Comparison of trophic control dynamics between two areas of the western European Shelf Seas, the Bay of Biscay and Gulf of Cadiz

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Contents

BRIEF INTRODUCTION TO THE PROJECT

1. General context

Developing Integrated Ecosystem Assessments (IEA) (Levin et al., 2009) is crucial for Ecosystem Based Management (EBM – also referred to as the Ecosystem Approach - EA) of marine systems , since they are the fundamental linkage between ecosystem science and advice also in marine systems (Dickey-Collas, 2014). Since the term *Ecosystem* was first defined by Tansley (1935) a whole research field has been develop both in terrestrial and marine environments. The Ecosystem Approach concept is a more recent topic, but still has quite a long trajectory in marine sciences in general and in fisheries science in particular (Ecosystem Approach to Fisheries Management – EAFM – or Ecosystem Based Fisheries Management –EBFM (Garcia et al., 2003; Jennings, 2005; Short et al., 2008). Besides the fact of being a quite well known concept and with an extensive literature available, the operationalization of EBM and EBFM has not been achieved yet (Patrick and Link, 2015)

Marine ecosystems contain detritus, hundreds of kinds of organisms including bacteria, phytoplankton, zooplankton, fishes, mammals, birds, etc., all connected in a complex food web by evolving interactions (Cury et al., 2003). These marine organisms are in continuous change and adaptation to both, the physical environment and other organisms, which becomes to a complex and sometimes chaotic dynamics. All this complexity translates on a necessity of a deep understanding of marine ecosystems dynamics. It will also bring to a need of a well understood and appropriate assessment of the goods and services these systems offer to the societies, adopting accurate management strategies that ensure their sustainability and allow keeping them in a good environmental status level.

The physical, chemical and biological processes that transform and drive the flow of energy or matter in an ecosystem are known as ecosystem functions (Naeem, 1998; Paterson et al., 2012). Marine ecosystems provide many important functions at a global, national and regional level. The functioning of an ecosystem refers to combined effects of all these functions and it is driven by the existing relationships between biotic and abiotic factors (Reiss et al., 2009; Humbert and Dorigo, 2005), and so, it represents an important component of the ecosystem health (Tett et al., 2013). This reinforces the relevance of improving the knowledge about marine ecosystems' components and processes in order to keep them healthy and safe the services they offer to societies, in all senses (including cultural, socio-economic and human health) (Rapport et al., 1998).

Ecosystems are then complex and dynamic systems that might lose their stability and resilience depending on the pressures they support. Most ecosystems across the ICES regions have been heavily exploited during quite a long time period, and this has also been occurring in the two study areas. And the effects of fishing pressures are known to alter fish and trophic dynamics and to have a cascading effect through food webs. But there are also 'natural' drivers that can force these changes and they should be taken into account.

Being this a very challenging issue, especially in the southern ICES areas where ecosystem science has historically been less developed it pushes the scientific community to establish some specific objectives. The main goal of this study has been focused on analysing the tendencies of different components of the trophic web as part of the biotic compartment of these two systems (the Gulf of Cadiz and the Basque Coastal marine ecosystems) ant try to link them to the anthropogenic activities and natural forcings that occurred in the study areas.

2. The study areas

The work proposed in this project is being developed in two exploited marine ecosystems, being both of them subareas of the ICES Ecoregion G - South European Atlantic Shelf: the Basque Coast (on the south-eastern corner of the Bay of Biscay) and the Gulf of Cadiz (see Figure 1). That means that there will be two different case studies with have some common points but each of them with different characteristics.

Both areas are also part of Region IV (Bay of Biscay and Iberian Coast) of the OSPAR Commission for the Protection of the Marine Environment of the North East Atlantic (OSPAR, 2000).

The whole ecoregion corresponds biogeographically to a subtropical/boreal transition zone. Its topographical diversity is reflected in the ecological richness of the area, containing a wide distribution of fish species, some of them with commercial relevance for the surrounding countries. This complexity make these two systems very interesting to be studied, but at the same time very complex to be completely understood.

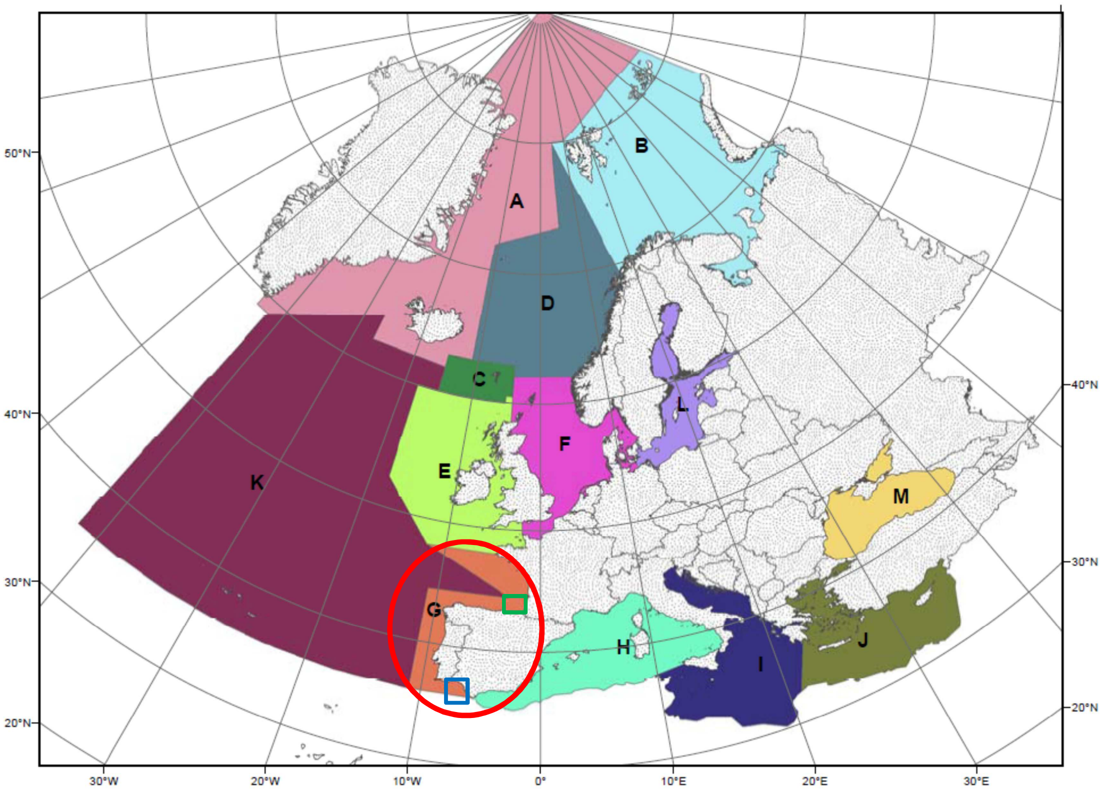

Figure 1. Study areas within ICES ecoregion G, marked with a red circle in the map. The green rectangle highlights the area of the Basque Coast and the blue one highlights the area of the Gulf of Cadiz (map source: www.ices.dk)

3. Main objectives and tasks

The study aimed to compare the trophic structure of two heavily exploited ecosystems in the southern ICES regions - the south-eastern Bay of Biscay and the Gulf of Cadiz – and to analyse historical changes in trophic controls of these two stressed systems. While has been relatively well studied in most of the European regional seas, such as the North Sea, Baltic Sea or Black Sea, it remains rather unexplored in the south western ecosystems.

The current understanding of the trophic structure of these exploited ecosystems under the given environmental conditions is very limited.

