4. IMPACTS ON MARINE ECOSYSTEMS AND THE FISHERIES SECTOR

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ABSTRACT

The climatic system is defined by the interaction between atmosphere and ocean, and climate change cannot be accounted for if we do not consider the role played by the ocean. In turn, the ocean is altered by changes in wind, temperature and rainfall regimes and continental inputs and evaporation. Temperature increases have been detected on all Spanish coasts, as well as changes in the seasonality and intensity of certain oceanic processes, such as upwellings. There is evidence that the change in oceanic climate has been accelerating over the last few years. Climate change will also affect the exchange of greenhouse gasses between the atmosphere and the ocean, reducing the solubility of carbon dioxide.

Spain presents a great variety of ecosystems and marine species, which provide resources (fish and shellfish fisheries, recreation, marine farming), goods and services. Ecosystems are affected by changes in the hydrographic and environmental conditions deriving from climate change, as occurs with terrestrial ecosystems. The change is generating multiple direct and indirect responses; some of these interact with other human uses (fisheries, developments on coastline, etc.) and generate uncertainty with regard to each of the factors at play. The effects will differ for upwelling ecosystems or those comprising stratified areas, and for coastal and oceanic areas. Reduced productivity is predicted in Spanish waters, due to their characteristics as subtropical or warm temperate seas.

Changes have been detected in species distribution, with an increase in species from temperate and subtropical waters. Likewise, there has been a decrease in the abundance of boreal/northern species. Changes have been detected in many groups of organisms, from phytoplankton and zooplankton to fish and algae. It is very likely that there will be modifications in the future abundance and distribution of many species. An increase has been detected in invasive species, but the role played by climate change in this respect has not been studied.

Changes in ecosystems and in marine trophic networks are affecting resource species, especially during the larval phase and recruitment. Certain species are fished less and others more. We are unaware of the future balance between profits and losses caused by these changes, which cannot be isolated from the changes caused by the exploitation of fish species.

Marine culture that is not provided with food supplements might be affected by reduced marine productivity. Increases have been noted in the abundance of species of toxic phytoplankton or of parasitosis in cultured species. The evidence appears to indicate increased losses in cultures associated with the presence of these species, favoured by temperature increases in coastal waters.
The areas and systems most vulnerable to climate change involve benthic communities, comprising organisms attached to substrate, or associated species. Among the most affected are seagrass meadows.

The management of coastal marine ecosystems and of marine species should be considered from multispecific ecosystem point of view. The search for solutions should be promoted in order to mitigate the effects of direct human activity, and to conduct medium and long-term follow-up of interventions.

Among the research needs, we can highlight the consolidation of long-term environmental and ecological follow-up networks, along with the use and improvement of existing ones. Accessible databases should be promoted. Spanish participation in international programmes should also be promoted, as well as research plans aimed at learning of the impacts of oceanic change on species and ecosystems, from both a retroactive and prospective point view.

4.1. INTRODUCTION

4.1.1. Brief description of the area and characteristics of the oceanic waters of Spanish coasts

The Spanish coastline, including the archipelagos, measures around 7,880 km, which is quite an appreciable figure. It is washed by the Atlantic and the Mediterranean, an ocean and sea, respectively, of very different characteristics. The continental margin are generally narrow, as the coastal waters are. There is a great diversity of environments, from Boreal-Atlantic conditions on the coast of Galicia, to subtropical ones of the coasts of the Canary Isles. On all Spanish coasts, a summer period of stratification has been detected, the duration of which is variable. Much of Spain's Atlantic coast is affected by upwellings, annual or seasonal, and by the circulation of the Subtropical Gyre and the eastern limit of this. This circulation is modulated on Spanish coasts by currents the direction of which varies according to the season of the year; there is a noteworthy current associated with the continental slope in the West and North of the Peninsula running in a northerly direction in autumn and winter. The Mediterranean coasts are affected by slope currents (cold for much of the year) and by a prolonged period of stratification. The different processes (physical, chemical and biological) taking place in the exchange thereof between the Atlantic and the Mediterranean and their influence on the hydrological characteristics of the ocean, have made Gibraltar a paradigm as far as Straits are concerned. In the south of the Peninsula, upwelling processes are associated with these exchanges.

4.1.2. State of the resources exploited. Importance in the national GDP

The participation of the fisheries sector in Spain's economic activities is very similar to EU average, at around 1% of the GDP. It is of greater importance in the Northwest and North of Spain, without forgetting other regions, in particular Andalucia and the Canary Isles.

The economy of certain regions depends to a great extent upon fisheries (which represents 10% of the GDP in the Galicia regional autonomy), which is of great strategic value for these regions. Around the primary fisheries sector, a series of related complementary activities has been generated, with a multiplying effect (marketing, transformation, shipbuilding, technology transfer, auxiliary industry and services), and these comprise an inseparable economic and social unit. In the areas where it exists, the fisheries sector constitutes a traditional activity, from which a valuable source of food resources is derived, makes technology transfer possible and promoting a geographic concentration of intersectorial relationships and activities. Fisheries and marine farming are considered to be very important for many coastal areas, because employment is associated with the capture and transformation of this resource, regardless of the amount captures or the efficiency of the processes, especially in the case of artisanal fishing.

The Spanish fisheries sector comprises a series of fleets working in national fishing grounds in the Atlantic and the Mediterranean, in mid-distance fisheries (for example, waters of Scotland and Ireland, Celtic Sea, Bay of Biscay, Northwest Africa) and more distant zones (Newfoundland, Malvinas, Gulf of Guinea, etc.). The artisanal fleets fishing close to the coast.

Total Spanish production of marine fisheries resources showed a sustained downward trend from 1970 (1.4 million t) to 2002 (1.1 million t) according to statistical data by the FAO (Figure 4.1.A). Spain's fisheries in the Mediterranean is stabilised above 100,000 t. The production of big oceanic pelagic species (tuna and swordfish) presented a sharp rise from 1970 to 1990, and has remained relatively stable since then (Figure 4.1.B).

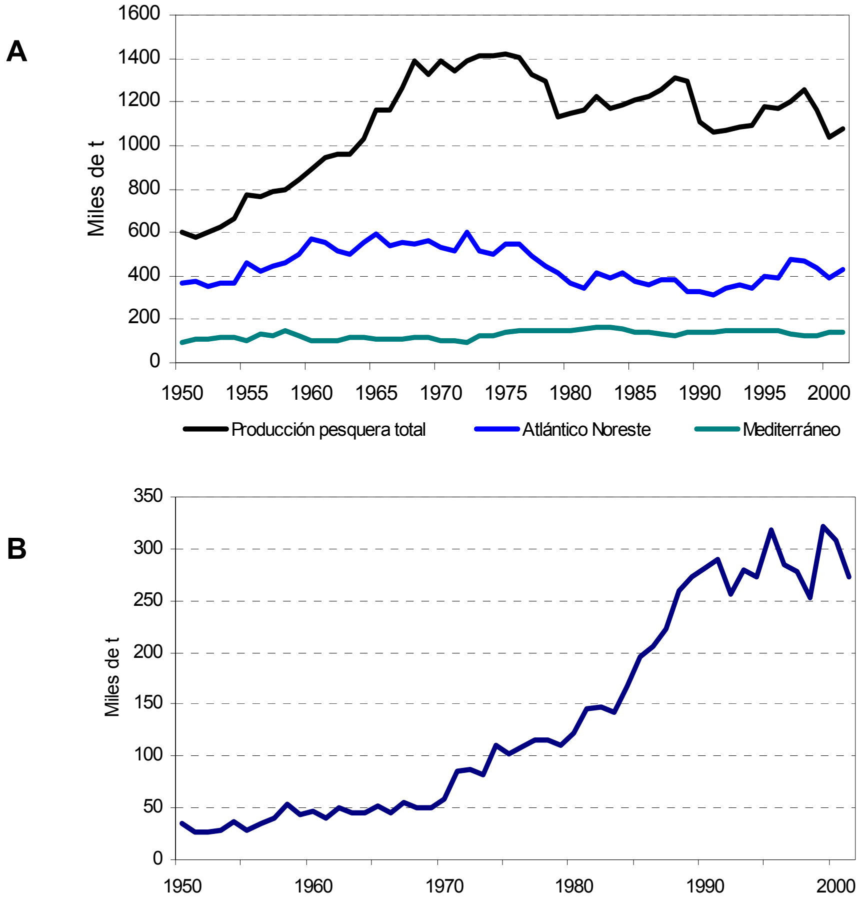

Fig. 4.1. *A: Marine fisheries production (fish, molluscs, crustaceans) (thousand of t) in Spain: total in the Northeast Atlantic and the Mediterranean, 1950-2001. B: Total Spanish catches of pelagic ocean species (tuna and swordfish), 1950-2001. (Source: FAO statistics).*

Approximately one third of Spain's fisheries production comes from the Northeast Atlantic, and the current contribution of groups of pelagic species and demersal species is very similar.

The fishing grounds of the Iberian area of the Atlantic are being intensely exploited and Spanish catches of the main pelagic and demersal species show a general downward trend which is more evident in demersal species (hake, angler fish, dory and Norway lobster), but other catches are increasing, such as mackerel, although these do not reach the same quantities.

Apart from fish, other marine products are taken from the Northeast Atlantic, such as algae, crustaceans and molluscs. The evolution of these catches has presented a downward tendency since the 70s, according to statistical data by the FAO (Figure 4.2). There appears to have been a sight increase in recent years in the production of algae and molluscs, although these statistics may not be reliable.

Spain's marine aquaculture production (Figure 4.2) was 320,000 t in 2003. Much of this production (approximately three quarters) corresponds to mussel culture in the *rías* of Galicia (Labarta 2000). The production of farmed sea fish (gilthead, sea bass, turbot, tuna) represents 6%, with a big increase in recent years, and production of other molluscs (clams, cockles, etc.) 4%, this figure having remained the same in recent years (Labarta 2000).

