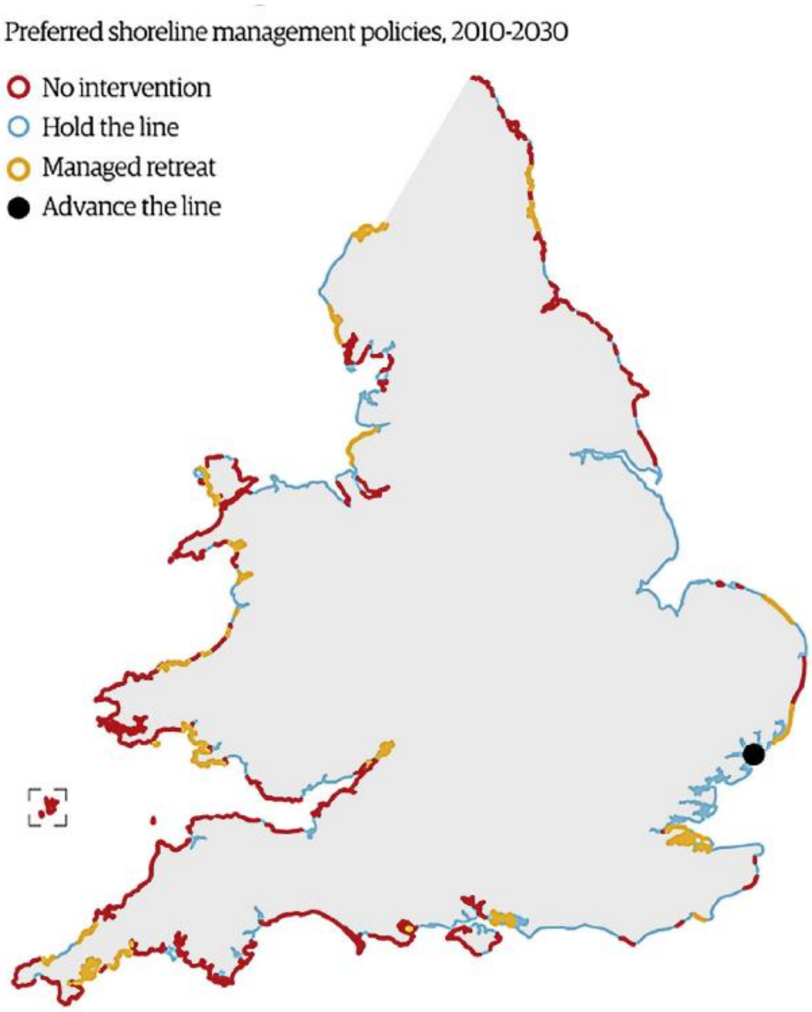


Figure 6.10. SMPs proposed for the United Kingdom (Williams et *al*., 2018).

6.4 *Management Plan for the Coastal Zone of the department of La Guajira (Colombia)*

This project intends to advance in the development of the diagnosis and zoning, basis for the management plan and Integrated Management strategies for the Coastal Zone (IMCZ) of the department of La Guajira (Alta Guajira Coastal Environmental Unit) (Figure 6.11) (INVEMAR – CORPOGUAJIRA. The IMCZ is a priority and a key instrument to guide in the short, medium and long term, in a coordinated and harmonious manner, all public and private efforts, directed towards the sustainable use of natural resources, as well as the ordering of actions for the socioeconomic development of the region (MMA, 2001).

The main objective of the Management Plan is to guide the integrated management of the Coastal Environmental Unit (CEU) Alta Guajira, through environmental management and the implementation of strategies for restoration, preservation and sustainable use that allow intersectoral and inter-institutional coordination, economic development, social welfare, ethnic and cultural strengthening and the participation of the different actors in the area.

Figure 6.11. Location of the La Guajira Department (Colombia).

A time horizon of 10 years (2013-2023) is proposed for the implementation of the Management Plan, in accordance with the different existing and current planning instruments for the area. In accordance with the validity and timing of the planning instruments, three management plan execution scenarios were established: short (1 to 3 years), medium (4 to 6 years) and long term (more than 6 years). In the medium term (year 2017) it is proposed to carry out the first evaluation of the Management Plan. The final evaluation is proposed for the year 2023 when the term for the execution of the plan is met. At that time, it will be necessary to identify new actions to ensure the sustainability of the results achieved, which will be implemented over the next 10 years as very long-term actions.

The general methodological framework used for the characterization and diagnosis of the Coastal Environmental Unit (CEU) Alta Guajira, was based on the "COLMIZC" methodology (Alonso et *al*., 2003, Rojas et *al*., 2010), which consists of a preparation phase and four subsequent stages, as shown in Figure 6.12.

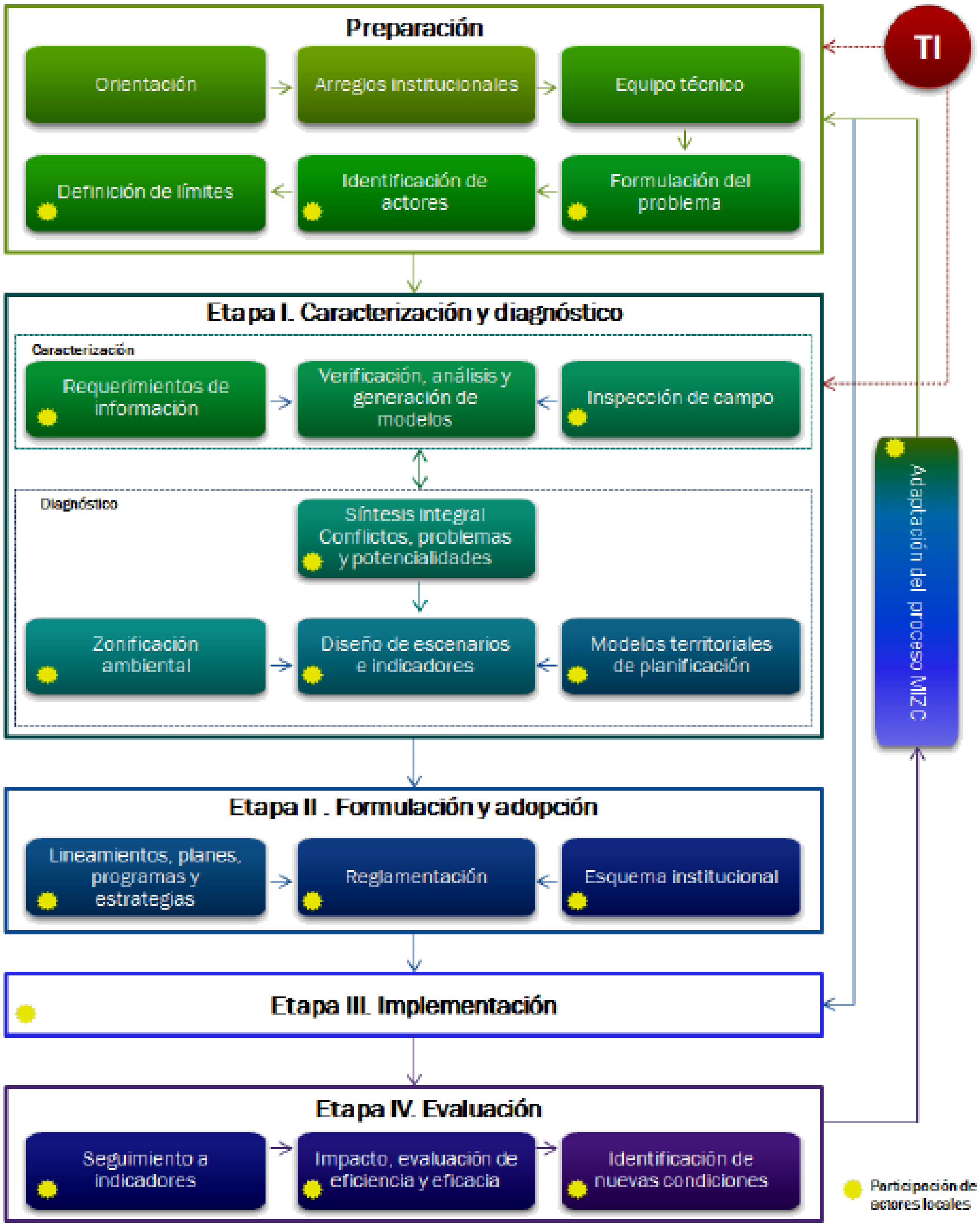
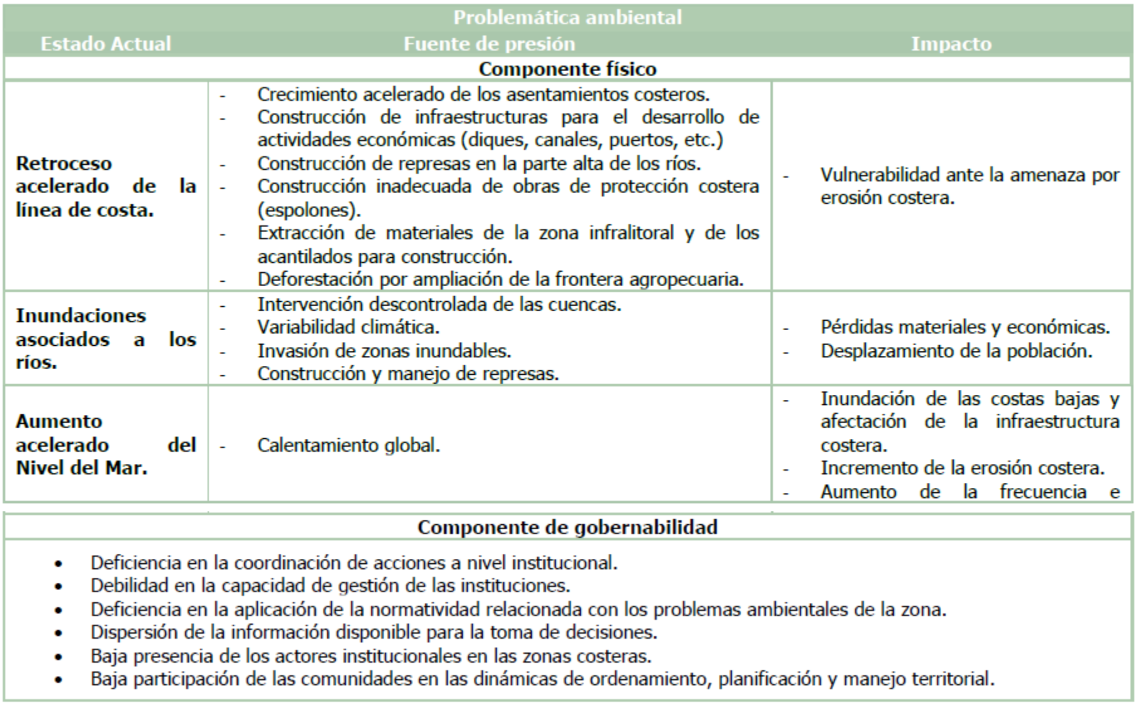


Figure 6.12. Methodological proposal for coastal management units (Rojas et *al.*, 2010).

6.4.1 Risks and threats

Based on the diagnosis made for the CEU-Alta Guajira, the problems were identified (Table 6.1).

Table 6.1. Main problems identified for the CEU Alta Guajira.



Estado Actual	Problemática ambiental Fuente de presión	Impacto
	Componente físico	
Retroceso acelerado de la línea de costa.	- Crecimiento acelerado de los asentamientos costeros. - Construcción de infraestructuras para el desarrollo de actividades económicas (diques, canales, puertos, etc.) - Construcción de represas en la parte alta de los ríos. - Construcción inadecuada de obras de protección costera (espolones). - Extracción de materiales de la zona infralitoral y de los acantilados para construcción. - Deforestación por ampliación de la frontera agropecuaria.	- Vulnerabilidad ante la amenaza por erosión costera.
Inundaciones asociados a los ríos.	- Intervención descontrolada de las cuencas. - Variabilidad climática. - Invasión de zonas inundables. - Construcción y manejo de represas.	- Pérdidas materiales y económicas. - Desplazamiento de la población.
Aumento acelerado del Nivel del Mar.	- Calentamiento global.	- Inundación de las costas bajas y afectación de la infraestructura costera. - Incremento de la erosión costera. - Aumento de la frecuencia e

Componente de gobernabilidad
• Deficiencia en la coordinación de acciones a nivel institucional. • Debilidad en la capacidad de gestión de las instituciones. • Deficiencia en la aplicación de la normatividad relacionada con los problemas ambientales de la zona. • Dispersión de la información disponible para la toma de decisiones. • Baja presencia de los actores institucionales en las zonas costeras. • Baja participación de las comunidades en las dinámicas de ordenamiento, planificación y manejo territorial.

