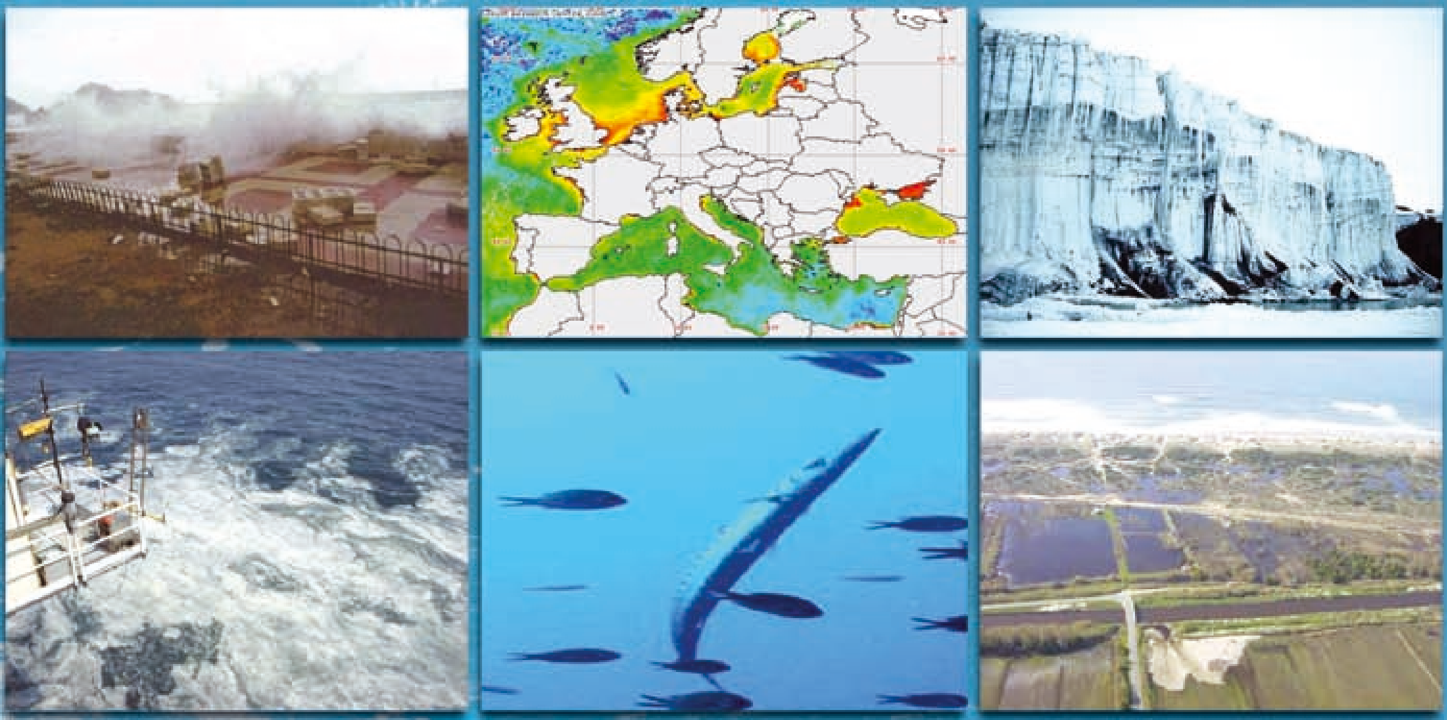
Marine and Coastal Dimension of Climate Change in Europe

A report to the European Water Directors



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A report to the European Water Directors

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Cover page illustrations:
(upper left) coastal storm in Spain (courtesy: A. Sanchez-Arcilla)
(upper center) surface chlorophyll map from satellite (JRC-IES archive)
(upper right) melting glacier in polar region (courtesy: G. Zibordi)
(lower left) mucilaginous water in North Adriatic (courtesy: G. Zibordi)
(lower center) Barracuda, Sphyraena flavicauda, in the Mediterranean Sea, Bay of Villefranche (courtesy: M. Lefèvre)
(lower right) Coastal flood in Portugal (courtesy: F. Veloso-Gomes)

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Foreword

In 2005 the European Commission's Directorate General Joint Research Centre (JRC) published a major report on 'Climate Change and the European Water Dimension' (http://ies.jrc.cec.eu.int/366.html). This report emphasizes the urgent need for a new approach to the climate change issue, particularly through the development and application of scenarios at the scale of regions and river basins to assess the response of land and water systems at the local level. The report introduced some of the likely issues affecting Europe's coastal waters and seas and the EU Water Directors have asked the Commission to further elaborate these topics.

Accordingly, the Institute for Environment and Sustainability (JRC-IES) organized a workshop attended by high-level experts from different countries and disciplines with the goal to review climate change issues in relation to the European marine environment; identify gaps in our current scientific and technical knowledge; and examine the implications for European Policies to focus on adaptation and mitigation strategies to marine climate change. This report arises from the workshop.

Europe is warming faster than the global average, particularly during winter months and the physical attributes of our Seas and coastal waters are changing accordingly. Sea level is rising and surface water temperature increasing. These physical changes in turn are implicated in the functioning of our regional climate, and of course in the biophysical and ecological functions of our marine environments.

Thanks to the efforts of the expert participants this report provides a comprehensive view of climate-related impacts on our coastal waters and seas as well as presenting governance and policy options to meet the challenges identified. I trust that it serves both as a record of conditions as they currently are, and as guidance for those who must develop mitigation and adaptation strategies confronting such change.

Prof. Dr. Manfred Grasserbauer
(Director of Institute for Environment & Sustainability)

Executive Summary

Within the last two decades, more and more scientific evidence indicates that environmental changes are occurring at all scales, as a result of climate change and climate variability.

This phenomenon has profound impacts on European Seas and Coasts.

The evolution of the physical variables in response to global warming is adjusting to the regional climate and circulation. Water temperature shows different progression and trend in the northern seas than in the Mediterranean Sea and Atlantic waters.

Sea level around Europe increased at a rate varying from 0.8 mm/y to 3.0 mm/y, interfering with local processes such as water temperatures, tides, sea ice extent, evaporation, and various tectonic developments.

In addition to changes in the mean climatic forcing (rising greenhouse gases, warming of surface temperature, rising sea level), episodes of extreme events (downpours, droughts, storm surges, floods) have become more frequent, affecting human life and causing considerable damage to the environment on land and sea.

These transformations are most clearly observable in low-lying coastal systems, deltas, coastal lagoons, estuaries with higher vulnerability to environmental changes, often aggravated by a severe anthropogenic pressure.

Identified trends/impacts due to climate change and variability in specific marine European systems include

- changes in the water characteristics and circulation,
- ecosystem modifications with distinct shifts northward of warm-water species associated to a decrease in the mean number of cold water species,
- phenological perturbations leading to a mismatch between trophic levels and functional groups,
- coastal recession and erosion along the western European coast as a result of sea level rise and storm surges,
- coastal floods and other environmental hazards/disasters as a result of tidal/storm surges.

Long-term projections under various scenarios have a tendency to exhibit similar evolution and trends for the future with more extreme seasonal-to-decadal climate fluctuations. However, large uncertainties are associated to each level of the process, from assumptions about greenhouse gases GHG emission and global warming to predictions of local impacts and system feedbacks.

A precise knowledge on the magnitude of these changes and the factors controlling their variability is thus prerequisite to reduce biases in climate models and to perform any decision making process related to coastal protection and marine security issues. Progress in computational power has considerably increased the capacity of these models to produce climate projections for centuries, and to simulate the response of several climate variables to different scenarios of greenhouse gases emissions. However, the scale issue needs first to be resolved to fully grasp the regional system behavior under climate change. Dynamical and statistical downscaling methods based on large-scale models (GCMS) have been used with some difficulties to produce regional climate scenarios. As an alternative, Regional Climate Models (RCMs) need to be developed and fully coupled with GCMs to represent scale interactions.

Regional climate variability and mesoscale atmospheric patterns, e.g. the North Atlantic Oscillation (NAO) are important to study the variability of marine processes in Europe, but its influence on forcing variables differs according to seasons and regions. The fluctuations of NAO and its relation with the global climate processes need to be better understood. The influence of NAO on European sea level and wave height have been largely documented from observational studies but there is a need to have them resolved and accounted for in regional climate simulations. The results can then be significantly different from IPCC estimates.

On the other hand, the management of marine resources depends on our ability to understand and model the impacts of climate variability on the ecosystem productivity (including harmful algal blooms) and species composition at different trophic levels, which are in turn extensively correlated to hydrodynamic conditions such as the variability in circulation, sea temperature, mixing and stratification conditions.

Research should focus on understanding the nature, significance, geographic distribution, and impact of climate change in the marine and coastal systems. New research themes include the extent of ocean acidification due to the marine uptake of anthropogenic CO_2 from the atmosphere; and its impacts on the plankton community and cold water coral reefs should be scrupulously monitored and analysed. Moreover, additional carbon cycle variables, e.g. water pCO_2, need to be systematically monitored to identify European regional hot spots of carbon sink and sources and reduce uncertainties in the overall carbon budget. Similarly, the present knowledge of the impacts of temperature, salinity and alakalinity changes on phytplankton population is poor and mostly relies on predictions of changing physical processes.

Except for particular locations where more than 100 years of sea level measurements from tidal gauges exist, very few other direct observations (e.g. wave conditions along the European coasts) have been conducted in the marine environment for more than two or three decades, justifying a number of studies on numerical models to provide hindcasts assessment of the past conditions. One of the main difficulties is to find the appropriate funding mechanisms that will ensure continuity of these measurements/observations over long time period. Oceanographic cruise surveys are crucial in documenting long term trends in the whole of the water mass and changes in the circulation. At present, however, oceanographic vessels are increasingly supported by autonomous and Lagrangian platforms with multiple, interdisciplinary sensors, large arrays of near-surface and profiling floats, and unattended instruments on-board ships of opportunity.

Supplementing field measurements, Earth Observation (EO) satellites with advanced radiometric sensors are extremely important to reduce uncertainties in the Essential Climate variables as defined under GCOS. They provide consistent methodology over all European Seas while capturing the regional and local variability. The information is however restricted to the surface layer of the ocean and integrated quantities such as sea level or gravity. It is important, therefore, to integrate EO techniques as a part of a comprehensive monitoring system which will be linked with systematic measurements of the oceanic interior.

The impact of Climate Change pressure to the coastal system is mainly acting through sea level rise and storm surges (also increasing wave height) which can result in shoreline recession, flooding, and salt intrusion inland, with further consequences on infrastructure and human life. The coastal vulnerability to these pressures depends on the natural properties of the environment (physical, chemical, biological), as well as the socio-economic elements that contribute to modify its natural dynamics. Both components are interacting in different ways and strengths, each element relying on their exposure, sensitivity and adaptive capacity to change in response to climate forcing variables. The physical disparity of European Seas and coastal areas and their various degree of population development commonly leads to regional differences in the causes and extent of vulnerability to climate forcing variables.

With 75 % of the human population expected to be living in the coastal zone by 2025, it is evident that an extreme competition for space with the natural ecosystem is occurring. Driving forces include population pressure, transport development, urban sprawl, industry and tourism, as well as global drivers and pressures such as climate change. Marine transport is one of the most important sectors of international trade. Ports and associated industrial development and tourism are responsible for land conversion/reclamation, loss of intertidal and other habitats, dredging and protection measures for the safety and operability of navigation. These additional pressures modify the natural transport of solids to the coast which become then more vulnerable to climate change effects.

Also, several time scales and processes are relevant when considering the repercussions of these changes and pressures to the morphological developments and habitats in coastal areas. The challenge of coastal configuration planning is therefore to integrate the natural elements and the socio-economic processes into complex engineering models explaining how the different elements interact, and allowing simulations of short-term and long-term changes in the coastal domain. Geo-spatial technologies (remote sensing, digital video cameras), Geographical Information Systems (GIS) and mobile technologies are rapidly evolving, and can also offer significant opportunities to increase knowledge and understanding of the coastal environment through rapid data acquisition at varying spatial and temporal scales. But an efficient implementation and monitoring of environmental measures related to climate change require interoperable spatial information across national borders, as well as an easy access and use of this information by all concerned stakeholders.

Mitigation and adaptation processes to reduce the adverse impacts of climate change and global warming on the marine environment are limited by the difficulty to manipulate and control both the ecosystem processes and the ocean dynamics. The global Emission Reduction Plan and EU compliance to Kyoto Protocol remains therefore extremely important to mitigate climate change impacts on the marine system. However, even under a scenario allowing drastic reduction in anthropogenic CO_2 emissions, the impacts of climate change will continue for centuries requiring adaptation measures to be taken with long-term perspectives.

Coastal zones are regions in which it is possible to effectively implement proactive strategies to reduce the vulnerability to climate change effect such as accelerated sea level rise and increased storm surges frequency. Adaptation strategies include accommodation, protection and retreat, each regrouping several options depending on the local conditions, shoreline morphology and dominant pressure field. The cost-benefit of the various strategies is, however, difficult to evaluate because of uncertainties in the long-term climate change impacts (related to uncertainties in current prediction models and climate scenarios), uncertainties in valuing the threatened land, and uncertainties in the long-term effectiveness of the protection scheme.

On top of that, the marine and coastal waters in Europe are continuously exposed to an increasing human pressure through activities such as fisheries, energy production, trade and commerce, tourism. The effect of climate change is thus difficult to untangle from direct anthropogenic activities. The latter often reduces the resilience property of the marine and coastal systems which then become more vulnerable to stresses due to climate forcing. Any decision planning to mitigate climate change impacts will then also depend on our ability to control human exploitation of the seas and coasts and to ensure sustainable management of the marine resources.

The objective of coastal development control is thus to reduce the environmental impacts from climate and non-climate related pressures and to prevent potential damages to existing and planned anthropogenic developments. For example, increasing the number of Marine Protected Areas can be a valuable option to alleviate fishing pressures; and the development of clean technology and management system for marine aquaculture would reduce eutrophication-related problems in the surrounding areas.

As for natural processes, the ocean is by far the largest active carbon sink, having stored half of the anthropogenic emissions since the beginning of the industrial era. Two types of artificial measures have been proposed to further use the ocean carbon reservoir as a potential mitigation option against increasing atmospheric CO_2: i) the fertilization of the oceans; and ii) the capture of man-made CO_2 and its injection into the deep sea or seabed layers. Both these measures have created a controversial debate within the community at large; the discussions being still very active at this time not only as regards the scientific basis, but also the legal framework upon which these measures can be applied.

Direct injections of carbon dioxide at depth in the ocean have raised concerns as the environmental effects at medium and long-term periods are completely unknown. That technology deserves, however, more research and testing when applied in sub-seabed geological structure.

Concerning European Policy Responses, the main elements taking into consideration with respect to climate change are related to energy efficiency and mitigation options to meet the target of the 8% greenhouse gases emission reduction relative to the 1990 reference level, as well as to get better understanding on climate change and its impact in all sectors requiring cost-effective, long-term adaptation plans for their development. No implemented regulations are presently addressing the protection of the marine environment as a whole against multiple stresses, including climate change. However, a number of water and marine-related Directives were established to deal with specific issues like water quality, and sustainable management of marine resources in response to political concern in restricting domains (e.g bathing, drinking water, fisheries).

The Water Framework Directive (WFD) provides a good example of an integrated catchment management and allows great flexibility in meeting good ecological and chemical status of coastal waters. In spite of being limited in embracing the marine environment at large, its successful implementation would increase the ecosystem capacity for resilience and reduce the vulnerability of these waters to climate change stresses. On the other hand, a rapid development and implementation of new and emerging Policies are essential to address Climate Change and the marine environment in an integrated manner. For example, the EU Flood Action Programme aiming at a European concerted and co-ordinated action to prevent, protect and mitigate flood events which are likely to increase as a result of climate change (increase rainfall and sea level rise). But most importantly, the European Marine Strategy, as the environmental pillar for the EU Maritime Policy Green Paper, would represent a unique integrated tool for the protection of the marine environment in Europe looking at issues in a holistic way, including present and future climate change impacts.

The development and implementation of these Directives entails to a sound scientific and technological programmes at the Community level, adopting a multisectorial and multidisciplinary approach, strengthening exchange and collaboration between national and regional institutions. The 7th EU Framework Programme for research and development includes Environment and Climate Change as a main thematic research area. But long term systematic observations and monitoring of the European Seas should, however, be promoted and supported in addition to the usual research funding if a good level of understanding of the risks of climate change is to be achieved within the next twenty years.

The development of environmental measures to control and reduce pressures on the marine system from anthropogenic and climate drivers have often been developed in a sector by sector approach resulting in a patchwork of policies and regulations at regional, national, European and international level. Good governance of seas and coasts is based on recognition of the interests of all stakeholders, integrating all concerns into an ecosystem-centred framework.

The principles of a marine stewardship are to ensure that economic development is framed in ways that both protect the marine environment and is socially beneficial to the people using that environment. To achieve this, information is an essential element of the governance; information on the nature of the environment, the potential threats from human activities and climate change, as well as information on the users, and the value of the shoreline and marine resources.

Moreover, enhanced collaboration between national institutions, European and international organizations is essential to make better use of complementary areas of expertise, and to harmonize decision-making processes in a domain, i.e. climate change and the Marine Dimension, where political boundaries have no real significance.

General Introduction

Europe, with 185 000 km of coastline (according to the Corine Land Cover database, and EEA 2006), is surrounded by a large number of seas, which over many centuries have played a key role in shaping the economic and cultural geography of the adjoining nations and beyond. Compared with other continents, the European Seas are all differing with respect to their physical structure and water content.

Typical morphologies range from quasi-enclosed basins (Mediterranean Sea, Black Sea, and Baltic Sea) to water masses widely open to the deep ocean (Celtic Sea, Bay of Biscay). Such a variety is also reflected in the trophic state of the water column, extending from blue oligotrophic systems in the eastern Mediterranean Sea to rather eutrophic situations in some part of the North Sea. As a result, the European Seas offer considerable, albeit unfortunate, opportunities to investigate the impacts of various pressures such as those due to climate change and increasing human activities on the ecosystems, and coastal morphology.

The climate of Europe, however, exhibits also considerable variability of which a substantial part is ruled by the North Atlantic Oscillation

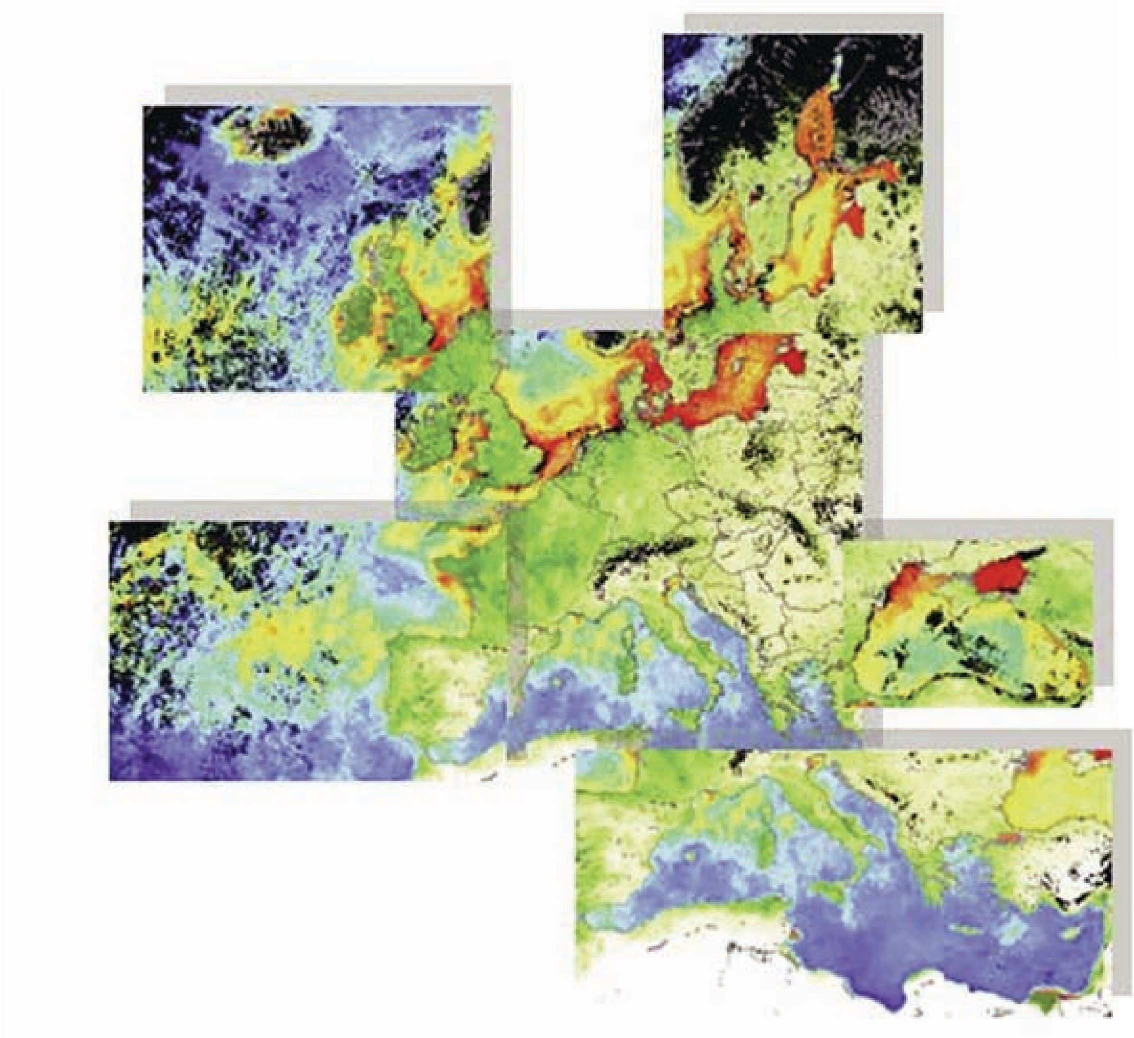


Figure 0.1. *Satellite view of Europe and European Seas. Colours are scaled on the surface chlorophyll concentration (marine) and the fraction of absorbed radiation (land). Source: JRC-Ispra.*

(NAO), a large scale atmospheric pattern driven by pressure difference between Iceland and the Azores/Iberia subtropical area. The natural variability of the NAO index, particularly in winter, affects the weather pattern in Europe with subsequent consequences on the marine and terrestrial environment.

The main objective of this report is to present a brief review of climate change issues in relation to the European marine environment, addressing the scientific and technical aspects, identifying gaps in our current knowledge, and examining the implications for society to develop adaptation and mitigation mechanisms. This report represents an attempt to highlight some important questions and concerns that have emerged from an Expert Workshop organized by the Joint Research Center of the European Commission in April 26-28th, 2006. The present document gives an account of the various topics presented and discussed during this workshop, including issues related to systematic observations and networks, modeling and data synthesis, ecosystem impacts and coastal responses, mitigation and policy adaptation strategies. Thus the report does not pretend to cover a complete and detailed assessment of all possible impacts due to climate change that affected each domain, each organism, and each area of the marine system.

Within the Framework Convention on Climate Change (FCCC), ‘climate change’ is defined in this report as a change of climate resulting from human activities (fossil-fuel combustion, land-use including agriculture and deforestation) that alter the composition of the global atmosphere. In this definition, climate change is identified on top of a natural climate variability (e.g. NAO) which refers to changes in climatic parameters that are not related to anthropogenic influences, e.g. changes in orbital parameters, internal adjustments/fluctuations of some atmospheric patterns, changes in the solar irradiance (Rind 2002) or volcanic eruptions (Robock, 2000). In practice, however, the natural variability of climate forcing occurs at all time-scales from months to centuries and millennia, which make the extraction of an anthropogenic signal very difficult (Staeger et al. 2003).
Therefore, this report is considering the broader IPCC (Intergovernmental Panel on Climate Change) definition of climate change, which accounts for ‘any change in climate over time whether due to natural variability or as a result of human activity’.

The global picture of climate change assessment
The IPCC Third Assessment report (TAR) was completed in 2001 (a 4th Assessment Report is presently under final preparation for publication in 2007) providing an increasing amount of evidence that notable changes is occurring in the global and regional climate. The Intergovernmental Panel on Climate Change (IPCC) was created in 1988 with the mandate to collect and synthesize, on a regular basis, all scientific and technical breakthroughs pertinent to improve our understanding of human-induced climate change, its impact on the environment and socio-economy, as well as to evaluate the various options for mitigation and adaptation.

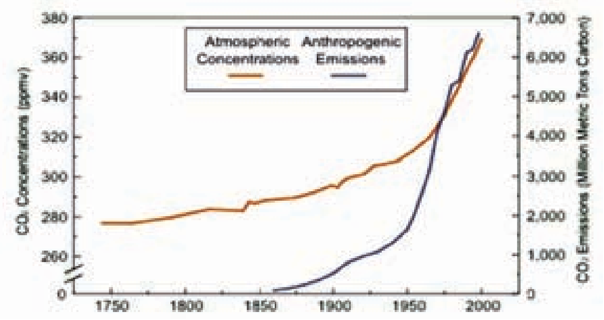


Figure 0.2. *Global atmospheric CO_2 concentration and anthropogenic CO_2 emissions (Source: Oak Ridge National Lab. Carbon Dioxide Information Analysis Centre)*

The IPCC Assessment Reports played a crucial role in establishing the UN FCCC (signed and ratified in early and mid-90s), and in the various international negotiations and meetings, particularly one that led to the Kyoto Protocol, assigning mandatory targets for the reduction of greenhouse gas emissions to signatory nations.
Over the last century, the global average surface temperature has increased by 0.6 ±0.2°C, representing, at least for the Northern Hemisphere, the largest increase within the past 1,000 years.

The performance of current models and new detection techniques enabled IPCC (2001) to further declare with some confidence that “most of the warming observed over the last 50 years is attributable to human activities” (fig. 0.2), mainly through carbon dioxide emissions from burning fossil fuels. Climate change and the atmospheric buildup of greenhouse gases will continue in the course of the next century to various extents, depending on the emission scenario that has been implemented in the model projection. However, many uncertainties remain, notably in the contribution due to natural variability of the system, and in the feedback mechanisms that determine the resilience of the climate system to further increase in greenhouse gases.

As the climate system becomes more and more affected by the increasing abundance of greenhouse gases in the atmosphere, coupled ocean-atmospheric models are further suggesting that the physics and biology of the ocean have changed and will change quite dramatically over the next few hundred years. These changes include increased water temperature, reduced sea-ice coverage, changes in water chemistry and pH, sea level rise, reinforcement of water stratification. In addition to the mean quantities, the distribution and frequency of extreme conditions (e.g. storm surges, heat waves) are being modified, reflecting changes in the atmospheric pressure systems, and the wind field at local, regional and global scales.

The European dimension of climate change

Europe is definitely not spared by climate change. As a matter of fact, Europe is warming faster than the global average, particularly during winter months (EEA, 2004). The number of extreme weather events and climate-related disasters has increased with different configuration for northern Europe (10-40% wetter) and southern Europe (up to 20% drier) (EEA, 2004). This north-south cleavage is expected to strengthen during the course of this century.

The physical, biological, and the morphological characteristics of the European seas and coasts are being affected accordingly, modifying their ecological structure, their functions and the goods and services they provide. A report from the European Environment Agency (EEA 2004) clearly indicates a rise in absolute sea level and an increase in surface water temperature in most of the seas around Europe since the last century, although the magnitude of these changes varies regionally depending on the main physical processes in place. In turn, these variables are affecting the marine ecosystems through changes in the species community and the food web organization, whereas storms and other extreme events contribute to coastal erosion, as well as inflicting damages to near shore habitats.

On top of that, the marine and coastal waters in Europe are continuously exposed to an increasing human pressure through activities such as fisheries, energy production, trade and commerce, tourism. The effect of climate change is thus difficult to untangle from direct anthropogenic activities. The latter often reduces the resilience property of the marine and coastal systems which then become more vulnerable to stresses due to climate forcing. Any decision planning to mitigate climate change impacts will then also depend on our ability to control human exploitation of the seas and coasts and to ensure sustainable management of the marine resources.

The report is structured into several sections providing an overview of key elements pertaining to climate change and its effect on the European marine environment. First, it includes a brief description of most marked indications of changes in different domains of the marine system, followed by some elements of discussion that would eventually contribute to a better understanding of the present and future status of the European seas. The third section considers specifically the coastal domain, addressing the difficulties to evaluate in a quantitative way the impact of climatic pressure in such complex environment excessively coveted and disturbed by human settlement. In section 4 and 5, some attention is given to some management measures that have been established or considered in response to environmental degradation or changes, looking at different sectors individually, as well as through the development and implementation of European policies. Finally, various options and cross-cutting issues are discussed to optimize environmental decision making processes, e.g. adopting an integrated approach to mitigation and adaptation strategies, and increasing dialogue between scientists and policy makers.

It is clear that each section or, even, sub-section of this report can represent the subject of hundred-page monograph. Restricting this information to a reasonable sized report has obviously imposed constraints on the inclusion of many aspects of climate change on European seas being only partially stated, if not omitted.

Suggestions to 'Further Readings' have, therefore, been inserted into the report where appropriate to provide the interested readers with other documents (usually reports available through the Internet) describing in more detailed some of the issues.

Further Readings:
IPCC, 2001: Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton, J.T.,Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 881pp.

EEA, 2004: Impacts of Europe's changing climate. An indicator-based assessment. European Environment Agency Report No 2, EEA, Copenhagen, pp.100.

Section 1

Signs of important changes on the European Seas and Coasts

Within the last two decades, there is more and more scientific evidence that environmental changes are occurring at all scales with profound impacts on European Seas and Coasts. Because the European climate is under the influence of both subtropical and arctic regimes, the evolution of the physical parameters (temperature, salinity, sea level) in response to global warming is adjusting to the regional climate and circulation. Water temperature shows different progression and trend in the northern seas (partly compensated by sea ice melting) than in the Mediterranean Sea and Atlantic waters. Sea level around Europe increased at a rate varying from 0.8 mm/y to 3.0 mm/y (EEA 2004), interfering with local processes such as water temperatures, tides, sea ice extent, evaporation, and various tectonic developments that may lead to crustal motion along the coastline, as well as with changes in the hydrological cycle on land.

Storm surges and other extreme meteorological events result from zonal variations in the wind pattern and in sea surface temperature, and their impacts on the marine ecosystems and coastal wetlands will then be regionally different.

As these climate variables evolve in Europe, there are more and more compelling signs that these are directly affecting the physics and biology of our seas and coasts with cascading effects from basin to regional and local scales. As an example, sea surface temperature has direct consequences on many physiological and reproductive attributes on marine life but also indirectly by modifying the marine environment, by influencing oceanic circulation, and by enhancing the stability of the water-column and hence nutrient availability. In this section, evidence of climate-related impacts is briefly described in three domains: ocean circulation and water mass characteristics, marine ecosystems and fisheries, and coastal dynamics. Although specific examples are given for each of these fields, some other documents may provide more complete and detailed analysis of climate change impacts for each individual sea basin in Europe (e.g. Philippart et al. 2006).

Further readings:

ESF, 2006. Climate Change impacts on European Marine and Coastal Environments. [C.J.M. Philippart, R. Anadón, R. Danovaro, J.W. Dippner, K.F. Drinkwater, S.J. Hawkins,T. Oguz, P.C. Reid (eds.)]. European Science Foundation Position Paper. Marine Board. (in press).

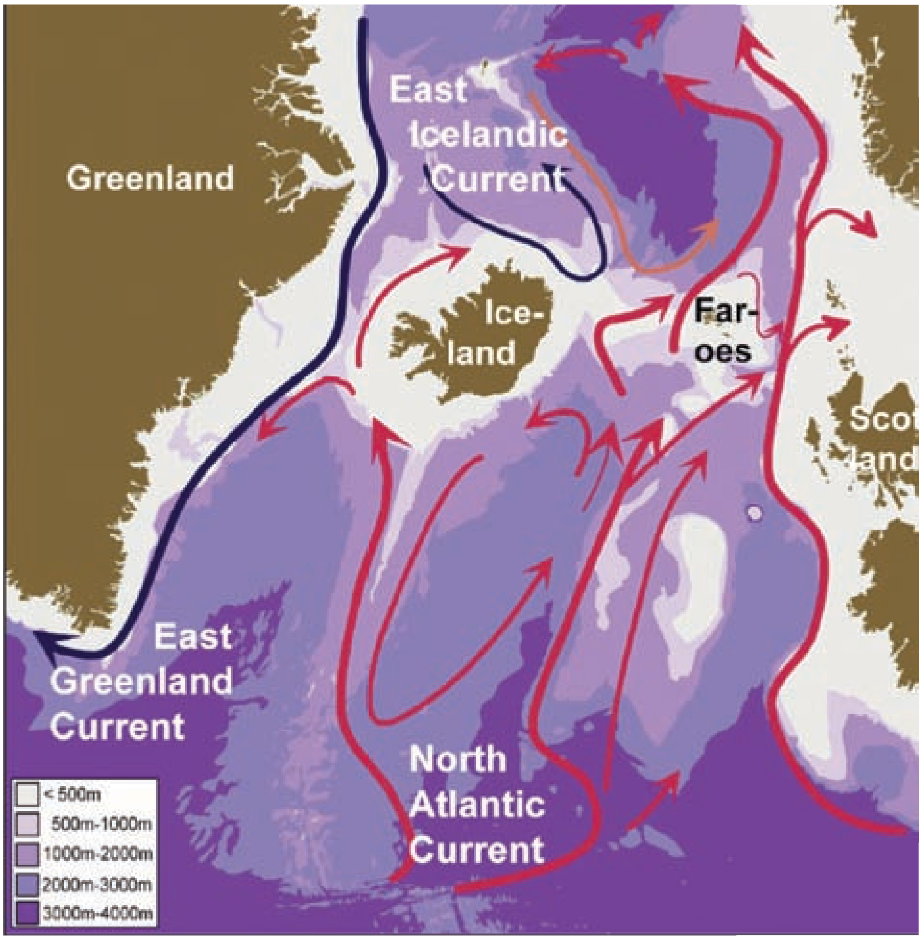


Figure 1.1.1. *Bottom topography (background colours) and surface circulation of warm (red arrows) and cold (blue arrows) currents.*

1.1 Changes in regional oceanography and water circulation

The water bodies that border Europe are the North Atlantic, the Arctic, and the Mediterranean. Climate change is affecting all of these areas in many different ways, and will likely continue to do so in the future through changes in temperature, salinity and water circulation. Global warming will, for example, tend to increase the sea surface temperature, change the freshwater balance into the marine system, both leading to changes in the water density.