To achieve it, different tasks were established, each of them with a more concrete goal but all complementary and necessary to reach the main big and ambitious objective. Each of these task, which are described in detail below, contained different sub-tasks which allowed the researchers to better plan the work developed during the project. One deliverable is expected to get out from each of these tasks during the timeframe of this project.

Task1. Review of existing information about the two studied systems. One of the first goals was to improve the current knowledge of these two systems by carefully reviewing the existing literature and gathering all the information available.

1.1. Exhaustive revision of scientific literature, reports, etc.

1.2. Gather all the available information in practical working documents for each case study

Deliverable 1: Working documents for each study area with the description of each ecosystem, containing also information on the existing natural drivers and human activities that occur in these areas.

Task 2. Review the available quantitative data related to the different components of these two ecosystems, from climatic and environmental factors to Low Trophic Level (LTL) and High Trophic Level (HTL) functional groups of the food web, including humans.

2.1. Review of existing databases that are available and accessible.

2.2. Build an internal database containing all the data found in 2.1. relevant for each of the case studies

2.3. Gap analysis

Deliverable 2: Create a database with all the quantitative information available, easily accessible and preferably able to account for the spatial resolution of this information.

Task 3. Review the existing statistical tools that could be used to assess the trophic control of these systems, but also to analyse temporal changes of this trophic structure given the changes on the external drivers (fishery related and environmental variables).

3.1. Revision of existing and applicable tools and selection of the most appropriate one

3.2. Apply the selection aiming to obtain the first results in the two areas

Deliverable 3: Report on the results of the applied models, which should allow end users to better understand the trophic structure of the two systems and how the anthropogenic activities (mainly fishing) could affect these dynamics under a continuously changing natural environment.

FIRST RESULTS

Bearing in mind that this was a quite ambitious project and that we were dealing with two very complex marine systems, it sounds quite sensible that most of the tasks are ongoing activities that will continue to be developed during the next years.

Anyway, there are some outputs from the work developed during this first year and that are detailed along the present document. Anyway, some explanations regarding the ongoing work will also be included, aiming to give the reader an idea of what is being done in each study area (and will continue to be done) mainly pushed by the ideas shared between the two partners within the project framework.

1. **Working documents for each study area with the description of each ecosystem, containing also information on the existing natural drivers and human activities that occur in these areas.**

Being this not a closed activity, which will need to be updated in the near future to incorporate all the new research that is been carried out in the study areas, a detailed document has been created for each region with the existing information on the abiotic and biotic components of these ecosystems and also with the climatic and environmental conditions and the main human activities of these regions. These two working documents have been included in **ANEX I.**

2. **Create a database with all the quantitative information available, easily accessible and preferably able to account for the spatial resolution of this information.**

Taking advantage of the recent availability of spatially explicit data concerning the different ecosystem components and also the human pressures in the areas, a database (in PostgreSQL in the case of the Basque Coast) is being developed for each case study.

Thought the creation of these databases is still ongoing and will presumably be a long task, the main points within this project have been focussed at the collection of available quantitative data and the consequent gap analysis.

Historical abundance data series of most important fish stocks (both from commercial and ecological perspective) and main zooplankton species for each of the case studies were required for implementing this approach. Chlorophyll-a values and fishing mortality rates were also needed as proxy of phytoplankton abundance and anthropogenic pressure respectively; and relevant environmental variables such as sea surface temperature, salinity and other more general climatic indices (i.e. the North Atlantic Oscillation (NAO), the East Atlantic pattern (EA) or the Atlantic Multidecadal Oscilation (AMO)) too.

Most of these time series have been collected at present, some of them from local dataset available at the involved research institutes, and some others directly downloaded from public datasets available for example from NOAA mainly containing information on climatic and environmental variables. The good thing of these datasets compared to some of the ones coming from local institutes is the long time series that they contain.

http://www.esrl.noaa.gov/psd/data/reanalysis/reanalysis.shtml

http://las.pfeg.noaa.gov/las6_5/servlets/dataset?catitem=70

http://www.cpc.ncep.noaa.gov/data/teledoc/telecontents.shtml

ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/tele_index.nh

Regarding HTL components of the system, main information was coming from the assessment Working Groups at ICES and also from more local surveys that cover the studied areas. There is also good data available about the fishing activity occurring in these two areas. But one of the things that arose from this exercise in the two areas was the low availability of quantitative time series regarding the dynamics of LTL components of the system; both the microbial ecosystem and the planktonic components of these systems were poorly monitored. Due to the relevance of these LTL compartments in most food web dynamics, some decisions are taken regarding future research need in the study areas.

In the Gulf of Cadiz, we identified and localized a considerable number of samples coming from several scientific surveys carried out in the area over the last decade. The sampling spatial and temporal distribution covered well the whole area. It consisted of several transects perpendicular to the coast from north to south (Fig 2) and covered a temporal span longer than a decade (2001-2014) with a (at least) seasonal resolution (3 times per year). These samples happened to be archived in the premises of IFAPA, a local research institute dependent on the Andalusian Government and showed a varying degree of preservation. Still, most of them could be processed. Despite the catastrophic situation of the scientific funding in Spain we managed to get some funds from other projects and could send out a number of samples for identification (currently we lack that expertise at our institute). We have now received the counts from a first batch of 60 samples from the Guadalquivir transect. With this information we have been able to reconstruct what is now the first time series of marine zooplankton abundances in the Gulf of Cadiz. In the coming months we expect to receive comparable information from the other transects, which will allow us to resolve, not only the temporal but also the spatial variability of this component.

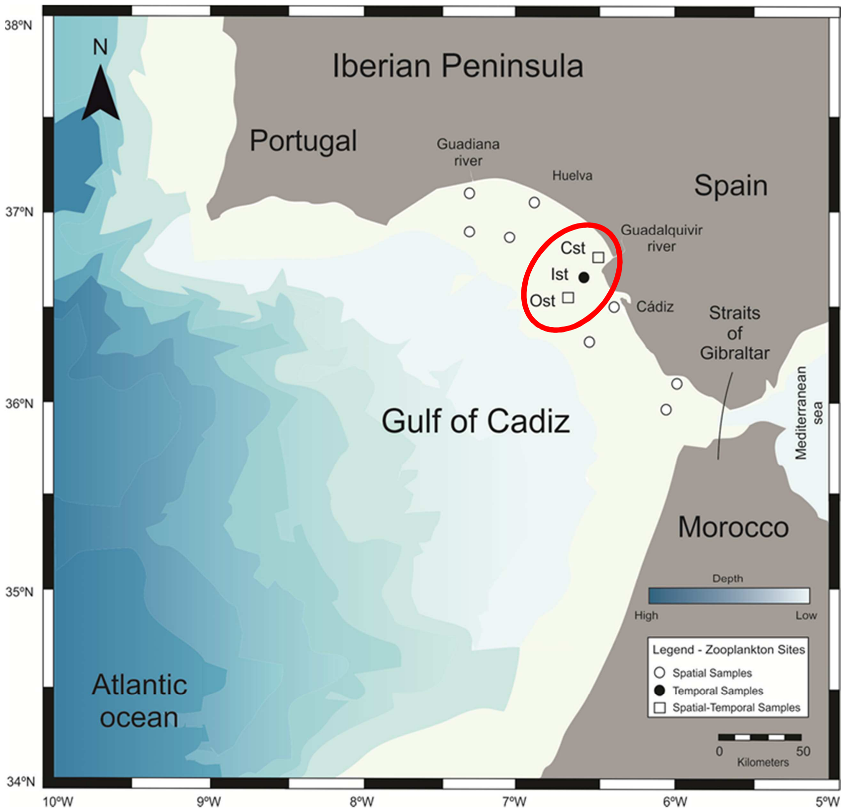

Figure 2. Map of the Gulf of Cadiz showing the position of the selected stations where zooplankton samples were available. 5 transects were selected from north to south, off the mouth of the Guadiana river, in front of the city of Huelva, off the mouth of the Guadalquivir river,

Cadiz city and Cape Trafalgar. Two stations (coastal and oceanic) were selected for each transect but the Guadalquivir river were we added and intermediate station (Courtesy of Carvalho-Souza).