According to an analysis carried out, it was concluded that the main environmental problems affecting the CEU-Alta Guajira are:

- Overexploitation of hydrobiological resources and fauna and flora.
- Precariousness in the living conditions of the population.
- Inadequate development planning and sectoral expansion and land use planning.
- Weakness in the management capacity of the institutions.
- Low presence of institutional actors in coastal areas.

6.4.2 Structure of the Management Plan

In order to achieve the management objectives and achieve the vision proposed in 2023, three lines of action were proposed with their respective programs, and three management instruments (Figure 6.13 and Table 6.2). These were established based on the identification of actions that help resolve environmental problems and conflicts in the coastal zone.

Figure 6.13. General structure of the Management Plan of the CEU-Alta Guajira.

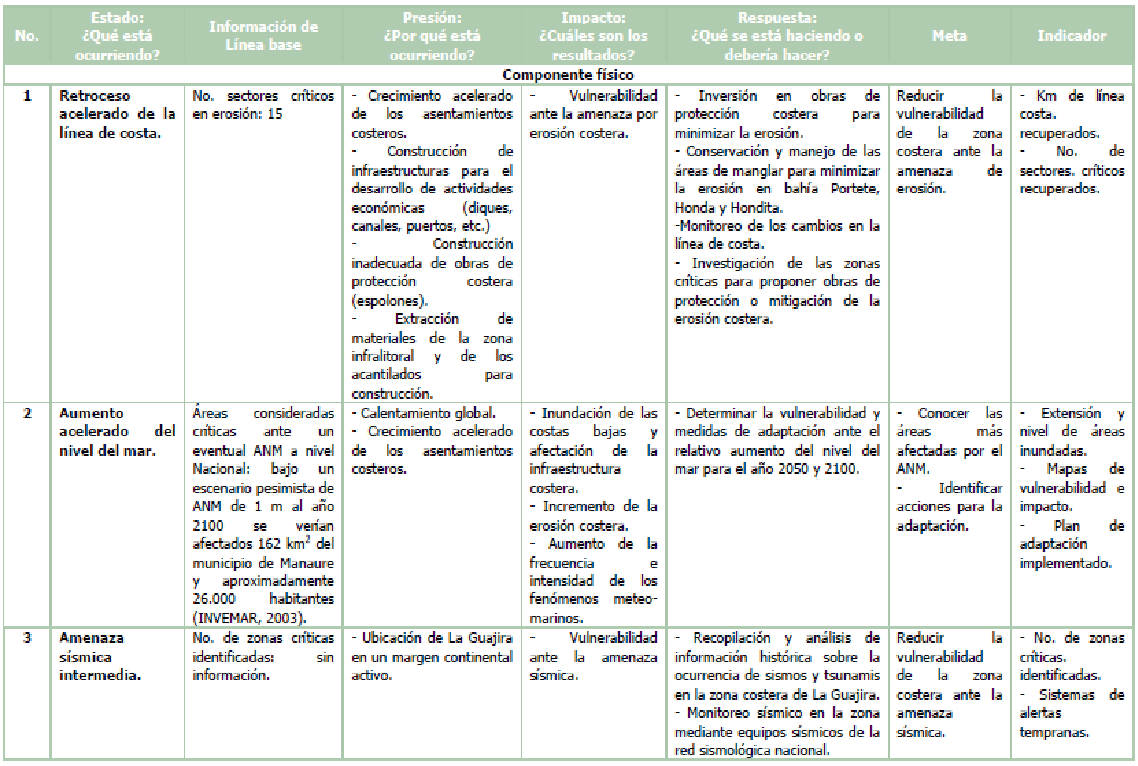
Table 6.2. Articulation of lines of action and management instruments.

Líneas e instrumentos	Programa	No. de proyectos	Zonas a las que aplica
Líneas de acción			
1. Sostenibilidad ambiental.	1. Calidad ambiental marina.	3	- Áreas protegidas. - Preservación. - Restauración.
	2. Conservación y manejo de especies de fauna y flora.	4	- Áreas protegidas. - Preservación. - Restauración.
	3. Conservación de ecosistemas marinos y costeros.	3	- Áreas Protegidas. - Preservación. - Restauración.
	4. Gestión integral del recurso hídrico.	2	- Áreas Protegidas. - Preservación. - Restauración. - Aprovechamiento sostenible.
2. Desarrollo económico y sociocultural.	1. Seguridad alimentaria y condiciones de vida.	2	- Restauración. - Aprovechamiento sostenible. - Producción sostenible.
	2. Fortalecimiento de sistemas productivos.	6	- Aprovechamiento sostenible. - Producción sostenible.
	3. Producción más limpia.	2	- Aprovechamiento sostenible. - Producción sostenible.
	4. Conservación del patrimonio étnico y cultural.	3	- Restauración. - Áreas Protegidas. - Preservación.
3. Ordenamiento ambiental territorial.	1. Directrices para el ordenamiento territorial.	2	- Todas las zonas
	2. Gestión del riesgo y adaptación al cambio climático.	4	- Restauración. - Desarrollo de asentamientos humanos.
Instrumentos de manejo			
1. Fortalecimiento institucional		5	Todas las zonas.
2. Investigación y monitoreo ambiental		18	Todas las zonas.
3. Educación y divulgación de información		5	Todas las zonas.

6.4.3 *Monitoring and evaluation system*

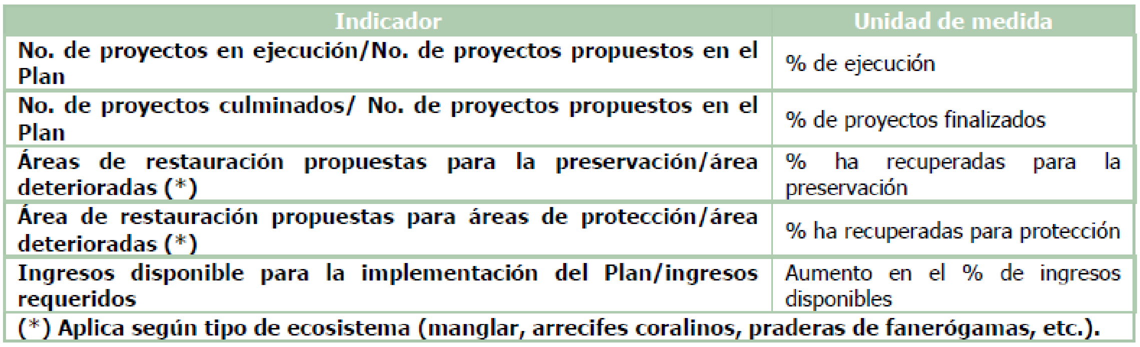
The Management Plan is proposed for a time horizon of 10 years counted from 2013. This implies monitoring and evaluating its implementation, through a series of impact indicators (Table 6.3) and management indicators (Table 6.4) that determine the degree of achievement.

Table 6.3. Impact indicators used to evaluate the effectiveness or impact of the Management Plan.



No.	Estado: ¿Qué está ocurriendo?	Información de Línea base	Presión: ¿Por qué está ocurriendo?	Impacto: ¿Cuáles son los resultados?	Respuesta: ¿Qué se está haciendo o debería hacer?	Meta	Indicador
Componente físico							
1	**Retroceso acelerado de la línea de costa.**	No. sectores críticos en erosión: 15	- Crecimiento acelerado de los asentamientos costeros. - Construcción de infraestructuras para el desarrollo de actividades económicas (diques, canales, puertos, etc.) - Construcción inadecuada de obras de protección costera (espolones). - Extracción de materiales de la zona infralitoral y de los acantilados para construcción.	- Vulnerabilidad ante la amenaza por erosión costera.	- Inversión en obras de protección costera para minimizar la erosión. - Conservación y manejo de las áreas de manglar para minimizar la erosión en bahía Portete, Honda y Hondita. -Monitoreo de los cambios en la línea de costa. - Investigación de las zonas críticas para proponer obras de protección o mitigación de la erosión costera.	Reducir la vulnerabilidad de la zona costera ante la amenaza de erosión.	- Km de línea costa. recuperados. - No. de sectores. críticos recuperados.
2	**Aumento acelerado del nivel del mar.**	Áreas consideradas críticas ante un eventual ANM a nivel Nacional: bajo un escenario pesimista de ANM de 1 m al año 2100 se verían afectados 162 km^2 del municipio de Manaure y aproximadamente 26.000 habitantes (INVEMAR, 2003).	- Calentamiento global. - Crecimiento acelerado de los asentamientos costeros.	- Inundación de las costas bajas y afectación de la infraestructura costera. - Incremento de la erosión costera. - Aumento de la frecuencia e intensidad de los fenómenos meteo-marinos.	- Determinar la vulnerabilidad y medidas de adaptación ante el relativo aumento del nivel del mar para el año 2050 y 2100.	- Conocer las áreas más afectadas por el ANM. - Identificar acciones para la adaptación.	- Extensión y nivel de áreas inundadas. - Mapas de vulnerabilidad e impacto. - Plan de adaptación implementado.
3	**Amenaza sísmica intermedia.**	No. de zonas críticas identificadas: sin información.	- Ubicación de La Guajira en un margen continental activo.	- Vulnerabilidad ante la amenaza sísmica.	- Recopilación y análisis de información histórica sobre la ocurrencia de sismos y tsunamis en la zona costera de La Guajira. - Monitoreo sísmico en la zona mediante equipos sísmicos de la red sismológica nacional.	Reducir la vulnerabilidad de la zona costera ante la amenaza sísmica.	- No. de zonas críticas. identificadas. - Sistemas de alertas tempranas.

Table 6.4. Indicators to evaluate the management and efficiency of management in the area.



Indicador	Unidad de medida
No. de proyectos en ejecución/No. de proyectos propuestos en el Plan	% de ejecución
No. de proyectos culminados/ No. de proyectos propuestos en el Plan	% de proyectos finalizados
Áreas de restauración propuestas para la preservación/área deterioradas (*)	% ha recuperadas para la preservación
Área de restauración propuestas para áreas de protección/área deterioradas (*)	% ha recuperadas para protección
Ingresos disponible para la implementación del Plan/ingresos requeridos	Aumento en el % de ingresos disponibles
(*) Aplica según tipo de ecosistema (manglar, arrecifes coralinos, praderas de fanerógamas, etc.).	

6.5 Methodological guide for a comprehensive coastal management applied to Pehuén-Co (Argentina)

The Integral Coastal Management (ICM) plans in Argentina are almost non-existent. In the southeast of the province of Buenos Aires (Argentina) planning is necessary due to the intensity of the coastal erosion that affects urbanized areas. It is necessary to trace ICM strategies that can be applied throughout the area in a sustainable manner. In this process, the participation and commitment of the social actors is fundamental. In Bustos (2017) a methodological guide for an ICM with social participation is built and applied to the town of Pehuén Co.

Pehuén Co is a coastal town in the southwest of the province of Buenos Aires, belonging to the party of Coronel Rosales (38º 59'51" South and 61º 33'16" West). It is located on a ledge known as Punta Pehuén Co, on which the urban center is located (Figure 6.14).