But there is great uncertainty as to how water circulation may be affected and how this may, in turn, impact the regional oceanography and climate. In this chapter, two important examples are given of climate-related impacts on regional circulation.

The Nordic Seas-Atlantic system

A key area in this respect is the exchange of water between the Atlantic and the Arctic. Between Greenland and Scotland there is a submarine ridge, the Greenland-Scotland Ridge, which rises above the surface in Iceland and the Faroe Islands and has sill depths ranging from a few hundred to more than 800 meter depth in various areas (Fig. 1.1.1). At large depths, this ridge acts as a barrier and large differences are seen in water bodies on both sides of the ridge.

Above the sill of the ridge, water is, however, exchanged between the two regions.

The 'Atlantic inflow' carries warm and relatively saline water northwards from the mid-latitude North Atlantic towards and into the Arctic region. This flow, which originates in the North Atlantic Current (Fig. 1.1.1), carries heat northwards and helps maintain large areas ice-free and many degrees warmer than they would otherwise have been. Moreover, this energy keeps northern Europe climate significantly warmer in winter time than at comparable latitudes elsewhere in the world.

The water, imported in this way to the Arctic region, returns back to the North Atlantic, partly as a surface outflow and partly as a deep overflow (Fig. 1.1.2). Only about one third of the

Atlantic inflow does, however, return to the North Atlantic in the surface outflow.

The main part of the return flow is carried by the deep overflow (Fig. 1.1.2), which flows southward across the ridge through several channels and depressions as a cold and dense bottom-near current. In this way, it becomes the main contributor to the North Atlantic Deep Water, which represents an essential component controlling the global thermohaline circulation of the oceans (see Section 2.6).

Figure 1.1.2. *Exchanges of water between the North Atlantic and the Arctic region across the Greenland-Scotland Ridge, showing the Atlantic inflow (red arrows), the surface outflow (green arrows), and the overflow (blue arrows). Numbers indicate the volume transport in millions of cubic meter per second (Sverdrup).*

The water bodies of the North Atlantic and Arctic regions are the home of abundant stocks of various fish species of great economic value. Fisheries and other research institutes in many countries have therefore expended large efforts to monitor temperature and other properties in the sea for more than a century. The most notable feature in these measurement series is an increasing trend in both temperature and salinity during the last decade, which has affected all three Atlantic inflow branches. Moreover, the Atlantic inflow seems to have been warmer and more saline in 2003-2004 than ever before observed (Hátún et al., 2005). This trend cannot, however, be interpreted as a general warming and salinification of the source waters. Rather, it seems to be related to the strength of the subpolar gyre (Hátún et al., 2005), itself linked to convection processes in the Labrador Sea (Häkkinen and Rhines, 2004) and the formation at depth of the Labrador Sea Water which will mix southward with the North Atlantic Deep Water (NADW). The recent warming period would seem to be mainly due to the low production of Labrador Sea Water since 1995.

Measurements of temperature and salinity can also shed some light on the water circulation by identifying water fronts and how they move. But systematic measurements of the distribution and intensity of ocean currents have only been initiated during the last decade, mainly as a result of technological advances. These measurements have made it possible to quantify the exchanges between the North Atlantic and the Arctic region (Fig. 1.1.2) and their short-term variations. Through these efforts, present-day values for volume, heat, and salt import to the Arctic by the Atlantic inflow have been estimated (Østerhus et al., 2005), but these measurements are of too short duration to allow determination of trends.

The Atlantic inflow is, however, part of an interlinked system (Figure 1.1.2) and for some of the other branches in this system, trend estimates have been published. Thus, Hansen et al. (2001) suggested that the overflow through the Faroe Bank Channel had decreased in volume transport by 20% from 1950 to 2000, and Bryden et al. (2005) estimated a 50% reduction in the total overflow contribution to the southward transport of NADW. The reduction of the strength of the overflow, together with a freshening of the Nordic Seas can have important consequences not only on the local climate (Hansen et al. 2004), but also globally in modifying the North Atlantic Thermohaline Circulation (THC, see section 2.6). Neither of these results are, however, based on direct current measurements and both of them rely on assumptions that are hard to verify. Certainly, the low values suggested by Bryden et al. (2005) for the present-day overflow contribution to NADW are hard to reconcile with direct transport measurements of the overflow and estimates of the entrainment contribution (Macrander et al., 2005; Østerhus et al., 2001).

The Mediterranean Sea Thermohaline Circulation

The Mediterranean Sea is a mid-latitude, semi-enclosed, deep (average depth 1.45 km, max. depth 5.5 km) and oligotrophic basin. It consists of two major interacting sub-basins, the western and eastern which are connected by the Straits of Sicily (~1000m). It has been characterized as a “miniature ocean” due to the analogies to the

Atlantic Ocean as far as the physical processes are concerned. It is also considered as an ideal test basin for climatic research due to its rapid response to external forcing. The Mediterranean area is influenced by some of the most relevant mechanisms acting upon the global climate system. It is located in a transitional zone, where mid-latitude and tropical atmospheric variability compete. It is affected by the westerly winds during the whole year. It is exposed to larger scale systems as the South Asian Monsoon (SAM) in summer, the Siberian High Pressure System in winter, the North Atlantic Oscillation (NAO) and the El Niño Southern Oscillation (ENSO) (e.g., Corte-Real et al., 1995; Maheras et al., 2000).

At the largest scales of interest, i.e. interannual and basin-wide scales, the circulation of the Mediterranean is determined by its exchanges of water and heat with the atmosphere through the sea surface, and water and salt with the adjacent seas through the Straits. The thermohaline circulation of the Mediterranean, the largest scale motion, is forced by the buoyancy exchanges and is driven by its negative heat and freshwater budgets. The Mediterranean is a “concentration” basin, where evaporation exceeds precipitation and river runoff, with high-density water production. It receives light waters from the Atlantic Ocean (Strait of Gibraltar, 15km wide, and 250m deep) and to a lesser extent from the Black Sea (Strait of Dardanelles, 4km, 55m) at the surface layers and exports dense and saline waters by underwater currents (“lagoonal” circulation). The warm and salty Mediterranean water injected into the Atlantic contributes to the North Atlantic thermohaline circulation. Any significant changes in its hydrological properties may have influence in the deep water formation processes in the North Atlantic. The deep layers of the Mediterranean Sea are renewed through deep vertical mixing in winter following two systems of thermohaline cells.

The first, the upper open conveyor belt, consists of (i) the non-return flow of low salinity Atlantic Water (AW), entering from the Gibraltar Strait, to the easternmost end of the Levantine Basin in the upper 150-200m and (ii) the formation and westward spreading of the warm and saline (S~39.00-39.1 at the source area) Levantine Intermediate Water (LIW), at depths 200-400m, to the Gibraltar, where it enters the Atlantic Ocean.

Secondly, there are internal thermohaline cells (closed conveyor belts) in each of the Mediterranean sub-basin driven by deep water formation processes (Theocharis et al., 1998) (Fig. 1a). In winter, at very well defined areas, where specific atmospheric (very low temperatures, strong and dry northerlies, increased evaporation) and oceanic (cyclonic circulation) conditions prevail, the winter cooling is episodically violent and the convection, reaches great depths and even down to the bottom. The Gulf of Lions and the Adriatic Sea are the basic sites of the deep water formation in the Western (WMDW) and the Eastern (EMDW) sub-basin respectively. The deep waters of the Mediterranean are confined in the deep and bottom layers of the respective sub-basins because of the existence of the sills at the Sicily and Gibraltar. The renewal of the deep waters is on the order of 80-100 years.

In the late 80s and early 90s, abrupt changes in salinity and in temperature caused continuous increase of density and massive deep water formation in the south Aegean (Malanotte-Rizzoli et al., 1999; Theocharis et al., 1999) that alter the thermohaline circulation of the eastern Mediterranean (Fig. 1a, 1b) (Robinson et al., 2001; Roether et al., 1996) with consequences

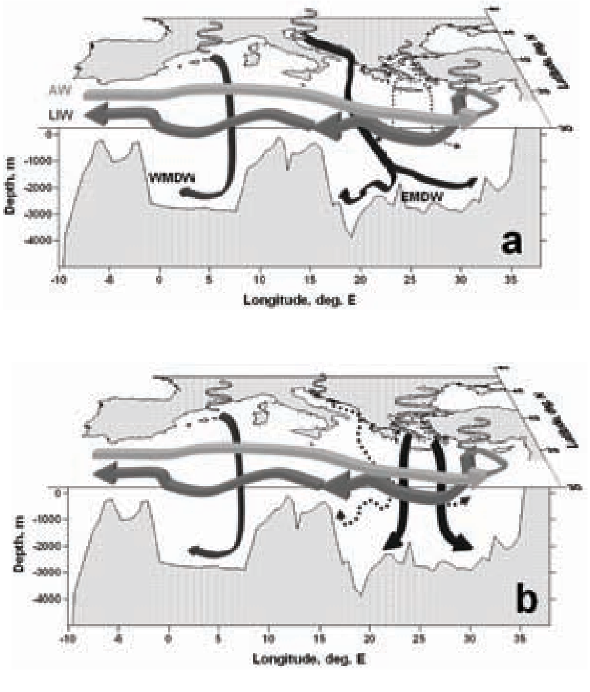


Figure 1.1.3. *The thermohaline cells of the Mediterranean Sea before the EMT (a) and after the EMT (b) (From Tsimplis et al., 2006)*

also in the distribution of other environmental parameters (Klein et al., 1999). This major event, unique in the oceanography of the Mediterranean since the beginning of the 20th century, evolved within the last 18 years and was called the "Eastern Mediterranean Transient" (EMT). The active convective region shifted from the Southern Adriatic to the Aegean. The signal of this change has been felt in the western Basin. The event has then gradually decayed since 1995 indicating its transitional nature (Theocharis et al., 2002). This abrupt event has been mainly attributed to local important meteorological anomalies (extended reduced rainfalls, change in wind patterns, exceptionally consecutive cold winters) (Theocharis et al, 1999; Lascaratos et al., 1999; Samuel et al., 1999), to changes of the AW and LIW circulation patterns and to the reduced Black Sea Water outflow (Malanotte-Rizzoli et al., 1999; Theocharis et al., 1999; Zervakis et al., 2004). The relationship between the heat loss and large scale atmospheric patterns (e.g. NAO) is also investigated. This climate-related episodic change has been superimposed to a longer-term trend in salinity observed in the eastern Mediterranean since 1950s in response to human alteration of the river basin in Russia and Egypt (Boscolo and Bryden 2001). On the other hand, some palaeoceanographic studies have also suggested the large sensitivity of the Aegean Sea to climatic variability.

The main modes of the circulation variability and their response to different modes of atmospheric variability are not yet fully resolved (Tsimplis et al., 2006). Therefore continuous monitoring of the circulation pattern at key points in the Mediterranean Sea is essential to assess future changes in the water masses under different warming atmosphere scenarios. The data would have enormous value to increase our scientific understanding of a possible climate–related switch in the oceanic thermohaline circulation, and to support decision-making processes in climate change mitigation.

So far, measurements of volume transport and exchange intensity have been funded mainly by research grants and, to some extent, this will also be possible in the near future, since there are still a number of unanswered questions of great scientific interest, but systematic monitoring of the exchanges, including all important contributions, can hardly expect prolonged funding from programs that rely purely on scientific merit. Systematic monitoring to identify any potential changes in circulation in a future global change scenario will therefore require a dedicated funding mechanism.

1.2 Marine ecosystem & Fisheries

While many changes in marine commercial fish stocks have been observed over the last few decades in the Atlantic it is extremely difficult to separate, in terms of changes in population densities and recruitment, regional climate effects from direct anthropogenic influences like fishing. Geographical range extensions or changes in the geographical distribution of fish populations, however, can be more confidently linked to hydro-climatic variation and regional climate warming. Recently long-term decadal observational studies have focused on known natural modes of climatic oscillations at similar temporal scales such as the North Atlantic Oscillation (NAO) in relation to ecosystem changes (Stenseth et al. 2002, 2003). However, approximating the effects of climate change embedded in natural modes of variability such as the NAO is extremely difficult and therefore direct evidence of biological impacts of anthropogenic climate change must be treated with caution.

Perhaps equally important to global climate change, in terms of modifying the biology of our European seas, is the impact of anthropogenic CO_2 on the pH of the oceans (Feely et al. 2004; see section 2.4). Other driving forces of change that are operative in our marine biological systems are overfishing and, in coastal regions, anthropogenic nutrient input and pollution.

Climate related impacts on marine ecosystems

There is an accumulating body of evidence to suggest that many marine ecosystems, both physically and biologically are responding to changes in regional climate caused predominately by the warming of air and sea surface temperatures (SST) and to a lesser extent by the modification of precipitation regimes and wind patterns. The biological manifestations of rising SST have variously taken the form of biogeographical, phenological, physiological and species abundance changes (Fromentin and Planque 1996; Reid et al. 1998; Edwards et al. 2001, 2002; Beaugrand et al. 2003; Richardson and Schoeman 2004). Some of the most convincing evidence for the biological response to regional climate variability comes from the bottom of the marine pelagic food-web especially from phytoplankton and zooplankton communities. Many other responses associated with climate warming on higher trophic levels are also indirectly associated with changes in the plankton and imply bottom-up control of the marine pelagic environment. It is therefore assumed that one of the ways in which populations respond to climate is partly determined by changes in the food-web structure where the population is embedded, with synchrony between predator and prey (match-mismatch) playing an important role.

In the North Atlantic, both phytoplankton and zooplankton species and communities have been associated with Northern Hemisphere Temperate (NHT) trends and variations in the NAO index. This has caused extensive changes in the planktonic ecosystem in terms of plankton production, biodiversity, species interactions and distribution, which have had effects on fisheries production and other marine life such as benthic organisms, seabirds and whales (see reviews by Reid and Edwards 2001, Drinkwater et al. 2003). In the North Sea, the population of the previously dominant and important zooplankton species, (the cold water species Calanus finmarchicus) has declined in biomass by 70% since the 1960s (Edwards et al. 2006). Species with warmer-water affinities are moving northward to replace the species, albeit not as abundant. Furthermore, recent macroscale research has shown that the increase in regional sea temperatures has triggered a major re-organisation in calanoid copepod species composition and biodiversity over the whole North Atlantic basin (Beaugrand et al. 2002). During the last 40 years there has been a northerly movement of warmer water plankton by 10° latitude in the north-east Atlantic and a similar retreat of colder water plankton to the north. This geographical movement is much more pronounced than any documented terrestrial study, presumably due to advective processes associated with the shelf edge current running north along the European continental margin (Fig 1.2.1).

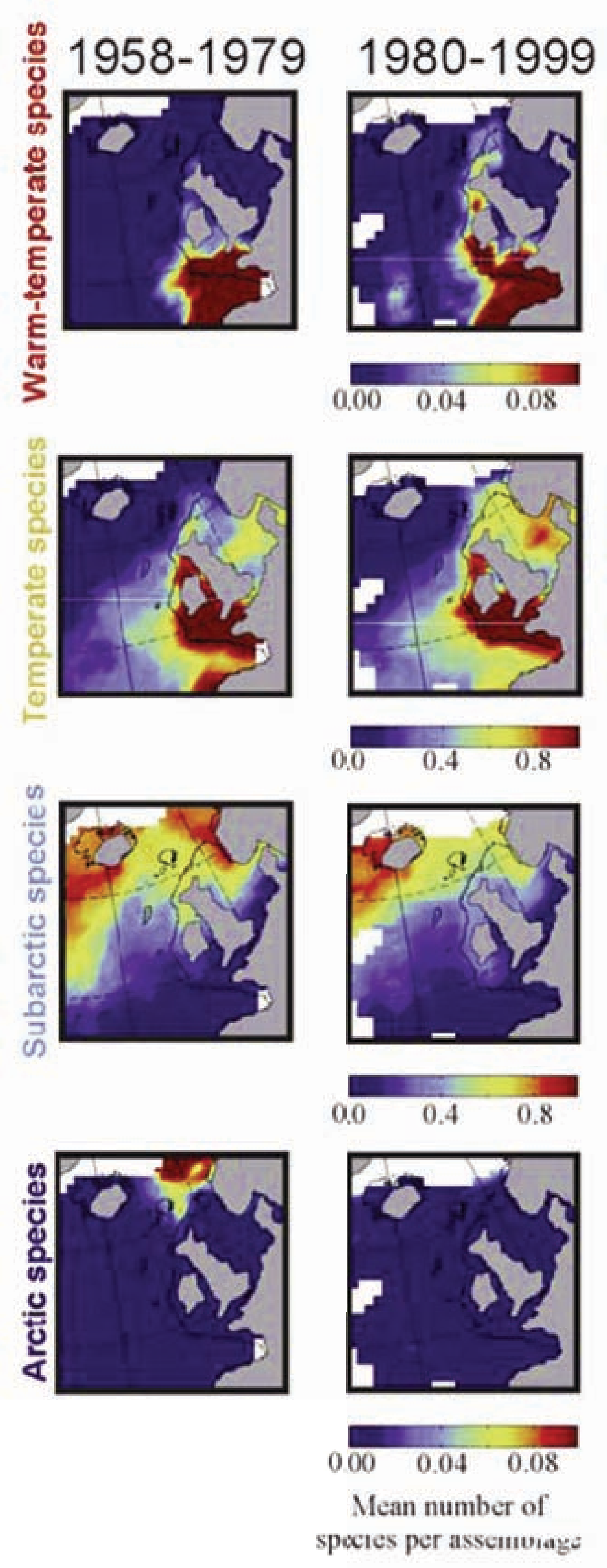


Figure 1.2.1. *Long term changes in the spatial distribution of the calanoid copepod species assemblage around UK and in the northern Notheast Atlantic. The northward movement of the warm-water species is associated with a decrease in the mean number of cold water species (from Beaugrand et al. 2002)*

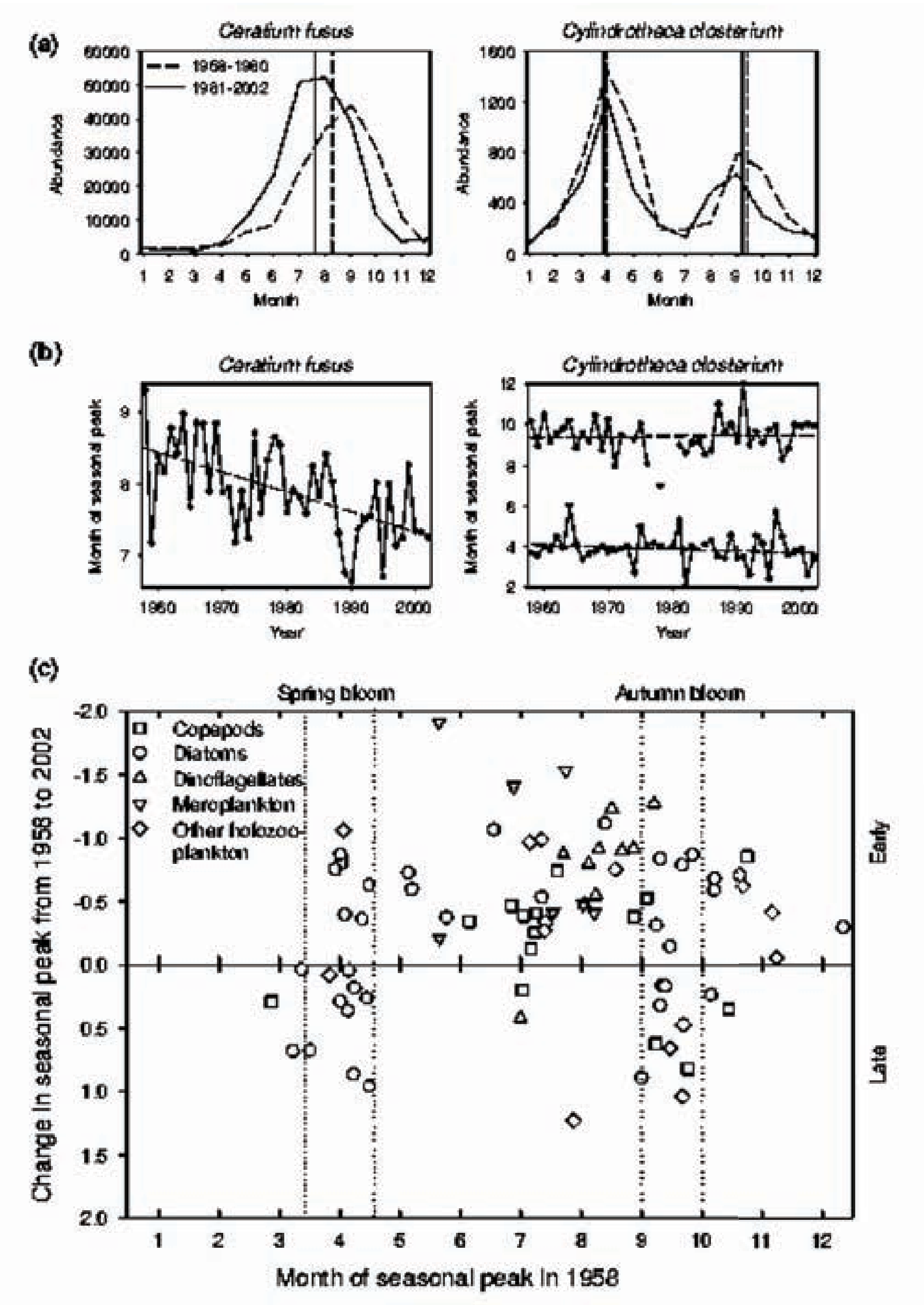


Figure 1.2.2. *Changes in phenology throughout the pelagic season.*
a) seasonal cycles for the dinoflagellate Ceratium fusus and the diatom Cylindrotheca closterium for the periods 1958-80 and 1981-2002.
b) Interannual variability of the seasonal peak for both species over the period 1958 to 2002. c) Differences in the timing of the seasonal peaks (in month) for 66 plankton taxa with respect to their seasonal peak in 1958. (from Edwards and Richardson 2004)

The ecological changes that have occurred in the North Sea and North Atlantic (predominately driven by rising temperatures) have also been documented in the Baltic Sea for zooplankton and fish stocks (Alheit et al. 2005), and in the Mediterranean Sea for zooplankton (Molinero et al. 2005). Note that the related changes that have taken place in these Northern European waters are sufficiently abrupt and persistent to be termed as ‘regime shifts’ (Beaugrand 2004).

In terms of the marine phenological response to climate warming, many plankton taxa have been found to be moving forward in there seasonal cycles (Edwards and Richardson 2004). In some cases a shift in seasonal cycles of over six weeks was detected, but more importantly, the response to climate warming varied between different functional groups and trophic levels, leading to mismatch in the prey-predator relationship (Fig 1.2.2). Temperate marine environments are particularly vulnerable to phenological changes caused by climatic warming because the recruitment success of higher trophic levels is highly dependant on synchronisation with pulsed planktonic production (Edwards and Richardson 2004).

Climate related impacts on fisheries

Similar to the observed changes in marine ecosystems many long-term changes in fish populations have been associated with known natural modes of climatic oscillations such as the North Atlantic Oscillation (NAO) (see reviews Stenseth et al. 2002; Heath 2005). For example, variations in SST driven by NAO fluctuations have been linked to fluctuations in cod (one of the major North Atlantic fish resources) recruitment (Stenseth et al. 2002; Chen et al.2005). Populations of herring, sardine, salmon and tuna have also been related to fluctuations in the NAO index (Beaugrand and Reid 2003; Drinkwater et al. 2003). These changes highlight the sensitivity of fish populations to environmental change. Direct evidence of biological impacts of anthropogenic climate change is, however, difficult to discern due to the background of natural variation on a variety of spatial and temporal scales and in particular natural oscillations in climate.

Northerly geographical range extensions or changes in the geographical distribution of fish populations have been recently documented for European Continental shelf seas and along the European Continental shelf edge (Brander et al. 2003; Genner et al. 2004; Beare et al. 2004; Perry et al. 2005). Catches of southern immigrant species to the southwest of England have increased as the water temperature of the North East Atlantic has risen from 1960 to 2001 (Stebbing et al. 2002). These geographical movements have been related with regional climate warming and are predominantly associated with the northerly geographical movement of fish species that have more southern biogeographical affinities. These include the movement of sardines and anchovies northward in the North Sea, and red mullet and bass extending their ranges northward to western Norway (Beare et al. 2004; Brander et al. 2003). New records were also observed over the last decade for a number of Mediterranean and northwest African species on the south coast of Portugal (Brander et al. 2003).

Regional climate warming in the North Sea has affected cod recruitment via changes at the base of the food web (Beaugrand et al. 2003). Cod, like many other fish species, are highly dependent on the availability of planktonic food during their pelagic larval stages. Key changes in the planktonic assemblage caused by the warming of the North Sea over the last few decades has resulted in a poor food environment for cod larvae and hence eventual recruitment success (Fig.1.2.3). These results are an example of how both the dual pressures of over-fishing and regional climate warming have conspired together to negatively impact commercially important fisheries. As the stocks are declining, fishes have become more sensitive to regional climate warming due shrinkages of the age distribution and geographic extent (Brander 2005).

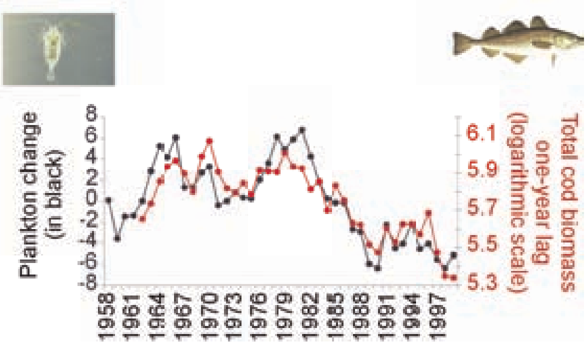


Figure 1.2.3. *Long-term changes (1958-1999) in the plankton index (biomass, mean size, and abundance of two Calanus species) and cod recruitment (one-year-olds) at lag one. In addition to an overfishing effect (top-down control), fluctuations in plankton due to climate change also result in changes in fish recruitment (bottom-up control). (from Beaugrand et al. 2003)*

Recent work on pelagic phenology has shown that plankton communities, including fish larvae, are very sensitive to regional climate warming with the response to warming varying between trophic levels and functional groups (Edwards and Richardson 2004). These changes, again seen in the North Sea, have the potential to be detriment to commercial fish stocks via trophic mismatch.

The ability and speed in which fish and planktonic communities can genetically adapt to regional climate warming is not yet known.

Future warming is likely to alter the geographical distribution of primary and secondary pelagic production, affecting ecosystem services such as oxygen production, carbon sequestration and biogeochemical cycling.

These changes may place additional stress on already-depleted fish stocks as well as have consequences for mammal and seabird populations.

Traditional North Sea target-species like cod are likely to continue to decline and they maybe replaced by species such as red mullet, sardines and anchovies. The interaction between fishing and climate change impacts need to be better analysed as it has important implications for management policies.

1.3 Coastal changes

Coastal zones are transitional areas in which processes are controlled by complex interactions and fluxes of material between the land, ocean and atmospheric systems. As a result, coastal zones are among the most dynamic, rapidly changing and most vulnerable environments on Earth. Natural factors that are expected to have the largest impact on coastal systems are temperature changes, sea-level rise, river runoff, wind patterns, and frequency and severity of storms. In all cases, however, these natural forcings are not acting individually on a specific compartment of the coastal system, but are instead interconnected in many ways and constantly associated with a human signature of some sort.

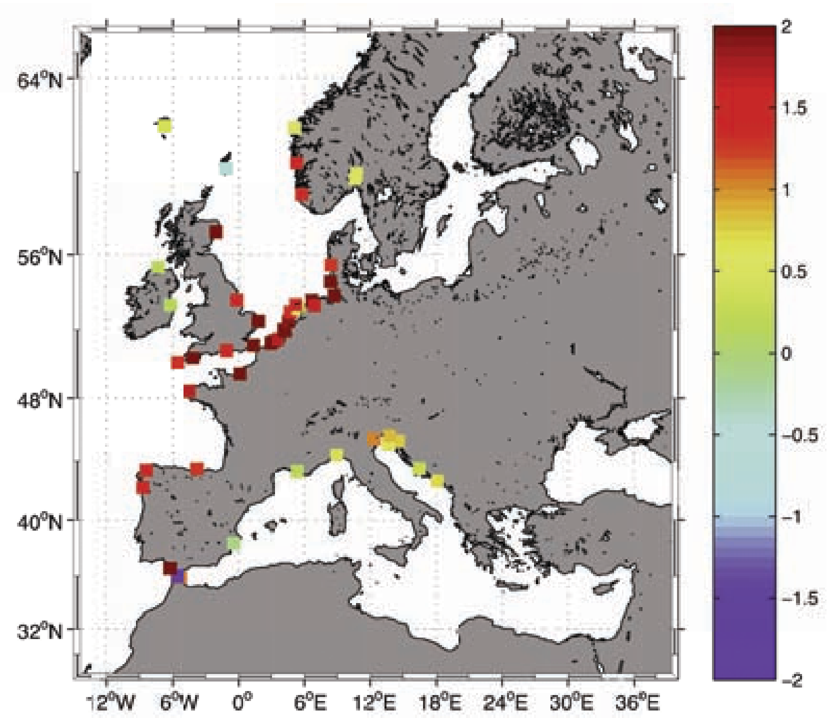


Figure 1.2.3. *Sea level trends at the European coast (with the exception of the Baltic Sea) for the period 1962 – 2000. Values are in mm/yr. Computed trends from sea level observations are corrected for glacial isostatic adjustment (GIA) by means of the ICE-5G (VM4) model. Only those tide gauge stations with data available for the entire period are considered in this plot. Other tide gauges covering different periods of time are available. Tide gauge data come from the Permanent Service for Mean Sea Level database. Standard errors are typically 0.3mm/yr. However, empirical determination of trends indicates that decadal variability can also introduce an additional 0.3mm/yr for records 40 years long. (Figure courtesy of Dr. Marta Marcos and M. Tsimplis)*

A rise in sea level resulting from the thermal expansion of sea water and melting of land-based ice will potentially inundate wetlands and lowlands, accelerate coastal erosion, exacerbate coastal flooding, threaten coastal structures, raise water tables, and increase the salinity of estuaries, bays, and aquifers. Sea level has been rising globally during the last century by a rate between 1 and 2 mm/yr (Church et al. 2001 in IPCC TAR). Since the early 1990s, both tide gauges and satellite-based altimeters agree to assign a rise in the global mean sea level of ca. 3mm/yr. The same IPCC report indicates sea level projections for this century to rise between 0.09 and 0.88 m for the period 1990-2100, depending on the emission scenarios selected as input to the model, and uncertainties in parameterization of the physical processes.

Part of these uncertainties results from insufficient knowledge on changes occurring in glaciers and ice sheets and how these are impacting sea level, on the magnitude and geographical distribution of increase in precipitation.

At the coast, however, the importance for coastal managers lies with the local rate of relative sea level, as measured from tide gauges.

These measurements integrate other processes such as land movements, tides and waves, changes in wind strength and directions, or changes in the coastal currents, in addition to the global thermal expansion of the water due to global warming. Accordingly, the relative mean sea level change along the European coasts shows a great deal of spatial variability, being even negative at some locations experiencing significant land uplift (isostatic rebound) or, conversely, strongly positive in areas of significant land subsidence.

Some of these processes that contribute significantly to uncertainties in the data and difficulty in measuring sea level at specific coastal locations are still not very well understood. Tsimplis and Rixen (2002) observed some discrepancies between steric sea level anomalies (based on temperature and salinity variations) and tide gauge measurements in the Mediterranean Sea, suggesting that change in the regional circulation may affect the magnitude of sea level at the coast. Sea level in the Black Sea rose on average by 2.87 to 3.14 mm/yr between 1921 and 1997, with large interannual fluctuations partly correlated with the rate of precipitation over the catchment area (Shuisky 2000), itself influenced by the North Atlantic Oscillation (NAO).

Coastal damage and flooding depend on extreme sea level events which combine sea level rise with the effect of tidal cycles, changes in the frequency of storm surges and changes in wave climate. There is concern that climate change and global warming may increase the frequency of storm events (IPCC 2001). As for the relative sea level, the frequency of storms is spatially variable depending on the regional climatic variations and trends in the dominant atmospheric patterns (e.g. North Atlantic Oscillation, see section 2.2). Zong and Tooley (2003) observed an increase in coastal flood frequencies in the south and southwest coast of Britain over the last century, and a decline along the west coast.

Figure 1.3.2. *Low-lying areas along European coastline. Red surfaces are areas below 5m elevation. (source : EEA 2006)*

Low-lying coastal areas (i.e. below the 5m elevation line) are particularly sensitive to sea level rise, amplifying their vulnerability to storm surge events and increasing wave heights. Countries like The Netherlands and Belgium are the most vulnerable countries with 85 % of the coast being under 5 m elevation (EEA 2006). A better understanding of the sea level variability in these areas is of utmost importance to work out an effective coastal planning and management system.

Further Reading:
EEA, 2006: The changing faces of Europe's coastal areas. European Environment Agency Report No 6, EEA, Copenhagen, pp.108.

Coastal change in Scotland: a case study

The coastal and marine environments of Scotland are some of the most dynamic and scenic areas in the World. They include many special and unique landscapes of national and international importance (e.g. sea lochs, maerl beds). Scottish waters are also among the most diverse in the World, supporting over 8,000 complex- and over 36,000 single-cell species of plants and animals (Scottish Executive, 2005). Extending from the River North Esk (Angus) to Inverness on the Moray Firth, it comprises a dynamic combination of both hard and soft coastline with some of the UK's best coastal geomorphology comprising cliffs, embayments, sand and shingle beaches, dune systems, estuaries, and spits. Over time the impacts of climate change and sea level rise may pose some threats particularly to low lying areas and habitat along the coastline through coastal flooding and inundation during storm periods, and changes through increased and more dramatic erosion events.