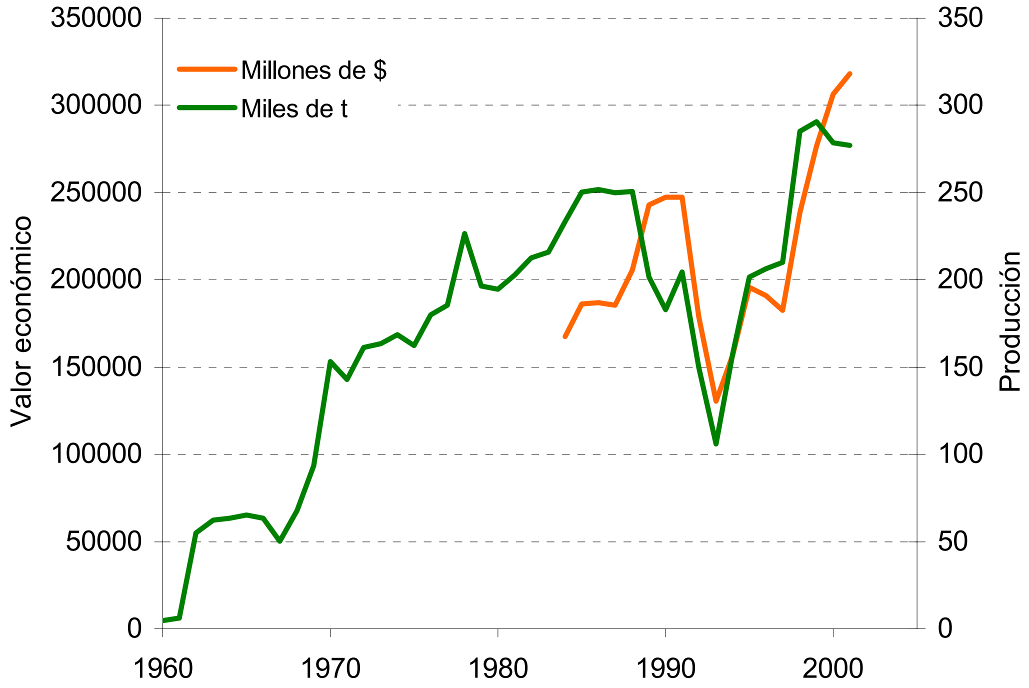

Fig. 4.2. *Spanish production of marine aquaculture and economic value. (source: FA statistics) and JACUMAR)*

Another series of activities, of which the main exponent is coastal tourism, in which sports fishing, diving and sailing should be included, constitutes an important set of resources, although these will be analysed in other chapters.

4.1.3. Marine biodiversity and protection

The great length of Spain's coastline, and the fact that this is washed by different seas over a wide latitudinal range, the Bay of Biscay, the Iberian Atlantic, the Mediterranean and the Atlantic islands, means that there is a great diversity of environments, coasts with greater or lesser tidal flow, upwelling areas (Canary Isles, Gulf of Cadiz, Malaga coast, Galicia and Bay of Biscay), coastal currents (Mediterranean and Atlantic coasts), areas of much exchange with the associated structures (eddies in the vicinity of the Gibraltar Straits; filaments on the coasts of the Canary Isles), very stratified subtropical areas (West of the Canary Isles), all of this involving very contrasted biogeographic situations. To this we can add communities of great specific richness, and the presence of very specific environments, such as submarine canyons. In short, all these characteristics confirm the fact that Spain has a great biodiversity in the marine environment and great potentiality with regard to resources. Of the marine ecosystems considered to be of great value as biodiversity reservoirs and protected by law in some regions of Spain, we can highlight estuaries and marshlands and fields of marine angiosperms (*Posidonia oceanica* in the Mediterranean; *Cymodocea nodosa, Zostera noltii* and *Halophila decipiens* in the waters of the Canary Isles; *Zostera marina* and *Zostera noltii* on the Iberian Atlantic coast, and the fields of algae in the intertidal and subtidal areas of the rocky coasts of the Atlantic and the Mediterranean. The coastal area is also rich in birds, some of whose populations are endangered; species of marine mammals are also frequent this area, most of these protected, as well as turtles.

Unlike the terrestrial environment, the network of marine protected areas was very poor until recently. According to data by the WWF in the years 1999, the Network of Marine Protected Areas (MPA) comprised 38 spaces, only 13 of which could be considered to be truly marine, whereas the rest involve protected terrestrial and coastal areas. The recent creation of the Atlantic Isles National Park merits a whole chapter in itself. The same can be said of the classification as Human Heritage of the fields of *P. oceanica* between the islands of Ibiza and Formentera. Furthermore, there are 18 Marine reserves of fisheries interest, managed by the Agriculture, Fisheries and Foodstuffs Ministry, by the respective Regional Autonomies or through mixed management (http://www.mapa.es/). The recent implementation of the Red Natura 2000 has led to a big increase in the number of protected coastal areas, particularly in the regions of the Mediterranean basin and the Canary Isles. Thus, for instance, the Canaries have 22 exclusively marine LICs and 3 terrestrial-marine ones. On the archipelago, there is a total of 172,215.9 ha of marine LICs (Canary Isles Protected Areas Network, 1995; Natura 2000, Canary Isles Regional Govt., 2000). All the protected marine areas, however, are on the coasts, and there are no reserves on the high sea or on the platform in the waters of Spain's exclusive economic area. Neither has the design of the protected areas been homogeneous with regard to territorial design, and the criteria used have not involved consensus among the different regional autonomies, and certain doubt therefore remains in relation to the complementary nature and optimisation of these areas.

There are protection measures specifically related to fisheries, in the form of reserve areas, closed seasons and prohibited areas, minimum sizes, restrictions of the use of certain types of fishing tackle and fisheries quotas for certain types of species (European, national or in regional autonomies). These measures are aimed at the sustainable use of the resources, rather than at the conservation of ecosystems in the strict sense. In any case, fisheries and conservation are considered to constitute a binomial that should be jointly developed in order to maintain the sustainability of the activity. Protection measures, in the case of migratory species (e.g. tuna, cetaceans or turtles) should encompass all the geographic ranges of these species, such as what is done with terrestrial migratory species. International regulation or co-operation should be promoted.

4.2. SENSITIVITY TO THE PRESENT CLIMATE

The ocean affects climate and this, in turn, affects the characteristics and dynamics of the ocean. Climatic variations and changes can directly affect the ocean, on varying flows of energy and gasses with the atmosphere, the amount of heat and salts transported (temperature and density), the formation and area of sea ice, and, as a result of all this, circulation. Modifications in evaporation and precipitation patterns, or accumulation-melting in continental ice fields can also make an impact. All these events can cause changes in the thermohaline circulation of the ocean (Broecker 1997, Broecker *et al*. 1999), and heat transport between the equator and the poles will therefore be reduced. This situation could give rise to very rapid climatic changes. They could also have an indirect effect on marine organisms and ecosystems (Fig. 4.3)

A second indirect effect could derive from changes in the arrangement of high and low atmospheric pressures and in wind intensity. This situation would generate change in sea currents and in the distribution and seasonality of these, and also in wave patterns. Changes in hydrodynamic conditions will have a direct effect on ecosystems and marine biodiversity, due to modifications in the distribution of temperature and nutrients in the upper layers of the ocean, in marine primary production, and, in short, the marine trophic network, where our main resources are found – fish, molluscs and crustaceans. Changes in the arrangement of mesoscale structures can influence the survival of the larval stage of multiple species, generating changes in exploited fish populations. An example of the effects of mesoscale structures can be seen in (González-Quirós *et al*. 2004).

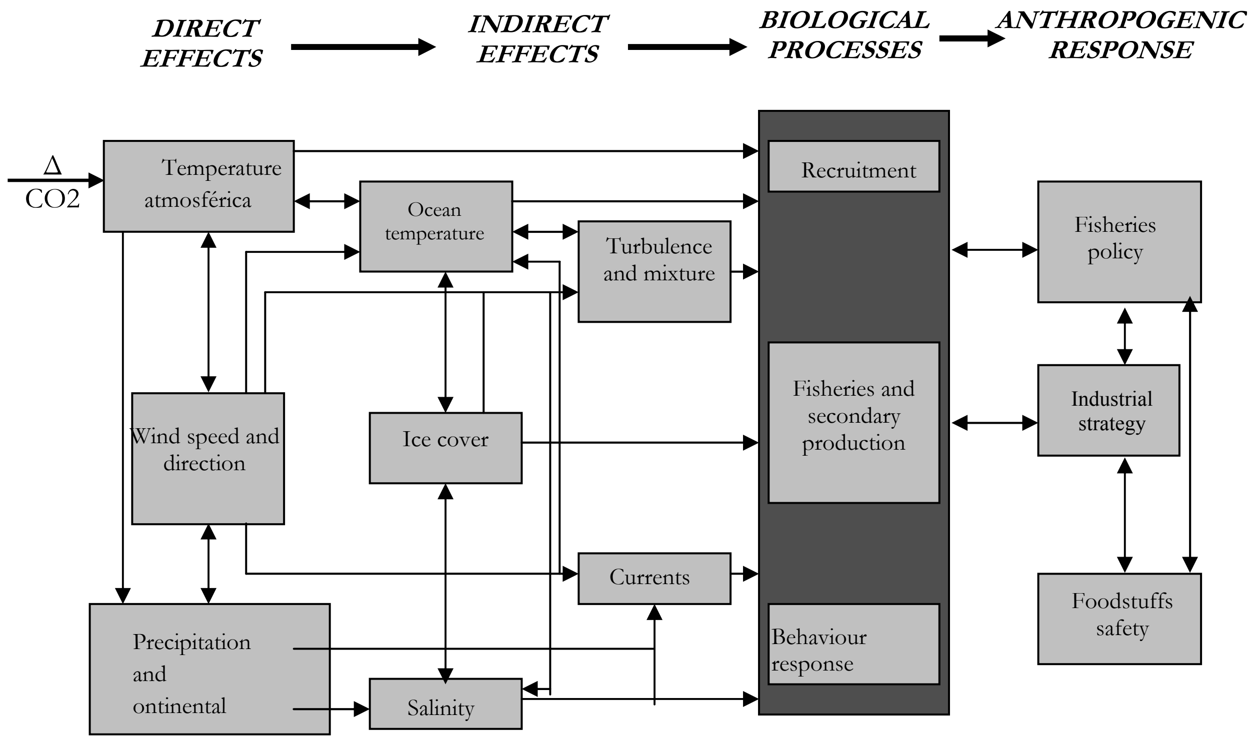

Fig 4.3. *Main channels through which climate change could affect marine populations and the exploitation of these, which are core objectives of the programme GLOBEC of the IGBP (GLOBEC 2003)*

To the modifications that could be generated by climate change, we must add the changes deriving from direct human action, such as the capture of populations of multiple species, and these should be framed within a term of higher rank, Global Change. Without any consistent information, it will be difficult to demarcate the effects of the different causes.