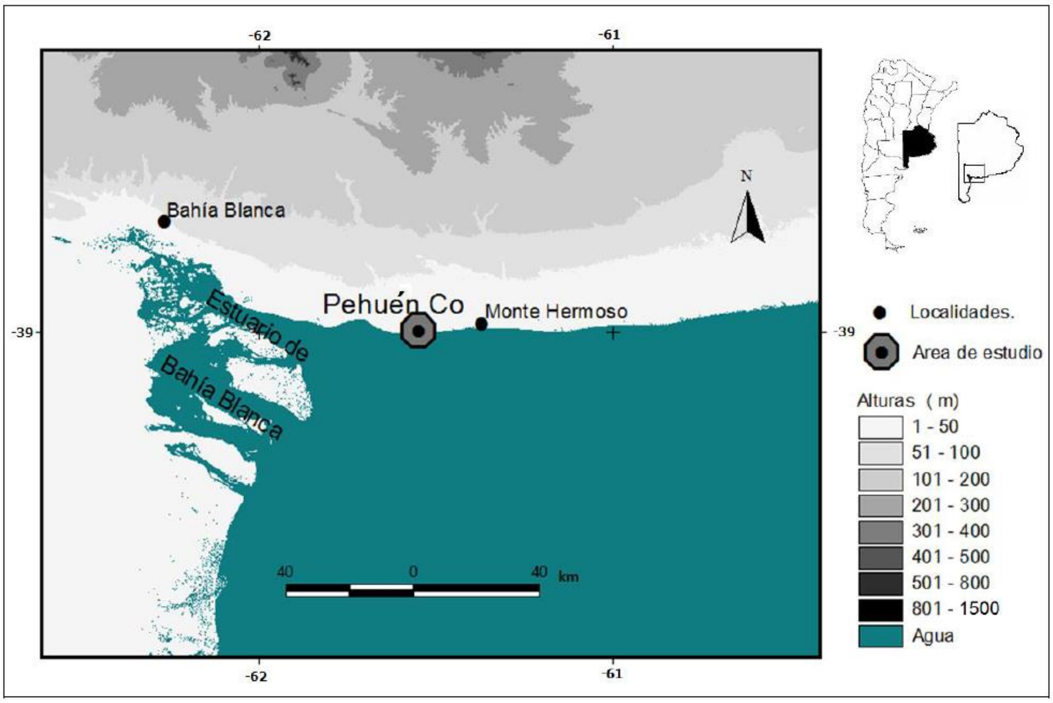


Figure 6.14. Location of Pehuén Co (Bustos, 2017).

6.5.1 Work Methodology

A new methodology was developed consisting of 7 steps that allows delineating concrete actions for an ICM (Figure 6.15) (Bustos, 2016). Below are the steps and in the results, the application of them in the study area:

1. *Definition of the problems and objectives:* Based on the scarce knowledge of the study area, the existing problems can be raised. As the objective derives from the definition of the problem (Schmelkes, 1988) its wording will be its consequence.

The delineation of the objective will be fundamental for the development of the method.

2. Characterization of the study area: At this stage, all the information available in the area to be studied should be collected based on the stated objective: cartography, geomorphological, oceanographic and meteorological data, censuses, exploration in the field, etc. This will allow us to know which data are feasible to obtain and which are not for the development of indicators. It should be complemented with interviews, surveys and/or workshops with social actors and/or decision makers to understand the current social situation.
3. *Development of indicators:* In this step the diagnostic method developed by the European Environment Agency (EEA) is applied, which is divided into Driving-Force - Pressure - State - Impact - Response (DPSIR; EEA, 1999). This model is based on a sequential evolution where the driving forces are the sectoral social and economic trends, environmentally relevant that are responsible for the situation. Social and economic development originates pressures in the environment that give rise to a series of changes in the state of the environment (Kelble et *al*., 2013). Consequence of these changes is the appearance of Impacts on health, behavior, environment, economy, etc. Motivated by this, there is a series of Responses by social and public agents aimed at improving economic and social management, to eliminate or reduce these pressures, to restore and recover the state of the environment and the alterations derived from the impacts (Aguirre Royuela, 2002).
4. *Conformity of the indicators:* In this stage it will be established if the written indicators are feasible to calculate, establish or measure. Otherwise, it will be necessary to return to step 3 to revaluate the proposal.
5. *Social and scientific weighting:* A hierarchy of indicators should be established to know which are the most important issues to be resolved at an environmental and socio-economic levels. This will be achieved with the knowledge acquired in step 2 and social interviews that validate or not the scientific hierarchy.
6. *Actions to be developed:* In this step, the objectives for the proposals for each thematic axis will be established and, based on them, all the relevant actions to put the ICM into work.
7. *Follow-up of the actions:* This step has the objective of carrying out a quick and practical evaluation of the positive or negative evolution of each proposal, as well as facilitating the emergence of new ones (Kitzmann and Asmus, 2004). Indicators that measure the progress of each action will be proposed through a unit of measurement (km, ha, %, n, etc.) (Louette, 2009). In the case of indicators with negative responses, it will be necessary to return to step 1 with a new problematic and the development of the successive steps.

Figure 6.15. Methodology for the development of indicators and actions for a Comprehensive Coastal Management plan (Bustos, 2016).

6.5.2 Identification of problems and objectives in the coastal region of Pehuén Co

Within the problems of the coastal environment of Pehuén Co, the erosion suffered by this beach is one of the most transcendental (Figure 6.16). Some studies have shown that there is a decline of the coast of about 50 m in the last 40 years (Pratolongo et *al*., 2006) and greater erosion in areas coincident with urbanizations compared with non-urbanized areas (Bustos, 2012).

On the other hand, it is known that Pehuén Co is a town whose economy is based almost entirely on beach tourism (Figure 6.17). Investments in tourism are a catalyst for the transformation in the use of land in coastal areas. In the last 10 years, Pehuén Co has suffered an increase in the construction of houses.

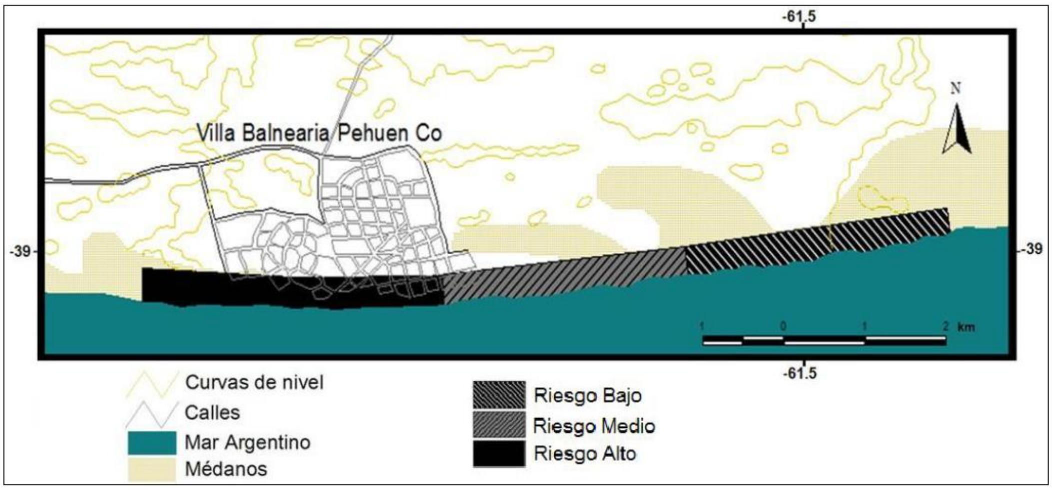


Figure 6.16. Erosion risk map for the Pehuen Co area (Argentina) (Bustos, 2016).

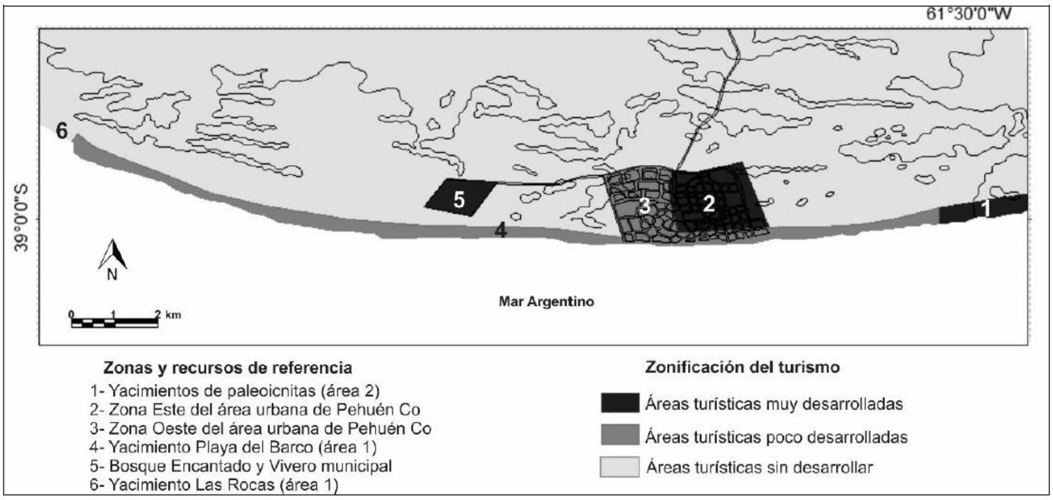
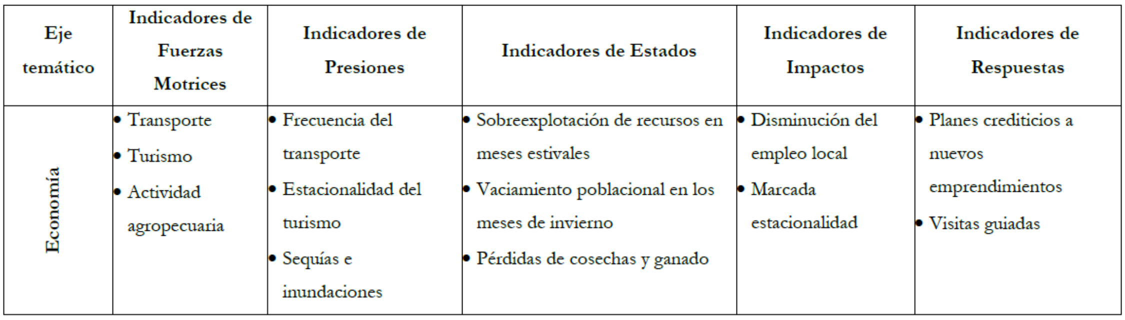


Figure 6.17. Zoning of tourism development for the Pehuén Co area (Argentina) (Bustos, 2016).

6.5.3 Development of Indicators

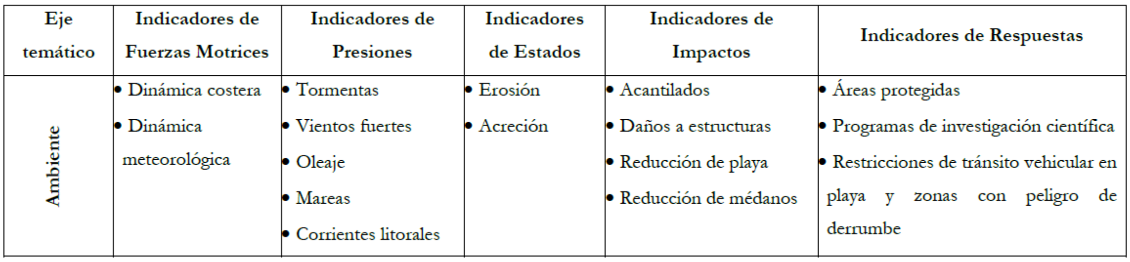
Indicators were generated for three axes: economy, environment and society. They are shown in Table 6.5, Table 6.6 and Table 6.7.

Table 6.5. Indicators of the thematic axis "Economy" (Bustos, 2016).