Scotland's coastline is approximately 11,000 km long, ca. 6% of the total coastline of Europe (as defined in the general Introduction), and comprises one of the largest inshore areas of any EU country (Scottish Executive, 2006). According to the Scottish Executive (SE), the effects of climate change are already being observed in Scotland. 50 years of data records have revealed a doubling of the frequency of winter storms and extreme weather conditions (Scottish Executive, 2005). Wave heights are also expected to increase and this is likely to be especially severe for Western

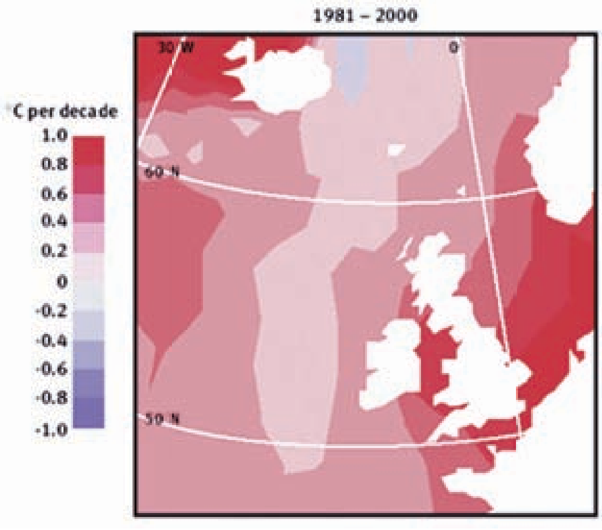


Figure 1.3.3. *Temperature trend in degrees per decade, 1981–2000 (red shading indicates warming and blue shading indicates cooling) (SEPA, 2006)*
Source: Scottish Ocean Climate Status Report 2002-2003 Fisheries Research Services, 2005.

and Northern Scotland. Some parts of the Scottish coastline may be particularly vulnerable to rising sea levels and any increase in storm surge activity, as a consequence of climate change, may well lead to increased erosion of intertidal habitats and a resultant loss of biodiversity.

Observations of the seas around Scotland have also revealed warming by 1°C over the last 20 years (Fig. 1.3.3). This has already been reflected by changes in composition, abundance and distribution of a number of marine species including plankton, fish, sea birds, whales, mammals, dolphins and porpoises (SEPA, 2006).

The City of Aberdeen, on the NE coastline of Scotland has some of the earliest tidal gauge records in the World, stretching back to 1862 (SEPA, 2006) (Figure 1.3.4). According to Werrity (2004), since 1900 there has been a 70mm rise in sea level in Aberdeen compared to a rise of 1-2mm globally. Furthermore, by 2050 a predicted rise in sea level of up to a possible 600mm could become a reality with inundation of vulnerable coastal areas where the terrain is below the 5m contour resulting in increased coastal flooding.

The low lying Western Isles, Northern Isles, and parts of the east coast of Scotland in particular are at risk from flooding (Werrity et al., 2002). This is also likely to be exacerbated when storm surges coincide with high tides and high runoff from river catchments.

Potentially flooding may have a serious impact on Scotland's economy, housing and transport, affecting nearly 100,000 properties, especially as 20% of the population lives within 1km of the coast and approximately 70% within 10km (Werrity, 2004). Furthermore, a 25% of Scottish businesses, accounting for 10% of Scottish turnover and 20% employment, are within 1km of the coast (Scottish Executive, 2005). Based upon the 5m contour approximately 7% of agricultural land is also vulnerable. In the coastal zone, properties located in the following coastal areas (the Carse of Gowrie, the lower Forth estuary, and the lower Clyde estuary), inland areas (the lower Tay, Earn and Isla, the lower Kelvin) and urban

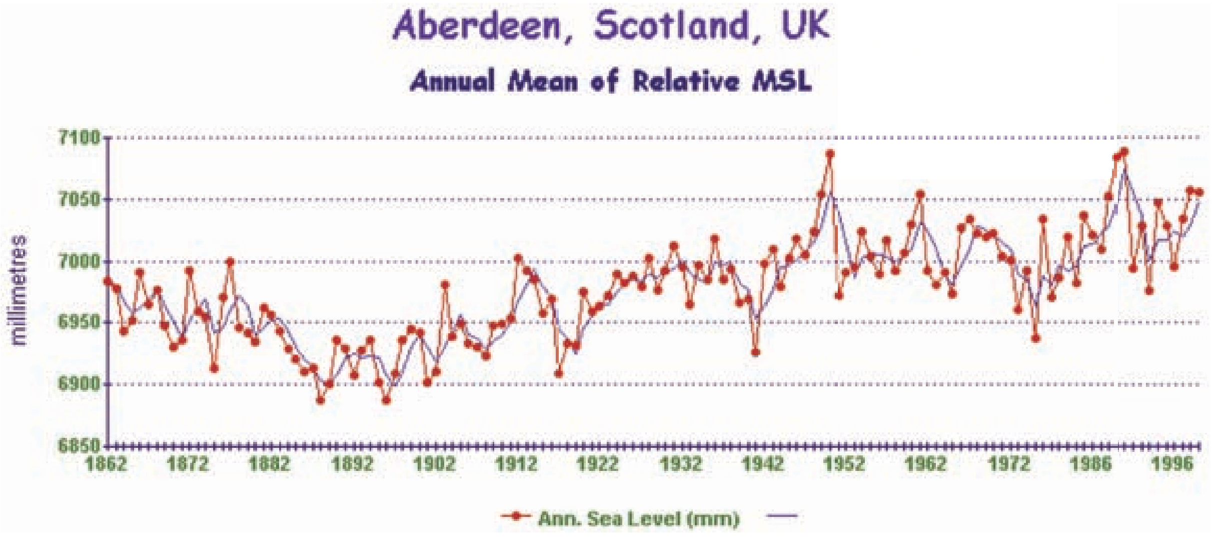


Figure 1.3.4. *Annual mean sea level at Aberdeen, Scotland, UK (Daly, 2000)*

areas (Paisley, Cathcart, Kirkintilloch and Kilmarnock) are considered especially vulnerable significance (Werrity et al., 2002).

There is of course some uncertainty associated with all data records and model predictions. For example, as noted by Daly (2000) it is not known to what extent local data records, such as those for Aberdeen, reflect global trends. Unless tide gauges are mounted on bedrock, then the data are subject to local errors resulting from (a) ground subsidence due to the weight of local building structures and changes in the water table a particular problem for cities located on low-lying alluvial coasts, and (b) because tide gauges are often mounted on man-made structures such as piers and docks.

Werrity et al. (2002) have suggested a future Scottish research agenda that will include examining the role of different factors in sea level rise as the basis for developing a better understanding of predictions.

In addition, they recognize the potential of remotely sensed data such as Lidar, Casi and SAR as a basis for monitoring, mapping and modeling, to provide higher resolution topographic data and land-cover and habitat maps to study flood inundation and coastal landscape change. Already some studies by Scottish Natural Heritage (Green et al., 2006) are utilizing a combination of archival aerial photography and Lidar data to generate Digital Elevation Models (DEMs) as the basis to establish where coastal change is occurring and by how much (erosion and accretion), as well as helping to identify the most vulnerable coastal areas to flooding, information that has not previously been available.

Section 2

Uncertainties, State of Science, and Research Needs

Research related to climate change in regional systems such as the European Seas includes a number of different aspects ranging from hydrographic conditions to circulation changes, ecosystems shifts, and sea level variability. Specifically, extreme weather situations and the resulting sea level changes are of vital interest for society. A precise knowledge on the magnitude of these changes and the factors controlling their variability is thus prerequisite for any decision making process related to coastal protection and marine security issues. On the other hand, the management of marine resources depends on our ability to understand and model the impacts of climate variability on the ecosystem productivity (including harmful algal blooms) and species composition at different trophic levels, which are in turn extensively correlated to hydrodynamic conditions such as the variability in circulation, sea temperature, mixing and stratification conditions. Even though some global variables (e.g. water temperature, sea level) can be addressed with a reasonable level of confidence, important gaps and questions still need to be investigated or answered to gain a better understanding of how marine and coastal environment will react in a high-CO_2 *system at regional scale, hence, to reduce uncertainties in prognostic models owing to a better formulation of these processes and higher accuracy of the parameter values. The following section articulates a number of elements that require specific attention to reduce biases in regional climate models, to improve closure in the biogeochemical cycles and the carbon budget between land, atmosphere and open ocean, and to better define the ecological processes and carrying capacity of the community structure. Observations are at the basis of all scientific understanding, and particularly, climate change studies require observational data to extend over long period of time. The challenge to sustain an appropriate marine/climate monitoring system in Europe is addressed, emphasizing on an essential integration between model and observation networks to optimize predictions*

2.1 Resolving scale issues from global to regional

Coupled atmosphere-ocean general circulation models (AOGCMs) are used extensively in climate change research (see also IPCC) for the projection of direction and rate of change of future climate. Progress in computational power has considerably increased the capacity of these models to produce climate projections for centuries, and to simulate the response of several climate variables to different scenarios of greenhouse gases emissions. However, they are designed to resolve phenomena of several hundreds of kilometre. Below this scale their results are typically not reliable (v. Storch, 2005). As a result, regional coastal systems are not resolved sufficiently, or not included at all in these models. Hence, they are only of limited value to answer questions about the impact of climatic variability on regional and coastal systems. Downscaling techniques, based on statistical relationships between global and regional parameters (e.g. Giorgi et al., 2001a) or the utilization of dynamic regional models (e.g. Giorgi and Mearns, 1991), are therefore required to resolve climate variability and change with focus on relevant regional systems.

Downscaling issues, regional climate models

Downscaling is the process of deriving regional climate information based on large-scale climate conditions. However, clear relations between local key processes and large scale climatic variability are difficult to identify for some parameters (e.g. biological productivity), and thus the application of statistical downscaling has some limitations. Further problems are to be expected in a changing climate which may cause changes in the statistical relationship between global and local parameters. In that case, the statistical downscaling process is likely to fail to predict regional system behavior. Regional climate models provide an alternative to overcome the downscaling issue. By considering deterministic process descriptions and, hence, allowing for consideration of complex and nonlinear interactions, they are applicable for regional predictions under various climatic conditions. Starting from the utilisation of uncoupled models (e.g. Giorgi et al., 2001b; Langenberg et al., 1998), regional climate models have been extended to cover the coupled ocean-atmosphere-cryosphere system (e.g. Janssen et al., 2001; Schrum et al., 2001; Döscher et al, 2002) and are currently extended to contain more components of the earth system, such as the biosphere (Schrum et al., 2006).

Example: Climate change in the North Sea

The following discussion of climate change in the North Sea focuses on 2 different topics: Firstly, the application of regional 2-D models to reconstruct historic sea level variability and wave conditions, and their utilization for impact studies; second, the dynamic downscaling for more complex systems such as the baroclinic marine environment and the marine ecosystem. The latter is centered on marine productivity at the first and second trophic level. In the North Sea, the chronological analysis of sea level variability based on observations only, are typically limited to coastal stations equipped with tide gauges (e.g. Woodworth and Blackman, 2002; Jensen and Mudersbach, 2004). Depending on the method used to analyse the data, the time period and station selected, some strong inter-annual variabilities can be observed in the data set, as well as a positive rising trend of sea level over several decades, which was found to be specifically amplified since about 1955-1960.

In addition, some investigations of past regional climatic conditions in the North Sea have identified clear anomalies in the wind forcing over the past decades (fig.2.1.1), in relation to sea level

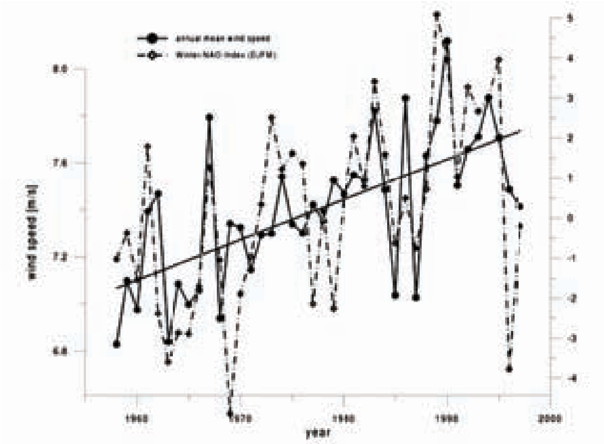


Figure 2.1.1. *Annual mean wind speed averaged over the North Sea and winter North Atlantic Oscillation (NAO) index (Siegismund and Schrum, 2001).*

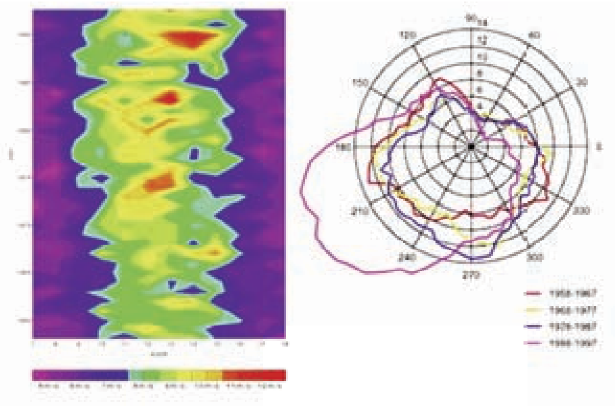


Figure 2.1.2. *Wind speed changes (left) and changes in wind direction and intensity (right) averaged over the North Sea. Figures adopted after Siegismund and Schrum (2001).*

changes. Changing positions of the North Atlantic air pressure system resulted in local wind forcing changes in the northern part of the North Sea, with an increase in the wind strength, changes in its direction and seasonality (fig.2.1.2, Siegismund and Schrum, 2001), as well as in storminess (Weisse et al., 2005).

Time series reconstructions, as performed with quasi realistic models, enable a dynamic interpolation of the observed data and, thus, a spatially extended recovery of the historical analysis. Various long-term reconstructions for several decades are now available for the North Sea area, providing among other things, 2-D high resolution data for water transport, sea level and wave heights (Flather et al., 1997; Langenberg et al., 1998; Weisse and Plüß, 2006; Gaslikowa and Weisse, 2005). These studies showed increasing trends in mean winter sea level, particularly severe along the coastline of Netherlands, Belgium and Germany with a maximum of about 2.5mm/yr for the Danish coast. These modelled results are consistent with the observations from tide gauge and with historical reconstructions of wind speed and storminess in the North Sea area (Schrum and Siegismund, 2001; Weisse et al., 2005). A sensitivity analysis clearly identified the wind forcing to be the major factor responsible for this trend. Furthermore, time series reconstructions from wave model showed clear increasing trends in significant wave heights for the southeastern North Sea, with a maximum above 2.1cm/yr in the German Bight (Prof. Hans v. Storch, pers. comm.). Recently, these models have been used to assess impact of future climate change on the regional scale. Such an exercise has been undertaken for the North Sea in the frame of the PRUDENCE project (Woth et al., 2006).

First attempts have been made to perform more complex historical reconstructions of the North Sea marine conditions (Schrum et al., 2000; Kauker and v. Storch, 2001; Schrum et al., 2003) using coupled models. Testing the validity of such models is difficult considering the large number of model parameters and interactions considered, when compared with 2-D barotropic hindcasts. Nonetheless, their ability to simulate marine system response to climate variability or climate change relies on comprehensive validation exercises and clever configuration scheme to nail down as much as possible the uncertainties. Such effort has been undertaken only for a few of these models (Janssen et al. 2001; Janssen 2002), using various observational data sets to evaluate the models performance and estimate models bias with respect to different time-, and spatial scales and different model parameters. Such a detailed validation is not yet available for other regional North Sea models, but the diversity of the model outputs obtained through model intercomparison exercises, e.g. EU-NOMADS project (Delhez et al, 2004), underline an urgent

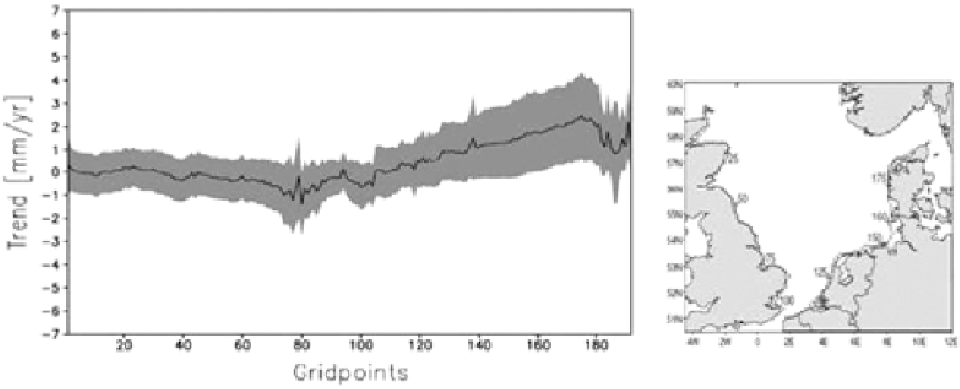


Figure 2.1.3. *Linear trend 1958-2002 for modeled winter (Nov-Mar) mean high water level (left); location of the grid point positions (Weisse and Plüß, 2006).*

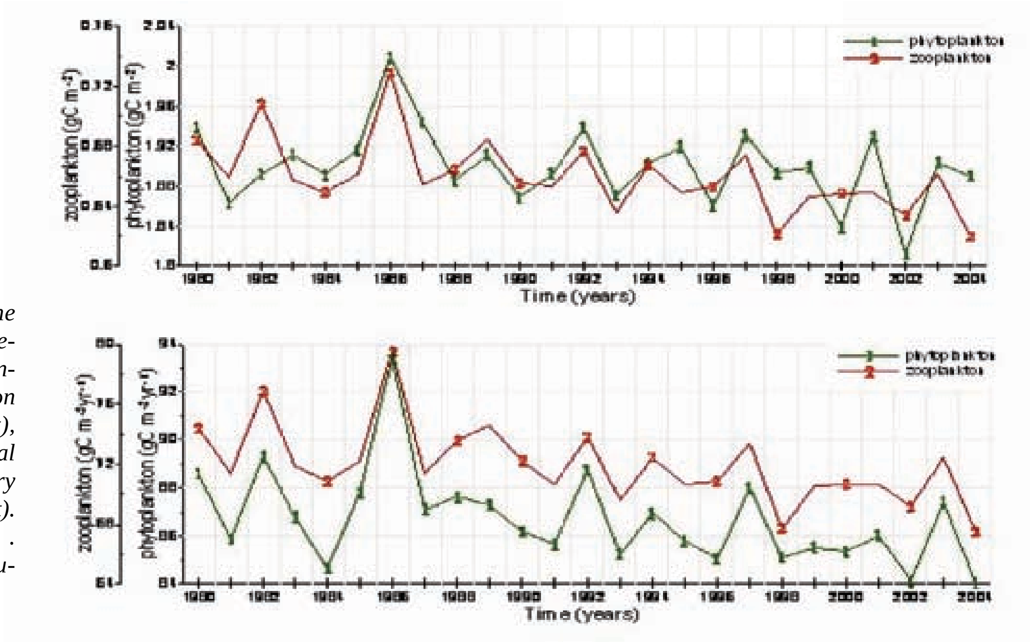


Figure 2.1.4. *Time series of modeled average annual phytoplankton and zooplankton biomass (upper plot), and integrated annual primary and secondary production (lower plot). (Schrum et al. 2006 . unpublished manuscript)*

need for more detailed model validations before they can be operated for climate research and inter-disciplinary applications. As a first test, a validated North Sea/Baltic Sea coupled model was run to hindcast the water productivity during the period 1980-2004.

The simulation (Fig. 2.1.4) indicates a clear decreasing trend in marine productivity which could be related to the thermocline variability (Schrum et al. 2006, unpublished manuscript) in the area. Although these preliminary results have to be taken with caution, the exercise demonstrates the capability of regional complex models to support climate impact studies.

Research needs, uncertainties

Regional climate models are particularly useful for investigation of regional systems under changing climatic conditions and there is an urgent need for dynamic models (dynamic downscaling) to provide better resolved data for utilization in the frame of regional systems management under changing climatic conditions. However, prerequisite to forecast, scenario test and predict regional climate changes and their impact are validated models which have shown their potential to describe a major part of climatic induced system variability.

Research needs on the regional scale can be summarized as follows:

- Performing historic reconstructions with different regional models
- Identification of uncertainties: Validation and comparative assessment of regional models using long-term observations, evaluation of the impact of uncertainties in forcing data and identification of deviations.
- Identification of sources for deviations in model predictions, model improvement and convergence, discussion of model approaches.
- Continuous efforts in further development of model approaches an all related aspects.
- Utilization of tested, validated and improved regional models to (i) improve system understanding, (ii) scenario test potential climate impact on regional systems and to (iii) forecast on different timescales (daily-weekly-seasonal)

The performance of regional climate models is critically dependent on the large scale climate models which will be used for the downscaling. Hence for improvement of regional climate assessments, continuous efforts are necessary in understanding the climate system, understanding the causes for deviating results of state-of-the-art climate models and in improvement of these models.

Further Reading:

ESF, 2005. Modelling in Coastal and Shelf Seas – European Challenges. [D. Prandle, H.Los, T. Pohlmann, Y.-H. de Roeck, and T. Stipa (eds.)]. European Science Fundation Position Paper No 7. Marine Board. pp. 28.

2.2 Accounting for regional climate variability

Any observational alteration in the marine environment associated with climate change should be considered against the background of natural variation on a variety of spatial and temporal scales. Of particular importance are the natural variations of the regional climate system. Europe extends from the Arctic Circle to the subtropics. Consequently, a multiplicity of regional atmospheric patterns can affect its weather conditions. Northern Europe is mostly affected by the North-Atlantic weather patterns, the Siberian low, as well as changes over the north pole whether these changes are termed the Arctic Oscillation, the Pacific Atlantic Oscillation, the North Atlantic Oscillation, or otherwise. On the other hand, the Mediterranean Basin is influenced by tropical and subtropical systems (Alpert et al. 2006) as well as mid-latitude variabilities (Trigo et al. 2006). Trigo et al. (2006) suggest that the most important impacts in the Mediterranean region are those associated with (a) the North Atlantic Oscillation (NAO), (b) the Eastern Atlantic (EA) pattern and Eastern Atlantic/Western Russia pattern (EA/WR), and (c) the Scandinavian pattern. The Mediterranean climate is also affected by several tropical and subtropical systems ranging from the Southern Oscillation (ENSO) and tropical hurricanes to the South Asian and African Monsoon responsible for large scale Saharan dust events (Alpert et al. 2006).

As seen in the sections above, many changes in the oceanic and coastal parameters have been found to be associated with changes in regional climate. The interannual and/or decadal variability of river runoff is dominated by the major factor controlling precipitation over Europe, that is, the North Atlantic Oscillation (NAO).
Northern European river flows are positively correlated, particularly in winter but also in spring, with the NAO index (measure of the atmospheric pressure difference between the Icelandic Low and the Azores High) , while rivers located in South Europe are negatively correlated (Shorthouse and Arnell 1997). The interannual variability related to the NAO pattern has also been confirmed in various Mediterranean rivers (for example Send et al. 1999; Struglia et al., 2004).

Similarly, the mean sea level variability around Europe has been found to be dominated: in the Mediterranean, by the NAO related pressure field in winter (Tsimplis and Josey, 2001); in the North Sea (Fig. 2.2.1) and Baltic Sea, by, mainly, the westerly wind field (Wakelin et al., 2003; Tsimplis et al., 2005), itself correlated with positive values of the NAO index (Siegismund and Schrum 2001); and in the Black Sea, spring sea level variability was found to be also linked to some extent with the NAO (Stanev and Peneva, Tsimplis et al., 2004). During the last 40 years the NAO index has increased by more than 2 units which generated a sea level rise of about 20 cm in the northwest European continental shelf, which is at least as much as global sea level rise driven by global warming over the last century (15-220 cm).

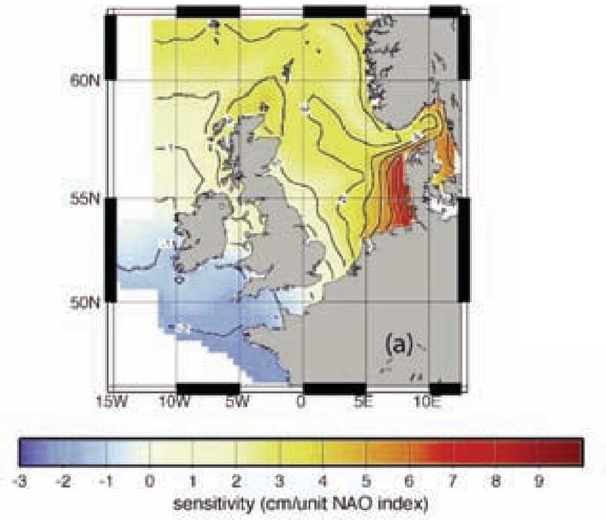


Figure 2.2.1. *Sensitivity of the sea level elevation to the winter-mean NAO index in cm/(unit NAO index) as calculated for a 2-d tide + surge model (Wakelin et al., 2003). Note the very high values found at the south-eastern coasts of the North Sea. Each unit change of the NAO contributes 10 cm of winter sea level increase there.*

The barotropic part of the water exchange at the Strait of Gibraltar is also linked with the NAO (Gomis et al., 2006) as well as currents at Sardinia (Vingudelli et al., 2000). Deep water as well as upper water variations in temperature and salinity have been linked with the NAO in the Mediterranean (Bethoux and Gentili 1999; Bethoux et al. 1999; Send et al. 1999; Tsimplis et al. 2006), in the North Sea (Tsimplis et al. 2006) and in the Black Sea in winter (Tsimplis et al. 2004).

The North Atlantic wave height and direction are also affected by changes in the NAO (Woolf et al. 2002), with changes in direction of up to 20˚ per unit NAO index (Tsimplis et al. 2005). The sensitivity of the mean monthly wave height to NAO index (Fig. 2.2.2), estimated by linear regression analysis against an altimeter-based climatology, is very high in northern Europe with ca. 70% of the variance explained in specific areas, west of Scotland (Tsimplis et al. 2005). Similarly in the Mediterranean changes of the wave field have been associated with the NAO and the Indian monsoon (Lionello and Sana, 2005).

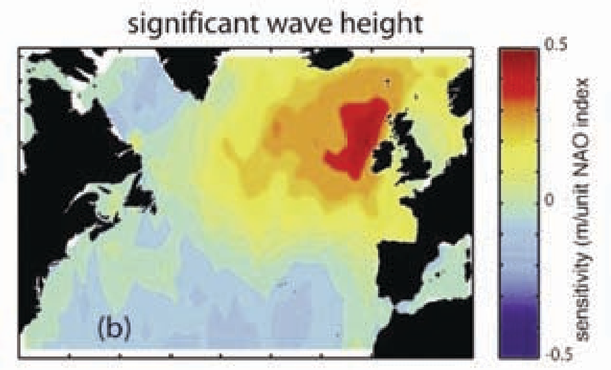


Figure 2.2.2. *Sensitivity of wave height to NAO index from satellite altimeter data. More than 1m of significant wave height increases have occurred in the north western Atlantic. This results are highly significant for transport of goods and people. (from Tsimplis et al. 2005)*

The relationships with the Southern Oscillation (ENSO) Index are more difficult to establish due to the nature of the phenomenon. However, changes in extreme sea levels at the Atlantic European coasts have been linked with reduced winds during El Nino (Woodworth and Blackman, 2004).

On the other hand, variations in a wide spectrum of hydro-meteorological and biogeochemical records in the Black Sea appear to be governed by the North Atlantic Oscillation (NAO) and East Atlantic-West Russia (EAWR) (Oguz et al., 2006).

Research needs

Climate change is likely to affect at least some of these weather systems. NAO, for example, clearly dominates the inter-annual atmospheric variability over Europe and the North Atlantic, especially in winter. However, a positive trend in the NAO index has been observed since the last 4-5 decades, suggesting a possible impact of climate change on the NAO cycle. In addition, it is also likely that the relative importance of the various regional patterns as well as their location may change thus complicating regional and local scale scenarios of what our future European environment will be. Therefore it is very important to identify the dominant physical mechanisms that affect the regional marine environment and link them with the regional and local climate.

Climate models have been producing regional forecasts based on coarse global models in spite of some of them being in significant disparity with each other (see for a review Giorgi and Hewitson, 2001 IPPC TAR, Chapter 10.). The need to downscale to regional and local level is self-evident as otherwise no impact assessment can be reasonably made with the appropriate accuracy (see section 2.1). The problems that models face presently are not only related to the spatial scales but also with the fact that their representation of regional patterns is not consistent between them or against the observations. However, significant progress has been made and continues to be made, and the new IPCC report is expected to synthesise this progress soon. It is clear that Europe and the Mediterranean are amongst the most responsive regions to climate change, (Giorgi, 2006).

2.3 The European Seas carbon budget along the land-ocean continuum

The European shelf seas provide an important transition area between land and the open ocean. They represent a large reservoir of particulate organic carbon resulting from both local high productivity rates and large inputs of land organic material via river runoff. Seasonal and horizontal gradients in CO_2 partial pressure can be high. A large part of this coastal carbon is recycled within the water column, while another part becomes buried and eventually recycled in the sediment, or exported into the sub-layers of the open ocean (so-called continental shelf pump), involving complex interactions between various processes which are sensitive to environmental forcing.

Also, shelf seas have short turnover times of years to decades, whereas the global ocean has a relatively long turnover time of up to 1000-2000 years. The difficulties in bridging temporal and spatial scales preclude any appropriate and operational representation of the shelf sea systems in global ocean climate model. Therefore, the integrated observation and modeling of the shelf seas and continental margins in the global carbon budget are still an actual field of research (Liu et al., 2000; see also IGBP core project LOICZ).

Carbon sinks and sources in European Seas and Coasts (biological aspects)

Before the Industrial Revolution, the exchange flux of CO_2 between the ocean and atmosphere was assumed to be in equilibrium. The coastal zone receiving additional organic and inorganic carbon from rivers was then considered as a net source of carbon to the atmosphere (Liu et al. 2000). With increasing atmospheric CO_2, those coastal waters, which are under-saturated with respect to CO_2, can turn into a net carbon sink (Tsunogai et al. 1999). In one of the rare attempts to include the continental shelf pump into a global circulation model, Yool and Fasham (2001) estimated a net uptake of 0.6Gt C.yr^{-1} imputable to the continental shelf pump.

At regional scales, however, important sources and sinks of carbon can be observed in the coastal zone and marginal seas (Borges, 2005), underlining the necessity to evaluate these fluxes across European seas and coasts to establish a comprehensive carbon budget, integrated over land and sea, for better assessment of mitigation strategies developed under the Kyoto Protocol.

According to Thomas and Schneider (1999), the Baltic Sea is absorbing annually 11 gC.m^{-2}.yr^{1}. In the North Sea, the high biological activity stimulated by an increasing input of nutrients, and a decoupling between production and respiration processes are the main factors controlling the water $p$$CO_2$ level, and Thomas et al. (2004) estimated there a net sink of 0.008Gt C per year, most of it being exported into the North Atlantic Ocean.

Frankignoulle and Borges (2001) estimated an annual sink of ca. 0.09-0.17Gt C for the European continental shelves with, however, a large variability in time and space depending on the physical conditions (temperature, stratification) and the duration of the phytoplankton growing season. According to the authors, situations of $p$$CO_2$ supersaturation in coastal waters (i.e. source of atmospheric CO_2) can occur, for example, in winter time with low productivity, in direct influence by rivers with supersaturated water, in period and/or areas of intense vertical mixing and sediment resuspension. In the well-mixed English Channel, water CO_2 undersaturation only occur from May to July when light is optimal for primary production (Frankignoulle and Borges 2001). Under global warming and increased stratification, the undersaturation period can increase due to enhanced primary production in the upper layer.

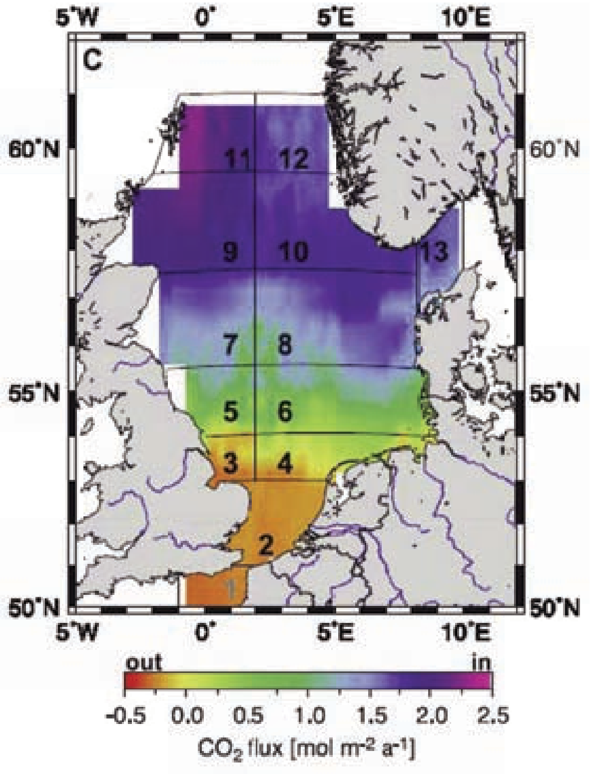


Figure 2.3.1. *Annual uptake rate of CO_2 in the North Sea. Highest annual uptake rates are observed in the most northern regions with values up to 2.5 molC.m^{-2}.y^{1}. On average, the basin-wide CO_2 uptake by the North Sea is 1.38 molC.m^{-2}.y^{1}. (from Thomas et al. 2004, with permission).*

The overall sink of European Seas may be potentially offset by a significant emission of CO_2 from near-shore coastal systems and estuaries. According to Gattuso et al. (1998, also in Frankignoulle and Borges 2001), proximal coastal areas directly under the influence of terrestrial inputs may often be considered as net heterotrophic systems with a net efflux of CO_2 to the atmosphere.

Large inputs of POC and high turbidity commonly set upper estuaries, i.e. upstream the turbidity maximum zone (TMZ), as net heterotrophic ecosystems with mineralization of particulate organic carbon (POC), resulting in CO_2-supersaturated waters. Frankignoulle et al. (1998) showed that European estuaries emit 0.03 to 0.06 GtC. yr^{-1} to the atmosphere, representing a CO_2 source equivalent to 5-10% of anthropogenic emissions for Western Europe. [– For comparison, the Europe's terrestrial biosphere absorbs 7-10% of European anthropogenic CO_2 emissions (Janssens et al. 2003) -]. On the other hand, the outer estuaries, downstream the TMZ, higher inorganic nutrients from POC mineralization and less turbidity favor the production of organic matter through photosynthesis, making the area as a net sink for atmospheric CO_2. The spatial distance from the coast contributes to the debate on the trophic status of the coastal system, and the impact of climate change on the carbon budget of coastal systems will thus depend on the regional manifestations of the dominant forces (e.g. higher runoff, intensification of the wind field) acting on TMZ .