4.3. FORESEEABLE IMPACTS OF CLIMATE CHANGE

4.3.1. Impact upon productivity

Analysis of the ecophysiological responses of marine microalgae, the photosynthetic capacity or growth of these, or changes in the ocean associated with CO_2 increases and with Global Warming, provides no clear information in this respect (Beardall and Raven 2004). However, the series of consequences of these effects upon nature probably reflect the complex interactions that can take place between the elements of climate change and other associated factors, such as nutrient availability. The predictable increase in the stratification period (Richardson and Schoeman 2004), or the change in mesoscale processes (upwelling, fronts, coastal currents) could significantly modify the ocean's production capacity, reducing or increasing primary production. This effect could spread to the production of coastal ecosystems, communities of macroalgae or to fields of phanerogams, although processes in the opposite sense might be generated. An increase in CO_2 partial pressure in the atmosphere and in surface waters could lead to increased productivity of the fields of phanerogams or communities of marine macroalgae, as they would be limited by CO_2 availability.

The change in marine productivity would directly affect food availability for the consumers, and in a secondary way, the whole marine trophic network. Certain extensive cultures of filtering organisms, mussels or clams, could be affected; other organisms of great economic interest, like the goose barnacle, could also be affected. If climate change causes a change in the intensity and frequency of waves, populations in the intertidal areas might be affected, some of which may be of commercial interest (Borja *et al*. 2004).

4.3.2. Impact upon species distribution

Associated with changes in the thermohaline properties of the ocean, and with changes in other related processes, we can expect changes in the distribution of many species, both pelagic and benthic ones. A temperature increase would have the direct effect of displacing the geographic ranges of many species (Southward and Boalch 1994, Southward *et al*. 1995, Alcock 2003). The change might speed up or slow down according to the effect of atmospheric changes upon currents or seasonality. Not all the changes will be negative ones, such as reduced species production, and neither will these occur in all parts of the coast. There may be increases in some species, although there is no analysis of the tendencies to be expected according to climate change models.

This displacement will affect mot groups of organisms, both plant and animal, leading to the appearance of species of southern origin, or to the disappearance of northern species. As an associated effect, we cannot rule out the possibility of interactions between the old and new species, biological relationships that have effects that do not directly depend on environmental change. Among the species that could be affected, are the anadromous ones (reproducing in rivers and growing in the sea), salmon, sturgeon or catadromous ones (reproducing in the sea and growing in rivers), eels. Changes are also foreseeable in the geographic range of exploited coastal species, or asociated to changes in abundance of the populations.

4.3.3. Impact upon fish populations. Recruitment and distribution

In the life cycle of exploited marine species, recruitment is a key process and is directly influenced by climatic variability. Variations in atmospheric circulation affect sea currents, and these can modify the transport and survival of larval and juvenile stages. At a greater scale, there could be changes in the trophic chain. Climate changes also indirectly affect marine systems. Marine, primary and secondary production could be affected, which in turn would affect the food available for fish larvae, which would determine the degree of success of recruitment, and, in the medium term, population size (GLOBEC 2003, ICES 2003). Described among the changes are shifts in circulation regimes, sometimes very rapid ones (Hare and Mantua 2002, Chavez *et al*. 2003), which can generate changes in the pelagic community, and even in the benthic one. By way of an example, (Chavez *et al*. 2003) calls them sardine regime and anchovy regime.

Another type of change is related to low-frequency modifications, like the North Atlantic Oscillation (NAO index). Impacts have been described on the growth and recruitment of commercial species of pelagic anddemeral fish in the Northeast Atlantic (Drinkwater *et al*. 2003). Climatic variation (represented by positive and negative phases of the NAO index) govern the alternation of periods of great or little abundance of herring and sardine in the Northeast Atlantic. The positive NAO index has increased in recent years, and we can therefore probably expect associated changes in the future. Associated with the NAO are fluvial discharges that present a relationship with species recruitment in the Mediterranean (Lloret *et al*. 2001, Lloret and Lleonart 2002). Upwelling systems are also associated, in which the production of pelagic species is controlled by processes of nutrient enrichment, food concentration and larval retention (Bakun 1996).

Changes in species can also occur as a physiological response to thermal or saline changes. As an example, it has been suggested that likely changes in the distribution range of species of anadromous fish, given that temperature change can influence proteic synthesis.

Indirectly, there could be alterations in the migration patterns and spatial distribution of certain oceanic pelagic fish (Atlantic bluefin tuna, Albacore among many others) caused by changes in the distribution and abundance of prey. Spanish Albacore fisheries in the Atlantic are seasonal and are exploited during the feeding migration of this species from waters of Madeira and the Azores to western Europe and the Bay of Biscay. The advance of the migration front is associated with a gradual increase in surface temperature. Substantial modifications in the seasonal distribution of the isotherms could affect migratory routes and, indirectly, fisheries in the Bay of Biscay. To the contrary, species of subtropical origin may appear in waters of the Iberian Peninsula (these are already present in the Canary Isles). Some of these species are subjected to sports fishing, and could therefore indirectly affect coastal tourism.

Although less studied, many of the aforementioned factors could affect populations of demersal, or benthic species, and even populations in very deep waters, such as populations typical of canyons. The transport of material from the productive layers of the ocean to the deeper zones may be very rapid. The indirect effects of climate change on exploited demersal populations, however, have not been studied in any depth.

4.3.4. Impact on marine farming

The predictable changes in marine productivity are still quite uncertain. Although changes in phytoplankton productivity associated with hydrographic modifications (Richardson and Schoeman 2004), have been recognised, the predictions of the effects of these upon marine farming are still quite uncertain. The culture of species that provide food supplements should not be affected much, given that modifications in the ration ought to be sufficient to compensate for changes in productivity. Another question is whether environmental change will exceed the physiological limits of the species (dissolved oxygen, temperature, salinity), in which case severe damage could be caused.

Cultured apecies with no food supplement and under an extensive system might be affected. This is the case of molluscs: mussels, clams, oysters and scallops in the *Rías* of Galicia, the Ebro delta and other places on the coast.

Extreme climatic events could have a potential effect on cultures. An intense and continued supply of fresh water in confined areas, such as the *Rías* of Galicia, for example, could reduce salinity, thus causing the mass death of organisms of the benthos, including molluscs in seabed or mussel rafts.

Potentially serious effects upon coastal ecosystems, associated with modifications in hydrographic conditions, but also with increased nutrient dumping by continental waters, involve the proliferation of harmful algae. Among these effects, we should consider changes in the stoichiometry of the dissolved nutrients, as an increase in N/Si relationship favours the proliferation of dinoflagellates over diatomites, and an increase in N/P increases the toxicity of certain species. This proliferation could affect certain sectors, such as mollusc aquaculture, and might also have consequences for human health.

The increase in parasites in the clam and oyster mariculture could be another serious effect of climate change on marine farming. The clam and oyster parasite *Perkinsus* on the coasts of Galicia, possibly introduced by the farming of Japanese clams and oysters, was recently detected and is favoured by temperatures of over 20 ºC. Summertime temperature increases could facilitate the spread of these parasites, along with the damage they cause.

4.4. MOST VULNERABLE AREAS

4.4.1. Vulnerability and Sensitivity of marine ecosystems and fisheries (species and alternatives)

Marine ecosystems are very vulnerable to the multiple simultaneous changes caused by climate change, which mostly affect coastal or shallow ecosystems. A rise in sea level might threaten the communities of marine phanerogams rooted on the seabed between depths of 0.5 m and 45 m, causing underwater erosion and habitat losses or increases, depending on the case.

Changes in seawater temperatures could make many species vulnerable whose temperature limits cause, as has been pointed out, changes in the biogeographic ranges of the species, with a tendency towards the proliferation of subtropical species, making the northern species of our coasts vulnerable. These changes in species distribution do not only influence the appearance of subtropical species, but also increase the risk of invasion by exotic species of subtropical origin which have been accidentally introduced. An example of this is the presence in the Canary Isles of the Australian species *Caulerpa racemosa* var. *cylindracea* (Verlaque *et al*. 2003). Furthermore, seawater temperature affects the life cycles of the species present on our coasts, and, in particular, the intensity and seasonality of sexual reproduction. Variations in recruitment deriving from these changes will cause changes in the demographic balances of the species involved, giving rise to modifications in the composition of communities. Another cause of vulnerability for many species or ecosystems is increased respiratory metabolism, which is sensitive to temperature increase, as this would lead to increased oxygen consumption, and CO_2 production in marine ecosystems and particularly in microbial activity.

The sustained increase in CO_2 partial pressure, on adjusting with the growing partial pressure in the atmosphere, is causing the acidification of the seawater, which can be seen in the detectable decrease in the pH of the water (Caldeira and Wickett 2003). This decrease is expected, within the next 50 years, to be sufficient to clearly reduce, and even halt, the deposition of carbonates in organisms with skeletons or calcified shells, such as bivalve molluscs, reef-forming corals and coccolithophorids among other. This makes them vulnerable. In the longer term, for the CO_2 concentrations expected for the end of the XXI century, there will be a sufficiently intense decrease in pH to initiate the dissolution of carbonates in coastal waters, which will affect CO_2 absorption by the ocean.

Variations in patterns of ocean currents and circulation brought about by changes in the distribution of bodies of water and wind regime caused by climate change will undoubtedly affect the recruitment of all the species depending on these currents to situate their propagules in areas favourable for the growth and survival of the recruits. The vulnerability that this causes in recruitment is difficult to predict, as the current patterns resulting from climate change are subjected to great uncertainty, particularly at local scale.

The pressure caused by climate change cannot be isolated from the direct pressure of human activity on ecosystems. The responses by the ecosystems and organisms to this simultaneous pressure is not necessarily accumulative, and synergic responses could be unleashed that magnify the effects of climate change in relation to those that would occur in ecosystems not subjected to additional pressure. All of this considered, the prediction of the effects of climate change upon marine ecosystems cannot be directly calculated as the sum of the responses of each one of the dimensions of climate change.

The additional pressure concurring with that directly caused by climate change in our country involves: (1) increased transport of nutrients and organic matter to the coast, (2) the impoverishment of fisheries stocks (3) the degradation of the seabed resulting from trawling and mooring, (4) habitat destruction and damage resulting from the development of the coastal area and the proliferation of structures and buildings on the coastline and (5) the increased risk of pollution episodes associated with increased sea transport deriving from the globalisation of the economy.