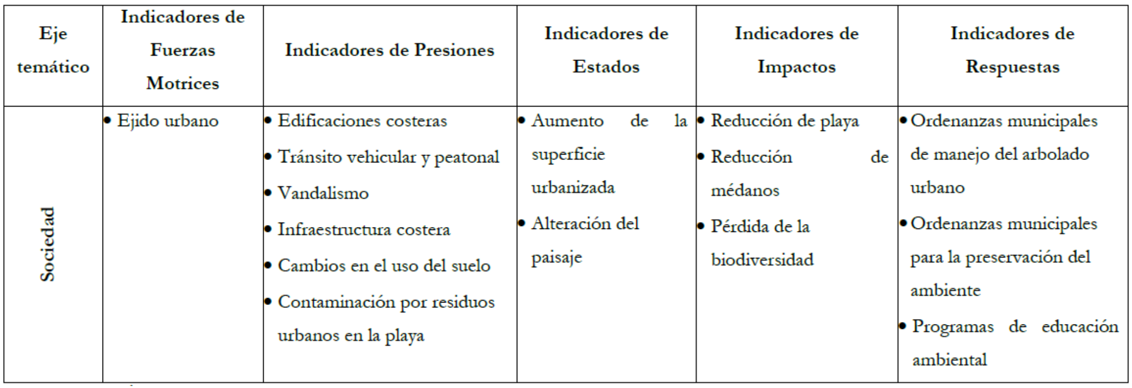
Eje temático	Indicadores de Fuerzas Motrices	Indicadores de Presiones	Indicadores de Estados	Indicadores de Impactos	Indicadores de Respuestas
Economía	• Transporte • Turismo • Actividad agropecuaria	• Frecuencia del transporte • Estacionalidad del turismo • Sequías e inundaciones	• Sobreexplotación de recursos en meses estivales • Vaciamiento poblacional en los meses de invierno • Pérdidas de cosechas y ganado	• Disminución del empleo local • Marcada estacionalidad	• Planes crediticios a nuevos emprendimientos • Visitas guiadas

Table 6.6. Indicators of the thematic axis "Environment" (Bustos, 2016).



Eje temático	Indicadores de Fuerzas Motrices	Indicadores de Presiones	Indicadores de Estados	Indicadores de Impactos	Indicadores de Respuestas
Ambiente	• Dinámica costera • Dinámica meteorológica	• Tormentas • Vientos fuertes • Oleaje • Mareas • Corrientes litorales	• Erosión • Acreción	• Acantilados • Daños a estructuras • Reducción de playa • Reducción de médanos	• Áreas protegidas • Programas de investigación científica • Restricciones de tránsito vehicular en playa y zonas con peligro de derrumbe

Table 6.7. Indicators of the thematic axis "Society" (Bustos, 2016).



Eje temático	Indicadores de Fuerzas Motrices	Indicadores de Presiones	Indicadores de Estados	Indicadores de Impactos	Indicadores de Respuestas
Sociedad	• Ejido urbano	• Edificaciones costeras • Tránsito vehicular y peatonal • Vandalismo • Infraestructura costera • Cambios en el uso del suelo • Contaminación por residuos urbanos en la playa	• Aumento de la superficie urbanizada • Alteración del paisaje	• Reducción de playa • Reducción de médanos • Pérdida de la biodiversidad	• Ordenanzas municipales de manejo del arbolado urbano • Ordenanzas municipales para la preservación del ambiente • Programas de educación ambiental

6.5.4 Actions to develop

As a final result, Bustos (2017) details the action proposals. These arise in the short term (ST), less than 2 years; medium term (MT), between 2 and 5 years; and long term (LT), more than 5 years:

Actions of the Environmental axis:

- Legally reject activities that alter the configuration of the beach and dunes. ST.

- Prohibit the construction of new permanent infrastructures on the beach (e.g. beach resorts) and the opening of new beach access. ST.
- Protect the cliff area by soft protection systems.
- Prepare a joint action plan between Pehuén Co and Monte Hermoso, in coordination with the Department of Protected Natural Areas of the province of Buenos Aires in order to provide protection to paleontological sites and native plant and animal species. MT.
- Delimit the effective extension of the blocks containing the tracks by deepening geological and paleontological studies. MT-LT.
- Prohibit vehicular traffic in the reserve area and restrict pedestrian circulation due to the degradation caused by souvenir collection and graffiti (vandalism). ST.
- Prohibit the transit of all-terrain vehicles over dunes of the West zone. ST.
- Signalling, disseminating and training the local population and tourists about the fragility of fossil footprint deposits. ST.
- Increase public awareness of the environmental risk in which the beach is located and commit it to the development and implementation of public strategies. MT.
- Add to the school topics talks and workshops on the basic principles of conservationism. MT.
- Attach the first 400 to 500 m of the frontal dune strip to the reserve. LT.
- Increase the presence of permanent park rangers during the summer season. ST.
- Maintain the prohibition of extraction of sand in the reserve and nearby sectors. ST.
- Implement a defence plan against coastal erosion through the conservation, construction and restoration of natural and artificial dunes. ST.

Actions of the Society axis:

- Identify and remove the constructions located on the coast that are currently in danger or in the process of collapse due to erosion, recovering the areas as a coastal public space. MT.
- Determine a minimum of 200 m from the line of high tides of storms towards the continent for the construction of roads, houses, beach resorts, etc. MT.
- Recondition the existing beach access by decreasing the slope, making them pedestrian only and sinusoidal. ST.
- Replace fishermen access. Substitute them for others located at a minimum of 1500 meters to the west and east of the urbanization. ST.

- Maintain and expand the prohibition of vehicular traffic on the coastal street in high season. ST.
- Set back the edification front and avoid compact edification. LT.
- Encourage urban growth towards the interior of the continent and not parallel to the coast. ST.
- Encourage the cleaning of the beach through, for example, community clean-up days. ST.
- Recovery plan, maintenance and expansion of green spaces (trees, streets, parks, squares, etc.). MT.

Actions of the Economy axis:

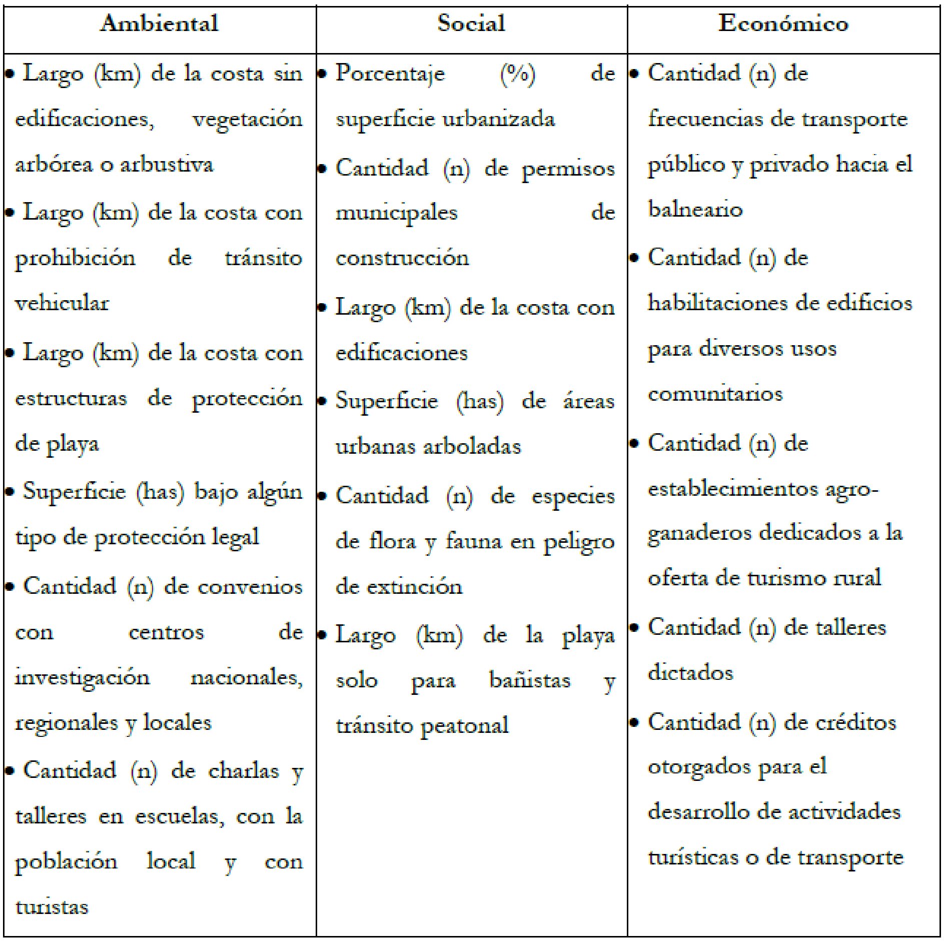
- Encourage private and public initiatives to expand the frequency and modes of transport to the beach from neighbouring towns to activate the segment of the population that does not own a private car. Small units adapted to rural roads and that allow the transport of diverse loads (chairs, umbrellas, luggage, etc.). MT.
- Program for the recovery of monuments and buildings that are currently in disuse to be reused for new activities for the community. MT-LT.
- Coordinate workshops between NGOs and other local, regional and national institutions, in order to raise awareness among the inhabitants and society as a whole about the value of tangible and intangible resources and the importance of their care and preservation. ST.
- Encourage tourism to other areas of the coast less developed. For example, increasing the number of lifeguards in different areas of the beach to better distribute visitors. ST.
- Encourage cultural tourism by expanding activities outside the summer season. Add sports activities, popular festivals, cultural events, etc. in winter season bearing in mind the bioclimatic benefits and regulation of the temperature of the areas with the highest tree coverage. MT.
- Design and promote a calendar that incorporates recreational activities, celebrations and local festivities. ST.
- Encourage rural tourism as an option for the diversification of sun and beach tourism, generating new jobs for the population. MT.
- Promotion of the rural-coastal zone through the development of circuits and enclaves, linked to production and tourism.

- Design a communication and exchange system that allows those interested to know the proposals and benefits achieved with the implementation of cultural and rural tourism (posters, brochures, radio and television press). ST-MT.
- Create a working calendar that contemplates the times of sowing, harvesting, shearing, breeding, fattening, etc., so that the visitors can program their activities. ST.
- Establish a system of financial and credit support at the municipal and regional levels that can be managed through the methodology of articulated projects between civil society and funding agencies. MT-LT.

6.5.5 Monitoring of actions

In the Bustos (2016) work, fast accessibility and visualization indexes are defined for the follow-up of the ICM. They are shown in Table 6.8.

Table 6.8. Indices for monitoring the MIC (Bustos, 2016).



Ambiental	Social	Económico
• Largo (km) de la costa sin edificaciones, vegetación arbórea o arbustiva • Largo (km) de la costa con prohibición de tránsito vehicular • Largo (km) de la costa con estructuras de protección de playa • Superficie (has) bajo algún tipo de protección legal • Cantidad (n) de convenios con centros de investigación nacionales, regionales y locales • Cantidad (n) de charlas y talleres en escuelas, con la población local y con turistas	• Porcentaje (%) de superficie urbanizada • Cantidad (n) de permisos municipales de construcción • Largo (km) de la costa con edificaciones • Superficie (has) de áreas urbanas arboladas • Cantidad (n) de especies de flora y fauna en peligro de extinción • Largo (km) de la playa solo para bañistas y tránsito peatonal	• Cantidad (n) de frecuencias de transporte público y privado hacia el balneario • Cantidad (n) de habilitaciones de edificios para diversos usos comunitarios • Cantidad (n) de establecimientos agro-ganaderos dedicados a la oferta de turismo rural • Cantidad (n) de talleres dictados • Cantidad (n) de créditos otorgados para el desarrollo de actividades turísticas o de transporte

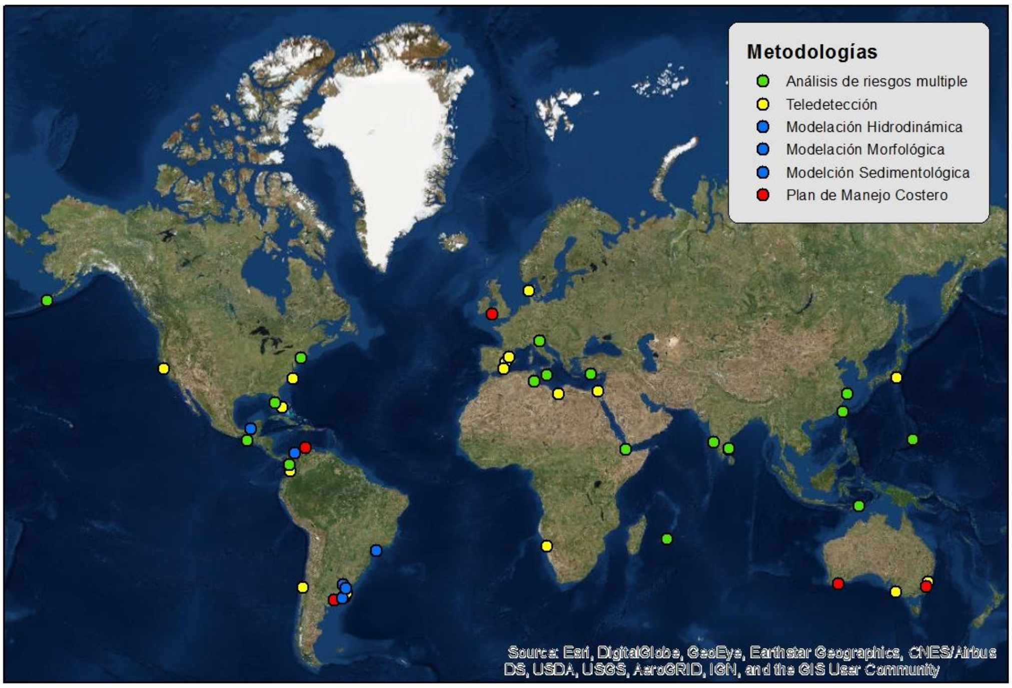
7 GEO-REFERENCED DATABASE

All the studies, works and management plans reviewed in this report were compiled in a geo-referenced database. It consists of a file in georeferenced vector format that contains all 17 fields whose attributes are the following:

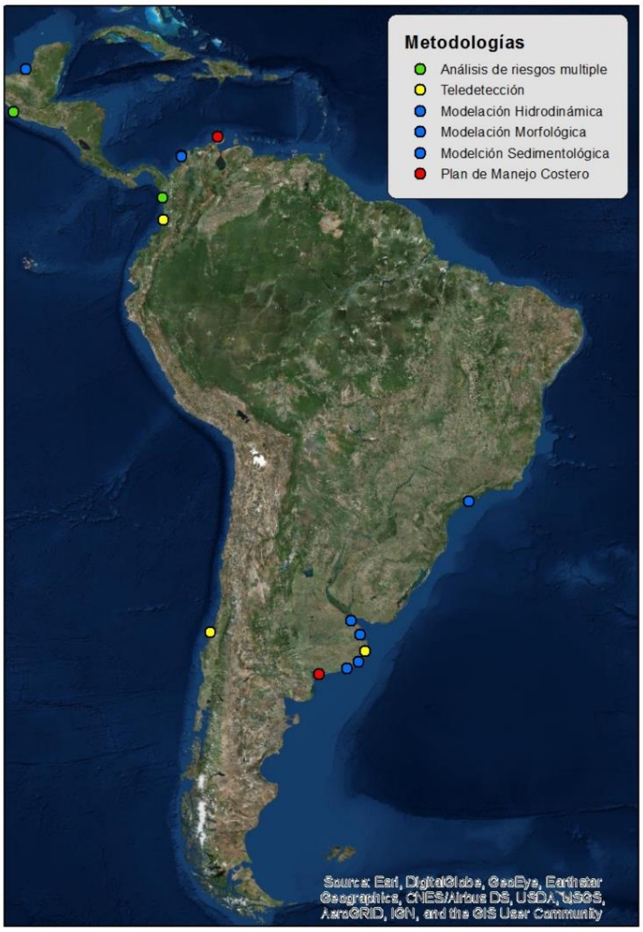
1. *País*: Indicates the country where the study and/or management plan was carried out.
2. *Estado/Región:* Indicates the state or region where the study and/or management plan was carried out.
3. *Ciudad/Municipio:* Indicates the city or municipality where the study and / or management plan was carried out.
4. *Metodología:* Indicates the methodology used in the analysis (Multiple risk analysis, numerical modelling).
5. *Herramienta_01:* Indicates the main tool used in the study.
6. *Herramienta_02:* Indicates the secondary tool used in the study.
7. *Herramienta_03:* Indicates the tertiary tool used in the study.
8. *Proyección_CC:* It indicates which Climate Change projection was used in the study.
9. *Instituto_01:* Main institution in charge of the study or management plan.
10. *Instituto_02:* Main and/or secondary institution in charge of the study or management plan.
11. *Autor_01:* Main author of the study and/or management plan.
12. *Autor_02:* Secondary author of the study and/or management plan.
13. *Autor_03:* Tertiary author of the study and/or management plan.
14. *Año:* Year of the study and/or management plan.
15. *Archivo_01:* Main file of the study and/or management plan.
16. *Archivo_02:* Secondary file of the study and/or management plan.
17. *Archivo_03:* Tertiary file of the study and/or management plan.

This geo-referenced database will be added to the Database that Technical Assistance plans to offer in Deliverable 3.

As examples, different figures with different classifications made from the database are presented below: Figure 7.1 shows the different methodologies used in each compiled study while Figure 7.2 shows the year of the studies.



a) Global view



b) Detail of the region

Figure 7.1. Methodologies used in the collected studies.

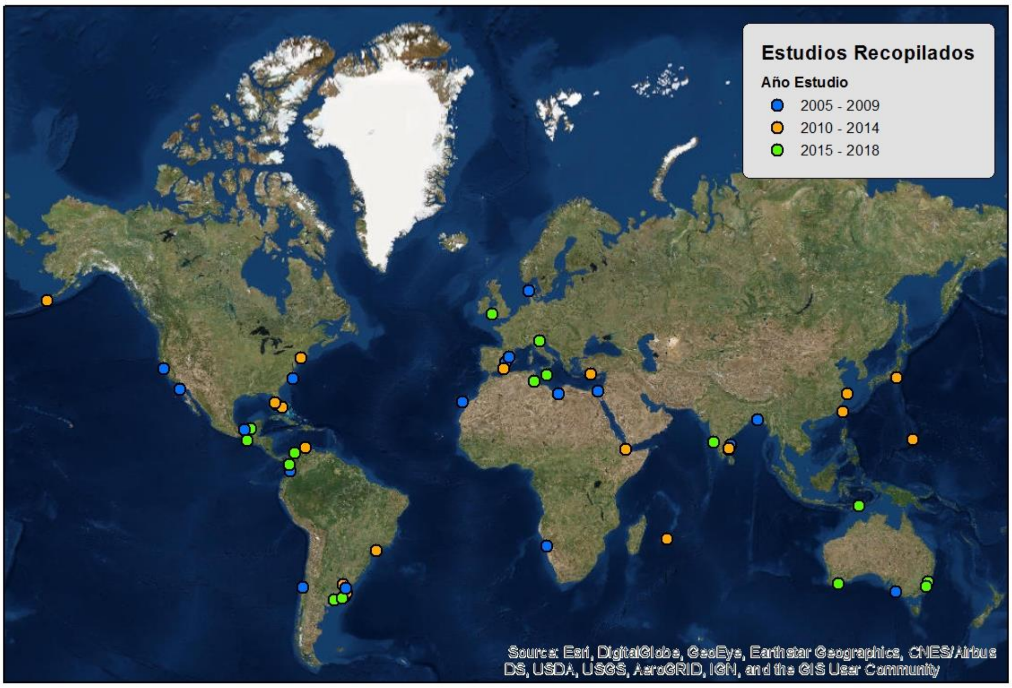


Figure 7.2. Year of the compiled study.

References

AEMA, 1999. Enviromental Indicators: Typology and Overview. Agencia Europea de Medio Ambiente. Technical report 25. Copenhagen.

Aguirre Royuela, M.A., 2002. Los sistemas de indicadores ambientales y su papel en la información e integración del medio ambiente. Anales del 1° Congreso de Ingeniería Civil, Territorio y Medio Ambiente. Editora Colegio de Ingenieros de Caminos, Canales y Puertos, pp. 1231-1256. Madrid, España.

Albrecht, F., Weisse, R., 2014. Pressure effects on regional mean sea level trends in the German Bight in the twenty-first century. Ocean Dyn. 64, 633–642. DOI:10.1007/s10236-014-0708-7

Alfredini, P., Arasaki, E., Pezzoli, A., Arcorace, M., Cristofori, E., Cabral de Sousa Jr., W., 2014. Exposure of Santos Harbor Metropolitan Area (Brazil) to Wave and Storm Surge Climate Changes. Water Qual Expo Health. DOI 10.1007/s12403-014-0109-7.

Alonso, D.A., Sierra Correa, P.C., Arias-Isaza, F.A., Fontalvo Herazo,. M.L., 2003. Conceptos y guía metodológica para el manejo integrado de zonas costeras en Colombia, Manual 1: preparación, caracterización y diagnóstico. Serie de documentos generales de INVEMAR N°. 12. 94pp. Santa Marta, Colombia.

Alsina, J.M., 2005. Development of a morphodynamic numerical model. Application to LCS impact assessment. Barcelona, Spain: Universitat Politècnica de Catalunya, Ph. D. thesis, 233p.

Archetti, R., Paci, A., Carniel, S., and Bonaldo, D., 2016. Optimal index related to the shoreline dynamics during a storm: the case of Jesolo beach, Nat. Hazards Earth Syst. Sci., 16, 1107–1122, doi:10.5194/nhess-16-1107-2016.

Aurora Environmental, 2018. Shire of Jerramungup Coastal Management Plan (Final). 2017-2027. Document Number: AA2017/003. Australia.

Barros, V.R., Menéndez, A.N., Nagy, G. (edit.), 2005. El Cambio Climático en el Río de la Plata. AIACC Project (Assessments of Impacts and Adaptations to Climate Change). CIMA-UBA/CONICET. 2005.

Blanco, P.D., Metternicht, G. I., Del Valle, H., Sione, W., 2007. In Rivas, R., Grisotto, A., Sacido, M. (eds.), Teletedetección: hacia un mejor entendimiento de la dinámica global y regional. Ed. Martin, Mar del Plata, 427-434.

Bértola, G. R., Merlotto, A., 2010. Los médanos de Lobería y Necochea. En: Isla, F. I and Lasta, C. A. (eds.), Manual de Manejo de Barreras medanosas de Buenos Aires. EUDEM, Mar del Plata, 129-158.

Bhatt, R., Macwan, J.E.M., Bhatt, D., Patel, V., 2010. Analytic Hierarchy Process Approach for Criteria Ranking of Sustainable Building Assessment: A Case Study, World Appl. Sci. J., 7, 881–888.

Boak, E.H., Turner, I.L. 2005. Shoreline Definition and Detection: A Review. Journal of Coastal Research, 21 (4), 688–703.

Booij N., Holthuijsen LH., 1987. Propagation of ocean waves in discrete spectral wave models. Journal of Computational Physics , 68 (2), 307-326.

Bozzi, S., Archetti, R., and Passoni, G., 2014. Wave electricity production in Italian offshore: A preliminary investigation, Renew. Energ.,62, 407–416, doi:10.1016/j.renene.2013.07.030.

Brière, C., Abadie, S., Bretel, P., and Lang, P. 2007. Assessment of TELEMAC system performances, a hydrodynamic case study of Anglet, France, Coast. Eng., 54, 345-356, doi:10.1016/j.coastaleng.2006.10.006.

Bristow, C.S., Lancaster, N., Duller, G.A.T. 2005. Combining ground penetrating radar surveys and optical dating to determine dune migration in Namibia. J. Geol. Soc. London, 162, 315-321.

Bristow, C.S., Pucillo, K., 2006. Quantifying rates of coastal progradation from sediment volume using GPR and OSL: the Holocene fill of Guichen Bay, south east South Australia. Sedimentology, 53, 769-788.

Brock J.C., Purkis S.J. 2009. The emerging role of LiDAR remote sensing in coastal research and resource management. Journal of Coastal Research 53, 1-5.

Bruun, P., 1962. Sea level rise as a cause of shore erosion. Journal of Waterways and Harbour Divisions, ASCE 88, 117-130.

Burcharth, H. F., Lykke Andersen, T., and Lara, J. L., 2014. Upgrade of coastal defence structures against increased loadings caused by climate change: A first methodological approach, Coast. Eng., 87, 112–121, doi:10.1016/j.coastaleng.2013.12.006.

Bustos, M.L., Piccolo, M.C., Perillo, G.M.E., 2012. Efectos geomorfológicos de fuertes vientos sobre playas. El caso de la playa de Pehuén Co, Argentina. Cuadernos de Investigación Geográfica, 37 (1), 121-142, 2012.