North Atlantic/Nordic Seas/Arctic Ocean carbon connection

The open waters of the northern North Atlantic Ocean and the Arctic Ocean are climatically important for the global carbon cycle with respect to two issues:

1. They deliver indicators for in the changes in the marine uptake of anthropogenic CO_2 from the atmosphere.
2. They serve as early warning indicators for climate change and its impact.

Lefèvre et al (2004) provided evidence for a change in North Atlantic sink strength for anthropogenic CO_2 by identifying a slightly higher increase in North Atlantic surface ocean CO_2 partial pressure than in the atmosphere between years 1982 and 1998. This trend for the so far efficient North Atlantic carbon sink was substantiated by Omar and Olsen (2006) through a comparison of historical data from the early 1970s and the late 1980s. Olsen et al. (2006) identified that Atlantic water entering the Nordic Seas from the south is already saturated with respect to anthropogenic CO_2. Upper waters in the Nordic Seas have shown a faster increasing CO_2 content than the atmosphere. It is expected that direct in situ uptake of anthropogenic CO_2 from the atmosphere within the Nordic Seas area is thus not significant though water carrying a high C_{ant} contribution is transported downward were deep and intermediate water production mechanisms work, such as the Greenland and Iceland Seas.

Locally significant net carbon sinks can occur in the Arctic Ocean shelf regions, when saline cold water forms during winter which then flows along the continental slope and rise towards deeper layers (Kaltin and Anderson, 2005; Anderson et al., 2004; Kaltin et al., 2002). A precise determination of the net carbon sink is difficult to assess by in situ measurements due to the large seasonal amplitude in biological activity. Changes in the delivery of DOC via the large Siberian rivers (Gebhardt et al., 2005; Benner et al., 2005) and sea ice cover can potentially modify the Arctic ocean carbon cycling within a short time frame of only few decades significantly. Though the Arctic Ocean's role for uptake of anthropogenic CO_2 is minor at present, the picture can change once sea ice cover is reduced on a larger scale. Then, e.g., highly productive zones for biological primary production could move away from the shelf areas to deeper more open waters and gas exchange between ocean and atmosphere could be enhanced (ACIA, 2005, ch. 9). The net effect of these changes on the atmospheric CO_2 concentration still remains to be quantified.

In polar Atlantic waters, vertical shifts in the saturation horizon for aragonite and $CaCO_3$ due to anthropogenic CO_2 uptake and associated pH changes are expected to reach the ocean surface earlier than in low latitudes (Orr et al., 2005). Time scales are a few decades for aragonite, 50-100 years later for $CaCO_3$. Impacts for biodiversity and ecosystem functioning may be substantial (e.g. ocean acidification, see section 2.4).

Natural and human-induced variability

The biogeochemistry of the European Seas is affected by both natural and man-made variability. Even without human interference, research on marine biogeochemistry would be essential in order to predict variations in ecology, e.g., due to natural hydrographic changes. Winter precipitations have substantially increased over Northern Europe, multiplying flooding events along river basins and increasing runoff of freshwater into e.g. the North Sea (Struyf et al. 2004). Under increased precipitation and run-off in northern latitudes, heavy water discharges decrease the residence time in the main estuarine channels, transferring nutrients and organic material more rapidly to the coastal waters with consequences on the biogeochemical cycles.

In parallel, changes in land use, fertilizer application, industrial activities, and human population density cause also variations in the riverine chemical processes in coastal waters. Accordingly, important elements such as the total dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) loadings can be scaled directly as functions of the population density and runoff magnitude (Smith et al. 2003). Consequences on the surrounding shelf seas biogeochemistry include eutrophication (Cloern 2001; Lundberg et al. 2005), changes in the chemical speciation and nutrient ratios of the coastal waters (Humborg et al., 2000), and changes in the carbon as well as alkalinity input to the ocean (Raymond and Cole, 2003).

Nutrient inputs from the atmosphere can have regionally a similar order of magnitude than those from river loads (Spokes and Jickells, 2005), with an important role in enhancing marine productivity. Global warming, i.e. drier climate in southern Europe, and higher winds, changes in land-use practices have modified the dust input in the adjacent seas and, thus, the controlling role of iron and other nutrients in plankton blooms (de Baar and La Roche 2002). According to Guerzoni et al (1999), the atmospheric input of inorganic nitrogen represents 60% of the total nitrogen entering the Mediterranean from continental origin; 66% of that flux is through wet deposition. Transport via the atmosphere is also recognized as an important route for reactive phosphorus (Garrison et al. 2003). The regional differences in the aerosol content of bio-available macro-nutrient contribute to a change in the nutrient ratio of coastal waters with possible shift from a nitrogen-limited ecosystem to a phosphorus-limited one, like it is observed in the Eastern Mediterranean (Herut et al. 1999, Kouvarakis et al. 2001).

A further example of land-sea-atmosphere teleconnection can be taken from deliberate actions taken on land to mitigate CO_2 increase in the atmosphere, which have produced unexpected side effects in adjoining marine waters. According to Ridgwell et al. (2002) such mitigation strategies on land could reduce up to 9% the rate of anthropogenic CO_2 uptake by the seas.

Research needs, uncertainties

Even though these flux values are still associated with large uncertainties, it becomes evident that any impact assessment of climate change on the biogeochemistry of European Seas requires a holistic view and understanding of all potential interactions between all other components of the earth system. Simulation models for the global carbon cycle that have been developed to verify and enforce the Kyoto Protocol Joint Implementation Plan, are based to a large extent on terrestrial carbon sink only. Well established integrated carbon budgets between land and seas are needed for the following reasons: (i) to allow optimal inverse determination of land based CO_2 fluxes; and (ii) to firmly prove changes in oceanic CO_2 sink strengths (as currently investigated in the Atlantic Ocean where largest column burdens of anthropogenic CO_2 exist, Sabine et al. 2004). Such an attempt could develop out of the two ongoing EU Integrated Projects CARBOOCEAN (http://www.carboocean.org) and CARBOEUROPE (http://www.carboeurope.org) and their follow-up projects. The attribution problem associated with recent anomalously high growth rates in atmospheric CO_2 as documented, e.g., in the Mauna Loa CO_2 record (http://cdiac.ornl.gov/trends/CO2/sio-mlo.htm) may be solved through such an integrated effort.

2.4 Marine acidification

As the level of atmospheric carbon dioxide is increasing due to the burning of fossil fuels and other anthropogenic activities, about a third of this gas is taken up by the ocean, changing the chemistry of sea water with subsequent repercussions for marine life. A large proportion of the absorbed carbon dioxide mingles with water molecules to form carbonic acid which then dissociate into hydrogen ions (H^+), bicarbonate ions (HCO_3^-) and, to a lesser extent, carbonate ions (CO_3^{2-}). An increase in hydrogen ions would cause a drop in the pH of sea water, becoming then less alkaline (or more acidic). Moreover, an excess of hydrogen ions would contribute to a decreasing concentration of carbonate ions (CO_3^{2-}) to form further bicarbonate ions, thus impeding marine calcifying organisms to form calcium carbonate ($CaCO_3$) as part of their shells or skeletons.

In the overall picture, the process of marine acidification has to be perceived as a direct consequence of an increasing atmospheric CO_2, additional to its proper effect on the radiative forcing that is driving climate change and global warming.

In the past 200 years, the oceans have absorbed half of the anthropogenic CO_2, leading to a reduction of surface water pH of 0.1 units, equivalent to a 30% increase in hydrogen ions (The Royal Society, 2005). Simulations for the next century are predicting further reduction of the pH from 0.3 to 0.5 units, depending on which IPCC scenarios is adopted in the calculation (Caldeira and Wickett 2005), and a 45% reduction in carbonate ions relative to pre-industrial levels (Orr et al. 2005). Extending the simulations to several centuries, these authors could demonstrate a decrease of surface water pH by about 0.8 units by the year 2300.

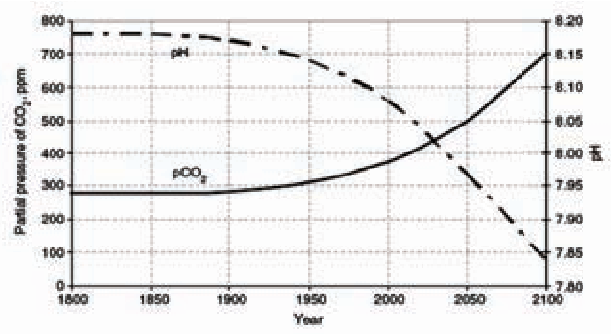
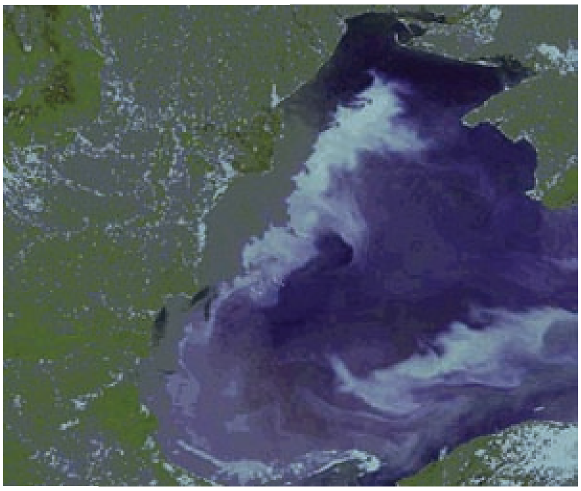


Figure 2.4.1. *Past and projected change in atmospheric CO2 and seawater pH assuming anthropogenic emission along "business-as-usual" scenario (after Zeebe and Wolf-Gladrow 2001; also in Turley et al. 2006)*

Regardless of the various assumptions and uncertainties associated with these predictions, the magnitude of these changes could be larger than any other levels estimated over the past 300 million years from various proxy data (Caldeira and Wickett 2003). But most importantly, the rate of changes would be much higher (x100) than in the past, aggravating even more the sensitivity of the marine organisms to ocean pH. Marine acidification is of particular concern for the European Seas, since 23% of the global marine anthropogenic CO_2 may be absorbed in the North Atlantic near surface waters (Sabine et al. 2004).

Moreover, the problem of acidification in semi-enclosed European Seas and coastal waters is intensified by specific activities on land, releasing more acidic compounds in the river systems and the atmosphere.
In the Baltic, sulfuric dioxide emitted from cargo ships significantly contributes to increase the acidity levels of surface waters. In the same way, shipping, road transportation and energy combustion are sources of nitrogen dioxide emissions in the atmosphere which is then deposited as acid rain in the surrounding seas and catchment area (e.g. HELCOM 2005). Evidence of acidification effects has been documented (AMAP 2006) in northern Scandinavia as a result of emissions from metal smelters, which adds to the long-range transported air pollutants in contributing to the acidification in some sensitive areas in the European Arctic.

Concerns about acidification from anthropogenic CO_2 increase as a threat to the marine environment are fairly recent and, therefore, little is known about the impacts of reduced pH values on the organisms and ecosystems. It is generally agreed that acidification and changes in the ocean carbon chemistry will negatively affect biogenic calcification and the abundance of calcifying organisms.
In a scenario of doubling the atmospheric CO_2 concentration, models are predicting a complete undersaturation of polar and subpolar surface waters with respect to calcium carbonate within the next 50 to 100 years (Orr et al. 2005), starting with the most sensitive forms, i.e. aragonite and magnesium calcite.
Under these conditions, key marine organisms such as pteropods mollusks, foraminifera, coccolithophores, or corals (including cold water corals along the northwest European continental margin) will have difficulties to build and maintain their external structure with serious consequences on the overall ecosystem and the rest of the food chain.



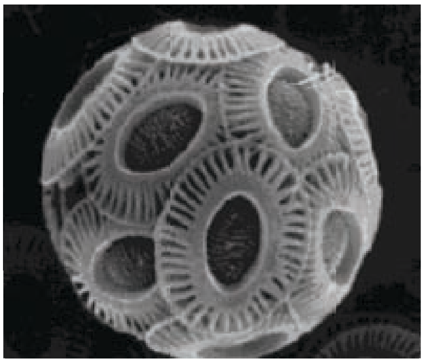


Figure 2.4.2. *Coccolithophore bloom in the Black Sea. True-colour image from satellite (MODIS-Terra, May 10th, 2002; source : NASA). Emiliana huxleyi cell covered with its coccolith plates .*

Coccolithophores are important calcifiers and represent an essential phytoplankton group in European Seas ecosystems. Large blooms of coccolithophores can be observed from true-colored satellite images ('bright/milky waters') in the northeastern Atlantic, the English Channel and the Black Sea. In these organisms, the calcification process (source of CO_2) is directly coupled with the production of organic matter through photosynthesis (sink of CO_2). The resulting effect on the carbon flux and the drawdown of atmospheric CO_2 depends on the ratio of both processes. In the North Sea, blooms of Emiliana huxleyi have shown to represent a net sink of carbon (Buitenhuis et al. 2001), also reported in mesocosm experiments (Delille et al. 2005). But most importantly, coccolithophores acting as ballast increase the efficiency of the biological pump, and the export of organic matter at the seafloor. Moreover, they have an important role in the sulfur cycle and the production of dimethyl sulphide (DMS) which is ventilated to the atmosphere and contribute to the formation of clouds, providing thus a feedback mechanism to global warming. At present, it is not clear whether a coccolithophore cell can survive/adapt in high CO_2 world, with a reduced or a complete loss of its external skeleton. Substitution by other species will modify the overall ecosystem, as well as the carbon budget in a way that still remain to be investigated.

Other effects of reduced pH include upsetting the carbon cycle as well as disrupting the nutrients ratios and other trace elements required for optimal growth, with consequences on the phytoplankton community structure. Acidification and the accumulation of CO_2 in the body fluids have an impact on several metabolic functions in small and large water-breathing organisms (Pörtner et al. 2004, 2005; Haugan et al. 2006), including reproduction, muscular activity and respiration.

Research needs

Indicative consequences of reduced pH are emanating from laboratory experiments and mesocosm studies (Riebesell 2004) maintained under high pCO_2 conditions (hypercapnia), as well as from freshwater studies. Most of these observations are associated with pH values and/or CO_2 concentrations that are exceeding any possible estimates predicted for the next centuries in marine waters.

Further investigations are, therefore, necessary to better understand the consequence on the marine system of a continuous addition of lower concentrations over a long time scale such as those projected by climate models.

Particularly, research is needed to better understand the vulnerabilities of the marine organisms, their resilience and capacity of adaptation at different stage of the life cycle. The combined impact of ocean acidification with climate-related changes in, e.g., sea surface temperature and nutrient speciation needs to be explored through dedicated models.

Some natural CO_2 leakages from geological reservoirs at the seafloor have been identified in several European Seas (Turley et al. 2004). These need to be methodically explored to evaluate the effect of such CO_2 release for the surrounding ecosystem, but also to assess the risks and benefits of intentional Carbon Capture and Storage projects (see section 4.5).

Further Reading:
Report of the Royal Society, 2005. Ocean acidification due to increasing atmospheric carbon dioxide. Document 12/05, the Royal Society, London, p.58. (http://www.royalsoc.ac.uk/)

2.5 Marine foodwebs

Climate change is predicted to have both direct and indirect effects on marine plants and animals, and consequently on marine foodwebs (Hughes 2000, Root et al. 2003, Parmesan & Yohe 2003). First, changes in temperature will directly affect metabolic and developmental rates in many animals, and processes such as photosynthesis and respiration in plants. Second, changes in mean annual temperature will affect changes in isotherms and subsequently in the distribution of marine organisms (e.g. to move into deeper waters and/or towards the poles). Third, alteration of life cycle events that are triggered by environmental clues related to climate (e.g. temperature thresholds for spawning, seasonal migration and breeding) may lead to decoupling of trophic interactions. Fourth, species with short generation times and rapid population growth rates might be able to adapt to the new environment as the result of evolutionary change.

Recent evidences clearly indicate that the increase in temperature over the last decade has had a primary role in influencing the ecology of our European Seas. Changes in intertidal rocky shore populations (Hawkins et al. 2003) and fish communities in European Shelf seas (Attrill and Power 2002; Genner 2004) and ecological changes in the southern North Sea (Perry et al. 2004) and English Channel (Southward et al. 2004) also appear to be closely related to climate-driven sea temperature fluctuations.

Other documented range shifts and recent appearances of warm-water species new to marine environments include tropical macroalgae and fish in the Mediterranean (Walther et al. 2002). Regional climate warming in the North Sea has also been associated with an increase in certain Harmful Algal Blooms (HABs) in some areas (Edwards et al. 2006).

Biodiversity & ecosystem functioning

Climate change and its biological consequences (changes in physiology, distribution, phenology and genetic composition) have already affected marine life in all European seas (e.g. Philippart et al. 2006, see section 1.2). Phytoplankton is regarded as the most important biomass producer in the oceans. These microscopic algae are responsible for removing carbon dioxide from the atmosphere (biological pump) and transferring the carbon to other trophic levels. As a result of being at the base of the trophic pyramid, any change in primary producers will have consequences on the marine food-web and on other trophic levels (e.g. fish, seabirds) through bottom-up control.

Shifts in plankton community composition resulted in changes in the ecosystem functioning of our seas, such as primary and secondary productivity (Fromentin & Planque 1996). A recent empirical model predicts an increase in global primary production between 1% and 8% (Sarmiento et al. 2004). In particular in the northern seas of Europe, and the Arctic, the open ocean plankton production is predicted to significantly increase in the large areas that will become ice-free in summer as the result of higher temperatures (ACIA, 2005). Such changes in productivity will affect the biodiversity and carrying capacity of these natural systems, as well as the potential for the use of the sea by society, for example, the exploitation of marine living resources.

Over the last several decades, changes of phytoplankton species in the European Seas have also created a problematic situation of anomalous phytoplankton blooms, often associated with harmful consequences (i.e., HABs) on humans and the surrounding ecosystem. Toxic material released from these blooms are causing mass mortalities of marine organisms, as well as affecting human health through contaminated shellfish and fish populations. There is some evidence from long-term studies in the North Atlantic that some HAB species have increased over the last decade.

These increases have been correlated with regional climate variability and warming (Edwards et al. 2006). The increasing frequency of these blooms and their socio-economical impacts have lead to the development of important regional and national programmes such as EUROHAB

(Granéli et al. 1999) to investigate on possible causes of HABs events, and to better understand the dynamics and trophic interactions. At present, it remains difficult to privilege climate shifts or man-induced pollution to explain the instigation and maintenance of these blooms. Peperzak (2003) showed the importance of increasing temperature and stratification in doubling the growth rate of harmful algae, concluding that the risk of HABs due to climate change will rather increase than decrease in the future. Alternatively, the increasing occurrence of these blooms in the Baltic has been linked to anthropogenic eutrophication of the coastal waters (Poutanen and Nikkilä 2001).

Likely, the resulting effects of both types of environmental pressure would ensure ideal conditions to favor the massive growth of toxic algae (Marzur-Marzec et al. 2006).

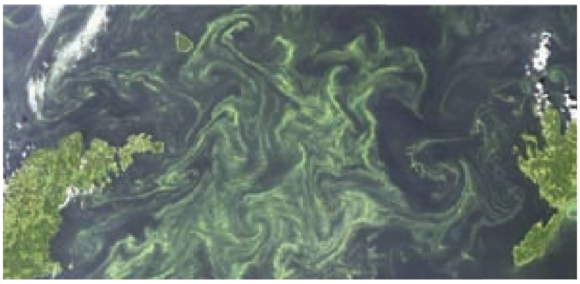


Figure 2.5.1. *Bloom of Nodularia in the Baltic Sea from the satellite sensor MODIS-Aqua (July 30th, 2003; source: NASA)*

The physiological responses of benthic sessile organisms to different levels of physical gradients are flexible, tolerating in most cases moderate changes over reasonable adaptive time scales. However, they are very vulnerable to abrupt and extreme events. Successive heat waves over the Mediterranean Sea and subsequent peaks in the water temperature field have been lethal to some invertebrates like sponges and Gorgonians (Laubier et al. 2003). Seagrass beds which have an important role in the marine storage of carbon, and in stabilizing the bottom sediment against erosion may suffer considerably through an intensification of extreme weather patterns through storms, wave action, re-suspension of sediment in the water column, as well as sudden pulses of freshwater water runoff (Duarte 2002).

After such events, the re-colonization of the benthos can take several tens of years, or even centuries, particularly with species having less successful sexual reproduction.

In spite of the importance of biodiversity for ecosystem functioning, we have limited knowledge on the effects of climate change on this aspect of our seas. Whilst our oceans cover more than 70% of the surface of our planet, less than 10% of published research on biodiversity dealt with marine systems (Hendriks et al. 2006).

Trophic interactions

Temperature changes may locally affect community structures and food webs by altering the interaction between a species and its competitors, mutualists, predators, prey or pathogens (Lubchenco et al. 1991). Temperature-sensitive key interactions, viz. interactions contributing disproportionately to maintaining the food web, may act as leverage points through which small changes in climate could generate larger changes in natural communities (Sanford 1999).

Recent climatic changes have been reported to disrupt tight trophic interactions between predator and prey.

Already at the beginning of the previous century, Hjort (1914) recognized that the interannual variability in fish recruitment to be a function of the timing of the production of their food. More than 75 years later, Cushing (1990) proposed the temporal match-mismatch hypothesis referring to climate-induced coupling/decoupling of such phenological relationships (relative timing of life cycle events). Most recently, it is recognized that not only the timing and the quantity, but also the seasonal and interannual variation in the quality of the food (e.g. species composition of zooplankton, lipid-content of fish) is likely to be an important mechanistic link between climate variability and the observed changes in recruitment success of marine organisms such as fish (Beaugrand et al. 2003) and seabirds (Kitaysky et al. 2005). Another recent research over a 30 years period has established a climate link between four trophic levels in the North Sea. Changes in the phytoplankton and zooplankton caused by climate variability have had a direct effect on sandeel populations which has led to consequences for the breeding success of many seabirds (Frederiksen et al. 2006).

To study such interactions further, we need to understand the nature of the trophic interactions based on detailed information about “who eats what under which circumstances”. Although relatively much work has been done on diet of marine birds and mammals, there are still major gaps in our knowledge of the food requirements of marine organisms at lower trophic levels, such as zooplankton and benthic invertebrates.

The Baltic Tellin example

Population dynamics of common intertidal bivalves, such as Cockles, Mussels, Sandgapers and Baltic Tellins, are strongly related to seawater temperatures. In north-western European estuaries, series of mild winters followed by low bivalve recruit densities generally lead to small adult stocks. More detailed studies on the Baltic Tellin revealed that the recent rise in seawater temperatures has affected their recruitment success in, at least, three ways.

Figure 2.5.1. *Tellinid bivalve larvae Macoma balthica with phytoplankton Diatom chains*

First, high winter temperatures resulted in a decrease in reproductive output (viz. the number of eggs per female). Second, high temperatures during late winter most probably resulted in a spring advancement of spawning of this bivalve of 8 days per °C. Because the timing of the spring bloom is not related to temperature, the planktivorous larvae came out too early to feed on the phytoplankton. Third, temperature has led to an increase of predation on the post-larvae due to an advancement of the spring migration of juvenile shrimps of 16 days per °C (Philippart et al. 2003).

Apparently, global warming upsets the evolved reproductive strategy of this marine bivalve to tune its reproduction to the most optimal environmental conditions for the first vulnerable life stages, most importantly the match/mismatch of time of spawning with that of the phytoplankton bloom and the settlement of juvenile shrimps on the tidal flats. Such examples illustrate the need for detailed studies on main ecological processes (reproduction, prey-predator interactions) of individual key-species to be able to understand and predict the consequences of climate change for marine foodwebs.

Research needs

European marine conservation policies, such as the Bird and Habitat Directives and Natura 2000 network, currently focus on biodiversity, viz. the sum of species, ecosystems and genetic diversity. Further temperature rises are likely to influence whole ecosystem assemblages (Genner et al. 2004) as well as having profound impacts on exploitation of living marine resources (Perry et al. 2005) by affecting ecological processes (e.g. reproduction, recruitment, dispersal, species interactions, disturbance, and additional inputs of nutrients and other resources) that, along with evolutionary mechanisms, underlie these patterns within the marine foodwebs (Leslie et al. 2005).

In order to predict the effects of climate change on marine foodwebs, we must try to understand the effects of climate change on ecosystem processes. For example, by taking into account the quantity, quality and timing components of food availability, we will improve our ability to detect effects of climate change on trophic interactions and subsequently on the biodiversity and structure of the marine foodwebs in European seas.

Further Reading:

EC-NSF 2003. The EU-US Scientific initiative on Harmful Algal Blooms. Report from a workshop jointly funded by the European Commission – Environment and Sustainable development Programme, and the US National Science Foundation. p. 56. (http://www.whoi.edu/redtide/announcements/EU_US_Sci-Init.pdf)

2.6 Threats from the Arctic – towards a 'blue Arctic'?

The Polar Regions are important in regulating the Earth climate, and as such they are also regions that will be most influenced by any changes in the climate variables. Air temperature in the Arctic has increased as much as 3-4ºC in the past 50 years and is expected to rise up to 7ºC during the next century (ACIA 2005). The average sea-ice extent has decreased accordingly by about 8% over the past 30 years, and is projected to decline by more than 50% in summer with some models indicating a complete ice-free summer Arctic Ocean by late this century (Johannessen et al. 2004).

In addition to a significant reduction of sea ice, an intensification of the hydrological cycle and thawing permafrost is modifying the salinity, the density of the surface waters, and the surface albedo, with profound modification in the water circulation and multiple implications for the Arctic marine biota.

From the Arctic to the North Atlantic Thermohaline Circulation (THC)

The surface and deep currents that exchange water between the North Atlantic and the Arctic region (section 1.1) are a key component of the global ocean circulation (Fig. 2.6.1) and the global climate system and potential changes in these currents will have global implications. It is, however, the areas in the northern parts of European seas that are most affected by these currents and it is these areas and the European landmasses bordering them that will be most impacted if the currents weaken as part of global change.

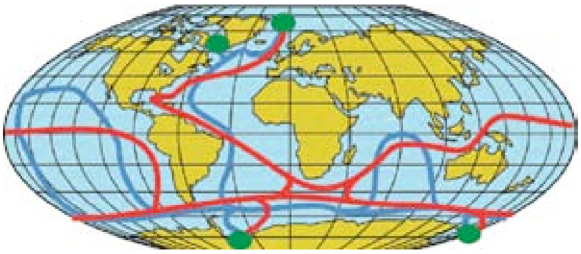


Figure 2.6.1. *Schematic depiction of the global THC. Green circles indicate ventilation areas, blue curves indicate deep water flow away from the ventilation areas, and red curves indicate upper layer flow towards them.*

In addition to the wind-driven circulation of the upper ocean, there is a global circulation system, traditionally termed “Thermohaline Circulation (THC)”, which is driven by water density differences at high and low geographical latitudes. Cooling and ice-formation at high latitudes increase the density of surface waters sufficiently to cause them to sink. Several different processes are involved, which collectively are termed ventilation. When active, ventilation main-tains a persistent supply of dense waters to the deep high-latitude oceans. At low latitudes, in contrast, vertical mixing heats the deep water and reduces its density. Together, high-latitude ventilation and low-latitude mixing build up horizontal density differences in the deep ocean, which generate forces. In the North Atlantic, these forces help drive the North Atlantic Deep Water (NADW) that supplies a large part of the deep waters of the World Ocean.

In the northern hemisphere, there are two ventilation areas, of which the one in the Arctic region, north of the Greenland-Scotland Ridge, contributes most to NADW production. This generates a deep southward flow, which is augmented by entrainment of ambient water south of the ridge. This southward transport of water at depth has to be compensated by a northward flow of similar transport magnitude (Fig. 2.6.2) and it is this compensating flow, which directly affects European sea and land areas. The compensating flow is in the upper layers and its various branches carry heat and salt northwards. They are to a large extent responsible for the mild conditions widely found in the northern parts of European seas. This flow is affected by the wind and may be modified by wind forcing, but regardless of the wind, the compensating flow must carry sufficient amounts of water northwards to replenish the water exported southwards. It is therefore the intensity of ventilation and entrainment that can maintain a stable compensating flow. This is the reason why there is worry about a possible weakening of the THC. In the coming decades, global change is expected to increase the freshwater supply to the Arctic (Dickson et al. 2002; Peterson et al. 2002). This will tend to reduce the salinity and hence the density of surface waters. Warming of the atmosphere in the high Arctic will also tend to reduce the sea surface density. It has therefore been suggested that the ventilation may be reduced with a weakened North Atlantic THC as a consequence. Most modern climate models support this although there is considerable disagreement as to how much the flows will weaken.

A potential weakening of the North Atlantic THC would affect the deep waters of the world ocean in the long run, but would have more immediate effects on the climate in some regions. Since most of the compensating flow passes nor-

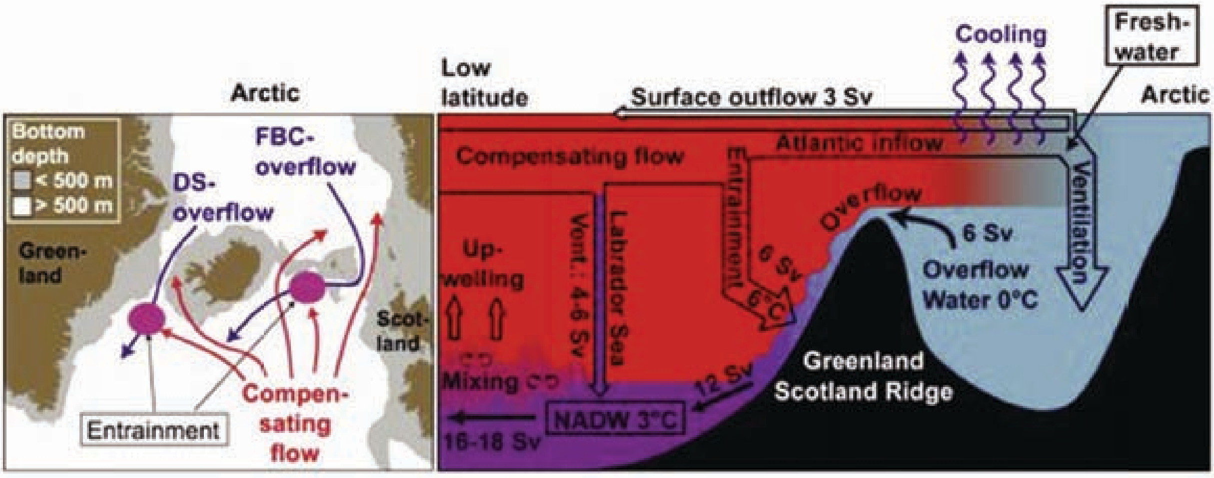


Figure 2.6.1. *Schematic illustration of the coupling between the North Atlantic and the Arctic region. In the Arctic region, ventilation maintains a pool of cold dense water north of the Greenland-Scotland Ridge, which continuously overflows the ridge. Shortly after crossing the ridge, the overflow water entrains large amounts of ambient water and the mixture of these two becomes the main component of NADW. Balance is maintained by a northward compensating flow of similar magnitude as the combined transport of the overflow with its entrained water and the surface outflow (neglecting a small contribution from the Pacific through the Bering Strait).*

thwards along the coasts of Europe, it is especially the sea and land areas of Europe that may be affected. Forecasts of the future intensity of the THC and its effect on regional climate must be based on climate models and efforts to develop and implement more reliable models should be supported. It must also be recognized, however, that some of the critical processes involved – especially entrainment – are difficult to implement in coarse-resolution climate models. Monitoring of the various components of the North Atlantic THC should therefore be strengthened in order to enable early identification of changes and to serve as benchmark for model development.

Polar Ecosystem in an ice-free ocean

With severe reductions in Arctic sea ice, as foreseen during this century (e.g., Weatherly and Arblaster 2001; Gregory et al. 2004; Stroeve et al. 2005), considerable changes in Arctic ecosystems are expected, including changes in biodiversity with critical consequences for organisms that depend on sea-ice to complete their life cycle (ACIA 2005), particularly top-predators such as polar bears, seals, and marine birds.

On the other hand, the projected warming and subsequent increase of the sea ice melt-season may lead to biologically higher marine productive zones with the micro-organisms benefiting from a favorable nutrient and light environment (Smetacek and Nicol 2005). The overall carbon cycle will also be modified as more extended area of open waters will become available for gas exchange. The loss of sea ice from the Barents Sea would result in a more than doubling the present levels of primary production (ACIA 2005). Accordingly, the rest of the food chain, including important fish stocks such as cod and herring, would then benefit from these conditions, not only because of the variability in the food supply, but also as a direct stimulus of higher temperature on the fish growth.

Natural changes in sea-ice coverage and temperature fluctuations have occurred in the past. Not so long ago, a warming period between 1920 and 1940 in the northern Seas resulted in a northward extension of cod along the west coast of Greenland and some very productive year-classes during late 40s and early 50s. (Brander 2003). Further back in time, e.g. during the transition from the last glacial maximum to the Holocene and also in the later phase of the Holocene, important changes in biological productivity seem to have occurred in the northern Nordic Seas (Ślubowska et al., 2005). Paleoclimatic proxies would indicate an early Holocene ice cover minimum with an opening of the Northwest Passage (Fisher et al. 2006). The future temperature in the Arctic is expected to be significantly higher than during these past events, but the changes that occurred ca. 10Ky ago or during these more recent warm periods can give important information on possible alterations in the Arctic biogeochemistry and ecosystem in response to human-induced warming and decrease in sea ice coverage. Moreover, the capability to model the ecosystem in the Arctic relies on sufficient understanding of the natural variability in the driving forces influencing critical processes. Long term analysis of melt seasons duration in the Arctic Ocean shows significant positive correlations with winter strength of the Arctic Oscillation.

Research needs

Will the Arctic be ice-free in summer? The answer to that question is heightening awareness not only of the scientific community, but also industrials and politicians for who a rapid retreat of sea ice represents considerable savings in shipping cost between continents, an opportunity to explore new sites for oil, gas and minerals, as well as a larger productive area for fishing. Climate change impacts in the Arctic is therefore a good example of a burning issue requiring rapidly further knowledge for decision planning to protect the marine environment and the coasts in Northern Europe.

