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<th>VULNERABILIDAD DE LOS SISTEMAS BIOGEOFÍSICOS Y SOCIOECONÓMICOS EN LA COSTA CATALANA Y GOLFO DE VALÈNCIA DEBIDO AL CAMBIO CLIMÁTICO</th>
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ABSTRACT

| **Title:** | Vulnerability of biogeophysical and socio-economic systems on the Catalan Coast and the Gulf of Valencia due to climate change. |
| **Author:** | Tamara Roldán Díaz |
| **Tutor(s):** | Octavio César Mösso Aranda  
| | Juan Pablo Sierra Pedrico |

This thesis studies how climate change affects human and nature systems through a significant cluster of biogeophysical and socio-economic indicators. For this purpose, firstly observed data collected from the Catalan Coast and the Gulf of Valencia were studied using time series analysis. Secondly, an ensemble project of multiple climatic models was conducted to obtain an average future trend projection of parameters such as air-sea temperatures, precipitation and sea-level rise.

Once observed trends and future predictions were acquired, impacts on systems were able to be identified and described with the aim of understanding likely future negative effects. Then a proposal of adaptation and mitigation measures was designed to reduce those impacts in the near future and to avoid the application of future drastic measures. The decision-making process, will not be only conditioned by risk and vulnerability of affected areas, but also will probably be influenced by other social and economic aspects as population growth, economic crisis and land use changes among other.

Experimental results show that, trend analysis might be highly conditioned by different factors such as the temporal scale considered. This local variability that results suggest may be explained by physical and social factors (atmospheric processes, air temperature or social conflicts). On the other hand, simulated results show high variability and therefore future uncertainty.

**Keywords:** Biogeophysical and Socio-Economic indicators, observed trends, future projections, impacts, adaptation and mitigation measures, CIRCE project.
RESUMEN

Título: Vulnerabilidad de los sistemas biogeofísicos y socioeconómicos en la costa Catalana y el Golfo de Valencia debido al cambio climático.

Autor: Tamara Roldán Díaz

Tutor(es): Octavio César Mösso Aranda
Juan Pablo Sierra Pedrico

La presente tesina estudia cómo el cambio climático afecta a los sistemas humanos y naturales a través de una serie de indicadores biogeofísicos y socioeconómicos. Para lograr dicho objetivo, datos experimentales fueron recogidos (en estaciones a lo largo de la costa Catalana y del Golfo de Valencia) y estudiados mediante el análisis de series de tiempo para la obtención de tendencias. Además, se llevó a cabo un ensamblaje de modelos climáticos de los cuales se obtuvo la proyección media de todos los modelos.

Una vez se disponía de las tendencias observadas y las predicciones futuras, impactos en sistemas pudieron ser identificados y descritos con el objetivo de entender posible efectos futuros negativos. En base a los resultados, se desarrolla una propuesta de medidas de adaptación y mitigación frente al cambio climático que probablemente evitaría la aplicación en un futuro (medio plazo) de medidas más drásticas. Sin embargo, durante el estudio se detectan otras presiones sociales y económicas como el crecimiento de la población en zonas costeras, el cambio de los usos del suelo y la crisis financiera, que afectarán en el proceso de toma de decisiones.

De los resultados experimentales se desprende que el análisis de tendencias está altamente condicionado por factores como la escala temporal considerada. La variabilidad local detectada, puede ser explicada por factores físicos y sociales como son procesos atmosféricos, temperatura del aire o incluso conflictos sociales. Por último, la diferencia entre los resultados simulados muestran una alta variabilidad y por tanto una sensación de incertidumbre hacia el futuro.

Palabras clave: Biogeofísicos y Socioeconómicos indicadores, tendencias observadas, proyecciones futuras, impactos, medidas de adaptación y mitigación, proyecto CIRCE.
1.- INTRODUCTION

Within the Mediterranean area, the highest population densities are found in coastal zones. Since human settlements have always been established near water bodies, the development of activities such as agriculture, fishing, transportation, trade and tourism are key factors which have led societies to growth near seaside. These coastal areas are characterised by their dynamic nature always in a fragile equilibrium between sea, land, rivers and atmosphere, where natural extreme events (e.g., increased storminess) may have significant negative long-term biogeophysical effects, such as sea-level rise, storm surges, coastal flooding, shoreline erosion, sediment loss, salt-water intrusion into coastal aquifers and loss of coastal wetlands or infrastructure (Mösso et al., 2009). This natural extreme events may be triggered as a natural consequence of the climate variability and the negative impacts (hazards) by the population growth which has pushed to a fast development of inhabited areas, increasing the vulnerability of coastal populations and ecosystems to natural disasters and may lead to a change in status that is not be compatible with present uses and infrastructure.

According to the Intergovernmental Panel on Climate Change (IPCC), vulnerability is “the degree to which a system is likely to be negatively affected by the nefarious effects of climate change, including climate variability and extreme phenomena. Vulnerability depends on the severity, amplitude and rhythm of climate change to which a system is exposed, its sensitivity and adaptation capacity”. An assessment of the vulnerability at regional scale is required to slow down the relentless progression of climate change and to adapt societies to current changes.

This problem was addressed in this thesis, developing management strategies, including adaptation and mitigation measures against impacts of climate change specifically on coastal areas. Their natural and social consequences have been measured by biogeophysical and social indicators and presented as results.

It was previously necessary to identify and quantify trends of climatic drivers or stressors such as wave height, air temperature, precipitation and frequency of occurrence of storm surges on the study area, information which was obtained from the CIRCE project aimed at developing for the first time an assessment of the climate change impacts in the Mediterranean region.
1.1.- CIRCE PROJECT

The Climate Change and Impact Research: the Mediterranean Environment (CIRCE) was an European project which for first time studied the effects of climate change specifically on the Mediterranean region, not only in regard to scientific data, but also in relation to the economic and social impacts. This project was granted under the Sixth Framework Programme (FP6) and coordinated by Antonio Navarra from the National Institute of Volcanology and Geophysics (INGV, Italy) and Laurence Tubiana from the Institut du Développement Durable et des Relations Internationales (IDDRI, France).

The main purposes of the CIRCE project were to predict and to quantify physical impacts of climate change at regional scale and then on basis of these, to assess the consequences for human societies, their economy and ecosystems (CIRCE Integrated Project: Annex I, 2006). It was totally necessary to develop a regional scale investigation, considering crucial parameters such as particular features of the Mediterranean area, resources, demands, actual and future pressures and significant sectors in order to create and apply response measures according to real needs of the region.

Areas surrounding the Mediterranean Sea are characterised by a particular weather, since it is localised at the edge between the tropical climate zone and the middle latitude climate belt. In most of the region precipitation is concentrated during winter months and although summers are relatively dry and hot, summer storms are significant (General overview CIRCE project, http://www.circeproject.eu/). In terms of the development and functioning of this region, four significant sectors have been identified as important points of study: health, tourism, energy demand and human migration.
To achieve mentioned objectives, 64 partners from Europe, Middle East and North Africa, the main part of which were research institutions, working together into 13 different research lines (RL) whose organization is shown by figure 1.

![Research lines of the CIRCE project](http://www.circeproject.eu/)

All the knowledge gathered by the different specialised investigations mentioned above, was collected to form an integrated approach designed that studied the total effect of climate change in the Mediterranean region and combined with communities needs to reach the final objective: the identification of adaptation and mitigation strategies and their implementation in collaboration with regional stakeholders. (*CIRCE Project Description, http://www.circeproject.eu/*).

To detect trends and to observe changes in climate variables, CIRCE not only considered the existing modelling such as those from the IPCC but also developed specific modelling scenarios for the Mediterranean area, including a wide range of climate parameters like temperature, precipitation, atmospheric humidity, wind, waves, sea-level rise, surface radioactive fluxes, balance between evaporation-precipitation, saline output to the Atlantic, water vapour export, frequency and distribution of extreme events, nutrient load into the sea and sensitivity to water stress were also studied in this project.
1.2.- BIOGEOPHYSICAL AND SOCIAL INDICATORS

Environmental indicators appeared with the need for integrating the environment into sectorial policies, facilitating the assessment and monitoring these integration policies. According to the Spanish Environmental Ministry, an environmental indicator is “a variable which has been provided with an added meaning apart from its own scientific configuration, to show in synthetic way, social concerns related to the environment; being therefore key part in decision-making process”.

Likewise, social indicators identify features of a society which can be measured, which vary over time and are taken as revealing some underlying aspect of social reality; such as health and mortality data (Source: http://www.eionet.europa.eu/).

An indicator should fulfil certain features and criterions, from which following are the most important ones:

- Relevance at national scale, although they could be used at regional or local scale if was required.
- Pertinent in front of followed objectives.
- Comprehensible, clear, simple hence no ambiguous.
- Available within national statistic system limits, they should be available with the lowest possible cost.
- Representative of an international and national consensus.

According to their utility, environment indicators show the following main functions:

- Providing information about environmental troubles.
- Supporting policies development, establishing priorities and identify the key factors are pressuring systems.
- Taking part into monitoring of response policies and mainly over integration policies.
- Representing an information tool within wide range of levels, namely for politicians, experts, specialists, scientist and citizens.

Anyway, the definition of environmental indicator, which belongs to indicators system, must follow necessity of:
Setting indicators comprehensible easily by non-specialist people.

Each indicator has to represent a clear expression of status and tendency, which should be understood in the context.

The reality of environment has to be represented by set of indicators.

In short, indicators system follow important objectives as: to facilitate the assessment of environmental situation in a territory or specific problems, to show equivalent data among different regions or countries, allowing to compare situations or make up worldwide data base and finally to provide easy and synthetic information around environmental situation that everybody could understand (Aguirre, 2001).

1.3.- JUSTIFICATION AND OBJECTIVES OF THIS STUDY

According to the CIRCE approach researches at Mediterranean regional scale are needed to consider specific features and needs of certain areas. Although factors such as climate change and its impacts on territories are current topics of concern, population awareness is increasing, institutional frameworks and legal agreements related to climate change have been created and many studies have been conducted, very little research effort has been focused on the regional scale of the Mediterranean area.

This study was carried out within the framework of the CIRCE project RL 11, specifically focused on the coastal case studies and it will contribute to develop an integrated approach in order to study the total effect of climate change on the region, from local scale.

The first step was to develop effective and real mitigation and adaptation measures suitable to be applied to the study area, taking into account local conditions, such as potential for adaptation, which can be defined as the possibility to conduct these measures on basis of local economy. The next step was to assure that future scenarios developed for this task consider all the needed aspects which participate within the process. Such factors are natural environmental processes (climate change role), intentional and unintentional human interventions in coastal system and socio-economic changes.
Regarding social and economic changes, some fundamental points are: population growth that is, how the number of people living in vulnerable and stressed areas is projected to change, evolvement of local economies, energy production and changes in land uses. Regarding this point, land use affects territory response in front of extreme meteorological events where soil permeability is a crucial factor in its behaviour. For example in coastal areas when sea level falls after a storm tide it may destabilize land slope causing landslides. In urban areas with high percentage of sealed soil, the infiltration capacity is reduce increasing surface runoff.

According to previous information, the realization of this study has two main objectives. On one hand to evaluate future pressures on the study area due to the effect of climate change and socio-economic changes by means of a set of biogeophysical and social indicators, shown at figure 2, developed specifically for the Mediterranean environment, following a common framework of the CIRCE project.

![Figure 2.-Set of biogeophysical indicators](image)

On the other hand to develop an action plan for the study area, including adaptation and mitigation measures aim to decrease both vulnerability and future pressures risk. It can be seen at figure 3 how climate change and adaptation/mitigation responses are variables which influences risk, since risk can be understood as function of two parameters likelihood of occurrence and its negative consequences on the study area.
Vulnerability of Biogeophysical and Socio-Economic Systems on the Catalan Coast and Gulf of Valencia due to Climate change

Figure 3.-Climate change risk assessment (Source: Kilsby, (2013) Impact assessment and adaptation policy Unit 5 (lectures notes, Newcastle University)).
2.- DESCRIPTION OF THE STUDY AREA

As the origin of its name indicates, from the Latin *Mediterraneus* meaning “inland or in the middle of the land”, the Mediterranean is a semi enclosed sea located between three continents Asia, Europe and Africa. The Mediterranean coastline, with about 46,000 km long, is considered as an ecoregion due to its climate, the richness of its biodiversity, landscapes and cultures, 40% of the population of the surrounding countries (roughly 100 million people) lives near the coast. For these reasons the Mediterranean Sea is very vulnerable, not only to climatic variability but also to anthropogenic activities.

This thesis focuses on part of the Spanish Coast, mainly in the north-western Mediterranean littoral located in front of the Balearic Islands. This stretch of about 750 km includes the Catalan Coast and the Gulf of Valencia, from the Creus Cape in the north to La Nao Cape in the south. Some distinctive features of this region such as its location and topography define the wind and wave climates, which are characterized in general terms by low to medium average winds (Sanchez-Arcilla et al. 2008a), short fetches owing to the presence of the Balearic Islands, high wind variability in time and space (Mösso et al. 2007) and wave calms during the summer and energetic storms from October to May. The next figure 4 offers a perspective of the study area within the Spanish Coast.

![Figure 4.-Spanish Coast and the study area (Source: http://www.andalucia-andalusia.com/).](image-url)
Locations such as the Ebro Delta and Cullera Bay within the study area are very vulnerable to environmental pressures, socio-economic changes and impacts of climate change. The following information remarks features and main problems in the aforementioned areas.

The Ebro Delta (figure 5), which is formed by the Ebro River arriving into the Mediterranean Sea, has an estimated surface of 320 km$^2$ and is divided by the river into two hemi deltas; approximately the 77% of the Ebro Delta is used for agriculture while the remainder comprises natural areas of beaches, marshes and lagoons. Due to the necessity of water supply for agriculture and domestic purposes, dams were constructed along the Ebro River, covering social needs but also causing environmental pressures in the area; the reduction in river flow and therefore in sediment transport is significantly contributing to coastal erosion. Effects of climate change such as sea-level rise and wave storminess also enforce this situation; these factors enhance the main problems identified for the Ebro Delta: coastal erosion, subsidence (largely due to natural or enhanced compaction from the reduction of fine sediment supplied by the river or pumping from groundwater aquifers) and water quality (Sánchez-Arcilla, et al., 2007). The combination of these factors will probably affect water availability, coastal fringes and natural ecosystems in a near future.

Figure 5.-Location of the Ebro Delta (Source: Sánchez-Arcilla, et al., 2007.)
The case of Cullera Bay (figure 6) is also worth mentioning. It is a shallow basin with maximum depths of around 10 m where the estuary of the Júcar River is located; the Cape of Cullera, a rocky mass that protrudes into the sea, limits the bay on its northern side, whereas the southern end of the bay is open.

A main problem in Cullera Bay is related to water quality. Housing, along with agricultural and industrial activities are the main pollution sources; abstraction of freshwater, which is later returned to the river loaded with pesticides and fertilizers, and the discharge of partially treated wastewater from riverbank towns and industries into the lower reaches of the river, are some of the mechanisms that contribute to river pollution. Moreover, the increment of population in summer seasons not only contributes positively to region economy but also might accentuate problems of water quality and coastal erosion in the bay.

Social pressures increase the vulnerability of the region to impacts of climate change, such as warming of sea temperatures and sea-level rise. Warmer temperatures would enhance eutrophication, causing degradation of water quality and an augment in mean sea level would affect river discharge leading to freshwater resource salinization. The addition of all these factors may have negative impacts on ecological systems, tourism sector, fishing industry and therefore local economy of the area.
As starting point, the CIRCE project was aimed at focusing on above mentioned areas the Cullera Bay and Ebro Delta. However due to data scarcity this was no possible to conduct leading to an amplification of the study area towards the north. Climatic data and marine conditions such as air temperature, rainfall and sea-level were collected from stations of Fabra, Barcelona and Estartit (both in the north of the study area).

3.- REVIEW OF THE LITERATURE

This chapter aimed at providing the evolvement of the climate change concept up to now. For this purpose information from different approaches has been collected. Firstly, basic principles of the environmental conscience worldwide will be described and then significant organizations and legal agreements will be remarked such as the Kyoto Protocol or Agenda 21. Finally, to narrow down the scope of this review, it will be focused on the Mediterranean region and particularly into the Catalan Coast and the Gulf of Valencia.

3.1.- CLIMATE CHANGE WORLDWIDE

The first sign of environmental conscience was drawn by the United Nations (UN), which was established officially on 24 October 1945, when the UN Charter was signed by the founding members. It was created to facilitate cooperation in international issues among countries, such as world pace, law, security, economy development, social progress and human rights.