Bustos, M.L., 2016. Guía metodológica para un manejo integral costero aplicado a Pehuén Co (Argentina). Revista InterEspaço, 2 (6), 96-121. DOI: 10.18764/2446-6549/interespaco.v2n6p96-121

Buynevich, I.V., FitzGerald, D.M., van Heteren, S., 2004. Sedimentary records of intense storms in Holocene barrier sequences, Maine, USA. Marine Geology, 210, 135-148.

Cáceres, R.A., Zyserman, J.A., Perillo, G.M.E., 2016. Analysis of Sedimentation Problems at the Entrance to Mar del Plata Harbor. Journal of Coastal Research, 32 (2), 301 – 314.

Cáceres, R.A., Castellano, R., 2012. Dinámica litoral en el entorno de la escollera sur del Puerto de Mar del Plata. AADIP 2012, Congreso Argentino de Ingeniería Portuaria.

Camus, P., Losada, I.J., Izaguirre, C., Menéndez, M., Pérez, J., 2017. Statistical wave climate projections for coastal impact. Earth's Futur. 5, 918–933. DOI: 10.1002/eft2.234

Carson, M., Köhl, A., Stammer, D., Slangen, A., Katsman, C.A., van de Wal, R.S., Church, J., White, N., 2016. Coastal sea level changes, observed and projected during the 20th and 21st century. Clim. Change 134, 269-281. DOI: 10.1007/s10584-015-1520-1

Casas-Prat, M., Wang, X.L., Swart, N., 2018. CMIP5-based global wave climate projections including the entire Arctic Ocean. Ocean Model., 123, 66–85. DOI: 10.1016/j.ocemod.2017.12.003

Castro-Castro, Vicente, 2018. Análisis preliminar de riesgo por cambio climático en la costa del municipio de Tapachula, Chiapas, México. Espacio I+D Innovación más Desarrollo, 7(18), 92-116. DOI: 10.31644/IMASD.7.2018.a05

Cortizo, L.C., 2010. Los médanos del Partido de San Cayetano y Tres Arroyos, Buenos Aires. En Isla, F.I. y Lasta, C.A. (eds.) Manual de Manejo de Barreras medanosas de Buenos Aires, EUDEM, Mar del Plata, 183-196.

Chang, H. K., Liou, J. C., Chen, W.W., 2012. Protection priority in the coastal environment using a hybrid ahp-topsis method on the Miaoli coast, Taiwan, J. Coast. Res., 28, 369–374, DOI: 10.2112/jcoastres-d-10-00092.1.

Chang K., 2010. Introduction to Geographic Information Systems. McGraw Hill. 488pp.

Costas, S., Alejo, I., Rial, F., Lorenzo, H., Nombela, M.A. 2006. Cyclical evolution of a modern transgressive sand barrier in Northwestern Spain elucidated by GPR and aerial photos. J. Sedimentary Research, 76, 1077-1092.

Critto, A., Rizzi, J., Zabeoa, A., Furlan, E., Marcomini, A., 2016. DESYCO: A decision support system for the regional risk assessment of climate change impacts in coastal zones. Ocean & Coastal Management, 120, pp. 49-63.

Cueto Fonseca J. E., Otero Díaz L. J., 2018. Respuesta morfodinámica de las playas del caribe colombiano ante eventos extremos de oleaje. XXVII Congreso Latinoamericano de Hidráulica, Buenos Aires, Argentina.

Daniels, D. J., 2004. Ground Penetrating Radar. 2nd Edition. IEE Radar, Sonar and Navigation Series, 15, 726 pp.

Danish Hydraulic Institute, 2011a. MIKE 21 & MIKE 3 Flow Model FM. Hydrodynamic and Transport Module Scientific Documentation. Horshølme, Denmark: DHI Water & Environment, Inc. Scientific Documentation, 52p.

Danish Hydraulic Institute, 2011b. MIKE 21 Spectral Wave Module. Horshølme, Denmark: DHI Water & Environment, Inc. Scientific Documentation, 66p.

Danish Hydraulic Institute, 2011c. Noncohesive Sediment Transport in Currents and Waves. Horshølme, Denmark: DHI Water & Environment, Inc. Scientific Documentation, 66p.

DEFRA, 2006. Aims and objectives, 2. Shoreline Management Guidance, 1. HMT, ODPM, DT, DEFRA, London.

DEE, 2017. National Climate Change Adaptation Research Facility, Department of the Environment and Energy. Australia. http://www.environment.gov.au/climate-change

Di, K., Ma, R., Li, R. 2003a. Geometric Processing of Ikonos Stereo Imagery for Coastal Mapping Applications. Photogrammetric Engineering & Remote Sensing, 69 (8), 873–879.

Di, K., Wang, J., Ma, R., Li, R. 2003b. Automatic shoreline extraction from high-resolution IKONOS satellite imagery. ASPRS Annual Conference Proceedings, Anchorage, Alaska.

D'Onofrio, E.E., Fiore M.E., Ruiz, E.H., 2003. Tendencia relativa del nivel medio del Río de La Plata en el Puerto de Buenos Aires. Contribuciones a la Geodesia Aplicada, Instituto de Geodesia de la Facultad de Ingeniería de la Universidad de Buenos Aires, 1.

Fortunato, A.B., Meredith, E.P., Rodrigues, M., Freire, P., Feldmann, H., 2018. Near-future changes in storm surges along the Atlantic Iberian coast. Nat. Hazards, 1–18. DOI: 10.1007/s11069-018-3375-z

Fredsøe, J., 1984. Turbulent boundary layers in wave–current motion. Journal of Hydraulic Engineering, 110 (8), 1103–1120.

Gagliardini, D., Aliotta, S., Dogliotti, A., Clemente-Colón, P., 2005. Identification of bed forms through ERS SAR images in San Matías Gulf, Argentina. Journal of Coastal Research, 21, 1, 193-201.

González Marco, D., 2005. Modelado numérico de la propagación del oleaje. Una herramienta para la Ingeniería Marítima y la Predicción Operativa. Barcelona, Spain: Universitat Politècnica de Catalunya, Ph. D. thesis, 304p.

Gómez Ortiz, D., Martín Crespo, T., Rodríguez Santalla, I., Sánchez García, M.J., Montoya Montes, I., 2009. The internal structure of modern barchan dunes of the Ebro River Delta (Spain) from ground penetrating radar. Journal of Applied Geophysics, 68, 159-170.

Greene, R. and R. Skeele. (2014). Climate Change Vulnerability Assessment for the Island of Saipan. Prepared for CNMI Office of the Governor - Division of Coastal Resources Management. Saipan: Commonwealth of the Northern Mariana Islands. 102p

Hapke C.J., Reid D., 2007. National Assessment of Shoreline Change, Part 4: Historical Coastal Cliff Retreat along the California Coast. United States Geological Survey Open File Report 2007-1133. Disponible en: http://pubs.usgs.gov/of/2007/1133/of2007-1133.pdf

Hapke C.J., Reid D., Richmond B., 2009. Rates and trends of coastal change in California and the regional behaviour of the beach and cliff system. Journal of Coastal Research, 25, 603-615.

Hapke C., Plant N., 2010. Predicting cliff erosion using a Bayesian probabalistic model. Marine Geology 278, 140-149.

Hemer, M.A., Fan, Y., Mori, N., Semedo, A., Wang, X.L., 2013. Projected changes in wave climate from a multi-model ensemble. Nat. Clim. Chang., 3, 471–476. DOI: 10.1038/nclimate1791

Hemer, M.A., Trenham, C.E., 2016. Evaluation of a CMIP5 derived dynamical global wind wave climate model ensemble. Ocean Model., 103, 190–203. DOI: 10.1016/j.ocemod.2015.10.009

Hemer, M.A., Fan, Y., Mori, N., Semedo, A., Wang, X.L., 2013. Projected changes in wave climate from a multi-model ensemble. Nature Climate Change, 3, 471–476, DOI: 10.1038/nclimate1791.

Idier, D., Rohmer, J., Bulteau, T., and Delvallée, E., 2013. Development of an inverse method for coastal risk management, Nat. Hazards Earth Syst. Sci., 13, 999–1013, doi:10.5194/nhess-13-999-2013.

INVEMAR-CORPOGUAJIRA, 2012. Plan de manejo para la zona costera del Departamento de La Guajira, UAC-Alta Guajira. Informe Final. Convenio CORPOGUAJIRA-INVEMAR, No. 0002. PRY-GEZ-002-12. ITF-001.

IPCC, 2013. Climate Change 2013 the physical science basis: Working Group I contribution to the fifth assessment report of the intergovernmental panel on climate change, Climate Change 2013 the Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

IPCC, 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

Izaguirre, C., Méndez, F.J., Menéndez, M., Losada, I.J., 2011. Global extreme wave height variability based on satellite data. Geophysical Research Letters, 38 (10). DOI: 10.1029/2011GL047302

Jaime, P.R., Menéndez, A.N., 1999. Modelo hidrodinámico Río de la Plata 2000, Informe LHA INA 183-01-99, INA, Argentina.

Kalnay, E., Kanamitsu, M., Kistler, R., et al., 1996. The NCEP/NCAR 40-Year Reanalysis Project. Bulletin of American Meteorological Society, 77, 437-471.

Karambas, T. V., 2014. Modelling of climate change impacts on coastal flooding/erosion, ports and coastal defence structures, Desalination and Water Treatment, 54, 1–8, doi:10.1080/19443994.2014.934115.

Karambas, T. V. and Samaras, A. G., 2014. Soft shore protection methods: The use of advanced numerical models in the evaluation of beach nourishment, Ocean Eng., 92, 129–136, doi:10.1016/j.oceaneng.2014.09.043.

Karvetski, C.W., Lambert, J.H., Keisler, J.M., Sexauer, B., Linkov, I., 2011. Climate change scenarios: risk and impact analysis for Alaska coastal infrastructure. Int. J. Risk Assessment and Management, 15 (2/3), 258–274.

Keeney, R.L., Mc Daniels, T.L., 2001. A framework to guide thinking and analysis regarding climate change policies, Risk Analysis, 21 (6), 989–1000.

Kelble, C., Loomis, D.K., Lovelace, S., Nuttle, W.K., Ortner, P.B., Fletcher, P., Boyer, J.N., 2013. The EBM-DPSER Conceptual Model: Integrating Ecosystem Services into the DPSIR Framework. PloS one, 8 (8), 1-12.

Kitzmann, D.I.S., Asmus, M.L., Laydner, C., 2004. Gestão costeira no Brasil: estado atual e perspectivas. Rio Grande: Programa de Apoyo a la Gestión Integrada en la Zona Costera Uruguaya, Ecoplata.

Knuuti, K., 2002. Planning for sea level rise: US Army Corps of Engineers Policy, Chapter in Ewing, L. and Wallendrof, L. (Eds.): Conference Proceedings of Solutions to Coastal Disasters Conference.

Kron, W., 2005. Flood Risk = Hazard • Values • Vulnerability. Water International, Special Issue—Prospects of Living with Flood in the 21st Century, 30 (1), pp 58-68.

Kuc Castilla, A.G., Mendoza E., Posada Vanegas G., Silva Casarín R., 2018. Caracterización morfológica e hidrodinámica de la playa Sabancuy en Campeche, México. XXVII Congreso Latinoamericano de Hidráulica, Buenos Aires, Argentina, Septiembre.

Lamon, L., Rizzi, J., Bonaduce, A., Dubois, C., Lazzari, P., Ghenim, L., Gana, S., Somot, S., Li, L., Melaku Canu, D., Solidoro, C., Pinardi, N., Marcomini, A., 2014. An ensemble of models for identifying climate change scenarios in the Gulf of Gabes, Tunisia. 2. Reg. Environ. Change 14, 41-40.

Laugel, A., Menendez, M., Benoit, M., Mattarolo, G., Méndez, F., 2014. Wave climate projections along the French coastline: Dynamical versus statistical downscaling methods. Ocean Model. 84, 35–50. DOI: 10.1016/j.ocemod.2014.09.002

Le Cozannet, G., Garcin, M., Bulteau, T., Mirgon, C., Yates, M. L., Méndez, M., Baills, A., Idier, D., Oliveros, C., 2013. An AHP derived method for mapping the physical vulnerability of coastal areas at regional scales, Nat. Hazards Earth Syst. Sci., 13, 1209– 1227, DOI: 10.5194/nhess-13-1209-2013.