The main challenge in this area is thus to build up a long term monitoring program to track changes in both the water circulation and marine ecosystem dynamics, to develop physiological studies on the capacity of the marine organisms to adapt even slight changes in water temperature, and to quantify the role of climate variability on recruitment, growth, migration and distribution of fish stocks.

Further Reading:
ACIA, 2005. Arctic Climate Impact Assessment. Cambridge University Press, pp. 1042.
(http://www.acia.uaf.edu)

2.7 Towards an integrated and sustained marine observing system

Reducing uncertainties in climate projections and impact simulations over the European marine and coastal system requires long-term and sustained observations of key physical, chemical, and biological variables at relevant time and space scales. Sustained observations are important to depict episodic/extreme events with significant impacts on the marine ecosystems and coastal morphology, and also to decouple climate change impacts from those attributable to the human activities and natural variability. Such observations should include time-series at specific sites extending over multiple decades to capture possible trends out of multi-year cyclic patterns.

Oceanographic cruise surveys are usually expensive and, thus, are happening on an occasional basis for short periods of time within the framework of specific short term projects. Although such monitoring campaigns (particularly if repeated through ships-of– opportunity experiments) remain an important observing strategy, newer sampling technologies (autonomous underwater vehicles, profiling Lagrangian floats, gliders) should be incorporated as often as possible to the field measurement design. Drifters and profiling floats (e.g. the Argo network) are self-complementary to give information on the surface and mid-depth circulation, enhancing ship-based measurements by tracking features over several months. Gliders, equipped with self-navigation system, are capable of sustained sampling operations in coastal and open ocean environments for time periods as long as seasons.

Evidence for observed changes is often biased towards areas that have had some form of monitoring in place over a consistently long period. For this reason some of the strongest evidence detected for observed changes in marine ecosystems comes from the North Atlantic where an extensive spatial and long-term biological survey exists in the form of the Continuous Plankton Recorder (CPR) survey (see below). Thus, systematic long term monitoring scheme needs to be extended to other European Seas.

Except for the more than 100 years sea level measurements from tidal gauges, very few time series observations have been conducted in the marine environment for more than a decade or two. One of the main difficulties is to find the appropriate funding mechanisms that will ensure continuity of these measurements over long time period. Framework for research and development in Europe is usually based on 3 or 4 years projects. Although these projects are essential to foster innovation and performance in European science and technology, they do not emphasize on the basic fact that all ecosystems are in a process of long-term changes.

Example: The Continuous Plankton Recorder survey

The Continuous Plankton Recorder (CPR) survey is a long-term marine plankton monitoring programme consisting of a network of transects towed each month across European shelf seas and in major geographical regions of the North Atlantic. It is the longest (starting in 1931), most spatially extensive (pan-Atlantic) marine biological survey in the world and contains a unique dataset of marine biodiversity (~500 taxa) that provides a wide range of environmental and climatic indicators. In terms of our scientific understanding of the impacts of anthropogenic change on marine ecosystems, the CPR survey is of global importance. Work by the Survey contributed to the next IPCC report on observed impacts of climate warming on marine ecosystems, and significantly to the European Environment Agency's report on the 'impacts of Europe's changing climate' (EEA 2004). CPR data has been increasingly used to address major marine management issues ranging from fisheries, harmful algal blooms, biodiversity, pollution, eutrophication, and climate warming in European waters, and forms an integral part of the ICES (International Council for the Exploration of the Sea) regional ecosystem and OSPAR Commission assessments of the North Sea. In addition, the CPR survey is of importance in fulfilling a number of national monitoring and research requirements and also makes a significant contribution to international programmes such as GOOS and GLOBEC. The CPR survey is operated by a charity and is currently dependant on consortium funding, in many cases, on a year to year basis. For a long term (76 years) survey, this funding system lends to considerable insecurity. While truly European in scale, the EU does not contribute to the support of this survey. Support from the EU would remove the current funding insecurity and lack of sustainability due to limited long-term commitment and investment.

Remote Sensing Data

Earth Observation (EO) from satellite has considerably changed our view on how the marine system works, providing information at unprecedented scales on many Essential Climate Variables (ECVs) as defined in the Global Climate Observing System (GCOS)'s implementation plan. The remote sensing technique is also granting consistent methodology over all European Seas while capturing the regional and local variability over a wide range of disciplines (marine biomass and biological production, wind speed and direction, sea level, wave height, surface heat flux, ocean currents), each of them being captured by sensors that are perceptive to active or passive radiations emitted at specific intervals within the electromagnetic spectrum.

The effective use of Earth Observation and other spatial data in climate studies hinges, however, on the availability of methods, tools and techniques to extract useful information from the satellite sensors in a timely and accurate manner. These include: developing algorithms that will convert the raw electromagnetic signal from the data providers (e.g. space agencies) into climate products; benchmarking of these algorithms and evaluating the adequacy and accuracy of the resulting products; proposing advanced specifications for future observing instruments taking advantage of recent scientific progress; improving the analytical methods used to operationally process the satellite data; and re-analysing past archives based on new scientific breakthroughs.

The information from satellite is restricted to either the surface layer of the ocean or some water-column integrated quantities such as sea level or gravity. It is important, therefore, to assimilate EO techniques as a part of a comprehensive monitoring system which will be linked with systematic measurements of the oceanic interior.

European integration for operational monitoring

Understanding climate change in the marine environment requires multi-disciplinary and concerted actions to collect information on the past, present and future hydrographic, chemical and ecological state of the coastal waters and seas. Moreover, measuring the state of European seas and forecasting their future conditions under various scenarios entails to accessible, sustainable, and reliable data sets. Inter-operable data centers providing access for global and European scale data analysis and synthesis are prerequisite to reduce current uncertainty in climate change projections.

A number of organizations and networks have already been created to provide distributed access to marine data in specific domains. The Sea-Search portal (http://www.sea-search.net/) provides an overview of these different instances and a link to other ocean and marine data information collected and managed by various research institutes and data holding centers in Europe. Recently, the EU project SeaDataNet (2006-2011; http://www.seadatanet.com/) will expend this Network further with the objective to build a standardized system for managing the large and fragmented data sets collected by oceanographic campaigns and new automatic observations systems. The European Environment Information and Observation Network (EIONET, http://www.eionet.europa.eu/) is coordinated by the European Environment Agency (EEA) in partnership with member and participating countries to collect and disseminate data and information on the European environment. A special section, EIONET-water, focuses on transitional, coastal and marine waters, with emphasis on marine eutrophication issues in support to the implementation of the EU Water Framework Directive (see section 5.1).

An example of valuable network for climate change studies is the European Sea Level Service (http://www.eseas.org/) that is networking all tide gauges operators along the European coasts, as well as sea level information from other sources such as satellite. The Argo floats Network is also an international initiative to provide global measurements of temperature, currents and salinity in real time. Argo floats data are freely available and already used in Europe to measure sea-state and as inputs to ocean circulation models. With respect to marine ecosystem, the International Council for the Exploitation of the Sea (ICES; http://www.ices.dk/) regroups one of the largest databases on fish inventories and statistics, as well as many other hydrographic and ecological variables, covering the North Atlantic and adjacent European Seas such as the North Sea and the Baltic Sea.

Other networks such as the international Global Ocean Observing System (GOOS) and particularly its European and regional components (EuroGOOS, MedGOOS, Black Sea GOOS) and its recent coastal module (UNESCO IOC 2005) are greatly beneficial to improve the community capacity to detect and predict the effect of global climate change on the European Seas and coastal systems. These networks are promoting the inte-

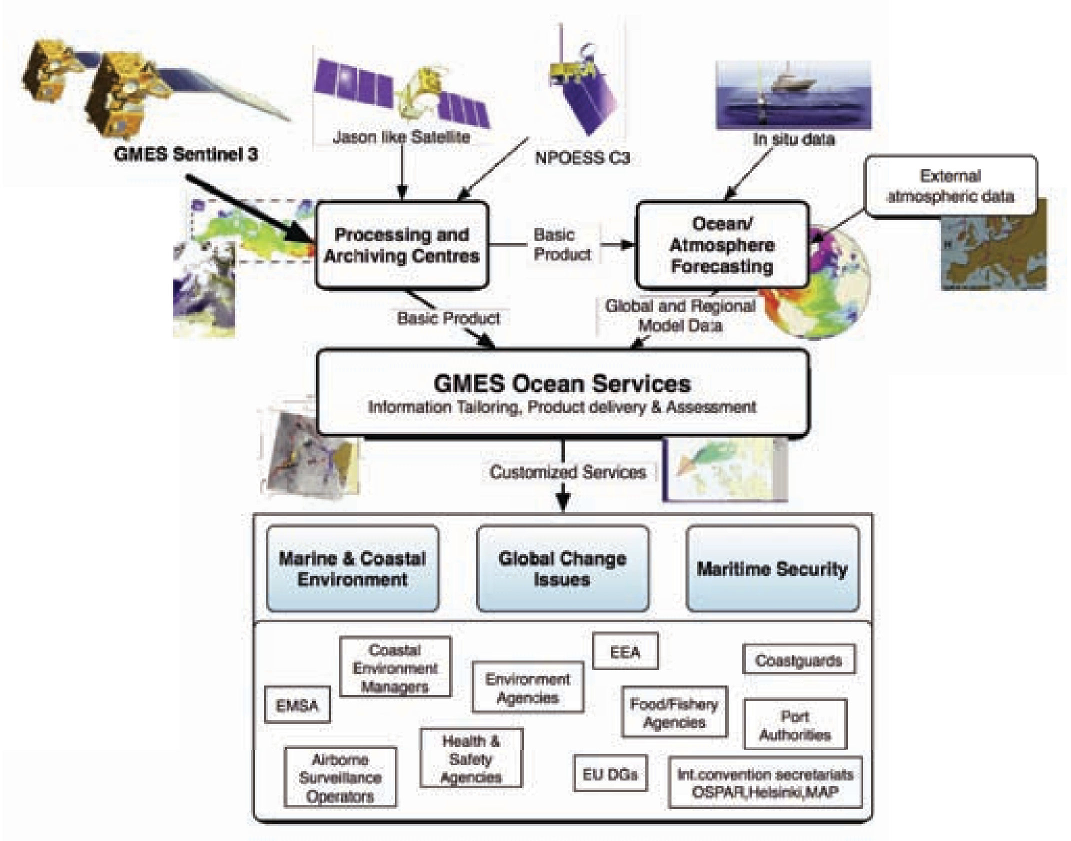


Figure 2.7.1. *Diagram of the GMES Marine Core Service (in Drinkwater et al. 2005, with permission)*

gration of observations, modeling and analysis of marine variables to support continuous services for the protection of the environment and health in the European coastal and shelf seas.

The Regional Marine Conventions (e.g. OSPAR. HELCOM, see section 6.3) are also holding useful databases covering a large range of biological, physical, and chemical variables for specific geographical areas in Europe.

These efforts to develop a European capacity in operational oceanography are now being integrated and expanded through the joint EC/ESA initiative for Global Monitoring for Environment and Security (GMES). The marine component (or Marine Core Service, fig. 2.7.1) of GMES aims at providing the EU with the capacity to effectively address today's challenges and threats in a variety of policy areas related to the marine environment.

The Marine Core Service (MCS) will provide the common denominator data (observational and model data) for all users in the marine sector, delivering regular and systematic reference information on the state of the oceans and regional seas. Its implementation will built on the integration of existing service components and facilities, focusing at first on the physics and some primary marine ecosystem state variables. On the same basis, the EU integrated project MERSEA (http://www.mersea.eu.org/) is now developing a pre-operational monitoring and forecasting system by 2008.

One of the MCS objectives is to provide re-analysis of long time series past information about the marine state at global and regional scales. The harmonization of these data at known quality and accuracy will be extremely beneficial to climate change analysis, e.g. to calibrate and validate regional climate models. However, the prediction capability of MCS is presently defined over time scale of days to weeks, to mimic the scope of the European Centre for Medium-Range Weather Forecast (ECMWF). It is, therefore, recommended to extend the MCS dimension to decade and century scales, such that it can also address climate change related stress in the European Seas.

Section 3

Assessing Coastal Vulnerability to Climate Change

Vulnerability has been defined in different ways. According to IPCC TAR (IPCC 2001), vulnerability is defined as 'the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity'. To keep it more general, it is recommended to define vulnerability as 'the characteristic of a system that describes its potential to be harmed' (Goulby and Samuels 2005). In coastal systems, vulnerability is associated with the natural properties of the environment (physical, chemical, biological), as well as the socio-economic elements that contribute to modify its natural dynamics. Both components are interacting in different ways and strengths, each element depending on their exposure, sensitivity and adaptive capacity to change in response to climate forcing variables (Nicholls and Klein 2005). The physical disparity of European Seas and coastal areas and their various degree of population development commonly leads to regional differences in the causes and extent of vulnerability to climate forcing variables. Also, several time scales and processes are relevant when considering the repercussions of these changes and pressures to the morphological developments and habitats in coastal areas.

The challenge of coastal configuration planning is therefore to integrate the natural elements and the socio-economic processes into complex engineering models explaining how the different elements interact, and allowing simulations of short-term and long-term changes in the coastal domain.

Together with models, the geospatial technologies offer opportunities for exploratory data analysis, examining data from a geographical perspective that helps to reveal distributions, patterns, and changes over space and time with the possibility to move beyond observation and recording to analysis, explanation, and communication.

Further Reading:
Vermaat J., L. Bouwer, K. Turner, and W. Salomons (Eds.), 2005. Managing European Coasts: Past, Present, and Future. Springer, Berlin, p. 387.

3.1 Causes and extent of coastal vulnerability to CC in Europe

Coastal fringe changes can be classified into several components with an associated temporal and spatial scale (Sanchez-Árcilla and Jiménez 1997; Jiménez and Sanchez-Arcilla 1997), each of which being related to specific littoral processes and their corresponding forcing agents. On the long-term scale and large geographical extent (fig. 3.1.1), the agents inducing changes are the relative sea level rise, long term variations of atmospheric and marine processes, land movements, and longshore transport effects.

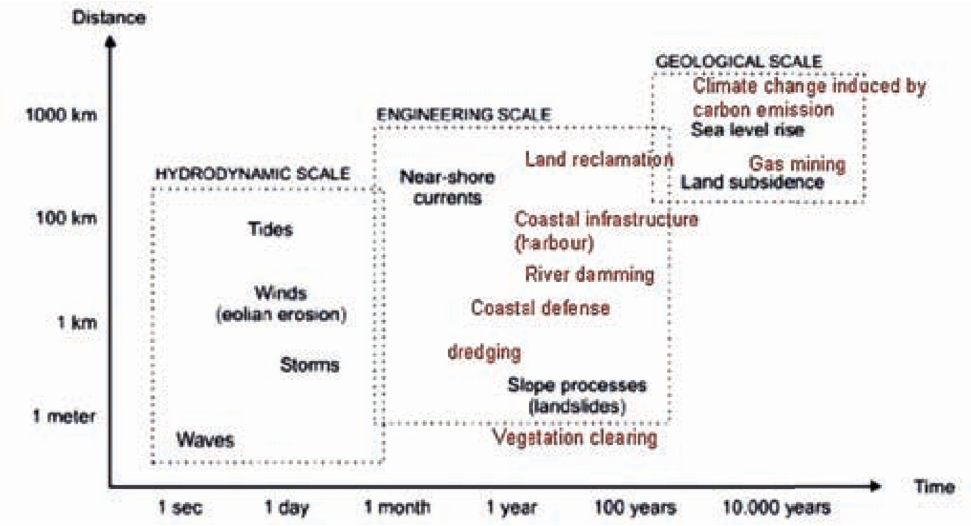


Figure3.1.1. *Time and space patterns of natural factors and human-induced factors (red colour) of coastal changes. (source: EUROSION 2004)*

The medium-term scale is related to systematic coastal changes and evolutive trend of a coastal stretch at a spatial scale of the order of kilometers and temporal scale of several years. The driving agent would be, for example, the net longshore sediment transport induced by time-averaged wave climate, but also the action of near-shore currents, and a variety of land-sea interactions contributing to coastal reshaping.

Finally, the hydrodynamic scale includes both waves and tides actions which operate on very short time scales, and the episodic events.

The latter is defined by the action of very energetic and extreme agents with a relatively long return period, producing important modification of the coastal zone over a short period of time. To some extent, coastal erosive episodic events are followed by coastal recovery processes which may take place at longer time scale, contributing thus to the evolution of the coastline at the medium-term scale.

Climate change acts on all these scales through e.g., sea level rise, changing the strength of coastal current, increasing the frequency of storm surges. In addition to these natural pressures, human development and infrastructure along the coast would also impact on the coastal landscape and ecosystems according to their own spatial and temporal scales.

Among human induced factors causing coastal changes are coastal engineering for various purposes (tourism, industrial zones, protection), works in the river basin, dredging, or mining. Therefore the vulnerability of a coastal system to climate change drivers like sea level rise depends on the sensitivity, exposure and adaptive capacity of both the natural and socio-economic elements of that system (Klein and Nicholls 1999, Nicholls and Klein 2005).

The natural element impacts on the socio-economic developments, which in turn influence the natural progression through planned adaptation. These multiple interactions and their associated feedbacks are difficult to evaluate but, on the other hand, it is essential to analyse the potential risks they incur to the coastal system. Integrated vulnerability assessments are therefore recommended to increase our understanding of the system sensitivity to changing climate conditions, to identify most vulnerable coastal regions or sectors (hot spots), and to support the development of adaptive strategies to limit the impacts while maintaining the system sustainable.

Vulnerability assessment framework

Starting with the Common Methodology for Assessing the Vulnerability of Coastal Areas advocated by IPCC (1992), several assessments were performed within different contexts in response to different concerns, including climate change and sea level rise (Nicholls and Mimura 1998, Sanchez-Arcilla et al. 1998, Klein et al. 1999). Most of these experiments are based on multidisciplinary analyses of the potential consequences of climate change, integrating the assessment (vulnerability indicators) of both the impacts of sea level rise and the adaptation options, as well as integrating climate change with other non-climatic stresses. A conceptual framework for vulnerability assessment as proposed by Klein and Nicholls (1999, fig. 3.1.2) takes into account the vulnerability of both the natural system and the socio-economic interests to coastal change, as well as their interactions.

Accordingly, defining vulnerability as the potential of a system to be harmed, its assessment can be performed for a given coastal stretch (coastal cells and sub-cells, estuaries, deltas) or for a sector or activity within it (e.g. physical, ecological or socio-economic subsystems). The ‘harm’ is resulting from the susceptibility of the coastal stretch to the forcing term (e.g. sea level rise) and its resilience or natural capacity to cope with the effects. The ‘harm’ is normally evaluated as the expected value of the "damages" to both the natural system (biophysical effects) and the exposed socio-economic structures (residual impacts), after considering the natural (autonomous) and planned adaptation strategies.

Following this approach, vulnerability can be quantified in any unit which can represent the system of interest, identifying the type and magnitude of the problem, and the possible solutions to reduce the impacts. Accordingly, the geomorphic vulnerability of a coastal unit can be expressed in terms of i) its horizontal extent which depends on the erosion rate, and ii) its vertical position with respect to mean sea level which is a measure of the potential for flooding. The indicator will then be the subaerial surface elevation (Day et al. 1997) or subaerial surface position (Sanchez-Arcilla et al., 1998) of the coastal stretch. Both measures should be integrated to provide a single and more holistic value of the concept, which for a given time scale should be a useful indicator of the ‘health’ of the coastal system. The selection of the spatial and temporal time scale is therefore a critical issue when defining vulnerability. Likewise the reference state to which the present and future evolution is compared constitutes another key point to properly interpret the vulnerability value obtained and therefore to take decisions from it.

Coastal vulnerability to erosion in Europe

By nature, coastal morphodynamics is continuously eroded and shaped through various physical forces such as waves, tides, littoral drift currents, winds and seasonal storms. This natural momentum, however, is modified by i) on-going global warming acting on changing the magnitude and distribution of these forces, and ii) increasing human settlement and infrastructure developments re-designing the coastline and, thus,

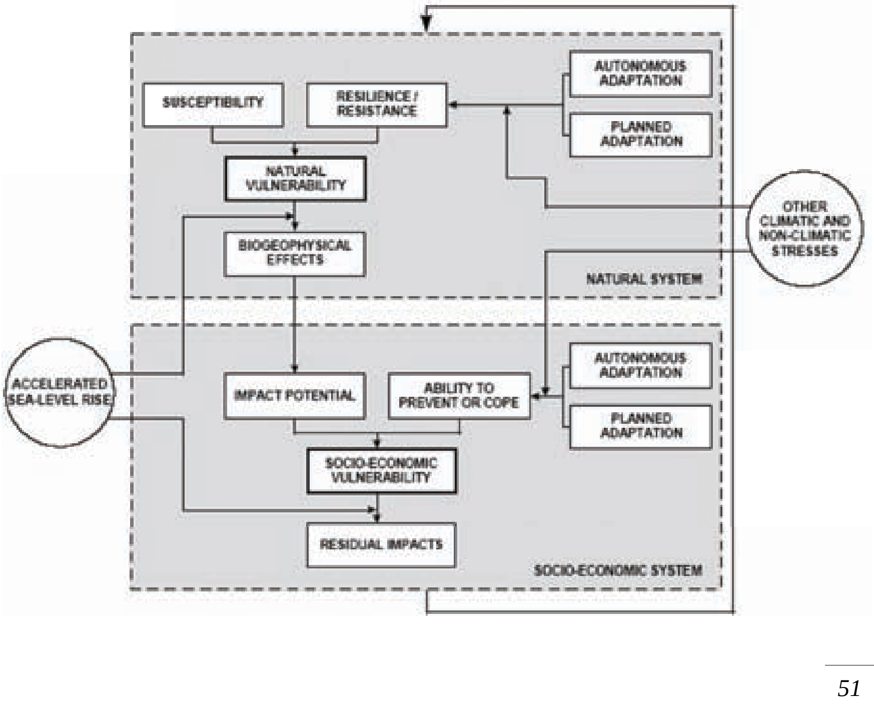


Figure3.1.2. *A conceptual framework for coastal impact and vulnerability assessment of sea level rise (source: Klein and Nicholls 1999, with permission)*

altering the intrinsic vulnerability of the coastal system. As a result, the area lost or seriously impacted by erosion along Europe is estimated to be 15 km^2 per year (Salman et al. 2004, fig. 3.1.3), with considerable economic consequences due to loss of lands and properties, flooding of agricultural areas, habitats degradation.

Figure 3.1.3. *Coastal erosion patterns in Europe (for 2004): aggradation (in green); erosion (in red); and stable coastline (in blue). Source EEA 2005, based on EUROSION project data)*

The effects of erosion are different according to the specific conditions of each coastal zone. Particular attention must be given to the effects of a potential increase in: wave energy, tide levels and tide propagation, probability of floods, salinity intrusion in estuaries and lagoons, and the alteration of sedimentary dynamics. The effects of these will be provisionally more critical where the coastal zone is at lower elevation and less protected by natural rock outcrops. Climate and global warming-related forcing are causing an increasing frequency and severity of storm impacts on world shorelines, and thus an increasing rate of coastal erosion. But climate change can also induce changes in wind directional spectra and, consequently, wave directional spectra which would tend to augment erosion rates in some areas (e.g. coast of Portugal).

Given the predictions for climate change, it is expected that half of the coastal wetlands in Europe could become submerged as a result of sea level rise (Salman et al. 2004). Even in areas equipped with coastal defense structures, many shore stretches have not yet reached equilibrium with the present littoral processes, leaving thus the population and economy at risk. This is the case for example at various localities in Portugal (Veloso-Gomes et al. 2004) where most of the measures that were taken to prevent erosion provide only local solutions in time and space and do not address the underlying cause of erosion and long-term processes.

3.2 Interaction with non-climatic pressures and socio-economic changes

In many cases, visible changes in the coastal morphology cannot be explained by climate change only. With 75 % of the human population expected to be living in the coastal zone by 2025, it is evident that an extreme competition for space with the natural system is occurring (‘coastal squeeze’). This human development has led to urbanisation (and mega-cities), increases in transport networks (canalisation and harbours) and tourist sites, together with extensive sea defense and coastal protection works, at the expense of the footprint available for the ecosystem. Impacts include changes in substance flow (e.g., sediments, water, nutrients and contaminants), loss of habitats, bio-diversity and related cultural assets. The relative contributions due to climate/natural forces and human development on coastal changes are not uniform across Europe, and dictate the policy responses at regional and local scales. For example, coastal recession along the Portuguese coast during the last 100 years is mainly concerned with direct anthropogenic pressures (Veloso-Gomes et al. 2006). In this case, erosion has been identified as a coastal response to dwindling river basin sediment sources and river sediment transport, to the construction of dams, breakwaters, and to the human occupation of the waterfronts. As an additional process, sea level rise and increasing storm surges may be responsible for 10 to 20% of the total recession (Veloso-Gomes et al. 2006). In Denmark, the contribution of climate forces to coastal changes could be more significant (Fragua et al. 2004).

Therefore, the driving forces to coastal changes need to be carefully reviewed for each coastal unit, not only to describe what was done in the past but also to better understand the critical factors which are responsible for the present state of vulnerability.

At the generic level, all European countries are engaged in growing and extensive trading activities. This is putting severe pressure on 'local' coastal areas, as well as possibly shifting other environmental cost burdens to other regions around the globe. Maritime transport increased by 35% in the EU between1975-85 but has since leveled off or slightly increasing (e.g. 3.3% total tonnage volume increase between 2003 and 2004 in EU-25, Eurostat 2006). Nevertheless, it accounts for 10-15% of total SO2 emissions in Europe and puts the marine environment at risk with oil spill and related nuisance because of the volume of traffic. Ports and associated industrial development are responsible for land conversion/reclamation, loss of intertidal and other habitats, dredging and contaminated sediment disposal, increased flood protection measures and also facilitate the spread of invasive exotic species thereby causing 'local' biodiversity loss.

The increasing physical growth of the European economies manifests itself, among other ways, in massive new construction of buildings and infrastructure. The spread of the built environment is having profound effects on catchment-wide processes, leading to increased flood risk, changes in sediment fluxes (and contamination risks) as well as habitat and biodiversity loss in the catchment-coast continuum. Direct physical alteration and destruction of habitats because of 'development pressure' is probably the most important single threat to the coastal environment. But human-induced changes in the natural flow of sediments are also a contributory threat to coastal habitats. Deltaic areas such as the Po, Rhone and Ebro have suffered from sediment starvation as hydrological changes in catchments (dams etc) have cut sediment supplies. The built environment expansion has multiple causes, but two factors are especially relevant for coastal areas, transport and tourism.

Europe's coasts host around 66% of the total tourist trade, and in the Mediterranean, for example, arrivals have grown from 135 million per annum in 1990s (EEA 2003) to 250 million travelers in 2001 (Sardá et al. 2005). Tourism's main environmental impacts are also generated via transport requirements, together with use of water and land, energy demands and waste generation. In some popular Southern European localities irreversible environmental degradation has probably already been inflicted. Tourism-related demand for passenger transport (pre 'nine eleven') has grown remorselessly; arrivals in South Western Europe grew by 91% 1985-2000. The environmental impacts are highly concentrated and seasonal within or close to resort areas. But lateral expansion along coastlines is also a common phenomenon and the construction of second homes (the Mediterranean and Baltic areas are prime examples) is a particular concern. With regard to climate change it is expected that low-lying areas and those on already eroding coasts will become more vulnerable and might lead to losses in the resorts themselves, but additionally might make those areas less attractive. In the Mediterranean area climate change will affect groundwater recharge, a commodity, which is already scarce in some areas.

Europe's semi-enclosed and enclosed seas (with their limited water exchange) are particularly sensitive to pollution threats. Marine and coastal eutrophication from elevated nitrogen levels (riverine transport and atmospheric deposition) quickly emerged as a worrying trend, the impacts of which were exacerbated by the loss of natural interceptors such as coastal wetlands. Severe eutrophication has occurred in the Black Sea and in more limited areas in the Baltic and Mediterranean. A majority of European countries have made significant progress in combating point-source pollution of watercourses, estuaries and coasts (e.g. sewage treatment plants and industrial facilities). So discharges of heavy metal and organic substances into the North East Atlantic fell during the 1990s. Nitrate concentrations fell by 25% in the Baltic and North East Atlantic over the period 1985-98 and phosphate concentrations also fell in North Sea areas. Waste water treatment levels and discharges are still problematic in the Mediterranean, Adriatic and Black Sea areas. However, the issue of diffuse pollution at the catchment scale and beyond remains generally problematic (fig. 3.2.1).

Agricultural activities and run-off are one of the contributors to this problem. Overall consum-

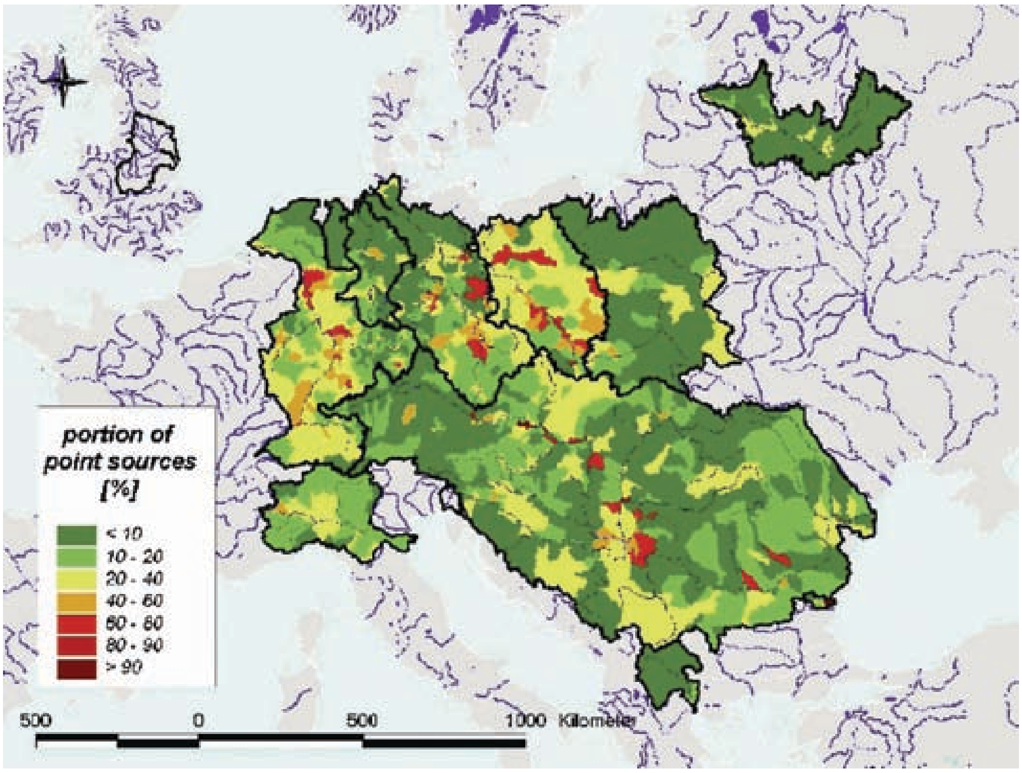


Figure 3.2.1. *Point sources for nitrogen in % of total emissions for a number of catchments in Europe (Behrendt in Salomons 2005).*

ption of fertilizers in Europe has stabilised in recent years following a fall in the early 1990s in Central and Eastern Europe. Current levels of fertilizer and pesticide use are probably not environmentally sustainable and measures such as integrated crop management need to be adopted more widely (3% of the utilised agricultural area of Europe is under such integrated management by 2003). Irrigated cropland retains a significant share of the agricultural areas in Western, Central and Eastern Europe, ranging from 11% to 18% respectively. Irrigated land continues to expand in some Western European and Mediterranean areas. This type of production has serious water resource implications and also poses a major threat to wetlands. Although the threats are varied some 31% of Europe's population now lives in countries that use more than 20% of their annual water resource.

Climate change is expected to cause significant impacts across Europe, but the south and the European Artic are possibly the most vulnerable areas (with the caveat that some 'local' areas are especially at risk for sea level rise e.g. South East England. All areas face hydrological and water resource risk increases, which may then affect ecosystems and biodiversity, as well as human health. If the modelling predictions about changes in marine water circulation patterns turn out to be correct then there are significant negative implications for regional seas in terms of eutrophication and contamination.

Europe's forests can play an important role in any climate change mitigation policy. The total area of forest in Europe is increasing and there is a future opportunity to diversify its service functions in order to provide watershed protection from soil erosion and floods and excess sedimentation, as well as realise carbon sequestration, recreation and nature conservation benefits. This reinforces the point that coastal zone management requires an appreciation of measures deployed within the relevant catchments if it is to be effective.

The concept of a more integrated coastal management approach has been advocated for more than a decade but so far full adoption has not been practiced anywhere. In Western Europe, awareness has been raised but sectoral policies have not been radically modified, let alone integrated. More generally, only 15% of Western Europe is under national designation for nature conservation and 9% or less elsewhere in Europe

(EEA 2003). Figure 3.2.2 presents an overview of a D-P-S-I-R scoping exercise for European coastal areas. This table shows combined results from expert opinion during an Eloise conference in 2003 and additional literature information; it is based on the LoiczBasins approach to identify and predict future impacts on the coastal zone. (Turner 2005, Salomons et al. 2005).
The individual tables for European region include:

- Drivers: the drivers at the catchment which impact on the coastal zone
- Major Coastal Impacts: The nature of the coastal impacts through catchments
- Present pressure status: The severity of the impact in minor (green), medium (yellow) and high (red)
- Trend expectation: An expert judgment whether the impacts will increase, remains constant or decrease.

Inspection of the various regional seas shows that eutrophication is and will remain an issue for the coastal zone. Both agriculture and in particular urbanisation are the main drivers. Pollution (e.g. toxic chemicals) is relatively of less importance; however the legacy of past pollution is an issue. Toxic chemicals are stored in waste dumps, behind dams, in soils and are present in deposited sediments in the catchments. These natural and man-made repositories (surficial filters, see figure 3.2.2) are in principle subject to erosion and further transport in the direction of the coastal zone. Changes in the hydrological regime (e.g. climate change) can mobilize these stored contaminates (Salomons and Stigliani, 1995; Salomons 2005).
In southern Europe damming causes a reduced freshwater flow to delta's and a decrease in sediment supply. Both affect the stability of wetlands and delta's as well as bio-diversity in those areas (SEDNET 2004 http://www.sednet.org/). Again climate change may aggravate these issues.