In 1972, at the UN Conference on the Human Environment held in Stockholm, Sweden, it was proposed the creation of a global body to act as the environmental conscience of the UN systems. After this conference, the United Nations Environmental Programme (UNEP) was set up to assess the state of the global environment, to establish a programme of action priorities and to approve their funding. The Stockholm Conference marked the formal agreement by the international community that development and environment are strongly linked. From this moment the UNEP started to build up researching and awareness mechanism in favor of environmental issues, providing the impetus for set new national, regional and international legislation.
On the other hand, in 1950 the World Meteorological Organization (WMO) was created by the International Meteorological Organization (IMO), which was founded in 1873. The WMO became the specialized agency of the UN in 1951 for meteorology issues like weather, climate, operational hydrology and related geophysical sciences.

The UNEP and WMO were instrumental institutions in the climate change field, organizing the first two World Climate Conferences. The first of them, essentially a scientific conference, was held in 1979 in Geneva, Switzerland and played a decisive role in the formation of the Intergovernmental Panel on Climate Change (IPCC) in 1988. The main role of IPCC was to prepare a comprehensive review and recommendations with respect to the state of knowledge of climate change science worldwide, including social and economic impacts of climate change and possible response strategies.

The proliferation of environmental conferences and conventions were notable over the world. Apart from the first World Climate Conference mentioned before, other were carried out; one of the most successful and well-known conference was the 1987 Montreal Protocol of the Vienna Convention for the Protection of the Ozone Layer, which is an example of international environmental cooperation.

In 1990, two events took place; the first IPCC assessment report was released, showing for first time the importance of climate change and the requirement of a political platform among countries to tackle its consequences. That same year, the second World Climate Conference was celebrated at Geneva, Switzerland. Both occurrences played a decisive role in the UN Conference on Environment and Development (1992, Rio de Janeiro, Brazil), leading to the creation of the United Nations Framework Convention on Climate Change (UNFCCC). It is an international treaty with the objective of "stabilize greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with climate system" (UNFCCC Essential Background, http://www.unfccc.int/). This conference gathered an unprecedented number of representatives from governments, civil society and private sector, reason why it was known as the Earth Summit.

It is also worth pointing out two significant documents released at this conference, the Rio Declaration and Agenda 21. The first one reaffirmed the principles elaborated twenty years early in Stockholm, while Agenda 21 gave the world an action programme to build sustainable development into the 21st century. With its groundbreaking
synthesis of social, economic and environmental elements into a single policy framework, Agenda 21 gave new impetus and importance to the work of UNEP.

Summarizing, the Earth Summit gave birth to two major conventions, the UN Framework Convention on Climate Change and the Convention on Biological Diversity; it also saw the creation of the UN Commission on Sustainable Development (CSD).

The participants of this Convention decided on having regular meetings at Conferences of the Parties (COPs) on a regular basis to work on the implementation of the Convention’s objectives. The first Conference of the Parties was conducted in Berlin in 1995, year in which the Second IPPC Assessment Report was released as well. After two meetings, in 1997 the third COP was held in Kyoto, Japan, whereby the Kyoto Protocol (KP) was formally adopted.

In short, the Kyoto protocol sets binding emission reduction targets for 37 industrialized countries and the European community in its first commitment period. It only binds developed countries because it recognizes they are largely responsible for the current high levels of GHG emissions in the atmosphere after over 150 years of industrial activity. Unfortunately its implementation wasn’t immediate.

Finally few years later some significant occurrences succeeded. In 2001 the Third IPCC Assessment Report was released and the “Marrakesh Accords” at COP7 were established, detailing rules for implementation of Kyoto Protocol setting up new funding, planning instruments for adaptation and establishing a technology transfer framework. In 2005, the Kyoto Protocol entered into force and the first Meeting of the Parties took place in Montreal (MOP 1). According to Kyoto requirements, different Parties launched negotiations on the next phase of KP, which became the Nairobi Work Programme on Adaptation. In 2007, the Fourth IPCC Assessment Report was released and the COP17 was celebrated in Durban, the Parties to KP decided that a second commitment period from 2013 onwards would follow the end of the first commitment period.
Figure 7 shows a scheme of the evolution of environmental institutions and legal agreements signed during last decades.

Figure 7.-Worldwide evolvement of climate change conscience.
Nowadays several regional-scale studies of climatic variability, extreme events and their impacts on territories have been conducted. However few of them are focused on the Mediterranean region. As it has been explained before, the CIRCE project was the first study developed following that approach, reason why all information included in local info sheets has been the essential base needed to build this study.

Apart from the CIRCE project, it is worth mentioning the study on Climate Change and Energy in the Mediterranean Area carried out by Mediterranean institutions and experts from countries such as France, Tunisia and Egypt; it is a report of the Plan Bleu (environmental tool in favour of cooperation between the 21 riparian countries of the Mediterranean Sea and the European Commission) with the financial support of the European Investment Bank as the main sponsor of the study.

On a local level in Catalonia, there are several institutions which have been working on establishing a regional view of the global warming in this area. In order to create and develop its own strategy is important to project its weather’s features, possible weather changes in medium-term and its consequences or impacts in Catalonia.

The Expert Group on Climate Change in Catalonia (GECCC) is a cluster of experts in climate change, whose aim is to produce significant surveys of climate change in Catalonia. This group analyses regularly all the information released in its own country about this topic, detects which part of this information can be applied to Catalonia and tries to find and solve the existing gaps in the knowledge of this matter, drawing possible future guidelines (Expert Group on Climate Change in Catalonia, http://www.gencat.cat/).

In 2005, their First Climate Change Report was released in Catalonia supported by the Advisory Board to Sustainable Development (CADS). The Second Climate Change Report was produced during 2009 and 2010, including available data up to 2008; it was ordered by the Interdepartmental Committee on Climate Change of the Government of Catalonia (CICC) in 2007 and gives continuity to the first one. Over 2007, the CICC established a group of institutions, including the CADS, the Catalan Office for Climate Change (OCCC), the Institute of Catalan Studies (IEC) and the Meteorological Service of Catalonia, aiming to facilitate the development of this second report and ensuring

During the last years, the number of studies on climate change in Catalonia has increased noticeable; however, approximately half of these are focused on the study of climate change over the vegetal environment, probably due to the existence of significant institutions in this field. Regarding Valencia, nowadays a local strategy against effects of climate change already exist; nevertheless these general overviews need to become more specific in order to facilitate their implementation and the obtaining of results and improvements.

It is evident that in the study area there is a lack of studies addressing present and future effects of climate change on the coastal area, in terms of an integrated strategy including mitigation and adaptation measures. In general terms it can be said that the scientist structure which supports researching on climate change is still fragile and weak and definitely should be improved.

4.- METHODOLOGY

4.1.-DATA ACQUISITION

The observed data used to forecast future predictions and behaviours of significant variables such as mainly sea level, average rainfall and sea/air surface temperatures were obtained from different sources along the study area. Methodology may change depending on the type of data working with. In general data can be obtained experimentally or numerically and punctually or regularly, according to objectives and resources of the study. It is possible to acquire descriptive knowledge or diagnosis to understand the dynamic generation of a studied phenomenon and predictive knowledge or forecast to deduce from the obtained data future behaviours.

Climatic data and marine conditions were collected from different hotspots of the coastal area on the basis of data availability. In case of the northern territory of the
study region, information was gathered from the following sources (Sánchez-Arcilla. et al., 2007):

- **Marine climate data**

  Two wave buoys (Cap Tortosa and Tarragona) provide observed data on significant wave height, maximum wave height, mean wave period, maximum peak period, wave direction and water temperature (from early 1990s onwards). SIMAR-44 data (HIPOCAS project) includes numerical simulation of significant wave height, mean wave period, maximum peak period, wave direction, wind velocity and direction and sea level between 1958 and 2001.

- **Tidal gauge (Barcelona Port)**

  Sea level was collected over the period from 1992 to 2007.

- **Marine water quality data**

  It was obtained from the projects FANS and PIONEER, including current velocity, nutrients, oxygen, chlorophyll, water temperature and salinity, fluorescence, transmissivity, suspended matter and phytoplankton concentrations between 1996 and 2000.

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**The HIPOCAS Project**

The Hindcast of Dynamic Process of the Ocean and Coastal Areas of Europe (HIPOCAS) aim at obtaining a 40-year hindcasted data of wind, wave, sea-level and current climatology for European waters and coastal seas for application in coastal and environmental decision processes.

The hindcast and remote sensed data are compared in order to assess the level of uncertainty involved in using the different type of data. Statistical analysis is performed to extract several important long term characteristics of the data, concerning mean tendencies, variability and extremes.

*Hindcast: it is a way of testing numerical models when the end outcome is already known; in this process past information is used to forecast past behaviours and therefore determine how accurate is the model used to simulate and to predict the future.*

---

➢ Meteorological data

Three stations in the region (Deltebre, Port de l’Ampolla, Sant Carles de la Rapita) provided observed data on wind velocity and direction, air temperature and atmospheric pressure, water temperature and sea level; from 1997 onwards.

➢ Hydrological data

Daily mean discharge was available for the Ebro River during the period 1912-2004.

Regarding the southern area of the study region, data was convened from the following sources (Sánchez-Arcilla et al., 2007):

➢ Wave buoy (Valencia)
Data on significant wave height, maximum wave height, and mean wave period, 1985-2005.

➢ SIMAR-44 data (HIPOCAS project)
Data obtained from numerical simulation, including significant wave height, wave period, maximum peak period, wave direction, wind velocity and direction and sea level; 1958-2001.

➢ Water quality data (ECOSUD projects)
Included nutrients, chlorophyll, water temperature and salinity, suspended matter and phytoplankton concentrations. Data obtained from different cruises between 2002 and 2003.

➢ Tidal gauge (Valencia)
Sea level was collected over the period from 1992 to 2007.

➢ Júcar River discharge (Cullera)
Total monthly discharge assembled during the period between 1911 and 1997.
4.2.-TIME SERIES ANALYSIS

According to the StatSoft Electronic Statistics Textbook, time series data are sequences of consecutive measurements taken at equally (when possible) spaced time intervals that follow non-random orders, assumption in which the analysis of time series is based on. Time series analysis accounts for the fact that data points taken over time may have an internal structure (such as autocorrelation, trend or seasonal variation) that should be considered (Engineering Statistics Handbook, http://www.itl.nist.gov/).

To identify the nature of the phenomenon represented by the sequence of observations and to forecast (predicting future values of the time series variable) are the two main goals of time series analysis; both of these require identifying the pattern of observed time series data. Most of the time series patterns can be described in terms of four basic classes of components: trend, noise, seasonal component and cyclic component. The former represents a general systematic linear or nonlinear component that changes over time and does not repeat or at least does not repeat within the time range captured by our data. The latter may have a formally similar nature, however it repeats itself in systematic intervals over time.

As in most other analyses, in time series analysis it is assumed that the data consist of a systematic pattern (usually a set of identifiable components) and random noise (error) which usually makes the pattern difficult to identify. Most time series analysis techniques involve some form of filtering out noise in order to make the pattern more salient (Time Series Analysis, http://www.statsoft.com/textbook/time-series-analysis/).

As it has been mentioned before, once data have been collected regularly, it is possible to conduct a time series analysis process in order to obtain different type of information depending on objectives. Data available for the CIRCE project were collected and analysed to acquire trends and future projections following different methods, between which it is worth remarking.

Linear regression and Mann-Kendall methods were employed to achieve lineal trends whereas the Gaussian smoothing, moving average smoothing and the use of filters such as Band Pass and Hodrick-Prescott were applied to obtain flexible trends. The time series spectral analysis was used to acquire temporal periods and to observe the main changes.
4.2.1.- TREND ANALYSIS

Trend in a time series is a slow, gradual change in some property of the series over the whole interval under investigation. Trend is sometimes loosely defined as a long term change in the mean as Figure 8 shows, but can also refer to change in other statistical properties. In traditional time series analysis, a time series was decomposed into trend, seasonal or periodic components, and irregular fluctuations, and the various parts were studied separately. Modern analysis techniques frequently treat the series without such routine decomposition, but separate consideration of trend is still often required (Detrending, Lecture Notes 2009).

![Figure 8.-Simulated SSH at the Gulf of Valencia. The black line is the average series based on the different simulations (1950-2050 and 1950-2060). (Source: Sánchez-Arcilla, 2011).](image)

4.2.1.1.- LINEAL TREND

Seeking linear trends of the dataset two methods were mainly employed. On one hand linear regression (LR) is a method used to model the linear relationship between a dependent variable and one or more independent variables. In case of one independent variable it is called simple linear regression, whereas for more than one independent variable, it is called multiple linear regression (MLR). The dependent variable is sometimes also called the predictand, and the independent variables the predictors. MLR is based on least squares: the model is fit such that the sum-of-
squares of differences of observed and predicted values is minimized (Multiple Linear Regression. Lecture Notes 2009).

In linear regression, data are modelled using linear predictor functions, and unknown model parameters are estimated from the data. Such models are called linear models. Most commonly, linear regression refers to a model in which the conditional mean of $Y$ given the value of $X$ is an affine function of $X$. Less commonly, linear regression could refer to a model in which the median, or some other quantile of the conditional distribution of $Y$ given $X$ is expressed as a linear function of $X$. Like all forms of regression analysis, linear regression focuses on the conditional probability distribution of $Y$ given $X$, rather than on the joint probability distribution of $Y$ and $X$, which is the domain of multivariate analysis (Linear regression, http://en.wikipedia.org/).

On the other hand, linear trends (increasing or decreasing) can also be estimated by the use of the **Mann-Kendall test**. It is suitable for cases where the trend may be assumed to be monotonic and thus no seasonal or other cycle is present in the data. The Mann-Kendall test is applicable in cases when the data values $X_i$ of a time series can be assumed to obey the model

$$x_i = f(t_i) + \epsilon_i$$

Where $f(t_i)$ is a continuous monotonic increasing or decreasing function of time and the residuals $\epsilon_i$ can be assumed to be from the same distribution with zero mean. It is therefore assumed that the variance of the distribution is constant in time.

It is test the null hypothesis of no trend, $H_0$, i.e. the observations $X_i$ are randomly ordered in time, against the alternative hypothesis, $H_1$, where there is an increasing or decreasing monotonic trend. In the computation of this statistical, are used both the so called $S$ statistics (Gilbert, 1987) and the normal approximation ($Z$ statistics). For time series with less than 10 data points the S test is used, and for time series with 10 or more data points the normal approximation is used (Salmi et al., 2002).

### 4.2.1.2.- FLEXIBLE TREND

A second procedure for dealing with a trend is to use a linear filter, which converts an original time series $\{X_t\}$ into a smoothed or filtered series $\{Y_t\}$ by the linear operation
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\[ y_r = \sum_{i=-q}^{+q} a_i x_{r+i} \]

Where \( \{a_i\} \) is a set of weights

In order to smooth out local fluctuations and estimate the local mean, it should be clearly chosen the weights so that \( \sum a_r = 1 \), and then the operation is often referred to as a moving average.

Gaussian smoothing is similar to moving average but more sophisticated and often gives better solutions. This is due to during weighting process the nearest points to the centre of the smoothing window receive greater weight than those at the edges of the window. Whereas moving average assigns the same weight to all data of the smoothing window, for Gaussian smoothing values of weights follow a Gaussian distribution form. Theoretically, the Gaussian filter should be able to eliminate better the high frequency noise distributed normally over data, maintaining the shape of the sign.

However, there are also other types of filters that may be used depending on objectives and information required from time series data, case of the Band Pass Filter and Hodrick Prescott (HP) Filter. The former allows a specific frequency range to pass while blocking (attenuating) lower and higher frequencies, which are frequencies outside the range.

The later was proposed by Hodrick & Prescott in 1980 as a flexible method to obtain trend suppressant, separating time series into a non-seasonal trend component \( \{g_t\} \) and a seasonal cyclic residuum \( \{c_t\} \).

\[ x_t = g_t + c_t \]

The HP Filter isolates the cyclic component minimizing the mean square error whose expression is:

\[ \sum_{t=1}^{T} (x_t - g_t)^2 + \lambda \sum_{t=2}^{T-1} \left[ (g_{t+1} - g_t) - (g_t - g_{t-1}) \right]^2 \]

Where the first term is an adjustment measure of the time series and the second one is related with the smoothing. The conflict between goodness-of-fit and smoothing is monitored by the parameter of compensation (\( \lambda \)). It can be noticed that when \( \lambda \) is zero \( \{g_t\} \) tends to the original series whereas if \( \lambda \) tends to infinite \( \{g_t\} \) reaches a lineal trend. The HP Filter eliminates data trend resolving a least squares problem.
4.2.2.- SPECTRAL ANALYSIS

The spectral analysis procedure is employed to identify the periodic behaviour from a temporal series. Rather than analysing variability from a temporal point to the next one, this method analyses variation of series as a whole with periodic components of different frequencies. Spectral analysis allows transforming time series into a domain of frequencies and then analyse its features within that domain. From this analysis several parameters can be obtained such as the magnitude (fluctuations amplitude), phase, periodogram and spectral density apart from the possibility of checking series seasonality. From spectral density, seasonal components can be identified.