The most vulnerable ecosystems are therefore those where all these types of pressure concur, and within these, those comprising the more long-lived, slow-growing organisms, like the Mediterranean red coral and the Canary Isles black coral; the fields of algae at certain depths, marshes and fields of *Posidonia oceánica* in the Mediterranean Sea, the fields of *Cymodocea nodosa* and populations of *Zostera noltii in the* Canary Islands, and the fields of *Z. noltii* and *Z. marina* of the Iberian Atlantic coast, and the fields of brown algae found on all of Spain's coasts.

It is particularly complicated to establish which species will be the most vulnerable ones. General criteria can be applied, such as the length of the life cycle, species associated with vulnerable ecosystems, specialist species, but there will always be great uncertainty with regard to the modifications caused by climate change.

4.4.2. Analysis of the vulnerability of coastal and long-distance fisheries

One aspect of the fisheries sector that cannot be forgotten is that part of the decreases in catches could be due to overexploitation, and this should therefore be considered within a higher framework, that of Global Change. But we cannot rule out an interaction between increased fishing capacity and modifications in the environment caused by climate change, which affect the lives of species subjected to capture (Francis and Sibley 1991). Faced with the lack of definitive data, we can only suspect that the loss of some fishing grounds Is due to this cause.

With the exception of species subjected to very fluctuating catches (anchovy, horse mackerel, pacific sardine and japanese pilchard and abadejo de Alaska), most commercial species have been globally subjected to overfishing since 1980. It is estimated that big subsidies will be needed to keep the world fishing fleet afloat, as this is operating at an overcapacity of 30-50%. The present state of the fisheries sector presents a very limited capacity for increase (fig. 4.4.A), given that most of the world's stocks are now at maximum capacity (FAO 2000) (fig 4.4.B).

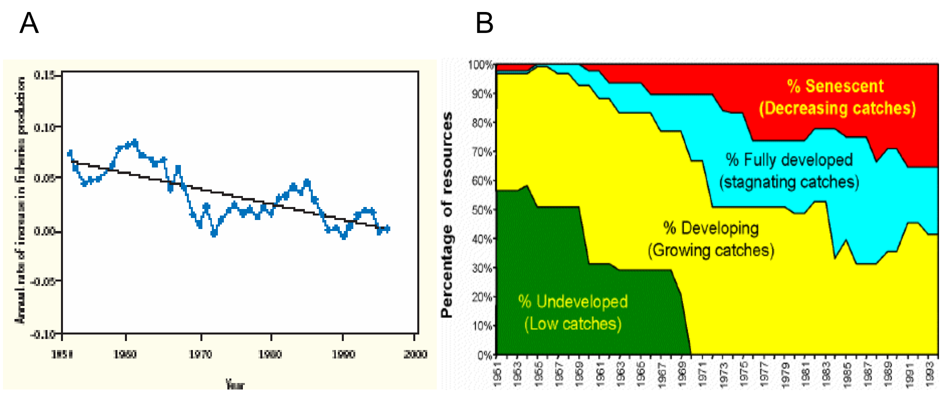

Fig. 4.4. *Global tendencies in world fisheries, A: Annual rate of increase in fisheries production. B: Proportion of stocks being exploited to the maximum capacity or overexploited (FAO 2000)*

There is an evident overexploitation, however, of certain resources, such as depredating fish, throughout the world (Myers and Worm 2003), including in the temperate and tropical Atlantic.

Overfishing of adults can cause evolutionary changes in maturation age, and, in a secondary way, the collapse of stocks (Olsen *et al*. 2004). In any case, the interaction between overfishing of adults, evolutionary changes and changes in the recruitment generated by modifications in mesoscale circulation could bring about the collapse of currently exploited populations of species, or benefit other species. We can only speculate upon which species with long life cycles and low reproduction rates, that is, a low population growth rate, will be most affected.

This is the case of sharks, but the tuna species may also find themselves in this situation.

The aforementioned effects of climate change on recruitment might be the cause of the decline of certain species or could be influencing accessibility to traditional areas (Beare *et al*. 2004)

4.4.3. Analysis of the vulnerability of keystone organisms in the marine environment

Keystone species are those that organise or structure ecosystems. Among these are architect species which, due to their morphology or degree of development, create new environments that can be used by other species, or species which, due to their interspecific relationships, are capable of altering the trophic networks within which they are framed.

Species of marine phanerogams, which form meadows constitute one of the significant cases on Spanish coasts. The role they play ranges from sediment fixation to protection of the coast from waves and storms to providing habitats to sustain the recruitment of a large number of vertebrate and invertebrate species. The fields of phanerogams are registering a sharp decline on Spain's coasts and worlldwide; the global loss rate is 2 % annually. The loss rate of the fields of *P. oceanica* in the Mediterranean is ever higher, with an average loss rate of around 10% per year on peninsular coasts, somewhat (3 % per year) on the coasts of the Balearic Isles. The field of *Zostera noltii* in the Canary Isles are also retreating. Half-way through the 90s, the field was reduced to very few specimens, and was included in the Canary Isles Threatened Species Catalogue (BOCA 23 julio 2991, Decreto 151/2001) with the category of “ Endangered”.

This loss of area reflects aspects of climate change, such as the generalised tendency towards underwater erosion deriving from a rise in sea level, which uproots the rhizomes of these plants, increasing their vulnerability to storms and intense waves. The degradation of the fields of *P. oceanica* has also been associated with the proliferation of the invasive species of macroalgae of subtropical origin *Caulerpa taxifolia*, accidentally introduced into the Mediterranean, and *Caulerpa racemosa*, introduced through the Suez Canal, which reached the coasts of the Balearic Isles a few years ago and which has recently been located in the Canary Isles (Verlaque *et al*. 2003),where it is associated with fields of *Cymodocea nodosa*, a taxon with the category of “Sensitive to habitat alteration” and *Halophila decipens,* with the category of “of special interest”, included in the Canary Isles Threatened Species Catalogue. Although we cannot blame climate change for the introduction of these species, it has been suggested that the increase in sea temperature, as we are dealing with species of subtropical origin, could favour their capacity to exclude the autochthonous flora, in particular the fields of *P. oceánica* (Mediterranean) and *C. nodosa* and *H. decipiens* (Canaries).

It should be noted, however, that in the loss of these ecosystems, other causes intervene which are related to human activity: deterioration of water quality due to dumping from land, the proliferation of structures on the coastline which cause underwater erosion, and the direct impacts of anchors and trawling tackle.

Whereas the re-colonisation time for fields of species of marine angiosperms in the Atlantic is approximately one decade, the recovery of the fields of *Z. noltii* and *P. oceanica*, slower-growing phanerogams, involves time periods estimated at several centuries, and losses must therefore be considered as irreversible with regard to the management of coastal ecosystems. The loss of fields of *P. oceanica* leads to the loss of the species this houses, some of these protected ones, such as the fan mussel (*Pinna nobilis*), a bivalve reaching 1 m long in the Mediterranean, or the fields of *Z. noltii* in the Canary Isles, containing the habitat of species of protected fauna.

Although the long-term effect of climate change upon *P. oceanica* is unknown, recent data suggest that no mechanisms exist to reduce these serious losses in the short term. There is recent evidence of changes in the flowering and fruit and seed production of this species. The compilation and reconstruction of the flowering process of *P.* oceanica in the Mediterranean sea shows two episodes of increased flowering in two years with high temperatures: in the year 2001, following a summer in which seawater temperatures above normal ones were reached, when no seed production occurred, and in 2003, when higher maximum surface seawater temperatures were recorded, which led to the mass production and release of fruits and seeds that are taking root on the seabed in the summer of 2004. If we extrapolate this relationship to estimate the effect of warming of between 1 and 4 ºC, which is expected for the year 2050, it indicates that the prevalence of flowering should increase by between 10% and 40%. This increased sexual production could increase the species' capacity for re-colonisation, although this will never be sufficient to compensate for the losses.

Other communities of marine macrophytes are also retreating, although the role played by climate in this retreat has not been clearly established; this is the case of fields of brown algae of the genus *Cystoseira* in the Canary Isles, which has been repeatedly indicated in reports and projects.[1]

4.5. MAIN ADAPTATIONAL OPTIONS

4.5.1. Alternatives in exploited species, in fisheries structures, fishing species in other areas, compensation with product price, intervention strategies in fisheries

The carrying capacity of the different stocks could be gradually modified as changes take place in the ecosystems. Modifications (increased or reduced production rates) will involve adaptational fisheries strategies. Modifications in reproduction rates will determine changes in the biomass of stocks which will need to be adjusted to the fisheries effort. This becomes complicated in the case of multi-species and fisheries with multiple fishing methods like those in the Iberian Atlantic Region and the Canary Isles. No simulations, however, of possible scenarios have been made. If climate change were to cause stocks to diminish in time, total annual catches would decrease and the fisheries sector would present a long-term tendency towards decline.

The problems deriving from reduced stocks could be camouflaged by price rises and profits for the fishermen. In the long term and economically, the losses may be marginal. If the fisheries sector is to seek maximum economic yield, the systems used for fishing the older age classes (bigger, more profitable fish) might displace or eliminate the activity of other types of fisheries aimed at the capture of smaller-sized fish. Other cases that might arise involve a drastic

[1] "Quantification of marine communities and assessment of the Biodiversity in the El Palmar coastal section"; "Bionomics cartography of the Tenerife coastal fringe (1st part: Teno-Rasca)"; An inventory of the species inhabiting in the reefs and underwater caves in the Canary Isles"; "Study of the biology and ecology of the sea urchin *Diadema antillarum* and of the succession communities in the different pipe-clay areas of the Canary Isles"; "Binomics cartography of the coastal fringe of Tenerife (2nd part: Punta Negra- Roques de Fasnia)

reduction of carrying capacity and the collapse of stocks which would cause a significant reduction of fishing, leading to marginal changes in reproduction capacity which would not affect fishing capacity, or that there would be an increase in the stocks already exploited, or that fishable species would appear that had not previously existed. In the latter cases, the adaptation of the fleets or equipment would be much simpler.

A similar change to stock reduction occurs when some species modify the routes or the seasonality of their migration (Beare *et al*. 2004), and when the fleets that fish them cannot gain access to the stock in this new situation. The mechanisms for adaptation would be similar to those needed when changes in reproduction rates occur. Planning the fleets' activity would require knowledge of the new routes and the reasons for the variations in these, and new interventions would probably be established in European or international relations.