3.3 Integration through the Catchment-Coast continuum

The catchment influences the coastal zone trough the flow of water, sediment and nutrients and chemicals dissolved in the water or attached to the sediment. In a wider sense the catchment activities will put "demands" on the coastal region through roads and harbours for transport. In this section will focus on the fluxes of water,

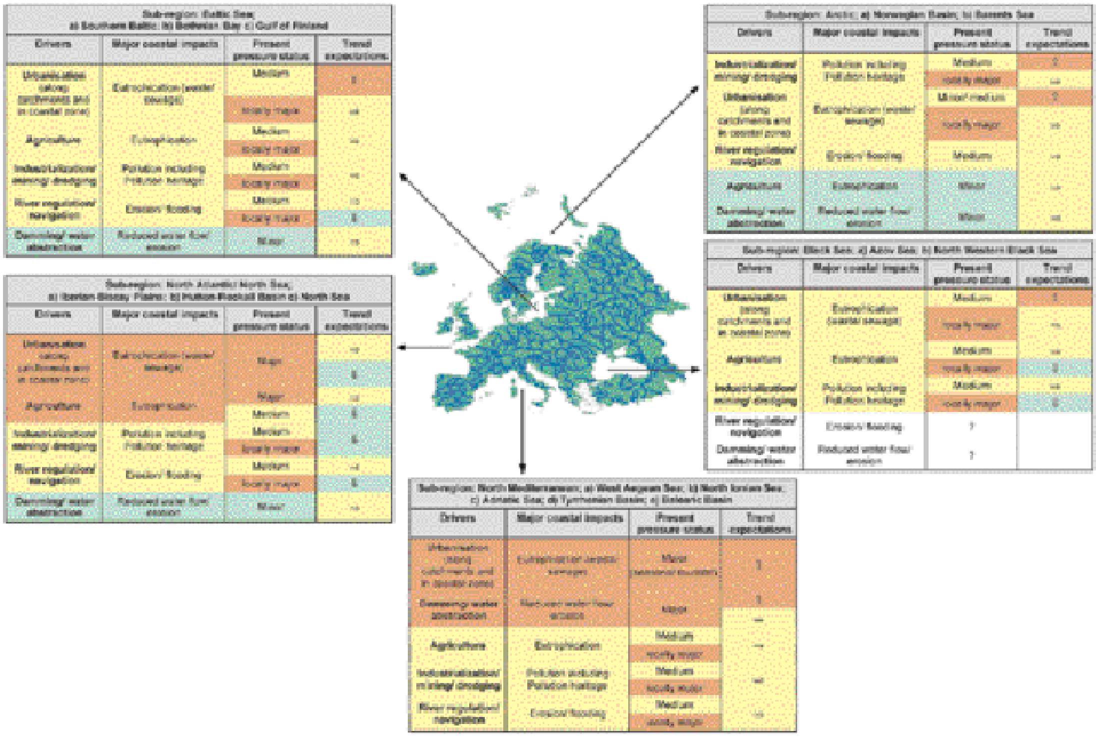


Figure 3.2.2. *The LoiczBasins assessment for Europe. The colouring of the table refers to major (red), Medium (yellow) of Minor (Green) (Salomons et al. 2005)*

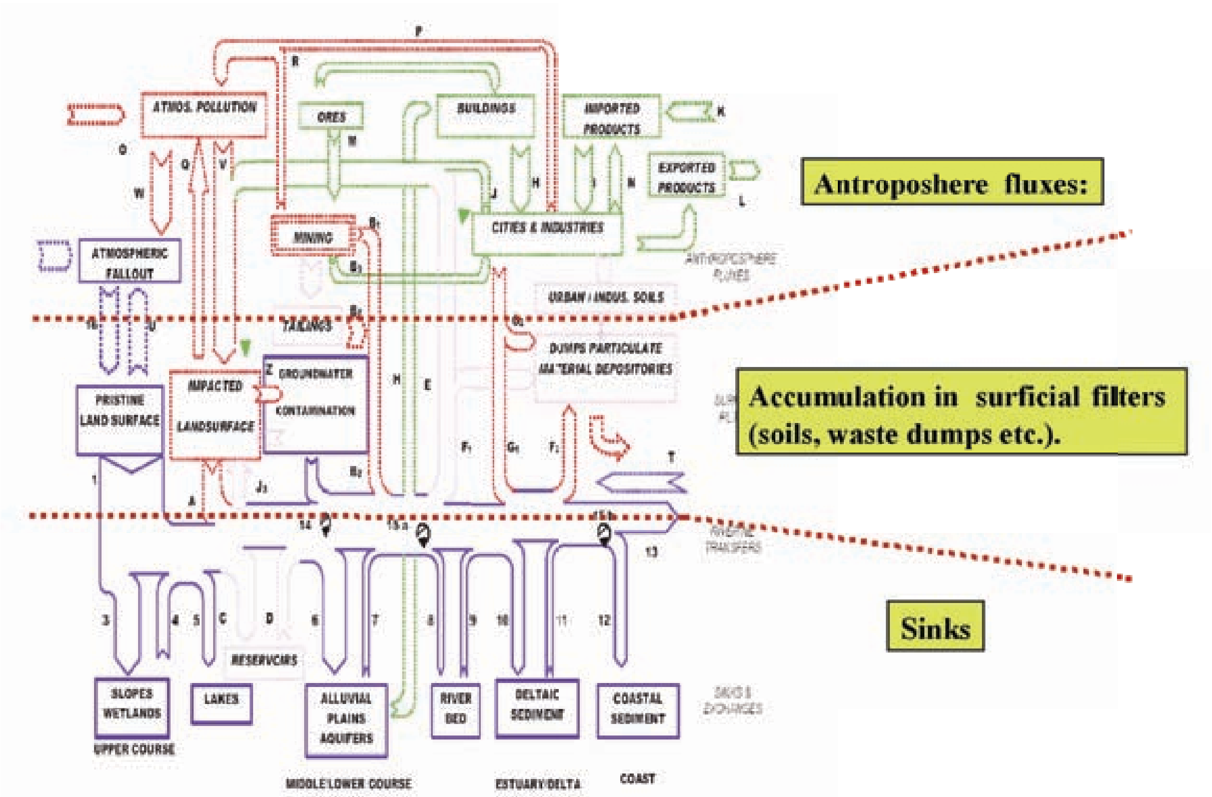


Figure 3.3.1. *Current origin and pathways of material and sediment at the catchment basin scale (Meybeck et al. 2004)*

sediment and chemicals/nutrients. Even this situation is complex (fig. 3.3.1) in assessing the current state but even more so in making predictions for future scenarios of change. In particular for coastal management it is essential to identify those drivers which are of global nature (e.g. cannot be managed by the regional manager) and those which are of regional origin and in principle can be managed.
In more detail it will be necessary to:

- Identify those *global changes* which affect the local system: such as natural variability, climate change and associated changes in the hydrological cycle, and those due to changes in the global economy/trade and policy;
- Identify the *regional (trans-boundary and supra-national) changes* which are primarily the result of regional and national drivers and pressures in the coastal zone;
- Identify the *regional changes* at the river catchment level (damming, land use change) which affect the downstream coastal zone;
- Map the existing *stakeholders interests and differences* in the perception of coastal values at regional scales including differences which need adaptation of management options to local social conditions, beliefs and attitudes;
- Map the existing *stakeholders interests and differences* in the perception of coastal values at regional scales including differences which need adaptation of management options to local social conditions, beliefs and attitudes; and
- Formulate and implement efficient and effective policy responses, which minimise the scaling mismatch problems and promote sustainable management

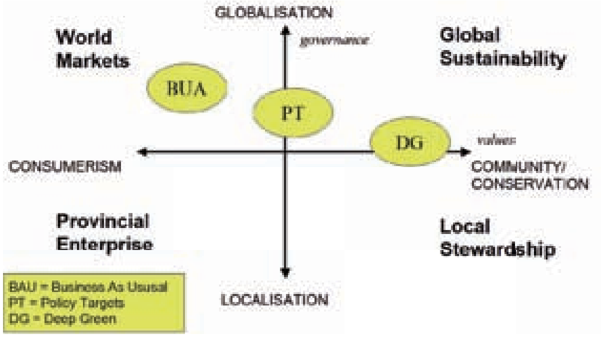


Figure 3.3.2. *The Business as Usual (BUA), the Policy Targets (PT) and the Deep Green (DG) EuroCat standard scenarios in the concept of "Environmental Futures Scenarios (to 2080). OST/DTI, Environment Futures, Foresight, OST London http://www.forsight.gov.uk/."*

Scenarios are an integral part of Eurocat's approach. Scenarios adapted to local conditions have to be developed through story lines considering a Business as Usual (BAU), Policy targets (PT) and Deep Green (DG) scenario (Fig. 3.3.2). The scenarios generate an array of inputs for the catchment- coastal zone modelling and the results can be analysed in terms of their impacts on the coastal zone (e.g. nutrient reduction, sediment flow).

Case study: The Humber estuary

A good example of the holistic approach including scenarios is a nutrient reduction study in the Humber Estuary (Cave et al. 2003). The three options (fig. 3.3.3) are available for nutrient reduction were analysed with a const-benefit analysis and for various scenarios.

The Humber Estuary is an example of a post-industrial estuary. It has been massively modified over the last centuries both in terms of chemical inputs and its physical structure through human activity and climate change. More than 90% of the total wetland habitat within the estuarine system has been lost to reclamation over the last 300 years or so and with this process some habitats such as freshwater bogs and wetland forests have been completely eliminated, while others such as salt marshes were greatly reduced in area. In terms of chemical inputs, the area has long been subject of human activities; indeed the catchment is the cradle of much of the UK Industrial Revolution. Mining has gone on since Roman times and the waste spoil from this activity still dominate the fluxes of some metals within the catchment. In the twentieth century the estuary shoreline itself was developed with intense industrialisation and port development including metal smelting activity. Much of this heavy industry has now gone, though a vibrant petrochemical industry remains. However, the sediments retain the history of the smelting and other industrial activity. Over the last two hundred years the catchment population has grown dramatically increasing waste discharges and

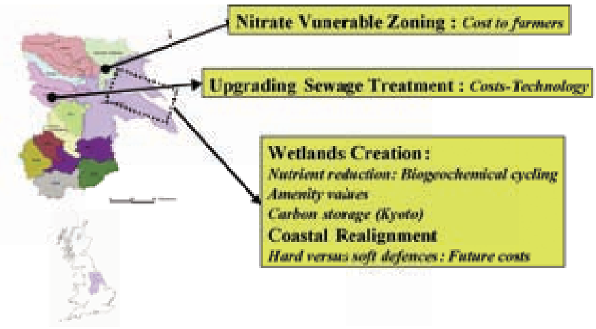


Figure 3.3.3. *The Humber estuary and the options for nutrient reductions.*

EuroCat'st conceptual framework for scientific analysis of Catchment-Coast Management issues.

1. SCOPING ANALYSIS
    DP-S-I-R framework, preliminary identification of priority science/policy issues
2. INSTITUTIONAL, STAKEHOLDER AND POLICY ANALYSIS
    Legislation, regulations, institutions across local, national and regional sea spatial scales
3. SCENARIO ANALYSIS
    construction of basic scenarios in order to differentiate between worldviews
    Business As Usual (BAU) - trend future
    Policy Targets (PT) - compliance plus future
    Deep Green (DG)-environmentalist objectives over the medium term but constrained by technological feasibility (BAT) and social attitudes and cultural changes
4. CATCHMENT-COASTAL ZONE MODELLING
    Adaptation, set-up, validating of existing models for the catchments, estuary and coastal zone
5. TRANSLATION OF SCENARIOS: INPUT TO BIOPHYSICAL MODELS:
    Running of the scenarios, analysis of output.

6. POLICY ANALYSIS OF THE SCENARIOS

Turner (2002)

intensification of agriculture has dramatically increased. Coastal realignment aims at restoring part of the former landscape with its extensive wetlands, and provides a protection against climate-related rising tides and coastal flooding.

Natural science models showed that the combination of point source reduction and managed realignment are the most effective at reducing ammonia concentrations in the estuary. Point source reduction has no noticeable effect on nitrate concentrations, but reducing river inputs is effective. A small increase in intertidal area is effective in removing ammonia, but not in removing nitrate, as it is buffered by the nitrification of ammonia. However, extensive increases in intertidal area are effective in reducing nitrate concentrations, comparable to the effect of reductions in the riverine inputs. Reductions in riverine input are reasonably effective in reducing the concentrations of dissolved-P in the estuary, but the effect is not significantly enhanced by point source reduction. Small amounts of managed realignment have very little effect on P concentrations, but extensive realignment is very effective at reducing dissolved-P and reasonably effective at reducing concentrations of total-P in the inner and middle estuaries.

Given the findings reported above, an economic cost-benefit analysis has been undertaken to test the proposition that compared to traditional sea defense and coastal protection schemes (‘hold the line’ hard engineering works) against climate-related forcing, managed realignment is an economically efficient policy option. Further, the modelling results show that managed realignment schemes can also generate additional environmental benefits. The analysis therefore takes as a core starting assumption that coastal managed realignment policy will be an important component of any future planning for the Humber estuary and catchment. But the key insight is that managed realignment (and its impact in terms of increased intertidal habitat) carries with it a number of positive externality effects. It creates more habitats with potential biodiversity, amenity and recreational values; a more extensive nutrient and contaminants storage capacity; and a carbon sequestration function. All these potential economic benefits are in addition to its sea defense/coastal protection benefits in terms of increased flexibility in response to sea level rise and climate change and therefore reduced maintenance costs.

Therefore the policy response to the problem of meeting future higher water quality standards should be to find the most cost-effective set of measures around the estuary and in the catchment that can provide additional nutrient reduction effects, once the baseline effect of increased intertidal habitat (via realignment) has been quantified. The analysis has investigated improved sewage treatment and nitrate zoning and related measures in agricultural areas as elements of the overall pollution reduction programme, given a range of water quality targets in the estuary.

The main findings were as follows:

- Managed realignment, if implemented on a reasonably large scale, could be an effective way of improving the water quality of the Humber estuary. In the scenarios outlined above, farming practices throughout the more than 25,000 km2 of the catchment would have to be radically changed in order to achieve reductions in concentrations of nutrients throughout the estuary comparable to those realised by creating 75 km2 of new intertidal area around the estuary and tidal rivers by realignment of flood defences.

  Measures to tackle diffuse nutrient pollution from agriculture (such as those implemented in NVZ designated areas) are more cost-effective than upgrading/construction of tertiary treatment at STWs. This is particularly the case for nitrogen and may also apply to phosphorus.
- Managed realignment has a number of environmental benefits (habitat creation, carbon sequestration, etc) the value of which can more than offset of the costs associated with this option and can result in substantial positive net present values.

3.4 Quantifying coastal behaviour and coastal changes

When assessing the effects of human activities as well as the consequences of climate change on the coastal zone, it is necessary to develop an integrated approach taking into account the catchment-coast continuum paradigm (fig.3.4.1). In fact coastal zone managers are confronted with several alternatives to produce similar results. For example, to decrease eutrophication in the coastal zone, nutrient reduction may be obtained by reducing diffuse pollution from agriculture or by reducing point sources, e.g. improving the waste water treatment systems, but also by removing nutrients already in the coastal zone by means of shellfish farming and developing a system of emissions trading (Ferreira et al., 2006). The selection between all these different alternatives is a complex task that requires the help of modelling tools able to quantify these alternatives not only from environmental but also from the socio-economic point of view.

For the above mentioned reasons, it is important to develop a general modelling framework that implements the different modelling modules able to describe the system components, i.e. river basin and coastal waters, as well as the ecosystem functioning and the hydrodynamics. Afterwards, model outputs of different scenarios may be used to compare system responses and to calculate water quality indicators and, linked to economic indicators, may become the input for a Decision Support System (DSS) to help coastal managers (e.g. DITTY Project, http://www.dittyproject.org/).

While models are diverse in design and scope, i.e. watershed, fluid-dynamics, biogeochemical, all have the same fundamental goal, i.e. to account realistically for the processes that drive the dynamic behaviour in coastal zones so that their status may ultimately be predicted and the effects of mitigation actions be properly evaluated, resulting on a series of good management practices that increase their sustainability.

Modelling the watershed

Watershed modelling refers to a class of tools able to describe the movement of water in a river basin, both in terms of hydrological cycle and hydraulic routing. For coastal zone management they should also include the transport of nutrients, thus accounting for their decay, precipitation, dissolving, dispersion and chemical reactions. Many of them can realistically consider detailed watershed morphology; land use and land cover distribution; point sources and water protection/water management infrastructures.
Watershed-scale models simulate the generation and movement of pollutants from land surface (point or diffuse source) to water bodies, as well as the transformation within the watershed and it water bodies (lakes, estuaries, etc.), including eutrophication and simulation of biological communities, respectively. The models may be classified according to:

- the temporal scale dealt by the model (event based versus annual or continuous);
- the approach used to describe the various processes (empirical, physically based);
- the spatial scale (lumped, where the watershed is treated as a box with input and output, versus distributed, were transport is simulated taking into

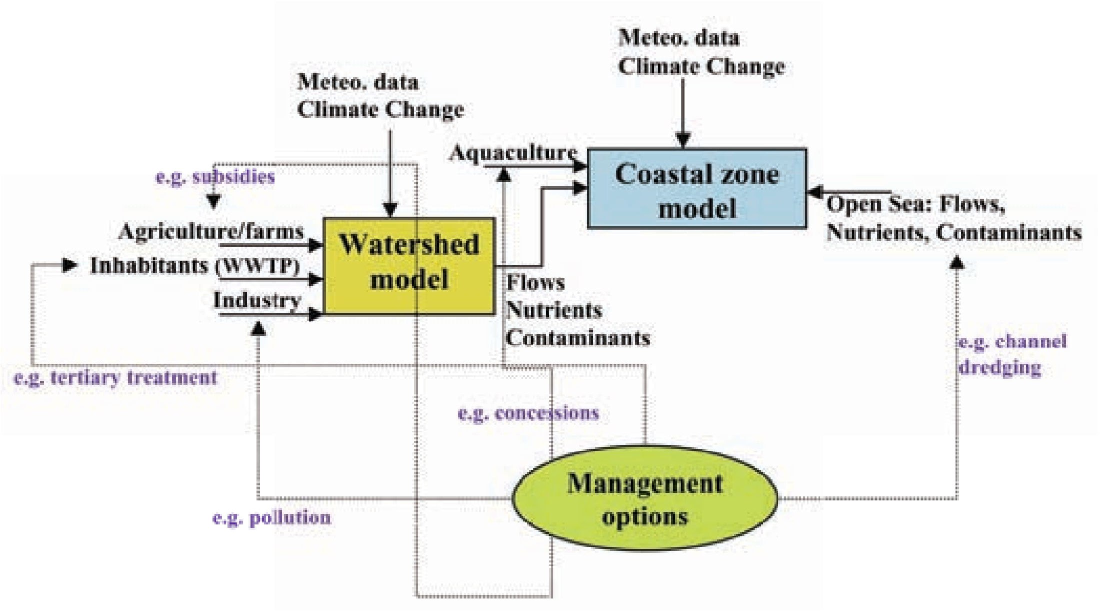


***Figure 3.4.1.** Integrated modelling approach watershed-coastal zone.*

account the spatial variability of the physical characteristics of the watershed and its land cover).

Following the increasing computing capabilities and the mounting wealth of data collected though the monitoring networks, along with the recent development of geographic information system (GIS) tools, researchers have poured considerable effort into developing distributed models. Such class of model is more apt to the exploration of research oriented issues and to detailed description of the movement of pollutants and the effects of land use change.

Even though, there are several models available at different levels of complexity, e.g. SWAT (Soil and Water Assessment Tool, http://www.brc.tamus.edu/swat/soft_model.html), still research is necessary concerning the modelling of intermittent rivers that bring the main part of pollutant loads during flood events (Chu et al., 2006). If climatic changes exacerbate these effects in the Mediterranean area, the role of nutrient pulses in coastal zone ecosystems should be better analysed.

Modelling the coastal zone

The coastal zone modelling should be modular and comprise several components, depending on the issues of interest:

- *Hydrodynamic models*

Hydrodynamic models are tools built to describe fluid flow and related variables (temperature, salinity, etc.) for a given environment. The well known Navier-Stokes' equations are the base for mathematical modelling of geophysical fluid dynamics. Unfortunately such kind of non-linear partial differential equations are very difficult to solve. Instead, a simplified form of the equations, known as Boussinesq equations, is often used in the field of oceanography to build mathematical models. That system of equation derived from classical mechanics theory needs a turbulent closure (Mellor and Yamada, 1982) and a state equation for sea water in order to be solved. Then numerical techniques can be applied to solve the equations after initial and boundaries conditions have been specified. Example of such a model can be found in Luyten et al. (1999) and an application to analysing herbicides from the watershed in Carafa et al. (2006).

- *Biogeochemical (ecological) models*

This term refers to mathematical modelling of ecosystems including biogeochemistry, with emphasis on nutrient cycling, physiologic processes, such as respiration and feeding, population level processes, such as mortality and recruitment, and community level processes, such as predation and competition. Biogeochemical models consist of compartments, which may be biotic (different biological species or functional groups) or abiotic (e.g. dissolved substances and suspended matter), represented by state variables and described by differential or difference equations, governing the transfer of material between them (Taylor, 1993). The choice of variables is guided by the scientific questions that the model is created to address, the available knowledge about the ecosystem and also the subjectivity of the modellers regarding the importance of different processes and variables.

Even though, there are general equations that can be used to determine how material is transferred between variables of an ecosystem model (Wiegert, 1979), the processes and coefficient considered change from model to model because the equations are not based on known quantitative laws as the physical equations of motion, but normally represent mass or energy balances. Therefore, it is common to simplify most of these coefficients to either constant values, functions of time or space, or functions of the physical forcing (Taylor, 1993).

In a distributed model, the biogeochemical equation must be solved for each model box providing the "sources-sinks" term of the transport equation.

The type, quality and quantity of data available for a particular ecosystem, as well as some of its structural and functional characteristics, limit the number of processes that are represented in models, as well as the degree of detail used.

In the case of shallow-water coastal systems benthic processes tends to important (Chapelle, 1995) as well as benthic species, with particular relevance to macroalgae, macrophytes and bivalve species (e.g. Plus *et al*, 2006; Duarte et al., 2006).

- *Sediment transport models*

In case of interest in studying the dynamics of coastlines and its morphodynamics, sediment transport models are necessary (e.g. Prandle *et al*., 2000; Umgiesser *et al*., 2004; Simpson and

Castelltort, 2006). These models allow calculating the changing surface morphology through time and space, with areas of net deposition and areas of net erosion, at different time scales also they allow predicting the effects of human interventions such as dredging operations in the system, new constructions as ports and marinas, etc..

Of course, the combination of several modules will depend on the questions formulated by the coastal zone managers and on the level of detail necessary to have a complete picture of the spatio-temporal variability typical of coastal systems. Furthermore, concerning climate change short- and long term-effects should be taken into account.

Case study: Impacts of climatic variability on shellfish farming

Sacca di Goro coastal lagoon (Northern Adriatic Sea, Italy) is the second site in Europe for the production of the Manila clam *(Tapes philippinarum)*. By using an integrated watershed- 3D hydrodynamics/biogeochemical coastal zone model, three scenarios concerning normal (643 mm precipitation and 13.3 °C annual mean temperature), dry (532 mm and 14.1 ºC) and wet (720 mm and 12.6 °C) years were identified after analysing meteorological data over the last 40 years. Changes in climatic conditions have a significant effect on coastal zone inflows increasing by 50.4% under wet conditions and decreasing by 19% under dry years. As a result, Sacca di Goro will receive an 80-120% excess of dissolved inorganic nitrogen (DIN) and total phosphorous (TP), whereas a deficit of 15-20% will occur during dry years. All these changes accounted for a loss in clam productivity of about 20% during dry years (fig.3.4.2), due to shortage of food supply, which corresponds approximately to 18 million €assuming a market price of 4 € per kg of clams (Marinov et al., 2006).

This study demonstrates the effects that climate change may have on economic activities on the coastal zone and, in particular, to shellfish aquaculture that has been increasing annually around 8% over the last 30 years (FAO, 2005).

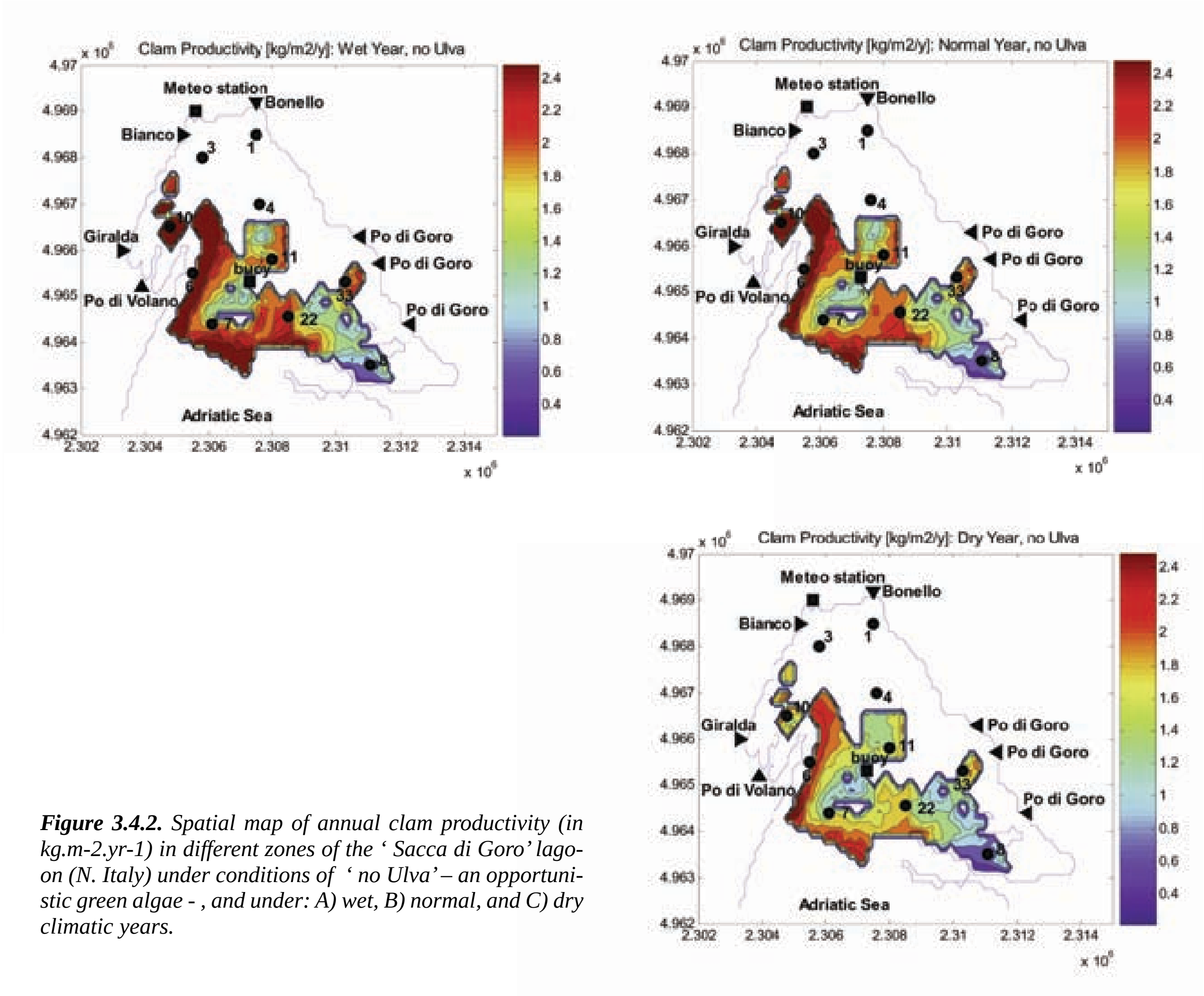


Figure 3.4.2. Spatial map of annual clam productivity (in kg.m-2.yr-1) in different zones of the ' Sacca di Goro' lagoon (N. Italy) under conditions of ' no Ulva' – an opportunistic green algae - , and under: A) wet, B) normal, and C) dry climatic years.

3.5 Geo-spatial data and technologies

It is increasingly widely recognized that tools to handle geographical or spatial data can play a very valuable role in the study of marine and coastal environments in the context of database creation, monitoring, mapping, modeling and visualization. Such tools provide an important aid to scientific research in the data into information pathway and can be useful to integrate multiple and disparate sources of data as well as to help communicate the results of scientific studies to a wider community including the *policy maker* and the *public*.

Remote Sensing

A wide range of both imaging and non-imaging remote sensing is currently in use for monitoring, data collection and mapping of the coastal environment. Satellite imagery from Landsat TM, for example, has been used to map coastlines, and at low tide, intertidal sandbanks, especially in estuarine areas, to monitor pollution from pipeline outlets, whilst oil slicks and discharges from ships have been monitored using Radar. Satellites, such as Quickbird and IKONOS, now provide much higher resolution imagery and data, whilst a number of the radar sensors carried on the ERS, Radarsat and Envisat satellites have provided all weather capability, particularly useful for monitoring coastal areas with high cloud cover.

Airborne data by contrast, provides a different but complementary data source. Coastal features such as defence and protection works, cliffs, beaches and areas of erosion and coastal habitat can all easily be detected from aerial photography and airborne sensors such as video, CASI, and ATM. LIDAR provides unparalleled opportunities to collect high resolution topographic heighting data as the basis for Digital Elevation Models (DEMs), as well as bathymetry (fig. 3.5.1). As an example of a hyperspectral instrument, CASI has successfully been used for measuring water column depth, monitoring algal blooms, and mapping eel grass, as well as the health of coral reefs which are a potential indicator of climate change.
Below water, sidescan sonar offers detailed high resolution imagery and data from the seabed, the best and most striking recent example of which is the Royal Navy imagery gathered under the Indian Ocean of the sea bed immediately following the Boxing Day tsunami of 2004. This provides complementary data to that obtained by other sources. Lidar bathymetry, using system like SHOALS-1000T, for example, and image acquisition offers considerable potential for shoreline, seabed, and habitat mapping.

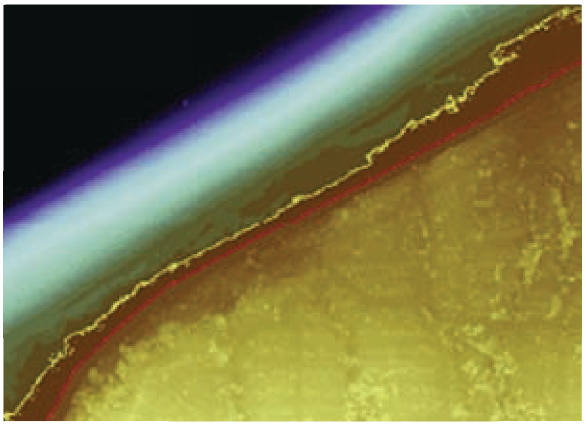


Figure 3.5.1. *Shoreline delineation obtained by using topographic and bathymetric Lidar (courtesy of Fugro Pelagros [http://www.fugro-pelagos.com/lidar/lib/pres/CoastalSurveyApplications.pdf)](http://www.fugro-pelagos.com/lidar/lib/pres/CoastalSurveyApplications.pdf)*

Geographical Information System

Geographical Information Systems (GIS) is an essential tool for integrating land and marine datasets. They provide the ability, for example, to view land elevation data, as well as bathymetry. Marine features can be shown in relation to terrestrial features. Temporal comparison can be carried out to reveal the geographical position of a coastline at different points in time, or coastal change can determined from differencing two DEMs, the result being mapping of the accretion or erosion and estimates of volumetric change.

GIS software provides a variety of tools to display and visualise map- and image-based datasets in 2D and 3D, and is now widely used to communicate the results of spatial analyses. Some GIS also have functionality to undertake the analysis of remotely sensed images, and in some packages customised extensions have been developed to work with specific datasets, e.g. the Oceanographic Analyst 1.4. Extension (http://www.absc.usgs.gov/glba/gistools/). Many mathematical models also utilise GIS for visualisation whereby data and or model output is imported into the GIS.

Over the past few years, GIS has steadily been migrating from large mainframe computers onto smaller desktop PCs (personal computers). This trend has been further developed with the progressive evolution and widespread use of the Internet and World Wide Web (WWW), and today, there are many forms of GIS available on the WWW, ranging from basic image-maps, image maps created using a special plug-in for ArcView (see Alta4 Map Viewer), JavaScript tools and Java Applets (ESRI ArcView Internet Map Server, Autodesk, PCI Spans). With the expansion of GIS onto the Internet, access to geographic data, and the manipulation of it, will become even easier for the environmental manager who may not necessarily be a computer applications specialist or scientist.

A recent extension of this concept, which clearly demonstrates the potential for access to information, is Google Earth (earth.google.com) providing a global image and topographic basemap. The use of various software utilities allows for user customization of Google Earth to develop local information systems including map and image overlays. The combination of a 3D interface to Google Earth and the capability to 'fly-through' the terrain also offers considerable visualization potential (Green, 2006).

Mobile Field Data Collection

Many environmental sciences, as well as environmental applications, require regular collection of data and information in the field. With rapid advances in computer hardware and software technology it is now possible to take palm-sized (Personal Digital Assistants – PDAs) or hand-held computers into the field, equipped with Global Positioning Systems (GPS) to collect geographical data directly into a digital spatial environment, making the process of collecting field data more efficient and effective, as well as improving the way that this data is then added to and stored in database and integrated with other data sets. With the aid of mobile phones it is also possible to transfer data collected in the field to a remote computer and to both upload and download data collected in the field or for use in the field Tablet interfaces, folding keyboards, handwriting recognition, and voice activation have all played an important role in recent years to improve mobility.   As the technology has become more affordable, portable, and easier to use so more applications have been found. These range from simple map updating exercises, to tracking and recording the location of an individual, to accessing information on-the-fly through an Internet browser on a PDA or mobile phone. Mobile tracking devices with spatial locators also offer potential for field data collection.

Data Infrastructures, Data Sharing and Communication

The importance of being able to share scientific data has received increasing attention in the last few years from many researchers. A considerable amount of time and effort has already been directed towards the development of data models, data formats and spatial data infrastructures (SDI) to help overcome the problems associated with data sharing. ESRI (www.esri.com), for example, has been working with marine experts to develop the Marine Data Model (http://dusk2.geo.orst.edu/djl/arcgis/). A great deal of work has also been undertaken on SDI in nearly every country (see Global Spatial Data Infrastructure (http://www.gsdi.org/).