The spectral representation of a time series \( (X_t) \), with \( t = 1, \ldots, n \), splits \( X_t \) into the sum of sinusoidal components with random and non-correlated coefficients. From this point, it can be acquired the separation of auto-covariance and auto-correlated functions in sinusoids.

Data sources used were: Servei Meteorologic de Catalunya (SMC), Puertos del Estado, from the Spanish Ministry of Public Works (http://www.boiescat.org and http://www.puertos.es), Xarxa d'Instruments Oceanogràfics i Meteorològics (XIOM Network) from Universitat Politècnica de Catalunya and the Catalan Autonomous Government.

5.- RESULTS: IMPACTS OF CLIMATE CHANGE

5.1.-FUTURE PROJECTIONS

With the available numerical model projections, the CIRCE project assessed the evolution of some of the most important climate indicators such as temperature, precipitation and sea level in the study area. According to Mösso et al., (2010) in general terms, observed data are quite consistent in the evolution of the air and water temperature, showing a similar and even parallel increasing evolution with time. The less consistent results are those of the precipitation, showing a higher variability in its general trend.
Future projections are presented as a result of models ensemble in the study area, aimed at investigating present and future climate changes for the period 1950-2050 running CIRCE project climate models. Within this investigation, the CIRCE climate covered different areas with different spatial resolution over the Gulf of Valencia (Figure 9). The following coupled atmosphere-ocean CIRCE models were used: ENEA CNRM and Instmed06 (Sánchez-Arcilla et al., 2011).

Figure 9.- Gulf of Valencia areas covered by the atmospheric and oceanic components of the CIRCE climate models. (Source: Sánchez-Arcilla et al., 2011).

Following future climate and marine projections presented are structured in three subsections: What is it?, What does this show? and Why is this important?. Aiming to easily explain concepts, to show clearly likely future trends, changes in climate and finally to understand possible repercussions or consequences.
5.1.1.- AIR TEMPERATURE

What is it?

Mean, minimum and maximum air temperature trends are expressed as a rate of change (°C/decade), with 95% confidence limits. Temperature indicators are derived on an annual and seasonal basis, and data were obtained from the Catalan Meteorological Service (SMC), for the stations Ebro (centre of the study area) and Fabra, Barcelona (north of the study area).

What does this show?

According to Mösso C. et al. (2010), results from time series analysis of observed data show that annual mean temperature has been increasing at a rate of warming which ranges between +0.17ºC / decade and +0.24ºC / decade for the whole Catalunya region. Particularly significant is the temperature increase from 1950 to 2008 measured at Fabra and Ebro (Figure 10), shown with 95% confidence intervals in Table 1.

Moreover, the rate of increase for the annual mean maximum temperature (+0.23ºC to +0.32ºC / decade) has been about twice that for minimum temperature (+0.08ºC to +0.18ºC / decade). In addition, the summer season shows the fastest warming trend, with a mean rate of increase of over 0.3 ºC / decade. Similar results were reported by Miró et al. (2006) for the littoral and surrounding area of Valencia (southern part of the study area), for the years 1958 to 2002. The observed warming trend for Valencia was strongest in summer and spring and weakest in autumn and winter.
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Figure 10.- Annual mean temperature (in green) and 11-year running mean (in blue) for the stations Ebro (previous page) and Fabra (above). Data provided by SMC. (Source: Mösso et al., 2010).

<table>
<thead>
<tr>
<th>Station</th>
<th>Mean decadal temperature trend</th>
<th>95% confidence level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabra, Barcelona</td>
<td>+0.16</td>
<td>[0.12-0.20]</td>
</tr>
<tr>
<td>Ebro</td>
<td>+0.15</td>
<td>[0.12-0.18]</td>
</tr>
</tbody>
</table>

Table 1.- Mean annual temperature trends (°C/decade) with 95% confidence interval (Source: Mösso et al., 2010).

Figure 11 shows the mean temperature evolution in the Gulf of Valencia simulated by the ensemble of CIRCE models for the period 1950-2050. Mean values and trends are summarized in Table 2.

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>T max (°C) Trend (°C/decade)</td>
<td>18.502±2.56 [0.077 → 0.094]</td>
<td>19.612±2.37 [0.3 → 0.4]</td>
<td>+18.719±2.58 [0.17 → 0.23]</td>
</tr>
<tr>
<td>T min (°C) Trend (°C/decade)</td>
<td>12.185±1.99 [0.062 → 0.112]</td>
<td>13.272±2.27 [0.31 → 0.4]</td>
<td>+12.915±2.08 [0.16 → 0.23]</td>
</tr>
</tbody>
</table>

Table 2.- Mean values and trends of temperature simulated by the coupled models in the Gulf of Valencia area based on ensemble averages, for the “present”, 1961-1990 and “mid-century”, 2021-2050 periods. Mean “long-term” changes between the periods 1961/1990 and 2011/2050 are also shown. Values inside the brackets show the tendency range. (Source: Sánchez-Arcilla et al., 2011).
From this study can be drawn that mean air temperature is projected to increase at an accelerating rate. The different models show a similar behaviour. The numerical projections show that the minimum and maximum temperatures are increasing between 3 to 4 times faster for the 2011-2050 period compared to the 1961-1990. The overall trend is increasing and consistent in all models. When considering the range values between the numerical projections, there is a significant uncertainty between them. The correlation between minimum and maximum temperatures, despite being positive (which means that they show the same trend), are moderate, with values between 0.51 and 0.64.

Therefore, on basis of these estimations and independent of exact numbers, some general conclusions can be observed. On one side it has been detected an increment of the mean annual temperature with fastest warming trend in summer season. This increment of mean air temperature occurs at accelerating rate, which is greater for the annual maximum temperature than for the minimum temperature. However, correlation between minimum and maximum temperature trends is moderated.
• **Why is this important?**

An increase in air temperature is one of the clearest signals of regional and global climate change. The simulated trends of minimum and maximum temperature show that they are increasing at a similar and faster rate, between 3 to 4 times faster for the “future climate” projections compared to the “past climate” ones. A preliminary analysis (not shown here) of the Tx95 for the gulf of Valencia shows that this value will increase close to 1.5 °C, and thus, the number of very hot days per year will increase around 65% (75% for the Ebro Delta area). The warming trend observed for the two stations representative of the Gulf of Valencia could incur substantial regional impacts, especially during the summer season, when increasing air temperature translates to greater evaporation, and an increase in the use of scarce fresh water resources and energy through a greater use of air conditioning.

Atmospheric warming may also contribute to the expected sea-level rise and an increase in sea temperature which can alter the abundance and composition of marine species in coastal ecosystems.

Warming would have a profound impact on tourism producing shifts in the pattern of demand. Increasing temperature also has the potential to significantly alter the conditions for crop production due to the foreseen decrease in the precipitation regime that would affect the yield distribution considerably. Southern Mediterranean areas will probably have to face increasing water shortage and incidence of extreme adverse events, reducing crop yields and the area for cropping. Moreover, the higher temperatures are likely to increase crop water requirements and more irrigation water will be needed per hectare.

5.1.2.- TOTAL RAINFALL

• **What is it?**

Total precipitation is derived on an annual and seasonal basis for the stations Ebro and Fabra, Barcelona. Data were obtained from the Catalun Meteorologic Service (SMC). Also estimated precipitation is shown for the Gulf of Valencia, based on ensemble model results.
• **What does this show?**

Firstly, observed data analysis (Figure 12) shows that while a slight decreasing trend in annual precipitation is observed in northern parts of the Gulf of Valencia (Fabra Station), a slightly increasing trend is observed in central (Ebro) parts.

*Figure 12.* Annual precipitation anomalies for the Fabra (low, 1914-2008) and Ebro stations (upper, 1906-2008) with a Gaussian Smooth fit and slope estimate (red line) with the 95% confidence interval (blue dashed line). Data provided by SMC. (Source: Mösso et al., 2010).
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For the complete record these trends are not significant (p > 0.1). Standardized precipitation anomalies for the Catalan Mediterranean system show considerable variability, a characteristic of the Mediterranean climate (Saladié et al., 2004). However, a Gaussian smoothing to precipitation anomalies suggests that there seems to be a precipitation decrease at Ebro from 1970 to 1980 and a slight increase since then, while at Fabra there is a decreasing trend from 1994 to the present day.

Secondly, figure 13 shows the precipitation evolution in the Gulf of Valencia simulated by the ensemble of CIRCE models for the period 1950-2050. Mean values and trends during the “past climate” (1961-1990) and the “future climate” (2011-2050) are summarized in next Table 3. The overall trend and the statistical significance of the “long-term” period (1950-2050), were obtained by the Mann-Kendall test (Mann, 1945; Kendall, 1975).

The correlation between precipitations in all the models is most of the times very poor; with values close to zero, and in some times, the sign is negative. The projected trend also may have different sign, which means that the variability and uncertainty between models is important. Regarding the correlation between temperature and precipitation, in most of the times it is negative with very low values or close to zero.

![Figure 13. Simulated atmospheric Precipitation (mm) in the Gulf of Valencia from a set of numerical models for the period 1950-2050. The grey lines are the time-averaged series for the different nodes of the models used in this analysis. The coloured lines are the averaged values, plotted with the observed trend or the different periods and the overall trend of the whole time series. (Source: Sánchez-Arcilla et al., 2011).](image)
Models employed along the study area do not show a common pattern related to future precipitation trends, which means that some models predict increasing trends whereas other decreasing trends. Climate variability and uncertainty are significant factors which do not let models arrive to a definitive conclusion.

- **Why is this important?**

An increase in winter and autumn precipitation, and a decrease in summer precipitation may produce opposing effects. Floods and droughts may occur in different seasons for the same region and year (e.g., a drought in summer and floods in winter and autumn). Less precipitation in summer could lead to water and soil quality degradation in “dry” river courses and adjacent coastal areas. More intense precipitation events could result in more pulsed river discharge that more easily crosses the continental shelf leading to a higher risk of sediment and nutrient loss to the shelf waters.

5.1.3.- **STORM SURGES (SEA LEVEL)**

- **What is it?**

Sea level varies according to a wide range of influences, such as storm surges (closely related to climate), tides and seasonal cycles. Annual mean sea level related to storm surges is presented for three sites: Barcelona to the north (observed, 1992-2007), Valencia in the south (observed, 1992-2006), and the Ebro Delta in the centre of the region (HIPOCAS hindcast model data, 1958-2001).

- **What does this show?**

The observed 16-year and 15-year time series of storm surge data for the ports of Barcelona and Valencia respectively (Figure 14) show that there is a slight overall decreasing trend (-0.04 cm/decade and -0.03 cm/decade) over the time period.
Figure 14. Annual mean sea level due to atmospheric factors at Barcelona, 1992-2007 (previous page), Valencia, 1992-2006 (in this page). The estimated slope (red line) with the 95% confidence interval (blue dashed lines). Modified from Mösso et al., 2009. (Source: Mösso C. et al., 2010).
However, the series are short and the detected trends are not statistically significant since there is little annual variation for much of the previous decade. Using a longer hindcast data for the Ebro Delta, the results (Figure 15) reveal that there is a clear statistically significant decreasing trend of about -0.54 cm/decade- which has been also seen in the hindcast data for Barcelona and Valencia.

![Figure 15](image)

*Figure 15.* Annual mean sea level due to atmospheric factors at Ebro Delta, 1958-2001. The estimated slope (red line) with the 95% confidence interval (blue dashed lines). Modified from Mösso et al., 2009.

(Source: Mösso et al., 2010).

The sea surface height (SSH) predictions presented here (Figure 16) are simulated results from the ensemble of CIRCE models. A future wave climate for the year 2050 was projected based on the trend found for the 44-year wave hindcast time series.

In the context of climate change, this is obviously an approximation for present conditions because it does not consider explicitly the greenhouse effect. Table 4 shows the mean values and trends for SSH for the periods 1961-1990 (past) and 2021-2050 (future). It also shows the change rates between these two periods ('long-term' changes but with present conditions). The inter-model ranges are shown as the standard deviations.
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Figure 16.- Simulated SSH (sea surface height) at the Gulf of Valencia. The black line is the average series based on the different simulations (1950-2050 and 1950-2060). (Source: Sánchez-Arcilla et al., 2011).

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<tbody>
<tr>
<td>SSH (m)</td>
<td>0.96±0.15</td>
<td>1.7±0.15</td>
<td>1.26±0.41</td>
</tr>
<tr>
<td>Trend (m/decade)</td>
<td>[0.13]</td>
<td>[0.12]</td>
<td>[0.14]</td>
</tr>
</tbody>
</table>

Table 4.- Mean values and trends of SSH simulated by the CIRCE coupled models in the Gulf of Valencia, for the two periods ("past climate": 1961-1990; "future climate": 2021-2050). Mean changes and mean change rates between the two periods 1961/1990 and 2021/2050 (“long-term” changes) are also shown. Inter-model ranges are shown as the standard deviations between estimates from the used models. (Source: Sánchez-Arcilla et al., 2011).

- Why is this important?

The Mediterranean coast is highly vulnerable to variations in sea level. Sea level rise increases the likelihood of storm surges, landward intrusion of salt water and endangers coastal ecosystems and wetlands. Decreasing sea level may impact port operations and coastal structures performance. This is the case of the Gulf of Valencia, where Mösso et al. (2010) shows how sea level variations along its coasts are highly variable and there is no correlation between observations for the study sites.
This variation could be explained by atmospheric processes governing sea level at a local and regional level. Changes in storm tracks and the variation of sea-air temperatures must also have played a role in this “apparent” local variability, although the available time series length is too short and the detected trends of the observed data are not statistically significant to allow more definitive conclusions.

However, Sánchez-Arcilla et al. (2011) concluded that numerical projections of sea height show a significant increasing trend, of about 3 to 4 times the state of the art projections, and showing almost the same trend through all the series, suggesting that there could be a numerical spurious effect. Nevertheless observational evidences show that at the gulf of Valencia, the present sea level is rather constant (Mösso et al, 2009).

5.1.4.- SEA SURFACE TEMPERATURE

• What is it?

The oceans have a large capacity for storing and redistributing heat. When storing heat, the upper water column expands and increases the sea level. Annual mean, maximum and minimum sea surface temperatures are presented for two sites, at l’Estartit (lat: 42º 03’ N; long: 3º 15’ 15” E) for the years 1969 to 2008, and Cap Tortosa (lat: 40º 43.29’ N; 00º 58.89’ E) for the years 1990 to 2008. Data are provided by the Catalan Meteorological Service (SMC).

• What does this show?

The analysis of observed annually averaged sea temperature at different depths [surface (Figure 17), -20, -50, -80 m] at l’Estartit, shows a parallel increasing trend to that for air temperature. Although more limited in series length (continuous from 1974) this warming trend (about 0.33ºC/decade) is significant, especially close to the surface.

The observed decadal trends, obtained using the Mann-Kendall test are 0.48ºC, 0.28ºC and 0.06ºC (all significant at the 0.001 level) for surface maximum, mean, and minimum temperatures respectively (Figure 17). An increasing trend of approximately 0.93ºC/decade (significant at the 0.01 level) in the surface monthly averaged mean temperature is also observed at Cap Tortosa, Ebro Delta (Figure 18). Statistical significance is limited by a short time series, missing values, and outliers.
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Figure 17.-Annual mean (yellow), maximum (red) and minimum (blue) sea surface temperature (SST) at l’Estartit, 1969-2008; note that 1972/73 values are missing (left). Data source: SMC. (Source: Mösso et al., 2010).

Following figure 19 shows the Sea Surface Temperature (SST) simulated values, until the year 2050. These were projected according to the same scenario than SSH that is
based on the trend found for the 44-year wave hindcast time series (without considering explicitly the greenhouse effect). Table 5 shows mean values and trends for SST for the periods 1961-1990 (past) and 2021-2050 (future). It also shows the change rates between these two periods (‘long-term’ changes but with present conditions). The inter-model ranges are shown as the standard deviations.

![Figure 19. Simulated SST (sea surface temperature) at the Gulf of Valencia. The black line is the average series based on the different simulations (1950-2050 and 1950-2060). (Source: Sánchez-Arcilla et al., 2011).](image)

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>SST (°C)</td>
<td>16.92±0.36</td>
<td>18.25±0.8</td>
<td>+17.55±0.87</td>
</tr>
<tr>
<td>Trend (°C/decade)</td>
<td>[0.086 → 0.092]</td>
<td>[-0.413 → 0.343]</td>
<td>[0.188 → 0.221]</td>
</tr>
</tbody>
</table>

Table 5.-Mean values and trends of SST simulated by the CIRCE coupled models in the Gulf of Valencia, for the two periods ("past climate": 1961-1990; “future climate”: 2021-2050). Mean changes and mean change rates between the two periods 1961/1990 and 2021/2050 ("long-term” changes) are also shown. Inter-model ranges are shown as the standard deviations between estimates from the used models. (Source: Sánchez-Arcilla et al., 2011).