Additionally, a new PhD project has been started that will be developed by Gustavo Freire de Carvalho Souza and supervised by Marcos Llope at the Insituto Español de Oceanografía, in Cadiz (Spain). This PhD project is directed to describe the zooplankton community of the Gulf of Cadiz and also to reconstruct time series that could be used in food web or ecosystem models afterwards. First results about the characterization of the zooplankton have already been obtained and showed in different forum such as the ICES Working Group on Ecosystem Assessment of Western European Shelf Seas (WGEAWESS) this year.

Preliminary community analyses revealed cladocerans (mainly *Penillia avirostris*) as the most abundant species in all stations, particularly abundant at the intermediate station (Fig 3). Next steps are (1) to extract individual time series of the most abundant species, (2) assess the importance of those dominant species with regards to the diet of small pelagics and (3) transform the abundances of the finally selected key species into a proxy of zooplankton biomass. Once this process has been completed we will be finally ready to relate zooplankton to other trophic levels and environmental variability.

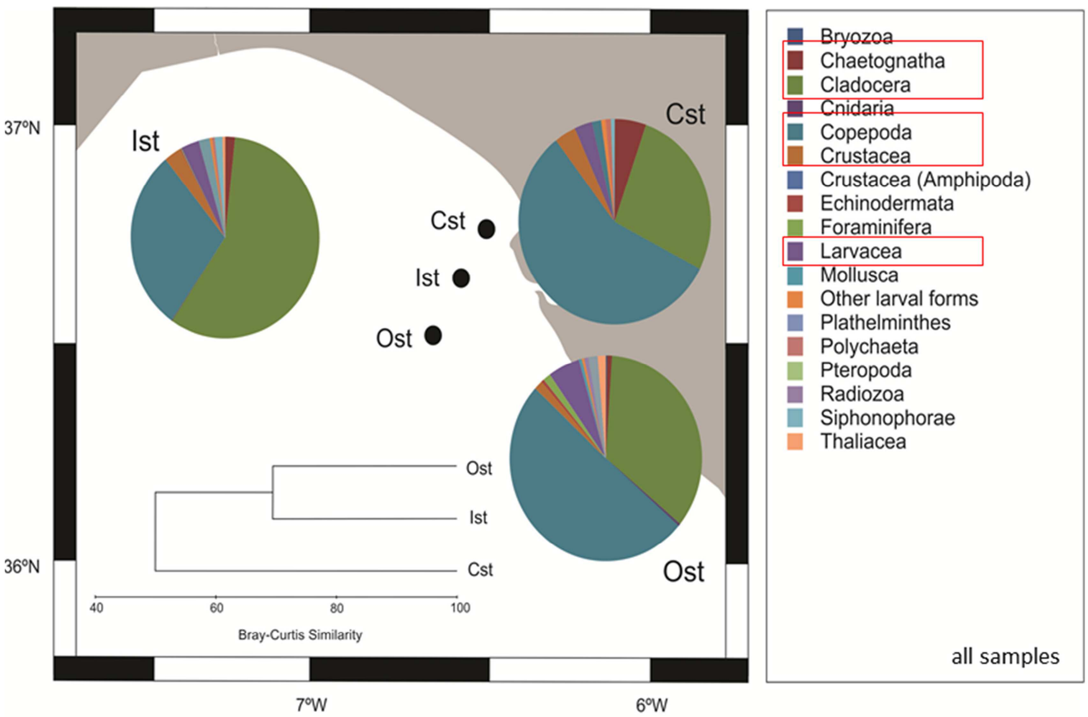

Figure 3. Relative abundances of the main groups of zooplankton at the Guadalquivir transect (oceanic, intermediate and coastal stations). Carvalho-Souza & Llope (*in preparation*).

In the Basque Coast case study the status quo was quite similar: there were samples collected by scientific surveys in the area, but not processes yet, so there was no availability of data to be used in modelling. Additionally, there was a need of getting more information on zooplankton aiming to cover the temporal variability of this community that was not covered by these surveys.

Once this situation was identified, two decisions have been taken: first, a plan has been set up for processing all the samples available and getting useful quantitative information of the zooplankton community in this area. Second, a sampling program is started, aiming to get information about the temporal dynamics of this community.

Although some information is now available for the two case studies, it has not been possible to get all information ready during this project. But this activity will also continue in the next years, so we hope to be able to achieve our goals in the near future.

3. Report on the results of the applied models, which should allow end users to better understand the trophic structure of the two systems and how the anthropogenic activities (mainly fishing) could affect these dynamics under a continuously changing natural environment.

Being this the less developed task, and where no preliminary results were obtained yet, the conceptual framework has already been discussed for the two case studies.

The complexity of the food webs of the two ecosystems will be simplified to a low number of trophic levels (TL). Lowest TL will be composed by phytoplankton (primary producers); second TL will be composed by zooplankton (secondary producers, possibly split in three subgroups by size); third one by forage fish species (planktivorous fish like anchovy); and HTL will be composed by predator fish species (piscivorous fish like hake).

Hypothesising that there might be non-linear but also non-additive relationships between all these variables, generalized additive models (GAM) and threshold generalized additive models (tGAM) seem to be the most suitable models to be tested in both cases.

Being this also an ongoing activity that will probably take long time to produce the first results, there are some models ready to be tested once we manage to obtain the required data. Average biomasses of trophic levels will be then estimated from the included biotic and abiotic information, accounting for existing regime-dependent relationships in the systems and allowing the assessment of the trophic control of the two selected systems.

This work will develop a more flexible approach than the parametric or fully additive traditional statistical techniques. Furthermore, it will allow us to implement an empirical exploration of data and to get quantitative solution for multiple time series for regime-dependent dynamics. In fact, these techniques have been and are still being widely used across Europe, and have also been proposed as first steps towards an Integrated Ecosystem Assessment by different expert groups in the ICES community (WGINOSE, WGIAB).

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ANEX I

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1. The Basque Coast as part of the Bay of Biscay ecosystem

The Physical Environment

The Bay of Biscay is a large gulf of the Atlantic Ocean located off the western coast of France and the northern coast of Spain, between 48.5 and 43.5°N and 8 and 3°W (Fig. 2). Together with the Iberian Atlantic coast, is a marine subregion comprised within the 'Atlantic Ocean' ecoregion. It is included under the OSPAR Commission for the Protection of the Marine Environment of the North East Atlantic (OSPAR, 2000 - IV Region) and contains several areas of the International Council for the Exploration of the Sea (ICES), such as VIIIa, b, c and d (see Fig 2). It corresponds biogeographically to a subtropical/boreal transition zone. Its topographical diversity is reflected in the ecological richness of the area, containing a wide distribution of fish species, some of them with commercial relevance for the surrounding countries. Furthermore, it holds habitats (i.e. pockmarks, canyons) and species (e.g. *Phocoena phocoena*) considered of interest for conservation under the Habitats Directive.