If the objective is the sustainable management of fisheries (Pauly *et al*. 2003) suggest two types of considerations. Environmental ones, which would involve the regulation of subsidies aimed at avoiding overfishing, which in turn, would require the reduction of the fleets. And considerations related to foodstuffs safety, which would involve the discovery of new fisheries or the alternative use of the existing ones, with the problem of affecting other, poor countries, or of transferring environmental damage to their coasts. But we could contemplate alternatives that mix both principles, promoting social equality and environmental regulation. In any case, all this would involve changes in the fisheries regulation systems and agreements among the interested parties.

The establishment of protection areas, in which fishing is prohibited or limited, acting in synergy with the exploited areas, therefore mitigating the effects of fishing on populations or those of environmental change, is a strategy that should be consolidated (Castilla 2003). Thus, the sustainability of a functional and diverse ecosystem, in which the resource species develop their life cycles, would be favoured (Pauly 2002). Advances are being made in the holistic vision of fisheries, and consideration is being given to changes in the ecosystem containing the populations subjected to fishing (Bostford *et al*. 1997), and to anthropogenic influences (physical changes in the ocean resulting from climate change, habitat destruction, pollution, harmful algae blooms).

4.5.2. Adaptation strategies in marine farming

The establishment of new species farming, both of animal and plant ones, could constitute an adaptational response to changes in the environment. But we must keep in mind the dangers posed by the introduction of foreign species for breeding to autochthonous populations and to the ecosystems that contain these. Parasite control of introduced species should be a priority. Parasites introduced with certain farming species can cause damage to the existing ones, especially if their response increases with a temperature rise. The principle of caution should always be applied to prevent the introduced species from escaping from the established controls and from becoming established as invasive species.

Establishing the sustainable carrying capacity of the ecosystems in which the cultured species are introduced, as well as the influence these can have in the environment could constitute a basic adaptational measure aimed at sustainable production. Weather and coastal environment forecasts providing sufficiently timely and accurate warning of possible extreme climatic events (torrential rains that reduce salinity in the environment), together with action procedures, would enable the damages to be limited.

4.5.3. Strategies for the preservation of keystone species

There seems to be a pressing need for species preservation, given the influence of biodiversity on the ecosystems' capacity for resistance and absorption of changes generated by external environmental pressure. In this respect, the preservation of keystone species plays a vital role, given their capacity to affect the structure and functionality of the ecosystems.

Although the number of ecosystems studied on Spanish coasts from the functional point of view is low, and has therefore not been well established, reducing the pressure therein appears to be the best adaptational decision. Apart from the influence of environmental change, we must consider the protection of spaces where these species are safe from human pressure and production, tourism and recreation-related activities, or from development and population growth in coastal areas. The definition of a network of marine protected areas (MPA) in waters of the Exclusive Economic area should take these criteria into account, along with those related to the complementary nature and uniqueness of these spaces, in order to promote conservation and sustainability (see (Palumbi 2001, Castilla 2003).

4.6. REPERCUSSIONS FOR OTHER SECTORS OR AREAS

The increase in the flowering of harmful algae, but also of urticant animal species, such as siphonopophorid jellyfish during warm months is at least partly related to an increase in water temperature and in organic nutrients. This can be troublesome for the tourism sector. Increases have been detected in the flowering of toxic dinoflagellates in coves of the Catalonia coast and in the Canary Isles and of jellyfish in the Mar Menor. There may be more sightings of this kind in the future. The effects of this upon tourism cannot be estimated, but it seems logical to think that it would restrain demand. Increasing our knowledge of the causes thereof and correcting these if possible would be the best adaptational strategy.

Water quality in tourist or production areas could be affected by urban or industrial dumping, which are not directly related to climate change. Changes in local circulation caused by this could alter the current situation. The best adaptational option is to establish and correct these emissions.

4.7. MAIN UNCERTAINTIES AND KNOWLEDGE GAPS

4.7.1. Relationship between warming of the sea and the role played by this as a carbon sink

For time scales of less than 1,000 years, the ocean is the main deposit of carbon dioxide. Atmospheric CO_2 of natural origin and that produced by the burning of fossil fuels are only a small fraction of that found in the sea and in sediments. Approximately 35% of anthropogenic emissions of CO_2 in the last 100 years has been absorbed by the sea. Relatively small adjustments in ocean circulation could significantly affect the amount of CO_2 in the atmosphere, even if the emissions of anthropogenic origin were to become stabilised. If stratification increases in the oceans, water convection will cease and the deepth mixing mezcla profunda will be reduced. CO_2 will not be transferred to the deeper layers of the ocean, the storage capacity of which will therefore be limited.

Another negative factor will be the change in pH caused by the dissolution of the CO_2 itself; this could displace the CO_2 – bicarbonate balance, limiting the ocean's CO_2 storage capacity (Feely *et al*. 2004). Effects associated with the reduced pH would involve: 1) reduced calcification in organisms with carbonated skeletons, which would limit the long-term (sink) withdrawal of dissolved carbon and 2) the potential elevation of the lisocline (depth limit at which carbonates are dissolved), which might favour the dissolution of carbonates accumulated in the sediment; in extreme cases, which cannot be ruled out, the lisocline would rise to the surface, which would cause rapid and radical emission of CO_2 into the atmosphere, thus increasing the greenhouse effect.

Although they have not yet been quantified, positive change in biogenic carbon storage would increase CO_2 absorption and reduce the greenhouse effect.

4.7.2. Seasonal changes in winds and recruitment

We have already mentioned the described effect of changes in the NAO and recruitment, whether through a direct relationship (effect on larval transport) or indirect (interaction with the prey community).

4.7.3. Sea level rise and coastal communities

The rise rates in sea level are sufficiently slow to allow most species to make significant changes in their distribution ranges. On rocky costs, this would involve the colonisation of higher areas, on exposed sedimentary coasts, and if the sediments were to be rearranged, no appreciable changes in communities could be expected, except in those where erosion can occur (see the case of *P. oceanica*). The areas corresponding to estuaries or coastal lagoons will possibly be the ones most affected. The impossibility of re-siting sediment deposits could cause the disappearance of certain environments, or the modification of others, through salinisation. In these conditions, the distribution area of some communities could easily be restricted. Birds might be among the organisms affected.

4.7.4. Interactions between fisheries and climate change

Changes and tendencies related to catches appear to be related to a previous increase in fishing, due both to technological capacity and to the bigger fleets in many countries. We could therefore consider that they are the result of Global Change (GC), rather than climate modifications. In spite of this, there is increasing evidence that, at least during larval stages, changes in coastal circulation, thermohaline conditions, productivity and availability of prey might be responsible for the tendencies observed.

The problem becomes exacerbated when we are dealing with multispecific fisheries. To the responses by each species we must add the existence of interactions among different species, which are not well-known at present. There is a need for more in-depth study of the concept of the fisheries ecosystem (Large Marine Ecosystem) (Sherman *et al*. 1992), and to acquire information that provides us with a more complete view of the synergic effects linking fisheries, climate change and species interactions.

4.8. DETECTING THE CHANGE

4.8.1. Time series of oceanographic variables

Different types of information are available on the variability related to climate change in the North Atlantic basin. Analyses based on temperature observations in the XX century in relation to the calory content of the surface layer of the water (Levitus *et al*. 2000, Levitus *et al*. 2001), of the origin or thermohaline properties of the Atlantic (Curry *et al*. 2003) are a good example. The

study of data series at key points also reinforces the idea of a change in oceanic conditions, such as decreased salinity in deep arctic waters (Dickson *et al*. 2002).
The detection of changes in temperature and salinity are based on the existence of databases over prolonged time periods. The extension of the data series conditions these studies and their capacity to make predictions of future variations. But circulation variability also has an influence, as well as the alterations that can be caused by climate change itself, as both mechanisms can give rise to the advection of the waters in different areas.

Using as a reference the series of COADS (1844-2000) of surface temperature in the Bay of Biscay, certain oscillations can be appreciated in the last century. A surface temperature increase from 1900 to 1960 was followed by a decrease up to 1980. Since then, the increase has been continuous and accelerated up to the present (Southward and Boalch 1994, Planque *et al*. 2003). It is in this framework that we should interpret the higher values detected on our coasts in recent years and which are shown in table 4.1. In short, there is very consistent information relating to surface water temperature increases around the Iberian Peninsula, of approximately 0.4 – 0.5 ºC per decade. Changes have also been detected in intermediate and deep waters, a fact that tallies with the results obtained in studies covering a greater geographic range.

Table 4.1. *Temperature increase rate (ºC per decade) and salinity at points close to the coasts of Spain, with an indication of the length of the time series analysed, situation, depth and reference.*

Site	Situation	Length of the series (years)	Depth (m)	Rate of (ºC decade)	Increase (psu decade)	Author
Bay of Biscay	English Channel	1860-1990	Surface	0.06		(Southward and Boalch 1994)
Bay of Biscay	Ocean	1870-1990 1970-1999	Surface Surface	0.13 0.6		(Planque *et al*. 2003)
Bay of Biscay	Ocean	1972-1993	Surface	0.66		(Koutsikopoulos *et al*. 1998)
Donostia (San Sebastian)	Coast	1947-1997	Surface	-0.062		(Borja *et al*. 2000)
Santander	Ocean	1992-2002	10	0.60	0.04	(González-Pola *et al*. 2003) (Cabanas *et al*. 2003a)
		1992-2002	200	0.54	0.084	(González-Pola *et al*. 2003)
		1994-2003	900-1000	0.1	0.06	
Asturias	Coast	1993-2003	10	0.43	No tendency	(Llope *et al*. 2004)
	Ocean	1993-2003	10	0.16		(Llope and Anadón 2002)
La Coruña	Coast	1990-2003	10	0.53		
Vigo	Coast	1994-2000	200	0.28		(Cabanas *et al*. 2003a)
Murcia		1996-2001	200	**	0.54	(Vargas-Yáñez *et al*. 2002a)
Malaga	Coast Coast	1992-2001 1914-2001	10 200	0.2 0.2		(Vargas-Yáñez *et al*. 2002b)
Balearic Isles	Coast	1994-2001	200	0.2	**	(Vargas-Yáñez *et al*. 2002a)
Gerona	Platform	1974-2001	3 80	0.4 0.25		(Salat and Pascual 2002)
Mediterráneo	Ocean	1959-1989	2000	0.04	0.01	(Bethoux *et al*. 1990)
Subtropical Atlantic (24,5 N)	Ocean Ocean	1957-1993 2001-1993	800 100 400	0.09 0.57 0.4	 0.07	(Parrilla *et al*. 1994) (Vargas-Yánez *et al*. 2004)

Future predictions speak of sea surface warming in a range slightly lower than the modelled changes in atmospheric temperatures (see chapter on climate), in consonance with a balanced radiative balance between atmosphere and ocean. The increase would be greater in summer and on the Mediterranean coast, where there could be, depending on the emission scenario, a 4 degree increase in the last third of the century. For the same reason, we can expect warming of the North Atlantic Central Waters that washes Spain's coasts (ENACW). A visualisation of the foreseeable increase in surface temperature in the Northeast Atlantic can be seen in fig. 4.5 (Alcock 2003), based on the predictions of temperature rises generated by the NOAA-CIRES for around 2025.