In conclusion both studies determine that waters of the study area are undergoing a warming increasing trend (especially for the maximum temperatures). Although projected data may show different temporal trends within the regional study depending
on the model, for the studied periods (1961-1990 and 2011-2050) the overall tendency shows a clear increasing behaviour.

- **Why is this important?**

The increase in sea-water temperature may have a direct impact on the coastal water quality. Warmer waters combined with a continuous input of nutrients and pollutants from the densely populated coastal zone may induce a proliferation of jellyfish and other invasive species, which could directly affect tourist activities. An increase in sea-water temperature could lead to more frequent convective flash flood events. This is related to an enhanced occurrence of convective storms due to the difference in sea-air temperatures, and has frequently been observed along the Spanish Mediterranean coast.

5.1.5.- WAVE STORMS

- **What is it?**

A wave storm is defined as an event of (a) $H_s$ (significant wave height) $\geq 1.5$ m or (b) $H_s \geq 2.0$ m with duration of at least 6 hours. The directional distribution of waves along the coast (Figure 20) shows a predominance of NW and N wave conditions at the southern and northern sections of the Catalan coast, and E and S wave conditions in the central part of the coast. The largest waves come from the E or E-NE, where the largest fetches and stronger winds coincide. The available observed data date from 1990 to 2006.

![Directional wave distribution along the Catalan coast](image)

*Figure 20.-Directional wave distribution along the Catalan coast. The radial axis indicates frequencies of occurrence. (left) Llobregat corresponds to Barcelona, (centre) Cap Tortosa corresponds to the Ebro Delta and (right) Cullera Bay (Source: Sánchez-Arcilla et al., 2008 (left, centre) and Mösso et al., 2007 (right)).*
• **What does this show?**

The mean annual number of recorded storms varies according to the chosen threshold; 27 moderate (Hs ≥ 1.5 m) and 8 severe storms (Hs ≥ 2.0 m). There is a slight net increase in the number of moderate storms (+2/decade), and a slight decline (-2/decade) in severe storm events (Figure 21 top). The severe storms tend to be of slightly shorter duration than the moderate storms, but the duration tends to increase (2.16 hrs/decade) over the observation period (Figure 21 bottom). These trends are very moderate in magnitude and are not statistically significant (in all cases, p > 0.1). They could, however, provide an explanation for the “perceived” larger damage experienced by coastal protection works and beaches in recent years.

*Figure 21.* Storm number (upper) and mean duration of storms (low) at Cap Tortosa (Ebro Delta), 1990-2006. (Source: Mósso et al., 2010).
Additionally the ensemble of CIRCE models presents following preliminary results (Figure 22) of wave climate simulated with numerical models employing data of Regional Climate Models (RGM).

![Figure 22.-Simulated Hs and Direction for the Gulf of Valencia (left). The map shows the Hs ratio for the period 2081-2100 compared to 1991-2010 obtained with numerical simulation (Casas-Prat and Sierra, 2011). The wave roses, obtained from extrapolations of hindcast data (centre, right) show that there will be an increase of the number of waves coming from the south (Casas-Prat and Sierra, 2010).](image)

- **Why is this important?**

Wave climate is a key factor for determining coastal hazards for the Mediterranean where a narrow strip of land supports a wide variety of uses. From time series analysis it can be drawn that available series are too short to allow identification of any long-term trends. Nevertheless, the records suggest that energetic storms are becoming less frequent but of increasing duration. Longer storms translate to higher sediment transport rates, and higher risk of coastal erosion.

From future simulations, it can be said that, with respect to wave height and direction for the future scenario, it was detected in annual terms, a slight decreasing trend of Hs, in particular in the Catalan Coast. Moreover there is a shift of energy from the waves throughout the year, as there is a reduction of Hs in autumn and winter, while in general the spring and summer would be more energetic.

These changes in seasonal patterns can influence the future coastal management, since the pressure on the beaches is strongly seasonal, being highest in spring and summer (Casas-Prat & Sierra, 2011).
5.1.6.- SEA SURFACE SALINITY

- **What is it?**

The sea surface salinity (SSS) projection presented here come from the Mediterranean Sea model run by the CIRCE project. Like previous marine variables, a future wave climate for the year 2050 was projected based on the tendency found for the 44-year wave hindcast time series (it does not consider explicitly the greenhouse effect).

- **What does this show?**

Table 6 shows the mean values and trends of SSS for the periods 1961-1990 (past) and 2021-2050 (future). It also shows the change rates between these two periods (‘long-term’ changes but with present conditions). The inter-model ranges are shown as the standard deviations.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SSS (PSU)</td>
<td>37.19±0.38</td>
<td>36.46±0.4</td>
<td>36.83±0.5</td>
</tr>
<tr>
<td>Trend (PSU/decade)</td>
<td>[-0.091 → 0.118]</td>
<td>[-0.059 → 0.107]</td>
<td>[-0.089 → -0.050]</td>
</tr>
</tbody>
</table>

Table 6.- Mean values and trends of SSS simulated by the CIRCE coupled models in the Gulf of Valencia, for the two periods (‘past climate’: 1961-1990; “future climate”: 2021-2050). Mean changes and mean change rates between the two periods 1961/1990 and 2021/2050 (“long-term” changes) are also shown. Inter-model ranges are shown as the standard deviations between estimates from the used models.

(Source: Sánchez-Arcilla et al., 2011).

**Figure 23.-Simulated SSS (sea surface salinity) at the Gulf of Valencia. The black line is the average series based on the different simulations (1950-2050 and 1950-2060).**

(Source: Sánchez-Arcilla et al., 2011).
The projected values (previous Figure 23) show an opposite behaviour between the “past” (with an increasing trend) and “future” periods (with a decreasing trend), though the overall trend is decreasing.

- **Why is this important?**

Most of the important coastal hazards related to climate change are those derived directly from the rising air and water temperature. Sea temperatures control atmosphere-ocean exchanges and are, thus, linked to evaporation and precipitation rates. The associated hazards come, mainly, from coastal flooding due to continental run-off. Water temperature also controls the solubility of certain substances (among them dissolved oxygen) and primary production (Manasrah et al., 2006; Markfrot and Hondzo, 2009).

Water temperature regulates ecosystem functioning both directly, through physiological effects on organisms, and indirectly, as a consequence of habitat loss. The warming process can induce the “tropicalization” of the Mediterranean Sea. Climate change combined with Atlantic influx, lessepsian migration and the introduction of exotic species by humans may favour the occurrence and establishment of warm-water species. Stronger or more frequent extremes (storms, floods, etc.) associated with the increase in air and water temperature and sea level would cause physical damage, population displacement and adverse effects on food production and freshwater availability and quality. An example of this is the shoreline position which is a direct response to, mainly, the sea level and wave storminess (Sánchez-Arcilla et al., 2008).

5.1.7.- RISKS OF CURRENT CLIMATE AND MARINE HAZARDS

As it was mentioned, future climate and marine hazards presented here are projections of two studies, one treating observational evidences and another numerical runs. Results from the local study which covers specifically the study area are summarized in Table 7 together with the observed change and associated likelihood. Each indicator is derived for between one and three stations on an annual or seasonal basis. There is an evident significant increase in the air and sea surface temperature (from 1950 and 1969 respectively, to 2008), although there is no solid evidence that it is affecting the precipitation pattern (because of large natural variability) or the sea level (which may be affected more by local climate conditions rather than a change in the Mediterranean
climate). There is evidence of a decrease in the number of energetic storms per year, although their mean duration shows a significant increase over the observation period.

The terminology for likelihood (table 7) of occurrence is based on the standard terms used in the IPCC 2007 report: Virtually certain > 99% probability; Extremely likely > 95% probability; Very likely > 90% probability; Likely > 66% probability; More likely than not > 50% probability; About as likely as not 33 to 66% probability; Unlikely < 33% probability; Very unlikely < 10% probability; Extremely unlikely < 5% probability; Exceptionally unlikely < 1% probability.

<table>
<thead>
<tr>
<th>Climate Indicator (hazard)</th>
<th>Change (per decade)</th>
<th>Region (or stations)</th>
<th>Time period</th>
<th>Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature</td>
<td>Warming trend (+0.18 to +0.21°C). Maximum temperature increasing at a faster rate than minimum temperature. The warming is strongest in July.</td>
<td>Fabra (Barcelona), Ebro and Valencia</td>
<td>1950-2008</td>
<td>Very likely</td>
</tr>
<tr>
<td>Rainfall</td>
<td>Considerable variability in annual precipitation. Seasonal trends (Fabra; Ebro): winter (+3.6mm; +2.3mm) autumn (+1.5mm; +2.9mm) summer (-1.2mm; -0.8mm)</td>
<td>Fabra (Barcelona) and Ebro</td>
<td>1901-2000</td>
<td>Likely</td>
</tr>
<tr>
<td>Storm surges (sea level)</td>
<td>Overall downward decadal trend in annual hindcast mean sea level: Barcelona -0.84 cm Valencia -1.35 cm; Ebro -0.54 cm</td>
<td>Port of Barcelona Port of Valencia Ebro Delta</td>
<td>1958-2001</td>
<td>Likely</td>
</tr>
<tr>
<td>Sea surface temperature</td>
<td>Significant increase in mean sea surface temperature: l’Estartit +0.28ºC/decade Cap Tortosa +0.93ºC/decade.</td>
<td>l’Estartit Cap Tortosa</td>
<td>1969-2008 (1972/73 missing) 1990-2008</td>
<td>Very likely</td>
</tr>
<tr>
<td>Wave storms</td>
<td>Number of storms: Hs ≥ 1.5m has increased +2/decade Hs ≥ 2.0m has decreased -2/decade. The mean duration for both has increased: Hs ≥ 2.0m at a rate of 2.16 hr/decade Hs ≥ 1.5m at a rate of 0.1 hr/decade.</td>
<td>Cap Tortosa, Ebro Delta.</td>
<td>1990-2006</td>
<td>Likely</td>
</tr>
</tbody>
</table>

*Table 7: Change in the climate and marine indicators (hazards) for the Gulf of Valencia.*
(Source: Mösso et al., 2010).
Table 8 shows observed and projected variables from the study area obtained from the second study. It is worth mentioning that although nowadays the basic forcing mechanism of climate variation due to greenhouse gases is relatively well known, the multiple feedback mechanisms that amplify this effect are not.

These feedbacks along with multiple factors such as data availability limitation, data quality and difficulties in the identification and separation of the climatic and non-climatic influences on the indicators; makes it difficult in distinguishing between the effects and the vulnerability in biogeo-physical and socio-economic indicators. The determination of thresholds values on changes in climate change drivers at which adaptation measures must be taken and the systematic use in the identification of coping ranges, are all processes that will probably not diminish the uncertainty about predictions for the 2100 climate.

The uncertainty associated to future projections will only start to decrease when observations about what happens to the climate will become available, together with a better use of climate models, making explicit their range of uncertainty, achieve higher resolution and accuracy.

<table>
<thead>
<tr>
<th>Observed Projected</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(2021-2050)</strong></td>
</tr>
<tr>
<td>SST (°C) ↑</td>
</tr>
<tr>
<td>SSS (PSU) ↑</td>
</tr>
<tr>
<td>SSH (steric, cm) (↑)</td>
</tr>
<tr>
<td>Precipitation (mm) ←</td>
</tr>
<tr>
<td>Beach Erosion (↑)</td>
</tr>
<tr>
<td>Water Quality ↓</td>
</tr>
<tr>
<td>Tx95 (↑)</td>
</tr>
<tr>
<td>Number of very hot days (↑)</td>
</tr>
<tr>
<td>Human Health related to heat ↓</td>
</tr>
<tr>
<td>Human Comfort related to heat ↓</td>
</tr>
<tr>
<td>Economic Impact (↑)</td>
</tr>
</tbody>
</table>

Table 8: Summary of observed (last few decades) and projected (2021-2050) impacts and vulnerabilities for the Gulf of Valencia. ↑: observed/projected increase, ↓: observed/projected decrease, ←: no trend/change identified. Brackets () indicate very small/uncertain trends/changes. -: not analysed. (Source: Sánchez-Arcilla et al., 2011).
5.2.- BIOGEOPHYSICAL AND SOCIAL INDICATORS

On the basis of observed and projected evolution of climatic and marine hazards, following physical and socio-economic impacts particularly vulnerable and sensitive to weather and climate can be identified on the study area. Not only nature and ecosystems are affected but also human systems, which will probably have to adapt their structures to future conditions.

On one hand, the projected increment of air and water temperature along with sea level rise, have a direct impact on flooding, shoreline dynamics, erosion and public domain extend of vulnerable areas such as the Ebro Delta. In such case if coastal population keep growing, vulnerability and therefore risk at flooding of these areas will increase inevitably. A significant number of buildings and infrastructures gathered on coastal areas may suffer damages being exposed to increased mean-sea-level and enhanced wave storm. Moreover, touristic shores of the study area might undergo a re-shaping process to reach a new equilibrium state with new wave conditions.

On the other hand, air and water temperatures and precipitation events have direct impacts on human health, energy demand, biodiversity, water quality and freshwater resources between others. But these factors can also have indirect consequences for human systems and their economy; while punctual positive aspects arise such as the lengthening of the tourist season due to warmer temperatures, other negative factors may decline future situation. However, all of those indicate a progressively more pressurised coastal zone whose compatibility with present day conditions is becoming a challenge.

A brief introduction of impacts generated by climate change has been presented here. 9 impacts can be developed in order to amplify the knowledge on the topic and afterwards propose adaption and mitigation actions to decrease negative impacts on the study area. This chapter is based on the information generated in this work on the study area; likewise than previous section and with the same purposes, following information is structured in three subsections: What is it?, What does this show? and Why is this important?.

45
5.3.-PHYSIC IMPACTS

5.3.1.- COASTAL BIODIVERSITY

- **What is it?**

Biodiversity is the degree of variation of life forms within a given ecosystem, and is also a measure of ecosystem health, with greater biodiversity implying greater health. There is substantial observational and experimental evidence that the first biological effects of climate change have occurred in recent decades in the coastal ecosystems of the Gulf of Valencia and Catalonia. Present climate patterns have been showing increasingly less resemblance to past seasonal patterns, with tangible effects on both humans and the natural environment. Drought, forest fires and invasive alien species (observed in the figure 24) have caused serious damage to some of the study area most vulnerable ecosystems.

![Jellyfish at the beaches of the Gulf of Valencia](http://www.elpais.com, 30/10/2010)

- **What does this show?**

Observational and experimental evidence is now available with regard to the first biological effects of climate change in Catalonia and the Gulf of Valencia. According to Mösso et. al. 2011 these phonological changes due to earlier spring temperatures and later winter temperatures may result in:

- Plants are flowering and fruiting earlier.
- Advanced insect emergence due to acceleration in larvae stages in response to warming.
- Desynchronized species interactions have also been observed between, a) plants and pollinators; b) plants and herbivores; and c) birds and food.
• An increase of tropical species of algae, invertebrates and vertebrates, favouring more thermophile species in contrast to those which are more characteristic of temperate seas. Invasive marine species have become established in coastal waters.

• Also according to the Second Report on Climate Change in Catalonia released in 2012 forecasts the following changes:
  
  • The growing season has lengthened by four days per decade over the past fifty years. This has important implications for biodiversity and the environment, e.g., some species have shifted to higher latitudes and altitudes. In severe cases, some populations are now threatened, mostly due to the synergy between the stress caused by climate change, which makes their habitats unsuitable, and the modification of their habitats due to changes in land use.

  • Land fragmentation also impedes the migration of certain species to habitats that would otherwise provide better conditions for their survival. In addition, in recent decades, while vegetation has made more efficient use of available water, given the enduring drought, the new conditions have resulted in increasing defoliation and reduced vegetative growth of many species of trees.

  • A decrease in the ability of the Mediterranean to capture atmospheric CO2 as a result of previous changes and the diminution of the solubility of this gas with higher temperatures in the sea water.

  • Heightened growth of phytoplankton and smaller herbivores as a result of the lengthening of the period of water stratification, and gelatinous carnivores such as jellyfish. Increased water temperature will favour their reproduction in the same way that the lack of rainfall increases the likelihood of their being pushed towards the coast by sea breezes.

• Why is it relevant?

There is some evidence that the Spanish Mediterranean coast is progressively becoming more tropical as a consequence of climate change. There is a growing number of invasive species, mostly coming from warmer seas (e.g., through the Suez Channel).