The Basque Coast ecosystem is a small fraction of the ecosystem of the Bay of Biscay, which lies from between Cape of Ajo (ca. 43°30'N, 3°35'W) and Cape Ferret (ca. 44°47'N 1°8'W). This area is located between two different countries (Spain and France) as part of the Bay of Biscay and so, the Atlantic Ocean (see Fig 1A). Compared to other parts of the Bay of Biscay, there is a warming period during the summer in these waters, at the same time an upwelling takes place in Galician and Brittany coasts. All these characteristics make this area a very interesting zone in terms of marine diversity.

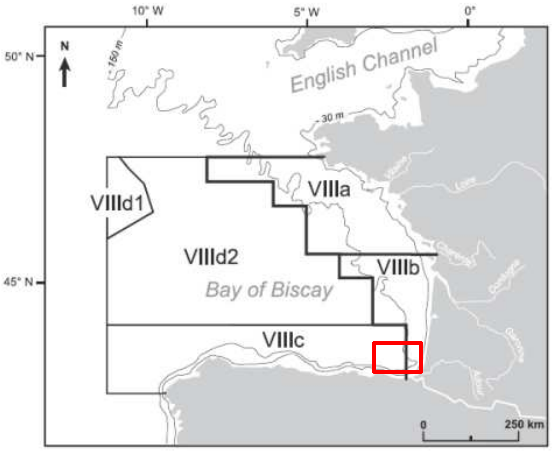

Figure 1A. ICES Divisions in the Bay of Biscay (adapted from Lassalle et al. (2014)), highlighting the Basque Coast within the red rectangle.

The Cape Breton Canyon could be considered as a natural barrier between this ecosystem and the one that extends along the French coast, highly influenced by rivers runoff. Below a water depth of 4500 m, there is an abyssal plan, which constitutes the real oceanic section of the bay. Some submarine mountains rise in this area, often aligned in an east-west direction (Pascual et al., 2004). Bordering this abyssal plain, the Basque continental shelf appears to the south, located within the eastern section of the northern Iberian Peninsula shelf. As the whole Cantabrian shelf, it is characterized by its narrowness, ranging from 7 km in front of the Matxitxako Cape to 20 km in front of Orio. Beyond 200 m water depth, there is a steep slope with submarine canyons (Pascual et al., 2004). The Basque inner shelf is covered by an almost continuous belt of rocks, interrupted regularly by the presence of sandy sediments caused by the of river mouths, rias, etc. (Rey and Medialdea, 1988).

On the eastern limit of the abyssal plain is the Aquitaine Basin, which extends 330 km northward from the point where the Pyrenees reach the Atlantic Ocean. Structurally the Aquitaine Basin can be divided into two provinces separated by a prominent fault zone, the so-called North Aquitaine Flexure. This fault zone extends from Arcachon to Carcassonne and represents the continuation of the continental slope onshore. All the French part of this sub-area is comprised inside this basin, corresponding to the Southern Province of Aquitaine. Compared to the neighbouring shelf of the Basque coast, this shelf is quite wider, ranging from 60 to over 200 km.

This area is highly influenced by the Gulf Stream and the atmospheric westerlies, in the middle and upper troposphere. So, the annual mean temperature is higher than 10ºC. The climate is temperate, oceanic with moderate winters and warm summers. It is therefore associated with a Cfb climate (marine west coast-mild) according to the Köppen climate classification system (Usabiaga et al., 2004). The average yearly precipitation during the period 1928 – 2001 was 1559 mm. The maximum and minimum values over the same period are 2200 mm·yr^{-1} and 1038 mm·yr^{-1}. On average, it rains during about 200 days in a single year, occurring more frequently during autumn and with another relative maximum in March-April (Usabiaga et al., 2004). On the other hand, the distribution of the winds is relatively is very different from season to season, and some special atmospheric events occur over the area: the so-called *'galernas'* (mesoscale storms), which appear mainly in summer, and the Foehn Effect (Barry and Chorley, 1998; Usabiaga et al., 2004).

Historical warming trends and the potential future impacts of climate change on the Basque coast and the pelagic systems within the south eastern Bay of Biscay are reviewed in Chust et al. (2011).

The region is affected by both gyres, depending upon latitude. However, the general water circulation in the area follows mainly the subtropical anticyclonic gyre, in a relatively weak manner (1–2 cm.s^{-1}) (Koutsikopoulos and Le Cann, 1996). Onshore Ekman transport dominates in autumn and winter, in response to westerly and southerly winds. In spring and summer, easterly winds create weak coastal upwelling events, which compensate partly the convergence and downwelling (Borja et al., 1996; ICES, 2006; Fontán et al., 2008). In general, the distribution patterns, trends and anomalies in oceano-meteorological time-series data sets are highly dependent on spatial and temporal scales. Frequently, it is possible to observe opposing trends, when different time periods are considered (Koutsikopoulos et al., 1998; Borja et al., 2000). It is a temperate sea system with high wave exposure, due to its long (>4,000 km) fetch. Recent studies developed in the area showed a warming trend over the Bay of Biscay continental shelf, with an increasing trend of ~+0.3°C per decade in the 80s (Huret et al., 2009), similar to the SST trend analysed from in situ and satellite data over the whole Bay of Biscay (Michel et al., 2009). This trend shows a seasonal dependence with higher values in summer (Gómez-Gesteira et al., 2008; Michel et al., 2009). Also this fast warming trend followed a cooling period, so the trend is slower (0.2°C per decade) looking at the period 1965-2005 (Michel et al., 2009).

Biological communities

Heterotrophic bacteria are recognized to be the major consumers of organic matter and nutrient regenerators, as well as an important means for the re-entry of carbon into microbial food webs (Azam, 1998; Rivkin and Legendre, 2001; Hoppe et al., 2002; Orive et al., 2004). The average abundance and production of these bacteria along the Basque and the Aquitaine shelf increases when moving from marine shelf waters to estuaries and coastal plumes. Phytoplankton growth and accumulation is limited to the periods of low river flow and, hence, by low turbidity and relatively large residence time of the water (Orive et al., 2004). This pattern occurs typically in summer, always depending on the annual river flow regime. Generally, small centric diatoms such as *Cyclotella atomus*, *C. meneghiniana* and *Thalassiosira weissflogii* form extensive blooms at these sites, accompanied by different species of chlorophytes and the dinoflagellate *Peridinium foliaceum* during the warmer periods (Franco, 1994; Trigueros and Orive, 2001; Orive et al., 2002; 2004).These assemblages reach higher densities in the estuaries than in rivers (due mainly to the shallowness of the rivers).In contrast, marine water dominate the seaward end of rivers and estuaries, and there, the phytoplankton assemblages reflect well the seasonal cycle observed in coastal waters (Estrada, 1982; Reguera, 1987; Fernández and Bode, 1992; Varela, 1996). The onset of the phytoplankton bloom may start in the late winter (water temperature around 12ºC) and nutrients are still present (Revilla et al., 2002; Ansotegui et al., 2003). Large diatoms are characteristic of their winter-spring bloom, such as *Asterionallopsis glacialis, Lauderia annulata, Detonula pumilla, Leptocylindrus danicus* and several species of Pseudo-nitzschia, Rhizosolenia and Chaetoceros (Trigueros and Orive, 2001; Orive et al., 2002; Ansotegui et al., 2003). Phytoplanckton measurements differ locally along the Spanish west coast during the last 10 years (Valdés et al., 2007; Llope et al., 2007), but no significant changes have been observed in the long term (Bode et al., 2009). Along the Basque coast, slight decrease in surface chlorophyll a concentrations has been detected, whereas a significant increase was found in the water column (Chust et al., 2011).This increasing trend has also been observed in the areas which encompass offshore waters in the Bay of Biscay (Edwars et al., 2009; Chust et al., 2011).