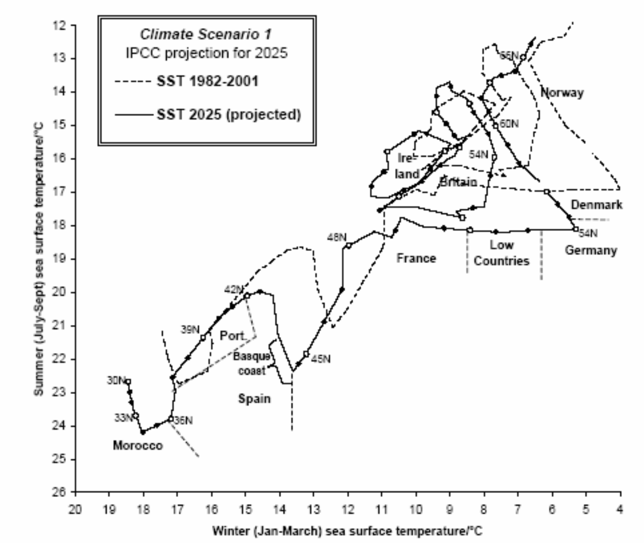

Fig.4.5. *Projection of sea surface temperature on the Northeast Atlantic coast in summer and in winter (taken from (Alcock 2003)*

It should be considered that the temperature increase resulting from the reduced winter mixing, caused by surface warming, could cause an upward tendency. The expansion of the tropical eddy detected (McClain *et al*. 2004) might be an indication of this process.

Long-term variations in salinity are less evident, due to the high interannual variability.. Furthermore, there is a lower number of databases containing this variable. Salinity is a magnitude that is very much related to the evaporation-precipitation balance, to inputs from rivers and water convection. As an example, in the Bay of Biscay and the adjacent Atlantic area, salinity oscillates according to the presence of water of subtropical origin (poleward current) or subpolar waters in the area. Depending on the balances, salinity anomalies occur which are displaced in the upper layer of the different Atlantic areas. This decadal variability is reflected in the surface data on salinity in the Atlantic at our latitudes (Dickson *et al*. 1988, Hudges and Lavín 2003) and has been associated with wind forcings (Cabanas *et al*. 2003b), constriction of the subpolar eddy due to a negative NAO (García-Soto *et al*. 2002).

In spite of these limitations, existing data indicate a slight increase in both surface and deepwater salinity (table 4.1). This is the tendency detected in the whole North Atlantic at our latitudes (Curry *et al*. 2003).

Predictions of changes in salinity are more difficult to make than those related to temperature, as precipitation is one of the factors at play. The distribution of changes in precipitation is irregular in space and throughout the annual cycle, and changes in inputs should not be very significant. In this panorama, evaporation should be estimated in order to get a clearer idea.

4.8.2. Sea level time series

The determination of changes in relative sea level is a complex task. In spite of this, there is evidence of an increase in sea level at global scale and of the causes thereof (Miller and Douglas 2004), and data also exist of variations at specific points of the Spanish coast (Cabanas *et al*. 2003b, Miller and Douglas 2004, Marcos *et al*. submitted). Sea level has risen by around 1.5 mm per year in the last century. Ice melting has contributed, with about 0.4 mm annually, thermal expansion with around 0.8 mm a year and terrestrial movements account for the rest (Douglas *et al*. 2001). The rise in relative sea level has increased in the last few decades, and is currently estimated at 3 mm per year.

4.8.3. Change in climate forcing

Little information is available on the changes in circulation and seasonality in the oceanographic conditions of Spain's coasts. Empirical evidence derives from the analysis of meteorological series, fundamentally of the distribution of centres of high and low pressures in the Atlantic (NAO index), and of winds influencing coastal currents.

Variations have occurred in the last 100 years in the NAO; these have been notoriously seasonal, with a predominance of a positive winter NAO in the last 25 years (http://www.cpc.ncep.noaa.gov/data/teledoc/nao.html). These modifications have been associated with changes in the intensity of coastal circulation in the North and Northwest of the Iberian Peninsula (García-Soto *et al*. 2002), or with modifications in winds, surface sea temperature and with riverine inflow (Planque *et al*. 2003). All the changes generated by modifications in the NAO can alter sea circulation at large scale, and therefore biological activity in the Iberian environment.

Changes were detected in the intensity and duration of winds in the last decade of the XX century in comparison to preceding decades, in particular an increase in south-westerly winds on the coast of Galicia (Cabanas *et al*. 2003b) and a summertime decrease in easterly and north-easterly winds on the Cantabrian sea (Llope and Anadón 2002). These values coincide with the increase in downwelling values after 1997 compared with the values for 1958-1976 and are duplicated, (no tiene coherencia en español) coinciding with high turbulence (Valencia 2004). Changes have also been detected in the seasonality of winds (Cabanas *et al*. 2003b, Llope *et al*. 2004). All these changes have led to reduced spring-summer upwelling in the Northwest (Lavín *et al*. 2000) and North (Llope *et al*. 2004) of the Iberian Peninsula. (Lavín *et al*. 2000) calculate reduced upwelling by approximately half between the 70s and the 90s of the last century.

Based upon information on barometric changes predicted by the UCLM model, changes related to seasonality are to be expected. In the last third of a century, the pressure gradient between the Greenland-Iceland high pressure nuclei and the Azores may be reinforced in winter. Consequently, there could be an increase in westerly and/or northerly winds. The response by the ocean would involve reinforcing the currents passing the Iberian Peninsula towards the poles, and a foreseeable advance in the termination of these. In summer, when upwelling events predominate, the changes would be inverted, with pressure increases in the North and decreases to the South of the North Atlantic, which would be that of the pressure gradient, giving rise to generally gentler winds. In the ocean, this would be seen in less intense upwellings on the west coast of the Peninsula, and also in the North. Furthermore, this would involve an advance in finalisation compared to the present. If the predictions are correct, the tendencies that have been detected will become prolonged in the future.

4.8.4. Signs of Climate Change seen in Biological Responses

(Gregg *et al*. 2003) based on satellite data, described an average increase in chlorophyll at high latitudes of the Atlantic, and a slight increase at medium latitudes. Using another methodology and data on phytoplankton abundance (based on data from SAHFOS) (Richardson and Schoeman 2004) concluded that abundance of phytoplankton is decreasing in areas of the Atlantic with warm mean temperatures, whereas it is increasing in the cold areas; among the warm areas are the Bay of Biscay and the coast of Galicia; this is possibly occurring in other warm seas. Information based on time series, both in the Cantabrian sea and the Mediterranean appear to back this up, although the series available are short and phytoplankton variability is high, thus hindering any irrefutable conclusions.

Changes were noted in the abundance of zooplankton species in the North of the Bay of Biscay from 1930 to 1990 (Southward *et al*. 1995) and in communities of pelagic copepods in the North Atlantic (based on data from SAHFOS), including the coastal waters of the North of the Iberian Peninsula (Beaugrand *et al*. 2000). This modification in the composition and size of zooplankton organisms has affected cod recruitment in the North Sea (Beaugrand *et al*. 2003). Given the positive relationship between the abundance of phytoplankton and of herbivorous zooplankton in the North Atlantic detected by (Richardson and Schoeman 2004), we can expect a reduction of zooplankton in the aforementioned areas of the Peninsula. Changes in the seasonality of hydrographic processes have had an influence on the abundance of zooplankton in the Atlantic (Beare and McKenzie 1999), and on the phenology of species or groups, causing trophic decoupling among these (Edwards and Richardson 2004).

The reorganisation processes generated by climate change can give rise to permanent changes, as can be seen in the relationship between the abundance of *C. finmarchicus* and the NAO. Since 1989 the abundance of this species has declined in the North Atlantic (Fromentin and Planque 1996, GLOBEC 2003) probably due to the reduction of the hibernation areas of copepodites V.

There are few publications dealing with climate-.related changes in the composition of pelagic communities on Spanish coasts. In the Cantabrian sea (Villate *et al*. 1997) detect changes in the abundance of copepods, although the time lapse studied is very short, and (Llope *et al*. 2004) have also observed changes in the abundance of copepod species. Depending on species, there may be a continued increase or decrease, or a sudden increase in abundance. Similar responses are being observed in the Mediterranean (Molinero 2003).

During the last century, changes have been detected in the abundance and distribution limits of species (spread and retreat) living on the coast, associated with environmental changes (Anadón 1983, Southward *et al*. 1995). Although there are recent data on the appearance of macroalgae in the warmer waters of the Cantabrian coast (Fernández and Rico, per. Comm.), it is difficult to justify the presence of these species by invoking climate change. The most notable changes have involved the presence of *Sargassum muticum* in some communities dominated by macroalgae. This invasive species has successfully colonised some communities in the N and NW of the Iberian Peninsula, causing changes in the structure of the receptor community (Sánchez *et al*. submitted).

(Alcock 2003) made a prediction of the distributrion of certain coastal species considering their present temperature limits, along with the projection of these in future temperature scenarios (Fig. 4.5). It was shown that climate changes can affect the distribution of many species whose distribution limit is on Spanish coasts. As has already been mentioned, the change could accelerate if synergic effects occurring between temperature and coastal circulation, as these could influence basic factors such as the concentration of nutrient salts.