In Cullera Bay, 40 km south of the City of Valencia, an important change in the trophic chain in the coastal waters has been reported, leading to algal blooms in spring and summer (bioindicator of eutrophic waters) which have displaced the former population of Posidonia oceanica (bioindicator of oligotrophic waters). Until recently, data on the
biodiversity response to climate change are scarce. However, it is likely that temperature warming influences the distribution of marine species, demography and gender distribution, food webs, and could lead to disease and toxic blooms.

5.3.2. SHORELINE RETREAT / COASTAL EROSION

- **What is it?**

The shoreline position is a very sensitive indicator of the available sediment budget and coastal processes such as sea level and energy dissipation rates. The natural migration of the shoreline is seasonal and erosion mainly occurs in seasons when storms that generate erosional wave regimes and higher water levels are more frequent. The degree of erosion that occurs within a particular erosional phase can be highly variable, and is related to the magnitude and frequency of coastal storms. Figure 25 shows the erosion trend occurring in the Catalan Coastline.

![Figure 25.-Beach erosion and shoreline retreat at the Ebro Delta after a storm event. (Source: EUROSION Database).](image)

**EUROSION Database:** An European initiative for sustainable coastal erosion management; as part of its objectives, EUROSION has produced a GIS database at scale 1:100,000 meant to provide baseline information on the different factors influencing coastal erosion processes and the value of assets at risk.

Box 3.-General overall of the EUROVISION Database (Source: [http://www.eurosion.org/](http://www.eurosion.org/)).
• **What does this show?**

Shoreline position is a direct response to climate-driving mechanisms, mainly sea level and wave storminess. Global low-frequency sea-level trends are dominated by the steric component and associated ocean volume increase (Levitus et al., 2000; Calafat and Gomis, 2009). Within recent decades, the NW Mediterranean has experienced some of the most severe storm events ever recorded in the area (Sánchez-Arcilla et al. 2008a). According to the EURSION database (Figure 25), 33% of the Catalan Coast experiences erosion, while only 3% experiences accretion.

Figure 26 shows an estimation of the future coastal erosion rate (in average) based on a simplified version of the Bruun’s rule for cases with subsidence (Ebro Delta) and no subsidence (central part of the Gulf of Valencia).

![Figure 26.- Shore-line erosion rates in horizontal meters, due to SLR (left) and SLR + storm effects (right) for the last century (Recent Past), Present conditions (Present) and by the year 2100 (Near Future)](source: Sánchez-Arcilla et al., 2011).

It should be explicitly stated that the actual response will vary from beach to beach, depending on sediment and profile features and the availability of space for the required beach erosion (Sánchez-Arcilla et al., 2010). Because of these numbers, expressed in horizontal meters of erosion, should be considered as rough estimates to illustrate the variability across the coasts of the Gulf of Valencia. Regarding wave energy, there appears to be a slight increase in the amount of wave energy in spring and summer, probably due to an increase of the temperature gradient between land and sea.

Relative sea-level rise increases the likelihood of storm surges, enforces landward intrusion of salt water and endangers coastal ecosystems and wetlands. Any change in wave / storm characteristics will play a critical role in determining coastal impacts, since the present shoreline configuration is in dynamic equilibrium with present meteo-
oceanographic characteristics, reflecting sediment availability, climate (including extremes), coastal infrastructure, and mean-sea level (Mösso et. al., 2011).

- **Why is it relevant?**

Even if storm frequency and intensity do not change due to global warming, the return period of extreme water levels induced by storm surges at the coast will be shortened due to relative sea-level rise (Sánchez-Arcilla et al., 2008b). This will eventually lead to a higher frequency of flooding events in coastal low-lying areas. Incident waves with larger average heights will result in stronger coastal currents, which will eventually lead to enhanced coastal sediment transport and erosion rates.

According to the Catalan Government, the beaches in Tarragona province are losing 3 million m³ of sand per year, from which 82% corresponds to the Ebro Delta. The combined erosion for the year 2100 is, therefore, around 70 m for the most favourable cases of the Spanish NW Mediterranean Coast where there is no subsidence, while it goes up to 95 m or even 110 m for subsiding areas (Ebro Delta). This illustrates the high vulnerability of many of the beaches located in the gulf of Valencia which, for the urban beaches, seldom have widths in excess of 100 metres (Sánchez-Arcilla et al., 2011).

An increased frequency of moderate storms also contributes to coastal erosion because the coast has insufficient recovery time between successive storm events. Shoreline retreat results in land loss of territory and is a threat to coastal infrastructure. The existing margin (buffer) for natural coastal processes is determined by shoreline retreat and the available sediment in the coastal fringe.

The changes in seasonal patterns of wave height and direction can influence the future coastal management and harbour operability, since the pressure on the beaches is strongly seasonal, being highest in spring and summer, and the wave direction is rolling towards the south, which will largely affect the sheltering performance of ports in its current configuration.
5.3.3.- SALT-WATER INTRUSION

What is it?

Salt-water intrusion is the influx of sea water into an area of coastline that is not normally exposed to high levels of salinity. This includes the inflow of seawater into a freshwater wetland / aquifer common around estuaries and low-lying areas. Salt-water intrusion can be measured either in length of the intruding salt-wedge through the river basin or phreatic (below the water table) water level. Figure 27 shows seawater intrusion in the Ebro River.

![Figure 27.- Salt-wedge intrusion time (percentage) for sections of the Ebro River (01-01-99 to 29-02-00) calculated for different river flow regimes (provided by the Confederación Hidrográfica del Ebro) and sea level (measured at the Ebro Delta). (Source: Mösso et al., 2011).](image)

What does this show?

Saline intrusion occurs in response to a number of natural processes (storms or flooding) or human action (such as dredging for navigation). As sea level rises, saline water overcomes natural barriers to encroach into low-lying areas previously dominated by freshwater. Rising sea levels can also force seawater into coastal freshwater aquifers.

While impacts may not be apparent at the surface it can affect groundwater seeping into estuaries and groundwater abstracted for human use (drinking water, agriculture etc). The two main rivers of the Gulf of Valencia (Júcar and Ebro) are highly regulated, making it difficult to relate river flow to climate change. However, the demand for stored water has increased due to severe drought in the last two decades, leading to less fresh water flow into the sea. The water of the last 3 km of the Júcar River is 99% marine water, while almost 50% of the time, a salt wedge is observed in the last 20 km of the Ebro Delta (Mösso et. al., 2011).
The estuarine environment of the Ebro River is typically 32 km long, and has a mean depth of 6.8 m and mean width of 237 m. Only one mouth is currently open, but under high flows, an extra mouth (Migjorn) can remain temporarily open. The low tidal range causes the existence of a salt wedge estuary, with a maximum saline intrusion of 32 km. Its hydrological dynamics is mainly controlled by the river discharge. The mean annual river flow is, approximately, the critical flow that determines the formation and the breaking up of the salt wedge.

The topography of the estuarine bed is also important for the advance and retreat of the salt wedge. There are several steady positions determined by shallow reaches in the estuary. When the river discharge is between 300 and 400 m$^3$/s the salt wedge can occupy the last 5 km of the estuary, but with discharges lower than 300 m$^3$/s the salt wedge advances quickly until a shallow sill at Gracia Island (18 km from the mouth). The salt wedge remains in this position until the river discharge is less than 100 m$^3$/s, and then it advances quickly to its maximum extent (a shallow sill 32 km from the mouth) (Ibàñez et al., 1997).

- **Why is this important?**

A potential impact of climate change is an increase in the variability and intensity of severe storms. Higher magnitude storms produce larger storm surges and combined with sea-level rise can result in much higher rates of coastal erosion and consequently saline intrusion. In Mediterranean estuaries, a reduction in river discharge (during drought) enhances marine water intrusion within the estuarine basin (Sierra et al., 2004). For example, marine species captured at Amposta, 42 km from the river mouth, signals a shift from riverine to marine conditions in the Ebro Basin.

Salt-water intrusion has wide-reaching direct and indirect impacts on socio-economic systems, including a loss of freshwater resources for agriculture and forestry, fisheries and aquaculture, biodiversity, and human settlement.

The salinization of the Ebro River and the saline contamination of phreatic water increases fresh water use for rice farming, which is the main economic activity in the area. Potential water diversion schemes would further enhance salinization problems in the region (Mösso et al., 2011).
5.3.4.- WATER QUALITY DEGRADATION

• What is it?

Water quality relates to the composition (chemical, biological and physical) of water as affected by natural processes and human activities. Measured constituent concentrations are commonly compared to water quality standards.

Recreational, fisheries and aquaculture uses of coastal waters for human activities can degrade water quality. This deterioration is indicated by a decrease in the dissolved oxygen concentration, which is induced by both changes in nutrient and pollutant inputs/cycling of the already polluted rivers of the study area and warming of coastal water bodies. Coastal water quality is strongly related to climate dynamics in terms of precipitation and dissolved oxygen in the water column. Precipitation affects water quality, determining the concentration of pollutants coming from river discharges or from the distributed continental run-off. Higher precipitation rates produce a higher dilution and therefore should improve water quality although the amount of discharged pollutants may also become larger. Figure 28 shows polluted waters at the Gulf of Valencia (plume).

![Figure 28.-Foam delimiting the Júcar river plume in waters with increased phytoplankton biomass in the Gulf of Valencia (Source: Mósso et al., 2011).](image)

• What does this show?

The role of oxygen in the water column accounts for more than 25% of the biochemical factors determining the water quality. Dissolved oxygen (DO) depletion in coastal and estuarine waters increases the incidence of anoxic (depleted of dissolved oxygen) and hypoxic (low oxygen conditions) events. Severe DO depletion in the coastal zone is usually associated with two of the strongest characteristics of the study area:
- Density stratification of coastal waters, characterised by low levels of tidal mixing and subject to elevated nutrient loads (e.g., the coasts of the Ebro Delta in Catalonia or Cullera Bay in Valencia).
- Temperature stratification resulting from solar warming of surface waters (Sánchez-Arcilla et al., 2010), restricting vertical mixing and therefore the replenishment of bottom water with oxygen derived from the atmosphere.

Future precipitation trends based on observational and numerical predictions are not very clear; however, water quality is expected to change affected by precipitation pattern (Figure 29). More pulsed river discharges and greater torrential precipitations concentrated in time may increase the amount of pollutants released on the coastal water bodies.

In terms of temperature, both air and sea surface temperatures follow a clear upward trend for the annual mean. Since water quality is also related to temperature by means of the level of dissolved oxygen, those predictions will probably lead to a reduction in dissolved oxygen and therefore in water quality.

![Gulf of Valencia WQ related to climate change](image)

*Figure 29.* Water quality decrease (in terms of dissolved oxygen) due to the increase of water temperature (Source: Sánchez-Arcilla et al., 2011).

### Why is this important?

The environmental problems of the chain of brackish water wetlands along the Spanish Mediterranean Coast are described in detail in many publications (Sierra et al., 2004; Mösso et al., 2008). These range from anoxia events in the estuarine salt wedge and brackish water wetlands (e.g., the Valencia Albufera) to toxicity, habitat loss or even in the worst case to species extinction.
Most water quality degradation problems occur close to the larger cities of the Catalan Coast and the Gulf of Valencia in summer seasons and are mainly due to the great amount of pollutants discharged and warming water that control hydrological characteristics (e.g., stratification) of the water column, the solubility of certain substances (mainly, DO) and primary production (related to nutrient cycling) (Mösso et al., 2011). Key socioeconomic sectors where water quality has a strong direct impact are fisheries and aquaculture, human health, recreation and tourism, and biodiversity. Other indicators of coastal water quality include the content of chlorophyll a (eutrophication) and CO2 (pH).

It is possible to concluded that the combination of several factors such as the increment of sea surface temperature, possible decrease in average precipitation in hot seasons, more concentration of torrential events, low levels of tidal mixing and a high amount of nutrients / pollutants discharged into coastal water bodies will probably lead to lower values of dissolved oxygen in the study area, and therefore to a degradation of water quality and ecosystem conditions.

5.4.-SOCIO-ECONOMIC IMPACTS

5.4.1.- EXTENT OF THE MARITIME-TERRESTRIAL PUBLIC DOMAIN

• What is it?
Spain has about 7880 km of coastline which has been increasingly impacted and degraded by a massive inflow of population to the coast as it can be observed in figures 30 and 31. Much of the Spanish coast is urbanized or plans to be developed, particularly along the Mediterranean coastline. According to Levitus, 2000 the maritime-terrestrial public domain (MTPD), or coastal common land, is defined as, the area of land between the lowest equinoctial spring tide level, and maximum known level reached either by storm waves, or the highest equinoctial spring tide level. This zone extends along river banks to the point at which tides are observed. The definition presented here is not rigid, but varies according to maritime parameters that are very sensitive to climate change.

• What does this show?
The MTPD is suffering a two-pronged attack. On one side it is being adversely affected by pressures arising from population growth in the coastal strip (Figures 30 and 31),
and on the other side through shoreline retreat induced by regulation of rivers (reducing sediment inputs), changes in sea level, and increases in the frequency and magnitude of storm events. Thus, during the period 2004-2006, there were several adjustments in the delimitation of this area, giving priority to those coastal stretches under higher urban pressure. Process in which several unpopular actions such as expropriation and demolition of urban infrastructure were carried out during the last few decades. Particularly, in Spain there were 61 demolitions in this time period, 23 of which took place in the Gulf of Valencia (Mósso et al., 2011).

Figure 30.-Oversaturation of urban infrastructure, invading the ‘free’ common coastal space at Oropesa del Mar (Source: Mósso et al., 2011).

Figure 31.-Evolution of the coastal urbanised area at Oropesa del Mar, Castellón over the last decades (Source: http://sociedad.elpais.com)
Why is this important?

The Spanish Ministry of Environment is responsible for preserving the integrity of the MTPD when regional and urban development plans are not in line with the Spanish strategy for coastal sustainability. This also applies to plans that are vulnerable to climate change impacts and other coastal processes.

The problem appears when each government adapt the law according to their ideas or interests. A good example is the new Spanish Coastal Law released the 9th of May 2013 which reverse the previous and established aim of gradually release stretches of the coast into the public domain. However, future sea level rise and shoreline retreat will force a review of the status of dozens of buildings that are occupying the beachfront.

5.4.2.- TOURISM

What is it?

The Mediterranean is one of the main tourist destinations in the world. Due to its weather, in Spain tourism activity peaks in summer, coinciding with the time when natural freshwater availability reaches the lowest level. Figure ¡Error! No se encuentra el origen de la referencia. shows a very crowded beach in Barcelona. Freswater needs of the highly populated urban coastal areas and ever-increasing number of tourists is met principally by storing water in dams and extracting groundwater. This is one of the reasons why Spain has the highest number of dams per capita in the world and several water transfers.

Figure 32.-Crowded Beach at Barcelona (Source: http://mdqtravellers.blogspot.com/)
• What does this show?

‘Good’ weather conditions, especially along the Mediterranean coast, are a decisive factor influencing tourist destination choice. According to the Tourism Highlight Report of the World Tourism Organization (WTO), 2012 edition, Spain is still the second largest earner worldwide and the first in Europe (60 billion USD) in international tourism receipts, while ranking fourth in the world by arrivals with 57 million of visitors.

However, tourism not only improves the economy of the country but also makes a major contribution to the degradation and destruction of water ecosystems as rivers are being fragmented, groundwater levels are falling and wetlands are drying out. Lower groundwater levels are not only causing habitats to disappear but are having a negative impact on human communities as the groundwater used for drinking water and irrigation is becoming saltier.

• Why is this important?

Climate change impacts could affect choice of tourism destinations, and may lead to changes in the already highly fragile Mediterranean ecosystems. Water shortages, which could become more frequent, will cause problems in functionality or viability of certain resorts.

A good example of this, that can be mentioned, is the urban project approved by the Cullera City Council in 2007 (figure ), which includes the construction of 33 skyscrapers, one port, one golf course and a sport navy. All of these infrastructures are projected to be built near the Júcar estuary, despite the Confederation of the River Júcar Basin has already advised the existing impossibility of supplying freshwater to a larger population which almost would double current population.

Sea level rise will threaten the current location of some settlements and tourist infrastructure, like in the Valencian Albufera and Ebro Delta respectively. These impacts will have worse repercussions on the most impacted areas, those with major imbalances between supply-demand and subject to a greater combination of different climate effects. The most vulnerable areas to climate change are located in the highly developed coastal fringe comprising the main Spanish tourist product (sun and beach) but are also located in mountain ski resorts.
5.4.3.- INSURANCE SECTOR

• **What is it?**

Detection of climate change impacts in the Spanish insurance sector focuses on the study of property damage related to extreme climate events such as flood, storms, frost, hail and drought. Other areas, such as health, personal accident or transport, do not reveal such sensitivity to climate.