Copepods are the dominant group of the zooplankton community in the southern Bay of Biscay (Villate et al., 2004). However, their contribution to the total zooplankton is higher in the shelf and coastal areas (60-70%) than in the estuaries (40-60%). In contrast, the abundance of holoplankton groups (Cladocerans, appendicularians and some cnidarians) is higher in estuaries than in shelf waters. Gastropods and echinoderms are the principal meroplanktonic groups in meroplanktonic community on the shelf, whereas the coastal and estuarine communities are dominated by cirripeds. In the microzooplankton, polychaetes are dominant, constituting more than 5% of the zooplankton bigger than 45 µm (Villate et al., 2004). Protozoans are also a very abundant group particularly *Noctiluca scintillans* and some acantharians species. Doliolids are important constituents of the neritic holoplankton in the Basque coasts, usually representing more than 1% of the total mesozooplankton. Ichthyoplankton assemblages are also a component part of the plankton community. Valencia et al. (1988) described the seasonal fluctuations in the abundance of fish eggs and larvae in the Basque shelf. Pelagic species eggs were the most abundant, the higher densities corresponding to sardine eggs (*Sardina pilchardus*). A significant negative relationship was found between total egg abundance and water surface temperature, due to the abundance of species which spawn mainly in cold waters, such as sardine and mackerel (*Scomber scombrus*). Some other commercial species were found in lower densities, such as *Merluccius merluccius*, *Dicentrarchus labrax* and *Solea vulgaris*. Last observations suggest that zooplankton concentration is stable or has declined both on coastal and offshore waters in the Bay of Biscay (Valdés et al., 2007; Chust et al., 2011).
The relevance of this Low Trophic Level (LTL) community in driving the trophic control of the Bay of Biscay ecosystem has been recently highlighted (Lassalle et al., 2011; Chaalali et al., 2015). Similar works are being developed in the south-eastern corner to evaluate if there is a similar role of this LTL community in this particular system, which has been poorly studied (mainly referring to zooplankton community) until now.

Within the Bay of Biscay, the Basque coast presents some unique biogeographical characteristics (Borja et al., 2004), which could cause the differences existing between the flora of the Basque coast and the neighbouring areas (Bornet, 1982; Sauvageau, 1897; Beauchamp, 1907). These differences are mainly based upon the scarcity or absence of several large brown algae (fucoids and laminarians) in the Basque coast (Ibáñez, 1989; Borja et al., 2004). Hence, the dominance of several warm-temperate red algae, together with a minor presence of large brown algae typical of cooler waters, shapes a particular zonation and enforces the meridional character of the flora, which has been corroborated by several phycologists (Borja et al., 2004). This area could be then considered as a refuge for some Mediterranean species (Gorostiaga and Limia, 1985). Several species considered endemic of the Mediterranean, the Moroccan Atlantic or more southern coast, have been found in the study area, due to the biogeographical peculiarities of this coast. The main causes of this peculiarity are both, the abnormal warming of surface waters and the cooling of the waters of Galicia (Díez et al., 2000), which limits the distribution and development of several flora and fauna species. Ospar (2008) consider the Flat oyster (*Ostrea edulis*) to be a species under threat and/or in decline.

Within the fish community, European hake (*Merluccius merluccius*), anchovy (*Engraulis encrasicolus*), and tunas (*Thunnus alalunga* and *Thunnus thynnus*) are presently some of the most important commercial fish species in southern the Bay of Biscay. Whilst tunas are a large-scale migratory species, European hake and anchovy can be considered as the main fisheries, restricted to the Bay of Biscay ecosystem (considering the ecosystem and the use by the human communities). Other fish species are also present in these waters, like horse mackerel (*Trachurus trachurus*), mackerel (*Scomber scombrus*), sardine (*Sardina pilchardus*) and blue whiting (*Micromesistius poutassou*). *Raja clavata* seems to be a very relevant species in this ecosystem too, along with *Scyliorhinus canicula* (Quincoces et al., 2011). Pelagic and benthic cephalopods are also relevant species in this system.

The South-Eastern Bay of Biscay includes essential habitats as spawning and feeding grounds for several fish species (e.g. hake, megrim, anchovy, and mackerel) as well as for endangered species of birds and cetaceans. OSPAR (2008) list 17 species of fish as threat and/or in decline in the Bay of Biscay: these include the Sturgeon (*Acipenser sturio*), European eel (*Anguilla anguilla*), Gulper shark (*Centrophorus granulosus*), skates and rays (*Dipturus batis*, *Raja montagui,* and *Rostroraja alba*) seahorses (*Hippocampus* spp.), spurdog (*Squalus acanthias*) and salmon (*Salmo salar*).

Historically, one of the most relevant sea mammals in this area has been the northern right whale (*Eubalaena glacialis*), known nowadays as the "Basque whale". However, this species disappeared from the region long time ago. Information on other marine mammal species is somewhat scarce. Cetaceans are the most abundant marine mammals in the Bay of Biscay. Five whales (Mysticety) and fifteen toothed whales (Odontocety) have been recorded and catalogued. The fin whale (*Balaenoptera physalus*) is the commonest large whale occurring in the area, along with the minke whale (*Balaenoptera acutorostrata*) and the sei whale (*Balaenoptera borealis*), the humpback whale (*Megaptera novaenglidae*) and the blue whale (*Balaenoptera musculus*). However, along with the northern right whale the blue whale is considered by Ospar (2008) to be species under threat and/or in decline. The other species (Odontocety) are: the sperm whale (*Physeter catodon*) and pygmy sperm whale (*Kogia simus*), the Cuvier's beaked whale (*Ziphius cavirostris*), the Sowerby's (*Mesoplodon bidens*) and northern bottlenose whale (*Hyperoodon ampullatus*), the common dolphin (*Delphinus delphis*), the striped dolphin (*Stenella coeruleoalba*), the bottlenose dolphin (*Tursiops truncatus*), the white-beaked dolphin (*Lagenorhynchus alboristris*), the killer whale (*Orcinus orca*), the false killer whale (*Pseudorca crassidens*), the Risso's dolphin (*Grampus griseus*), the long-fined pilot whale (*Globicephala melas*), the pygmy killer whale (*Feresa attenuata*) and the harbour porpoise (*Phocoena phocoena*) (Castro et al., 2004). Species such as *Phocoena phocoena* and *Tursiops truncatus* are also included in Annex II of the Habitats Directive.Two turtle species, Loggerhead turtle (*Caretta caretta*) and Leatherback turtle (*Dermochelys coriacea*), occur in the area and both are considered by Ospar (2008) to be species under threat and/or in decline.