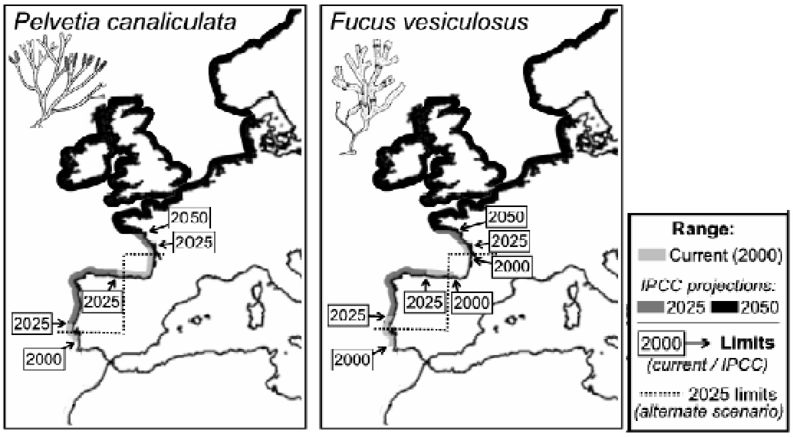

Fig. 4.5. *Variation in distribution limits of two species of macroalgae according temperature changes predicted by the IPCC models (in Alcock, op.cit.).*

There is evidence of mass deaths of gorgonians and of red corals in the Mediterranean, associated with years of high water temperature (Cerrano *et al*. 2000, Garrabou *et al*. 2001). An increase in sea temperature resulting from climate change could have a negative impact upon these organisms.

Long-lived benthic organisms can provide vital information on the response of organisms to climate change, filtering short-term oscillations and integrating environmental variations. By reconstructing the production and growth of *P. oceanica* for the last 25 years (Marbá and Duarte 1997), deduced a maintained increase during this period, which is probably associated with climate change. It has been possible to reconstruct an increase in flowering frequency in the same species, a very conspicuous phonological sign, in a similar period. This increase can be related to a higher surface sea temperature; the predicted temperature increases could favour flowering in this species. Changes in the area of these ecosystems also present a clear sign of climate change. The upper limit of the fields *P. oceanica* in the Balearic Isles, established with the use of aerial photography, appears to have retreated by around 25 m in the last three decades. This is attributed to underwater erosion caused by the rise in sea level.

The presence has been detected of certain species of tropical and subtropical origin in the Northeast Atlantic, both in the Canary Isles and on the Iberian Peninsula (Brito *et al*. 1996, Quero *et al*. 1998, Brito *et al*. 2001, Stebbing *et al*. 2002). This is interpreted as a response to large scale hydroclimatic changes, whjich would favour immigration of species towards the North. Thus, for example, *Dicologgossa cuneata* and *Boos boops* showed increases in abundance and range at their northern distribution limit in the Bay of Biscay (Poulard *et al*. 2003). The appearance and proliferation of species of subtropical affinity in the Balearic Isles constitute another clear sign of the influence of climate change (Grau and Riera 2001).

There have also been sightings that push the limits northwards of other groups of organisms, such as molluscs and cetaceans (Guerra *et al*. 2002, Williams *et al*. 2002). Unfortunately, the systematic observation series in our country leave much to be desired, particularly in the Mediterranean. Thus, many biological signs of climate change may be appearing without being recorded, and these could provide an early warning of environmental changes associated with climate change. This prevents accurate predictions of future changes from being made, although the observations made to date can be expected to become accentuated.

4.8.5. Climate change, fisheries and mariculture

Climatic variability in the North Atlantic is attributed to decadal and long-term fluctuations governed by atmospheric forcings related to the in the North Atlantic Oscillation (NAO). The NAO has been related to the frequency and intensity of storms in the Atlantic, significant wave height, evaporation and precipitation patterns, regional fluctuations in temperature and salinity, etc. These hydrographic changes have a great impact upon marine ecosystems and fisheries production (Parsons and Lear 2001, Drinkwater *et al*. 2003). There is abundant information on the relationships between the NAO index and catches or recruitment of exploited species by Spanish fleets on our coasts; the anchovy in the Bay of Biscay, the Atlantic tuna or the recruitment of the sardine in Galicia and the swordfish in the Atlantic (Santiago 1997, Borja *et al*. 1998, Riveiro *et al*. 2000, Borja and Santiago 2001, Guisande *et al*. 2001, Borges *et al*. 2003, Mejuto 2003). Something similar has been observed in recent years in the Canary Isles, with the greater abundance of *Sardina pilchardus* (Carrillo *et al*. 1996).

Demersal fish (cod, haddock, whiting, saith) are also influenced by the NAO. The 60s (with good recruitment rates) coincided with periods in which the NAO persistently remained at negative values. In the 90s, the yields of these gadiform species declined to the verge of collapse, coinciding with the change of the NAO to a positive phase at the end of the 80s and the start of the 90s. Although the specific processes linking recruitment and environmental factors during these phases are as yet unknown, global correlations have been established between the tendencies of stocks, the NAO and sea temperature (ICES 1999), and relationships have also been demonstrated that are governed by changes in zooplankton (Beaugrand *et al*. 2003). Given the predictions that the NAO index will present an upwards trend, future changes in the same sense can be expected.

Apart from the general influence of the NAO, the influence of other processes at smaller scale has been noted, and these appear to act in a multivariate way on catches and recruitment of the sea species caught. Among these, the following phenomena have been described: upwelling in Galicia and the Cantabrian, slope currents in the North and Northwest of the Iberian Peninsula and slope currents associated with fresh water inflow – Ródano, Ebro – in the Mediterranean, filaments of the Canary isles upwelling, transport in Gibraltar, eddies in the Cantabrian, temperature changes or turbulence. Among the species studied that present some type of relationship with these conditions, are pelagic species – mackerel, anchovy, horse mackerel (Lloret *et al*. 2001, Sabatés *et al*. 2001, Borja *et al*. 2002, Lavin *et al*. 2003, Lloret *et al*. 2004), o demersal ones –hake- or benthic ones –dory, Norway lobster- (Sánchez *et al*. 2003a, Sánchez *et al*. 2003b, Fariña *et al*. in press). The transport of the larvae of many ecploited species by currents, and the dispersal or concentration of these, have very important potential effects (Sánchez and Gil 2000, Sabatés *et al*. 2001, González-Quirós *et al*. 2004, Lloret *et al*. 2004), although detailed study thereof has only recently begun.

The effects of changes in hydrodynamic factors at mesoscale referred to in the 90s do not appear to have had any great impact in community structure in the short term (Poulard *et al*. 2003, Sánchez and Serrano 2003).

One of the most notable variations that has taken place on Spain's coasts and which affected some fisheries is the change in the distribution of spawning or migration areas of some species. In recent years, the anchovy in the Bay of Biscay appears and lays its eggs further North, and at different times of year than previously (Borja, com. per.), and this phenomenon occurs parallel to an increase in catches of anchovy and sardine to the North of the North Sea (Beare *et al*. 2004). There are indications of changes in migration routes and in the seasonality of certain age classes of tuna fish (e.g. Albacore *Thunnus alalunga*) situated further North than in previous periods. In the Canary isles, this affected the seasonality of fisheries as well as the catches, and therefore, the fisheries effort applied to other species (Carrillo *et al*. 1996).

Changes in the abundance of tuna fish could affect certain recently developed tourism activities, such as sports fishing. The appearance of other species of tropical origin (marlin), subjected to sports fishing on the coasts of the Canary Isles, and in the North of the Peninsula, could have a compensatory effect. But no information is available regarding the importance of both of these: the number of boats working professionally, the added value of the catches, the amount of people temporarily employed in this activity, among other socioeconomic components.

The reduced catches of Atlantic salmon detected in the North of the Iberian Peninsula might be a reflection of changes in temperature and marine circulation. We have no capacity, however, to determine the intervention of other components, such as the pressure applied by fishing in the sea and in rivers, or the effect of pollution in rivers on populations.

There is little available information on the direct effects of climate change on mariculture. There is evidence that changes in the intensity of the summer upwelling are associated with the quality (% meat weight in relation to total weight) of mussel culture in Galicia (Blanton *et al*. 1987). Given the predictions of reduced primary production (see previous sections), changes in farming yields are to be expected. We can also expect modifications in the growth and physiological state of the cultivated organism.

But there is evidence of indirect effects, due to the action of harmful algae blooms (HAB), which can affect some cultured species or the marketing of these or human health. Although the spread of these could be due to transport by humans, their prevalence could also be associated with water warming, which would favour their increasing appearance.

Since 1976, when cultured mussels in the Rías of Galicia, which had been fed on toxic phytoplankton, caused numerous cases of intoxication causing paralysis in several European countries, these blooms have been recorded and studied. After 1982, new cases of intoxication caused by molluscs were recorded, in this case of the diarrhoeic type. This time, the identity of the culprit species was known. The human response might have been confused with bacterial infections, in which case we would not be dealing with a new case.

Given that the dynamics of phytoplankton populations depend upon water dynamics, changes are to be expected therein. It has been suggested that an increase in the intensity of summer upwelling, a consequence of increased winds, associated with changes in the NAO index caused by climate change, could lead to an increase in the booms of dinoflagellates, such as *Gymnodinium catenatum* (Fraga and Bakun 1993, Garcia *et al*. 1997, Hallegraeff and Fraga 1998, Gómez-Figueiras and Reguera 2004).

Detected recently on the coasts of the Mediterranean and the Canary Isles are species of toxic benthic dinoflagellates of the genus *Ostreopsis* (*Ostreopsis* cf. ovata) which could be considered as tropical (Vila *et al*. 2001). In waters of the Canaries, another typically tropical dinoflagellate has been observed, *Gambierdiscus* (Fraga, pers. comm., Ojeda, unpublished data), which produces one of the strongest toxins known. Its tropical nature appears to indicate a future increase in abundance caused by global warming, and a northward expansion of its range and probable entry into the Mediterranean.

The change in conditions could be associated with the reduced abundance of certain toxic species. This appears to be the case of *Lingulodinium polyedrum* on the coasts of Galicia, which has caused the three oldest cases of red tides described in scientific literature. It is now considered to be a rare species (Fraga 1989).

Apart from the effects on farming, species of harmful algae could cause other types of economic damage. Many very attractive beaches for tourism on the Mediterranean and the Atlantic are affected by frequent blooms of algae, which tourists take to be dirt. Since the first observation of the dinoflagellate *Alexandrium catenella* in waters of Catalonia in 1987(Garcés *et al*. 1999), the mass presence of this has become a frequent phenomenon in the western Mediterranean (Vila *et al*. 2001). The centric diatom *Atteya armatus* causes brownish-green colouring on some tourist beaches in the Canary Isles. An increase has been described in the recurrence and intensity of this in the last 4 years (Ojeda 2004).

The projection of future changes should follow criteria similar to those described in this section. Increases in warm waters species, and decreases in cold waters species, with the corresponding changes in abundance and distribution limits will be expected. More difficulty is involved in predicting the time lags within which these changes will occur, as well as the intensity of these.