• **What does this show?**

The economic losses with the most significant impact on the insurance sector in the last four decades are due mainly to extreme flooding events and cyclonic wind storms. According to the Insurance Compensation Consortium, from 1971 to 2011, flooding and atypical cyclonic storms represent 80% of the total compensations paid for property damage, in terms of net economic impact. The remaining 20% is due to other major issues such as earthquakes, terrorism, and population tumult.

• **Why is this important?**

Data from the major reinsurers, insurance institutions and Insurance Compensation Consortium in Spain indicate that in recent years, global claims related to weather events (including extreme events) have increased. However, the available statistical
data for Spain cover 30 years at most, which is too short a series to determine whether (and to what extent) it is possible to attribute this increase in claims to climate change. Moreover, the available data are for Spain as a whole, and there is no specific information for the study area.

Figure 34.-Percentage of total compensations classified by cause of damage in Spain, 1971-2011. Others include Earthquakes, Landing of Celestial Bodies, Mutiny, Population Tumult and Armed Forces Actions. Data provided by the Insurance Compensation Consortium of the Spanish Ministry of the Economy and Finance (Source: www.consorseguros.es)

5.4.4.- HUMAN HEALTH

- **What is it?**

  Typically, mortality has been considered as an indicator of population health and age distribution. Various studies in different countries suggest that there is a seasonal behaviour of daily mortality as a function of diverse environmental variables, especially temperature (Sánchez-Arcilla et al., 2010). Interactions between climate and human health are varied and complex and most of them are due to:

  - Changes in morbidity and mortality in relation to temperature.
- Health effects related to extreme weather events such as floods, storms, hurricanes, and precipitation extremes.
- Increased air pollution and associated health effects.
- Indirect climate impacts on water-borne, food-borne and vector-borne diseases.

Typically, mortality has been considered as an indicator of population health. Various studies in different countries indicate seasonal behaviour of daily mortality as a function of diverse environmental variables, especially temperature. According to Basagaña et al. (2011), after investigating the association between the occurrences of extremely hot days (days with maximum temperature above the 95th percentile) and mortality, the following conclusions were observed.

On the basis of the number of deaths occurred in Catalonia during warm seasons between 1983 and 2006 (503,389 deaths), numbers pointed out that exists larger mortality risk in elderly population, with increasingly higher risks as age above 60 years increase. Regarding infant mortality, girls seemed to be more susceptible to the heat effects after birth than boys; moreover, extreme heat can have deleterious effect on the health of people who are already sick. Investigators found that 1.6% of all deaths in warm seasons could be attributed to heat, which means that 40% of these deaths did not occur during the usual definition of heat wave (period of at least 3 consecutive hot days).

Therefore if plans to prevent consequences of extreme temperatures are just activated when a weather forecast predicts a series of consecutive days above certain temperatures there is a percentage of population belonging to risk groups that are not sufficiently protected.

•  **What does this show?**

Despite a degree of adaptation, extreme low temperatures affect the circulatory and respiratory system, while extreme high temperatures can lead to heat stress and sudden death, mainly in older populations. The two hottest summers in Catalonia were recorded in 1995 and 2003. These summers were characterised by an unprecedented number of tropical nights with minimum temperatures at or above 20°C. Several recent studies in the Iberian Peninsula show the existence of a maximum daily temperature threshold from which there is a sharp rise in mortality.
According to García-Herrera et al. (2005), the maximum daily temperature that triggers mortality in Barcelona and Valencia are 30.3°C and 33.3°C respectively (Figure 35). High temperature can also lead to photochemical pollution induced by chemical reactions of hydrocarbons and nitrogen oxides, and producing significant amounts of ozone.

![Figure 35.-Mortality temperature thresholds (Source: García-Herrera et al., 2005) for the study area](image)

Projections presented in this thesis, indicate that the available models show an increase of the mean temperature at a rapid rate. However, it may be more noticeable for the Tx95 indicator (very hot summer days), which, will increase around 1.5 °C within the gulf of Valencia. This indicator also show that its value is higher (for the past climate period) at the southern part of the Gulf of Valencia (Figure 36). However, the main temperature increase, in terms of the number very hot days (T>Tx95) per year, will be at the northern part of the gulf of Valencia, with an average increase of around 64 % (Sánchez-Arcilla et al., 2011).
Vulnerability of Biogeophysical and Socio-Economic Systems on the Catalan Coast and Gulf of Valencia due to Climate change

• Why is this important?

Human health is very sensitive to climate. There is a clear relationship between temperature and morbidity and mortality which is exacerbated in cases of extreme heat or cold (when maximum temperature is above the 95th percentile or below the 5th percentile value).

A significant proportion of the Spanish population is in (or close to) the elderly age, and thus very vulnerable to high temperatures. According to the Spanish Ministry of Health the official number of deaths in 2003 was 141, while the National Centre for Epidemiology stated that the number of deaths attributable to heat was 6,500 persons. There are other circumstances in which health may be affected by climate change. An increase in the number of very hot days may increase these numbers.

Furthermore the region is a stopping place for migratory birds and people from countries where vector-borne disease is endemic. Climate change could heighten the risk of vector-borne disease. An increasing trend scenario of rainfall may increase the number and viability of vector breeding sites, and produces a higher density of...
vegetation for ecosystem habitat (such as the tiger mosquito in the northern part of the Gulf of Valencia) and more food for rodent hosts.

5.4.5.- ENERGY DEMAND

**What is it?**

The energy sector is a strategic sector, since almost all other economic sectors are dependent on energy. Spain has a huge “international energy” dependency, mainly on petroleum, derived products and natural gas, and less dependency on hydropower and other renewable forms of energy. According to Energy in Spain (2011) published by the Industry, Energy and Tourism Ministry of Spain, the energy dependency of the country has a downward trend (Figure 37). It may be due to the energetic consumption has been slightly reduced, and the production capacity of renewable (wind, solar and geothermal) energies has been strongly amplified, however economic crisis is also linked with this consume reduction.

Historically, Spain has had one of the lowest levels of primary energy-use intensity in Europe, and a lower consumption per capita. In recent years, the biggest increases in electricity demand have occurred in the central, southern and Mediterranean areas, and this trend is expected to continue in the coming years.

According to the Country Analysis Note conducted by the Energy Information Administration (EIA) in 2013, Spain is currently the fifth largest energy consumer in Europe and has virtually no domestic production of liquid fuels or natural gas. As it can be observed in the Figure 38, liquid fuels are still the largest source of Spain's total energy consumption, mostly in the transportation sector. However a positive aspect is the production of energy from renewable energy sources. Particularly Spain generates a significant amount of power from wind energy, in fact is the second country with the greatest production in Europe behind Germany.

Some other interesting data from about the evolution of Spain in terms of the Energetic sector are (http://www.eia.gov/countries):

- Government regulation limits the percentage of total oil and gas imports any single country may sell to Spain to ensure diversity of supply.
The Spanish government authorized offshore electricity generating facilities in 2007 to promote the development of offshore wind energy. However, the current government's renewables reform (2013) and cuts to wind power sales may suppose a significant step backwards for the evolution of wind power generation in Spain, its energy dependency and the worldwide position as one of the leader countries within this sector.

Up until the 2008 financial crisis, Spain was one of the fastest-growing natural gas markets in Europe. Although growth has slowed since then, Spain was the third-largest importer of liquefied natural gas (LNG) in the world after Japan and South Korea in 2011, according to PFC Energy.

The country has nine refineries with a total crude oil refining capacity of almost 1.3 million barrels per day, according to the Oil & Gas Journal. However, Spain is still a net importer of petroleum products.

Spain has six active LNG regasification terminals to process imports, with a seventh scheduled to come on line in 2013. Spain also receives significant natural gas supplies from Algeria through the undersea Maghreb-Europe Gas Pipeline, which came on line in 2011 after a number of delays.

Up until the 2008 recession, Spain was slowly phasing out its coal production subsidies. However, coal production and consumption increased in 2011 after the Spanish government introduced domestic coal production subsidies and gave preferential access to the wholesale power market to coal-powered generators. This has caused electricity producers to substitute away from renewables to coal.

There are eight operating nuclear reactors in Spain, which supplied about 20 percentage of the country's electricity generation in 2011.
Total Energy Consumption in 2011

Figure 37.-Evolution of the Energy Dependency in Spain.
(Source: Ministry of Industry, Energy and Tourism of Spain).

Figure 38.-Final energy consumption in Spain 2011
(Source: Ministry of Industry, Energy and Tourism of Spain).

- What does this show?

Energy generation and consumption in Spain depends on a wide range of factors of different nature. Non-climatic factors such as the increase in the Gross Domestic Product (GDP) may contribute to it. However, it is clear that the projected air temperature increase, which affects the human health and comfort, is directly related to energy demand. In Spain, 18°C is considered a comfort temperature threshold (López Zafra et al., 2005), and the temperature at which energy demand is lowest. As
temperature increases above this value, energy consumption starts to rise. Average electricity demand is very sensitive to variations of ± 1°C either in summer and winter (Mösso et al., 2011).

In order to preserve the comfort during very hot days, the use of energy for air conditioning increases significantly, and in recent years, the biggest increases in electricity demand have occurred in the central, southern and Mediterranean areas of Spain, and this trend is expected to continue in the coming years due to the increase of the environmental temperature. Figure 39 shows a prediction of the energy consumption in Spain based on data of the period from 1980 to 2010; as it can be seen, the projection presents a clear upward trend for the near future.

Figure 39.- The extrapolated energy consumption (Billion Kilowatt-hours per year) by the end of 2050 (Source: Sánchez-Arcilla et al., 2011).

- **Why is this important?**

The energy sector is a key contributor to climate change but it is also one of the most sensitive to it. There is a direct relationship between air temperature and natural gas consumption (in winter) and electricity (throughout the year). Thus, warmer winters lower consumption of both natural gas and electricity, while warmer summers lead to increases in electricity demand for cooling purposes.

A decreasing trend scenario of long-term decline in rainfall and increase water temperature will affect the structure of hydropower supply, as well as nuclear power plants requiring cooling water. For these reasons total energy supply and demand are sensitive indicators of climate change.
5.5.-ADDITIONAL PRESSURES

5.5.1.- POPULATION GROWTH

The Spanish Mediterranean coastal zone is an important area for human habitation. Almost 25% of the Spanish population is currently concentrated in five large urban areas (Barcelona, Tarragona, Castellón, Valencia and Alicante), whereof the first four are within the study area. Figure 40 shows immigration phenomenon to coastal areas and reflects population preferences for Mediterranean climate.

![Figure 40.-Benidorm as it was in (left) 1960 and (right) 2007 (source:www.guardian.co.uk, 2009 01.25).](image)

Population grows at a faster rate along the Spanish coastal zone, relative to the national average (Serrano, 2003). This phenomenon has become more evident during the latter half of the last century and current data confirms this trend. Figure 41 ratify the trend and moreover shows how the greatest density of the Spanish population is concentrated on the study area of this thesis.

The coincidence of a series of favourable characteristics, such as, mild temperatures, attractive landscape (mountain, beaches, sea) combined with enhanced economic productivity (agriculture, industrialization and increased provision of goods and services)are common attractiveness that have favoured population growth and economic development.

During the last century, life expectancy in Spain has increased from 69 years in 1960, to 82 years in 2012, and the mean age of the Mediterranean population is younger than that of Spain. Consequently, the pressure on the coast exerted by continuing population growth in the next few decades will likely be extreme. Remedial action is required to alleviate the stresses of high population density on natural resources and
the environment. The quality of life in these areas will largely depend on physical planning policies and their application. Population growth in the region has the potential to further increase vulnerability to climate change.

5.5.2.- LACK OF SPACE

It is a fact that the study area contains some of the settlements with highest population density within the country. The great urban growth experimented by coastal areas during last decades, has led to a significant concentration of infrastructures. Big residential and recreational areas were projected and constructed along the shoreline, everything needed to meet development objectives.

Therefore the progressive adaptation of the coastal areas to the development of tourism, energy industry (gas and petroleum supply) and maritime trade overshadowed traditional activities such as fishery and agriculture. This trend of massive use of coastal spaces has generated environmental, social and economic disequilibrium, which should be identified to reach a new future orientation according to sustainability principles.
Factors such as the lack of integrated knowledge and management coordination of coastal areas along with the priority of certain interests have also facilitated this trend. It can be said that nowadays, migration to inner areas from much crowded coastal zones is complicate and almost impossible in the study area.

5.5.3.- LAND USE CHANGES

The environmental crisis of the Ebro Delta started in the 60’s, when the mechanization and the chemical agriculture arrived and they strongly increased the impact of human activities on the environment. Formerly, the percentage of urbanized soil has increased substantially along the study area. The soil capability of infiltration is inversely proportional to the percentage of urban soil, being therefore seriously reduced. The result is an increment of the flood vulnerable area and therefore an increase of flood risk for population and properties.

Catalan and Valencian Coasts are two of the most pressured Spanish coasts. Particularly, next figure 42 shows the increasing urban trend that Catalan Coast has underwent for the period between 1987 and 2002.

![Urban Surface Evolution in the Catalan Litoral](image)

*Figure 42.-Urban Area Evolution in the Catalan coast from 1987 to 2002 (Source: Environmental Department of the Catalan Government, Generalitat de Catalunya).*
As it can be observed, the graph displays a clear increment of the total urban surface covered during last decades. The trend line for the stretch of 1km wide has a higher slope caused by the greater development along the first line of the beach.

5.5.4.- FINANCIAL CRISIS

The role played by the Spanish Government and the emphasis applied to different kind of policies are key issues for the region development. According to some actuations, it is seemed than in general for the current government, ecology is less important than economic growth. In 2013, political decisions such as the modification of the Spanish Coastal Law, fishery politics benefiting industrial and destructive fleets, increment of taxes to renewable energies and indifference towards climate change, indicate the approach followed by the public administrations as a step backward in the defence of the environment. The closure of the Santa María de Garoña nuclear power station (cooling from the Ebro water) has been the only pro-environment measure taken by the government within the last period of mandate (http://www.europapress.es/).

As it has been mentioned before, the new coastal law extends the privatization of the Spanish Coast for 75 years more, which leads to enhance ecosystem vulnerability, omitting climate change hazards.

In conclusion, the reduction of the environment economic budget will probably difficult the application of adaptation and mitigation measures to climate change in the study area. The challenge now is to find opportunities in economic development that also can ameliorate the ecologic development of the region.
6. ADAPTATION AND MITIGATION MEASURES

With accordance to the IPCC adaptation is the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. Three different types of adaptation (anticipatory, autonomous and planned adaptation) can be distinguished; particularly, the third one will be developed in this section, it can be understood as the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and planned adaptation actions are required to return, to maintain or achieve a desired state.

However, mitigation measures are taken to permanently eliminate or reduce the long-term risk and hazards of climate change to human life and property. The IPCC defines mitigation as “an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases.

In order to design these actions, on basis of projections and impacts on systems it is possible to list main biogeophysical and social vulnerabilities of the study area. Then stakeholders’ relationship and governance are described, as well as some important features of the Ebro Delta (particular area within the coast) to finally conclude with a proposed group of adaptive and mitigative actions.

Vulnerabilities of the study area

Vulnerability is the degree to which a system is susceptible to adverse effects of climate change (including variability and extremes), and unable to cope with those. Several factors influence and determine vulnerability; such are character, magnitude and rate of climate change and variation to which the system is exposed, system sensitivity and its adaptive capacity.

Two classes have been presented in relation with the nature of the system analysed; Biogeophysical and social vulnerabilities. Within those, areas of actuation wherein is needed to handle with threats suffered by sectors and systems are listed herein.
Biogeophysical Vulnerabilities

- Coastal
  - Area of land used as coastal buffer
  - Coastal outflow of freshwater - nutrient load/fluxes

- Marine Ecosystems and fisheries
  - Marine pollution – water quality
  - Fish stocks
  - Coastal outflow of freshwater – nutrient load/fluxes

- Freshwater resources
  - Freshwater quality – nutrient load
  - Salinization of freshwater aquifers vulnerable to inundation - salt-wedges
  - Runoff – river discharge
  - Abstraction: surface and groundwater sources

- Agriculture
  - Soil quality – erosion
  - Water availability
  - Salinization – inundation – (related to shoreline retreat)
  - Area of arable land

- Tourism
  - Coastal environment (coastal erosion – shoreline retreat – inundation – pollution)
  - Change of favourable/unfavourable weather conditions in summer (excessive warming and seasonal shift)

- Health and Wellbeing
  - Air pollution

- Urban infrastructure (including energy)
  - Coastal erosion – shoreline retreat
  - Inundation – Coastal flooding
Social Vulnerabilities

- Coastal
  - Discharges – sources of pollution
  - Population / Industry / Infrastructure / Tourism facilities location in coastal zone
  - Coastal Protection (e.g. expenditure, area protected; number of treaties)
- Marine ecosystems and fisheries
  - Density of population, industries and infrastructures located in the coastal zone
  - Coastal protection expenditure, quotas and marine protection areas.
  - Discharges and sources of pollution
- Freshwater resources
  - Total consumption by sector
  - Per capita use of freshwater
  - Water resources and environmental management (expenditure, area protected)
- Agriculture
  - % employed in agriculture
  - Contribution of agriculture to the GDP
- Tourism
  - % employed in tourism and the contribution of tourism to GDP
  - GDP per capita
- Health and Wellbeing
  - Health expenditure per capita, access to healthcare
  - Population <5 years and >65 years
- Urban Infrastructure (including energy)
  - % of urban area (industry and residential) located in flood vulnerable zone
  - Coastal protection (e.g. expenditure, area protected, number of treaties)
Stakeholders and governance

Current evolutionary stage of the integrated management within the study area can be identified as coordinated between the existing three possibilities (fragmented, coordinated and integrated). This is a classification regarding the management of an area that may help to understand key issues and try to both improve and solve them. A coordinated stage has been chosen since in the studied region there are several organizations responsible for different functions such as water supply, coastal management or legal framework among others.