An efficient implementation and monitoring of environmental measures related to climate change require interoperable spatial information across national borders, as well as an easy access and use of this information by all concerned stakeholders. The recent agreement (Nov. 2006) reached by the European Parliament and Council on the proposal for a Directive establishing an infrastructure for spatial information in the Community (INSPIRE) will open scientific data to a new dimension and provide new opportunities to increase our understanding of European-wide impacts of climate change.

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[1] COM(2004) 516 final. http://inspire.jrc.it/ . Proposal for a Directive of the European Parliament ando f the Council establishing an infrastructure for spatial information in the Community (INSPIRE). SEC(2004) 980.

Section 4

Mitigation and Adaptation Strategies

The transformation of European seas and coastal areas by anthropogenic global warming and changes in the water chemistry calls for a response from the community to reduce adverse impacts of climate change and variability on the both the environmental and human systems. Mitigation processes include reducing the emission of greenhouse gases (GHG) and enhancing their sinks, whereas adaptation refers to a series of actions performed on selected systems at local or regional scale to moderate negative effects of climate change. Considering the difficulty to manipulate and control the marine environment, the global Emission Reduction Plan and EU compliance to Kyoto Protocol remains extremely important to mitigate climate change impacts on the marine system. However, even under a scenario allowing drastic reduction in anthropogenic CO_2 *emissions, the impacts of climate change will continue for centuries requiring adaptation measures to be taken with long-term perspectives.*

Coastal zones are regions in which it is possible to effectively implement proactive strategies to reduce the vulnerability to climate change effect such as accelerated sea level rise and increased storm surges frequency. This section gives an indication on the possible adaptation strategies and the complexities of any decision-making process due to interactions with multiple stakeholders competing for the coastline and the marine resources. In many cases, adaptation to climate change is obtained indirectly through enhancing the adaptability of vulnerable systems or natural biological stocks by reducing pressures from non-climatic stresses. For example, a judicious development of Marine Protected Areas and aquaculture system can be seen as valuable options to alleviate pollution and overfishing effects on the marine ecosystems which would then become more resilient to climate-related drivers.

By nature, the global ocean represents an important sink for atmospheric CO_2*. Artificial methods to increase such storage capacity are presently under investigation through various pilot-studies evaluating for each options potential risks and benefits.*

4.1 Coastal adaptation strategies

Reducing coastal vulnerability to adverse effects of climate change (and non-climate pressures) embraces three major options: accommodation, protection, and retreat (Klein et al. 2001). Accomodation strategy relies on the society's attitude to cope with natural hazards e.g. by doing nothing to prevent the land from being flooded, or rebuild infrastructures further on land after being damaged. 'Retreat' plans consider restricting land use over a particularly vulnerable area, thus reducing the risk of potential damage. 'Protection' usually refers to the construction of hard structure or specific geomorphologic operations that would reduce the probability of potential damage to occur in a classified vulnerable area. Each of these three option categories contains a range of different adaptive measures requiring various levels of technology (Klein et al., 2001).

Traditionally, adaptation to coastal hazards has been on protecting the land using hard structures. Over many centuries, The Netherlands has used dykes and other sea-defence structures to prevent inundation from the North Sea (Verhagen 1990). Likewise in Portugal, coastal zone management up to the late 1980s was mostly directed to coastal engineering with many groynes and seawalls built wherever human development was being threatened by coastal erosion (Anon 2003, Veloso-Gomes et al. 2004).

More recent adaptation measures include 'soft' engineering options like beach nourishment, dune rehabilitation and elevation of the land surface, commonly thought to have fewer impacts on the environment and ecosystem than 'hard' structure such as seawalls. According to Salman et al. (2004), public expenditure dedicated to coastline protection against the risk of erosion and flooding in Europe has reached 3,200 Meuros in 2001.

In many cases, however, coastal protection structures have been built arbitrarily as an immediate response to storm damages or economic interests, without knowing whether these structures were appropriate and effective in the medium- and long-term with respect to the physical processes and social development in place. As a result, some of these coastal defences may have turned into an environmental problem, strengthening coastal erosion in adjacent areas, thus building on other anthropogenic activities like damming, harbouring, and dredging. Climate change with sea level rise and increased frequency of storm surges would represent an additional problem to the system.

Coastal development control

The objective of coastal development control is to reduce the environmental impacts from climate and non-climate related pressures and to prevent potential damages to existing and planned anthropogenic developments. In a dynamic and vulnerable coastal system including human settlement, several planning options can be envisioned with respect to existing or new waterfront development (fig.4.1.1). Each of these options needs to be evaluated carefully so as to achieve sustainable development in both the environmental and socio-economic dimensions.

No response strategy to coastal change can really be an ideal solution to completely eradicate impacts on both the environment and socio-economy. Artificial beach nourishment is used to restore and eventually expand the recreational beaches. However, the cost of sand extraction and its transport could make such option rather expensive, particularly if applied in a dynamic area where the operation has to be repeated regularly at intervals of few years. Beach recharge seems to be very cost-effective solution in lower-energy littoral, regardless of the length of the coastal stretch (Magalhães et al. 2004).

Planned 'retreat' might be an option in undeveloped or moderately-developed coastal areas where the environmental and aesthetic factors have a significant value in the public opinion. But this approach may become expensive and socially less acceptable in more intensively developed and populated areas, particularly if the option is decided on the basis of potential risks that may occur within a time frame of a century. In area of high settlement levels, hard coastal protection systems may be necessary to safeguard existing urban infrastructures, as the cost of building these protective structures would be far less than the total value of the urban areas.

Another important issue in coastal planning is to ensure that decisions are made according to cross-sectoral and integrated policies, and guidelines linking the objectives and targets of the dif-

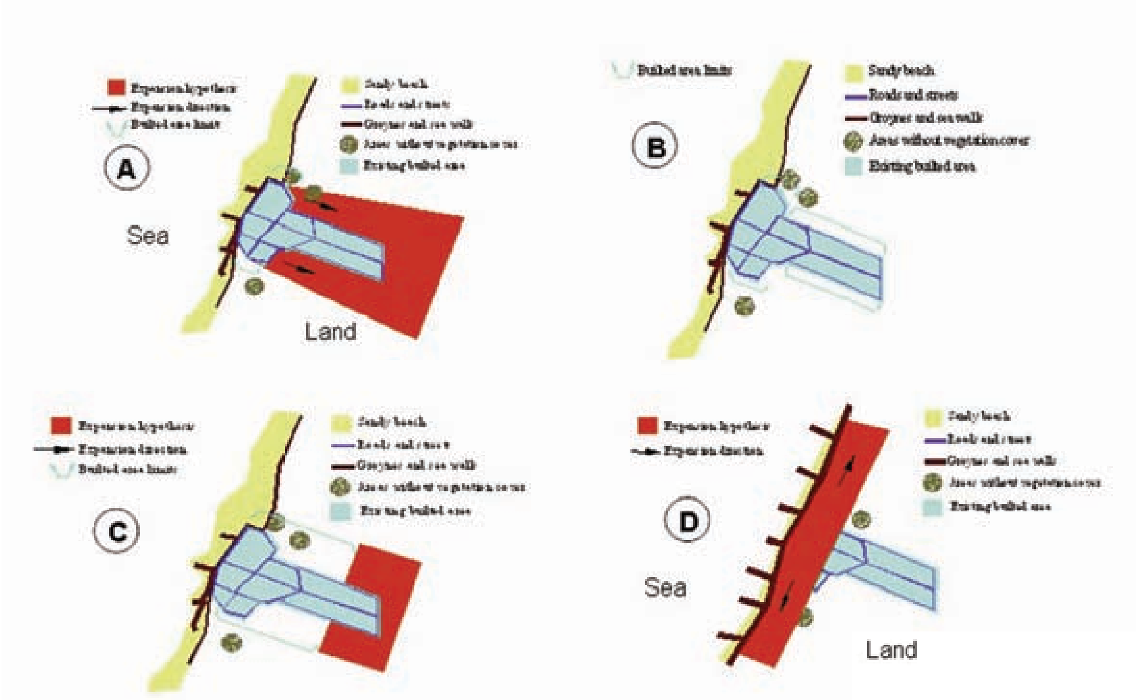


Figure 4.1.1. *Coastal development control. Examples of (adaptation) planning scenarios for a hypothetical coastal urban system. A) urban development control with building expansion towards mainland. B) freeze on any type of developments and maintenance of existing structures. C) planned retreat with respect to new building developments. D) engineering protection at the coast allowing alongshore urban expansion. (adapted from Veloso-Gomes et al. 2006)*

ferent stakeholders. Information and public awareness is critical for coastal adaptation. Inappropriate and uncoordinated sectoral legislations and policies have often worked in prejudice of the sustainable management of coastal zones (Veloso-Gomes et al. 2004). The issue is particularly acute with climate change and predicted impacts that may occur sometime in the far future. The lack of information and top-down decision-making process can cause major social conflicts, as well as environmental problems. Therefore, an adequate coastal zone planning development requires combining different policies and measures that have been evaluated and discussed in a coordinated way at the local, regional and national levels, by the government, local people, and all relevant NGOs and socio-economic actors.

Conceptual Framework for Coastal Adaptation

To minimize the degree of uncertainties associated with coastal processes (natural and socio-economic) and climate change predictions, any technological options for coastal adaptation need to be designed and implemented in "an appropriate economic, institutional, legal and socio-cultural context" (Klein et al. 2001). Best practice in coastal adaptation to climate change should be a multi-stage and iterative process involving four steps (fig. 4.1.2. Klein et al. 1999; 2001):

- Information development and awareness rising
- Planning and design
- Implementation
- Monitoring and evaluation

Information and data collection are essential to identify the adaptation needs for a particular

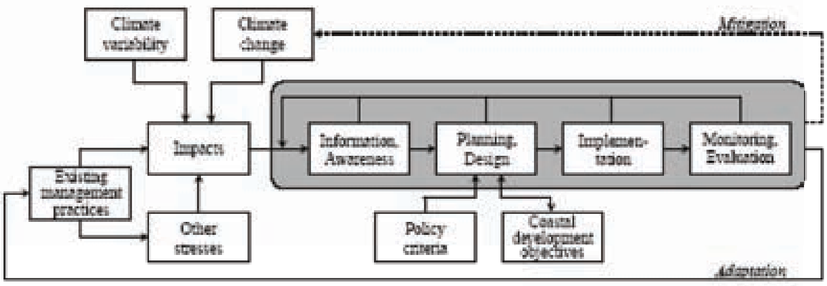


Figure 4.1.2. Conceptual Framework for coastal adaptation to climate change and variability. The concept is based on long-term coastal management experiences in the Netherlands, the UK and Japan, with emphasis on coastal protection. (Klein et al. 1999, with permission).

area. Typically, information type may include an adequate understanding of past coastal change, current physical processes, constraints imposed by the geological characteristics of the area, the functioning and value of the ecosystem and habitats, the patterns of human behavior, and a good perception of the dominant climate forcing variables and its potential consequences on the coastal system under study. Data repositories with easy access on internet such as the European Sea level Service (http://www.eseas.org/), the EUNIS Habitat classification (Davies and Moss 2002; http://eunis.eea.eu.int/habitats.jsp), the MarLin Biology and Sensitivity key Information database (Hiscock and Tyler-Walters 2006), the EU-SEASED database for marine geological data (http://www.eu-seased.net/), and the IGBP-LOICZ typology database can be very helpful to establish a good information background for coastal planning

In addition, a number of numerical models are now available to assist coastal zone planning and management (see section 3.4). These models range from simple, linear relationship between sea level and shoreline retreat, known as the Brunn Rule (Brunn 1962), to more sophisticated coastal models enabling long-term predictions of shoreline evolution (e.g Jiménez and Sánchez-Arcilla 2004) taking into account both anthropogenic and climate change scenarios and delivering better coastal engineering solutions for erosion control and climate change impacts. Geographical Information Systems (GIS) are also an important technology for spatial planning to identify the appropriate adaptation scheme and optimal location for implementation (Pye and Blott 2006).

Owing to several EU projects and other national initiatives, modeling performance are increasing rapidly, as well as the technologies to design adaptation strategies and to monitor and evaluate their efficiency and usefulness over different time and space frame. But the uncertainties remain considerable due to scarcity of information and the general low perception of the coastal public to long-term effects of climate change. In addition, existing institutions and legal frameworks may still be inadequate to implement appropriate adaptive response to climate change. Cases of resettlement, coastal realignment, transboundary implications of coastal planning, are still challenging topics reflecting insufficient integration of environmental concerns into social and economic policies.

There is a need for more impact and adaptation assessments at the coast and more effective communication and consultative process involving all stakeholders. In a comprehensive coastal zone management system, such a conceptual framework would facilitate the integration of the broad range of coastal adaptation options and the large number of societal sectors that are directly or indirectly concerned.

Further Reading:
EEA, 2006. The changing faces of Europe's coastal areas. European Environment Agency Report No 6, EEA, Copenhagen, pp.107.

4.2 Marine Ecosystems and Fishery management

Eco-regions and Marine Protected Areas

An ecosystem can be defined as . Accordingly, an ecological province or eco-region would legitimately represent the area where these interactions occur. It is possible to examine over manageable scales many environmental stresses, which represent a risk to the ecosystem's sustainability. The management of these threats, through international conventions or EU Directives, implies the selection of geographical areas where formal and prescriptive guidelines can be reasonably implemented to mitigate the effects on ecosystems.

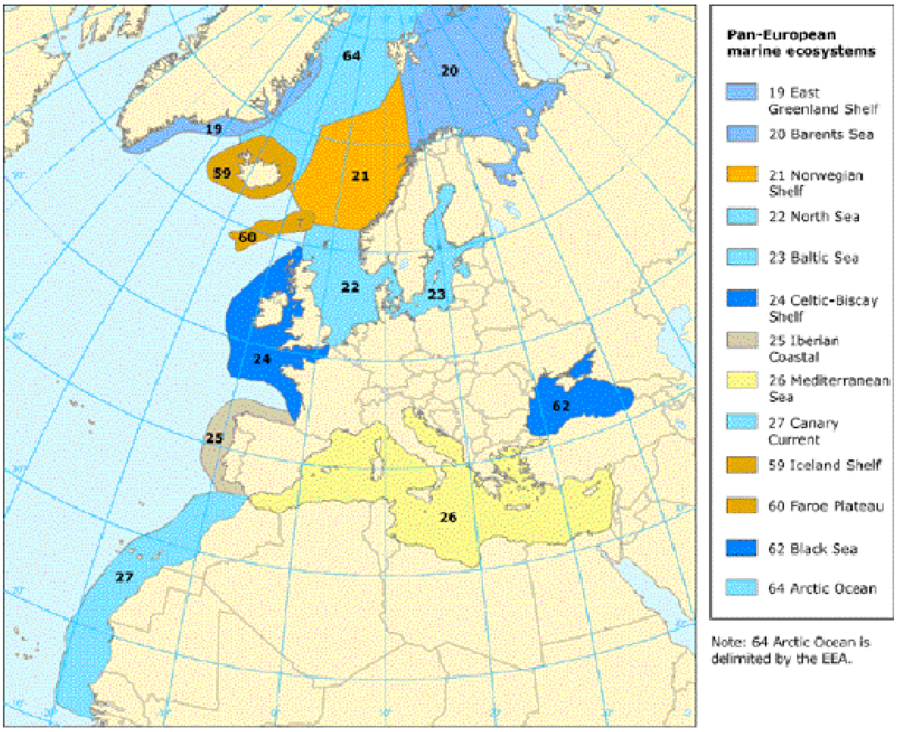
In the context of climate change, a strategy for the conservation and protection of the marine environment also requires, for management practice, the identification of eco-regions with spatial dimension that reflect over a given period of time the physical scale of all processes (represented by specific indicators) associated with a specific ecological issue. Shoreline Management Plans, for example, foresee the division of the coast into 'littoral cells', each being characterized by a peculiar hydrodynamic system, which, once known, enable an adaptation strategy to be executed (e.g. beach nourishment) and monitored.

In open shelf and marine waters, natural boundaries between eco-regions turn out to be more fuzzy and mobile as a result of the natural variability in the ocean dynamic, and the impact of climate change on this dynamic. In contrast, eco-regions with boundaries fixed in time and space do not allow the observations of seasonal, inter-annual or longer-term variability in the ecosystem that may result from climate change and /or climate variability. Moreover, a real and fixed ownership of marine waters and its content cannot be indisputably identified due to the lack of physical borders that would confine the biota into geographical and administrative limits (e.g. the Exclusive Economic Zones).

Several examples of marine partition have been adopted by various groups and organizations using criteria based on purely geo-political concerns, or on more biogeographic and oceanographic examination. In most cases, e.g. FAO and ICES “major fishing areas”, OSPAR regions in the North Atlantic, the divisions of marine waters reflect an attempt to merge both oceanographic features and, to a greater extent, the existing socio-political management structures. Longhurst (1998) provided a scheme to partition the world’s ocean into biogeographical units (see fig. extracted map for European waters) based on the present knowledge of relevant physical features and of typical responses of the pelagic organisms to physical forcing.

These regions have adopted fixed boundaries which are not exactly compatible with marine ecosystem dynamics. To be effective, eco-regions attributes should fulfill similar requirements as for indicators, i.e., specificity to an environmental issue (in this case climate change), ability to be monitored, and sensitive to changes in one or a set of indicators. In addition, eco-regions boundaries should be tangible and dynamic rather than fixed and conceptual, mirroring the natural processes. Two problems are then arising: first, the identification of such eco-regions requires a high degree of knowledge on the processes occurring in the whole studied area, and on setting boundaries that could be monitored at an appropriate time scale; second, dynamic boundaries varying on too short time (monthly, seasonal, or even annually) may cause difficulties, from a management perspective, to develop and implement appropriate environmental measures. As a compromise, boundaries of eco-regions could be re-evaluated on a regular basis (e.g. 5-10 years) to account for climate change impacts on the ecosystems.

Large Marine Ecosystems (LMEs) were proposed by Sherman and Skjodal (2002) as a framework for an ecologically-driven management of global coastal fish populations, in support of the Agenda 21 resulting from the UN Conference on environment and development (UNCED 1993). Criteria for LMEs include hydrographic characteristics, as well as biological components such



Note: 64 Arctic Ocean is delimited by the EEA.

Figure 4.2.1. *Large Marine Ecosystems as identified for the European marine continental shelves. (source EEA.2006 http://dataservice.eea.europa.eu/atlas/).*

as fish population and their life cycle. This division can be used as a basis for selecting protected areas and marine reserves ensuring that these are covering a representative set of different marine habitats. The applicability of LME boundaries should be verified, and places within an appropriate objective framework so they can be updated periodically.

Marine Protected Areas (MPAs) and other marine reserves are important to preserve the biodiversity and habitats from an excessive exploitation of the marine resources by a continuously increasing human population at the coast. They have also an important scientific value to study the impact of climate change and climate variability on ecosystems that are only slightly or not influenced by other external pressures. In Europe, protected areas have been established as a network of sites, Natura 2000 (http://www.natura.org/), under the frame of the EU Habitats Directive and the Birds Directive (see section 5.1). With respect the marine environment, protected areas are also administered by the various Regional Conventions. MPAs have been developed in all European Seas. However, the sea surface coverage (2.7%) remains low compared to the surface covered by protected areas on land (14.1%).

The open boundaries of MPAs make difficult a total protection of the environment from pollution in adjacent areas, and migration of different organisms, including larval stages or juveniles, outside the limits. Moreover, MPAs present limited defense against environmental change and climate-related pressure (increased water temperature, acidification), and many MPAs have failed to meet their conservation objectives (Jameson et al. 2002). The benefits from MPAs and marine reserves are, therefore, being challenged by several sectors in the marine and maritime industry. However, increasing evidences demonstrate that protected areas are effective in enhancing local biomass and average size of various species, including commercial fishes, and species diversity (Gell and Roberts 2003, Halpern 2003, Micheli et al. 2004). Furthermore, protected areas can boost local fisheries through spillover of juveniles and increased egg output in adjacent fishing grounds (Roberts et al. 2001). On the whole, protected areas contribute to the good health of the ecosystem which then could become relatively more resilient to environmental changes in comparison with those affected by additional anthropogenic pressure. Also, MPAs could provide the structure for the development of an integrated approach to managing different threats including climate change (CBD 2005). The creation of new MPAs, including ‘no-take’ zones, in the European Seas should thus be encouraged in consultation with all interested stakeholders, giving specific attention to the choice of the area and the management requirements such as to ensure long term objectives.

Aquaculture

With the increasing exploitation of marine fish stocks at or beyond maximum sustainable levels (Jackson et al. 2001), and other anthropogenic pressures such as water pollution, habitat degradation, the introduction of alien species, the fish populations are often surviving at a limit below which stock recovery may become challenging (Worm et al. 2006). Climate change or global warming is just an additional trauma to the organisms acting either directly on their metabolism or through the food web (see section 1.2 and 2.5). In that context, aquaculture and fish farming would compensate for the decline in high-value fish species, and, in addition, may be considered as a mean to alleviate some of these pressures (e.g. opening alternative jobs to fishermen) on the natural fish stocks and increase their resiliency to other stresses, including climate impacts.

Marine aquaculture production accounted for 75 % of total aquaculture production in Europe in 2003 and has increased by 110 % over the last 13 years, from 0.8 Mt in 1990 to 1.7 Mt in 2003 (Eurostat 2005). Major marine organisms farmed in Europe are the Atlantic salmon, the seabream and seabass, as well as mollusks such as mussels, and oysters. Northern Europe centers its aquaculture production around the salmonidae, whereas in the Mediterranean Sea, aquaculture has evolved toward more diversification passing from 18 species in 1981 to 40 in 2001 (IUCN 2004). With respect to traditional fisheries, the domestication of marine organisms under controlled conditions enables potential adaptation strategies to climate change, including the protection of aquaculture sites to some environmental pressures, the repositioning to more suitable areas as identified by simulations under various scenarios, the development of species more resistant to environmental changes. A better understanding of the species life cycle, their degree of tolerance to environmental parameters such as temperature, the conditions affecting their growth rate and mortality, is prerequisite to improve the efficiency of these strategies and to guarantee sustainability in marine food supply.

Aquaculture development is still a matter of debate as it can cause a great deal of environmental concern (Naylor et al. 2000). An increasingly significant effect of intensive fish culture is coastal eutrophication. The accumulation of nutrients from fish excretion and excess food supply in rejected waters provides ideal conditions for algal blooms, occasionally driving to anoxia at depth (EEA, 2001). Moreover, aquaculture of carnivore fishes, paradoxically, can stimulate sea fisheries through collecting the necessary food supply for fish farming (Pauly et al. 2003). This may have contributed to certain stock declines in the North Sea (Naylor et al. 2000). Therefore, there is a need to better understand potential consequences of aquaculture in terms of pollution of surrounding waters, changes in indigenous wildlife and the introduction of invasive species, as well as to develop methods to reduce fish meal and fish oil inputs in the feeding diet of farmed fishes.

Successful aquaculture development in coastal areas relies on a careful planning taking into account resources, existing institutions, as well as the environmental regulations and policies in place.

4.3 Options for reducing the airborne fraction of anthropogenic CO_2 – a marine view

Facing the danger of climate change and global warming, a number of proposals have been suggested to trim down CO_2 emissions from fossil fuel burning. These include market-based mechanisms (tradeable permit programme, carbon taxes), use of alternative energy source, and enhancement of natural carbon sequestration processes. As for natural processes, the ocean is by far the largest active carbon sink, having stored half of the anthropogenic emissions since the beginning of the industrial era (Sabine et al. 2004). Two types of artificial measures have been proposed to further use the ocean carbon reservoir as a potential mitigation option for climate change: i) the fertilization of the oceans; and ii) the capture of man-made CO_2 and its injection into the deep sea or seabed layers. Both these measures have created a controversial debate within the community at large; the discussions being still very active at this time not only as regards the scientific basis, but also the legal framework upon which these measures can be applied.

Marine fertilization

Through photosynthesis, the marine phytoplankton is responsible for about half of the carbon fixation on Earth. Part of this carbon sinks into the deep layers, contributing then to a long-term sequestration of atmospheric CO_2 (biological pump, see section 2.3). An intentional stimulation of the phytoplankton productivity through enrichment of the surface waters with nutrients could therefore instigate appealing cascading reactions toward intensification of the biological pump and carbon export, on the one hand, and an outburst of the marine food web, on the other hand. Natural fertilization is occurring in different parts of the world ocean through e.g. upwelling of nutrient-rich deep waters, inputs from river runoff, as well as atmospheric dust emissions. The latter has been even considered as partly responsible for the drop in atmospheric CO_2 during glacial-interglacial variations, supplying iron to boost the biological pump (Martin 1990).

Accordingly, a number of small to medium scale experiments or ‘ocean nourishment’ processes were designed to stimulate phytoplankton production with the addition of nutrient compounds, particularly iron, at selected oceanic regions. The results from these studies demonstrate in all cases an effective increase in particulate organic carbon, associated with a decrease in inorganic carbon in the upper productive layer (fig.4.3.1; de Baar et al. 2005). However, the conclusions remain questionable with respect to CO_2 gas flux into the sea, and carbon sequestration into deep waters (Buesseler and Boyd 2003; de Baar et al. 2005). Many aspects are still to be clarified, including the role of secondary production to replenish inorganic carbon into seawater after the bloom event, the subsequent emission of other important gases such as nitrous oxide (Law and

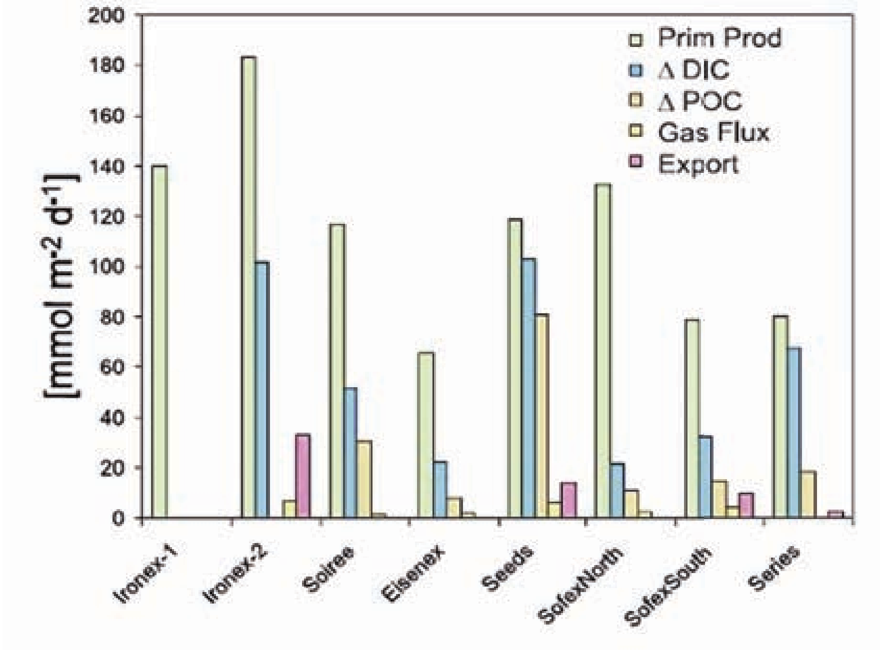


Figure 4.3.1. *Depth-integrated primary production (Prim Prod), and depth-integrated inventory changes in dissolved organic carbon (DIC), particulate organic carbon (POC), air to sea* CO_2 *flux (Gas Flux) and export of POC in deep water (Export) for 8 iron fertilization experiments in various parts of the world ocean. (after de Baar et al. 2005)*

Ling 2001) and dimethyl sulfide (Liss et al. 2005) which may have positive or negative feedbacks on the climate system. Further investigations are also required on potential alteration of the food web structure and the overall biogeochemical cycles.

The debate on marine fertilization goes beyond a simple question on its efficiency to remove atmospheric carbon dioxide (Chisholm et al. 2001; Johnson and Karl 2002). The idea of an industrialized deliberate ‘eutrophication’ of sea waters over large scale would unquestionably affect the entire ecosystem in some presently undefined modes, and would conflict in essence with policy regulations implemented for other water bodies such as lakes and coastal waters (see section 5.1)

Deliberate marine storage of anthropogenic CO_2

Purposeful capture and storage of excess CO_2 from industrial point sources is currently discussed as a potential mitigation option for climate change (IPCC, 2005; e.g., Jean-Baptiste and Ducroux, 2003). Proven technology is now available to capture efficiently CO_2 gas from industrial emissions and concentrated it into liquid or dense gas phase to be stored and transported at selected dumping sites (IEA 2002). The subsequent injection of CO_2 into intermediate or deep marine waters would ensure a sequestration of the gas for several hundred years. However, this idea has been more or less abandoned in view of potential negative effects on the marine ecosystem resulting, among other matters, from changes in the water chemistry and pH reduction (see section 2.4). This mitigation strategy cannot be supported under the Clean Development Mechanism as defined in Article 12 of the Kyoto Protocol.

On the other hand, CO_2 capture and storage (CCS) in geological structures on land or under the sea floor are strongly considered within IPCC (2005) and the OSPAR Commission (http://www.ospar.org/eng/html/whatsnew.htm) as technically feasible using existing machinery. Direct injection can be made in oil and gas reservoirs which are either depleted or in function, or in deep saline aquifers. In Europe, the North-East Atlantic and the North Sea offer significant potential for CCS that would handle most of the European Union's CO_2 emissions for several centuries (OSPAR 2006). The example of the Sleipner gas field in the North Sea tends to demonstrate the value of CCS, as nearly 1 Mt of CO_2 per year is injected in a saline aquifer, 1000m below the seabed, since 1996 (Torp and Gale 2004). Solid rock formation overlying the injection site would guarantee CO_2 storage for several hundred thousands years.

Recently, however, CCS reliability with respect to environmental safety has been under doubts (New Scientist 2006), with potential CO_2 leakage following changes in acidity and dissolution of the surrounding minerals. Therefore, these storage options are not without risk and some uncontrolled leakages of concentrated CO_2 would have large consequences on the environment and ecosystem (Turley et al. 2004). Several issues need to be carefully addressed such as environmental integrity, compliance with international marine conventions, site selection criteria, monitoring, as well as legal and regulatory aspects. Multi-disciplinary research is needed to study the impact of potential seepages of CO_2 from CCS. Some insights may be gathered from marine sites where natural emissions occur (e.g. in the Mediterranean Sea) as a result of volcanic activities. Model simulations should be systematically conducted to study the short and long term geophysical and chemical behaviour of massive injection of CO_2 in a variety of geological structure, including potential tectonic events that could be triggered by massive CO_2 intrusion. With this respect, the results of several projects funded under the 6th Framework Programme will provide important information on the reliability and long-term stability of CCS (European Communities 2004), as well as on potential measures to reduce methodological costs.

As for legal and liability issues, new amendments to the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (so-called London Convention) were recently adopted by the Contracting Parties to regulate CO_2 capture processes in sub-seabed geological formations as a mean for sequestration of CO_2 streams (EED Nov. 2006).

Section 5

European Policy Response to Marine and Coastal Change

In a recent Communication[2], the European Commission has established the bases of a future EU climate change strategy including a full implementation of existing policies, the development of new measures in coordination with other European policies, more research, enhancement of international cooperation, and increase public awareness. The main elements taking into consideration are related to energy efficiency and mitigation options to meet the target of the 8% greenhouse gases emission reduction relative to the 1990 reference level, as well as to get better understanding on climate change and its impact in all sectors requiring cost-effective, long-term adaptation plans for their development. Independently of climate change, European concern for sustainable environment can be set back as early as 1973 when the First EC Environment Programme called for preventive actions at the Community level against environmental pollution. Since then, a number of water-and marine-related Directives were established addressing specific issues (e.g., water quality) in restricting domains (e.g. bathing, or drinking water).

This section briefly reviews some of these legislations progressively pointing toward the need for a more integrated approach in water policy and water management in Europe. The Water Framework Directive institutes a legal structure for protecting inland surface waters, transitional waters, ground waters, and to some extent, coastal waters from negative human impacts, including long-term pressures such as climate change. Recently, similar policy integration was felt necessary for the oceans and seas, looking at marine and maritime themes in a holistic way and emphasising on protecting the marine environment against a number of threats, including impacts of climate change and variability.

The development and implementation of these Directives entails to a sound scientific and technological programmes at the Community level, adopting a multisectorial and multidisciplinary approach, strengthening exchange and collaboration between national and regional institutions. The 7th EU Framework Programme for research and development includes Environment and Climate Change as a main thematic research area.

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[2] COM (2005) 35 final.
http://eur-lex.europa.eu/LexUriServ/site/en/com/2005/com2005_0035en01.pdf
“Winning the battle against global climate change” {SEC(2005) 180}.
Official Journal C 125. 21 May 2005.

5.1 Benefits from existing European Policies and Legislations

Combating climate change constitutes a challenge across many sectors in society and hence, a number of EU policies could contribute to facilitate and support the mitigation and adaptation processes addressed in specific climate change policies and legislation. Pressures on the coastal and marine environment (ecosystems) resulting from climate change add on pressures resulting from human activities like pollution and fisheries to name only two of the many. Some assessments conducted in the European regional seas and the analysis of major system parameters reveal that the marine ecosystems are not properly functioning and not showing a desirable ecological status of all its components (SRU 2004; HELCOM 2004). The successful implementation of related policies and legislations would result in moving the ecosystem away from the unfavorable conditions, leading to a potential increase of the ecosystem capacity for resilience and reduction of the vulnerability to climate change stresses.

The Water Framework Directive / WFD[3] aims to achieve ‘good status’ for and prevent deterioration of all waters, including coastal and transitional waters (and territorial waters for chemical status), by a set deadline comprising two fundamental elements: ‘good ecological status’ and good chemical status’. In view of climate change the quantitative elements defining the biological, hydrological and chemical characteristics of ‘good status’may change, increasing the difficulties to achieve the various steps recommended by the Directive in specific regions (Wilby et al. 2006). Due to iterative management system under the WFD, where the complete cycle of monitoring, assessment, planning and measures which have to be reviewed every 6 years, the WFD will take into account modifications due to climate change/variability implicitly (e.g. redefinitions of reference conditions). Furthermore, the river basin management as a single system of water management could provide a frame needed for a flexible adaptation to the regional specific impact of climate change.