4.9. IMPLICATIONS FOR POLICIES

4.9.1. Fisheries policies

Given that climate change can cause changes in the production of stocks, local or regional impacts could be extreme. Climate predictions will have to be considered in long-term yield projections of stocks of commercial species, and in relation to management systems and social and economic structures (markets, structures, investment), in order to adjust to the new conditions, which will possibly involve less available resources.

The present objective of fisheries resources management is the sustainability thereof, and it is believed that the greater effect on the size of stocks is the result of fishing. Climatic variability is believed to affect the short and medium-term abundance of some stocks of pelagic species and should be considered in management plans in order to avoid collapses in abundance, and losses, not strictly in relation to fisheries, but to investments associated with the sector. There are EU proposals to implement plans for the recovery of certain species (hake, Norway lobster) on the Iberian Atlantic coast and continued overexploitation is believed to prevent the recovery of stocks.

The new ideas relating to the management of stocks of exploited marine species propose basing this management on multispecific fisheries, as an intermediate step towards a type of management based upon the ecosystem. The concept of “ecological approach” can be subjected to two complementary interpretations: consideration of the effects of fishing on the ecosystem, or consideration of the responses by ecosystems to fishing. This management is developed through two channels: the production of adaptational models based on easy-to-obtain information on stocks, or through indicators of the state of quality of the ecosystems based on the definition of desired levels of conservation. All of these approaches lie within the framework of Large Marine ecosystems (http://www.edc.uri.edu/lme). Apart from the objectives related to maintaining and recovering resources in the fisheries sector, this approach contemplates other objectives related to the protection and recovery of habitats that are complementary to fishing, the maintenance of biodiversity, or ones related to the economic and social sectors (Castilla 2003). All of these aspects will affect a great deal of institutions, local, regional, national and European ones. As much of Spain’s fisheries production comes from long-distance fishing grounds, outside community waters, policies relating to international co-operation will also be affected.

Placing more emphasis on product quality, with ecological labelling aimed at ensuring sustainable fishing could also help to attenuate impacts and to support fishermen within a context of scarcity of resources. These measures will reduce collateral effects in ecosystems and fish populations such as those caused by bycatch and others.

4.9.2. Marine farming policies

The policy on marine farming affects state policies and those of the regional autonomies, because they refer to inland waters. The policy of intense development undertaken in the last few decades should be evaluated, and attention should be paid to changes in productivity, and therefore to yield and sustainability.

Policies relating to the introduction of foreign species should be reviewed in relation to farming, and the principle of caution ought to be applied. The interaction between these and autochthonous ecosystems and species could cause unforeseen negative changes if they were to escape human control. Furthermore, if there is insufficient sanitary control, there might be an increase in the number of pathogenic organisms, which would cause serious damage to the pre-existing mariculture.

4.9.3. Coastal development policies

Coastal development policies will affect the EU, the central administration and the regional autonomies. Local administrations will also be affected. Increased human activity in coastal areas may cause many of these to be affected by change, particularly by a rise in sea level. The combined effect of hydrographic changes and increased human activity could contribute to the development of harmful algae blooms, thus affecting resources and human health.

The prevention of erosion and the negative consequences of this for ecosystems should be considered with regard both to maintaining beaches and other elements of interest for the tourism sector, and to conserving ecosystems that are vulnerable to changes in sea level. We should therefore consider the impacts of the construction of infrastructures and housing on the coast within the context not of current impacts, but rather of those generated by a rising sea level. The maintenance of sediment balance should govern coastal development policies. The impacts of climate change on the demand for infrastructures should also be considered.

There is much social pressure to develop new and better port facilities, both commercial ones and marinas, and moderation is called for in this respect in order to avoid impacts upon coastal sediment dynamics (e.g.: The construction of the future Granadilla Port in the Canary Isles). All facilities should have the necessary infrastructures (tanks for collecting sewage waters, oils, etc) to avoid the impact of the wastes that these facilities generate.

There seems to be a need for control networks dealing with the development of toxic or urticant blooms, which have already been set up in some Regional Autonomies, and these should be implemented immediately in order to establish a basis for future decision-taking. This need has been recognised in other countries suffering from problems related to certain potentially dangerous species for our farmed species or to humans (for instance *Pfeisteria* in the USA).

4.9.4. Ecosystem conservation and management policies

This will involve all levels of administration, from the EU to the administrations of the Regional Autonomies. Given the precedents of the direct effects of human activity and the foreseeable modifications caused by climate change, there appears to be a need for a policy for the protection of exploited fish populations and of coastal ecosystems, which are the ones that will foreseeably be most effected by the changes. Network design criteria should be considered relating to the complementary and unique nature of Marine Protected Areas (MPA). The population should become involved and profits should be generated through complementary conservation and fisheries strategies, along with the necessary dissemination of these.

4.10. MAIN RESEARCH NEEDS

4.10.1. Detecting changes in oceanic conditions

One of the main deficiencies in marine sciences in Spain, which have been highlighted in numerous scientific forums, involves the scarcity of time series for the marine environment, in a permanent observation system similar to the meteorological one, either with direct sampling using boats or with the use of buoys and satellites. This is much more important if we are to document and predict the response by the ocean to climate change.

This deficiency has been partially corrected through initiatives by some institutions, the Spanish Oceanography Institute, State Ports, AZTI, or initiatives by other institutions (CSIC - higher centre of scientific research - in Blanes, CSIC in Vigo, Oviedo University in collaboration with the SOI), or private centres (San Sebastián Aquarium), and even personal initiatives (Josep Pascual en L'Estartit, Girona). The establishment of a well planned and co-ordinated observation network, suitably funded, with appropriate guarantees of quality and which covers the observation needs of the marine environment in the long term is an unavoidable necessity. To this end, an Oceanographic Data Centre would be needed.

There is also a need to increase the existing oceanographic databases and to promote the compilation of the information available in existing databases or of that generated by research projects, past or future ones, financed by the Public Administration. This would allow for more rational and efficient use of oceanographic data, to respond more effectively to our compromises with international programmes dedicated to climate change in the ocean, and to make significant contributions to the management of our resources. Co-ordination with certain international initiatives would be desirable. An example of this is the Open-source Project for a Network Data Access Protocol (DODS) (http://helium.gsfc.nasa.gov/Data/portals/dods/index.html) linked to oceanographic databases, (http://helium.gsfc.nasa.gov/Data/portals/dods/param_search/OCEANS.html), or the French one, co-ordinated by IFREMER that attempts to monitor ocean climate (http://www.ifremer.fr/merseaip//).

There is a need to develop satellite image databases (CREPAC-INTA, IEO, AZTI), and to co-ordinate the way in which these are obtained and stored, and to facilitate the use thereof. Variables such as surface temperature, chlorophyll, altimetry and winds are very useful for analysing change at large scale. Systems similar to the Comprehensive Ocean Atmospheric Data Set (COADS), widely used by the scientific community, which provide specific data on meteorology and sea surface temperatures (SST) for our zone could be of great interest, if rigour and quality are used in their implementation. New long-term control initiatives are also needed, such as the European project FerryBox on the Porstmouth – Bilbao route (http://www.soc.soton.ac.uk/ops/ferrybox_index.phppp), as these provide low-cost continuous data.

The promotion of national programmes for the study of Climate Change and of the responses by ecosystems and marine populations, defined in the International Programmes IGBP (GLOBEC, SOLAS, JGOFS, GOOS,…….) could provide the necessary impulse to fill the many knowledge gaps detected during the drafting of this report.

4.10.2. Atmosphere-ocean interactions and climate system

Given the close relationship between atmospheric and oceanic processes, and their relevance of these in the causes and intensity of Climate, it seems necessary to increase Spain's participation in the study of the interactions between both systems, within the framework of the pertinent international directives and projects. Directives on Research plans should consider the role played by the ocean as a modulator of change in the concentration of greenhouse gasses in the atmosphere, or as a transporter of heat on the Planet.

There appears to be a need to consider changes in wind regimes, given they role they play in forcing many mesoscale processes influencing primary productivity and in the recruitment of multiple species. These changes are associated with climate change.

4.10.3. Relationships between the dynamics of marine ecosystems and hydrographic conditions

As with oceanic conditions, one of the gaps detected is the absence of credible, contrasted and standardised databases on fisheries production, which are very scare in the monitoring of populations or ecosystems not subjected to fishing. Indeed, monitoring is almost non-existent if this is considered in relation to climate change. Analysing inter-species interactions within the framework of the ecosystem in which the species live and recruit, provided this is framed within the context of environmental change, including fishing by humans, would provide information for predicting future change and for designing management mechanisms to adapt the production system, the conservation of resource species and ecosystems.

The behaviour of ecosystems, effects on inter-species interactions, or general changes, depending on whether key species are affected or not, are fields for which very little information is available, but we do know that climate change can cause big changes in ecosystems. The co-ordination of the monitoring networks of biological responses existing in different regional autonomies or in co-ordination with the aforementioned marine environment systems, would provide knowledge practically in real time of the state and tendencies of these ecosystems and would enable us to learn of the effects of climate change.

4.10.4. Metabolisms of significant species and interactions among species

Given the complex functioning of ecosystems, long-term monitoring of the physiological responses of selected species, or phenological cycles (reproduction period and intensity) would enable us to understand the mechanisms of environmental change. Study of certain long-lived species would enable us to reconstruct species response to the change that has already occurred (Marbá and Duarte 1997, Kennedy *et al*. 2001), thus increasing our knowledge of the times and speeds of the changes. Predicting the rhythm of the changes will facilitate adaptational response and the adoption of consistent environmental policies.

Another urgent need involves defining the significance of biodiversity in ecosystem functioning, and the use of this from the point of view of adaptational resources management, in order to satisfy needs related to fisheries through environmental sustainability.

4.10.5. Summary

Table 4.2 summarizes the main foreseeable impacts and the probability that these will materialize. Knowledge on these effects want be a research priority

Table 4.2. *Processes affected by global change in the future in Spain and Probability of occurrence*

Processes affected by global change in the future in Spain	Probability of occurrence
Surface warming of seawater in the future	***
Changes in the salinity of sea water	*
Changes in carbon dioxide exchange between the atmosphere and the ocean	**
Changes in mesoscale circulation	**
Rise in sea level	***
Changes in the distribution limits and abundance of plankton species	***
Changes in the distribution limits and abundance of benthic species	***
Effects upon larval survival and the recruitment of exploited species	**
Effects upon marine productivity	**
Changes in the composition and dynamics of communities	**
Effects upon the presence of toxic or stinging species	*

**** Very high probability; ** Medium probability; *Little probability*

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