The nesting seabird community of the region is very poor in comparison with other European Atlantic areas, in terms of abundance and species diversity. The two most limiting factors for breeding seabird populations are prey abundance and availability close to breeding areas and availability of good nesting places (Franco et al., 2004). In spite of this limitation, some important breeding colonies exist within the area. Four seabird species can be considered as regular breeders on this area: the European storm-petrel (*Hydrobates pelagicus*), the European shag (*Phalacrocorax aristotelis*), the yellow-legged gull (*Larus michahellis*) and the black-backed gull (*Larus graellsii*) (Franco et al., 2004). The Basque coast is located on the migratory routes of many European birds, whilst the Bay of Biscay is an important area for some species during winter. During this period, seabirds take advantage of the presence of small-to-medium-size pelagic fishes (anchovy, sardine, mackerel and horse mackerel). More than 30 species can be considered seabird migrants along this coast. The most abundant one are northern gannets (*Morus bassanus*), auks (Alcidae; specially the common guillemot (*Uria aalge*) and the razorbill (*Alca torda*), black-headed gulls (*Larus ridibundus*), Yelkouan shearwaters (*Puffinus yelkouan*), lesser black-backed gulls (*Larus graellsii*) and black-legged kittiwakes (*Risa thidactyla*). The Atlantic puffin (*Fratercula arctica*) is also a regular winter visitor to the Bay of Biscay; however, this species clearly prefers the more open waters. The Great cormorant (*Phalacrocorax carbo*) typically arrives to the study area in the end of August (Franco et al., 2004). Ospar (2008) consider the Balearic shearwater (*Puffinus mauretanicus*), Roseate tern (*Sterna dougallii*), and Iberian guillemot (*Uria aalge*, synonyms: *Uria aalge albionis*, *Uria aalge ibericus*) to be species under threat and/or in decline.

Human activities and pressures on the marine environment

According to preliminary results from current EU projects (MESMA[1] and MARNET[2]), there are more than 60 maritime activities in this area that have had or could have an impact on the marine ecosystem. Traditional activities in this area are related to the extraction of the marine resources. An important activity in the south-eastern Bay of Biscay is fishing (NACE Code A3.1.1). Industrial and artisanal fishing have a very long tradition in the area and they have historically caused a great damage in the ecosystem. In addition to the non-desirable or threat situation that some of commercial species have been reduced to during some time periods in the last decade (e.g. *Engraulis encrasicolus* in the Bay of Biscay - ICES, 2013), damage to the seafloor caused by the trawling activities has been identified by surveys using high resolution multibeam echosounder and Remotely Operated Vehicles (ROVs). Due to the decrease of the number of commercial boats during the last decade, the recreational fishery is becoming a

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[1] MESMA- EU-FP7- contract n° 226661: http://www.mesma.org

[2] MARNET– INTERREG IV B -2011-1/165: http://marnetproject.eu

relatively important activity in the south-eastern Bay of Biscay (there are about 300 commercial boats and more than 5000 recreational fishing boats in the Basque Country); and so, it has increasingly important consideration in the management of marine fisheries (Zarauz et al., 2013), as in many other countries around the world (Pawson et al., 2008; Mora et al., 2009; Ihde et al., 2011; FAO, 2012). This activity, together with other sport and recreational marine activities (NACE Code R93), is highly relevant to tourism in the area. Similarly, marine aquaculture (NACE Code A3.2.1) has become increasingly important during recent decades. Other extracting activities are related to crude petroleum and natural gas (NACE Codes B6.6.1 and B6.6.2 respectively). While natural gas storage is the most important activity, its extraction has also been economically relevant in the south-eastern Bay of Biscay. Recent surveys, carried out by petroleum companies in the area, and preliminary results of studies carried out under the framework of the MARNET EU project, suggest that extraction of both natural resources will increase and become a relevant activity in the near future. While the production of electricity (NACE Code D31.1.1) from marine energy devices is in a preliminary stage, the transmission of electricity (NACE Code D 35.1.2) is high. Renewable resources are expected to reach great importance in the next few decades. Dredging activities are also important and may cause a great impact on the ecosystem. In Spain, these activities are limited to sand extraction for beach nourishment. The extraction of material for construction is prohibited. Maritime transport (NACE Code A.3.2.1) is also very important in this area, which contains very important commercial harbours like Bordeaux, Bilbao, Gijon and Brest. Passenger transport is also relevant (NACE Code H50). The EU project MARNET is analysing the socio-economic impact of all these activities and some new information about this is expected to be available by the end of 2013. Due to the high population level inhabiting these coasts, coastal discharges are also very high. As a result of the implementation of regional, national and European environmental legislation (mainly the Water Framework Directive (EC, 2000)), waste water treatment processes have been improved and increased in the last 10 years, producing a decrease on the discharge of some products and contaminants to the marine waters. All these activities exert a high pressure on the studied ecosystem, some of them already listed in the literature (Eastwood et al., 2005; Robinson et al., 2008) and in the current legislation (Marine Strategy Framework Directive – MSFD (EC, 2008; EC, 2010)).

Some of these pressures, already been identified in the southern Bay of Biscay include: 'Modification of bottom relief', 'Physical abrasion', 'Underwater noise', 'Alteration of thermal regime', 'Nutrients (eutrophication)', 'Catches by harbour', 'Non-indigenous / invasive species', etc. As shown in Borja et al. (2010), there is a whole set of indicators of each aspect of the descriptors of the MSFD of which the impact caused by these pressures on them has also been measured in the south-eastern Bay of Biscay. Lorance et al. (2009) also assessed the impacts of the human activities on the Bay of Biscay ecosystem corresponding to ICES Divisions VIIIa-b. In summary, in the early 1990's, fishing appeared to be the sole activity exerting widespread documented impacts on several ecosystem components. Terrestrial activities had some possible and documented widespread impacts. With the exception of marine transport impacting seabirds at the regional scale through oil pollution, other activities had only local impacts, mostly nearshore. In addition to that, the French and Spanish documents about the implementation of the MSFD provide some information about this. For example, the Spanish document regarding the North Atlantic territory[3] gives a first assessment on how all these pressures and impacts are reflected in the environmental status of the southern Bay of Biscay waters. It is shown for example, that the selective extraction of marine resources caused by fishing activities are highly affecting descriptors 3 and 4 (Exploited fish and shelfish and Food webs respectively). It is also shown how the introduction of non-natives species is causing an impact on descriptors 1, 2, 3, 4 and 6 (Biological Diversity, Non-indigenous species, Exploited fish and shellfish, Food webs and Seafloor Integrity).

2. The ecosystem of the Gulf of Cádiz

The Physical Environment

The Gulf of Cádiz (Fig 2A) is the basin that connects the North Atlantic Ocean and the Mediterranean Sea. The north, east and south boundaries of the basin are the Iberian Peninsula and Northwest African coasts whereas the west boundary is not well defined. The 9ºW meridian running through Cape San Vicente would be a good choice for

[3] http://www.magrama.gob.es/es/costas/temas/estrategias-marinas/em_noratlantica.aspx

delimiting the Gulf of Cádiz to the west. Cape San Vicente is a sharp topographic feature where the shoreline changes orientation from north to east at al-most right angle, separating the oceanographic regime west of Portugal from the more peculiar regime of the Gulf of Cádiz. The prominent cape Beddouzza, close to Cape San Vicente longitude, could be considered a nominal southern limit.

The northern part of the Gulf of Cádiz, where this study is focused, contains the area north of 36ºN (the latitude of the Strait of Gibraltar). In addition to Cape San Vicente, this area has two other noticeable capes, Santa María and Trafalgar. Cape Santa María is an abrupt break off where continental shelf hardly exists. The continental shelf extends offshore to depths of around 100 m where the shelf slopes down and the continental slope begins. It is divided by Cape Santa María in two different portions with distinct characteristics. West of the cape, the continental shelf is narrow (around 15 km), it is cut by the pronounced Portimao submarine canyon and there are hardly any inputs of continental freshwater. East of the cape, on the contrary, the shelf widens (around 50 km) and important rivers like Guadiana, Guadalquivir, Tinto and Odiel feed it with freshwater and other dissolved or suspended substances from the continent. East of Cape Trafalgar the shelf narrows again as the Gulf of Cádiz faces its eastern limit at the strait of Gibraltar.