It should be considered that there are:

- Two local governments: the Government of Catalonia (Generalitat de Catalunya) and the Government of Valencia (Generalitat Valenciana). These institutions have their own attributions in land use planning, infrastructures, environment, tourism and agriculture among other.

- Water management: the Catalan Government has most of the attributions in water cycle and water management on the Catalan Water Agency (Agència Catalana de l’Aigua, ACA).

- Watershed management: regarding basin management of the rivers two institutions can be remarked the Hydrographic Confederation of the River Ebro and the Hydrographic Confederation of the River Júcar. These are national institutions controlled by the Government of Spain.

- Watershed transfers between different catchments are controlled by the Environmental Ministry, which is in charge of the government of Spain.

- The central government is also in charge of the coastal management in all the public land, mostly the coastal fringe (Coastal General Directorate - Dirección General de Costas).

- The city councils are also in charge of land use planning, but always under the criteria determined by the regional government. The Natural Park of the Ebro Delta is in charge of nature conservation of the protected areas.
On basis of this information, the system can be classified as coordinated so there is no an only organization able to cope with problems of the whole and implement solutions. It seems that exist little coordination between the different administrations and between the different departments of each administration. Such governmental organizations adapt their actuations, approaches and policies to different political parties, for these reason environmental actions conducted and law established may vary in short-term periods, that is every 4 years when political elections are celebrated.

Two needs can be clearly identified. On one side the evolvement from the current coordinated evolutionary stage to an integrated stage as much as possible, since coordinated stage are acceptable while demands on system are not too great but it may become unstable (supply-demand balance) and it starts appearing problems when demand exceed supply. On the other side, lengthen perspective and design long-term environmental policies are fundamental aspects to create a consistent and stable integrated management system.

Moreover, in case of a particular area such as the Ebro Delta, the absence of an only institution for the integrated planning and management of the entire delta, is a very important issue that will probably affect the conservation of the area if no action is taken early. The only existing planning of the entire delta is the “Pla Director del Delta de l’Ebre”, which is a land use planning (mostly urban planning) elaborated by the regional government in 1995. The most recent Plan of Integral Protection of the Ebro Delta (2006) is mostly an environmental restoration plan, but not a proper management plan. On the other hand, the Natural Park is the institution responsible for doing some vertical integration of management from the local to the national level, but it is only in charge of 25% of the delta surface (the protected areas) and has no management plan for its own territory (Deltanet, http://www.deltanet-project.eu/ebro).

If they turn to analyse the Ebro Basin evolutionary stage, it is notice that this is quite similar to the one of the whole studied region; existing little coordination between administrations. However, at that range there is the Hydrologic Plan of the Ebro Basin (Plan Hidrológico de la Cuenca del Ebro) which is a water management plan of the catchment, elaborated by the basin authority (Hydrographic Confederation of the River Ebro), that was updated in 2010. It is mostly aimed at developing hydraulic infrastructures (dams, irrigation canals, water treatment plants, etc.) and controlling of water quality and uses. This plan has not included an environmental flow regime for the
lower Ebro River and delta, and this subject is a matter of conflict between the lower basin and the upper basin stakeholders and administrations.

The Ebro Delta

Regarding the Ebro Delta, it is necessary to know the main issues of the area in order to propose measures to improve its current and future situation. It is worth mentioning that the main use of the Ebro Basin is agriculture, with approximately the 90% water use in the catchment this has a clear negative contribution to the water of the Ebro River. As a result of industrialization and rapid population growth in the 19th and 20th centuries, the use of chemical products to increase field capacity production such as pesticides and fertilizers became a common and extended pattern between farmers.

On one hand the cyclic use of chemical products may lead to soil salinization, contamination of the subsoil and groundwater, but also induce to water contamination through sediment transport. On the other hand, the reduction and regulation of the river flow by the construction of several reservoirs during the 20th century affected to water quality and the pollution problem, leading to an increase eutrophication of the river water and pollution of river and coastal water bodies.

River sediment transport into the delta at the end of the 19th century was estimated to be about 30 million m$^3$/year (Ibáñez et al., 1996). At present, after the construction of about 200 dams in the basin, the solid discharge is only around 0.1 million m$^3$/year (Rovira & Ibáñez, 2007), therefore more than 99% of the sediment flow is retained in the reservoirs.

The Delta plain has a surface of 320 km$^2$, whereof around 80% has suffered changes in land use for rice field agriculture. It can be said that at present, agriculture is the main human activity of the Delta and rice fields play a crucial role in its economy and its ecology.
6.1.- ADAPTATION - MITIGATION MEASURES

Building on the knowledge gathered in this thesis, following measures aim to improve current but above all future situation of the Northeast Spanish Coast. These have been designed based on forecasted future conditions and considering changes in human systems which will probably pressure even more existing societies and infrastructures. Both actions tackling the cause of climate change (reducing CO$_2$) and coping with its consequences have been included in the following.

6.1.1.- SALINIZATION

The contamination of freshwater due to seawater intrusion into coastal aquifers (enhanced by anthropologic causes) and to the excessive use of fertilizers in agriculture are the two most important causes of groundwater contamination in Spain. According to López-Geta and Gómez-Gómez (2007), marine intrusion may happen in three different ways. Those can be: general intrusion covering the whole aquifer, zonal intrusion and local intrusion by the formation of saline cones (up-coning). Figure 43 shows marine intrusion according to those types.

![Figure 43.-Marine Intrusion Distribution in the aquifers of the study area (left) and the intrusion degree in coastal HU (right). (Source: López-Geta J. A and Gómez-Gómez J., 2007).](image)
It can be observed that along the Mediterranean littoral (which is not completely shown in this picture) a total of 95 hydrogeological units (HU) have been defined; these represent around the 25% of the total amount of units in Spain. Each hydrogeological unit may represent one or various aquifers. In terms of occupied surface by HU, the biggest one is the Júcar Basin with 5.286 km². It can be seen (right, figure 43) that, the Catalan coast has an amount of 6 HU generally contaminated by salt intrusion and within the Júcar catchment zonal intrusion predominates.

Aquifer protection and control

Before any measure is conducted, it is needed to guarantee a correct hydrogeological functioning knowledge (behaviour, contaminant processes, etc.) of aquifers as hydric source and to assess their available resources.

* It is fundamental to evaluate water extractions, also permanent monitoring aquifer water quality (through measuring electric conductivity) and piezometric level variations. To achieve it, to have a sounding network available is necessary.
* Construct risk maps showing the vulnerability of the Coast so areas suffering greater (temporal or permanent) pressure on freshwater sources.
* Publishing those maps and creating an online public platform, population awareness may be augmented and demand pattern might be slightly changed.
* On basis of these maps it may be needed to reduce, redistribute or deplete completely water extraction where drinking water sources are undergoing a high danger.
* Increment noticeable the use of recycled water (treated water) in areas with high freshwater demand and salinization problems.
* Establish legal tools to achieve a correct compliance of more strict regulations to assure future groundwater availability.

Aquifer Recovering

* Reducing the amount of pumped groundwater will probably lead to a great discharge of freshwater into the sea reducing saline intrusion. Although it is an
immediate solution there is not always chance to carry out it, since often there are no alternative sources of drinking water within the area. On the other hand, if the amount of pumped water is reduced this may be loss into the sea.

* Redistribution of existing pump stations (deep pump stations near shore) in others, extracting fewer water quantities and located in areas further from the coast. In this way the interphase landward advance (between freshwater and seawater) may be reduced without modifying the total amount of extracted freshwater (Padilla et al., 1997).

* Artificial recharge of aquifers, injecting treated water to increase water availability and decrease the advance of salt water intrusion is another option already being implemented in particular localities within the study area. It consists in creating and maintaining a ridge of freshwater near and parallel to the coast, with enough height above the sea level to reject seawater entrance (to this purpose it can be used treated urban water). A good example can be found at Sant Vicenç del Horts (locality situated in the Llobregat River Valley) where a decantation and infiltration ponds of 4.000 m² and 5.600 m² respectively were constructed to increase water availability.

6.1.2.- POLLUTION

With the application of following measures, water quality in rivers and coastal areas will probably be improved. It has to be taken into account that exist different sources of pollution and may be necessary to treat differently water contamination issues depending on its precedence.

Two types of source can be distinguished as point-source (location can be identified) and non-point source pollution (mainly diffuse agricultural source). There is great potential for agricultural management to become a major part of improved strategies for controlling runoff and pollution.

According to the Scottish Environment Protection Agency, diffuse pollution occurs when (often driven by rainfall and land use activity) sediment, nutrients, bacteria and chemicals are lost from the land to rivers, lochs and groundwater. This kind of contamination may lead to multiple negative effects, including faecal contamination of bathing waters, excess nutrients causing algal blooms in lochs and estuaries and toxic
substances affecting drinking water quality. Although water management has led to huge improvements in water quality over the last 50 years, diffuse pollution is usually one of the largest sources of pollution and a coordinated approach is needed to address it.

**Diffuse Pollution (mainly from surface runoff)**

In order to reduce diffuse pollution in coastal water bodies the following measures should be applied:

* Decrease polluted sediments coming from the River. In areas where agriculture is a significant activity it should be applied a specific strategy to reduce the amount of sediments discharged directly from crop production through surface runoff into the river. To develop a common vision for area management centred around local knowledge and understanding, it is necessary to conduct a local study, considering territory features, crop production, chemical products used, current state (drainage systems, flow connectivity) of fields, trying to reduce the gap between stakeholders and farmers and of course with the objective of reducing impact to water.

A good initiative was performed by a cluster of British universities (Newcastle University, Durham University, Lancaster University, Cumbria University and Aberystwyth University along with environmental institutions). After investigating the issue of diffusive agricultural pollution in UK and designing an action strategy, they presented a National Demonstration Test Catchment (www.edendtc.org.uk). The aim of the project is to produce evidence to test the hypothesis that it is possible to cost-effectively reduce the impact of agricultural diffuse pollution to water through the implementation of multiple on-farm measures on ecological function while maintaining food security.

Constructing buffer strips and planting native woodlands are just two of the proposed actions within the mentioned project; buffer strips not only help to trap pollutants, but also provide a valuable habitat for wildlife, contribute to landscape character and help mitigate climate change.

* Monitoring water quality at river and coastal water bodies is crucial in order to follow evolution of implemented measures.

* Promote environmental-friendly agriculture linking subsides with the efficient use of fertilisers and other chemical contaminants.
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* Increase population awareness and farmer environmental conscience. By means of farm visits and advice to farmer of nutrient management and solutions.
* Identify points of leakage in sewer installations and submarine emissaries, solve polluted water infiltration and improve maintenance programs.
* Amplify knowledge related to this objective from more advance countries where the pollution issue has already been treated achieving good standards of water quality. An example can easily be found in the Rhine River Catchment, where strict pollution normative was applied by the International Commission for the Protection of the Rhine River after the great problems of contamination that happened in this river few decades ago.
Although the evolutionary stage of the integrated river basin management of the Rhine River among riparian countries is also coordinated, the legal policies and actuations have let to reach the current situation which can be considered as a model to other countries such Spain.

**From Point Source**

Next actions aim at reducing pollutants coming from localized sources.

* Application of new technology for relevant industrial branches to achieve pollution reduction at the point source discharges.
* Permanent monitoring and control of discharged water standards at industrial submarine emissaries.
* Toughen disposal standards wherein areas with several water quality problems and exist evidence that contamination is threatening local species.
* Increase connectivity of industrial plants and households to waste water treatment to augment amount of water treated before disposal activities.
* Within the study area the most significant chemical industry is situated. For this reason, public administrations have to toughen current legislation and overall require its compliance. In case the industry sector contaminates illegally river or sea water, government will collect fine money and this money will be used to first of all solve contamination caused and then other environmental issues.
* Monitoring process and compliance of legal requirements (European Directives, National and local standards). Increment noticeable monitoring at industry point
sources; it will be necessary to create a figure responsible for the maintenance of these new control installations.

The concentration of functions in the study area (including coastal and river water bodies) such as water supply, navigation, energy generation, fisheries, recreation activities and wastewater disposal have different purposes that usually lead to conflicts between conservation and disposal activities. For example water availability may be affected by abstraction for water supply but a certain amount is needed to protect aquatic habitants and fisheries; with water quality happens the same, on one side use of rivers for potable water supply and on the other side the use of same rivers for wastewater disposal.

To minimize conflicting objectives of all stakeholders who are dependent of the finite resources by a process involving quantitative and qualitative elements is essential to ensure the correct functioning and sustainability of the study area in the near future. Quantitative elements are multi-objective or multi-criteria analysis based on data and models such as those presented by the CIRCE model, that help stakeholders to identify the best option(s) between a proposed list of future actions/measures. However, qualitative elements refer to create dialogue between all stakeholders involved in the management, leading to conflict resolution through compromise.

6.1.3.- EROSION

In coastal erosion risk management have resulted in a predominance of engineering solutions (sea defences and coastal protection) to a constantly changing dynamic system. However these actions just solve locally and temporarily erosion resulting in enhanced coastal erosion problems in other locations. In many cases, this has led to catastrophic consequences for the resilience capacity of coastlines to respond in front of environmental stresses, and to adequately perform socio-ecological function.

Low-lying areas like deltas, estuaries, coastal plains, and barrier coasts are especially vulnerable to sea-level rise and climate change generally. In the near future, it is not known how the whole coastal system might evolve in response to sea-level rise and extreme climate events, although a number of “expected shocks,” such as the total
disappearance of some renowned Mediterranean beaches, is anticipated (Mösso et al., 2011).

According to future predictions exposed in previous section 4.3, there appear to be a slight increase in the number of moderate wave storms experienced during the fall season in the Catalan region. Although the number of more energetic wave storms appears to be decreasing there is an increase in storm in duration (based on a limited set of data for the Catalan region).

The profile of beach erosion associated with wave storms depends both on intensity and duration. If, an increase in storm duration of 2 hours per decade is assumed, the corresponding increase in eroded volume is approximately 2 m$^3$/m (Sánchez-Arcilla et al., 2010). This results in an increase erosion rate of 2 m per decade, using a berm (over-bank deposit) height of between 1 and 2 metres, (since they also included part of the submerged beach profile to calculate the balance).

On average, it would then be needed to allow a coping range of 2m/decade, plus the background long-shore erosion, and the transverse erosion due to a few consecutive storms. This results in a width of between 100 and 150 m for most beaches in the area (Sánchez-Arcilla et al., 2010). The following list of measures will probably reduce erosion risk in the study area:

* Based on the requirement of 100-150 metres to guarantee future conservation of coastlines, the first measure would be to assess the current situation of the coastal study area and to elaborate a risk map to show vulnerability suffered by shoreline graphically.
* Publishing those maps population is introduced a bit more into public domain management. People may modify their behaviour to a positive way regarding beaches conservation.
* By risk and vulnerability maps, decision-making process may be facilitate and accelerated to stakeholders. Being easily detectable which areas need adaptation and mitigation measures and possible to design a list of priority actions.
* Favouring actions which lead to stabilization of beaches, dunes and sediment transport rehabilitation in areas suffering erosion. Implementing flexible and cost-efficient engineering measures to retain sand within beaches and to stop land movement.
Flexible actuations are characterized by modifying the coast without making it rigid. A general classification of flexible actions based on the material employed can be done in two main groups; the first one uses sediment as basic material, these can be artificial feeding along the shoreline, dry beach, artificial feeding over submerged beach profile, sand dykes perpendicular to the beach, etc. The second group uses other materials, being: floating breakwater or vegetation covers to fix sediment and reduce its motion. The vegetation covering can be emerged (e.g., vegetation used to promote and fix the creation of dunes) and submerged (e.g., Posidonia meadows helping to fix the submerged beach profile in the Mediterranean area).