Two other important pieces of water legislation aim at preventing the environment from being adversely affected by pollution are the Urban waste Water Treatment Directive / UWWT[4] and the Nitrates Directive[5] . Whereas the UWWT targets the reduction of discharges of nitrogen and phosphorus compounds from urban and industrial waster waters the Nitrates Directive aims to tackle the pollution of Community waters by nitrates from agricultural sources. Excessive phosphorus and nitrogen discharges into estuarine and coastal / marine waters are leading regularly to eutrophication in many European regional seas (e.g. manifested through severe anoxic and hypoxic events). Increased precipitation as a result of climate change, particularly in northern Europe, is expected to exacerbate the eutrophication process through increased nutrient leaching in catchment areas. A reduction of the nitrogen and phosphorus loads as a consequence of a successful implementation of the two Directives will reduce the vulnerability to eutrophication and, thus, improve the resilience to climate change effects in European coastal/marine waters.

The frequency of extreme events (droughts, storm surges, floods) has increased and is also attributed to climate change. The proposed Directive on the assessment and management of floods[6] , closely to be coordinated with the implementation of the Water Framework Directive, aims at reducing the risk to human health, the environment and economic activities associated with floods. The text proposed for the Directive explicitly mentions climate change to be taken

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[3] COM (2000) 60 http://europa.eu.int/eur-lex/pri/en/oj/dat/2000/l_327/l_32720001222en00010072.pdf *Directive (2000) 60 of the European Parliament and of the Council establishing a framework for Community Action in the field of water policy*

[4] COM (91) 271 EUROPA - Environment - Water quality in the EU - Directive 91/271/EEC on Urban Waste Water Treatment. *Council Directive on Urban Waste Water Treatment*

[5] COM (91) 676 EUROPA - Environment - Water quality in the EU - Implementation of nitrates Directive Council Directive *concerning the protection of waters against pollution caused by nitrates from agricultural sources*

[6] COM(2006) 15 http://ec.europa.eu/environment/water/flood_risk/pdf/com_2006_15_en.pdf Proposal for a Directive of the European Parliament and of the Council on the assessment and management of floods.

into account when assessing the likelihood of future floods and the estimated consequences.

Rising water temperatures, the changing hyrdo-morphological and weather conditions will affect fauna and flora[7] in aquatic ecosystems. The Directive on the conservation of natural habitats and wild fauna and flora can play an important role in the context of climate change adaptation and mitigation for mainly two reasons: 1) the major aim of the Directive is to contribute towards ensuring biodiversity through the conservation of natural habitats and of wild fauna and flora in the European territory by setting up a coherent European ecological network of special areas of conservation (Natura 2000) enabling the natural habitat types and the species' habitats concerned to be maintained or restored at a favorable conservation status in their natural range. By this their vulnerability to climate change could be reduced; 2) although climate change is not specifically mentioned in the Directive amendments are possible for adapting the lists of habitat types and animal and plant species e.g. to technical and scientific progress. This would open the door to appropriately account for climate change pressures.

Changes in water characteristics and circulation in the oceans and regional seas as already recorded in some areas will impose an additional threat to the fish stocks and their sustainable renewal required for healthy fisheries. The Common Fisheries Policy / CFP is the European Union's instrument for the management of fisheries and aquaculture. It shall ensure exploitation of living aquatic resources that provides sustainable economic, environmental and social conditions. The precautionary approach should be applied in taking measures designed to protect and conserve the living aquatic resources. This would apply also to the issue of climate change. The Commission has issued a Communication[8] to set out a Community Action Plan to integrate environmental protection requirements into the CFP. Although not specifically indicated the proposed Action Plan would allow for suitable consideration of climate change with a view to remedial action. Member States should fulfill their obligations concerning the nature protection Directives (Directive on the conservation of natural habitats and of wild fauna and flora and Directive on the conservation of wild birds) supporting the CFP. Application to the coastal and marine ecosystems would help such ecosystems to adjust to natural changes and increase the robustness to environmental shocks.

Coastal zones are among the most vulnerable areas identified in climate change impact studies. In many coastal regions climate change will exacerbate an already delicate situation caused by inappropriate excessive human use of a complex dynamic nature system. Since coastal zones are of critical importance to Europe the European Commission has issued a Communication on Integrated Coastal Zone Management: A Strategy for Europe[9]. The Strategy asks to advance sustainable development and the integration of environment into all other European policies for the significant and strategically important coastal zone. In the list of problems the coastal zone is facing climate change is not included. However, the Communication stresses the need to ensure that Community policies affecting the coastal zone are coherently conceived at the EU level and also that these policies are applied coherently through integrated planning and management at the local level. In addition, further support is required for the generation of factual information and knowledge about the coastal zone. These provisions would facilitate the consideration of climate change in Integrated Coastal Zone management and related mitigation and adaptation processes. In Annex I to the Communication a long term perspective is emphasized; 'Successful planning and management for the coastal zone must acknowledge the inherent uncertainty of the future, and must be set in an institutional framework that looks beyond the present political cycle'.

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[7] *Official Journal L 206 , 22/07/1992 P. 0007 – 0050 EUROPA - Environnement - Nature and Biodiversity Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora*

[8] COM(2002) 186 European Commission - Fisheries - 2002 Reform of the CFP Communication from the Commission setting out a Community Action Plan to integrate environmental protection requirements into the Common Fisheries Policy

[9] COM(2000) 547 http://eur-lex.europa.eu/LexUriServ/site/en/com/2002/com2002_0186en01.pdf Communication from the Commission to the Council and the European Parliament on Integrated Coastal Zone Management: A Strategy for Europe

5.2 European Marine Strategy

The Commission proposed in October 2005 a Thematic Strategy on the Protection and Conservation of the Marine Environment[10].

The Strategy is to be seen within the broader context of the development of a new EU Maritime Policy whose scope and objectives were presented in the Green Paper: Towards a Future EU Maritime Policy for the Union: A European vision for the oceans and seas adopted by the Commission in June 2006[11].

The Marine Strategy will deliver the environmental the environmental pillar of the future EU Maritime Policy. It will set out the course of action required to protect marine ecosystems upon which the sustainable wealth, productivity and employment opportunities, and broader human welfare derived from oceans and seas depend.

The overall objective of the proposed Marine Strategy Directive is to achieve good environmental status of Europe's marine environment by 2021. The proposed timetable would coincide with the first review of River Basin Management Plans under the Water Framework Directive, allowing for synergies on the further implementation of both Directives.

Under the proposed Directive, European Marine Region and potentially also Sub-Regions are to be established as management units for implementation on the basis of hydrological, oceanographic and bio-geographic features.

For the marine waters under their sovereignty or jurisdiction within each Marine Region or subregion, Member States will be required to develop in close co-operation with one another Marine Strategies including an assessment of the state of the marine environment, a series of environmental targets, a monitoring programme to assess progress towards good environmental status. On this basis, Member States will be requested to develop and implement programmes of measures in order to achieve good environmental status in close collaboration with other Member States and third countries concerned. In order to do so, Member States should work within the framework of established regional seas conventions – OSPAR for the Northeast Atlantic, HELCOM for the Baltic Sea, Barcelona Convention for the Mediterranean (and Bucharest Convention once the Black Sea becomes an EU sea upon accession of Bulgaria and Romania) (see section 6.3).

The achievement of ‘good environmental status’ of Europe's marine environment would, as in the case of 'good ecological status' for the Water Framework Directive, create a buffer to cope with the impact of climate change on the marine environment.
However, in view of climate change the expression of 'good environmental status' will need to take into account the fact that the initial base line may shift due to climatically induced large scale changes to the marine ecosystem – climate change as well as climatically driven hydrographic changes – or ocean acidification. The potential base line shift should be addressed as part of the assessment of the state of the marine environment in each Marine Region or Sub-Region and in determining 'good environmental status'. The flexible and adaptive approach of the proposed Marine Strategy Directive as well as the reliance on Marine Regions and Sub-Regions as management units should allow for a flexible adaptation to the regional specific impacts of climate change.

5.3 EU Climate Change Research

Conducting European research policies and implementing European research programmes is a legal and political obligation in the EC and EU Treaties. EU research has been supported within the consecutive Framework Programs (FP) since 1984.

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[10] COM(2005)504 Communication from the Commission to the Council and the European Parliament – Thematic Strategy on the Protection and Conservation of the Marine Environment; COM(2005)505 – Proposal for a Directive of the European Parliament and of the Council establishing a framework for Community Action in the field of the Marine Environment (Marine Strategy Directive).

[11] COM(2006) 275 final – Green Paper - Towards a future Maritime Policy for the Union: A European vision for the oceans and seas.

First EC research projects dealing with climate change were supported already as early as the Second Framework Program (1987–1991) which included research projects such as 'Global climate change and CO2: the role of oceanic circulation' and 'Interdisciplinary studies of the carbon cycle'.

The Third Framework Programme (1990-1994) was the first to investigate the possible effects of global climate change. Under the heading: "Climatic impacts and climate related hazards" such projects like "Climate change, sea level rise and associated impacts in Europe", "Climate of the 21 century" and "Climate during the last 30.000 years" were supported. The projects within the Third Framework Programme were pioneering true European wide collaborative integrating projects of relatively large scale in important areas of climate change.

With an increased budget the Fourth Framework Programme (1994-1998) covered already a wide research and technological development activities. Within this programme, the "Environment and Climate" part contributed to European environmental research by supporting RTD projects and networks in the following areas: 1) Research into the natural environment, environmental quality and global change 2) Environmental technologies 3) Space technology applied to Earth observation and environmental research 4) Human dimensions of environmental change. The Fourth Framework Programme was also the first to call for research on effect of climate change on water resources.

Also within this framework program a specific marine research programme was included, the "Marine Science and Technology Programme" (MAST). This program was to develop the scientific and technological base for the sustainable exploitation of marine systems, as well as determining their precise role in global change. The third phase of the MAST programme, initiated under the Fourth RTD Framework Programme (1994-98), focused on four research areas: Marine science, Strategic marine research, Marine technology and Supporting initiatives.

Fifth RTD Framework Programme (1998-2002) further extended the scope of climate change research and introduced "Energy, Environment and Sustainable Development" as one of the thematic programmes. This program was further divided into a number of key actions including one on "Global Change, Climate and Biodiversity". It emphasised the global and regional environmental problems that may have a significant impact on Europe, such as climate change, ozone depletion, biodiversity loss or loss of habitats and fertile land. Integration and synthesis across global change problems were receiving particular attention.

The Global Change, Climate and Biodiversity key action covered a range of research projects also helped to underpin EU policies related to environmental conventions and treaties such as Kyoto Protocol, Montreal Protocol, and Convention on Biological Diversity, Desertification Convention and the Air Pollution Convention.

In the Fifth RTD Framework Programme marine research was not separated under a specific program like MAST but took a form of the key action "Sustainable Marine Ecosystems". This action aimed to underpin the emergence of new concepts for integrated management of European seas in the open ocean as well as in the coastal zone.

"Sustainable development, Global change and Ecosystems" was the 6th thematic priorities for the **Sixth Framework Programme**. Community action concentrated on three major fields like Sustainable energy systems, Sustainable surface transport and Global change and ecosystems. The later field embraced a wide range of research incorporating global climate change problems like ozone layer depletion (SCOUT project), water cycle including soil-related aspects, operational forecasting and modelling in particular of climate change or risk assessment. This framework program strongly supported applied research to reduce greenhouse gas emissions– generated by energy, transport (e.g. project QUANTIFY), industry and agriculture (e.g. project INSEA) – and to evaluate solutions offered by carbon sinks. Several large scale projects focused on ocean research like CARBOOCEAN (carbon sources and sinks assessment); DAMOCLES (arctic modelling for long term studies). The Network of Excellence EUR-OCEANS aimed to achieve lasting integration of European research organisations on global change and pelagic marine ecosystems and the relevant scientific disciplines.

The Joint Research Centres carry out in house "direct" research also in the field of climate change. Also JRC research teams are involved in many joint European research projects. The JRC carries out action on data quality system for greenhouse gas (GHG) emissions and sinks and gives scientific and technical support towards a European approach on assessment and monitoring of the coastal and marine aquatic environment.

The **Seventh Framework Program** further emphasise the need to continue climate change research. The FP7 incorporates the activity Climate change, pollution and risks, under the Environment thematic area. Integrated research is needed to gain a better understanding of how the earth system and climate work, including the ocean and the polar regions, and to determine the causes of changes in the past and to predict better their future evolution. This will enable the development of effective adaptation and mitigation measures to climate change and its current and future impacts. The focus will be on analyses of pressures on the environment and climate from natural and anthropogenic emissions and improvement of our understanding of the complex climate system. Ocean acidification, possible changes of the thermohaline circulation will be given particular attention. Advanced climate change models from the global to sub-regional scales will permit to assess possible environmental changes, ecological and socio-economic impacts and critical thresholds. Observation, analysis and modelling must be used to assess climate induced changes to atmospheric composition, greenhouse gases and to the water cycle and related extremes (floods, droughts), on the cryosphere, impacts on ecosystems, feed-back mechanisms and abrupt changes. Beside the above mentioned themes, other activities such as managements of natural resources and environmental technologies will contribute to climate change research.

The results will help to implement international commitments, contribute to the Inter-Governmental Panel on Climate Change (IPCC) and address the research needs of existing and emerging EU policies, including the Second European Climate Change Programme and the 6th Environmental Action Plan.

Research is a cornerstone that supports quality of life, competitiveness and sustainable development. Quality research which engages stakeholders and communicates in a trustworthy and relevant way is a major contribution to develop solutions to complex problems such as climate change. European Research is contributing to education, development of new skills and creation of knowledge based jobs. Several Commission Communications underline also the importance of climate change threat and the need for appropriate policies and research.

Section 6

Cross-cutting Issues and Governance

Part of the problems in managing and improving some of the European Seas can be put down to weak governance. The development of environmental measures to control and reduce pressures on the marine system from anthropogenic and climate drivers have often been developed in a sector by sector approach resulting in a patchwork of policies and regulations at regional, national, European and international level. The proposal of the European Commission about an EU Marine Strategy Directive and Maritime Policy is to create some degree of cohesiveness and coordination in the vertical and horizontal dimensions of marine affairs, vertically among the Member States and local institutions, and horizontally between sectors, activities and programmes. Some aspects of governance in marine and coastal management are examined in this section taking examples from both European and national systems. Good governance of seas and coasts is based on recognition of the interests of all stakeholders, integrating all concerns into an ecosystem-centered framework. The principles of a marine stewardship are to ensure that economic development is framed in ways that both protect the marine environment and is socially beneficial to the people using that environment. To achieve this, information is an essential element of the governance; information on the nature of the environment, the potential threats from human activities and climate change, as well as information on the users, and the value of the shoreline and marine resources. Community participation and community consultation enables all concerned actors to engage as partners in the process of defining objectives, identify needs and planning for actions or adaptation strategies. Enhanced collaboration between national institutions, European and international organizations is essential to make better use of complementary areas of expertise, and to harmonize decision-making processes in a domain, i.e. climate change and the Marine Dimension, where political boundaries have no real significance.

6.1 Integrating Science and Policy development

Marine stewardship

Addressing marine climate change issues in a sensible way lies on the basic assertion that a healthy marine environment will be more resilient to climate change impacts and its carbon sequestering capacity will be less vulnerable to disruption. At national level, the UK, for example, is trying to achieve this through the delivery of a marine vision of "clean, healthy, safe, productive and biologically diverse oceans and seas" (DEFRA, 2002) inviting all stakeholders to be involved in protecting the seas and coasts, to strengthen co-operation amongst the implicated sectors for spatial planning, and to be an integral part of the decision-making process.

At the European level, the EU Marine Strategy and proposed - Marine Strategy Directive, which will require Member States to achieve "Good Environmental Status" by 2021 through the development and implementation of marine strategies at the level of Marine Regions or Sub-Regions will structure the marine environment protection in Europe. Climate considerations were included from the outset in the conception and development of the EU Marine Strategy. It will make an essential contribution to adapting to climate change by reducing pressures we place on marine ecosystems so that the combined pressures do not push them to a point beyond which they are unable to recover.

Unlike in the terrestrial system, there is a more limited set of policies marine managers can take to mitigate the climate change impacts. Few techniques to sequester carbon, such as the capture and storage in geological structures under the seabed are now being discussed at EU level under the European Climate Change Programme II. The UK, Holland and Norway are actively pursuing this work through the London Convention, although these options are not without risk and are not currently sufficiently understood (see section 4.4). Although commonly accepted as a mitigation option, the position of the EU in respect of carbon capture and storage in geological structure is that CCs projects should be in conformity with relevant multilateral agreements and IPCC guidance (UNFCCC 2006).

Developing a better understanding of the oceans, the immediate and cumulative impacts of human activities and the mitigating actions we are taking requires a good and concrete scientific knowledge base that relies on long term robust monitoring systems and research programmes. These, in turn, need to be co-ordinated at the European and/or national government level to optimize an effective use of the scientific knowledge in policy-making development.

The Marine Monitoring and Assessment Strategy in UK (UKMMAS) have been set in preparation of the European Marine Strategy in order to begin to provide answers to all the complex ecosystem science questions. Climate change impacts are one of these complex issues.

A UK-model: The Marine Climate Change Impact Partnership (MCCIP)

The UK government is developing a partnership to undertake specific assessments of the climate change impacts. The Marine Climate Change Impact Partnership MCCIP (see http://www.mccip.org/) has the primary aim to provide a co-coordinating framework for the transfer of high-quality marine climate change impacts evidence and advice to policy advisors and decision-makers.

In particular, the Partnership will act as the primary focus for the supply of evidence and advice to partners to enable them to individually and collectively plan for the challenges and opportunities presented by the impacts of climate change in the marine environment.

Launched in 2005, the key objectives for the MCCIP are:

- To develop and maintain a coordinating framework.
- To build the knowledge base and create effective mechanisms for the efficient transfer of high quality marine climate change knowledge from the scientific community to policy advisers and decision makers.
- To facilitate uptake of tools and strategies to assist stakeholders in developing and assessing adaptation strategies.

The partnership will also help:

- To identify gaps in knowledge and recommend priority areas for research.

- To assemble community views and partner requirements for climate change tools and information (e.g. marine scenarios of climate change).
- To advise on the development of an integrated marine climate impacts monitoring programme.

The MCCIP incorporates a range of **marine stakeholder organisations** concerned about the impacts of climate change. MCCIP has been set up as a response to gaps identified in the report **'Charting Progress: an Integrated Assessment of the State of UK Seas'** and its primary **aims** are to streamline the transfer of marine climate change knowledge to policy advisors and decision makers.

MCCIP will use the scientific understanding developed through programmes such as **MarClim**, the **Continuous Plankton Recorder** (see section 2.7) and the UK Climate Impacts Programme **(UKCIP)**. In conjunction with our partners, we aim to build upon this existing knowledge base to provide broad based scientific information for end-users.

The annual report card (ARC) will provide one of the most important outputs of the MCCIP programme, synthesising the previous years work in a highly accessible and actionable format.

Our express aim is to provide an annual account of developments in UK marine science in the form of a: "Short, comprehensive, quality assured, high level assimilation of knowledge set out in a visually impacting way that would enable the results to be quickly and easily understood and used by policy advisors, decision makers, Ministers, Parliament and the devolved administrations". The first annual report card is due to be published in late 2006.

Like the atmosphere, the oceans are global commons and it is not the UK's actions alone that influence their healthiness.

We therefore need to work with partners within each nation, Europe and internationally.

6.2 Information flow and public awareness

An important element to consider in the battle against climate change, regardless of its domain of impacts, is to deliver timely information and relevant scientific conclusions to all stakeholders, the decision-makers and the public at large. Scientific results on the patterns, model projections and consequences of climate change and variability and their associated uncertainties from relevant EU and national projects should remain the basis for policy making and the development of strategies to ensure sustainable management of coastal and marine resources.

A number of reports are being published by experienced and knowledgeable environmental organizations synthesizing most recent scientific findings on climate change research, drawing attention to requirements and priorities for further actions in specific domains. These reports are either global in scope (e.g. IPCC Assessment Reports), or focus on climate change impacts at European and National levels with usually a chapter or special issue dedicated to coastal and marine systems. Few of these organizations working at the European level are mentioned below.

The European Environment Agency (EEA, http://www.eea.europa.eu) regularly reports on the status of the environment over Europe, providing information, analyses and assessments in support to thematic strategies and key policy development, including the Water Framework Directive and EU marine strategy. Recently, several reports were specifically dedicated to climate change in Europe (EEA 2004, 2005) reviewing the trends and major impacts of climate in various sectors (including coastal and marine) of the European environment and society, and describing the state of vulnerability and adaptation planning in EEA member countries. In this context, the EEA is preparing an updated report on climate change impacts in Europe to be published in 2008. Another document (EEA 2006) gives a comprehensive picture of European policies concerning the coast, addressing the need for a spatial approach to integrated management of the land-sea interface.

Specifically for the marine environment, the International Council for the Exploration of the Sea (ICES, http://www.ices.dk/) acts as a meeting point for a large community of scientists from countries around the North Atlantic (incl. the North Sea and the Baltic Sea). Scientists working through ICES gather information about the marine ecosystem and fisheries, drawing attention to gaps in existing knowledge, and providing analyses and trends that are further developed into unbiased, non-political advice. In addition to the annual reports of the ICES Advisory Committees on fishery management, marine environment and marine ecosystems, document series are regularly published by specific working groups (ICES Cooperative Research Reports, e.g. ICES 2005). The Coastal Union (EUCC, http://www.eucc.nl/) regroups 40 countries and a network of scientists, engineers, environmental managers, policy makers to promote marine and coastal management, mobilizing experts and stakeholders and implementing demonstration projects aiming at a sustainable use of the coastline in the European Union.

Most of the documents and reports published by these organizations are freely available on internet and could then be used by the decision-makers and the general public, particularly communities and individuals who are most likely to be directly affected by the consequences of future climate change. The general public benefits from the coastal and marine and as such represents an important stakeholder with the right to be informed and participate in the preparation and adoption of coastal policy measures. An effective information and communication would ensure cooperation, mutual understanding and receptive collaboration between all stakeholders in the preparation and adoption of environmental measures for coastal and marine management.
In that sense, a specific EU Directive[12] should ensure public consultation on environmental plans and programmes before their adoption. The Directive establishes that detailed information should be provided by the project coordinator to the authorities and the public, and gives the opportunity for the public to express its opinion during and after the implementation of the planning measures. In the coastal and marine domain, management plans are typically local or regional in nature and the arrangements for information and consultation are under the responsibility of each Member State, with the possible drawback of having different level of accommodation in the Directive interpretation and implementation.

A continuous effort is recommended to strengthen and harmonize information and communication activities involving public participation to all stages of the decision-making process, as well as to integrate coastal and marine concerns into education and training programmes.

6.3 European and International cooperation

The marine dimension of climate change goes beyond the national and EU's borders for two reasons: i) even though climate change strikes in a different way at local or regional scales, the driving mechanisms are global; ii) the physical, chemical, and biological dynamics of seas and oceans have no political boundaries. The broad scope and complexity of climate change and marine research require therefore an international cooperation to define research and operational programmes, exchange scientific observations and data, harmonize decision-making process for mitigation and adaptation strategies, and concur in emerging environmental issues.

Regional Marine Conventions
Facing the difficulties to build an efficient stewardship of the sea at national level only, regional marine conventions for the protection of the marine environment have been established over the years for all European Seas, each being dedicated to a specific geographical area. These conventions are the Oslo-Paris Convention (OSPAR, http://www.ospar.org/) for the North-East Atlantic, the Helsinki Convention (HELCOM, http://www.helcom.fi/)
for the Baltic Sea, the Barcelona Convention (http://www.unepmap.org/) for the Mediterranean Sea, and the Black Sea Convention (also called the Bucharest Convention, http://www.blacksea-commission.org/main.htm) for the Black Sea. The objectives of these Conventions are commonly to protect the marine environment and the coastal zone from all sources of pollution and hazardous substances, to maintain favourable status of the ecosystems and biodiversity, to combat eutrophication, and to make sure that maritime activities (shipping, offshore industry) are carried out in an environmentally friendly way. Even though climate change may not be explicitly mentioned in these priority issues, it is clear that climate change could very strongly affect the achievement of ecological objectives associated with them. It is expected that some greatest effects would be on biodiversity, but other impacts can be anticipated on eutrophication as well.
The strategy of the Conventions in relation to cli-

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[12] Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment. http://europa.eu.int/comm/environment/eia/home.htm

mate change should aim at limiting or mitigating adverse impacts, as well as to enhance the resilience of the marine environment such as to improve its capacity to cope with climate change pressure. It is thus necessary to continue to improve measures:

- to mitigate eutrophication by intensifying the reduction of nutrients in waterborne and airborne inputs;
- to continue and intensify measures to reduce inputs of heavy metals and persistent or hazardous organic pollutants;
- to reduce emissions (both from fuel combustion and from ship antifouling treatments) from maritime transport and to prevent ballast water releases;
- to enhance the protection of marine and coastal landscapes and habitats and, particularly, the conservation of native species.

The implementation of the strategic Baltic Sea Action Plan, which is currently being drafted by HELCOM to further reduce pollution in the sea and repair the damage done to the marine environment, will provide a basis for enhancing the resiliency and adaptive capacity of the Baltic Sea environment. In this Plan, the effects of climate change is taken into consideration (HELCOM 2006) using the most recent results from the BACC project (BALTEX 2006).

OSPAR has recognized the need for a proactive approach to climate change by asking all its strategy committees to consider the issue and how it should be taken into account in their work. Recently, OSPAR has published reports on two major climate change-related topics on ocean acidification (see section 2.4) and sub-seabed CO2 storage (see section 4.3), and is pursuing, in cooperation with ICES, work on change in marine biodiversity in relation to climate change.

Climate change has been highlighted as a topic of priority at the 1st bi-annual scientific conference of the Black Sea Commission ('Black Sea Ecosystem 2005 and Beyond', May 2006) in preparation of the Strategic Action Plan for Rehabilitation and Protection of the Black Sea (http://www.blacksea-commission.org/main.htm).

Moreover, most of the Conventions recommend the contracting Parties to carry out monitoring programmes and to cooperate in the development of data quality assurance methods and assessment tools (e.g the Joint Assessment and Monitoring Programme, JAMP at OSPAR; the HELCOM Monitoring and Assessment Programme MON-PRO).

For a better understanding of climate change and its impacts on their respective areas, the Conventions would need to continue these long-term data collections and to develop monitoring programmes further to take into account climate change-related aspects. Another benefit from these Conventions is to promote cross-sector and interdisciplinary scientific research on the one hand, and co-operation between the scientific and management communities, on the other hand. The former is essential for a better knowledge of ecosystem processes and to reduce model uncertainties, while the latter is prerequisite to develop cost-efficient and effective measures for adaptation.

International Scientific cooperation

The Earth System Science Partnership (ESSP) brings together scientists from various fields, and from across the globe, to undertake an integrated study of the Earth system, its structure and functioning, the changes occurring to the system, and the implications of those changes for global sustainability.

Through ESSP, four global scale research programmes are addressing the physics and related chemistry of global change (World Climate Research Programme, WCRP), the biology and biogeochemistry of global change (International Geosphere-Biosphere Programme, IGBP), the human dimension of global change (International Human Dimension Programme, IHDP), and biodiversity science (Diversitas Programme).

Europe plays an important role in the development (including funding) and implementation of these programmes, of which several of their core projects have European counterparts (e.g. ELOISE, EUROGLOBEC, EuroCLIVAR) supported by the European Commission. EuroGOOS identifies European priorities for operational oceanography and contribute to international planning and implementation of the international Global Ocean Observing System (GOOS) and promoting it at national, European and global level.

The ICES/GLOBEC Cod and Climate Change programme has revised its strategic Action Plan for 2005-2009 (Ottersen et al. 2004) to include investigations on the impact of climate change scenario on cod distribution and production in the North Atlantic, as well as on the variability of the prey-predator relationships.

At the thematic level, the EU-US scientific initiative on harmful algal blooms (HABs; EC-NSF 2003) is a good example of an expansion of community knowledge that has stimulated new research and exploration. Benefits include the exchange of data and new technologies, the intercomparison of numerical model outputs in various conditions and geographic area, the development of a common approach to understand the dynamics of HABs which may lead to a better comprehension and better management of local HABs events.

Implementing International Rules

The protection of the marine environment and biodiversity in marine waters beyond national jurisdiction has become an important priority of the international community.

In this respect, Europe has a long marine and maritime heritage and therefore can use of its influence and expertise in these domains to contribute substantially to a better implementation of international instruments and a prompt ratification of international conventions. The European Community and its Member States are affiliates of United Nations Convention on the Law of the Sea (UNCLOS).

The EU's voice is particularly strong with UNCLOS agenda on the conservation and sustainability of marine biodiversity and the contribution of fisheries to sustainable development (Commissioner J. Borg's address to the Conference of the International Tribunal for the Law of the Sea, Hamburg, Sept. 2005).

Furthermore, following the 2002 Johannesburg World Summit on Sustainable Development, the EU and many other European countries recognized the value of biodiversity and strongly commited themselves to a Plan of Implementation setting objectives, and partnerships that are relevant to the Convention on Biological Diversity target (Council of the European Union, 2004. http://register.consilium.eu.int/pdf/en/04/st10/st10997.en04.pdf)., i.e. reducing significantly the current rate of loss of biodiversity by 2010 (see also Balmford et al. 2005).

Other EU objectives include preventing the decline of fish stocks and restoring them to sustainable levels no later than 2015, and minimizing the harmfull effects on human health and environment from the production of chemicals by 2020.

Conclusions & Recommendations Summary

A large number of European and national research programmes have led to significant progress in our understanding and management of the European Seas and Coasts, providing stronger evidence of climate change impacts in all aspects of the marine and coastal system. These impacts are manifested through changes in the water circulation and water chemistry, ecosystem shifts and species extinction, as well as shoreline degradation and flooding. Nevertheless, the complexities of the interactions between all the components of the system, including natural and socio-economic, non-linearities and multiple feedbacks are currently limiting our capacity to assess accurately the effects of climate change, and to decipher the natural variability of the system from human-induced changes. Increasing our knowledge is, therefore, essential to reduce uncertainties in model projections, to optimize management strategies, and to provide a proactive approach to adaptation.

Owing to regional climate models, high resolution climate change scenarios are now experimented in simulations of climate impacts and adaptation studies, thus overcoming the limitation of global models to capture the large variety of fine scale structures characterizing Europe atmospheric processes. New research areas, new scientific and technical challenges have emerged addressing the impacts of elevated CO2 levels and increased temperature on marine life, its functional and evolutionary trends, as well as on the carbon cycle and dissolution of calcium carbonate. But many questions remain to be solved rapidly in order to supply accurate predictions on how the marine and coastal environment will be in the next few 10's or 100's years. Of importance, for example, is the change in the water circulation at critical key points (e.g. Greenland-Scotland Ridge, Gibraltar Strait), the impacts of melt water on Arctic and sub-Arctic marine biodiversity, the responsibility of anthropogenic processes in the phase and amplitude of regional atmospheric variability (e.g. NAO oscillations).

At the coast, a number of assessments carried out in Europe underline the large potential impacts of sea level rise on coastal ecosystems, as well as on coastal societies and economy. The occurrence and response to these impacts vary according to the local and regional differences in biogeophysical properties of the marine and coastal system, the morphological structure of the shoreline, and the degree of human settlement. A conceptual framework for vulnerability assessment and coastal management planning needs, therefore, to include both the natural system and the socio-economic vulnerability to climate change, and their interactions. A thorough assessment of the relative sea level rise, particularly in northern Europe and along the Atlantic frontage, the role of GIS and other geo-spatial technologies, and the availability of high quality geospatial data are more and more vital to assist coastal planners to identify and optimize adaptation options and locations for implementation.

Further recommendations

1. **There is a need for sustained funding to enable the collection and analysis of long term records to assess and decouple the impacts of climate change from other anthropogenic and natural variability in the oceans and seas, and to build sustainable monitoring and assessment capacities.**

2. **Basic science and experimental approaches in relation to expected climate change scenarios should be encouraged. For example, Research on the impacts of global warming and increasing water pH on the marine ecosystems, food-web interactions and the carbon cycle should be strengthened.**

3. **There is a need for Regional Climate and coupled model systems, and two-way nesting**

of regional and global models to represent regional scale processes and feedbacks to the global system.

4. A European marine and coastal observing Network should be developed and implemented with an open data policy to provide timely and unrestricted access to real-time, high frequency data from in situ observing platforms and satellite missions.

5. Continuity in the Earth Observation system from satellites, and overlap between successive missions are absolutely necessary to ensure consistent time-series of important climate variables (sensu GCOS) in the marine environment.

6. Considering the strong interactions between natural changes and anthropogenic forcings in the catchment-coast continuum, more emphasis should be made on including land use changes, urban sprawl, and sediment transport scenario in coastal management planning.

7. In terms of adaptation to climate change, we must be able to determine the combined stresses on the marine environment and where they are likely to prevent ecosystem adaptation and have the means to reduce those stresses where necessary. Therefore policy instruments which allow for spatial planning and the flexible management of human activities (such as fisheries) and protection of marine ecosystems (e.g. through Marine Protected Areas) should be encouraged.

8. The marine sector is also involved in mitigation of climate change impacts (offshore renewables and carbon capture and storage). There is a need for a legal framework and for scientific and technical guidelines for assessing the feasibility of the storage of CO2 under the seabed, and subsequent risk management if the technique is applied.

9. A multidisciplinary approach centered on ‘sustainability’ (environment and socio-economic) is required at all stages of the development and implementation of a marine and coastal management plan, reflecting the interests of all stakeholders.

10. We must allow for adaptive management processes to be implemented at all levels (local, regional and international) to respond to the changing risks. (i.e. flexible policy instruments are preferred to those which would have fixed targets and limits).

11. The Water Framework Directive and other European water-related Policies need to be fully implemented across Europe with objectives to reduce vulnerability of the coastal system to climate change and increase resilience.

12. There is a need for an improved mechanism for ensuring timely quality controlled data and information reach decision makers and users of the marine ecosystem (e.g. the UK MCCIP).

13. Any synthesis documents on climate change (e.g. report, editorial, commentary) targeted at the community at large should be submitted to some form of peer-review process to ensure that the given information is based on sound scientific statements, and that the uncertainties are appropriately represented.

14. There is a need to improve international cooperation with EU and non-EU countries to avoid conflicting situations when implementing mitigation/adaptation plans on marine resources and coastal morphology.

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