Lecertua, E., 2010. Análisis de riesgo de duración de inundaciones en las áreas costeras del Río de la Plata considerando Cambio Climático. Tesis de grado. Ingeniería Civil, Facultad de Ingeniería, Universidad de Buenos Aires.

Levin, N., Ben-Dor, E., Karnieli, A., 2004. Topographic information of sand dunes as extracted from shading effects using Landsat images. Remote Sensing of Environment, 90, 190-209.

Li, R., Di, K., Ma, R. 2003. 3-D shoreline extraction from IKONOS satellite imagery. Marine Geodesy, 26, 107– 115.

Lin N., Emanuel, K., Oppenheimer, M., Vanmarcke, E., 2012. Physically based assessment of hurricane surge threat under climate change. Nat Clim Chang, 2, 462–467. DOI: 10.1038/nclimate1389

Louette, A., 2009. Compêndio de indicadores de sustentabilidade das nações. São Paulo: Antakarana Cultura Arte e Ciência.

Linkov, I., Satterstrom, K., Kiker, G. Batchelor, C., Bridges, T., 2006a. From comparative risk assessment to multi-criteria decision analysis and adaptive management: recent developments and applications, Environment International, 32, pp.1072–1093.

Linkov, I., Satterstrom, K., Seager, T.P., Kiker, G., Bridges, T., Belluck, D., Meyer, A., 2006b. Multi-criteria decision analysis: comprehensive decision analysis tool for risk management of contaminated sediments, Risk Analysis, 26, 61–78.

Linkov, I., Wenning, R., Kiker, G. (Eds.), 2007. Managing Critical Infrastructure Risks: Decision Tools and Applications for Port Security, Springer, Amsterdam.

Linkov, I., Ferguson, E. and Magar, V. (Eds.), 2008. Real Time and Deliberative Decision Making: Application to Emerging Stressors, Springer, Amsterdam.

Linkov, I., Bridges, T., 2011. Climate: Global Change and Local Adaptation, Springer, Amsterdam, 630 pp.

MAFF, 2000. A Review for Shoreline Management Plans 1996-1999. MAFF Publications, Ministry of Agriculture Food and Fisheries, London.

Marcomini, S.C., López, R.A., 2010. Erosión y manejo costero en Las Toninas, Partido de la Costa, Provincia de Buenos Aires. Revista de la Asociación Geológica Argentina, 66 (4), 490-498.

Martín Miguez, B., Le Roy, R., Wöppelman, G., 2008. The use of radar tide gauges to measure variations in sea level along the French coast. Journal of Coastal Research, 24, 4C, 61-68.

Melet, A., Meyssignac, B., Almar, R., Le Cozannet, G., 2018. Under-estimated wave contribution to coastal sea-level rise. Nat. Clim. Chang., 8, 234–239. DOI:10.1038/s41558-018-0088-y

Menéndez, A.N., 1990. Sistema HIDROBID II para simular corrientes en cuencos, Revista internacional de métodos numéricos para cálculo y diseño en ingeniería, 6 (1).

Mentaschi, L., Vousdoukas, M.I., Voukouvalas, E., Dosio, A., Feyen, L., 2017. Global changes of extreme coastal wave energy fluxes triggered by intensified teleconnection patterns. Geophys. Res. Lett., 44, 2416–2426. DOI: 10.1002/2016GL072488

Merlotto, A., Verón, E., Sabuda, F., 2008. Riesgo de erosión costera en el Balneario Parque Mar Chiquita, Provincia de Buenos Aires. Párrafos Geográficos, 7 (1), Geografía de riesgos costeros.

Micallef, S., Micallef, A., Galdies, C., 2018. Application of the Coastal Hazard Wheel to assess erosion on the Maltese coast. Ocean & Coastal Management, 156, 209-222.

Morim, J., Hemer, M., Cartwright, N., Strauss, D., Andutta, F., 2018. On the concordance of 21st century wind-wave climate projections. Glob. Planet. Change, 167, 160–171. DOI: 10.1016/j.gloplacha.2018.05.005

MME, 2011. Serie de tiempo histórica de producción y exportaciones de carbón relacionado con producción de carbón por departamentos contiene información desde 01/01/1990 hasta 30/09/2012. Ministerio de Minas y Energía. Colombia. Consultado en: http://www.upme.gov.co/generadorconsultas/Consulta_Series.aspx?idModulo=4&tipoSerie=121&grupo=371&Fechainicial=01/01/1990&Fechafinal=30/09/2012

Monier, E., Scott, J.R., Sokolov, A.P., Forest, C.E., Schlosser, C.A., 2013. An integrated assessment modeling framework for uncertainty studies in global and regional climate change: the MIT IGSM-CAM (v 1.0), Geosci. Model Dev., 6, 2063-2085, DOI: 10.5194/gmd-6-2063-2013, 2013.

Moore L.J., Griggs G.B., 2002. Long-term cliff retreat and erosion hotspots along the central shores of the Monterey Bay National Marine Sanctuary. Marine Geology 181, 265-283.

MP Rogers and Associates, 2017. Jerramungup First Pass Coastal Hazard Assessment. For Aurora Environmental and the Shire of Jerramungup. R902 Rev 1.

Muis, S., Verlaan, M., Winsemius, H.C., Aerts, J.C.J.H., Ward, P.J., 2016. A global reanalysis of storm surges and extreme sea levels. *Nat Commun*. DOI: 10.1038/ncomms11969.

Murthy M.V., Usha T., Pari Y., Reddy N.T. 2011. Tsunami vulnerability assessment of Cuddalore using numerical model and GIS. Marine Geodesy 34, DOI:10.1080/01490419.2011.547797

Neumann, J.E., Hudgens D.E., Herter J., Martinich J., 2010. The economics of adaptation along developed coastlines. Wiley Interdisciplinary Rev Climatic Change, 2(1), 89–98.

Neumann, J.E., Price, J., Chinowsky, P., Wright, L., Ludwig, L., Streeter, R., Jones, R., Smith, J.B., Perkins, W., Jantarasami, L., Martinich, J., 2015. Climate change risks to US infrastructure: impacts on roads, bridges, coastal development, and urban drainage. Climatic Change, 131 (1), 97–109.

NOAA, 2018. WAVEWATCH III (WW3). Marine Modelling and Analysis Branch. Obtenido de ftp://polar.ncep.noaa.gov/pub/history/waves/

ODIN, 2015. ODIN: Módulo de ayuda a la Caracterización del oleaje. Manual de Usuario ODIN 3.0. Universidad de Cantabria.

Osorio, A.F., Ortiz, C.A., Pérez, J.C., Medina, R., 2010. HORUS: Sistema de video para cuantificar variables ambientales en zonas costeras. Caso de aplicación Cartagena, Colombia. XXVII Congreso Latinoamericano de Hidráulica, Punta del Este, Uruguay, Septiembre.

Ozyurt, G., Ergin, A., Baykal, C., 2012. Coastal vulnerability assessment to sea level rise integrated with analytical hierarchy process, Coast. Eng. Proc., 1, DOI: 10.9753/icce.v32.management.6.

Padilla, N.A., Benseny, G., 2016. Transformaciones litorales asociadas al desarrollo urbano turístico. El caso de Miramar (Argentina). Revista Universitaria de Geografía, 25(1), 93-113. ISSN 0326-8373.

Paillou, P., Schuster, M., Tooth, S., Farr, T., Rosenqvist, A., Lopez, S., Malezieux, J.M., 2009. Mapping of a major paleodrainage system in eastern Libya using orbital imaging Radar: The Kufrah River. Earth and Planetary Science Letters, 277, 327–333.

Paltsev, S., Monier, E., Scott, J., Sokolov, A., Reilly, J., 2013. Integrated economic and climate projections for impact assessment. Climatic Change. DOI: 10.1007/s10584-013-0892-3

Pardo-Pascual, J.E., Ruiz-Fernández, L.A., Almonacid, J., Rodríguez-Recatalá, B., Gracia, G., 2007. Métodos para la determinación automática de la línea de costa con precisión subpixel, En: L. Gómez Pujol y J.J. Fornós (Eds.). Investigaciones recientes (2005-2007) en Geomorfología Litoral. Universidad de las Islas Baleares. Palma de Mallorca. 39-40.

Pardo-Pascual, J.E., Ruiz Fernández, L. A., Palomar Vázquez, J. M., Calaf, X., Colmenárez, G. R., Almonacid J., Gracia G. 2008. Teledetección, GPS y LIDAR: Nuevas técnicas de análisis y evolución de la línea de costa y de los espacios playa-duna. Actas de las Jornadas Técnicas "Las nuevas técnicas de información geográfica al servicio de la gestión de zonas costeras: Análisis de la evolución de playas y dunas".

Pardo-Pascual, J.E., Almonacid-Caballer, J., Ruiz, L.A., Palomar- Vázquez, J., 2012. Automatic extraction of shorelines from Landsat TM and ETM+ multi-temporal images with subpixel precision. Remote Sensing of Environment, 123, 1–11.

Paskoff, R., Manríquez, H., 2004. Las dunas de las costas de Chile. Instituto Geográfico Militar de Chile, Santiago, 112 pp.

Pedersen, K., Clemmensen, L.B. 2005. Unveiling past Aeolian landscapes: A ground-penetrating radar survey of a Holocene coastal dunefield system, Thy, Denmark. Sedimentary Geology, 177, 57-86.

Peixoto R., Silva R., Marino B., Thomas L., Gallo M., 2018. Simulación de las condiciones de sedimentación en un estuario con una singularidad batimétrica. XXVII Congreso Latinoamericano de Hidráulica, Buenos Aires, Argentina, Septiembre.

Pérez, J., Menéndez, M., Camus, P., Méndez, F. J., Losada, I.J., 2015. Statistical multi-model climate projections of surface ocean waves in Europe. Ocean Modelling, 96, 161–170. DOI: 10.1016/j.ocemod.2015.06.001

Phukon, P., Chetia, D., Das, P., 2012. Landslide Susceptibility Assessment in the Guwahati City, Assam using Analytic Hierarchy Process (AHP) and Geographic Information System (GIS), Int. J. Comput. Appl. Eng. Sci., 2, 1–6.

Pickering, M.D., Horsburgh, K.J., Blundell, J.R., Hirschi, J.J.M., Nicholls, R.J., Verlaan, M., Wells, N.C., 2017. The impact of future sea-level rise on the global tides. Cont. Shelf Res., 142, 50-68. DOI: 10.1016/j.csr.2017.02.004

PNUD, 2018. National Coastal Vulnerability Assessment and Designing of Integrated Coastal Management and Adaptation Strategic Plan for Timor-Leste.

Pratolongo, P., Salinero, G., Perillo, G., 2006. Evolución de la línea de costa frente al balneario Pehuén-Co, provincia de Buenos Aires, entre los años 1969 y 1996. In: JORNADAS DE CIENCIAS DEL MAR, 6, Puerto Madryn.

Rahman, M.R., Shi, Z.H., Chongfa, C., 2009. Soil erosion hazard evaluation-an integrated use of remote sensing, GIS and statistical approaches with biophysical parameters towards management strategies, Ecol. Model., 220, 1724–1734, DOI: 10.1016/j.ecolmodel.2009.04.004.

Rangel-Buitrago, N., Williams, A., Anfuso, G., 2017. Hard protection structures as a principal coastal erosion management strategy along the Caribbean coast of Colombia. A chronicle of pitfalls. Ocean & Coastal Management. In Press, Corrected Proof. DOI: 10.1016/j.ocecoaman.2017.04.006

Re, M., 2005. Impacto del Cambio Climático Global en las costas del Río de la Plata. Tesis de Maestría, Maestría en Ciencias Ambientales, Facultad de Ciencias Exactas y Naturales (FCEyN), Universidad de Buenos Aires (UBA), pp. 120.

Reguero, B.G., Losada, I.J., Díaz-Simal, P., Méndez, F.J., Beck, M.W., 2015. Effects of Climate Change on Exposure to Coastal Flooding in Latin America and the Caribbean. PLoS ONE 10(7): e0133409. DOI: 10.1371/journal.pone.0133409

Reguero, B.G., Mendez, F.J., Losada, I.J., 2013. Variability of multivariate wave climate in Latin America and the Caraibbean. Journal of Global and Planetary Change, 100, 70-84.