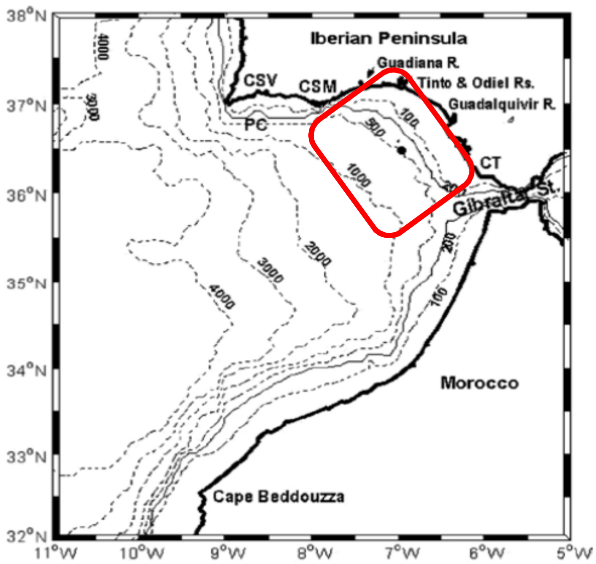

Figure 2A. Overall boundaries and bathymetry features of the Gulf of Cádiz. CSV, CSM and CT stands respectively for capes San Vicente, Santa María and Trafalgar. PC stands for Portimao Canyon. The red rectangle contains the northern part of the gulf, the study area of this project.

In broad terms the climate in the Gulf of Cádiz follows the Mediterranean pattern with hot and dry summers and mild and rainy winters. Nevertheless, the Atlantic influence softens this pattern towards milder and less dry summer and more rainy winters.

The mid-latitude and eastern Atlantic location of the Gulf of Cádiz makes this basin very sensitive to the North Atlantic Oscillation (NAO). NAO conditions the precipitation in the region and, therefore, the river run off with its subsequent impacts on the circulation, fertilization and nursery dynamics of some HTL species.

Wind regime at the Gulf of Cádiz seems less connected to NAO and more influenced by the local control exerted by the strait of Gibraltar.

Although the Gulf of Cádiz continental margin is located within the context of the eastern sector of the central North Atlantic it shows unique morphological, structural and sedimentary features. The presence of unstable substrata and the predominance of along shore processes have resulted in a distinctive broad slope and slope terrace morphology (Hernández-Molina et al., 2006). Following the overall highly dynamical nature of a basin that connects two seas (Atlantic and Mediterranean) and two continents (Africa and Europe), the sedimentary system has generated a highly heterogeneous and complex pattern. A very singular feature of the Gulf of Cádiz bottoms is the abundance of mud volcanoes at the continental margin, that are receiving increasing environmental focus owing to the need for protecting such singular ecosystems from deep-sea trawling activities.

The surface circulation in the Gulf of Cádiz is affected by the seasonal fluctuations of the North Atlantic subtropical gyre. The size and position of this gyre follows the displacements of the Azores atmospheric high, which extends northwards in summer and reduces its size in winter. Following these fluctuations, the eastward-flowing Azores current would flow at a latitude greater than the Gulf of Cádiz latitude when the North Atlantic subtropical gyre is large, whereas it would be displaced to the south when the subtropical gyre diminishes the size. This seasonality is mirrored by the circulation along the eastern boundary of the mid-latitude North Atlantic. An example is the winter appearance of the Poleward Current flowing northwards at the surface along the Portuguese coast (Frouin et al., 1990; Haynes and Barton, 1990), which is replaced by the equatorward upwelling jet during the upwelling season from May to October (Wooster et al., 1976; Fiúza et al., 1982; Haynes et al., 1990; Peliz and Fiúza, 1999).

The Gulf of Cádiz circulation is sensitive to these large-scale variations. Relvas and Barton (2002) suggest that, when the upwelling jet formed in summer reaches Cape San Vicente, it spreads preferably to the east along the shelf break and slope of the northern part of the Gulf of Cádiz, providing a generalized anticyclonic circulation in the basin..

Biological communities

The Gulf of Cadiz is probably the least known region of the European Western Waters when it comes to bacteria and plankton.

Prieto et al. (1999) made a comparative analysis of bacterioplankton distribution in the Alboran Sea, Strait of Gibraltrar and Gulf of Cádiz. They found higher bacterial abundance in productive regions while lower overall biomass was present in the open-ocean regions. In this work a positive and significant correlation was found between bacterial abundance and chlorophyll concentration.

Also, chemosynthetic bacteria have been reported to significantly contribute to the nutrition of deep-waters bivalves in the mud volcanoes of the gulf (e.g., Rodrigues *et al.*, 2010).

It also lacks consistent time-series of phytoplankton. Apart from a few isolated studies on general groups (Prieto et al. 1999), most of the information comes from indirect studies based on satellite colour. Navarro and Ruiz (2006) describe 5 zones which roughly correspond to the hydrographical features mentioned above (Figure 5.6). It's recommended to incorporate phytoplankton to the existing monitoring programmes in order to generate information on the structure and changes of this component and be able to report possible trends.

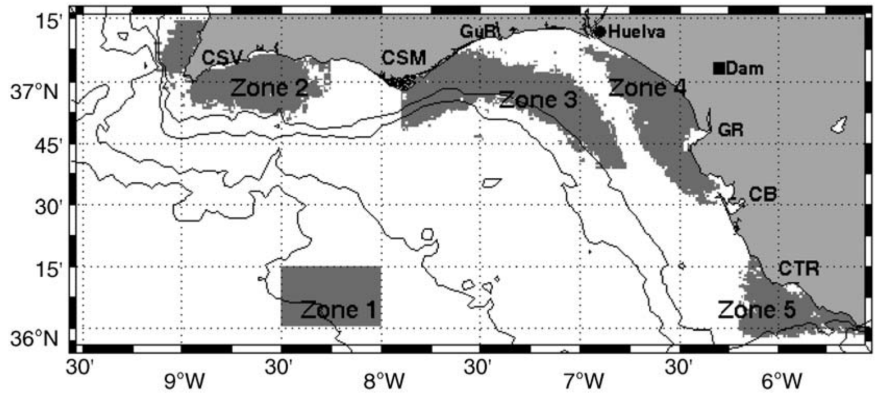

Figure 4. Regionalization based on EOF analysis of colour satellite imaginery. Zone 1 (open ocean), Zone 2 (Cape San Vicente), Zone 3 (Cape Santa María), Zone 4 (coastal zone between Guadiana and Guadalquivir river mouths), and Zone 5 (Cape Trafalgar). See Navarro and Ruiz (2006).

Similarly to phytoplankton, to date there is no readily available historical information on this component apart from a few isolated studies (e.g.. Vives, 1970, 1972; Neto and Paiva, 1984, Cunha, 1993; Villa *et al.* 1997; Mafalda et al. 2007). These studies suggest for example that the most abundant copepods species are *Calanus helgolandicus* and *Neocalanus gracilis* with the copepod community composed by around 122 species (end of spring – summer period). They also conclude that copepods populations in the area were mainly composed of neritic species, being in general species typical from the Atlantic Ocean in the first 300 m of the water column, and never found in Mediterranean Sea, as e.g. *Chirudina streetsi*, *Undenchaeta plumosa*, *Scaphoca-lanus echinatus*, *Metridia lucens*, *M. venusta*, *Phyllopus helgae* and *Conaca rapax*.