- To assess the current state of existing coastal defences and evaluate their performance according to changing patterns explained in this paper (wave direction, height, etc). On the basis of needs detected from this study, it will be necessary to develop a strategy plan aimed at modifying structures to meet new requirements.
- Facilitating the inner migration of wetlands and marshlands, favouring retreat strategies.
- In highly vulnerable areas, it is fundamental to avoid future urban development.
- Demarcation of the MTPD according to sea-level rise and new flooded areas.
- Establishing strategies for governments for buying territory and converting it into public domain guaranteeing conservation purposes.
- Creating a new environmental law to reach separation of ecology and politics, aimed at prohibiting modifying environmental approach depending on economic interests. With this proposed tool, the updated Spanish Coastal Law of 2013 would not have been released since the new perspective (privatization of the coast) is against previous implemented approach (retreat strategies and more public territory).

6.1.4.- FRESHWATER AVAILABILITY

Several measures can be implemented in a wide range of sectors to improve freshwater consumption and guarantee as much as possible future drinking water availability. However, population behaviour is a crucial factor affecting this topic; to achieve a good performance from people, they need to know the real situation of water
sources, how their behaviour (in terms of water demand) affect to those, what are pressures may occurring in the near future and to learn what kind of improvements, changes and in short little contributions from inhabitants might benefit the region.

With the aim of improve water use in the agricultural sector, following proposals can be applied:

* Forming a group of experts in irrigation systems to advise farmers on efficient irrigation techniques, and try to design real ameliorations to adapt farm consumption to crop needs, over all when droughts occur.
* Linking subsidies to the modernization of irrigation systems could increase the amount of water saved through technology. In all cases saved water has to be reverted into ecosystems with the aim of augment water reserve.

Proposals to enhance efficiency in cities, industry and the tourism sector:

* Applying technological advances to urban irrigation systems in order to reduce water irrigation consumption of parks and green areas.
* Improve metering network in households, business, industry and others. Effectuating regular maintenance tasks it is possible to find and solve problems and illegalities in supply network; population has to be aware of how many litres are spending per day.
* Promoting saving strategies of binding compliance (by law).
* Leakage management strategy is totally needed in this region. According to the World Wildlife Foundation (WWF) although Spain has advanced considerably in this issue with an approximated current leakage average of 15%, is still far away to the 5% reached by developed countries such as Netherlands. Therefore applying the best existing technology to detect losses in water supply installations, to conduct reparations where detected and improve current maintenance of the network. The design of renewal and rehabilitation programmes will lead to a reduction of water losses in the network. This should be implemented in areas once areas with higher losses are located, in order to prioritise investment. With all those measures it will be possible to decrease the amount of lost drinking water at the same time stop changing soil configuration (since the percentage lost go into the ground) and increment future water availability.
- Charging policy (tariffs) by increasing the price of water could be used to change consumption patterns and to reduce water losses. This should be linked with better information and services by the water utilities.
- Water efficiency will probably increase after improving relationship between the water utility and the customer. Information about regular maintenance of the network, possible problems and water efficient programmes may be very useful for customers in order to improve water efficiency.
- Encouraging the use of alternative resources such as recycled water, to reduce pressure over freshwater sources. Reusing water, there will be an increase in water efficiency by reducing the amount of water needed from the main network. The use of grey water and rainwater harvesting in roofs are good examples of water that can be used for irrigation of fields, parks, green areas, cleaning parking lots, cars, etc.
- Requesting water efficient at new homes and gardening by the installation of efficient taps, toilets and dishwasher since many water utilities have programmes to reduce the volume of water used in cisterns (e.g. hippo bag which is a cistern displacement device which reduces toilet flush volumes). Another option to improve water efficiency is the appropriate use of plants in gardens that require less water.
- A fundamental point mentioned above, is the necessity to emphasize information and education on water saving in schools to bring water awareness to children, and institutions and business customers.
- Incorporating drought and scarcity factors into hydrologic plans as well as other plans (urban, rural, etc.), creating a new strategic approach about the future availability of hydric resources.
- In periods of intense rainfall, it is worth saving the excess of water which do not fit into existing reservoirs for example to meet demand requirements in high demand seasons. To this purpose, construct more dams is not an ecological measure, however constructing artificial storage areas two objectives can be met: to mitigate flooding at villages near to the rivers and store excess of water during significant rainfall allowing its posterior use. On the other hand, adaptation of existing dams, when current technical situation allows it, increasing permissible water height upstream may be necessary to carry out near in time.
6.1.5.- ENERGY CONSUMPTION

The economic crisis underwent by Spain has led to a slight decrease of greenhouse gasses emissions, reaching in 2012 a reduction of 1.9% with respect to the previous year. Factors such as the paralysation of the construction sector, sharp fall of car sales, decrease in electricity and natural gas demand as well as the increment of unemployment are partially responsible for the greenhouse gasses emission decrease. Thus, if this downward trend can be linked to the current negative economic situation, it is necessary to create energetic policies to maintain this trend when economic recovering appears.

Although during last years some management plans to deal with climate change were released by government, last energetic reforms will probably slow down the development of the renewable energy sector. Such changes affect negatively to Photovoltaic Solar Plants and to renewable sources in general due to the cancellation of economic incentives to new installations. In addition the closure of 48 railway lines (medium distance), the offer depletion in other 127 lines of about 32% and the increment of public transport fares do not facilitate the transition towards a sustainable transportation model. The following measures aim to improve current situation.

Renewable energies

* Promoting renewable energies, stopping the taxes increment established by the current government of Spain and guaranteeing enough reward to motivate development in this field.
* To promote regional projects and inner measures of greenhouse gasses emissions to all sectors.
* Augmenting future objectives (toughen them) of greenhouse gasses emissions.
* Keep improving the knowledge in alternative energy sources, such as the energy obtaining from wave power. Research is still needed to solve the main two problems of this form of energy, transportation and storage issues.
* Solve or try to improve regulatory uncertainty of the electric sector and its instability.
* Renewable energies need a stable legal framework, not subject to changes and uncertainties on rewards and normative.
* Studying new projects of renewable energy production. It may be a good chance to evaluate viability and efficiency of solar power projects; such have
been proposed to meet energy production worldwide covering big surfaces like the Sahara Desert. The implementation of new technology to obtain electricity generation should be studied for the Monegros Desert (area which is not within the coast).

**Transport**

* Increasing public transport efficiency and promoting its use, it may be possible to achieve a cost-effective transport, to reduce fare prices and a CO₂ emission savings. Considering the existing rail infrastructure in Spain it may be interesting to create a promotional campaign to impulse public collective transport by the use of trains in all kind of tracks.
* Creating tax benefits to electric transport may emphasize electric vehicles sales and help to emphasize the conversion and the change in pattern.
* Limiting the lifetime of cars allows decreasing the amount of obsolete cars whose amount of greenhouse gasses emission is greater than more modern cars while removing the vehicle fleet within the region.

**Other measures**

* Improving technologic innovation policies. If state and private investments in I+D increase, using current knowledge in renewable energies, an improvement on Spanish competitiveness will lead to a great economic growth contributing both to an enhancement of the regional industry and a reduction of energetic costs.
* Creating a rehabilitation and modernization plan to building structures (including industrial, public and private) two goals may be achieved, job creation while improving quality of life and energy efficiency.

**6.1.6.- WATER QUALITY**

To achieve high water quality, proposed measures (section 6.1.2) should be applied to fight against pollution existing in water bodies. However, alternative actions such as presented here, may also benefit water quality.
A group of Spanish universities have developed an interesting ecological project to recover Posidonia meadows existing in the Mediterranean Sea since this endemic plant is suffering a regression period, basically due to factors such as water pollution (nutrient load from rivers, brackish water from desalination stations) the construction of numerous ports along the coasts, illegal trawling fishing and even the appearance of other invasive species of plants. This experiment consists in creating submarine biodegradable structures as a seedbed of this species and then transport to deteriorate areas needed of artificial recovering. Posidonia meadows have several benefits for the Mediterranean since those provide great amount of oxygen, absorb great concentration of CO\(_2\), offer littoral protection to coastal erosion and concentrate more than 400 flora and fauna species (http://www.reservasmarinas.net/).

6.1.7.- EBRO DELTA PRESERVATION

On basis of problems described at the beginning of this section, some measures have been proposed:

**Erosion:**

- Somehow there is the necessity of increasing the amount of sediment arriving at sea since nowadays an enormous quantity of solids is retained into reservoirs. Considering that the Ebro Delta was formed of accumulated sediments, in order to compensate subsidence of the soil and decrease vulnerability of this area against sea-level rise and wave storms, sediment conveyance should be augmented.

- The reduction of sediment transport in the Ebro River is about 99 % of the existing mainly due to the construction of several reservoirs along the river. Under these conditions, the Delta has stopped its growth and the coast is being strongly reshaped by waves, though there is no net loss of surface so far. Additionally, sediment deficit and relative sea-level rise (rise + subsidence) imply a loss of land elevation of the deltaic plain. This means that approximately 50 % of the emerged plain will likely be under sea level at the end of the
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present century, causing wetland degradation due to salt stress and water logging (Ibáñez 2009).

Legal framework

* There is a need to integrate flood risk management plans and sediment management plans, since in most of cases the sediment imbalances are leading to an increase of flood risk and coastal retreat.
* Develop an integrated approach to the planning and management of the delta. Only by developing an integrated approach is it possible to deal with climatic, social pressures and the very dynamic development of urbanization, economic activities, infrastructure, natural and technological risks. Therefore an institution for a global management and protection of the entire delta is needed.
* The approach of the Ebro Delta Partnership has to be promoted and a coordinated delta-wide view among multiple stakeholders needs to be spread.

Conservation and sustainability of the area:

* Ensuring the continuity of rice cultivation and introducing changes in its practices tending to minimize the impact on the environment are priority goals for the conservation and sustainability of the deltaic system. In this sense, the application of the agro-environmental measures of the European Union and the organic farming represent an important step forward (http://www.deltanet-project.eu/ebro).
* Conservation of rice cultivation. The future possibility of transformation of rice fields into other non-flooded crops because of a decrease of rice price is a considerable threat to the deltaic environment. This transformation would imply a large loss of aquatic habitats and a most intensive drainage of the land that produces salt stress and drainage waters of low quality.
* Solve fragmentation and small surface of natural areas. The reduction of the marshes to a narrow belt around the lagoons and along the coast diminishes the ability of these areas to contain fauna, to conserve the natural gradients of plant communities and to accomplish the function of nutrient filtering. Consequently, the biodiversity and productivity of the lagoons is also affected, because the ecological functioning of both environments is closely linked.
* The effective protection and restoration of the river margins is not only an important conservation goal in the Delta but also a necessary condition for a sustainable use of the river for recreation purposes. The erosion of the margins
due to navigation causing the fall of trees and the accumulation of many types of waste are the main examples of this degradation.

The degradation and overexploitation of the lagoons have led to a strong reduction of fish captures in the four lagoons where fishing is carried out.

In the case of marine fishing, the total captures of the last years were around 6,000 tons per year despite of the increase of power and tonnage of the boats, thus indicating an overexploitation of the resource.

The habitat degradation because of fishing practices is a worrying question, especially when dragging fishing is concerned. The aquaculture had a big development in the eighties, mainly in the bays (Fangar and Alfac), where mussel and oyster cultures were developed. However, water quality problems (high temperature and low oxygen in summer) and the excess of exploitation permissions with no consideration of the loading capacity of the bays, caused a decrease of the production and problems of mussel mortality.

7.- SUMMARY AND CONCLUSIONS

General overview
This project has proposed some strategies to mitigate climate change in order to allow a smoother adaptation for society and environment of the studied area to climate change effects. For this purpose, on one hand future climatic and marine projections have been obtained from an ensemble of CIRCE models runs along the Coast of Catalonia and Valencia. On the other hand, observed data were collected at hotspots in a stretch of 750km, particularly from the Creus Cape, in the north (Girona) to La Nao Cape, in the south (Gulf of Valencia). Then from evidence collected, pattern trends were acquired by time series analysis.

Methodology
It is a fact that over late decades the evolution of technology and the appearance of numerical methods have represented a significant improvement in the analysis of physical problems through applied mathematics and engineering, leading to the obtaining of the best simulated results representing future real situations ever.
Although within a wide range of engineering fields, numerical simulation is a significant and very useful tool which helps human being to reproduce real situations, to amplify their knowledge about certain behaviours or patterns and to obtain estimated results; these are not 100% reliable and should be prudently considered. What it can be clearly observed is that nowadays, simulation processes represent crucial and indispensable aspects in decision-making, development and conduction of measures within a wide range of sectors, such as water management, environment and engineering between others.

**Experimental Results**

These observed trends of parameters such as air temperature, sea-surface temperature, sea-level rise, precipitation, wave storminess and sea-surface salinity (presented in this thesis), show their evolution from the past to the present time under changing economic and industrial activities that have affected the climate conditions. What it can be drawn is that, trend analysis might be highly conditioned by different factors. For instance within a same analysis, different trends may be identified depending on the chosen temporal scale, having therefore, not only a general lineal trend of variable evolution over the whole temporal domain but also inner linear and flexible trends covering smaller temporal periods within the general interval. Besides, fluctuations in observed trends and local variability could be explained by natural factors such as local atmospheric processes, changes in storm tracks and the variation of sea and air temperatures, and even social factors (technological development, social conflicts, etc.). All these aspects, along with limited observed data, hinder reaching an only observed behaviour and hence a robust conclusion.

**Numerical Results**

Regarding future climate and marine projections, results presented in this thesis proceed from an ensemble of CIRCE models, which after comparing several models uses an average value of those predicted. Although simulation processes have evolved largely during last decades in the context of climate change, uncertainty is still associated to future projections, since each model may use different parameters (data availability, calibration and verification processes, scenarios, etc.).

**Climate and Impact Indicators**

Through the identification and description of physical and socio-economic indicators, it has been possible to identify impacts of current and future climate conditions in the study area. With a holistic perspective, it is possible to assess how those changes
affect and influence human and nature systems. In terms of physic variations due to climate change, coastal biodiversity, coastal erosion, salt water intrusion and water quality were explained. With regard to consequences on societies, effects on human health and public territory (MTPD) were presented and described, as well as likely affections to tourism and insurance sectors and energy demand. Afterwards, additional social and economic pressures were considered since those will probably influence future development and therefore future stage. Such are how population evolve in coastal areas, the real lack of free space enclosing coastal urban areas, land use changes suffered over last decades and the current economic crisis which Spain is undergoing.

Barriers and constraints that were identified are not only those previously mentioned (population growth, lack of space, economic crisis and land uses changes) but also other deep issues that can be identified as modern society illness. The educational background, the big loss of moral values towards the territory in which human being is living and the profound politic crisis that the study area is currently suffering, are non-climatic factors able to influence and guide future development to one or another path.

**Strategies**

On basis of this information, a cluster of measures has been proposed to smooth future impacts in the Catalan Coast and the Gulf of Valencia. The current situation and real chances have been considered as a reference points in the proposal, since there is no point suggesting huge actions which are almost impossible to reach. Bearing in mind the high uncertainty of future projections, the best strategy for the study area, here suggested, is focused on the continuous application of gradual measures which will lead to a better prospective, instead of the future application of drastic and probably late actions.

From the stakeholders & final user point of view, it is very likely that, population awareness and environmental conscience increase, basically forming young generations on the basis of firm moral values such as respect, empathy, solidarity, sacrifice, constancy and generosity with the environment, inner conflicts of societies may be solved in a good atmosphere. This is particularly evident for the Spanish Mediterranean regions, since there is a very wide range of attractions and positive aspects such as Mediterranean food, a fantastic weather, beaches, no religion conflicts, good investment in renewable energies and a high level of experts in different themes between many other aspects that makes Spain the fourth most visited country in the world, and the second one earner in this sector.
For this reason, governments should be formed by experts in all subjects, it should be separated as much as possible environmental growth from economic growth and apply consistent and long-term policies with consideration of the whole system (no more local interventions). With this, nature conservation and environmental prosperity will be achieved; fundamental interests and attractions would be maintained, all of this leading to a sustainable development with an integrated framework and economic prosperity.

8.- ACKNOWLEDGEMENTS

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Within mentioned investigations, next data sources were used: Servei Meteorologic de Catalunya (SMC), Puertos del Estado, from the Spanish Ministry of Public Works (http://www.boiescat.org and http://www.puertos.es), Xarxa d'Instruments Oceanogràfics i Meteorològics (XIOM Network) from Universitat Politècnica de Catalunya and the Catalan Autonomous Government.

César Mösso merits a special mention, since the development of this thesis has been possible thanks to his support and help, knowledge and advices.
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