Reikard, G., 2009. Forecasting ocean wave energy: Tests of time-series models, Ocean Eng., 36, 348–356, doi:10.1016/j.oceaneng.2009.01.003.

Republic of Mauritius, Ministry of environment and sustainable development, 2012. Consultancy Services for the Development of an Inundation, Flooding and Landslide National Risk Profile, Maps, Strategy Framework and Action Plans for Disaster Risk Management. Studio Galli Ingegneria, DESAI & Associates Ltd. CMCC, UNDP -African Adaptation Program (Procurement reference no: AAP/ DRR/01/11).

Rizzi, J., 2014. GIS-based regional risk assessment and its implementation in a decision support systems for studying coastal climate change impacts. PhD Thesis. University Ca' Foscari Venice, Italy.

Rizzi, J., Gallina, V., Torresan, S., Critto, A., Marcomini, A., 2015a. A regional risk assessment addressing the impacts of climate change in the coastal area of the Gulf of Gabes. Sustain. Sci. DOI: 10.1007/s11625-015-0344-2.

Rizzi, J., Torresan, S., Gallina, V., Brigolin, D., Lovato, T., Carniel, S., Benettazzo, A., Critto, A., Pastres, R., Marcomini, A., 2015b. Analysis of water quality variations impacts in the North Adriatic Sea under changing climate scenarios using a regional risk assessment approach. Mar. Pollut. Bull. DOI: 10.1016/j.marpolbul.2015.06.037.

Roelvink, D., Reniers, A., van Dongeren, A., van Thiel de Vries, J., McCall, R., Lescinski, J., 2009. Modelling storm impacts on beaches, dunes and barrier islands. Coastal Engineering, 56, 1133–1152.

Rodríguez Santalla, I., Sánchez García, M.J., Montoya Montes, I., Gómez Ortiz, D., Martín Crespo, T., Serra Raventos, J. 2009. Internal structure of the aeolian sand dunes of El Fangar spit, Ebro Delta (Tarragona, Spain). Geomorphology, 104, 238-252.

Rojas Giraldo, X., Sierra-Correa P.C., Lozano-Rivera P., López Rodríguez A. 2010. Guía metodológica para el manejo integrado de las zonas costeras en Colombia, manual 2: planificación de la zona costera. Serie de Documentos Generales INVEMAR No.44, 74 p.

Rosendahl Appelquist, L., Balstrøm T., 2014. Application of the Coastal Hazard Wheel methodology for coastal multi-hazard assessment and management in the state of Djibouti. Journal Climate Risk Management, 3, 79-95.

Rosendahl Appelquist, L., Halsnæs, K., 2015. The coastal hazard Wheel system for coastal multi-hazard assessment & management in a changing climate. Journal Coast Conservation, 19 (2), 157–179.

Rosendahl Appelquist, L., Balstrøm, T., 2015. Application of a new methodology for coastal multi-hazard-assessment & management on the state of Karnataka, India. Journal Environmental Management, 152, 1-10. DOI: 10.1016/j.jenvman.2014.12.017

Rosendahl Appelquist, L., Balstrøm, T., Halsnæs, K., 2016. Managing climate change hazards in coastal areas - the coastal hazard wheel decision-support system. United Nations Environment Programme, Nairobi, Kenya.

Rosman, P., 2017. ReferênciaTécnica do SisBaHiA, http://www.sisbahia.coppe.ufrj.br.

Rousset, N., Torresan, S., Davis, M., Giannakopoulos, C., Dubois, G., 2014. Deliverable 1.3-Future Impacts at Case Study Level, 1-48. CLIM-RUN - Project No. 265192.

Ruiz, L.A., Pardo, J.E., Almonacid, J., Rodríguez, B., 2007. Coastline automated detection and multiresolution evaluation using satellite images. Proceedings of Coastal Zone 07. Portland, Oregon.

Santoro, F., Tonino, M., Torresan, S., Critto, A., Marcomini, A., 2013. Involve to improve: a participatory approach for a decision support system for coastal climate change impact assessment. The North Adriatic case. Ocean Coast. Manag., 78, 101-111.

Schmelkes, C., 1988. Manual para la presentación de anteproyectos e informes de la investigación. Mexico: Ed. Oxford Univ. Press.

Schuchman, R.A., Lyzenga, D.R., Meadows, G.A., 1985. Synthetic aperture radar imaging of ocean-bottom topography via tidal-current interactions: theory and observations. International Journal of Remote Sensing 6, 7, 1179-1200.

Shimura, T., Mori, N., Hemer, M.A., 2017. Projection of tropical cyclone-generated extreme wave climate based on CMIP5 multi-model ensemble in the Western North Pacific. Clim. Dyn. 49, 1449-1462. DOI:10.1007/s00382-016-3390-2

Sinha, R., Bapalu, G.V., Singh, L.K., Rath, B., 2008. Flood Risk analysis in the Kosi River Basin, North Bihar using Multi parametric approach of Analytical Hierarchical Process (AHP), J. Indian Soc. Remote Sens., 36, 335–349, 2008.

Slangen, A.B.A., Carson, M., Katsman, C.A., van de Wal, R.S.W., Köhl, A., Vermeersen, L.L.A., Stammer, D., 2014. Projecting twenty-first century regional sea-level changes. Clim. Change 124, 317-332. DOI:10.1007/s10584-014-1080-9

Solari, S., Alonso, R., 2016. A new methodology for extreme waves analysis based on weather-patterns classification methods, to be published in the Proceedings of the Coastal Engineering Conference ICCE 2016.

Solari, S., Losada, M. A., 2011. Non-stationary wave height climate modelling and simulation. Journal of Geophysical Research, 116 (C09032), 1–18. DOI: 10.1029/2011JC007101

Spalding, M.D., Ruffo, S., Lacambra, C., Meliane, I., Hale, L.Z., Shepard, C.C., Beck, M.W., 2014. The role of ecosystems in coastal protection: Adapting to climate change and coastal hazards. Ocean & Coastal Management, 90, 50-57.

Splinter, K.D., Mitchell, D.H., Turner, I.L., 2018. Remote Sensing Is Changing Our View of the Coast: Insights from 40 Years of Monitoring at Narrabeen-Collaroy, Australia. Remote Sens., 10 (11), 1744. DOI: 10.3390/rs10111744

Stockdon, H. F., Doran, K. J., Thompson, D. M., Sopkin, K. L., Plant, N. G., and Sallenger, A. H., 2012. National assessment of hurricane-induced coastal erosion hazards-Gulf of Mexico, U.S. Geological Survey, Open-File Report 2012–1084, 51 pp.

Stronkhorst, J., Levering, A., Hendriksen, G., Rangel-Buitrago, N., Rosendahl Appelquist, L. , 2018. Regional coastal erosion assessment based on global open access data: a case study for Colombia. Journal Coastal Conservation, 22 (4), 787–798. DOI: 10.1007/s11852-018-0609-x

Switzer, A.D., Bristow, Ch., Jones, B., 2006. Investigation of largescale washover of a small barrier system on the southeast Australian coast using ground penetrating radar. Sedimentary Geology, 183, 145-156.

Tamura, T., Murakami, F., Watanabe, K., 2010. Holocene beach deposits for assessing coastal uplift of the northeastern Boso Peninsula, Pacific coast of Japan. Quaternary research, 74, 227-234.

Tebaldi C, Strauss B, Zervas, C., 2012. Modelling sea-level rise impacts on storm surges along US coasts. Environmental Research Lett 7:014032

Tolman, 2002. User manual and system documentation of WAVEWATCH-III version 2.22. NOAA / NWS / NCEP / MMAB Technical Note 222, 133 pp.

Tomazin, N., 2016. Methodology for the assessment of wave energy potential combining numerical modeling and buoy data. 2nd International Seminar on Marine Energies, SIEMAR 2. Buenos Aires, Argentina, November.

Tomazin, N., Cáceres, R., 2014. Study of the wave climate in the Río de la Plata through the analysis of data from the olígrafo. VIII Argentine Congress of Port Engineering. Buenos Aires.

Torres Rodríguez, V., Márquez García, A., Bolongaro Crevenna, A., Chavarria Hernández, J., Expósito Díaz, G., Márquez García, E., 2010. Tasa de erosión y vulnerabilidad costera en el estado de Campeche debidos a efectos del cambio climático. En Vulnerabilidad de las zonas costeras mexicanas ante el cambio climático. Semarnat-INE, UNAM-ICMyL, Universidad Autónoma de Campeche, pp. 325-344.

Torresan, S., Critto, A., Rizzi, J., Zabeoa, A., Furlan, E., Marcomini, A., 2016. DESYCO: A decision support system for the regional risk assessment of climate change impacts in coastal zones. Ocean & Coastal Management, 120, 49-63.

US Army Corps of Engineers (USACE), 2009. Water Resource Policies and Authorities Incorporating Sea-Level Change Considerations in Civil Works Programs, Circular No. 1165-2-211.

Usha, T., Murthy, M.V., Reddy, N.T., Mishra, P., 2011. Tsunami vulnerability assessment in urban areas using numerical model and GIS. Natural Hazards, 60, 125-147.

van Duin, M. J. P., Wiersma, N. R., Walstra, D. J. R., van Rijn, L. C., and Stive, M. J. F., 2004. Nourishing the shoreface: observations and hindcasting of the Egmond case, The Netherlands, Coast. Eng.,51, 813–837, doi:10.1016/j.coastaleng.2004.07.011.

Vousdoukas, M.I., Mentaschi, L., Voukouvalas, E., Verlaan, M., Feyen, L., 2017. Extreme sea levels on the rise along Europe’s coasts. Earth’s Futur. 5. DOI: 10.1002/eft2.192

Vousdoukas, M.I., Mentaschi, L., Voukouvalas, E., Verlaan, M., Jevrejeva, S., Jackson, L.P., Feyen, L., 2018. Global probabilistic projections of extreme sea levels show intensification of coastal flood hazard. Nat. Commun. 9. DOI:10.1038/s41467-018-04692-w

Vousdoukas, M.I., Voukouvalas, E., Annunziato, A., Giardino, A., Feyen, L., 2016. Projections of extreme storm surge levels along Europe. Clim. Dyn. 47, 3171-3190. DOI:10.1007/s00382-016-3019-5

Wandres, M., Pattiaratchi, C., Hemer, M.A., 2017. Projected changes of the southwest Australian wave climate under two atmospheric greenhouse gas concentration pathways. Ocean Model. 117, 70–87. DOI: 10.1016/j.ocemod.2017.08.002

Wang, X.L., Feng, Y., Swail, V.R., 2014. Changes in global ocean wave heights as projected using multimodel CMIP5 simulations. Geophys. Res. Lett., 41, 1026-1034. DOI: 10.1002/2013GL058650

Williams, A.T., Nelson Rangel-Buitrago, Enzo Pranzini and Giorgio Anfuso. 2018. The management of coastal erosion. Ocean & Coastal Management. Volume 156, 15 April 2018, Pages 4-20. DOI: 10.1016/j.ocecoaman.2017.03.022.

Yasuda, T., Nakajo, S., Kim, S., Mase, H., Mori, N., Horsburgh, K., 2014. Evaluation of future storm surge risk in East Asia based on state-of-the-art climate change projection. Coast. Eng. 83, 65–71. DOI: 10.1016/j.coastaleng.2013.10.003

Yin, J., Yin, Z., Wang, J., Xu, S., 2012. National assessment of coastal vulnerability to sea-level rise for the Chinese coast, J. Coast. Conservation, 16, 123–133, DOI: 10.1007/s11852-012-0180-9, 2012.

Young, A.P., Ashford, S.A., 2006. Application of airborne LiDAR for seacliff volumetric change and beach-sediment budget contributions. Journal of Coastal Research 22, 307-318.

Zhang, K., 2011. Analysis of non-linear inundation from sea-level rise using LiDAR data: a case study from South Florida. Climatic Change 106, 537-565.

Zhang, K., Dittmar J., Ross M., Bergh C., 2011. Assessment of sea level rise impacts on human population and real property in the Florida Keys. Climatic Change 107, 129-146.