The gulf is a highly suitable habitat for the reproduction of many commercially important marine species (e.g., Jiménez *et al.*, 1998; Millán, 1999) being the Guadalquivir River a key player in providing suitable spawning and nursery conditions from many fish species (García-Isarch *et al.*, 2003; Ruiz *et al.*, 2006).

The main commercial species is European anchovy (*Engraulis encrasicolus*) being sardine (*Sardine pilchardus*) a much less targeted pelagic species for its comparatively low market prices and much less abundance. European anchovy is the main economic resource of the fishing fleet in the Gulf of Cádiz. Being a short living species, anchovy recruitment and landing largely fluctuate with environmental variability (Nakata *et al.*,

2000; Lloret *et al.*, 2001; Erzini, 2005; Basilone *et al.*, 2006). The sensitivity to the physical environment is particularly acute at the Gulf of Cádiz. The severe mortality imposed by the fishery avoids adults to survive from one year to the next. Without sustain of adults, the population totally relies on recruits to persist between years. Owing to the vulnerability that early stages have to ocean processes, the stock is, then, totally controlled in a BOTTOP fashion (mixed bottom-up and top-down; Ruiz *et al.*, 2007) with the human pressure making the stock extremely exposed to environmental oscillations.
Some commercially important benthic and demersal species in the area include hake (*Merluccius merluccius*), several Sparidae, wedge sole (*Di-cologoglossa cuneata*) cephalopods like octopus (*Octopus vulgaris*) or cuttlefish (*Sepia officinalis*), and crustaceans like *Squilla mantis* or *Melicertus kerathurus*. This fishery represents 49% of the total catches in the region with hake and octopus as the main captured species.

Catalan *et al.* (2006b) found a strong spatial gradient of the structure of demersal assemblages of the Gulf related to depth, sediment type, and bottom temperature (all related to the distance from the Guadalquivir River mouth) that was responsible for most of the explained variability in global values and demersal species structure. The shallowest stations, also close to the Guadalquivir River mouth, showed higher numerical abundance and biomass values but lower diversity and number of species. Typical or abundant species from those stations included fishes from the families Sparidae (particularly *Diplodus bellottii*), Haemulidae, Soleidae or the stomatopod *Squilla mantis*. Deeper stations were defined by higher relative densities of cephalo-pods and several pleuronectiform fish. Significant seasonal differences in the abun-dance of several species also were observed at most stations, mainly between summer and winter. Species like *Merluccius merluccius* were particularly abundant in winter, whereas *Arnoglossus laterna* was more abundant in summer

The Spanish Society for Marine Mamals has evidenced, through the Life program LIFE02NAT/E/8610, the presence of harbour porpoise (*Phocoena phocoena*) and the bottlenose dolphin (*Tursiops trunctus*) in the north sector of the Gulf of Cádiz. Extensive observations have also been conducted in the context of their migration through the Strait of Gibraltar by the non-governmental organization CIRCE (http://www.circe.biz/). They evidence the significance of the Strait of Gibraltar as a migratory route as well as the threatens they face as a consequence of increasing marine traffic through the Strait. These studies also point at the importance of the oceanographic singularities of the area for other marine mammals like killer whales (*Orcinus orca*) or common and stripped dolphins (*Delphinus delphis* and *Stenella coeruleoalba*). These species are included in the Spanish National and the Andalusian Regional Catalogues of threaten species. In addition, harbour porpoise and bottlenose dolphin are in Annex II of the Habitat Directive whereas for killer whales both the International Union for the Conservation of Nature (IUCN) and the Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and contiguous Atlantic area (ACCOBAMS) consider this as a species under critical extinction threat.

Human activities and pressures on the marine environment

Aquaculture (NACE Code A3.2.1) is a very relevant activity in this area. The principal aquaculture activity in the Gulf of Cádiz is performed within the salt marshes of the Cadiz Bay. Part of the exploitation is made by extensive methods (i.e., with no artificial food) with the rest being done in semi-intensive conditions (i.e., using natural water ponds and using limited food addition). Therefore, the impact of this activity (mainly excretion products from the fish farms) is very limited and only affects the nearby coastal areas.

But fishing (NACE Code A3.1.1) seems to be the most important activity in this area. The Gulf of Cadiz is a highly suitable habitat for the reproduction of many commercially important marine species (e.g., Jiménez *et al.*, 1998; Millán, 1999) being the Guadalquivir River a key player in providing suitable spawning and nursery conditions from many fish species (García-Isarch *et al.*, 2003; Ruiz *et al.*, 2006). The fisheries at the Gulf of Cadiz (included in ICES region IXa) have traditionally represented an important socio-economic activity for the coastal population of SW Spain. Fisheries are an economically important activity in the region, being a considerable percentage of the primary industry in the area. The fishing fleet is very heterogeneous from small, family-operated boats, to bigger industrial vessels. Also fishing techniques are diverse although the majorities of the catches are made by bottom trawl. The second more important fishing fleet is the purse seiners, mainly devoted to small pelagics (anchovy and sardine). Finally, in some harbors of the Gulf of Cádiz, line-fishing is economically relevant as catches with this type of gear are highly valued.

An important multispecies–multigear artisanal fishery exploits the coastal fringe of the Gulf (Sobrino *et al.*, 1994; Silva *et al.*, 2002), extending off-shore in the central region of the Gulf, between the Guadalquivir and Guadiana estuaries. Bottom trawling is forbidden at the first 10km offshore, which embraces a shallow area of a maximum depth of 30 m.

Species catches vary greatly in space and time in association with the highly diverse environmental traits encountered in the shelf and the species life cycles (Sobrino *et al.*, 1994; Ramos *et al.*, 1996). Some commercially important benthic and demersal species in the area include hake (*Merluccius merluccius*), several Sparidae, wedge sole (*Dicologoglossa cuneata*) cephalopods like octopus (*Octopus vulgaris*) or cuttlefish (*Sepia officinalis*), and crustaceans like *Squilla mantis* or *Melicertus kerathurus*. This fishery represents 49% of the total catches in the region with hake and octopus as the main captured species.

Fishing of eel-larvae with aggressive gear in the area of the Guadalquivir estuary is increasingly considered as a problematic issue because of the by-catch impact on many early life stages of economic and environmentally significant species.

Maritime transport (NACE Code A.3.2.1) is very intense in the inner region of the gulf, close to the Strait of Gibraltar, as this is the unique connection of the Mediterranean Sea with the open ocean. Therefore, this area is highly polluted in terms of underwater noise levels and is also a potentially dangerous area for accidental spills from the numerous vessels.

There is very little miner activities in the Gulf of Cadiz. Only some sandy bottoms are sporadically dredged to use the sand for beaches regeneration. Past mining accidents like Aznalcollar seems to have produced little long-term impact on the nursery habitat of Guadalquivir river. New mining activities are being undertaken in this area whose impact is still to be considered.

There are some important chemical industries in the Gulf of Cadiz coastline, especially on the salt marshes area near Huelva. Among this, there is also an oil refinery with a collection buoy located in the continental shelf in front of Huelva. This has suffered different oil spills in the past and is now under consideration for increasing oil-flow capacity.

Also, land-use in the Guadalquivir river vicinity (mainly rice-farming) pollutes the river runoff and controls the freshwater inputs to the estuary. These anthropogenic activities determine the environmental quality of the estuary and the nearby continental shelf area, which is the preferential spawning and nursery are for many fish species.

Habitat fragmentation or, directly, habitat destruction by coastal urbanization and its subsequent transformation of the coastal territory where many species nurse is a very significant pressure on this ecosystem.

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